

APPLICATION TO FSANZ

**Application to amend Standard 1.5.3
irradiation of Food of the Food Standards
Code to include apple, apricot, cherry,
honeydew melon, nectarine, peach, plum,
rockmelon, strawberry, table grape and
zucchini.**

Date submitted October 2013

This publication has been prepared by [REDACTED] Agri-Science Queensland,
Department of Agriculture, Fisheries and Forestry.

© State of Queensland, 2013.

The Queensland Government supports and encourages the dissemination and exchange of its
information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0
Australia (CC BY) licence.




Under this licence you are free, without having to seek our permission, to use this publication in
accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland as the source of the
publication.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

The information contained herein is subject to change without notice. The Queensland Government
shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts
all risks and responsibility for losses, damages, costs and other consequences resulting directly or
indirectly from using this information.


<i>contact</i>	<p>  Senior Principle Entomologist Horticulture and Forestry Science Agri-Science Queensland Department of Agriculture, Fisheries and Forestry </p> <p> 21–23 Redden Street PO Box 652 Cairns QLD 4870 </p> <p>  </p>
<i>prepared by</i>	<p>  Research Scientist Horticulture and Forestry Science Agri-Science Queensland Department of Agriculture, Fisheries and Forestry </p> <p> T  </p>
<i>contributors/ collaborators</i>	<p> Horticulture Australia Ltd (HAL) Australian Department of Agriculture, Fisheries and Forestry New Zealand Fresh Produce Importers Association, Inc. Steritech Pty Ltd Queensland Strawberry Industry </p>
<i>date submitted</i>	October 2013



Contents

Contents	iv
Executive Summary	8
Applicant	8
Purpose	8
The need for irradiation	9
Irradiation as a quarantine measure	10
Safety	10
Dietary Intake Assessment	12
Other implications	13
Conclusion	14
PART 1 – GENERAL INFORMATION	16
1.1 Applicant	16
1.2 Nature of application	17
1.3 Support for the application	17
PART 2 – SPECIFIC INFORMATION	18
2.1 Details of the application	18
2.2 Purpose and efficacy of the proposed variation	19
Efficacy –phytosanitary effectiveness	21
Efficacy – commodity tolerance	23
2.3 Justification for the application	25
Domestic trade	26
Export trade	29
Phytosanitary treatments	33
2.4 Costs and benefits	35
To consumers	36
To Governments	38
To industry	40
PART 3 – SAFETY ASSESSMENT CONSIDERATIONS	44
3.1 Nutritional data	44
Effects of irradiation on nutritional content and postharvest fruit quality	45
3.2 Toxicological data	52
3.3 Products or ingredient	56
3.4 Microbial data	56
PART 4 – REGULATORY/ LEGISLATIVE IMPLICATIONS	57
4.1 International standards	57
Codex Standard	57
International Plant Protection Convention	58
ASTM International	58
4.2 National standards or regulations	59
Australia and New Zealand	59
United States of America	60

European Union (EN)	62
Other nations	65
PART 5 – OTHER IMPLICATIONS	66
5.1 Cost considerations	66
5.2 Profit implications	67
5.3 Market share implications	67
5.4 Price implications	68
5.5 Trade implications	68
5.6 Environmental implications	70
5.7 Consumer acceptance	70
PART 6 – FOOD IRRADIATION CLEARANCES DATABASE	73
PART 7 – STATUTORY DECLARATION	75
APPENDIX 1. PRODUCE – STRUCTURE & PRODUCTION AND CONSUMPTION	75
APPLE	75
CHERRY	80
TABLE GRAPE	85
STRAWBERRY	89
MELON	94
PEACH, PLUM & NECTARINE	98
APRICOT	105
ZUCCHINI	109
APPENDIX 2. NUTRITIONAL VALUE AND FRUIT QUALITY	112
A2.1 Nutritional Value of Apple	112
A2.2 Nutritional value of Apricot	164
A2.3 Nutritional Value of Cherry	216
A2.4 Nutritional Value of Peach	267
A2.5 Nutritional value of Plum	317
A2.6 Nutritional value of Table Grape	369
A2.7 Nutritional value of Strawberry	420
A2.8 Nutritional Value of Honeydew melon	502
A2.9 Nutritional value of Rockmelon	506
A2.10 Nutritional value of Nectarine	510
A2.11 Nutritional value of Zucchini	514
APPENDIX 3 – LABELLING	624
APPENDIX 4 – FACILITIES, DOSIMETRY AND RECORD KEEPING	625
A4.1 Facilities	625
A4.2 Dosimetry	631



A4.3 Record-keeping	634
APPENDIX 5 – PACKAGING	638
APPENDIX 6 – METHODS OF VERIFICATION OF IRRADIATED FOODS	647
APPENDIX 7 – LETTERS OF SUPPORT	649
REFERENCES	665

Executive Summary

This application seeks a variation to the Food Standards Code, Standard 1.5.3 Irradiation of Food, by adding

1. Apple (*Malus domestica*)
2. Apricot (*Prunus armeniaca*)
3. Cherry (*Prunus avium*)
4. Honeydew (*Cucumis melo*)
5. Nectarine (*Prunus persica* var. *nectarina*)
6. Peach (*Prunus persica*)
7. Plum (*Prunus domestica*)
8. Rockmelon (*Cucumis melo*)
9. Strawberry (*Fragaria x ananassa*)
10. Table grape (*Vitis vinifera*)
11. Zucchini and scallopini / summer squash (*Cucubita pepo*)

under the same dose and usage conditions presently prescribed for tropical fruits, persimmon, tomato and capsicum, that are currently approved in the Australia New Zealand Food Standards Code. No other variation to Standard 1.5.3 is sought. The purpose of irradiation will be for a phytosanitary objective and the minimum and maximum doses will be 150 Gy and 1 kGy, respectively.

Applicant

This application is submitted by the Queensland Department of Agriculture, Forestry and Fisheries (QLD DAFF). QLD DAFF brings together specialist knowledge, networks and services to work with significant businesses and industry sectors to support the economic development for the benefit of all Queenslanders.

Purpose

The minimum dose requested for the phytosanitary regulatory treatment is 150 Gy and the maximum dose requested is 1000 Gy.

Apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini are potential hosts to fruit flies and other regulated pests, and are subject by regulation to phytosanitary treatments against specified pests as a condition of entry into many plant quarantine jurisdictions. This applies to both domestic and international markets.

Irradiation at levels between 150 Gy and 1 kGy is effective at killing or sterilising regulated insect pests, such as fruit fly, without posing a risk to human health or significantly affecting product quality.

Queensland Fruit Fly (Q-fly) is considered one of the world's worst pests of fruiting crops, and is listed as a pest requiring treatment by most international and interstate markets trading in the movement of fresh fruit.

Food Standards Australia and New Zealand (FSANZ) previously stated, "decades of research worldwide has shown that irradiation of food is a safe and effective way to kill bacteria in foods, extend its shelf life and reduce insect infestation."

Irradiation is potentially a valuable tool to help the apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini trade ensure biosecurity and that phytosanitary requirements are met. Irradiation treatment provides an end product treatment option for these affected industries.

The need for irradiation

Several approved options exist for phytosanitary treatments of apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini. Among the most commonly used are pre and postharvest treatments with insecticides. Following the review of dimethoate and fenthion use by the Australian Pesticides and Veterinary Medicines Authority (APVMA), many phytosanitary uses were lost or restricted.

QLD DAFF and the horticulture industry consider trade in these fruits and vegetable at risk of market disruption. The forecast value for total fruit and vegetables in 2012–13 is \$2453 million (mil), with total fruit and nuts accounting for \$1334 mil and total vegetables \$1119 mil (Qld AgTrends 2013). The Gross Value of Production (GVP) for grapes is forecast at \$1110 mil, apples \$402 mil, strawberries \$212 mil and melons \$159 mil (Horticulture Factsheet 2012). The volume of trade in the domestic trade of fruit and vegetables is by far the largest. Supplying the domestic market is the major focus of the horticulture industry in Queensland (overall approximately 70%). Access to interstate markets is vital to the ongoing economic viability of the state and industry and to regional health.

New Zealand Fresh Produce Importers Association (NZFPIA) represents wholesalers, traders and retailers who import fresh produce, including fruits and vegetables, into New Zealand. NZFPIA's members rely heavily on Australian produce, in particular imports from Queensland, to meet the needs of New Zealand consumers.

In addition to increased regulatory restrictions on the use of dimethoate and fenthion, there is growing awareness within the horticulture sector of the need for alternative treatments to insecticides due to consumer concerns about chemical residues and the potential occupational health and safety issues associated with the use of chemicals in the supply chain.

While methyl bromide is approved for use in all states and territories within Australia there are consumer concerns regarding chemical treatments. However, the lack of harmonisation on the use of systems approaches (e.g. pre-harvest cover sprays and postharvest inspection) within Australia could mean that the only option for entry into several Australian markets may be methyl bromide fumigation.

Irradiation already is an approved phytosanitary treatment for a range of tropical fruits and vegetables. The treatment would provide an alternative phytosanitary treatment for these affected industries. It is anticipated that industry can commercially incorporate irradiation treatment into their supply chain with minimal impact on efficiency and profitability of the supply chain.

Irradiation as a quarantine measure

International evidence supports irradiation against fruit flies and other regulated pests. The International Plant Protection Convention (IPPC) implemented several International Standards for Phytosanitary Measures (ISPM) relating to the use of irradiation for phytosanitary purposes. ISPM 18, "*Guidelines for the Use of Irradiation as Phytosanitary Measure*" provides technical guidance on the specific procedures for the application of ionising radiation that countries should adopt when trading in irradiated fresh fruits and vegetables. ISPM 28 "*Phytosanitary Treatments for Regulated Pests*" sets out minimum doses for a range of pests.

For fruits and vegetables that are hosts to the fruit fly the required treatment is applied in accordance with international requirements, under ISPM 18 Annex 7 (2003). The required treatment would specifically comply with ISPM 28, *Irradiation Treatment for Fruit Flies of the Family Tephritidae* (2007) with a minimum dose of 150 Gy for the prevention of the emergence of adult fruit flies in all fruits and vegetables.

Further support for the efficacy of irradiation as a phytosanitary treatment for fruit fly exists in the US. In 2006, the US Animal and Plant Health Inspection Service (APHIS) approved generic irradiation doses of 150 Gy to reduce fruit fly infestation on specific fruits.

In this application, the minimum dose requested is 150 Gy, which is a generic treatment for economic fruit fly species. The proposed treatment range of 150 Gy minimum dose and 1 kGy maximum dose will comply with ISPM 18 and 28 requirements and is identical to the current levels approved in Standard 1.5.3.

Irradiation treatment is suitable for these fruits as the minimum effective dose for a phytosanitary purpose is lower than the radiation tolerance of the fresh produce of concern. Studies on the effect of low dose irradiation on the eleven fruits - apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini (QLD DAFF 2012, 2013; Attachments 1–8) and previous studies (Part 3.1) show that the nutritional value and postharvest fruit quality of irradiated fruits were not significantly affected.

Additionally, a Codex Recommended Code of Practice for Radiation Facilities for Processing of Food and ASTM International Standards provide internationally accepted guidance on the establishment and routine operation of irradiation facilities, including detailed advice on dosimetry and record keeping.

Exports of irradiated Australian mango, papaya and litchi have been approved by Biosecurity New Zealand for several years and trade in irradiated fruits and vegetables, particularly in the US are increasing, with imports of irradiated fruits from many developing countries. In August 2013, Biosecurity New Zealand approved irradiated tomato and capsicum from Australia.

In 2011, the use of irradiation for phytosanitary purposes for domestic trade was approved and accepted by all states and territories in Australia. This treatment is available to businesses under the national Interstate Certification Assurance Scheme as Operational Procedure number 55 (i.e. ICA 55). It applies to all insects, excluding only Lepidoptera that pupate internally, and to all fruits for which FSANZ has approved the use of irradiation.

Safety

The safety of food irradiation has been thoroughly studied and evaluated comprehensively over the past 60 years. No food technology has ever been as extensively studied with respect to food safety as food irradiation. Panels of experts have systematically evaluated data from animal feeding tests and multi-generation tests in animals. In 1980, the Joint

FAO/IEAE/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI) affirmed that “Irradiation of any food commodity up to an overall average dose of 10 kGy introduces no toxicological hazard; hence toxicological testing of food so treated is no longer required”. The JECFI also stated that irradiation of food up to a dose of 10 kGy introduces no special microbiological or nutritional problems. Investigations since 1981 have continued to support the JECFI’s conclusions.

Codex Alimentarius issued a general Standard for Irradiated Foods (CAC1983, revised 2003), that any food irradiated up to an overall dose of 10 kGy is safe and wholesome. Irradiation for a phytosanitary purpose in this application has a maximum dose of 1 kGy. There is overwhelming evidence that irradiated food is toxicologically safe, and presents no special nutritional problems. The Food Irradiation Clearances Database shows over 60 countries that have at least one use of food irradiation, 30 countries have approved irradiation as a disinfestation treatment (includes approvals for delayed ripening and inhibition of sprouting), about 23 countries have approved irradiation up to 1 kGy for all fruit and vegetables and, 12 countries for specified fruits and vegetables (including Australia and New Zealand through FSANZ 1.5.3) (IAEA 2011).

Various studies on toxicology and chemistry of irradiated foods and food components have been reviewed, particularly of alkylcyclobutanones (ACBs). These substances also exist in non-irradiated foods and in foods processed by more conventional processes such as cooking. While minute amounts of such alkylcyclobutanones were detected in foods that contained high levels of total lipid and palmitic acid, such as in chicken and beef, the amounts as a result of irradiation at doses up to 1000 Gy, if any, would be minute and insignificant, and therefore would not pose a toxicological problem and is safe to eat. The lipid content of these fresh fruits is nil or very low compared to the 5–25% in meat products. No evidence of a hazard has been found on examination of radiolytic products produced.

The American Council on Science and Health (ACSH) and the Centres for Disease Control and Prevention in the US support food irradiation as a science-based technology that has been proven to be safe and effective (Loaharanu 2003, 2007). The use of irradiation provides consumers with a wider choice of safe, high-quality food. The most important public health benefit is its ability to destroy pathogenic organisms in food. The application in this submission is for a phytosanitary purpose, for a maximum dose 1kGy.

FSANZ has previously assessed the toxicological hazard and nutritional adequacy of various irradiated tropical fruits (breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya, persimmon and rambutan) and vegetables (tomato and capsicum) and concluded that there are no public health and safety issues associated with their consumption when irradiated up to a maximum dose of 1 kGy.

At dose ≤ 1000 Gy, carbohydrates, proteins, dietary fibre and levels of minerals or trace elements in fruits and vegetables largely were not affected. Overall vitamin changes were minimal or not significant between treated and untreated fresh produce. The impact of storage rather than irradiation generally impacted fruit nutritional and postharvest quality (QLD DAFF 2012, 2013 – Attachments 1–8) when these effects were reported. As with other food processes, vitamin losses can be mitigated by protective actions (Diehl 1995). Irradiated fruits will be consumed as part of a mixed diet, and the treatment therefore will have little or nil impact on the total intake of specific nutrients.

Irradiation of fresh produce for a pest disinfestation purpose has no microbiological implications and the maximum absorbed dose allowed (1 kGy) is one-tenth of the general maximum permitted under the Codex Standard.

Dietary Intake Assessment

A Dietary Intake Assessment (DIA) for the eleven fruits is useful but the weight of data and evidence obtained from the DAFF studies and other research indicate that irradiation up to 1 kGy is unlikely to have any marked effect on the nutrient content of apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini.

Differences in the levels of irradiation sensitive (pro) vitamins (beta-carotene and Vitamin C) in apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini were within the range of the vitamin losses that would have occurred during storage of non-irradiated fruit. Ripening and other food processing methods have been shown to have much larger impacts on vitamin levels than irradiation treatment.

An estimate of < 2% decrease on population intakes of Vitamin A and Vitamin C was projected in an assessment of the combined cumulative nutritional impacts of all the currently permitted irradiated foods (including tomato and capsicum) (FSANZ 2013 Risk and Technical Assessment report).

Available data indicate that macronutrients (carbohydrate, fat, protein) and minerals of foods are unaffected by irradiation at doses up to 1 kGy.

A robust and very comprehensive DIA was undertaken in a previous assessment (tomato and capsicum) for Australian and New Zealand populations (FSANZ 2013 Risk and Technical Assessment report). FSANZ concluded that the irradiation of tomato, capsicum and certain tropical fruits at up to 1 kGy, and assuming a maximum nutrient loss of 15% nutrient loss applied to all fresh tomato, capsicum, and tropical fruits already permitted in the Standard, is not likely to have any impact on population intakes for any irradiation-sensitive nutrients (i.e. water- and fat-soluble vitamins). Furthermore, dietary intake would typically be derived from a wide range of foods.

At the major food group level, 'vegetable products and dishes' and/or 'fruit products and dishes' are not major contributors (<5%) to thiamine, riboflavin or niacin intakes. The more frequently consumed banana is identified as the major contributor to Vitamin B₆ at the minor food group level. Therefore population dietary intakes of these nutrients in Australia and New Zealand will not be affected by irradiation treatment of these 11 fresh produce.

Vitamin B₁₂, Vitamin D and pre-formed Vitamin A (retinol) are not present in quantifiable amounts in these 11 fresh produce under consideration for irradiation treatment. Much of these vitamins are largely found in animal products (NHRMC 2006) and therefore these 11 fresh produce are clearly not dietary sources of these vitamins. Population dietary intakes of these nutrients in Australia and New Zealand will not be affected by irradiation treatment of these produce.

The impact of irradiation on Vitamin A is also minimal. The major sources of Vitamin A for Australian and New Zealand children are carrots, similar root vegetables and milk. In older age groups vitamin A contributions are sourced from animal organ meats and dairy products. In a previous assessment on tomato and capsicum, FSANZ found that even a worst case scenario of 15% carotene loss the impact of Vitamin A intakes was minimal (<1%) and mean intakes remained above the Estimated Average Requirements (EAR).

Similarly the FSANZ assessment on tomato and capsicum, using a worst case (15% loss) scenario for Vitamin C loss was 2% for older Australian and New Zealand population groups and ≤1% for all other population groups. Mean intakes were above the EAR in all population groups.

There is currently no data available on the proportion of fresh apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini that may be potentially irradiated. Estimates on production volume of these fresh commodities are provided in the application however the proportion available for sale as irradiated produce in Australia and New Zealand can be expected to be lower.

On the Australian domestic scene, fruit produced in endemic fruit fly areas that is being sent to areas free of fruit fly are required to undergo phytosanitary treatments. Current treatment options available for regulated pests include - cold disinfestation, heat treatment, chemical treatment (insecticides and fumigants), systems approach, conditional non-host status and irradiation (n.b not all treatment options are available for the crops listed in this application). However, not all fruit produced in endemic fruit fly areas requires treatments as the major markets on the east coast of Australia (Brisbane, Sydney, Melbourne etc.) are within endemic fruit fly areas and phytosanitary certification is not required. As such it is difficult to estimate the percentage of fruit within Australia that will require treatment.

For New Zealand, which is free of fruit flies, all imports from fruit produced in endemic fruit fly areas will require treatment. Fruit produced in fruit fly free areas (e.g Tasmania) will not require treatment. As such it is difficult to estimate what percentage of fruit will require irradiation treatment given that the need to treat fruit will vary with each commodity and where that commodity is produced.

Other implications

Irradiation at low doses is an effective alternative treatment that is safe to use. The treatment method overall does not significantly impact on the nutritional and postharvest quality of fruit. The approval for its use for a phytosanitary purpose will ensure continued access for fresh produce within Australia and overseas. Literature and QLD DAFF data show this to be the case for many fresh fruits and vegetables. The data indicated that the irradiated fruits treated under the same conditions for a phytosanitary purpose, would not present any nutritional concerns and postharvest quality is not severely impacted.

Packaging materials used for packing these fresh produce are made from the same materials currently approved for use with irradiated mango, papaya and litchi fruit. They are packaging materials suitable for irradiation treatment and comply with regulated articles both domestically and overseas, and approved for use in food irradiation by the US Food and Drug Administration (US FDA). The irradiation treatment does not impair package integrity nor deposit toxic radiation reaction products or additives on the produce.

Packages containing treated produce will be labelled in accordance with the labelling requirement as stated in FSANZ Code Standard 1.5.3. Labelling identifies that the fruit was treated by irradiation and ensures that all parties are informed, thus providing choice for consumers. Interestingly, foods that are chemically treated do not have to be labelled.

The irradiation facility carrying out the treatment will be a licensed and regulated radiation facility, and abides by requirements of good manufacturing practice (GMP) and acts in accordance with the Codex Alimentarius General Standard for Irradiated Foods (2003b) and its associated Code of Practice for the Operation of Irradiation Facilities Used for the Treatment of Foods (1983). Proper dosimetry systems and compliance by the approved irradiation facility with accurate records allow tracking of the irradiated produce from receiving through shipping.

Australia has very strict food safety standards that apply to retail, wholesale, exporting and processing. These standards are developed jointly by leading Australian retailers and Food Standards Australia New Zealand (FSANZ). All reputable Australian and New Zealand fruit and vegetable producers operate an independently audited HACCP-based

food safety system. These systems cover all facets of production and include periodic testing of fruit to ensure it complies with maximum residue level (MRL) requirements in proposed destination markets.

Conclusion

The approval of irradiation of apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini for a phytosanitary purpose will provide a safe and effective option to maintain market access throughout Australia and New Zealand for those fruit crops grown in areas with endemic fruit fly populations and/or other regulated pests. Consumers will benefit from the continued availability, choice and price stability of these fresh produce. The harmonisation of phytosanitary irradiation treatments for regulated pests could mean access to new markets for Australian and New Zealand fresh produce, particularly for commodities whose production period is counter-seasonal to that of the importing country.

PART 1 – GENERAL INFORMATION

1.1 Applicant

(a) Name of Organisation: Queensland Department of Agriculture, Fisheries and Forestry
A.B.N. 66 934 348 189

(b) Address: 21 Redden Street
PO BOX 652
CAIRNS
Qld 4870



(d) Nature of Applicant's Business:

Queensland Department of Agriculture, Fisheries and Forestry (QLD DAFF).

QLD DAFF brings together specialist knowledge, networks and services to work with significant businesses and industry sectors to support the economic development for the benefit of all Queenslanders.

The Department's mission is to maximise the economic potential for Queensland's industries on a sustainable basis. The Department strives to ensure Queensland's industries support sustainable production systems and use best practice in water management and water allocation, vegetation and pest management, and chemical use.

Profitable primary industries create jobs, expand Queensland's export markets and support economic growth.

(e) Other companies associated with application:

Horticulture Australia Limited (HAL)

Australian Department of Agriculture, Fisheries and Forestry (DAFF Aus)

New Zealand Fresh Produce Importers Association, Inc.

Steritech Pty Ltd

Vegetable R&D Levy

Bowen District Growers Association

Portions of this Application have been reproduced from applications previously submitted by the Queensland DAFF:

- A1038 Irradiation of Persimmon and;
- A1069 Irradiation of Tomatoes & Capsicums

1.2 Nature of application

This application seeks an amendment to an existing standard: Standard 1.5.3 – Irradiated Foods (FSANZ, 2003), to provide for the safe use of ionising radiation (irradiation) as a phytosanitary measure for Apple, Apricot, Cherry, Honeydew melon, Nectarine, Peach, Plum, Rockmelon, Strawberry, Table grape and Zucchini / scallopini only.

1.3 Support for the application

Letters of support (Appendix 7) from

Australia:

- Steritech Pty Ltd
- Queensland Strawberry Industry
- Cherry Growers Australia Inc.
- Australian Melon Association Inc.
- Apple and Pear Australia Ltd (Apple Sector)
- Low Chill Australia
- Bowen Gumlu Growers Association
- Bundaberg Fruit & Veg Growers
- AUSVEG
- Fruits of Byron
- CSI Group Pty Ltd
- LaManna Group
- Costa

New Zealand:

- New Zealand Fresh Produce Importers Association, Inc.
- Fresh Partners (Pacific) Ltd

PART 2 – SPECIFIC INFORMATION

2.1 Details of the application

This application seeks amendments to the Food Standards Code, Standard 1.5.3 to include the following fruits:

- apple (*Malus domestica*)
- apricot (*Prunus armeniaca*)
- cherry (*Prunus avium*)
- honeydew (*Cucumis melo*)
- nectarine (*Prunus persica* var. *nectarina*)
- peach (*Prunus persica*)
- plum (*Prunus domestica*)
- rockmelon (*Cucumis melo*)
- strawberry (*Fragaria x ananassa*.)
- table grape (*Vitis vinifera*)
- zucchini and scallopini / summer squash (*Cucubita pepo*)

For all commodities listed above there is a wide range of varieties available to producers but all significant commercial varieties fall into the respective genus above. The edible portions of zucchini/scallopini are botanically fruits, but are usually classed as vegetables in nutritional tables. This application will refer to zucchini as a fruit and all references to zucchini also include scallopini.

The above fruits are potential fruit fly hosts and are subject by regulation to plant quarantine (phytosanitary) treatments against fruit fly and other regulated pests¹ as a condition of entry and/or movement into certain plant quarantine¹ jurisdictions. This applies to both domestic and international markets.

The use of irradiation as a quarantine treatment for fruits and vegetables² harmonises the domestic and foreign requirements for the movement of all fruit and vegetables that are hosts of quarantine pests and relieves unnecessary restrictions for producers.

¹ Plant quarantine - All activities designed to prevent the introduction and/or spread of quarantine pests or to ensure their official control. Pest - Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (FAO 2010). A pest is considered neutralized when it is killed, rendered sterile or its further development into an adult is stopped.

² Fruit to be treated should be of good overall quality and reflect the results of good agricultural practices (GAP). Fruit should be in an acceptable hygienic condition appropriate for the purpose of such processing. Recommended handling and storage procedures should be used prior to and after treatment.

Under the proposed amendment to Standard 1.5.3 it would be permitted to irradiate apple, apricot, cherry, honeydew melon, peach, plum, rockmelon, strawberry, table grape and zucchini as a postharvest phytosanitary treatment between a minimum dose of 150 Gray (Gy) and a maximum dose of 1000 Gy. The defined minimum absorbed dose will depend on the specific pests to be treated and directives from quarantine agencies.

The amendment to Standard 1.5.3 would provide the affected industries with a phytosanitary option that is

- Justified (Part 2.3) due to a technical need for alternative options for phytosanitary treatments -
 - To provide an alternative method to using insecticide treatments;
 - To maintain existing and ensure continual access of the selected fresh produce from fruit fly endemic areas to other states of Australia which are either totally or partly free from fruit flies (and other regulated pests);
 - To re-open and further expand export markets such as New Zealand;
 - To assist and maintain the economic viability of important segments of the horticulture sector and health of regional communities;
 - To provide consumers with a full range of choice to these fresh commodities, with sufficient labelling to clearly inform consumers of the treatment method (Standard 1.5.3 Mandatory labelling, Appendix A).
- Toxicologically safe and which results in nutritionally adequate food (Part 3.2).
- Highly effective as a broad spectrum method of pest disinfection that is more practical than most other non-chemical treatment options and is cost-competitive (Part 2.2). Apple, apricot, cherry, honeydew melon, nectarine, peach, plum, strawberry, table grape and zucchini are radio-tolerant of low dose irradiation.
- Approved by the international authorities responsible for international standards and guidelines in the fields of human and plant health and by many national authorities (Part 4) and which is being put into practice in Australasia, North America and Asia (Part 2.2).

2.2 Purpose and efficacy of the proposed variation

Purpose

The purpose of the proposed variation is to provide the apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini industries with the option to use irradiation as a phytosanitary measure. Approval of an accepted phytosanitary measure for a disinfection purpose can ensure biosecurity and limit disruptions to market access and trade of these fresh commodities. The fruits of concern are potential hosts to fruit flies and other regulated pests, which are subject by regulation to phytosanitary treatments against specified pests as a condition of entry into many plant quarantine jurisdictions, in both domestic and international markets.

In Australia, usage restrictions have been imposed on the two commonly-used chemical insecticides, dimethoate and fenthion. Their restrictions and suspensions together exposes the horticulture industry to major market access disruptions, both domestic and export markets.

Suspensions and restrictions imposed on these chemical pesticides on a range of fruits and vegetables has resulted in the loss of market access protocols that incorporate postharvest use of the chemicals. For example the New Zealand export market trade in tomato and capsicum ceased until irradiation was approved in August, 2013. For domestic trade, these industries currently have several options available which include the use of systems approaches or methyl bromide fumigation.

The addition of irradiation as a regulatory treatment will diminish the dependence on other currently available treatments, such as insecticides, fumigants and thermal treatments. Its use to mitigate pest risks is less detrimental to the environment and to the fruit dispatched at the doses for tephritid fruit flies (Hallman 2007). The horticulture industry also has to deal with the rising costs and increasing occupational safety and health issues associated with the use of chemicals in the supply chain.

Other postharvest options for example, heat treatments, cold disinfestation, fumigants, new insecticides are available, although unsuited for use for particular fresh produce due to possible phytotoxicity and quality issues, length of treatment time, as well as costs or the time frame needed to gain approval from quarantine authorities. Irradiation is a cost-competitive disinfestation process that is simple, safe, efficacious and already in use for some Australian exports, for example, litchi, mango, papaya, tomato and capsicum.

While pesticide usage in these industries is being modified through increased utilisation of integrated pest management in the orchard and system approaches, the need for strategic pesticide use and other postharvest technological method continues. The purpose of the proposed variation is to provide industries with the option to use irradiation as a phytosanitary measure so that the marketing of fresh fruits between geographical regions within Australia will not necessarily be disrupted. This will apply also to international market access.

Irradiation is a proven and sound technique for insect disinfestation in a range of tropical fruits (Moy 1985, Moy and Wong 2002, Moy 2005). Irradiation is a rapid treatment and treated produce can be released into trade immediately. Approval to irradiate these fruits for a phytosanitary purpose will allow transition by the industry to irradiation technology and minimize potential economic loss to the horticulture industry.

Thus irradiation is potentially a valuable treatment for the apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini trade in ensuring biosecurity and phytosanitary requirements are met. It is anticipated that industry can commercially incorporate irradiation treatment into their supply chain with minimal impact on efficiency and profitability of the supply chain. Successful incorporation of irradiation treatment can be seen in the mango, papaya and litchi examples.

Approval for the use of irradiation regulatory treatment would promote and facilitate trade, the outcome being national trading protocols for fruit fly host product are consistent across Australia and New Zealand and with international standards.

Efficacy

Australian and New Zealand quarantine agencies support irradiation against fruit flies and other regulated pests. Previously both Aus DAFF Biosecurity and the NZ Biosecurity provided letters to FSANZ endorsing irradiation as an effective quarantine treatment for fruit fly and other pests that are of quarantine concern to Australia and New Zealand.

Further support for the efficacy of irradiation as a phytosanitary treatment for fruit fly exists in the United States (US), with approved generic irradiation doses of 150 Gy to reduce fruit fly infestation on specific fruits (USDA Animal and Plant Health Inspection Service (APHIS) 2006).

To date, FSANZ has approved the irradiation of herbs, spices and herbal infusions and the irradiation of ten tropical fruits (breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya, persimmon and rambutan) and two vegetables (tomato and capsicum). FSANZ has established that there is a technological need to irradiate these foods, and that there are no safety concerns or significant loss of nutrients as a result of irradiation.

The end point of phytosanitary irradiation is not acute mortality but prevention of further biological development and reproduction. Since insects do not rapidly die after irradiation, extensive research by various plant protection agencies and by the IPPC ensuring that the treatment is efficacious have been undertaken. This has resulted in the issue of an International Standard (IPPC 2003 as ISPM No.18) that addresses the concern regarding efficacy.

Examples of previous approvals by the New Zealand authorities for irradiation for quarantine purposes include, fresh mango (MAF 2009a), papaya (MAF 2009b), litchi (MAF 2008), capsicum (MAF 2013b) and tomato (MAF 2013c) from Australia to New Zealand (MAF 2013a, Standard 152.02 Importation and Clearance of Fresh Fruit and Vegetables into New Zealand). Irradiation is the approved treatment for the insects of concern to New Zealand and the minimum dose required by New Zealand for the insect pests of concern is 150 Gy.

Australia has approved irradiation as a treatment for Indian mangoes (BA 2008). In 2009, Malaysia approved irradiation as a treatment for Australian mangoes (DAFF MICOR 2013), with the minimum dose of 300 Gy.

In Australia the national Interstate Certification Assurance (ICA) Scheme as Operational Procedure Number 55 (ICA 2011) permits the use of irradiation for phytosanitary purposes for fresh fruits and vegetables for domestic trade. ICA 55 applies to any fresh produce approved by FSANZ and currently includes 10 fresh fruits and two vegetables. This procedure conforms to the principles of ISPM 18 and 28. The minimum doses required are 150 Gy for fruit flies of the family *Tephritidae*, 300 Gy for the mango seed weevil and 400 Gy for all pests of the class Insecta except pupae and adults of the order of Lepidoptera.

Efficacy –phytosanitary effectiveness

The principles of radiation processing are well-understood. Operational controls are based on internationally agreed and established protocols. While industrial radiation processing has been a global commercial business for over 50 years with applications that include sterilisation of medical, pharmaceutical and other products and the cross-linking of polymers (IAEA 2008), approval and uptake for irradiation processing of food has been slower. The main applications are to eliminate food pathogens, to control maturation of horticultural products and to provide a postharvest method of disinfestation for fresh produce.

Use of low dose irradiation to sterilise insect pests has been known for many years (Koidsumi 1930). Its use as a quarantine treatment however was not considered seriously until recently, in the USA. Bilateral agreements between countries (or states) are required

and there was no international guidance on how this could be safely and fairly conducted until 2003.

In 2003, the International Plant Protection Convention (IPPC) published its *Guidelines for the Use of Irradiation as Phytosanitary Measure* International Standards for Phytosanitary Measures 18 (ISPM 18 – IPPC 2003). ISPM 18 outlines basic protocols that countries should adopt when trading in irradiated fresh fruit and vegetables. This standard is recognized under the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) to which Australia and New Zealand are signatories (WTO 2011).

The required treatment efficacy for the eleven fruits will comply with ISPM 28, *Irradiation Treatment for Fruit Flies of the Family Tephritidae* (generic) (Annex 7) (IPPC 2009) at 150 Gy minimum absorbed dose to prevent the emergence of adults of fruit flies at the stated efficacy. This treatment should be applied in accordance with the requirements outlined in ISPM 18 (2003). This irradiation treatment should not be applied to fruit and vegetables stored in modified atmospheres.

ASTM International produced a *Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment* (ASTM 2006) where it details procedures for the radiation disinfestation of fresh produce for a quarantine treatment, with an absorbed dose range between 150 Gray (Gy) and 600 Gy. The practical maximum dose may be higher or lower, depending on the radiation tolerance of a particular type of fruit.

The International Database on Insect Disinfestation and Sterilization (IDIDAS) contains over 3300 references of technical data on irradiation studies of 300 species of arthropods (FAO/IAEA 2011a). For almost all insects the minimum phytosanitary doses lie in a narrow dose range, between 100 to 600 Gy (ASTM 2006, Hallman 2011, Arvanitoyannis and Stratakos 2010a). Irradiation is unique among phytosanitary treatments in its ability to be a broad-spectrum treatment for almost all important arthropod pests. In turn, this led to the consideration of a “generic” minimum dose that would guarantee sterility and/or mortality in all or a defined sub-set of arthropods in any host plant material (Follet and Neven 2006).

In 2006, the US Department of Agriculture ruled that 150 Gy was a generic minimum dose for all Tephritid fruit flies and that 400 Gy was a generic minimum dose for all insects except pupae and adults of Lepidoptera in all fruits and vegetables (USDA 2006). By 2009, the IPPC adopted ISPM 28 which includes acceptance of 150 Gy as a generic minimum dose for all Tephritid fruit flies in all host fruits and vegetables (IPPC 2009).

The USDA has accepted a set of generic irradiation doses for many fruits exported from Hawaii, Vietnam, Thailand, India, Pakistan, Malaysia and Mexico to the US mainland (USDA 2007a, b, 2008a, b, c, 2010, 2011a).

The use of irradiation for phytosanitary purposes for domestic trade was approved by all states and territories in Australia in 2011, under the national Interstate Certification Assurance (ICA) Scheme as Operational Procedure Number 55 (ICA 55). ICA 55 applies to all insects, excluding only Lepidoptera that pupate internally, and to all fruits and vegetables for which FSANZ has approved the use of irradiation, and conforms to the principles of ISPM 18 and 28.

ICA 55 also sets the minimum doses required as follows –

- 150 Gy for fruit flies of the family Tephritidae.
- 300 Gy for the mango seed weevil.

- 400 Gy for all pests of the class Insecta except pupae and adults of the order of Lepidoptera.

Efficacy – commodity tolerance

A phytosanitary treatment of a fresh fruit or vegetable may be effective but it will only be used commercially if it does not degrade the qualities valued by consumers. Reviews on radio-tolerance of various fresh commodities have been conducted by Akamine and Moy (1983), Kader (1986), Urbain (1986a), Thomas (1986a, b, c and 1988), Morris and Jessup (1994), Wall (2008) and Arvanitoyannis and Stratakis (2010b). Possible adverse effects of irradiation on fruit quality such as softening, altered ripening, pitting, darkening, discoloration, scalding, loss of flavour or aroma, lower vitamin C and organic acids were observed in various fruit and vegetables but the reports appear confusing and conflicting. Economics however dictate that growers and retailers will also be interested in any change in shelf-life.

Postharvest quality at potential maximum irradiation doses to ensure fruit quality while providing quarantine security is significant in considering using irradiation as a phytosanitary method. Many of these studies was completed before irradiation was recognized internationally as a phytosanitary option and at a time when the purpose of irradiation was usually to increase shelf-life either through delaying ripening or controlling spoilage organisms. Much of the literature describes fruit quality effects at doses exceeding 1 kGy and, significant decrease in storage decay in fresh produce generally involved doses in excess of 1 kGy.

QLD DAFF (2012, 2013) conducted assessments on the postharvest quality of Australian apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini after irradiation doses in the disinfestation range up to 1 kGy (see Attachments 1–8). Export quality fruit were tested. Postharvest fruit quality was assessed immediately after irradiation and after removal from recommended periods of cold storage. Tests included fresh weight, fruit firmness, skin and/or flesh colour, biochemical analyses for soluble solids and titratable acidity, and the incidence and severity of disorders and disease.

QLD DAFF (2012, 2013) concluded that the application of up to 1 kGy irradiation did not result in any detrimental damage to the postharvest quality of apple, apricot, cherry, peach, plum, rockmelon, strawberry, table grape and zucchini fruit. Fruit quality in honeydew melon and nectarine tolerated doses below 600 Gy. The fruit quality parameters assessed was impacted to a greater extent by storage time than by irradiation.

The absorbed dose, commodity maturity and physiological state at harvest, pre- and post-irradiation handling, storage environment and storage time all interact to affect product quality and shelf-life. Different outcomes after similar treatments can occur between different varieties of the same fruit or vegetable. These complex interactions and the varying extents to which researchers took them into account or reported on them have resulted in literature that can appear confused and conflicting, as noted by Thomas (1988), Morris and Jessup (1994), Wall (2008) and Arvanitoyannis and Stratakis (2010b) and QLD DAFF (2012, 2013 Attachments).

Irradiation at around 1 kGy can produce multiple effects on fresh fruits and vegetables, and can easily confound some of the generalisations (Morris and Jessup 1994). Some of these include

- initial softening in the first few hours after irradiation; better retention of firmness in irradiated unripe fruit; general softening after higher doses (> 1 kGy);
- an increase in respiration (CO₂ and ethylene production) in some pre-climacteric fruit which can be associated with accelerated ripening in some fruits or a delay in ripening in others; yet other fruit experience a delay in ripening with no increase in respiration;
- no delay found after the onset of climacteric respiration;
- some respiration increase in non-climacteric fruits, mimicking the climacteric;
- external and internal damage (discolouration, surface pitting, spotting, blackening, internal cell wall integrity);
- accelerated or delayed colour development.

Overall, there is agreement that majority of fruits and vegetables will be of acceptable quality irradiated at doses within the phytosanitary range up to 600 Gy (Arvanitoyannis and Stratakos 2010b, Heather and Hallman 2008a, b, QLD DAFF 2012, 2013) although many are radiotolerant up to 1 kGy. For example, different outcomes in nutritional quality after similar treatments can occur between different varieties of the same fruit (Thomas 1988, Morris and Jessup 1994, Lee and Kader 2000). It is a well-known fact that the values of nutritional components measured depends upon the degree of ripeness of the fruit, and quite different results would no doubt have been obtained had unripe or over-ripe fruits been analysed.

More types of fresh fruit and vegetables tolerate irradiation than any other commercially available phytosanitary treatment Hallman (2011). An exception may be products that naturally auto-oxidize rapidly, such as avocado. In general, as the dose delivered increases towards 1 kGy, a slight loss of quality can be observed in some fruits and vegetables with loss in firmness and other attributes at doses above 1.5 kGy.

2.3 Justification for the application

“Market access” and “biosecurity” are frequently used in reference to the adequate control of pests and diseases thus allowing the free movement and trade of fresh fruit and vegetables (and other commodities) across borders. The market access concerns relate both to facilitating exports to overseas markets and to interstate trade.

Fruit flies and other regulated pests can interrupt export shipments of fruit and vegetables that are fruit fly hosts to fruit fly free areas in Australia, New Zealand and other overseas markets where these pests are absent. Quarantine restrictions apply. Not unlike the Interstate Certificate Assurance (ICA) scheme in Australia, under a system of plant phytosanitary certification based on quality management principles, accredited businesses must be able to demonstrate it has effective procedures that ensure that the specified produce meets specified quarantine requirements in force.

The harmonisation of phytosanitary irradiation treatments for regulated pests (through ISPM No. 18, ISPM No. 28, ICA 55) to support efficient phytosanitary measures can enhance the mutual recognition of treatment efficacy, which would facilitate trade. Harmonisation of domestic interstate regulation improves and enhances Australia’s capacity to negotiate strong international market access arrangements.

While there are various options (pre- and postharvest) for phytosanitary treatments for apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini (see website DQMAWG, 2013a), the industries have relied quite heavily on the two insecticides, dimethoate and fenthion. A national response to any change in use patterns of these insecticides was co-ordinated by the Office of the Chief Plant Protection Officer (OCPPPO) and details of these activities can be found on the Domestic Quarantine and Market Access Working Group (DQMAWG 2013b) website. Variations in domestic trading regulations and operational procedures may result in added costs to industry and reduced competitiveness. Confusion in market access has already occurred.

This application to FSANZ to amend the Food Standards Code 1.5.3 – Irradiation of food to include apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini demonstrates that irradiation is an effective phytosanitary treatment that is safe and does not cause significant deterioration in the nutritional and postharvest quality of these fresh commodities. The treatment method is available for immediate implementation and already in use as a phytosanitary treatment in Australia and New Zealand and in many other trading partners. The decision to use this option will be a commercial decision by the industry, the supply chain and market.

Concern about pesticide and chemical residues is greater than concern about irradiation in the various surveys conducted in the UK and USA (FSA 2004, Johnson *et al.* 2004, Eustice and Bruhn 2006). This is also the case found in the few surveys in Australasia (Gamble *et al.* 2002, FSANZ 2008). Implications for predicting consumer acceptance of emerging food technologies, including food irradiation are highlighted in other studies (Nunes 2010, Farkas and Farkas 2011, Frewer *et al.* 2011).

In 2002, Moy and Wong indicated that markets in the US are not adverse to irradiated produce if the quality and price are decent and that consumers are increasingly accepting irradiated food. In 2006, the regulatory agency (US Department of Agriculture) had taken the initiative and moved to take the technology forward ruling 150 Gy was a generic minimum dose for all Tephritid fruit flies and that 400 Gy was a generic minimum dose for all insects except pupae and adults of Lepidoptera in all fruits and vegetables (USDA 2006). This ruling has opened up trade between the US and many developing nations such as Vietnam and Thailand.

Irradiated apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini at up to 1 kGy are as safe as non-irradiated apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini.

The Application seeks for permission relating to voluntarily irradiate the fruits of concern for a phytosanitary purpose. The Office of Best Practice Regulation (OBPR) previously stated “it has assessed that applications for permission relating to the voluntary irradiation of fruits and vegetables be treated as machinery in nature and as such do not require the preparation of a Regulation Impact Statement (RIS)” (FSANZ 2013).

This section is limited to providing data for consideration of a qualitative assessment of the costs and benefits accruing from the voluntary adoption of irradiation treatment for the fruits applied for in the Application. It is difficult to assign a dollar value to the impacts and the section has mainly focussed at trade and consumption. Moreover because the decision to adopt irradiation is voluntary, it will be an economic decision as producers would only adopt the option if there are financial gains in it for them.

Only limited amounts of Australian production is exported. In the Australian fresh market, competition is mainly between Australian producers so maintaining domestic market access is high priority. Moreover, the processed fruit and vegetable sector which comprises frozen vegetables and tinned fruit and vegetables accounts for 65 per cent of this sector by market share (DAFF no date).

The following section discusses domestic and export trade in general. For details of the structure of each industry and production, data are provided in Appendix 1. Estimates of consumption and trade are also provided separately in Appendix 1.

Domestic trade

In 2009–10 Australian horticulture had a gross value of production of \$8.407 billion; major product groups were fruit and nuts \$4,060 mil, vegetables \$3023 mil, and nursery, flower and turf production \$1324 mil (DAFF 2012 – Horticulture factsheet 2012). The flow-on benefits of this is significant to all state economies across Australia. The volume of trade in the domestic trade of fruit and vegetables is by far the largest. As most of Queensland’s fruits and vegetables are sold interstate, access to interstate markets is vital to the state, the industries’ ongoing economic viability and regional health.

In Queensland for example, the forecast value for total fruit and vegetables in 2012–13 is \$2453 mil, with total fruit and nuts accounting for \$1334 mil and total vegetables \$1119 mil (Qld AgTrends 2013). Table 1 shows forecast values of production for various fresh commodities.

Queensland DAFF and the horticulture industry consider trade in these fruits and vegetable at risk of market disruption. The forecast value for total fruit and vegetables in 2012–13 is \$2453 million (mil), with total fruit and nuts accounting for \$1334 mil and total vegetables \$1119 mil (Qld AgTrend 2013). The Gross Value of Production (GVP) for grapes is forecast at \$1110 mil, apples \$402 mil, strawberries \$212 mil and melons \$159 mil (Horticulture Factsheet 2012). Access to interstate markets is vital to Queensland’s fruit and vegetable industries as approximately 70% is sold interstate.

The availability of irradiation as an option for the phytosanitary treatment of fruit flies and other regulated pests will fulfil a technical need. Irradiation will provide a viable treatment option for these affected industries, exporters and importers with a chemical free postharvest treatment. Access to an effective treatment may help ensure the economic

viability of growers will not be compromised and consumers not are disadvantaged through decreased availability and increasing prices.

The national Interstate Certification Assurance (ICA) Scheme provides a harmonised approach to the audit and accreditation of businesses trading in fresh fruit and vegetables in Australia. ICA is based on documented operational procedures developed and established by the state or territory's quarantine authority in conjunction with industry and interstate quarantine authorities. Each operational procedure clearly describes the management system, process and controls implemented.

Table 1:GVP, first-round processing and total fruit and nut industry (and zucchini) estimates and forecasts, 2010–11 to 2012–13.

Fruit and nuts	2010–11 ^a (\$m)	2011–12 ^a (\$m)	2012–13 forecast, October 2012 ^b (\$m)	2012–13 forecast, April 2013 ^b (\$m)	Change from October 2012 to April 2013 (%)	Change from last 5-year average (%)
Bananas	283	360	500	500	0	36
Other fruit and nuts	129	232	198	200	1	0
Avocados	170	145	140	140	0	33
Strawberries	74	150	125	125	0	16
Mandarins	89	70	75	64	-15	-18
Pineapples	50	68	71	83	16	24
Mangoes	55	70	70	70	0	-2
Macadamias	35	44	52	52	0	80
Table grapes	32	50	50	50	0	43
Apples	60	40	40	50	25	15
Total fruit and nuts	978	1229	1321	1334	1	21
Zucchini and button squash	33	43	42	42	0	0

Source: Qld AgTrends update April 2013

http://www.daff.qld.gov.au/documents/BusinessAndTrade_IndustryTrends/2299_AgTrends-may-13.pdf

^a Australian Bureau of Statistics final estimates unless otherwise indicated.

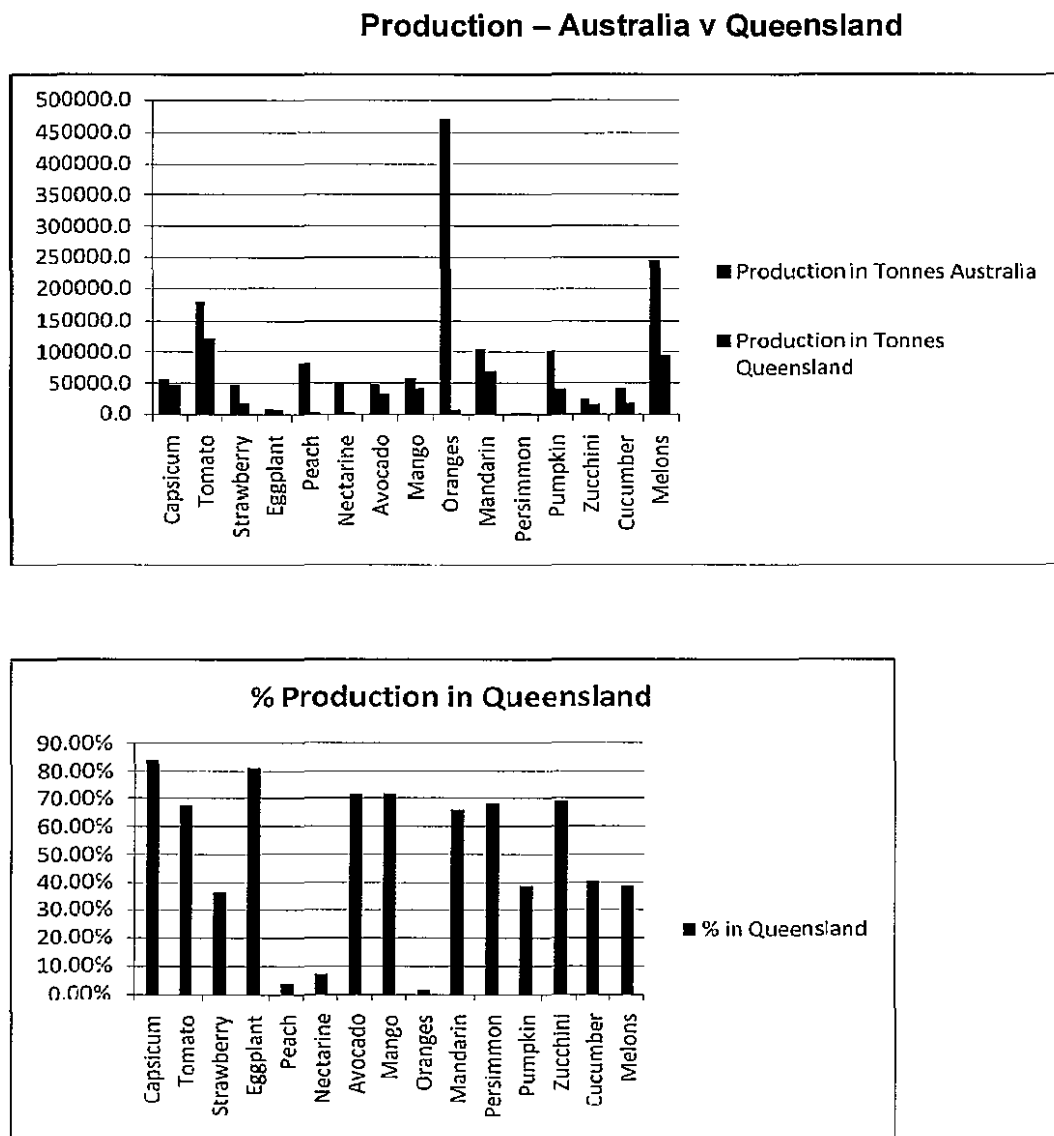
^b DAFF forecasts.

Within Australia, irradiation will be one of several options to replace dimethoate/fenthion treatments. Depending on the commodity, ICA treatments currently approved for domestic interstate trade in Australia include use of other approved chemicals, preharvest treatment or bait-spraying and inspection, unbroken skin condition of approved fruits, green condition or use of cold or heat treatments. The alternative treatments however are

commodity specific and not approved by all states and territories for access to interstate markets.

The production graphs below highlight the significant influence the various horticulture industries have on the supply of domestic product to Australian consumers. Of the Queensland crops, the industries most affected are strawberry, zucchini and melons while peach and nectarine are less affected. Apple and table grape are also affected but not presented in the graphs below. Cherry, plum and apricot are less important or not produced in significant quantities in Queensland. Depending on the production areas and the market destinations, treatment may not be required and other phytosanitary methods are available for the various crops.

Figure 1: Australian and Queensland production and value data for selected industry groups.



Source: QPIF 2009. Top graph – first bar represents Australian production, second bar is Queensland.

The actual volume and value of interstate trade to specific destinations are not fully known. The states expected to require measures to protect against Queensland fruit fly and which may import significant volumes of irradiated Queensland fruit are South Australia, Western Australia and Tasmania. The other states with existing fruit fly hosts will not need to treat these commodities with irradiation. Fruits produced in states other

than Queensland are also not expected to contribute significantly to the percentage of these 11 fresh fruits that may use irradiation treatment as a phytosanitary treatment in the near future.

The data in Table 2 represents estimated volumes and expected consumption of fruit (all types/varieties for that commodity) in Queensland and volumes distributed to South Australia, Western Australia and Tasmania, that may be irradiated. In Queensland, consumption of zucchini, strawberry, table grape and honeydew melon are less than production while consumption of apricot, apple, nectarine, peach and plum exceed Qld production. The data indicates approximate volumes as no accurate measures of commodity movements are available.

Table 2: Estimated production volume and consumption in Queensland and volumes exported.

Product	Qld production ('000 tonnes)	Share of national (%)	Qld consumption ('000 tonnes)	Qld surplus ('000 tonnes)	Likely volume that may be sent from Qld to			Total to Tas, WA, SA ('000 tonnes)
					Tasmania ('000 tonnes)	SA ('000 tonnes)	WA ('000 tonnes)	
Zucchini and squash	19.20	80	4.1	15.12	0.72	1.92	2.40	5.04
Strawberry	26.00	45	9.7	16.33	0.72	3.35	-	2.04
Table grape	14.40	12	13.6	0.76	2.27	4.86	4.34	1.38
Honeydew melon	3.71	44	1.4	2.29	0.24	0.71	-	0.947
Apricot ^a	-	0	1.4					
Apple ^b	31.54	12	44.9					
Nectarine ^b	2.26	6	6.7					
Peach ^b	1.50	6	4.5					
Plum ^b	0.50	3	3.2					

^a No measurable Qld production ^b No surplus – production less than demand
Source: Fresh Intelligence Consulting 2013a.

Export trade

Australia is considered a niche, high quality exporter of fruit and vegetables and can supply in counter seasons to the northern hemisphere although a very small player (1%) by world standards. Horticulture is the third largest industry within the agricultural sector in Australia and has a strong domestic market focus. With a strong domestic market in Australia, profitability is often higher than in export markets and is a disincentive to develop export competitiveness particularly with a high Australian dollar.

In a 2008 submission to the Department of Foreign Affairs and Trade Review of Export Policies and programs, HAL estimated that the overall constraint resulting from phytosanitary access was worth about \$400 mil of the level of fresh horticultural exports

(\$800 mil) at that time (HAL 2008). Irradiation as the phytosanitary option can lessen the constraint imposed.

The Australian horticultural industry consists of fruit, vegetables, nuts and nursery products, with various estimates, of approximately 10 % of total horticulture production exported. Export volume and value of the 10 fruit produce considered in the application are shown in Table 3. Zucchini data are difficult to find and the highly perishable produce typically is consumed domestically.

Table 3: Australian fruit exports 2010/2011.

	Exports (tonnes)	\$ mil
Apple	2508.52	6.02
Apricot	310.15	1.47
Dried apricot	103.11	0.71
Cherries	939.31	13.00
Melon	8332.37	13.48
Nectarine	2810.21	8.21
Peach	1155.85	4.45
Plum	3418.90	9.21
Prune	404.33	0.69
Strawberry	720.85	4.68
Table grape	29861.00	79.35
Dried grape	1750.12	6.09
Total		

Source: HAL (2012)

Asia remains the biggest market for Australian fruit and vegetable exports. Data from various sources indicate that fresh asparagus, carrots, cauliflower, onions and potatoes were the main vegetable products primarily exported to Japan, Malaysia and United Arab Emirates, and fresh fruit lines included apples, grapes and oranges, mainly to USA, Hong Kong and Malaysia. While the key markets are in Hong Kong, Japan, Malaysia and Singapore, there are opportunities in New Zealand, the USA and the European Union. China and India are recently opened markets for citrus, apple and mangoes.

A key impediment for accessing these markets is that the presence of various pests and diseases in Australia means potential Asian markets would require phytosanitary measures to be undertaken before market access is granted. The use of dimethoate and fenthion may no longer be acceptable and alternative options need to be developed and negotiated. For example, in 2009, Malaysia advised Biosecurity Australia that from 1 March 2009 all fresh mango fruit must be irradiated prior to export (DAFF MICOR 2013).

There are various import health standards for fruits and vegetables to New Zealand from Australia, and the treatments required to meet New Zealand quarantine requirements depends on the product. New Zealand currently approves irradiation as a disinfestation treatment for fresh mango (MAF 2009a), papaya (MAF 2009b) and litchi (MAF 2008) from Australia. Details for the importation and clearance of fresh fruits and vegetables into

New Zealand can be found on the MAF website (MAF 2013a). More recently, the approval for irradiation treatment for capsicum (2013b) and tomato (2013c) will provide a phytosanitary option to permit market access to lucrative New Zealand markets.

Tables 4a shows Australian export volumes for various fresh commodities from various states and territory, for which data were available and, Table 4b, the volumes of various fresh fruit commodities exported to New Zealand. Table grapes are by far the dominant product in this group of fresh commodities and mostly exported from Victoria. These commodities are exported mainly to non-regulated markets of Hong Kong, Singapore and Malaysia.

Table 4: Exports (tonnes) for selected Australian fresh produce (12 months to March 2013).

Fresh produce	NSW	Vic	Qld	SA	WA	Tas	NT	National
Apple	180.9	1601.9	1566.6	325.6	93.1	368.8		4164
Apricot	67.2	271.7	5.5	3.6	-	0.1		348
Cherry	837.0	514.9	6.2	37.9	-	1499.1		2895
Honeydew melon and Rockmelon	872.7	570.6	4181.1	109.7	1153.3	-	70.8	6958
Nectarine	655.6	4843.3	50.8	12.8	0.2	0.7		5564
Peach	618.9	1419.4	69.9	98.5	22.4	0.5		2230
Plum	1029.5	1569.9	42.6	131.8	428.2	0.5		3202
Strawberry	1.6	21.7	136.2	0.4	623.0	-		783
Table grape	3089.4	54 991.5	463.3	255.9	153.6	7.5		58 961
Zucchini *(Squash)	254.1	25	1134.5	35	5.4	0.2		1454

zucchini most likely included in squash, which includes pumpkin and squash

Source: Fresh Intelligence Consulting 2013b.

Table 4 b. Estimates of Australian export trade to New Zealand.

Fresh produce	Year		
	2010 (tonnes)	2011 (tonnes)	2012 (tonnes)
Apple	-	-	-
Apricot			20
Cherry	-	-	-
Nectarine	-	-	-
Peach	-	-	-
Plum	-	-	-
Rockmelon (includes honeydew melon)	1801	1727	1902
Strawberry	116	139	156
Table grape	1483	710	1968
Zucchini (no data recorded)			

Source: Fresh Intelligence Consulting 2013b.

Irradiation is increasingly approved in many countries for phytosanitary disinfection and approval for its use will provide plant quarantine authorities with an additional phytosanitary option to current phytosanitary measures for fruit flies of the family Tephritidae (ISPM 28, Annex 7). It is effective in promoting harmonization, facilitates trade and encourages bilateral collaboration through the WTO–SPS framework⁴.

Generic doses of 150 Gy for Tephritid fruit flies and 400 Gy for all insects except pupa and adult Lepidoptera was approved by USDA-APHIS (2006) and the generic and specific doses apply to all agricultural products.

⁴ The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) recognizes recommendations from relevant international organizations including the Codex Alimentarius Commission. A worldwide standard for irradiated food adopted by the Codex Alimentarius Commission accepts that irradiation is a food process comparable to heating and freezing preservation of food, accepts the safety and effectiveness of irradiation, and accepts that there are no microbiological and nutrition problems caused by irradiation of food.

Phytosanitary treatments

A range of phytosanitary treatments are currently approved for domestic interstate trade and for export market access. However with usage restrictions and suspensions imposed on dimethoate and fenthion it is essential that an alternative and effective quarantine treatment be available that can be implemented promptly otherwise there could be significant economic loss to industries. Overseas quarantine agencies are also reviewing their phytosanitary procedures and may well insist irradiation treatment for imports. For example, the Ministry of Health, Malaysia, advised Biosecurity Australia that on 1 March 2009 all mango (*Mangifera indica*) fruit must be irradiated prior to export with a minimum irradiation dose of 300 Gy because of Malaysia's concern about the detection of Mango Seed Weevil (MSW) in consignments of Australian mangoes (DAFF MICOR 2009).

The IPPC Recommendation on the replacement or reduction of the use of methyl bromide as a phytosanitary measure (IPPC 2008) has outlined alternative treatments that include cold treatment, high temperature forced air, hot water, quick freeze, vapour heat treatment, controlled atmosphere storage, chemical dip, phosphine, combination of treatments and irradiation as alternative phytosanitary measures for fresh fruit and vegetables. There are advantages and disadvantages for all the various quarantine treatments (EPA 1996, IPPC 2008).

Other protocols may involve the implementation of systems approaches, pest free areas (PFAs), areas of low pest prevalence (ALPPs), pest free places of production, pest free production sites and equivalence.

Irradiation is effective against a wide range of pests. The treatment method is more efficient and less phytotoxic than thermal, cold or fumigation treatments (Moy 1993, Moy and Wong 2002, Heather and Hallman 2008a, Hallman 2011, Follett and Sanxter 2000, 2002, 2003) with product quality generally maintained. From the point of market opportunities, irradiation at the doses for Tephritid fruit flies (<1000 Gy) is the most broadly applicable commercial treatment developed for a pest species.

The USDA supports the use of irradiation for phytosanitary treatments. The ruling by USDA-APHIS in 2006, approving generic doses of 150 Gy for Tephritid fruit flies (USDA-APHIS 2006), applicable to all agricultural products offers exporting countries an alternative to chemical treatments. Exporting countries negotiating trade in fresh fruit and vegetables can use the generic irradiation treatment, which is simple and straightforward. Since its introduction, there have been increasing imports of several tropical fresh produce from developing countries into the US.

Trading partners in Asia, for example, Thailand, Vietnam and India, have developed uniform quarantine treatments using irradiation technology to export fruit to the US and these same countries are currently considering moving to irradiation treatment for imported fruits and vegetables.

Market access is already disrupted and potential loss a serious concern in some commodities. The affected markets are experiencing a shortage of the produce leading to increased prices and they may seek the product from elsewhere. Meanwhile there will be excess supply and unreserved competition which would lead to reduced product price in non-quarantine markets.

Research on heat and cold treatments for example vapour heat treatment (VHT), controlled atmosphere and VHT, and VHT and cold storage has been undertaken but few protocols have been developed and established for the domestic or international markets for these commodities. Various concerns regarding postharvest quality, susceptibility to heat or cold damage, long treatment time and greater treatment costs (Lyons 1973, AFRA

undated, Ding *et al* 2002, Lim *et al* 2007, DQMAWG 2010, Lacson 2007) can make the protocol economically unviable.

The small concentrations of chemical residues in fresh produce treated with any chemical treatment and concerns about phytotoxic effects, are still of significant, increasing consumer concern (Johnson *et al.* 2004, FSA 2004, 2007) and have directed research to focus on non-chemical phytosanitary treatments. Radiofrequency heating, microwaves, ultrasound and pressure treatments are all at experimental stage (chapters in Heather and Hallman 2008b).

In contrast, irradiation does not produce chemical residues. It is known in advance that most fruits and vegetables are radiation-tolerant at low doses (≤ 1 kGy) and that there are approved generic minimum doses for Tephritid fruit flies, mango seed weevil and all other insects except pupae and adults of Lepidoptera in Australia, New Zealand and the USA.

Comparisons between costs for irradiation treatment with costs of other alternative disinfestation treatments while worthwhile are often not simple and straightforward since facility capacity, annual throughput, and amortization method are important factors in the calculation. Hallman (2011), in a more general categorisation, places heated air and irradiation as moderate cost alternatives and cold, hot water immersion and methyl bromide as low cost alternatives.

US\$30/tonne (1996 figures) was quoted for vapour heat treatment for a high throughput plant operating at near full capacity for 20 years (EPA 1996) with another up to US\$400/tonne in the Philippines for treating mangoes destined for China in 2009 (ABW 2009). Lacson (2007) presented Australian data indicating treatment costs of about \$250/tonne for hot water treatment, \$200–250/tonne for vapour heat treatment, \$46–600/tonne for cold treatment and \$50–600/tonne for forced air heat treatment.

The cost for irradiation treatment by an Australian facility is currently in the range A\$50–70 per tonne of fruit (Steritech, private comm.) but the cost is expected to decrease if greater phytosanitary use is made of the irradiation facility. Irradiation treatment cost is greater than the cost of the insecticide treatments although the cost differential would be reduced if the full costs of assurance, occupational safety and health and chemical disposal of insecticides were taken into account. However, the relative advantage of insecticide treatments becomes irrelevant if their use is withdrawn.

Industries will make commercial decisions based only partly on treatment costs. Superior quality of irradiated fresh produce (Hallman 2011, Heather and Hallman 2008b, EPA 1996), rapid turnaround time and convenience offer significant advantages of irradiation over other treatment options.

2.4 Costs and benefits

Horticulture is the third largest agricultural sector in Australia. For 2012–13, in Queensland alone, the total value of the state's primary industry commodities (combined gross value of production and first-stage processing) is forecast at \$15.124 billion (Qld Agtrends 2012). Fruit and nut is forecast at \$1321 mil and vegetables at \$1119 mil.

The approval of this application can ensure continued market access for the fruits of concern and safeguard the economic viability, related community and regional health and downstream effects that come with a mature horticulture industry. An overview of benefits and impacts is presented in Table 5 and considered further in the following sections.

Table 5: Summary of benefits to government and industry.

The Australian Government	State and territory governments	Australian horticultural industries and growers
Unified trade regulations and harmonisation	Improved state quarantine and streamlined regulations	New or improved market access
New and/or improved market access	Unified interstate trade regulations	Increased interstate trade
Reduced management costs	Reduced risk of the introduction of non-endemic fruit flies	Increased international trade
Reduced impact on the environment	Maintain healthy regional communities	Improved and streamlined regulations
Improved regional economies and healthy regional communities	Improved environmental WHS	Improved supply chain
Food security		Improved on-farm profitability
Improved value of non-commercial amenities		Reduced impact on the environment and farm WHS (chemical use)
		Reduced risk of non-endemic fruit flies
		Maintain healthy regional communities

The surveys conducted show that there is limited awareness and understanding of irradiation among consumers, and that the need for information evident. Some updates informing about the use of irradiation as a postharvest phytosanitary treatment option can be found from the various States and Territories and Commonwealth agencies portals.

Irradiation has the following practical advantages when compared with other phytosanitary options:

- it is the only treatment that is internationally endorsed as a generic treatment of fruit flies (ISPM 18, ISPM 28);
- it is a broad spectrum treatment (few insects and other arthropod pests have or can develop resistance);
- free of chemical treatment residues;

- well-tolerated by most fresh produce, generally better than alternatives such as cold, heat, hot water and methyl bromide (Hallman 2011);
- a cold process (no heat is generated during treatment and fruit can be harvested at a more mature stage than fruit that are heat treated);
- penetrating (treatment can be in the final package and is insensitive to the size and shape of the fruit);
- a simple operation depending only on the power of the source and the conveyer speed. It is not sensitive to temperature, humidity or other physical parameters;
- a rapid treatment and treated products are available for immediate distribution into trade;
- cost competitive (see Phytosanitary treatment options).

Discussion and reviews of the history, development and research on irradiation as a phytosanitary treatment can be found in Burditt (1996), Follet and Griffin (2006), Hallman (2000), Heather and Hallman (2008b), Hallman (2011). Molins (2001) provides a summary of the history of food irradiation development and its adoption while US regulatory considerations are examined by Morehouse (2002). Physiological responses of fresh produce - fruits and vegetables, tuber and bulbs - to irradiation are covered elsewhere (Morris and Jesup 1994, Thomas 1986a, b, c, d).

The approval of the application will impact on benefits and costs to exports and imports however the extent and dollar value will be difficult to measure. A report by NZIER (2007) on the benefits of imported fresh fruit and vegetables to New Zealand show gains in the order of 5% and 15% in allocative and dynamic efficiency gains. Productive efficiency gains of between 0.5% and 1.5% are suggested because of the comparative advantage of New Zealand fruit on already competitive world markets. NZIER concluded that welfare gains are between NZ\$19.4 mil and NZ\$58.2 mil for the benefits that they have valued.

The costs from imported fresh fruit and vegetables to New Zealand included perceived biosecurity threats associated with potential entry and establishment of pests and the competitive threat the imports pose to locally grown produce.

To consumers

Assuring the on-going, year-round supply of fresh produce throughout Australia will ensure that consumers can continue to access their favourite nutritious foods. Maintaining existing supply, including shipments from Queensland to other states, will guard against periodic shortages and price rises.

The benefits of irradiation as a safe and efficient treatment for the postharvest treatment of fruit and vegetable are well documented in as early as 1987 (Morris 1987). Irradiation of fruits at low levels, usually less than 1.0 kGy, is applied to control or kill insects and pests, and extend shelf-life or delay spoilage. This low dose treatment was shown to only cause minimal changes in nutritional and organoleptic qualities of fresh produce. This is also demonstrated more recently with research conducted by QLD DAFF across a wide range of fresh commodities (2012, 2013).

The safety of food irradiation has been studied more extensively than any other food preservation process, including freezing, canning, dehydration and chemical additives. Radiolytic products that may be formed are similar to thermolytic products in heat treatment of foods. The amounts that are found have been demonstrated to be non-toxic by any modern toxicological methods (Loaharanu 2003).

Part 3.1 considers the nutritional adequacy of irradiated produce. In summary, no significant change in dietary intake of nutrients will occur as a result of consuming irradiated (low dose) apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini. The nutritional value of fresh fruits and vegetables that have been irradiated is essentially unchanged (see 3.2 nutritional data). Postharvest fruit quality of these fruits generally is not affected by low dose irradiation with the exception of honeydew melon and nectarine, at doses ≥ 600 Gy. The irradiation treatment had significant effect on the quality of honeydew melon and, to a lesser extent, nectarine fruit. In both cases, the incidence and severity of symptoms (namely skin browning and pitting) increased with dose level; being observed only at the end of the recommended storage period. Specifically, symptoms in honeydew melon occurred only when treated to a dose of 600 Gy and above, with up to 51% of the skin surface area being affected. In contrast, irradiation damage in nectarine fruit was comparatively low across all the treatments ($< 1\text{cm}^2$ skin area affected), with only a small proportion of fruit (3%) affected at 150 Gy. However, this increased significantly to greater than 13% of fruit affected at a dose of 600 Gy and above.

Irradiation is an effective phytosanitary method that leaves no chemical residues. High quality fruits and vegetables can be shipped to quarantine sensitive regions and states and the possibility of cross-contamination prior to reaching the consumer is minimised since produce is treated after packaging.

The concept of chemiclearance is recognised to include all irradiated fruits and vegetables since they will be treated in the same way for a disinfestation purpose. Generic irradiation treatments at the low dose rate of 150 – 1000 Gy is proven and effective because irradiation is broadly effective against fruit flies at doses that typically do not harm product quality (Follett and Armstrong 2004, Follett and Neven 2006, Wall 2008).

In its assessment of Application A443 Irradiation of tropical fruits – breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya and rambutan, FSANZ concluded that “.... irradiation would have minimal impact on the nutrient status of the tropical fruits.

In its assessment of Application A1038 Irradiation of persimmon, FSANZ concluded that...”available data indicate that the carbohydrate, fat, protein and mineral content of foods are unaffected by irradiation at doses up to 1 kGy. Therefore, irradiation is unlikely to affect the presence of macronutrients and minerals in persimmons.”

In its assessment of Application A1069 Irradiation of tomatoes and capsicums, FSANZ concluded that “....there are no public health and safety issues associated with the consumption of tomatoes and capsicums which have been irradiated up to a maximum dose of 1 kGy. Available data indicate that the carbohydrate, fat, protein and mineral content of foods are unaffected by irradiation at doses up to 1 kGy.”

Packaging materials currently used by the produce industry are diversified however while FSANZ ruling does not specify the specific packaging materials, they comply with ASTM Standard *Guide F1640-09* (ASTM 2009), materials have been approved by the Food and Drug Administration in the US. These same packaging types are already in use for packing of shipments of mango, litchi and papaya that have been irradiated and shipped to New Zealand.

Consumers are assured that the processing and handling of fruit before and after irradiation adhere to good manufacturing principles and quality assurance systems. Additionally, the reduction in surface spoilage bacteria and mould of irradiated fruit and vegetables could reduce wastage and extend shelf life (Akamine and Moy 1983, Prakash and Foley 2004, Niemira and Fan 2006, Jordan 2007), which can offset the added costs of irradiation. The cost of irradiated foods is expected to decrease as irradiated foods become more widespread and continuously gaining acceptance.

Consumer attitudes and responses to irradiated foods are discussed in detail in Part 5.7. Nevertheless, the export of irradiated mango to New Zealand is a success story for Australian horticulture. According to the Australian Mango Industry Association (Sexton-McGrath 2010), New Zealand is the fastest growing market for Australian mango.

Consumers increasingly perceive a human health risk from chemical pesticide/insecticide residues in food. Their tolerance for more regulation or to pay more for residue-free food however varies (Baker and Crosbie 1993, Baker 1999, FSA 2004, 2007). Irradiation leaves no toxic residues in food while producing a safe, nutritionally adequate product (JECFI 1981, FSANZ 2011a). Surveys of public opinion have often shown initial reluctance among consumers to consider eating irradiated foods (Part 5.3). However, the level of support for irradiated food increases when accurate information is provided, and is greater than for chemically treated food (Gamble *et al.* 2002, Johnson *et al.* 2004, FSA 2004, Eustice and Bruhn 2006).

Some consumers are likely to always reject irradiated foods and want to avoid consuming them. The mandatory labelling requirements of Standard 1.5.3 (Appendix 3) will ensure that consumers are informed that the food has been irradiated and that they can make informed choices.

There is a published Codex Standard for Irradiated Foods (CAC 2003a) and Recommended International Code of Practice for the Operation of Radiation Facilities Used for the Treatment of Foods (CAC 2003b) and regulated by responsible government entities.

Research showed that macronutrients, such as protein, carbohydrates, and fat, are relatively stable to radiation doses of up to 10 kGy. Under optimal conditions, vitamin losses in foods irradiated at doses up to 1 kGy are considered insignificant. While the level of some of the B-group vitamins can be reduced by irradiation, the losses also occur in other food preservation technologies, such as canning or blanching. In general, the irradiation process produces very little chemical change in food.

To Governments

The horticulture industry is the principal driver of many local and regional economies. Overall Queensland accounts for about one third of Australian horticulture with another third along the Murray Darling Basin. 83 % of the land area in Queensland (173 million hectares) is used for agricultural production (Qld AgTrends 2012).

Queensland is Australia's premier State for fruit and vegetable production, growing one-third of the nation's produce with horticulture as Queensland's second largest primary industry, worth more than \$2 billion per year and employing about 25,000 people.

The horticultural industry contributes significantly to the prosperity of people living in rural and regional Australia. It is a primary and secondary source of income for families in regional Queensland and Australia. Horticulture also accounts for about 20% of total employment in agriculture, employing about 100 000 people (HAL, 2012). There are 63

300 people employed in Australia to grow fruit, vegetables and nuts for the domestic and export markets. Another 9800 are employed in fruit and vegetable processing (excluding wine manufacturing) (HAL 2012, source: DAFF Australian Food Statistics 2009–10).

Fruit and nuts and vegetables are major contributors to regional economies and the foundation of many regional communities. It is the most labour intensive of all agricultural industries with labour representing at least 50 % of the overall operating costs. It is an industry with a significant link to the tourism industry, providing income for backpackers each year. It supplies local, interstate and overseas markets through a range of outlets including wholesalers, supermarkets, green grocers, farmers' markets and direct to consumers. Excess production is traded. Phytosanitary measures are regulations to prevent introduction or spread of quarantine pests and must be followed if interested parties are to ship regulated articles (fresh produce) out of quarantine areas.

Growers will continue to produce the fruits and vegetables only while it is profitable. Imports are considered an alternative to domestic production and sales although Australia is a net importer of processed fruit and vegetable products and imports of fresh commodities are growing (Foster *et al.* 2010, HAL 2012 data). While 9 % of the vegetables Australia produces are exported, 19 % is imported for consumption and 13 % of fruit production is exported compared to the 34 % imported for consumption as processed vegetables and fruits (Growcom 2011). Thus, it is significant that access to markets be maintained.

There will be reduced use and less dependence of pesticides resulting in greater environmental benefit. The risks to environmental quality are negligible because of adherence and compliance to proper safety procedures regulated by the relevant authorities.

Reviews of the benefits of ionizing radiation as an alternative treatment for various purposes are well documented, as indicated previously, and there are international standards relevant to the irradiation of fruit and vegetables. Irradiation is a phytosanitary option used around the world including the United States and is approved by the World Health Organisation and Australian Government.

The treatment method has been successfully tried and tested and, been applied for several types of food in more than 30 countries, including Canada, Japan, France, the Netherlands, Belgium, South Africa, Australia, China, India, Mexico, Vietnam, Thailand and the United States. These clearances can be viewed on the IDIDAS Database (FAO/IAEA 2011a).

Extensive studies conducted over more than 50 years supports the safety of irradiated food for consumption (Diehl 1995, WHO 1994, WHO 1999). The overall conclusion is that there is very little chemical change in irradiated foods and the radiolytic products formed with irradiated fruit (if any) up to a maximum of 1 kGy does not present any health problems.

The FAO/IAEA/WHO Expert Committee on Food Irradiation (JECFI) concluded that "...the irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard, hence, toxicological testing of food so treated no longer required." In the same report, that "...irradiation of foods up to an overall average dose of 10 kGy introduces no special nutritional or microbiological problems" (WHO 1981).

Fruit is treated in a special fully licensed and regulated processing facility after grading and packaging thus avoiding re-contamination or re-infestation of the product. There are approved packaging materials suitable for irradiation treatment. The facilities that carry out the treatment are approved and licensed facilities for the purpose, the correct doses

used are as required by law and only good quality produce accepted for irradiation as the treatment cannot be used as a substitute for poor hygienic practices.

Various International Standards already exist for the application for irradiation of fruits and vegetables. New Zealand and Australia are members of the World Trade Organisation (WTO) and have obligations under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). The SPS Agreement (WTO 2011) recognizes the standards, guidelines and recommendations of competent international organisations. These international organisations include the Codex Alimentarius Commission for human health. Codex has adopted a General Standard for Irradiated Foods which in summary, recommends that irradiation should be regarded as any other food process and as providing a safe and nutritionally adequate product up to a maximum dose of, generally, 10 kGy (CAC 1983, 2003a).

ISPMs already in place, under the SPS Agreement (Australia and New Zealand are contracting parties), include:

- ISPM 18 – for harmonizing the use of irradiation as a phytosanitary treatment for international trade (IPPC 2003) and adopted a generic minimum dose of 150 Gy as a treatment measure for Tephritid fruit flies within ISPM 28 (IPPC 2009).
- ISPM No.18 – *Guidelines for the Use of Irradiation as a Phytosanitary Measure* (2003) provides technical guidance on the procedures for the application of irradiation as a phytosanitary treatment for regulated pests or articles. It is the international standard for harmonising the use of irradiation as a phytosanitary treatment.
- ISPM 28 – *Phytosanitary Treatments for Regulated Pests* (2009) describes the requirements for submission and evaluation of the efficacy data and other relevant information on a phytosanitary treatment, with *Irradiation Treatment for Fruit Flies of the Family Tephritidae (Generic)* in Annex 7.

FSANZ Standard 1.5.3 is in general conformity with the principles of the Codex Standard although it reserves the right to evaluate irradiated foods on a case-by-case basis. The amendment of Standard 1.5.3 to add the 11 fresh produce would therefore put Australia and New Zealand in further compliance with the SPS Agreement. It would be consistent with the SPS principles that all phytosanitary measures should be the least restrictive to trade possible and be based on sound scientific principles. ICA 55 (for Australia) and the Import Health Standards (for New Zealand) outline phytosanitary measures that are in conformity with ISPM 18 and ISPM 28.

There would be minimal disruption to domestic and interstate marketing and enhanced market opportunities and trade between Australia and New Zealand. Potentially new markets and other export opportunities could be developed in view of the international treaty relating to plant health and biosecurity (ISPM 18).

To industry

Horticulture in Australia is an \$8.5 billion industry and comprises fruit, vegetables, nuts, nursery, flowers, turf and nursery products. In 2009–2010, the gross value of production for fruit and nuts was \$4060 mil and vegetables worth \$3023 mil. Grapes were worth \$1100 million, apples \$402 million, strawberries \$212 million and melons \$159 million (DAFF Australia 2012).

In 2011–2012 fruits and nuts (excluding grapes) accounted for \$3050 mil and vegetables at \$3339 mil.

GVP estimates are presented for 2012 in Table 6.

Table 6: Horticulture, fruit and nuts and vegetables — 2012 GVP estimates. GVP is defined as the gross value of commodities produced.

Fruit and nuts	\$m	Vegetables	\$m
Bananas	500	Tomatoes	243
Other fruit and nuts	198	Other vegetables	223
Avocados	140	Capsicums (does not include chillies)	139
Strawberries	125	Beans	74
Mandarins	75	Mushrooms	64
Pineapples	71	Potatoes	54
Mangoes	70	Lettuce	54
Macadamias	52	Sweet potatoes	52
Table grapes	50	Zucchini and button squash	42
Apples	40	Melons (watermelon)	36
Total fruit	1321	Sweet corn	36
		Melons (rock and cantaloupe)	32
		Onions	25
		Carrots	24
		Pumpkin	21
		Total vegetables	1119
Total fruit and vegetables	2440		

Socio-economic benefit within the distribution and supply chain and the jobs involved in the horticulture sector are a significant addition to the jobs created on-farm. Total horticultural exports of fresh fruit, vegetables, nuts and plants, including flowers was worth \$751mil (2008 estimates). In 2009–10 an estimated 63 300 people were employed in Australia to grow fruit, vegetables and nuts for the domestic and export markets, with a further 9800 employed in processing (HAL 2012, data from DAFF Australian Food Statistics 2009–10).

A general overview of the industry can be obtained from publications of the Australian Bureau of Standards (ABS 2008, 2011a, b), the Rural Industries Research & Development Corporation (RIRDC 2010a, b), Queensland Primary Industries and Fisheries (QLD DAFF AgTrends 2012), HAL (2012), and Plant and Food Research (PFR 2013 website). Production volumes, farm gate and retail values and import/export figures

can differ quite dramatically year-on-year, but nevertheless the sector significantly contributes to regional economies and community health. Approval for the use of irradiation as a disinfestation treatment for these produce will provide an alternative phytosanitary measure for use on fresh produce shipped to pest-free areas within Australia at a time when existing measures are under threat of further restrictions or suspension.

A significant advantage of the treatment method is its tolerance by a majority of fresh produce. The availability of an alternative option can help reduce the risk of product shortages, higher prices and uninterrupted access. Some of the fruits of concern are among the highest priorities in the horticulture industries for maintaining domestic market access in Australia. Recently, approval was obtained to irradiate tomatoes and capsicums and this means renewed market access for these two popular fresh commodities, within Australia and exports to New Zealand.

Irradiation is a phytosanitary measure that can be implemented rapidly since ICA 55 is already in place in Australia and there is experience of exporting irradiated papaya, mango and litchi to New Zealand under existing approvals. No other alternative presently offers this advantage.

Approximately 80% of Australian fruit is sold domestically and it is not expected that the quantities will change significantly in relation to total domestic supply and any increased shipments may at least partially substitute for imports. However, not all the fruits produced will need to be irradiated as this will depend on the production areas and sale destinations. Entry of Australian fresh produce into other markets is not expected to have a significant economic impact on prices or production in export destinations, especially given the costs of treatment and transport.

Approval to permit irradiation of these eleven fruits for a phytosanitary purpose would ensure minimal economic loss to the industry and likely reduction in supply. With economies becoming global, the need to meet the high phytosanitary requirement of trade partners would be uppermost and irradiation treatment is suitable for this purpose.

Reduced use and less dependence of chemical pesticides is the principal environmental benefit. There would be no requirement to store and dispose of pesticides on-farm and there is no associated withholding period, no chemical residues are generated and cost-savings are expected with reduced wastage resulting from expected reduced damage to produce quality.

Furthermore, the ability to treat in the final packaging and in pallet loads is an obvious advantage.

The cost of irradiation to industry is not fully known however it is expected that these would be comparable to treatments currently employed. Treatment costs are currently 5–7 cents per kg of fruit or about A\$50–70 per tonne of fruit (Steritech, private comm). This is expected to decrease as volumes increase and consumer resistance to irradiated fruit lessen. In 2007, Lacson's data (2007) showed that the cost of irradiation at that time of \$25–50/tonne was significantly lower compared to other treatments, for example, \$46–600/tonne for cold treatment.

Incorporating irradiation treatment into the commercial supply chain could be effectively and efficiently achieved however, the decision to do so is a commercial one considered and assessed fully by the industry. Logistical bottlenecks resulting from current limited availability of the technology in Australia and New Zealand for the purpose of phytosanitary disinfestation is a disadvantage.

Benefits to industry would lead to stability in the fresh produce market and prices, and access to export markets is maintained. There is potential for increased export returns and new opportunities. The continued prosperity and growth of the horticulture sector and its associated supply chain partners would have a positive benefit to government revenue and regional communities and society generally.

PART 3 – SAFETY ASSESSMENT CONSIDERATIONS

3.1 Nutritional data

A wide variety of fresh produce is available in Australia and New Zealand. The five most commonly eaten fruits are apples > oranges > grapes (inc. wine) > banana > pear, while potatoes > tomato > carrot > onion > pumpkin are the five most commonly eaten vegetables (MOH 1999). Sub-populations may have a higher than average consumption for a fresh produce but overall, the 11 fruits of concern in the application are not a major part of the daily intake of any subpopulation in Australia and New Zealand. From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will come from foods other than apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini.

Discussions on each of these fruits (irradiated and untreated) are detailed separately in Appendix 2, together with the effects of irradiation after a period in cold storage.

Table 7 compares micronutrient and vitamin values for eight of the nine tropical fruits (no data for mangosteen), persimmon, tomato and capsicum that have been approved for irradiation by FSANZ and for the 11 fruits applied for in this Application, i.e. apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini. The table provides a good starting point for comparison and the fruit and vegetables (generally mixed sources). Differences in values may be the result of produce grown under different conditions, soils, or times of year or be of the same varieties. The differences seen in USDA and MOH values, and in the Qld DAFF studies could have been caused by anomalies of measurement or sampling, or changes in the food system.

The nutritional profile for each of the 11 fruits before and after irradiation treatment is discussed separately in the following sections. Compared to 20–30 years ago, fruit now are commonly harvested and delivered at a less mature stage for longer shelf life, which, in turn, can affect the nutrition value. A characteristic feature of the ripening of fruit is that its unripe green colour turns yellow due to the enhanced biosynthesis of carotenoids (Katayama *et al.* 1971), particularly of beta (β)-carotene (Dragovic-Uzelac *et al.*, 2007).

Generally the pattern of vitamin / mineral content is similar across these foods but each fruit may contain more or less of one or two vitamins. For example, rockmelon has a beta-carotene value of 1428 $\mu\text{g}/100\text{g}$ which is comparable with mango while apricot contains about half that amount and strawberry contains very little, approximately 3.5 $\mu\text{g}/100\text{g}$. Tomato and capsicum which are produce that are more commonly eaten on a daily basis contain beta-carotene values slightly higher than summerfruit. Strawberry contains 52 mg/100g Vitamin C, the highest for these 11 fresh produce and considerably lower than the other fruits and vegetables on the approved list by FSANZ. The more popular apple and table grape contain much less vitamin C (5 mg and 3.2 mg/100g Vit C respectively) (Table 7). The fruits are not expected to contribute significantly to the daily nutritional intake.

Pro-vitamin A (carotenes) and Vitamin C are present in other fresh produce and vitamin A in foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables, grains and dairy and egg products generally are excellent sources of Vitamin K and, nuts, seeds, vegetable oils and many fresh vegetables are good sources of Vitamin E. Folate can be found in small amounts in many foods with a major dietary source being enriched and fortified foods.

Although apples are popular and can be a significant part of the average consumer's diet their contribution to overall micronutrient intake will not be pre-dominant. Apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grapes and zucchini are also a useful sources of micronutrients, but they are consumed in smaller amounts or amounts equivalent to that of many other fresh produce crops and to lesser amounts than many popular fruit and vegetables. They will not be a significant contributor to overall micronutrient intake as daily intake of micronutrients will come from a range and types of foods. Furthermore, socio-economic position, preferences, parental intake, and home availability/accessibility are all consistently positively associated with intake.

Early studies on the effects of irradiation on fruit quality parameters, colour, flavour and texture showed that many factors can influence fruit responses to irradiation, including fruit maturity, cultivar, storage temperature and controlled atmosphere storage (Massey *et al.* 1964, Thomas *et al.* 1986a, b, c, 1988, Maxie and Abdel-Kader 1996, Bhushan and Thomas 1998, Miller and McDonald 1999). Arvanitoyannis *et al.* (2009) summarised the various applications of gamma irradiation in fruit and vegetables from 1978 through to 2007, focusing on nutritional and fruit quality and shelf life extension, reducing postharvest losses and controlling stored product insects and microorganisms. Compared to other widely employed processing methods, irradiation offered greater advantages in shelf life extension, no change in physical and organoleptic properties and at lower cost.

The absorbed dose, commodity maturity and physiological state at harvest, pre and posthandling, transportation, presence of microorganisms, storage environment and storage time all interact to affect product quality and shelf life. Different outcomes in nutritional quality after similar treatments can occur between different varieties of the same fruit, as noted by Thomas (1988), Morris and Jessup (1994) and Lee and Kader (2000). It is a well-known fact that the values of nutritional components measured depends upon the degree of ripeness of the fruit, and quite different results would no doubt have been obtained had unripe or over-ripe fruits been analysed. Furthermore, fresh produce today are generally harvested at a less mature stage for better product shelf life, than 15–20 years ago.

Effects of irradiation on nutritional content and postharvest fruit quality

There are many studies on the general effects of irradiation on the nutritional content of food. They have been extensively reviewed by several organisations and individual scientists (JECFI 1981, 1999, Murray 1983, FDA 1986, Urbain 1986b, Thomas 1988, Thayer *et al.* 1991, Diehl *et al.* 1991, Kilcast 1994, Morris and Jessup 1994, WHO 1994, Diehl 1995, FDA 2008, Crawford and Ruff 1996; SCF 2003, EFSA 2011).

The reviews are in broad agreement. Irradiation up to the general 10 kGy limit of the Codex General Standard has little or no effect on the energy, macronutrient (carbohydrate, protein, total fat and dietary fibre) and mineral content of foods. Many vitamins in food are largely unaffected by irradiation although some are destroyed with the extent increasing with increasing dose. Overall vitamin losses are minimal at doses below 1 kGy. Postharvest fruit quality of fresh produce after irradiation showed little change and many are the same changes that occur with aging and storage. The losses are generally within variations found between varieties of a specific food or the losses caused by storage and other preharvest or postharvest conditions (Mitchell *et al.* 1992, Farkas *et al.* 1997, Boylston *et al.* 2002, Fan and Sokorai 2008). Above 1 kGy losses may be significant but are no greater, and often less than, found after more conventional processing methods such as heating, freezing or canning (Kraybill 1982, Murray 1983, WHO 1994, JECFI 1999, SCF 2003, EFSA 2011).

JECFI evaluated the safety and wholesomeness of irradiated foods and concluded that “irradiation of food up to an overall average dose of 10 kGy introduces no special nutritional or microbiological problems” (1981). Nutritional changes were not ruled out by JECFI but the group believed that any changes that did occur would be similar to those found from other processing technologies and would not present any hazard to consumers with a reasonably varied diet.

Table 7: Vitamin values for fresh produce approved within Standard 1.5.3 and for apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, table grape, strawberry and zucchini per 100 g (FSANZ 2010, USDA 2011b). Average values for produce in application.

Commodity	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Niacin from tryptophan or protein (mg)	Niacin equivalents (mg)	Vitamin C (mg)	Alpha carotene (µg)	Beta carotene (µg)	Cryptoxanthin (µg)	Beta Carotene equivalents (µg)	Retinol equivalents (µg)	Vitamin E (mg)
Breadfruit	0.110	0.030	0.900			29	0	0	0			0.10
Carambola	0.14	0.16	0.367			34.4	24	25	0			0.15
Custard apple	0.05	0.08	0.8	0.2	1.03	43	10	0	0	5	1	
Longan	0.031	0.14	0.30			84						
Lychee	0.05	0.07	0.5	0.2	0.68	49	0	0	0	0	0	
Mango	0.018	0.037	0.56	0.3	0.84	26	9	1433	1516	2195	366	1.3
Papaya	0.03	0.03	0.3	0.1	0.37	60	0	240	1350	915	152	
Rambutan	0.015	0.065	0.79	0.2	0.96	70	0	0	0	0	0	
Persimmon	0.01	0.10	0.5	0.1	0.6	14	20	200	1230	825	138	0.73
Tomato	0.02	0.02	0.2		0.17	18	0	153	7		26	0.26
Capsicum (average)	0.034	0.038	0.7	0.3	0.97	125	12.5	220	1.11		122	2.04
Apple-red	0.018	0.018	0.1		0.13	5	0	19	10		3	0.21
Apricot	0.03	0.038	0.93		1.38	11	19	646	32		35	0.89
Cherry	0.03	0.029	0.327		0.63	13	0	47			9	0.07
Peach	0.015	0.027	0.908		1.21	8	1	105	0		0.023	0.72
Plum	0.032	0.036	0.499		0.72	7	2.5	169	0		21	0.13
Nectarine	0.027	0.033	1.168			9	3	108			14	0.8
Honeydew	0.03	0.016	0.309		0.32	19	0	30	0		5	0.02
Rockmelon	0.033	0.022	0.487		0.34	39	11	1428	24		71	0.03
Strawberry	0.022	0.036	0.243		0.22	52	0	3.5	0		0	0.305
Table grape-red	0.05	0.07	0.188		0.15	3.2	0.5	20	0		0.15	0.35
Zucchini	0.037	0.075	0.51		0.71	20	0.5	182	0		14	0.34

changes in relation to each particular food and its role in the diet, including for sub-populations). The American Dietetics Association (ADA 2000) and ACHS (Loaharanu 2003) concluded that the nutritional value of food is not adversely affected by irradiation up to an overall dose of 10 kGy, and supports the technology.

Thirty five countries including the USA and UK have approved the use of irradiation for pest disinfection or maturation control of fresh produce. Studies show that more fresh fruits and vegetables tolerate radiation than any other commercially available treatment (Heather and Hallman 2008a, b). FSANZ has also concluded that irradiation up to 1 kGy has no impact on the nutritional adequacy of 10 tropical fruits, persimmon, and in the more commonly consumed vegetables - tomato and capsicum (FSANZ 2003, 2012, 2013).

Sensitivities of water-soluble and fat-soluble vitamins and other key vitamins in foods are shown in Tables 8 and 9. Vitamin A, thiamin (Vitamin B1), ascorbic acid (Vitamin C) and alpha-tocopherol (Vitamin E) in foods are relatively sensitive to radiation while other B vitamins such as riboflavin, niacin and Vitamin D are not as sensitive.

Table 8: The radiation sensitivity of water and fat soluble vitamins [JECFI 1999].

Radiation sensitivity decreasing left to right	
Water-soluble	Thiamine (B1) > Vit C > Vit B6 > Vit B2 > Folate, Niacin > Vit B12
Fat-soluble	Vit E > Carotene > Vit A > Vit D > Vit K

Table 9: The radiation sensitivity of some key vitamins in food [Kilcast 1994].

High	Medium	Low
Vitamin C		
Thiamine (Vit B1)	K (in meat)	K (in vegetables)
α-tocopherol (Vit E)		Riboflavin (B2)
Retinol (Vit A)		Pyridoxine (B6)
		Cobalamin (B12)
		Niacin (B3)
		Folic acid
		Pantothenic acid
		Biotin (B10)

Irradiated apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini at the low dose (150 – 1000 Gy) requested is expected not to have any significant impact on the average dietary intakes of nutrients, essential vitamins and minerals. From Table 5 and the nutritional tables for each of the eleven fruits (Appendix 2), the particular fresh commodity overall does not provide significant amounts of any essential vitamin or micronutrient, with many fruits being

sasonal fruits. Although a particular fruit may be a popular fruit, for example apple, its consumption is not likely to make a significant contribution daily nutritional intake. Irradiated apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini at the low dose (150 – 1000 Gy) is as safe and nutritious as non-irradiated apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini. Taste, appearance, texture, composition and nutritional value of the food can be affected during irradiation treatment and the degree of the effects is dependent on the applied dose and other interactions as discussed previously.

The essential findings from numerous studies and reviews have concluded that the change in the chemical composition of the irradiated food is minimal and the resulting compounds are the same as those formed when food is cooked or processed in the more traditional ways (Josephson *et al.* 1978, Wilkinson 1985, Gholap *et al.* 1990, Diehl 1991, Diehl 1995, JECFI WHO 1999). Vitamin losses between varieties and those effects caused by growth conditions, physiological maturity and storage are greater than responses at low radiation doses < 1 kG. Carotenoid losses in mangoes and papaya irradiated up to 2 kGy were reported to be negligible compared with the considerable losses resulting from freezing or canning (Beyers and Thomas 1979).

Research on the radio-tolerance of these fresh produce (QLD DAFF 2012, 2013) just after irradiation and after a recommended period of cold storage show that changes to the chemical composition of these fruits are minimal. Storage time and not irradiation induced significant effects on several of the nutritional components. In studies with other fruit, such as, papaya, rambutan and Kau oranges, Boylston *et al.* (2002) found no significant changes in nutrient and chemical quality. There were no significant changes in ascorbic acid, carotenoid contents, pH, titratable acidity, and total soluble solids although aroma and flavour tended to be more intense in fruit irradiated at 750 Gy. Storage had a greater effect on ascorbic acid and carotenoid contents than irradiation.

Macronutrients, including carbohydrates, fats and proteins are essentially low-risk. Carbohydrates and proteins are not significantly affected at low doses and irradiation had not resulted in a change in the quantity of minerals or trace elements. (Polyunsaturated fatty acids are generally not altered although rancidity and odour or colour changes can occur when fats are oxidized). Except for avocado, fruits and vegetables generally contain negligible or nil amounts of fatty acids.

A critical review of the effects of radiation treatment on the chemical constituents of banana, mango and papaya by Thomas (1986a) reported that there was no significant loss of nutrients with these fruit irradiated at doses that were optimal for a disinfestation purpose or at doses tolerated by the fruit commodity. Changes during storage such as decreasing soluble solids, acidity, internal colour, and increasing pH were regarded as normal effects, and not affected by irradiation. The decrease in sugars and the increases in Vitamin C also were considered as normal storage effects (Mitchell 1992).

Most of the information available on the impact of irradiation on vitamins relates to the degree of survival after treatment. Reviews by Josephson *et al.* (1978), Thayer *et al.* (1991), Kilcast (1994) and JECFI (1999) concluded that vitamin losses from irradiated permitted foods would be minimal.

It is anticipated that irradiation of these fruits under the same dose range and conditions applied for a disinfestation purpose would result in similar effects on vitamins that would be no greater than with conventional heat processing and therefore, would have minimal impact on the vitamin status of the fruit.

At the radiation conditions (≤ 1 kGy) applied in apple, apricot, cherry, nectarine, peach, plum, rockmelon, table grape, strawberry and zucchini, the changes in carbohydrate nutrient and functional characteristics are not significant. Postharvest fruit quality attributes also are maintained for these fruits.

Honeydew melon and nectarine however, were less tolerant to doses ≥ 600 Gy. Beta-carotene was initially affected by irradiation immediately after treatment, being significantly lower in the ≥ 600 Gy treatment ($12 \mu\text{g}/100\text{g}$) compared with control fruit ($17 \mu\text{g}/100\text{g}$), although by the end of the 14-day storage period no differences were detected across any of the treatments. The beta-carotene level in honeydew melon however was naturally low to begin with and any changes could therefore have little or no impact.

At doses ≥ 600 Gy there was increased skin browning and pitting in honeydew melon and nectarine fruits with increasing dose in the QLD DAFF study but not in the studies reported by Mitchell *et al.* (1992). The incidence and severity of skin browning and pitting increased with dose level; being observed only at the end of the recommended storage period. Specifically, symptoms in honeydew melon occurred only when treated to a dose of 600 Gy and above, with up to 51% of the skin surface area being affected. In contrast, irradiation damage in nectarine fruit was comparatively low across all the treatments ($< 1\text{cm}^2$ skin area affected), with only a small proportion of fruit (3%) affected at 150 Gy. However, this increased significantly to greater than 13% of fruit affected at a dose of 600 Gy and above.

Apples (Olsen *et al.* 1989, Drake *et al.* 1999, 2003) and cherries (Drake *et al.* 1994, Drake and Neven 1997, Eakin *et al.* 1985, Eaton 1970, Kader 1986) treated with doses up to 1.0 kGy showed little or no loss in quality, demonstrating that irradiation at low doses can be used as a quarantine treatment for apples and cherries with little or no quality loss. These results are confirmed in the QLD DAFF study which showed that irradiation at doses ≤ 1 kGy produced little or no impact on the nutritional and postharvest fruit quality.

The primary sources of Vitamin A, carotenoids and other radiation-sensitive vitamins considered in the Australian and New Zealand diet are carrots, meats, dairy products, eggs, wholegrains and fortified processed cereals. In the context of total dietary intake, the vitamin levels and carotenoids in these fruits are minor compared to that in the major food groups. The amount and variety of foods consumed that contain vitamins are adequate to meet daily nutritional needs.

Losses in provitamin A (beta-carotene) will be small when irradiated up to 1000 Gy (QLD DAFF 2012, 2013) and the impact on the dietary intake of Vitamin A is insignificant. No effect on carotenoid content was detected in spinach irradiated up to 1000 Gy (Gomes *et al.* 2008a). Other fresh produce irradiated at doses greater than 1 kGy showed minor changes in carotenoids after treatment. Carotenoid losses in mango and papaya (Beyers and Thomas 1979), broccoli (Gomes *et al.* 2008b) irradiated up to 2 and 3 kGy were small.

With the exception of potassium intake, fruits and vegetables generally are not major contributors to Australians' intake of six minerals - potassium, sodium, calcium, magnesium, iron and zinc (Cunningham *et al.* 2002).

The US FDA (2008) concluded that irradiation of iceberg lettuce and spinach up to a maximum dose of 4 kGy will not have an adverse impact on the nutritional adequacy of the overall diet. The major components of these eleven fruits, as with most fruits and vegetables are water and carbohydrate, with protein as a minor component. Therefore it is also likely that the nutritional quality of these fruits irradiated at 150–1000 Gy will not be adversely affected.

The US FDA (2008) concluded that few reaction products that would be generated from the small amounts of protein in iceberg lettuce (<1 %) and spinach (<3 %) and the amino acid composition would not be significantly changed when irradiated at doses up to 4 kGy. It can be expected that reaction products generated would be minimal, if any, and that any changes to the amino acid composition would be negligible. Blakesley *et al.* (1979) found that free amino acid and total amino acid content in irradiated mango and papaya at 0.75 kGy and strawberry pulp at 2 kGy remained unchanged.

Many fruits and vegetables are good sources of Vitamin A and carotenoids. While Vitamin A and provitamin A carotenoids have been identified as radiation-sensitive fat-soluble vitamins however, the carotenoids in plant products are fairly radiation-tolerant. After careful review the US FDA concluded that while spinach is an excellent source of Vitamin A, the small losses that might result from irradiating up to 4 kGy will have little impact on the dietary intake of Vitamin A. Treatment of these eleven fruits are at doses \leq 1000 Gy and Vitamin A losses will be minimal, if any and therefore little impact on the dietary intake of Vitamin A. Food irradiation is a non-thermal process; the loss of heat-sensitive vitamins is expected not to be greater than with conventional heat processing.

3.2 Toxicological data

There is a history of safe consumption of irradiated foods in many countries (FSANZ 2013, section 2 of SD1). In Australia and New Zealand, FSANZ has not previously identified any public health and safety issues associated with the consumption of herbs, tropical fruits, persimmon, tomato and capsicum or other permitted irradiated foods.

The safety of food irradiation was previously examined by FSANZ in both long-term animal-feeding studies and in studies in humans - irradiated tomato and capsicum (2013), and persimmon (2012) - which found that irradiated tomato and capsicum and persimmon irradiated up to a maximum dose of 1 kGy are as safe to consume as non-irradiated tomato, capsicum and persimmon. Concerns regarding illnesses in pets in association with the consumption of jerky pet treat products imported from China are fully discussed in the approval reports. There is no evidence to date implicating irradiation as the causative agent.

The safety of irradiated food has also been extensively assessed by national regulators and international scientific agencies (e.g. the USFDA, Canada and European Union), they have approved the use of irradiation of specific foods following a safety assessment.

The position of the Food and Agriculture Organization (FAO)/ International Atomic Energy Agency (IAEA)/ World Health Organization (WHO) Joint Expert Committee on Food Irradiation (JECFI 1981) on chemical clearance or chemical implications of irradiated foods affirmed that when foods of similar composition are similarly irradiated their chemical and microbiological responses are similar and they are accordingly toxicologically equivalent. When an irradiated food in a class of similar foods is cleared as safe and adequate for consumption, then other members of that class are, correspondingly, wholesome and safe.

JECFI evaluated the overwhelming body of research studies assessing toxicological safety including the radiation chemistry of food components; *in vitro* and *in vivo* tests for mutagenicity, and feeding studies of a broad cross-section of animal species - rats, mice, dogs, quails, hamsters, chickens, pigs and monkeys. The feeding studies included sub-acute, chronic, reproductive, multi-generation and carcinogenicity studies. The data also included limited studies involving human volunteers. JECFI found no specific nutritional or toxicological adverse effects. Additionally, no adverse effects (nutritional and toxicological) have ever been reported over many years in which laboratory rodents, astronauts and immune-suppressed patients had received sterile diets irradiated at high doses (25 kGy) and whose health was well-monitored.

JECFI (1981) stated that “irradiation of food up to an overall average dose of 10 kGy presents no toxicological hazard and introduces no special nutritional or microbiological changes”. Hence toxicological testing of foods so treated is no longer required. This conclusion was a basis for the adoption of the original Codex Alimentarius General Standard for irradiated Foods (CAC 2003a, 1983).

In 1999, JECFI then concluded that foods irradiated with doses above 10 kGy were also safe and wholesome, “food irradiated to any dose appropriate to achieve the intended technological objective is both safe to consume and nutritionally adequate”. In the JECFI opinion, the dose applied to any food would be limited by considerations of marketable quality before any toxicological hazard would arise. As a result, the revised Codex General Standard for Irradiated Foods (CAC 2003a) states that the maximum absorbed dose delivered to a food should not exceed 10 kGy, except when necessary to achieve a legitimate technological purpose.

In a review on natural radioactivity and possible induced activity from consumption of irradiated food the authors concluded that the increase in radiation background dose from consuming irradiated food was insignificant and best characterised as zero (IAEA, 2002a).

An issue between 2007 and 2009 emerged regarding irradiated dry cat food (~25–53 kGy). Various studies and reviews (Thayer *et al.* 1987, Cassidy *et al.* 2007, Caulfield *et al.* 2009, Duncan *et al.* 2009, Child *et al.* 2009, EFSA 2001, FSANZ/Australian Veterinary Association) suggested that was a cat-specific effect. In commercial practice, food irradiation is generally limited to a maximum dose of 10 kGy and to 1 kGy for fresh produce. In addition, the cats were fed exclusively or almost exclusively on the irradiated diet, a situation that will not occur in human populations. However, given the strong other evidence for the toxicological safety of irradiated foods, the cat data appears of little relevance to low dose irradiation of fresh produce for human consumption.

Although 2-dodecylcyclobutanone (2-DCB) and 2-alkylcyclobutanones (2-ACBs) can be detected in trace quantities in irradiated foods (Boyd *et al.* 1991, Crone *et al.* 1992, European Committee for Standardization 2003, Marchioni *et al.* 2004, Gadgil *et al.* 2005), the available data do not suggest that irradiated food would be a toxicological concern and pose a significant risk to human health (Thayer *et al.* 1987, WHO 1994, European Commission 2002, Health Canada 2003, Sommers 2003, Sommers and Schiestl 2004, Sommers 2006).

In 2002, the World Health Organisation re-affirmed its 1994 opinion that food irradiation was a safe process (WHO 1994, 2002). In 2003 and 2011, the European Food Safety Authority (SCF 2003, EFSA 2011) published major evaluations of the chemical safety of irradiated food which considered in detail the findings or issues related to chemical and toxicological safety that had appeared since the 1999 JECFI. The EFSA concluded that the newer data supported the previous EFSA positions on the safety of irradiated foods.

In 2003, the World Health Organisation concluded that 2-DCB and 2-ACBs in general do not appear to pose a health risk to consumers based on scientific evidence at that time, including long-term feeding studies (WHO 2003), that irradiated foods are safe and nutritionally adequate.

The FDA considers ACBs to be “of no toxicological concern” (FDA 2005, 2008) and the EFSA states that “the genotoxic hazard associated with 2-ACBs is minimal, if any” (EFSA 2011). Many studies of their mutagenic and carcinogenic potential were conducted which have been subsequently reviewed by competent authorities (SCF 2002, WHO 2003, FDA 2005, FDA 2008 and EFSA 2011).

Radiolytic Products - 2-alkyl-cyclobutanones (ACBs) and 2 dodecyl-cyclobutanones (DCBs)

In the 1981 JECFI report, radiolytic products were all believed to be chemicals that were identical or structurally very similar to chemical constituents found in non-irradiated food or in food processed by heat treatments (Adam 1983, Nawar 1986). Since then trace amounts of 2-alkyl-cyclobutanones (ACBs) and 2 dodecyl-cyclobutanones (DCBs) have been identified in some irradiated foods containing high concentrations of total lipid and palmitic acid (Crone *et al.* 1992, Delincee and Pool-Zobel 1998, Gadgil *et al.* 2002, 2005, Gadgil and Smith 2004, 2006, Sommers *et al.* 2006). The concentrations have been found to be directly proportional to the radiation dose and the conditions of irradiation (Diehl 1995, JECFI 1999, Kim *et al.* 2004). With foods such as chicken and ground beef that contain high total lipid and palmitic acid (5–25% depending on the cut), minute

amounts ($<1 \mu\text{g/g}$ lipid per kGy) of 2-ACB and 2-DCB have been detected when they were irradiated at 10–60 kGy (Crone *et al.* 1992) and 0.5–7.0 kGy (Gadgil *et al.* 2002, Gadgil *et al.* 2005). More information on the impact of irradiation on the safety and quality of poultry and meat products is discussed in O'Bryan *et al.* (2008).

Although radiolytic products can be derived from lipids when exposed to irradiation treatment (Nawar 1986, Diehl 1995), many of these products are comparable to those observed during storage or with heat treatment (Nawar 1986, WHO 1994). The radiation chemistry and nature of the radiolytic products are described elsewhere (Raffi *et al.* 1981, Adam 1983, Diehl 1995).

In as early as 1977, Schubert reviewed aspects of the toxicology and chemistry of irradiated foods and food components, the radiation chemical considerations, combined effects, mutagenicity testing and compared irradiation with other food processes such as cooking and food additives. It was estimated that an average daily diet that contained 10% irradiated foods would result in consumption of between 0.05–2 % of radiolytic products generated from conventional food processing in the form of food additives and other contaminants.

Fernandez *et al.* (1984) evaluated the genetic risk of irradiated food consumption theoretically and experimentally. According to the model used in the study it predicted that if a man ingested 100 g of irradiated food daily for 30 years, the calculated probability of damage would be 100 000 times lower than the natural probability of genetic error. The model took into account the risk induced by consuming irradiated food directly and indirectly through an intermediate source.

In a few *in vitro* tests some ACBs were reported to be genotoxic but the positive tests generally involved simultaneous high cytotoxicity. There is no credible *in vivo* evidence of genotoxic hazard to humans. It is also known that ACBs are rapidly metabolized and largely eliminated from the body of rats (Gadgil and Smith 2006). Interestingly, ACBs were found in non-irradiated nuts and nutmeg and may not be unique radiolytic products (Variya *et al.* 2008).

Various mutagenicity studies found no 2-DCB induced mutagenesis (Sommers 2003, 2006, Sommers and Schiestl 2004). Gadgil and Smith (2004) found 2-DCB to be non-mutagenic and that the toxicity was so low in the assay that the authors concluded from the evidence that the potential risk from 2-DCB consumption, if any, is very low.

In 2008, commercial non-irradiated and fresh cashew nut samples were shown to contain natural amounts of 2-dodecylcyclobutanone and 2-tetradecylcyclobutanone while 2-dodecylcyclobutanone was found in non-irradiated nutmeg samples. The presence of 2-tetradecylcyclobutanone was also observed in both commercial and irradiated cashew nuts (Variyar *et al.* 2008).

In relation to this application it is relevant that individual radiolytic products such as ACBs are measured in trace concentrations (Crone *et al.* 1992, Gadgil *et al.* 2002, Gadgil *et al.* 2005). The doses applied to apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini will be under 1 kGy. Further, the concentrations of fats from which ACBS are formed are very low in apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini (QLD DAFF 2012, 2013, FSANZ 2010, USDA 2011b).

Radiolytic Products - Furans

Radiolytic furans have also been put forward as a potential hazard. The furans are produced mainly from irradiation of sugars and ascorbic acid (Vranova and Ciesarova 2009). Concentrations produced in a range of fresh fruits, however, are very low or undetectable even at doses above 1 kGy, and the furans are highly volatile (Fan and Sokorai 2008). The sugar levels (FSANZ 2010, USDA 2011) in to apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini are not high but still low levels of furan could be formed although of expected to have no toxicological effect.

In its assessment of Application 1038 (Persimmons) and 1069 (Tomato and Capsicum), FSANZ evaluated post-2002 data on the toxicological safety of irradiated foods. Detailed review of the various studies involving ACBs and furans lead FSANZ to conclude that there was no public health or safety issue associated with the consumption of irradiated persimmon, tomato and capsicum (FSANZ 2011a, 2013). The risk from irradiated apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini will be no greater than for irradiated persimmon, tomato and capsicum.

The FDA considers that furan concentrations in the diet will not be increased by irradiation of food (FDA 2008). EFSA (2011) has considered radiolytic furans and some hydrocarbons, cholesterol oxides and aldehydes. EFSA concluded that these compounds were also found in foods subjected to other processing methods and that the amounts formed upon irradiation were not significantly higher than produced by heat treatment.

The JECFI reports of 1981 and 1999 would have taken account of radiolytic products that were inevitably present in many of the irradiated foods tested in feeding trials in their assessment of toxicological hazard. No further radiolytic products that might be considered unique to irradiation or especially toxic from irradiation of fresh produce have been reported since the EFSA (2011) and FSANZ (2011a) reports.

In 2008, the US FDA concluded that irradiation of iceberg lettuce and spinach at a dose up to 4.0 kGy (US FDA 2008, 21 CFR Part 179) does not present a toxicological hazard. This ruling is relevant to this application. The basic principles of radiation chemistry which provides “the basis for the extrapolation and generalization from data obtained in specific foods irradiated under specific conditions to draw conclusions regarding foods of a similar type irradiated under different, yet related condition” was applied in that rigorous assessment.

In 2003, 2012 and 2013, FSANZ approved the irradiation of breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya and rambutan; persimmon and; tomato and capsicum, respectively, in *Standard 1.5.3*. In its assessment of the toxicological issues, the authority concluded that irradiation of tropical fruits, persimmon and, tomato and capsicum up to a maximum of 1 kGy employing good manufacturing/irradiation practices is safe for Australian and New Zealand consumers. FSANZ has not previously identified any public health and safety issues associated with the consumption of these or other permitted irradiated foods.

As the food components in apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini fall within the range of these fruits (see Section 3.1 Nutritional data), it would be safe to regard the same findings that irradiated apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini treated under the same conditions for a phytosanitary purpose will not pose a toxicological problem.

Ionising radiation is a safe and effective method for inactivating bacteria in food, and has been approved by the US Food and Drug Administration (US FDA). The American Medical Association (AMA) publicly supports food irradiation after it reviewed the toxicological data however; the purpose of this application is for a phytosanitary measure.

3.3 Products or ingredient

Not relevant to the request for a phytosanitary purpose.

3.4 Microbial data

Not relevant to the request for a phytosanitary purpose.

PART 4 – REGULATORY/ LEGISLATIVE IMPLICATIONS

4.1 International standards

The safety and benefits of food irradiation are supported and endorsed by the World Health Organisation and the Food and Agriculture Organisation of the United Nations.

Codex Standard

Essentially, the safety and nutritional aspects of irradiation of foods is ensured through compliance with the *Codex General Standard for Irradiated Foods CODEX STAN 106-1983, REV. 1-2003* (2003), which applies to foods processed by ionizing radiation that is used in conjunction with applicable hygienic codes, food standards and transportation codes. Information on the standard can be found at http://www.codexalimentarius.net/download/standards/16/CXS_106e.pdf.

As one of the technological requirements for irradiating food, irradiation should not be used by the food industry as a substitute for good manufacturing practices.

Irradiation doses greater than 10 kGy is allowed when "necessary to achieve a legitimate technological purpose". "The minimum absorbed dose should be sufficient to achieve the technological purpose, and the maximum absorbed dose should be less than that which would compromise consumer safety, wholesomeness or would adversely affect structural integrity, functional properties, or sensory attributes."

The code concerned with food products processed by gamma rays is contained in *Recommended International Code of Practice for Radiation Processing of Food (CAC/RCP 19-1979, Rev. 2-2003)* (2003b). This code covers the requirements of the irradiation process in a facility, aspects of the process as primary production and/or harvesting, postharvest treatment, storage and shipment, packaging, irradiation, labelling, post-irradiation storage and handling, and training⁵.

The code represents a new version of the original code the *Recommended International Code of practice for Operation of Irradiation Facilities used for the Treatment of Foods* (CAC 1983). Emphasis is on food safety and practice of HACCP as described in *Recommended International Code of Practice General Principles of Food Hygiene (CAC/RCP 1-1969, Rev 4-2003)* (2003d).

Annex B to CAC/RCP 19-1979 (Rev. 1-1983) (CAC 2003a) specifies technological conditions for individual food items. An average dose up to 1 kGy to control insect infestation is described for mango, papaya, pulses, rice, spices and condiments.

Food irradiation may be integrated as part of a Hazard Analysis and Critical Control Point (HACCP) system, *Recommended International Code of Practice General Principles of Food Hygiene (CAC/RCP 1-1969, Rev 4-2003)* (2003d) in the supply chain.

⁵ Codes of good irradiation practice and training manuals can be obtained from The International Consultative Group on Food Irradiation (ICGFI). Compilation of principles and international recommendations for regulatory control measures on food irradiation is published in *ICGFI Document 21: Control of irradiated food in trade*.

Irradiation is not a substitute procedure for good manufacturing practice and good agricultural and manufacturing practices should be employed. The *Code of Hygienic Practice for Fresh Fruits and Vegetables, CAC/RCP 53-2003* (2003c) addresses Good Agricultural Practices (GAPs) and Good Manufacturing Practices (GMPs) in the production of fresh fruits and vegetables from primary production to packing.

Various methods developed for the detection of irradiated foods are coded in *General Methods for the Detection of Irradiated Foods, CODEX STAN 231e, Rev.1-2003* (2003e).

International Plant Protection Convention

The main purpose of the International Plant Protection Convention (IPPC) and the responsibilities of the contracting parties are to prevent the introduction and spread of plant pests and promote appropriate measures for the control of regulated pests. Guidelines regarding phytosanitary measures endorsed by the IPPC are written as ISPMs.

The International Standards for Phytosanitary Measures (ISPMs) provides guidelines to achieve international harmonization of phytosanitary measures and can help facilitate trade. The harmonisation of phytosanitary measures can help avoid the use of unjustifiable measures as barriers to trade. ISPM Technical Panel on Phytosanitary Treatments (TPPT) is responsible for the development of internationally recognised treatments.

ISPM No. 18 Guidelines for the Use of Irradiation as a Phytosanitary Measure (2003), of the International Plant Protection Convention, provides technical guidance on specific procedures for the application of ionizing radiation as a phytosanitary treatment for regulated pests.

ISPM No. 28 Phytosanitary Treatments for Regulated Pests (2007, 2009) considers harmonizing phytosanitary treatments, particularly in international trade, which may also facilitate trade.

Viable phytosanitary treatments are those that are economically and technically feasible, and meet *ISPM No. 24 Guidelines for the Determination and Recognition of Equivalence of Phytosanitary Measures* (2005). This standard considers equivalent phytosanitary measures that achieve appropriate level of protection for the regulated pest(s) and accounts for the changing phytosanitary situations in exporting countries.

The Recommendation for the Implementation of the IPPC, Replacement or reduction of the Use of Bromide as a Phytosanitary Measure (2008) provides guidance to National Plant Protection Organisations on the replacement of or reduction in the use of methyl bromide as a phytosanitary measure towards reducing emissions of methyl bromide.

ASTM International (originally known as The American Society for Testing and Materials)

Current and equivalent ASTM International standards regarding food irradiation are;

ASTM F1355-06 Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment (2006) considers irradiation as a phytosanitary treatment to minimize the pest risk and to maximize the safety associated with the movement and use of fresh agricultural produce. The guide provides procedures for radiation disinfestation to

control regulated pests. The typical absorbed dose range is between 150 Gy and 600 Gy, for the control of certain insect pests of fresh fruits.

ASTM F1640-09 Standard Guide for Packaging Materials for Foods to be Irradiated (2009), provides a guide and parameters for selection and use of packaging materials for holding food that are destined to be irradiated. It also examines criteria for fitness for their use.

ASTM E2303 – 03 Standard Guide for Absorbed-Dose Mapping in Radiation Processing Facilities (2003) provides guidance in determining absorbed-dose distributions in products that are irradiated and analyses of dose map data.

Other associated codes include *ISO / ASTM51204 – 04 Standard Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing* (2004) and *ISO / ASTM51431 - 05 Standard Practice for Dosimetry in Electron Beam and X-Ray (Bremsstrahlung) Irradiation Facilities for Food Processing* (2005). The standards outline the installation qualification program for an irradiator and routine processing in the facilities that irradiate food from gamma sources in the former and with high-energy electrons and X-rays in the second.

Irradiation treatment of apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini (following approval) would comply with the relevant *IPPC, Codex, FSANZ 1.5.3, ASTM* and *ICGFI* standards.

4.2 National standards or regulations

Australia and New Zealand

FSANZ Standard 1.5.3. Irradiation of Food provides permission for the irradiation of specified foods where this method of processing fulfils a technological need. The absorbed dose applied should be the minimum required for the technological purpose to be achieved and conforms to good radiation processing practice. The standard also considers the packing materials used, labelling and record keeping in relation to the irradiation of food.

Currently, the Standard allows for the irradiation of specified fresh produce - breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya, rambutan, persimmon tomato and capsicum for a phytosanitary measure. However, such processing is not a substitute procedure for good manufacturing practice.

MAF Biosecurity New Zealand Standard 152.02: Importation and Clearance of Fresh Fruit and Vegetables into New Zealand (2008), and *Import Health Standard Sub-class: Fresh Fruit/Vegetables*; specifically provides for the import of irradiated mango (2004a), papaya (2009b), litchi (2008), capsicum (2013b) and tomato (2013c) from Australia, and papaya from Hawaii as a phytosanitary measure (2009c). The standards state that the strength of phytosanitary measures will generally be greater for high impact pests than for other regulated pests, reflecting the greater risks associated with these pests. New Zealand does not export irradiated fresh produce, as no food irradiation facilities are approved in New Zealand.

In August 2008, Biosecurity Australia (2008a) advised that the importation of fresh mango from India may be permitted subject to the Quarantine Act 1908, and the application of phytosanitary measures as specified in the *Final Import Risk Analysis Report for Fresh Mango Fruit from India* (2008b). The recommended quarantine measures are pre-export

irradiation treatment at 400 Gray, supported by an operational system to maintain and verify quarantine status.

FSANZ Standard 1.4.3. *Articles and materials in contact with food*, provides permission for materials and articles to be in contact with food. The Code however does not specify the details of the materials used in manufacturing the packaging and places this on the responsibility of the manufacturers.

Australian Standard for *Plastics Materials for Food Contact Use, AS2070 –1999* specifies materials and the procedures in the production of plastics materials, coating and printing of plastics items for food contact and subsequent use. This includes such items as packages, domestic containers, wrapping materials, utensils or any other plastics items.

This revised standard harmonises with the international Standards – US FDA regulations and EEC Directives.

United States of America

The safety and benefits of food irradiation in the US are approved by authorities including; the US Surgeon General, the Food & Drug Administration (FDA), the Centres for Disease Control, the US Dept. Health & Human Services, the US Department of Agriculture (USDA), the American Dietetic Association (ADA) and the American Medical Association.

In the US, the FDA and the Food Safety and Inspection Service (FSIS) of the USDA have given permission for the use of irradiation on a wider range of foods. For current information, the Code of Federal Regulations pertaining to irradiation is revised annually, which can be accessed at <http://www.gpoaccess.gov/cfr/index.html>.

The Electronic Code of Federal Regulations (e-CFR) is a currently updated version of the Code of Federal Regulations (CFR); however it is not an official legal edition of the CFR.

The FDA regulations are *Title 21 Part 179 Irradiation in the production, processing and handling of food, 21 CFR 179* (2009). Subparts are listed in Table 10.

The US FDA has approved the use of ionising radiation on various foodstuffs under defined conditions. These are specified in the Federal Register at *21 CFR Part 179 Irradiation in the Production, Processing and Handling of Food § 179.26 Ionizing Radiation for the Treatment of Food*, including meats such as pork, poultry, and packaged meats used solely in space flight programs, culinary herbs, spices, seeds, seasonings, wheat, fruits, and vegetables like lettuce and spinach.

In October 2002, US Animal and Plant Health Inspection Service (APHIS) approved the use of irradiation against 11 major species of tropical and sub-tropical fruit fly and other pests, regardless of commodities and countries of origin, *Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables*, thus opening up trade. In January 2006, APHIS established generic doses for all insects (400 Gy) except Lepidoteran that pupate internally and for fruit flies (150 Gy). From 2007 to the present day, approvals have been granted for the importation of irradiated fruit from several countries and pest specific doses have been established accordingly.

APHIS regulates the use of irradiation to meet quarantine requirements of products entering the USA and the interstate movement of horticultural produce from Hawaii, Puerto Rico and the United States Virgin Islands into the mainland.

Table 10: List of regulations Federal Register 21 Part 179 relevant to irradiation in the production, processing and handling of food.

Code	Description
179.21	Sources of radiation used for inspection of food, for inspection of packaged food, and for controlling food processing.
179.25	General provisions for food irradiation.
179.26	Ionising radiation for the treatment of food.
179.30	Radiofrequency radiation for the heating of food, including microwave frequencies.
179.39	Ultraviolet radiation for the processing and treatment of food.
179.41	Pulsed light for the treatment of food.
179.45	Packaging materials for use during the irradiation of prepackaged foods.

Source: <http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&sid=a734321f9234a292d78dbabf4671ba0b&rqn=div5&view=text&node=21:3>.

The *USDA Fresh Fruits and Vegetables Import Manual* (2008) provide background, procedures, and reference tables for regulating imported articles of fresh fruits and vegetables. The manual also contains the procedures for regulating foreign produce that is transiting the United States. This may be accessed at http://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/fv.pdf.

Rule 7 CFR Parts 305 and 319 (e-CFR Data 2009) Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables, APHIS, provides for the use of irradiation as a phytosanitary treatment for fruits and vegetables imported into the USA. The treatment provides an alternative to other currently approved treatments (fumigation, cold and heat treatments) against fruit flies and the mango seed weevil in fruits and vegetables.

Specifically, *7 CFR Parts 305 and 319, Docket APHIS-2006-0121* (2007a) allows the importation of irradiated mangoes into the continental US from India; APHIS–2006–0040 (2007) allows for the importation of litchi, longan, mango, mangosteen, pineapple, and rambutan from Thailand, treated with irradiation in Thailand; and APHIS–2008–0065 (2008) allows importation of irradiated dragon fruit from Vietnam.

7 CFR Parts 305 and 318 APHIS-2007-0050-0021 Interstate Movement of Fruits from Hawaii and Approval of Irradiation Treatments (2008b), allow mangosteen, dragon fruit, melon, pods of cowpea and its relatives, breadfruit, jackfruit, and fresh moringa pods to be moved interstate from Hawaii under certain conditions into continental US.

Import volumes of irradiated fresh produce shown in Table 11 shows increasing use of the “generic” treatment dose (USDA 2006) as a quarantine protocol.

In addition to USDA requirements, the Food and Drug Administration (FDA) and the Department of Homeland Security’s (DHS) Customs and Border Protection (CBP) have specific requirements for importing litchi, longan, mango, mangosteen, pineapple, and rambutan.

Table 11:
Eligible commodities and Irradiated imports into the USA.

Country	Eligible commodities
Ghana	Eggplant, Okra, Pepper
Hawaii	Abiu, Atemoya, Banana, Breadfruit, Capsicum spp., Carambola, Cucurbita spp, Dragon fruit, Eggplant, Jackfruit, Litchi, Longan, mango, Mangosteen
India	Mango
Malaysia	Rambutan
Mexico	Carambola, Clementine, Grapefruit, Guava, Mango, Manzano, Sweet lime, Sweet orange, Tangelo
Pakistan	Mango
South Africa	Grapes, Stone fruit, Pear, Persimmon
Thailand	Litchi, Longan, Mango, Mangosteen, Pineapple, Rambutan, Dragon fruit
Vietnam	Dragon fruit, Rambutan

Country	Fruit	2008(tonnes)	2009(tonnes)	2010(tonnes)
India	Mango	275	130	195
Thailand	Longan (mainly)	1700	1890	1800
Vietnam	Dragonfruit	0	100	850
Mexico	Guava	257	3521	9121
	Grapefruit	0	67	101
	Mango	0	0	239
	Sweet lime	0	0	600
	Manzano pepper	0	0	257
Total		2232	5708	13 163

Source: Roberts, P. (2012)

European Union (EN)

Currently regulations on food irradiation in the European Union are not fully harmonised. The Scientific Committee on Food (SCF) of the EU concluded after a revision of the 1986 SCF report that it would not deviate from their earlier position and that only those specific irradiation doses and food classes should be endorsed (SCF 2002, 2003).

Dried aromatic herbs, spices and vegetable seasonings are the only food group permitted across European Community boundaries, under *Framework Directive 1999/3/EC* (EU 1999b) of the European Parliament and of the Council for treatment with ionizing radiation.

Framework Directive 1999/2/EC (EU 1999a) establishes a framework for controlling irradiated foods, labelling and importation.

The framework *Directive 1999/2/EC* also covers general and technical aspects for radiation processing and conditions for authorising food irradiation. Foodstuffs must only be irradiated in approved irradiation facilities in member states or in facilities in third countries approved by the Community in accordance with *Article 4(4) of Directive 1999/2/EC*.

Member States maintain existing national authorisations for the irradiation of certain foodstuffs in their own countries. Currently Belgium, France, Italy, the Netherlands, Poland and the UK allow irradiation of foods other than herbs, spices and vegetable seasonings according to *Article 4(6) of Directive 1999/2/EC*, including grains, potatoes, onions, vegetables, pulses, strawberries, dried fruits and vegetables, seafood and other meat products.

European Commission Directive 2009/975/EC Amending Directive 2002/72/EC addresses plastic materials and articles intended to come into contact with food (EU 2009a).

Analytical methods for the detection of irradiated foods standardized by the European Committee for Standardisation (CEN) are described in Table 12, Section 4.6 (EU 2009b). These standards have been adopted by the Codex Alimentarius Commission as general methods. All except EN14569:2004 are coded in *CODEX STAN 231e, Rev.1-2003*.

Table 12: Analytical methods for the detection of irradiated foods, its use and source.

Code	Purpose
EN 1784:2003	Detection of irradiated food containing fat - Gas chromatographic analysis of hydrocarbons http://ec.europa.eu/food/food/biosafety/irradiation/1784-1996_en.pdf
EN 1785:2003	Detection of irradiated food containing fat - Gas chromatographic/mass spectrometric analysis of 2-alkylcyclobutanones http://ec.europa.eu/food/food/biosafety/irradiation/1785-2003_en.pdf
EN 1786:1996	Detection of irradiated food containing bone - Method by (electron spin resonance) ESR spectroscopy http://ec.europa.eu/food/food/biosafety/irradiation/1786-1996_en.pdf
EN 1787:2000	Detection of irradiated food containing cellulose by ESR spectroscopy http://ec.europa.eu/food/food/biosafety/irradiation/1787-2000_en.pdf
EN 1788:2001	Thermoluminescence detection of irradiated food from which silicate minerals can be isolated http://ec.europa.eu/food/food/biosafety/irradiation/1788-2001_en.pdf
EN 13708:2001	Detection of irradiated food containing crystalline sugar by ESR spectroscopy http://ec.europa.eu/food/food/biosafety/irradiation/13708-2001_en.pdf
EN 13751:2002	Detection of irradiated food using photostimulated luminescence http://ec.europa.eu/food/food/biosafety/irradiation/13751-2002_en.pdf
EN 13783:2001	Detection of irradiated food using Direct Epifluorescent Filter Technique/Aerobic Plate Count (DEFT/APC) - Screening method http://ec.europa.eu/food/food/biosafety/irradiation/13783-2001_en.pdf
EN 13784:2001	DNA comet assay for the detection of irradiated foodstuffs - Screening method http://ec.europa.eu/food/food/biosafety/irradiation/13784-2001_en.pdf
EN 14569:2004	Microbiological screening for irradiated food using LAL/GNB procedures http://ec.europa.eu/food/food/biosafety/irradiation/14569_2004_en.pdf

Other nations

Canada has a regulatory approach similar to Australia and New Zealand. The Canadian *Food and Drug Regulations Amending the Food and Drug Regulations, 1094 — Food Irradiation* (Health Canada 2002), provides for the treatment of foods with ionizing radiation.

Permitted provisions include irradiation of potatoes and onions to inhibit sprouting during storage; wheat, flour, and whole wheat flour to control insect infestation during storage; whole or ground spices and dehydrated seasoning preparations to reduce microbial load; and irradiation of mangoes as a disinfestation treatment to control fruit flies and the mango seed weevil. These are coded in the Canadian *Food and Drugs Regulations Div 26 Food Irradiation* (2009a).

Other related regulations are *Food and Drugs Regulations Div 23 Food packaging material* (2009b) and Canadian Food Inspection Agency (CFIA) *Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical, Food contact q1*.

The *recommended Canadian Code of practice for Food Irradiation* (Health Canada 2002b) identifies principles for the treatment of food products with ionizing radiation and subsequent processing with the requirements of Canada's Food and Drug Regulations.

Other countries continue to irradiate significant volumes of food, including spices, vegetables, fruit, grains, potatoes and meats. Large differences exist between the regulatory requirements concerning food irradiation in the Asia Pacific and the nations have begun to harmonise food irradiation regulations based on conformance with Codex requirements.

China is currently the biggest user of irradiation. Other countries with approval of food irradiation include Bangladesh, India, Indonesia, Iran, Israel, Japan, Korea, Pakistan, Philippines, Russia, Syria, Thailand in Asia; Costa Rica, Cuba, Mexico in North America; the South American countries of Argentina, Brazil, Chile, Peru, and Uruguay; and South Africa and Algeria in Africa.

PART 5 – OTHER IMPLICATIONS

5.1 Cost considerations

Chemical treatments for phytosanitary purposes (dimethoate and fenthion) have been restricted or cancelled and has affected access to fruit fly sensitive domestic markets for Australian fruit and vegetable growers, particularly for Queensland growers. The potential cost to the industry could be considerable.

In 2009–10 Australian horticulture had a gross value of production of \$8.407 bil, the industry consisting of fruit, vegetables, nuts and nursery products. The structure and production of each industry is discussed elsewhere in the application and their worth can be substantial to the industry and the regional communities that they support. Overall, 10 % of total horticulture production is exported (Part 2.3) however, it is pertinent to note that this application for use of irradiation is an option for a quarantine purpose. Other methods are available and not all fresh commodities will be required to be treated.

Phytosanitary protocols currently apply to the interstate movement of fresh produce that are hosts of fruit fly to fruit fly sensitive areas in Australia. Approval for irradiation could alleviate the market access situation as it is an efficacious, selective, less disruptive and economic alternative to chemical pesticides and methyl bromide fumigation. Treatment time is considerably less than other heat or cold alternative treatments.

Asia remains the biggest market for Australian fruit and vegetable exports, the main vegetable products primarily exported to Japan, Malaysia and United Arab Emirates, and fresh fruit lines included apples, grapes and oranges, mainly to USA, Hong Kong and Malaysia. While the key markets are in Hong Kong, Japan, Malaysia and Singapore, there are opportunities in New Zealand, the USA and the European Union. China and India are recently opened markets for citrus, apple and mangoes.

The presence of various pests and diseases in Australia means potential Asian markets would require phytosanitary measures to be undertaken before market access is granted. The use of dimethoate and fenthion may no longer be acceptable and alternative options need to be developed and negotiated. The major export markets in Asia currently do not require quarantine treatment for our fresh produce however the status is expected to change. For example, in 2009, Malaysia advised Biosecurity Australia that from 1 March 2009 all fresh mango fruit must be irradiated prior to export (DAFF MICOR 2009).

The potential loss of access to export markets will be costly to the industry and often is challenging and complex to re-enter, as these are very competitive markets.

Irradiation shows great potential for increasing both market access and profitability for Australian and New Zealand growers, and industry cannot afford to depend on markets with low phytosanitary requirements. These markets are generally volume sensitive and lower returning markets.

Any additional processing will add cost to the food however it will also add value to the treated product. Benefits include fruit quality, quantity, availability, convenience and quarantine safety. In general, the cost of irradiation is expected to be competitive compared to other treatments that achieve a phytosanitary purpose. In the US, the cost of irradiation to meet quarantine requirements is about 10–20% of that of vapour heat treatment (Loaharanu 2003).

There are limitations with current heat and cold treatments, including associated costs and time. Physical treatments, such as exposure to heat or cold and controlled atmosphere,

can either damage fruit or adversely affect the fruit in transit. It is understood that these treatments are generally more complex to apply and more costly as the type of disinfestation treatment, singly or in combination, that may be effective is governed by both the pest species and the ability of the commodity to tolerate the treatment. The time required to complete a cold treatment (including in transit) also can be costly.

5.2 Profit implications

Approval for the use of irradiation as a phytosanitary measure for these eleven fruits (apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini) will potentially maintain access for these industries for both domestic and export markets where a phytosanitary treatment is required (e.g. fruit fly is a pest of concern). This should ensure continued access, and in the longer term, could lead to increase in production with increasing demand and improved market outlook.

There will be opportunity to access additional markets. The increased volume and business could ensure that growers and industry service providers will gain economies of size and scale.

The countries in the northern hemisphere can provide significant market opportunities and improve profit for the Australian and New Zealand industry, particularly during the counter-season. Production in Australia and New Zealand however, is insignificant compared to other world production areas for these products. Approval of irradiation as appropriate treatment for pest disinfestations can potentially assist in accessing previously challenging markets.

5.3 Market share implications

The Queensland DAFF estimates the value of the State's fruit and nut production at about \$1.06 billion, while vegetable production is valued at about \$1.08 billion

There are both domestic and export markets for each of the fresh fruits concerned. The domestic market is small and sensitive to oversupply. The economics of growing fresh produce in Australia is strongly determined by what percentage of production meets export standards. Overall in 2010–11 Australia had a "trade deficit" of \$697 million for fresh and processed fruit, nuts and vegetable because of high imports in the processed, frozen and other sectors although there was a trade surplus in fresh vegetable and (QLD DAFF 2012). Export of fresh produce is limited by quarantine restrictions in several countries including USA, China, Japan, Korea and Taiwan. Similar quarantine restrictions apply for imported fresh produce into Australia.

Irradiation as a phytosanitary measure will provide growers with an alternative phytosanitary treatment as use of current chemical treatments have been restricted. This will allow the industry to maintain their market share against competitor and substitute products.

The biggest economic challenge lies in predicting market demand of irradiated fresh produce. While approximately 90%, in general, of Australian fruits and vegetables is sold domestically, it is not expected that the quantities will change significantly in relation to total domestic supply. Furthermore, not all produce destined for the domestic markets will need to be irradiated. In addition, imports of fresh produce and substitute fresh produce also add to the equation.

While there is potential to increase the domestic market, the volumes traded represent only a very small percentage in comparison to other fruit substitute commodities and

competition for market share from other well organized fruit industries within the country and overseas (see world production Tables 69–76).

Existing policy approved by Biosecurity Australia permits the importation of fresh produce from the overseas producing regions. Specific detail and import conditions for each fruit or vegetable can be accessed from the Australian Government Department of Agriculture, Fisheries and Forestry ICON Database portal <http://www.daff.gov.au/aqis/import/icon-icd>.

5.4 Price implications

It is anticipated that approval for the use of irradiation as a phytosanitary measure will lead to increased competition in the market place. The competition will be with untreated fruit and with other varieties of fruits.

While the price of irradiated produce cannot be predicted it seems likely that irradiated produce may cost a little more than non-irradiated fruit, but how much more is unclear.

However, pricing of fresh fruit is subject to the variables of seasonal supply and demand conditions. Prices in all major Australian cities can vary, reflecting the variability in quality and supply. Strong price pressure can occur when supplies from northern and southern production areas in Australia overlap.

It is also expected that there would be strong price competition in export markets from New Zealand exports targeting the same Southeast Asian countries. There is increasing competition from countries like China, Brazil and South Africa.

The market share of Australian and New Zealand fresh produce in these export markets is small and prices received in these markets for irradiated products are unlikely to be greatly affected as fruit quality is a main determining factor.

5.5 Trade implications

Overall Australia had a “trade deficit” in 2010–11 for fresh and processed fruit, nuts and vegetables of \$697 million because of high imports in the processed, frozen and other sectors. Australia has a trade surplus in fresh vegetables (that is, the value of exports exceeds the value of imports). Imports vs. exports for the past several years are shown in Table 13. The value for fruit and nuts are declining while vegetables have increased. Overall imports have increased over the period between 2005 and 2011. While the value of imports cannot be determined for each of these fresh produce, separate data provided in Appendix 1, suggests that the volumes of fruit traded will be not be impacted significantly from approval of the Application. By world standards, Australia and New Zealand are minor players.

Market access restrictions and intense import competition facing these horticultural industries work against the development of an export culture. The task of complying with phytosanitary aspects of market access including the completion of research to prepare protocols has become a major issue for an increasing number of horticultural industries and industries are unduly locked out of the export arena.

Table 13: Value (millions of dollars) of imports and exports of horticultural commodities.

		2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
Imports	Fruit & Nuts	741	846	928	991	943	1022
	Vegetables	528	621	731	842	744	786
	Total	1269	1467	1659	1833	1687	1808
Exports	Fruit & Nuts	829	774	760	898	778	651
	Vegetables	365	410	384	397	372	460
	Total	1194	1184	1144	1295	1150	1111

Source: Horticulture Fact Sheet - January 2012 [www.daff.gov.au/ data/.../Horticulture-fact-sheet-January-2012.pdf](http://www.daff.gov.au/data/.../Horticulture-fact-sheet-January-2012.pdf)

Most commodities treated with phytosanitary irradiation use generic treatments (Hallman, 2011). For example, the generic dose of 150 Gy for Tephritida is used for citrus fruit, manzano pepper and mango exported from Mexico to the US. For exports of several fruits and curry leaf from Hawaii, several fruits from Thailand, mango from India and Pakistan, guava from Mexico and dragon fruit from Vietnam to the US, the 400 Gy generic dose is used.

Whilst the main focus of phytosanitary requirements is on protocols that minimise risk of delivering pests with imported product and maximising delivered product safety (in relation to applied chemicals and treatments), the area is complex and does not readily allow streamlining. Growers increasingly are being required to find solutions and demonstrate an audit trail that complies with market access and phytosanitary regulation.

It comes back to overcoming impediments to market access over the long run that helps to underpin export market commitment, for domestic or export markets.

The Australian marketing season for many of the products applied for are counter-seasonal to export markets. The competition will come mainly from within the country and from countries in the southern hemisphere.

There are international standards and agreements governing trade in agricultural commodities established by the WTO. Governments who belong to the WTO including Australia and New Zealand are bound by rules of all multilateral trade agreements, particularly the SPS (Application of Sanitary and Phytosanitary Measurements) and TBT (Technical Barriers to Trade) Agreements.

A model protocol using irradiation as a quarantine treatment was developed for ASEAN nations to access the fresh fruits and vegetables market in the US, EU and inter-ASEAN trade (ASEAN, no date). A Harmonized Regulation on Food Irradiation for ASEAN, Food Handling Publication Series No. 2 and 3 (no date), provides for the treatment of food by ionizing radiation with technological dose limits, minimum 0.15kGy and maximum 1.0 kGy for fresh fruits and vegetables, for quarantine control.

It is anticipated that irradiation treatment will meet Thailand and Malaysian requirements in the event that phytosanitary disinfestation becomes an import health standard. It is also anticipated that irradiation will meet NZMAF Biosecurity requirements, thus facilitating trade between Australia and New Zealand.

Irradiation is an effective technology to resolve many of the technical problems in trade, and this is clearly illustrated as a positive step in the US where a range of irradiated fresh fruits imports have been approved by APHIS for entry into the US.

Australia has exported increasing amounts of irradiated fresh mango and litchi to New Zealand (Table 14). In the past occasionally, live insects have been found in irradiated shipments and this delayed clearance of the early shipments to New Zealand however the issue is not proving a practical barrier. Irradiation below 1 kGy guarantees insect sterility, not mortality.

Table 14: Australian irradiated fruits for export to New Zealand (tonnes).

Season	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11*	2011/12
Mango	19	129	201	346	589	1095	620	918
Litchi	-	5	10	20	57	110	15	32
Total	19	134	223	367	642	1205	635	950

Source: Richards, P. (2012)

*reduced cop volumes due to severe damaging weather conditions

5.6 Environmental implications

Fresh fruit and vegetable in Australia are currently irradiated at an AQIS approved facility in Narangba, Queensland.

The facility uses a cobalt 60 source and is regulated and licensed by the relevant federal, state and local authorities. The facility is designed with multiple fail-safe measures, and must establish extensive and well-documented safety procedures, occupational health and extensive worker training.

The approval of irradiation as an alternative phytosanitary measure will result in reductions in pesticides and storage of postharvest insecticides (dimethoate and fenthion) on-farm. Methyl bromide is on the list of banned ozone-depleting substances of the Montreal protocol (UNEP 2009), however it was granted a critical use exemption.

There is no chemical residue generated by irradiation treatment and no emissions or waste stream.

The USDA prepared an environmental assessment on "Irradiation for Phytosanitary Regulatory Treatment" (1997), and found that there was no need for an environmental impact statement. Potential environmental consequences were analysed, and no significant impact on the quality of the human environment was found for irradiation for phytosanitary regulatory treatment of fruits and vegetables. There were no adverse impacts to threatened or endangered species or their habitats from this regulatory action anticipated, and there were no disproportionate effects on any minority and low-income populations found.

5.7 Consumer acceptance

Limited information of Australian and New Zealand consumers' response to irradiated food is available. However there are consistencies in human responses to new food technologies and which were considered by FSANZ in Application 1069 Tomato and Capsicum. Some of these considerations are presented in this section. Consumer acceptance is based on a complex decision-making process with perceived risks and benefits considered and compared to existing options.

A quantitative investigation of Australian and New Zealand consumers by Gamble *et al.* (2002) confirmed an earlier qualitative study that a lack of knowledge about irradiation and suspicions surrounding the use of the technology influenced the intention of those surveyed to purchase irradiated products.

Overall, when respondents became aware of the purpose or need for the disinfestation treatment in fruits, they were more positive in supporting the use of the technology over other chemical alternatives. Consumers were more concerned about pesticide residues, preservatives and microbiological contamination than irradiation. Adequate labelling will give consumers informed choices for purchases of irradiated fruits, and the benefits from possible greater seasonal availability of fruits.

The results are consistent with that found in previous consumer and market research on irradiated foods in the US and other countries (Bord and O'Connor 1989, Bruhn 1995, 1999). Interviews with consumers and marketing tests showed that those who knew something about irradiation responded more positively about the technology. When consumers were informed about the technology and the purpose of the treatment, they were more willing to buy irradiated food products after having tried the irradiated food item.

There is considerable survey information elsewhere particularly in the US but these are mainly for meats (Bruhn *et al.* 1986, DeRuiter and Dwyer 2002, Nayga *et al.* 2005, Gunes and Tekin 2006). All studies revealed that accurate information about food irradiation could determine consumer choice in purchasing irradiated food products, hence expanding the market for these products. In essence, availability of irradiated foods in the marketplace is itself an endorsement of product quality and safety (Bruhn 1999).

Consumer education and market development activities in several ASEAN countries (IAEA 2001) have cleared the way for public acceptance and commercialization of food irradiation and trade development for irradiated food.

Consumer attitudes towards issues in food safety can be inconsistent. Brewer and Rojas (2008) showed that while the majority of consumers surveyed thought that irradiated foods, foods containing genetically modified organisms (GMOs) and food products from animals treated with hormones or antibiotics found safe by the US FDA are safe to eat, more than 20% have reduced their consumption and would pay more for untreated products.

Responsible and educational material can help consumers make better-informed choices regarding irradiated fruit. FSANZ has produced communication factsheets to assist consumer, industry and government understanding regarding food irradiation and irradiation of fruit in general. Queensland Health has a consumer factsheet about food irradiation (2010). The International Consultative Group on Food Irradiation has produced numerous publications and other information sheets about food irradiation to help address various aspects of concern. They may be retrieved from their website www.iaea.org.

In 2000, the US General Accounting Office reporting to congressional requestors concluded that the available research on food irradiation indicated that the benefits outweighed risks (2000). Currently, many US supermarkets carry irradiated food products ranging from fresh tropical fruit from Hawaii or Florida, dehydrated spices and ground meat products.

Research conducted in the US showed that consumers are more likely to buy clearly labelled irradiated food after being informed of the safety and benefits of the technology. Available research suggests that a successful market for irradiated foods can be achieved by educating consumers with the benefit and uses of the irradiation process. Farkas

(2006) summarised commercial applications and recent developments with irradiated foods, expressing wider acceptance and increasing global trade in irradiated food products.

In 1987 market trials in California showed that consumers chose irradiated papaya over hot-water-treated papaya from Hawaii at a ratio of 13:1. More than 90% of Chinese consumers were more inclined to choose irradiated apples over chemically treated apples once they were presented with the benefits of irradiation (Loaharanu, 2003).

The quantity and availability of irradiated food is expected to increase in the near future as irradiation is increasingly used as a sanitary and phytosanitary treatment in order to meet national and international trade requirements.

The USDA estimated that the American consumer will receive approximately \$2 in benefits such as reduced spoilage and less illness for each \$1 spent on food irradiation (Loaharanu, 2003), however this value applies to all food products.

Compared to the US and countries where irradiated food products have been available for the past decade, much would need to be done by Australian and New Zealand government agencies and suppliers to educate people about irradiation technology, and how irradiated foods compare nutritionally and safety-wise to similar products preserved in other ways.

A consumer attitudes survey revealed that Australians (13.4%) and New Zealanders (10.6%) were less concerned about irradiation of food or food ingredients than they were with food poisoning and food safety (FSANZ 2008).

PART 6 – FOOD IRRADIATION CLEARANCES DATABASE

At present, over 55 countries use irradiation for ensuring safety and quality of foods and for fulfilling quarantine requirements in trade, as set out in the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) of the World Trade Organisation.

The database is developed and maintained by the Food and Environmental Subprogramme of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and is available on the International Atomic Energy Agency (IAEA) website, <http://nucleus.iaea.org/ifa/>

The database provides information on country approvals of irradiated foods for consumption, and includes selections for country, food class, product, objective of irradiation, date of approval and the recommended dose limit.

PART 7 – STATUTORY DECLARATION

Statutory Declarations Act 1959

I, [REDACTED] Research Scientist, in Qld DAFF, 21 Redden Street, Portsmith Qld 4870 make the following declaration under the Statutory Declarations Act 1959:

1. the information provided in this application fully sets out the matters required
2. the information provided in this application is true to the best of my knowledge and belief
3. no information has been withheld that might prejudice this application, to the best of my knowledge and belief.

I understand that a person who intentionally makes a false statement in a statutory declaration is guilty of an offence under section 11 of the Statutory Declarations Act 1959, and I believe that the statements in this declaration are true in every particular.

[Signature of [REDACTED] making the declaration]

Declared at CAIRNS
on 10th of September 2013

Before me,

[Signature of person before whom the declaration is made]



[Full name, qualification and address of person before whom the declaration is made (in printed letters)]

Justice of the Peace (Qld)

4868

APPENDIX 1. PRODUCE – STRUCTURE & PRODUCTION AND CONSUMPTION

APPLE

Apple Structure and production

In 2010/11 the Australian apple industry produced 234 000 tonnes of apples, with an estimated gross value of production of \$605 mil (Table 15). This represents around 0.8 per cent of world production of apples. It is the third largest horticulture industry after grapes and citrus in Australia (HAL 2012, APAL 2010).

Table 15: Production details for apples in Australia.

PRODUCTION DETAILS				
	2007/08	2008/	2009/10	2010/11
Volume ('000 Tonnes)	265	295	264	234
GVP (\$ Million)	488	543	402	605
Farmgate Value (\$ Million)	420.9	480.6	402.3	na
Number Of Plantings ('000)	8590	8685	7642	7501

Source: HAL 2012

Victoria is Australia's largest apple producer, producing about 40% of the nation's apples – mostly from the Goulburn Valley area around Shepparton. The other four States each produce around 10% of the total crop - New South Wales, Queensland, Western Australia and Tasmania. See Table 16 and Figure 2.

Table 16: Australian and regional apple production in seasons 2008/09 and 2009/10.

State	Main Growing Region	2008/2009	2009/2010
Victoria	Goulburn Valley & Southern	134 241	113 127
New South Wales	Orange & Batlow	41 302	33 472
Western Australia	Donnybrook & Manjimup	33 089	36 413
Queensland	Stanthorpe	25 480	31 541
Tasmania	Huon Valley	35 085	31 229
South Australia	Adelaide Hills	25 937	19 620
TOTAL		295 434	264 402

Figure 2: Apple production regions within Australia (ABS 2008).

Queensland is the third-largest apple producing state with more than 95% grown in Stanthorpe. Queensland produces the earliest crop in Australia, which is estimated to be worth \$50 mil each year, with 95 per cent sold on the domestic market. Apples from fruit fly areas (Queensland) will require phytosanitary treatment to access fruit fly free domestic markets. Irradiation will ensure continued access to this increasingly competitive market. Not all the 30 000 tonnes however will need to be treated. The gross value of production of apples is forecast at \$40 mil for 2012–13, the same as QLD DAFF's final estimate for 2011–12 and 8 per cent lower than the average for the last 5 years (QLD DAFF AgTrends 2012).

Accurate production data is difficult to find. There has been some change in the value of Australian apple production over the past several years (Table 17). In the 2010/11 season, 234 000 tonnes of apples with the gross value of apple production (GVP) valued at \$605 mil was produced (DAFF 2012). Apple production for fresh sale and for processing totalled 264 402 tonnes in 2009–10. In 2008 only 1.3% (or 3042 tonnes) of the fresh apple crop was exported overseas.

Table 17: GVP \$m, first-stage processing and total primary industries estimates and forecasts, 2007–08 to 2012–13 and average for last 5 years.

	2007–08(b)	2008–09(b)	2009–10 (b)	2010–11(b)	2011–12(d)	2012 (Sept) (d)	Change Mar to Sept	Last 5-yr average	Difference from previous 5-yr average
Apples	50	33	34	60	40	40	0	43	–8

Source: QLD DAFF 2012 Qld Agtrends 2012–13

The Australian apple industry has a very strong domestic focus with import competition from New Zealand expected to commence. The industry estimates that fresh apple imports have the potential to reduce Australian domestic market share by up to a third and the returns to the industry by up to 40% (APAL 2010, Hicks 2012, Centre for International Economics 2011).

Overall Australian apple exports were valued at \$6.99m, 10 months to Oct 2010. Apple exports by market were to India and Indonesia/PNG, with growth in the UK / EU, Thailand, Vietnam and Japan however reduced exports were reported for Taiwan (HAL 2010).

World apple production is dominated by China, producing just under half the total production in 2011. Australia ranks 33rd and New Zealand 27th in world apple production (Table 18). In comparison, New Zealand and Australia are minor producers by world standards.

Table 18: World apple production estimates for 2011.

Country	Tonnes	Ranking
China	35 987 221	1
United States of America	4 272 840	2
India	2 891 000	3
Turkey	2 680 080	4
Poland	2 493 080	5
Italy	2 411 200	6
France	1 858 880	7
Iran (Islamic Republic of)	1 651 840	8
Brazil	1 339 000	9
Russian Federation	1 200 000	10
New Zealand	437 782	27
Australia	299 778	33
World Total	75635283	

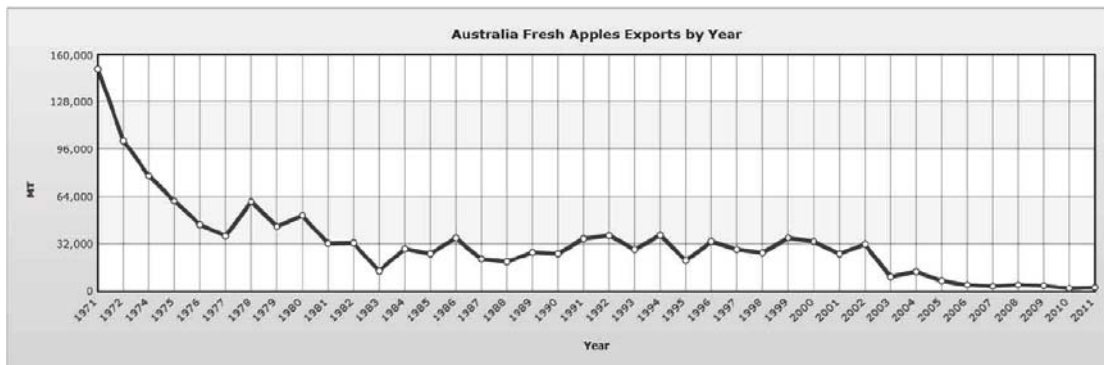
Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Apple Trade

Australia currently exports 2% of its apple production (APAL 2012). The apple industry has only a minimal profile in export markets and lacks an export culture. Apple exports totalled 2509 tonnes with Papua New Guinea, Indonesia and the UK as the top three markets for Australian apple accounting for 76% (\$6.02 mil) of apple exports in 2010/11 (HAL 2012). In the same period 702 tonnes of apples worth \$1.3 million were imported from China. Fresh apple imports have the potential to reduce Australian domestic market share by up to a third and the returns to the industry by up to 40% (HAL 2012, APAL 2010).

By international standards the Australian apple industry is uncompetitive and exports have been declining (Figure 3). APAL estimated that apple exports dropped by 90 % between 2000 and 2008 (APAL 2013 <http://www.apal.org.au/marketing-export-stats.cfm>).

Present Australian apple exports are limited to high value Pink Lady™ to the United Kingdom and commodity-style apples exported to India, Malaysia, Taiwan and Asian markets coming mainly from Queensland. Queensland accounts for greater than 50% of all the apple exports from Australia (Table 19).

Figure 3: Total Australian apple exports.

Source : <http://www.indexmundi.com/agriculture/?country=au&commodity=apples&graph=exports>

Table 19: Australian apple exports by state.

EXPORTS BY STATE (Tonnes)				
	2007/08	2008/09	2009/10	2010/11
Queensland	1,181.0	1,118.5	1,142.2	1,219.3
New South Wales	76.5	109.4	89.9	260.9
Western Australia	507.8	568.4	352.4	329.3
Victoria	344.5	252.6	756.8	392.5
Tasmania	1,153.8	2,182.5	2,326.7	247.4
South Australia	313.7	92.4	7.1	59.1
Total	3,577.3	4,323.7	4,675.1	2,508.5

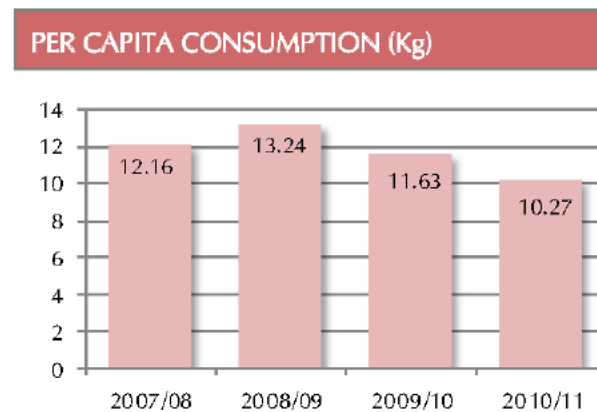
Source: GTIS - ABS

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Apple consumption

Most Australian apples are sold and consumed as fresh fruit with about 15% of the total Australian apple production processed for juice/cider, dried fruit, frozen fruit, fresh apple slices and canning (RIRDC 2010a). Furthermore import competition in the juice market results in low prices for fruit that is only suitable for processing.

Apples are among Australian consumers' top three favourite fruits with an average domestic consumption of around 10 kg per person per annum in 2010/11 (Figure 4, HAL 2012). In fact, there has been a decline in apple consumption over the past five years due to competition from a range of available fruits.

Figure 4: Per capita consumption of apples in Australia.

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Comparison of fruit consumption across different countries shows that Australians are not dedicated consumers of apples. A summary of the estimated consumption compiled for 2007 is shown in Table 20. Australian consumption is on average lower than in many other countries and under 75 % that of New Zealand's.

Table 20: Estimated apple consumption per capita in various countries in 2007.

Country	United Kingdom	Canada	United States	New Zealand	Australia	Average (32 countries)
Consumption (kg/head)	16.7	14.6	12.6	10.1	7.5	7.4

Source: "World Apple Review- 2008 Edition: <http://www.e-belrose.com/2008WorldAppleReview.html> Belrose, Inc. World Market Analysis 2008, extracted from APAL 2101 p 14.

Domestic competition from a variety of imported fruits such as table grapes and cherries has intensified with competition from imported fresh apples from New Zealand, Chile, South Africa, China and USA. Competitive pressures from apple imports are predicted to reduce prices received by growers by more than 20% (CIE 2010). APAL RDE 2010 forecasts the apple industry could contract by 20–40% within 5 years.

Hicks (2012) reported that it's "Crunch time – Apple imports", the market environment for the Australian apple industry has changed considerably in the few short years with imports likely from Japan, China, New Zealand and the US.

A 2010 report by the Centre for International Economics (CIE 2010) forecasts that, under a worst case scenario, imports would have a significant impact on the domestic apple industry. CIE predicts imported apples will secure 22 per cent market share in three years with the Australian apple growing industry potentially losing around \$140 million a year. Farm gate prices could be down by 21 % by 2014 (32 % drop in farm income), domestic production reduced by 11% although domestic consumption will increase by 17%.

CHERRY

Cherry structure and production

Cherry Growers Australia (website 2013) estimates production of up to 15 500 tonnes of cherries per annum with 80% consumed domestically. The Australian cherry industry produced approximately 10 000 tonnes fruit in the 2011/12 season with an estimated gross value of production of \$100 mil, Table 21 (HAL 2012). GVP and farmgate values are shown in Table 21 over several seasons. In comparison by world standards however, Australian cherry production is minor, accounting for less than 1% of world production (HAL 2010).

Table 21: Production details for sweet cherry fruit in Australia, 2007–2012.

Production details	2007/08	2008/09	2009/10	2010/11	2011/12
Volume ('000 Tonnes)	9	8	9.5	7.5	10
GVP (\$ Million)	na	126	na	75	100
Farmgate Value (\$ Million)	na	119	na	70	90

Source: HAL 2012

Australian cherries are available from mid/late October to late February. Figure 5 shows the cherry production areas in Australia with the industry spread across six states with diversity in climatic conditions and cherry varieties produced. The main cherry growing regions of Victoria are in north eastern Victoria, Goulburn Valley, Upper Goulburn/Strathbogie and the southern Victorian area. Young and Orange are key production areas in New South Wales with newer areas in Hillston, Mudgee, Wellington, Tumut and Batlow. In Tasmania, cherries are grown at the Huon Valley and Derwent Valley. The major cherry production areas in South Australia are the Mount Lofty region or the “Adelaide Hills”, the Riverland region and the South East of South Australia. Small pockets in Western Australia are located in the elevated southwest region and in Queensland, in the Granite Belt region of south east Queensland, centred at Stanthorpe.

New South Wales, Victoria and Tasmania are the largest cherry growing states in Australia, each producing in excess of 4000 tonnes per annum followed by South Australia and then Western Australia and Queensland with small quantities (Table 22). The rapid expansion in Tasmania is linked to its strong focus on export markets whereas fruit from Queensland and Western Australia are sold primarily to the domestic market. Potentially 4.436 tonnes cherry from NSW and Qld may be treated but this is highly unlikely as that would largely depend on the destination markets.

Table 22: Australian sweet cherry production by state – 2010.

	VIC	NSW	TAS	SA	WA	QLD	Total
Production (tonnes)	4.5	4.4	4.0	1.5–1.8	0.5	0.036	15
Area (ha)	800	800	560	590	70	20–25	2845

Figure 5: Australian cherry production areas.



Source: Cherry Growers Australia 2013 <http://www.cherrygrowers.org.au/>

The Australian industry predominately has a domestic fresh fruit focus with approximately 2000 tonnes of fruit exported in 2008/09 (HAL 2011). Fresh fruit is also imported counter seasonally from the USA and New Zealand. Based on 2010 figures, the gross value of production of Australian cherries is approximately A\$120 mil, of which A\$30 mil is attributable to export sales, despite the comparatively small export volume (HAL 2011).

Growing international demand is driving national cherry production expansion with forecasts however Queensland Fruit Fly is a major issue for the movement of NSW cherries into various markets. Phytosanitary solutions that comply with overseas and domestic market requirement would help achieve market access. However majority of the fruit will not require treatment since the main export production areas are from Victoria and Tasmania. Moreover, cold disinfestation as a phytosanitary treatment has been accepted by the USA. Irradiation would provide another option to key export markets such as China and the USA and also to the Taiwan market.

Australia ranks 27th in world cherry production and New Zealand is at 50th (Table 23), representing less than 0.05% of the total world production.

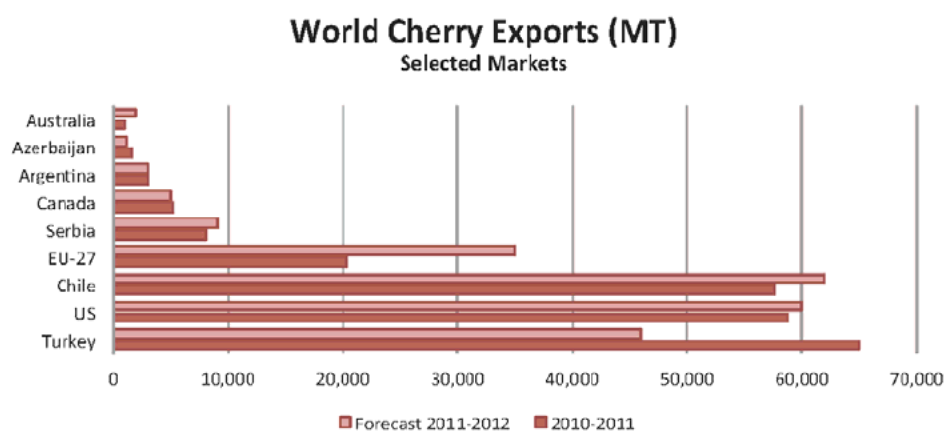
Table 23: World cherry production estimates for 2011.

Country	Tonnes	Ranking
Turkey	438 550	1
United States of America	303 363	2
Iran (Islamic Republic of)	241 117	3
Italy	112 775	4
Spain	101 729	5
Austria	92 520	6
Uzbekistan	82 000	7
Romania	81 842	8
Russian Federation	76 000	9
Ukraine	72 800	10
Australia	10 475	27
New Zealand	1 731	50
World Total	2 240 491	

Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Cherry Trade

Globally, the United States and Turkey are the largest fresh cherry exporters, followed by Chile and the EU (HAL 2012). In contrast, Australian cherry exports are minor (Figure 6) by world standards. Approximately 20 % of Australia cherry production is exported to over 20 different countries (Cherry Growers Australia website 2013)

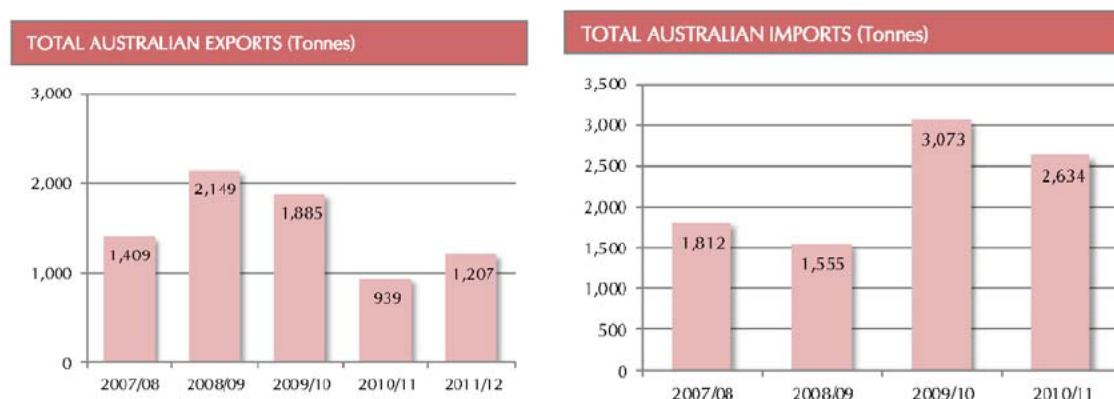
Figure 6: Volumes of world cherry exports by countries.

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Cherry exports were worth nearly A\$19 mil in 2010 (Webley *et al.* 2011). The volume of cherry exports was 1.2 thousand tonnes in 2011/12, an overall decline compared to the previous five years except for 2010/11 (Figure 7).

Cherry imports exceeded exports although they are counter-seasonal. They are mainly fruit from the United States and New Zealand and overall with an increasing trend (Figure 7).

Figure 7: Volumes of Australia cherry exports and imports for several seasons.



Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

In terms of value, Australia's top five cherry export destinations are to neighbouring Asian nations - Hong Kong, Taiwan, Thailand, Singapore and Malaysia (Table 24).

Table 24: Top Destination for Australian Cherry Exports by volume (tonnes).

Destination	2007/08	2008/09	2009/10	2010/11	2011/12
Hong Kong	349.8	731.1	701.2	211.4	317.2
Taiwan	323.7	312.1	373.2	210.8	236.3
Thailand	198.2	278.7	248.6	161.7	193.0
Singapore	183.1	237.7	122.3	51.4	111.8
Vietnam	15.0	17.7	36.9	53.5	77.3
Indonesia	12.6	24.5	26.9	53.5	49.9
Malaysia	37.9	75.6	57.2	61.8	46.9
Others	288.4	471.4	318.2	135.3	175.0
Total	1408.8	2148.9	1884.5	939.3	1207.3

Source: GTIS Australian Customs Data, 2010 - ABS
extracted from HAL, The Australian Horticulture Statistics Handbook 2012

Total exports from the various states have fluctuated over the past five years depending on the season. Tasmania is the largest exporter of cherry, followed by New South Wales and Victoria (Table 25). Market access is a high priority. Tasmania's fruit fly free status and relative disease freedom has provided the State access to more cherry markets than mainland Australia (Cherry Growers Australia website).

Table 25: Cherry exports by states over several seasons.

EXPORTS BY STATE (Tonnes)					
	2007/08	2008/09	2009/10	2010/11	2011/12*
Tasmania	679.7	847.0	1,040.0	546.4	508.2
Victoria	146.1	382.6	332.8	198.1	347.8
New South Wales	474.2	745.7	496.0	175.5	326.9
South Australia	101.7	35.6	13.1	18.8	15.5
Queensland	6.7	107.3	2.3	0.5	8.9
Western Australia	0.4	30.7	0.3	0.0	0.0
Total	1,408.8	2,148.9	1,884.5	939.3	1,207.3

Source: GTIS - ABS

Note: * 2011/12 covers the period October 2011 to February 2012, GTIS data (for this year) provided by Cherry Growers Australia

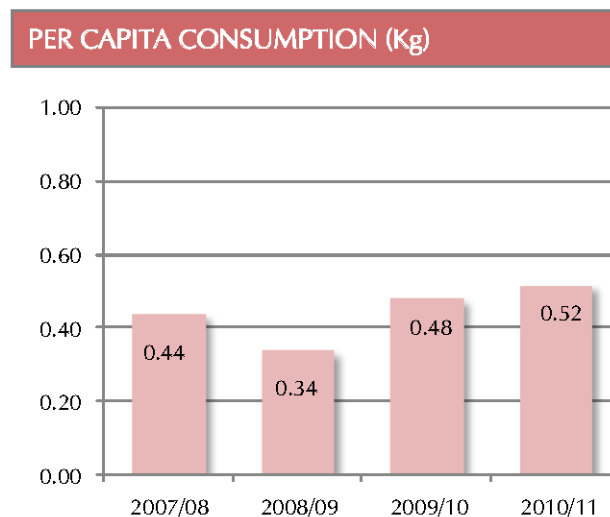
Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Cherry consumption

Eighty percent of the national production is destined for domestic consumption. The industry is a small niche industry within Australia's agricultural sector and is enjoying expansion with increasing strong export focus over the past few seasons.

Cherries are consumed in a variety of ways - fresh, frozen and canned, or as juice, wine, brined or dried. Cherries have been a popular niche fruit for consumption in Australia, and more recent attention on the health benefits of cherries (Alleaume 2010) has helped boost consumption to an average domestic consumption of cherries of around 0.5 kg per person per annum in 2010/11 (HAL 2010-Australian Bureau of Statistics ABS). See Figure 8.

Research (Australian Cherry Strategic Marketing Plan) revealed cherries are largely an impulse buy and consumers often associated cherries purchase with stonefruit.

Figure 8: Per capita consumption of cherry in Australia.

Note: Figure extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

TABLE GRAPE

Table grape structure and production

In Australia, a diverse range of table grape production areas spread from the west coast of Western Australia to Queensland's east coast and from the Tropic of Capricorn to the river lands of southern Australia. Large growing regions of green, red and blue or black table grapes are Sunraysia and the Murray Valley in Victoria, the Riverina in New South Wales and south-eastern Queensland. Other growing regions are in Carnarvon, the Swan Valley and south-west Western Australia, central NSW, the Riverland in South Australia and the central Northern Territory. In Queensland, more than 40 per cent of Queensland's table grapes are grown in the Balonne area and a third of production occurs in the Emerald area (Figure 9).

Figure 9: Australian grape growing regions.



Production volumes are shown in Table 26, between 2007 and 2011. Table grape production declined significantly in that period from 101.8 tonnes to 77.7 tonnes. Farmgate value was worth \$330 mil for 2010/2011. Gross value of Queensland grape production is forecast at \$50 million for 2012–13 season (Qld AgTrends QLD DAFF 2013).

Table 26: Production (volume '000 tonnes) for table grape fruit in Australia.

Production details	2007/08	2008/09	2009/10	2010/11
Volume ('000 Tonnes)	101.8	119.5	124.5	77.7

Source: HAL 2012

The season for fresh grapes runs for about six months, beginning in November, peaks in February and March and closes in May. Main table grape varieties include Thompson Seedless, Menindee Seedless, Crimson Seedless and Red Globe.

World grape production is shown in Table 27. Australia is ranked 10th by world standards and New Zealand at 36th in 2011. Australian grape production accounts for about 2.5% while New Zealand produced a mere 0.3 % of world's grape production.

Table 27: World grape production estimates for 2011.

Country	Tonnes	Ranking
China	9 174 280	1
Italy	7 115 500	2
United States of America	6 692 950	3
France	6 590 810	4
Spain	6 100 000	5
Turkey	4 296 350	6
Chile	3 149 380	7
Argentina	2 837 810	8
Iran (Islamic Republic of)	2 241 300	9
Australia	1 715 720	10
Brazil	1 542 000	11
New Zealand	234 284	36
World Total	69 654 926	

Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

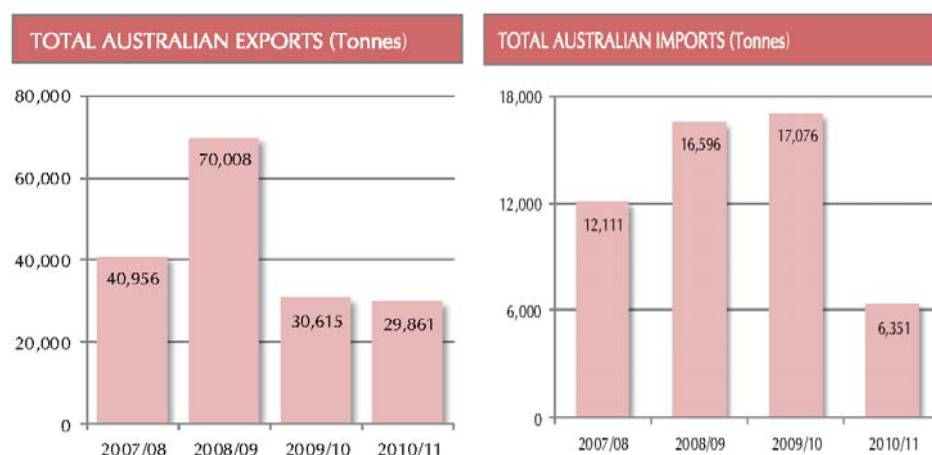
Table grape Trade

Over 90% of total grape exports come from Victoria and New South Wales. Australia's key exporting advantage is being counter seasonal to production and availability in the northern hemisphere, complementing trade with suppliers there.

Globally, Chile is the largest fresh table grapes exporter followed by Italy and USA (HAL, 2012 Statistics Handbook). In comparison by world standards Australian table grape exports are minor accounting for less than 10 % of world trade (HAL 2012), exporting 29 000 tonnes of the 3740 000 tonnes traded in 2010 (Figure 10).

Hong Kong was the largest export market for Australian table grapes last season followed by Indonesia, Thailand, Vietnam, Singapore, Malaysia and the Middle East (Table 28). Compared to the United States, Europe and South America, Australia's geographical location allows for shorter shipping times to Asia. Imports have declined although they are counter-seasonal with fruit coming mainly from the USA.

Not all the grapes produced will need to be treated for export in view of where they are produced and the markets where they will be sold.

Figure 10: Total Australian table grape exports and imports over past few seasons.**Table 28: Major export destinations for Australian table grapes.**

MAJOR AUSTRALIAN EXPORT MARKETS (Tonnes)				
Importing Country	2007/08	2008/09	2009/10	2010/11
Hong Kong	11,152.7	25,701.8	7,508.3	9,862.8
Indonesia	7,306.0	8,842.0	7,698.8	5,750.8
Thailand	4,769.7	8,266.9	3,591.5	2,760.1
Vietnam	2,347.2	4,271.3	1,545.0	2,538.5
Singapore	3,012.4	5,428.8	2,487.8	2,414.1
Malaysia	3,217.4	5,213.4	2,260.8	1,452.0
United Arab Emirates	1,748.5	3,009.1	1,074.7	1,256.2
Others	7,401.7	9,278.8	4,448.3	3,826.5
Total	40,955.5	70,012.1	30,615.4	29,861.0

Source: GTIS - ABS

Note: May include re-export data, resulting in variance with total export by state

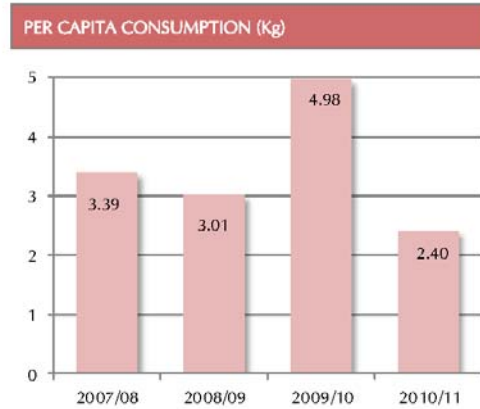
Note: Fig and Table extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Table grape consumption

According to the Australian Table Grape Association (ATGA 2013 website) demand for Australian table grapes has seen local production double in the past 10 years, from 65 000 tonnes in 1998 to about 120 000 tonnes currently (although a marked decline was observed between 2007 to 2011, Table 26), of which approximately 55% of grapes are consumed domestically.

Domestic consumption of fresh table grapes in Australia for several seasons is shown in Figure 11, with a significant decline in the 2010/11 season. Consumption was around 3.5 kg per capita between 2007 and 2011.

Figure 11: Fresh table grapes consumption in Australia.



Sources: ABS, Production estimates from Australian Table Grape Association Inc.

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

STRAWBERRY

Strawberry structure and production

Reliable statistics relating to strawberry production in Australia are difficult to obtain. There are over 300 core growers in Australia producing in excess of 72 000 tonnes in 2010/11 (Table 29), an increase from 58 000 tonnes in 2009/10 (HAL Strawberry Industry Annual Report 2012, Strawberry Aust Inc. website). The gross value of strawberry production in Queensland is forecast at \$125 million for 2012–13 (Qld AgTrends 2013).

Table 29: Australian strawberry production by state - 2010/11.

	QLD	VIC	WA	SA	NSW and Tas	Total
Production (tonnes)	24 000	25 000	13 000	7500	3000	72 500
Value (\$mil)	131	151	65	37	16	400

Queensland and Victoria are the major producers of strawberries with the Queensland being the major producer of winter strawberries for domestic markets (Table 29). Overall Queensland and Victoria account for about 35% each of the total annual production followed by Western Australia (19 %) and South Australia (10 %) with the remainder from Tasmania and New South Wales. Strawberries are grown all year round in all states due to the diversity of the Australian climate. Production is concentrated in coastal regions, namely the Sunshine Coast area of QLD, the Camden region of NSW, the Yarra Valley region in Victoria, the Adelaide Hills, SA, and Wannaroo and Albany in WA (Figure 12).

While fresh strawberries are available all year round, the bulk of production occurs from June to October when Queensland and Western Australia are at peak production. Southern growers reach their peak during the warmer months from October to May.

On the world scale, Australia is not a significant strawberry producer by volume and value. In 2011 the USA, Spain and Turkey were the top three strawberry producing nations (FAO Stat Agricultural Database 2013) (Table 30).

Figure 12: Strawberry growing regions in Australia.



Source: Strawberries Australia

With the suspension of dimethoate use and the closure of southern market access for Queensland strawberries interstate access for south east Queensland strawberries is primarily via the 'winter window option' (ICA 34). Queensland strawberry will require a phytosanitary option to ensure market access to fruit fly free markets.

The industry is focussed on domestic fresh fruit marketing; however exports do occur on a largely opportunistic basis. Imports of fresh fruit have declined to almost negligible levels, although there are significant imports of processed strawberry products.

Table 30: World strawberry production estimates for 2011.

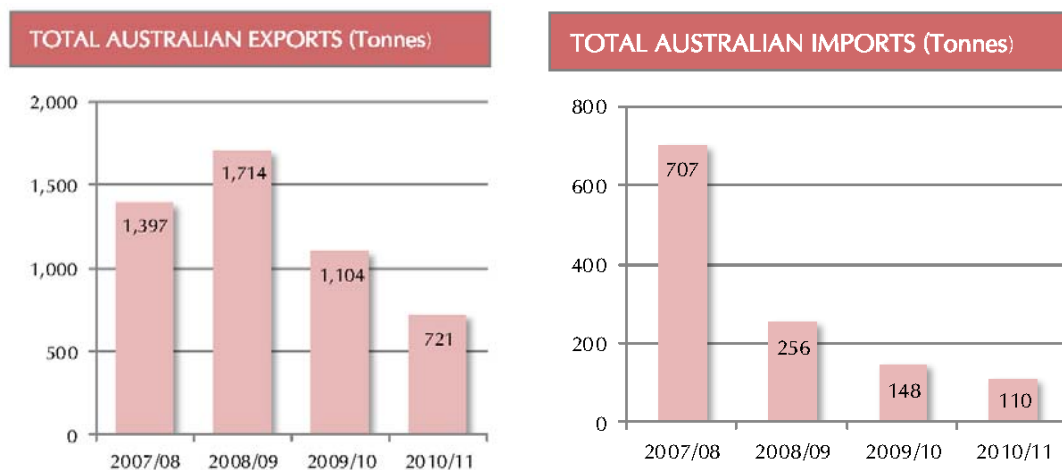
Country	Tonnes	Ranking
United States of America	1 312 960	1
Spain	514 027	2
Turkey	302 416	3
Egypt	240 284	4
Mexico	228 900	5
Russian Federation	184 000	6
Japan	182 091	7
Republic of Korea	171 519	8
Poland	166 159	9
Germany	154 418	10
Australia	30 897	22
New Zealand	6453	43
World Total	4 594 540	

Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Strawberry Trade

The industry is focussed on domestic fresh fruit marketing, with exports occurring on a largely opportunistic basis. Export trade currently accounts for about 5% of annual production. The Australian strawberry industry has been experiencing a period of steady decline in exports since 2008/09 dropping from a peak of 1714 tonnes in 2008/9 to 721 tonnes in 2010/11 (Figure 13) resulting from improved domestic demand. Imports for fresh fruit have also seen a significant decline over the same period as the domestic market continues to grow.

Figure 13 shows recent trend information for exports and imports of fresh strawberry fruit.

Figure 13: Exports and imports of fresh strawberry fruit.

Note : Figures extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Western Australia has been the highest exporter accounting for over 85% of the national total (614 tonnes), with Queensland following a distant second at 88 tonnes in 2010/11 (Table 31).

The key Australian fresh strawberry export markets are in Asia (except for New Zealand), with Singapore, Thailand, New Zealand, Hong Kong and Malaysia being the most prominent (Table 32).

Table 31: Exports of strawberry in Australia by state.

EXPORTS BY STATE (Tonnes)				
	2007/08	2008/09	2009/10	2010/11
Western Australia	1,184.6	1,382.6	885.6	613.5
Queensland	198.3	315.2	204.9	88.1
New South Wales	4.4	2.4	3.4	12.6
Victoria	9.2	14.1	10.5	6.6
Tasmania	0.0	0.0	0.0	0.1
South Australia	0.1	0.0	0.0	0.0
Northern Territory	0.0	0.0	0.0	0.0
Total	1,396.7	1,714.3	1,104.4	720.9

Source: GTIS - ABS

Note : Figures extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Table 32: Export markets for Australian strawberry.

MAJOR AUSTRALIAN EXPORT MARKETS (Tonnes)				
Importing Country	2007/08	2008/09	2009/10	2010/11
Singapore	285.1	370.3	256.0	270.0
Thailand	86.5	92.0	89.1	118.6
New Zealand	193.6	311.1	193.4	115.7
Hong Kong	312.8	304.3	139.6	94.6
Malaysia	107.1	62.0	61.2	69.7
Others	411.5	574.7	365.1	52.3
Total	1,396.7	1,714.3	1,104.4	720.9

Source: GTIS - ABS

Note : extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Fresh strawberry fruit are imported mainly from New Zealand (68 tonnes) and the USA (41 tonnes), however total volumes have declined significantly (Table 33). Imports of fresh fruit have declined to insignificant levels in the past 4 years, down to only 110 tonnes in 2010/11 from 707 tonnes in 2007/08 although there are still significant imports of processed strawberry products. The US has historically been our largest exporting country.

Table 33: Volume of total strawberry imports.

TOTAL AUSTRALIAN IMPORTS (Tonnes)				
Exporting Country	2007/08	2008/09	2009/10	2010/11
New Zealand	6.7	0.7	36.5	68.3
United States	678.4	249.7	111.4	41.4
Others	22.0	5.5	0.0	0.0
Total	707.0	255.9	147.9	109.7

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Strawberry consumption

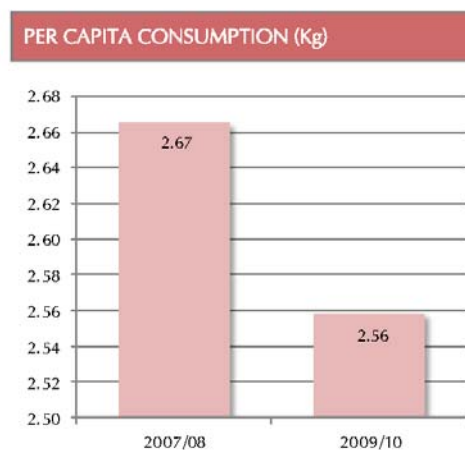
The combination of production across most Australian states provides a year-round national supply, primarily as fresh fruit for the retail or hospitality market. 95 % of the national production is destined for domestic consumption and is a growing niche industry within Australia's agricultural sector. Strawberries are consumed mainly as fresh fruit while second and third-grade fruit is frequently frozen and sold to processors for products such as jam.

Strawberries have been a popular niche fruit for consumption in Australia with average domestic consumption of about 2.6 kg per person per annum in 2009/10 (HAL 2012 -

Australian Bureau of Statistics ABS) (Figure 14). Consumption is expected to increase as comparison of global consumption rates also demonstrates a potential for growth in demand although total Australian fresh and processed strawberry consumption per capita for 2011 was 2.01 kg (Fresh Logic 2012).

Over the last two decades, the strawberry industry has experienced increased rates of consumption of strawberry and suggests that strawberries are gaining in popularity as one of the preferred fresh fruit in Australia and New Zealand, behind bananas, apples, oranges, grapes and pears. In the December quarter 2011, strawberries were the fourth most frequently purchased fresh fruit (Fresh Logic 2012).

Figure 14: Per capita consumption (kg) of strawberry in Australia.



Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Strawberry imports were 5910 tonnes for the year ending December 2011. This was made up of 110 tonnes of fresh produce and 5800 tonnes of processed product (FreshLogic 2012).

MELON

Melon structure and production

Fresh watermelons (seedless and seeded), rockmelons and honeydew melons are the major melon products. They are produced all year round and sold on the domestic market as fresh fruit or fresh cut preparations. A small quantity of melons is exported, mainly rockmelons, to Southeast Asia and New Zealand. Most fruit is marketed at capital city wholesale markets in Sydney, Melbourne, Brisbane, Adelaide and Perth.

Overall, the Australian melon industry tends to be fragmented. Melons are grown across all states and territories within Australia, with negligible amounts are grown in Tasmania and none are grown commercially in the Australian Capital Territory (Figure 15 and Table 34). Queensland, Western Australia and New South Wales are major producers of melons with the Northern Territory, Victoria and South Australia producing smaller volumes (HAL 2012).

Figure 15: Melon growing regions in Australia.



Table 34: Australian melons – watermelon, rockmelon and honeydew melon production by state.

AREA BY STATE (Ha)								
Season	Selected Variety	NSW	VIC	QLD	SA	WA	NT	Total
2007/08	Watermelon	873	230	2,032	27	744	524	4,430
	Rockmelon	647	67	796	6	577	115	2,208
	Honeydew Melon	106	0	100	2	134	0	342
2008/09	Watermelon	728	63	2,298	37	572	470	4,168
	Rockmelon	1,022	15	1,237	8	487	120	2,889
	Honeydew Melon	125	N/A	206	N/A	141	N/A	472

Source: Subtropical and Tropical Fruit Industries: Size, Value and Potential 2010-2025 A Growing Profile

Note: All figures are unpublished or estimated data from industry peak body organisation

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Rockmelon and honeydew melon production volumes and gross domestic product values are presented in Table 34 (2007 –2009 data). Approximately 60 500 tonnes of rockmelon and honeydew melon worth \$65 mil (GVP) and a farmgate value of \$53 mil were produced in 2010/11 (HAL 2012). Both volumes and values have remained stable while the area of plantings halved (Table 35).

Table 35: Production details for rockmelon and honeydew melon in Australia.

PRODUCTION DETAILS: ROCKMELON AND HONEYDEW MELON		
	2007/08	2008/09
Volume ('000 Tonnes)*	58.9	60.5
GVP (\$ Million)	67	65
Farmgate Value (\$ Million)	54.3	53.0
Area Of Plantings (Ha)*	2,208	1,077
Businesses*	122	168

Sources: ABS, *AUSVEG

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Estimates of world melon production are provided in Table 36, with Australia ranked 32nd and New Zealand at 63rd.

Table 36: World other melons (incl cantaloupe) production estimates for 2011.

Country	Tonnes	Ranking
China	13 085 500	1
Iran (Islamic Republic of)	1 801 830	2
Turkey	1 647 990	3
Egypt	1 038 410	4
United States of America	1 000 430	5
India	948 869	6
Spain	869 475	7
Mexico	564 366	8
Morocco	558 019	9
Italy	536 229	10
Australia	76 283	32
New Zealand	3079	63
World Total	27 295 907	

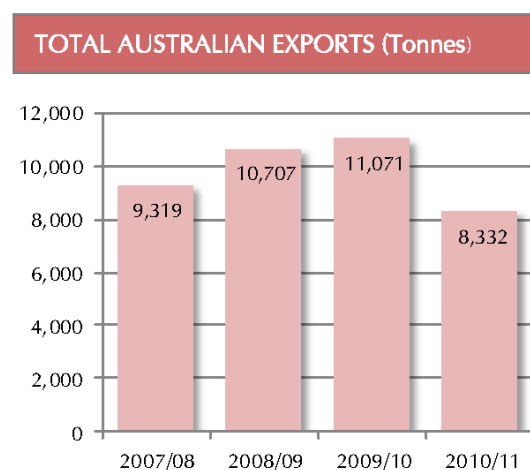
Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Melon Trade

An export industry exists predominantly for rockmelons; however, the industry is relatively minor with approximately 5% exported. Figure 16 shows Australian melon fruit exports from 2007/08 – 2010/11. HAL (2012) reported that in 2010/11, a total of 8332 tonnes were exported, predominantly to UAE (2785 tonnes) and Singapore (2562 tonnes) and smaller amounts to New Zealand (1667 tonnes) and Hong Kong (499 tonnes). Processing of melons makes up a very minor section of the industry in Australia. Insignificant amounts are imported, about 12 tonnes in 2010/11 (HAL 2012).

Melons are a fruit fly host, and quarantine restrictions in markets such as Japan and Korea are currently preventing access.

Figure 16: Exports of melon fruit.



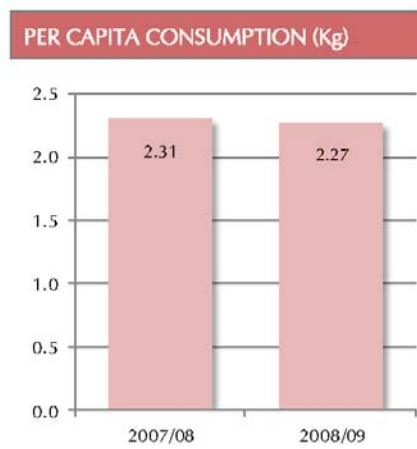
Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Melon consumption

The majority of the national rockmelon and honeydew melon production are destined for domestic consumption as fresh fruit or fresh cut preparations. The average domestic consumption of rockmelon and honeydew melon is around 2.3 kg per person per annum (HAL 2012). See Figure 17.

Melons produced in Queensland destined for interstate and export markets will require phytosanitary treatment if a quarantine barrier is crossed.

Figure 17: Per capita consumption (kg) of rockmelon and honeydew melon in Australia.



Sources: ABS, Production estimates from Subtropical and Tropical Fruit Industries: Size, Value and Potential 2010-2025 A Growing Profile

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

PEACH, PLUM & NECTARINE

Peach, Plum, Nectarine and Apricot - structure and production

Australian summer stonefruit is produced in about 26 regions in all states across the country with Victoria and New South Wales as the largest producing states however South Australia, Queensland and Western Australia are also important production states (Figure 18). These areas of production cover low, medium and high chill fruit, and produce in excess of 100 000 tonnes of peaches, nectarines, plums and apricots between October and April.

Low chill stonefruit varieties are produced in the area North of Coffs Harbour in NSW to the Atherton Tablelands in QLD, and in the area north of Gingin in WA. Medium chill varieties are concentrated around Stanthorpe in Queensland, the Central Coast of NSW through to the Sydney basin and extending to Swan Hill and the Riverland of SA. High chill fruit is produced in cooler climates including Southern NSW, the Goulburn Valley in Victoria, SA, Southern WA, and Tasmania. Renmark, Swan Hill and the Goulburn Valley constitute more than 50% of production. Treatment of low chill summerfruit from Qld and from other fruit fly zones in Australia will require a phytosanitary treatment if the produce crosses a quarantine barrier.

Figure 18: Australian summer stonefruit production areas.



Source: HAL

The season extends from October through to April. Early season fruit comes from sub-tropical Queensland and northern areas of Western Australia and New South Wales followed by fruit from central to southern New South Wales and Western Australia, Swan Hill in Victoria and the Riverland of South Australia. Fruit from cooler climates are last to market.

Limited summerfruit production details are presented. Overall volumes of production are shown in Table 37 and 38, with Victoria accounting for more than 80% of the tonnage produced (Table 37) and peaches leading the summerfruit produce (Table 38). In 2008/09 Vic produced 62 500 tonnes peaches of the 76 800 tonnes total national

production. Qld is a minor producer of peach. In that same year, Qld produced 1541 tonnes peach or about 2% of the total production.

Table 37: Production volume of summerfruit crops in Australia by states.

PRODUCTION BY STATE: PEACH (Tonnes)*							
Season	NSW	VIC	QLD	SA	WA	TAS	TOTAL
2007/08	**8,516	55,351	**1,757	1264	*1,355	*127	68,370
2008/09	*6,409	62,490	*1,541	4276	*1931	*144	76,791

Source: ABS

Notes: *Estimate has a relative standard error of 10% to less than 25% and should be used with caution

**Estimate has a relative standard error of 25% to 50% and should be used with caution

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Table 38: Production details of summerfruit crops in Australia.

PRODUCTION DETAILS									
	Peach			Nectarine		Plum		Apricot	
	2007/08	2008/09	2009/10	2007/08	2008/09	2007/08	2008/09	2007/08	2008/09
Volume ('000 Tonnes)	68	77	78	N/A	40	N/A	16	N/A	14
GVP (\$ Million)	93	100	112	102	102	47	N/A	32	N/A
Farmgate Value (\$ Million)	85	92	104	N/A	92	N/A	N/A	N/A	N/A
Number Of Plantings ('000)	2,270	2,127	2,077	N/A	N/A	N/A	N/A	N/A	N/A
Businesses	N/A	N/A	778	N/A	N/A	N/A	N/A	N/A	N/A

Source: ABS

Note: extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

About 40 000 tonnes nectarine was produced in 2009/10 however it was worth substantially more per tonne than peach \$102mil. 78 000 tonnes peach was worth \$112 mil (GVP) and 40 000 tonnes nectarine was worth \$102 mil in the 2009/10 season.

Plum and apricot are produced in smaller quantities compared to peach and nectarine. About 16 000 tonnes plum and 14 000 tonnes apricot were produce in 2009/10.

Apricots are particularly site specific in their climatic requirements in comparison to other stone fruit, which has limited their production to a few localities and varieties, with Victoria producing the largest quantity (see also separate section for apricot data).

World production estimates are presented in Tables 39 and 40. Australia (not available) and New Zealand (ranked 23rd) are minor producers of summerfruit by world standards. In 2011 Australia produced 97 547 tonnes (ranked 22nd) and New Zealand produced (62nd) 7486 tonnes of peach and nectarine.

World production details for plum and apricot could not be sourced at the present time.

Table 39: World stonefruit production estimates for 2011.

Country	Tonnes	Ranking
Iran (Islamic Republic of)	201 759	1
China	135 000	2
Afghanistan	44 713	3
Uzbekistan	32 800	4
Turkey	17 332	5
Hungary	13 643	6
Algeria	13 000	7
Ukraine	12 300	8
Lao People's Democratic Republic	11 415	9
Poland	11 205	10
New Zealand	2251	23
Australia	na	
World Total	567 070	

Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Table 40: World peach and nectarine production estimates for 2011.

Country	Tonnes	Ranking
China	11 528 801	1
Italy	1 636 750	2
Spain	1 335 600	3
United States of America	1 171 450	4
Greece	690 200	5
Turkey	545 902	6
Iran (Islamic Republic of)	498 346	7
Egypt	332 487	8
Chile	319 919	9
France	301 180	10
Australia	97 547	22
New Zealand	7486	62
World Total	21 528 690	

Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Peach, Plum, Nectarine and Apricot Trade

Nectarines, peaches, plums and apricots are exported from Australia with Australian growers having a reputation as quality niche market suppliers. Australia provides counter-seasonal summerfruit to complement northern producers and help keep customers supplied with fresh fruit year round.

Australian summerfruit exports of 8202.55 tonnes were valued at \$24.74 mil in the 2010/11 season due to a good supply of quality fruit and favourable exchange rate (HAL 2012).

Major export markets are to Hong Kong, the Middle East and Singapore. Dominant players in the world export market for a range of summerfruit include France and Spain (HAL 2012). Overall plum and peaches/nectarine exports each have fluctuated around 3500 tonnes while apricots were around 250 tonnes for the past decade to selected markets (Figure 19).

Figure 19: Total Australian exports of peach, nectarine, plum and apricot.



Note: Figures extracted from HAL, The Australian Horticulture Statistics Handbook 2012.

Following approval of a protocol in Australia in July 2013 shoppers in Australia will be able to buy peaches and nectarines grown from California in the winter period.

Peach, Plum, Nectarine and Apricot Consumption

Summerfruit is one of Australia's more popular seasonal fruit, with around 80% of Australian households purchasing summerfruit in season (University of Technology Sydney 2010). This represented a year-on-year rise of 4.5% or 275 500 households. Other data can also be obtained from the Summerfruit Industry.

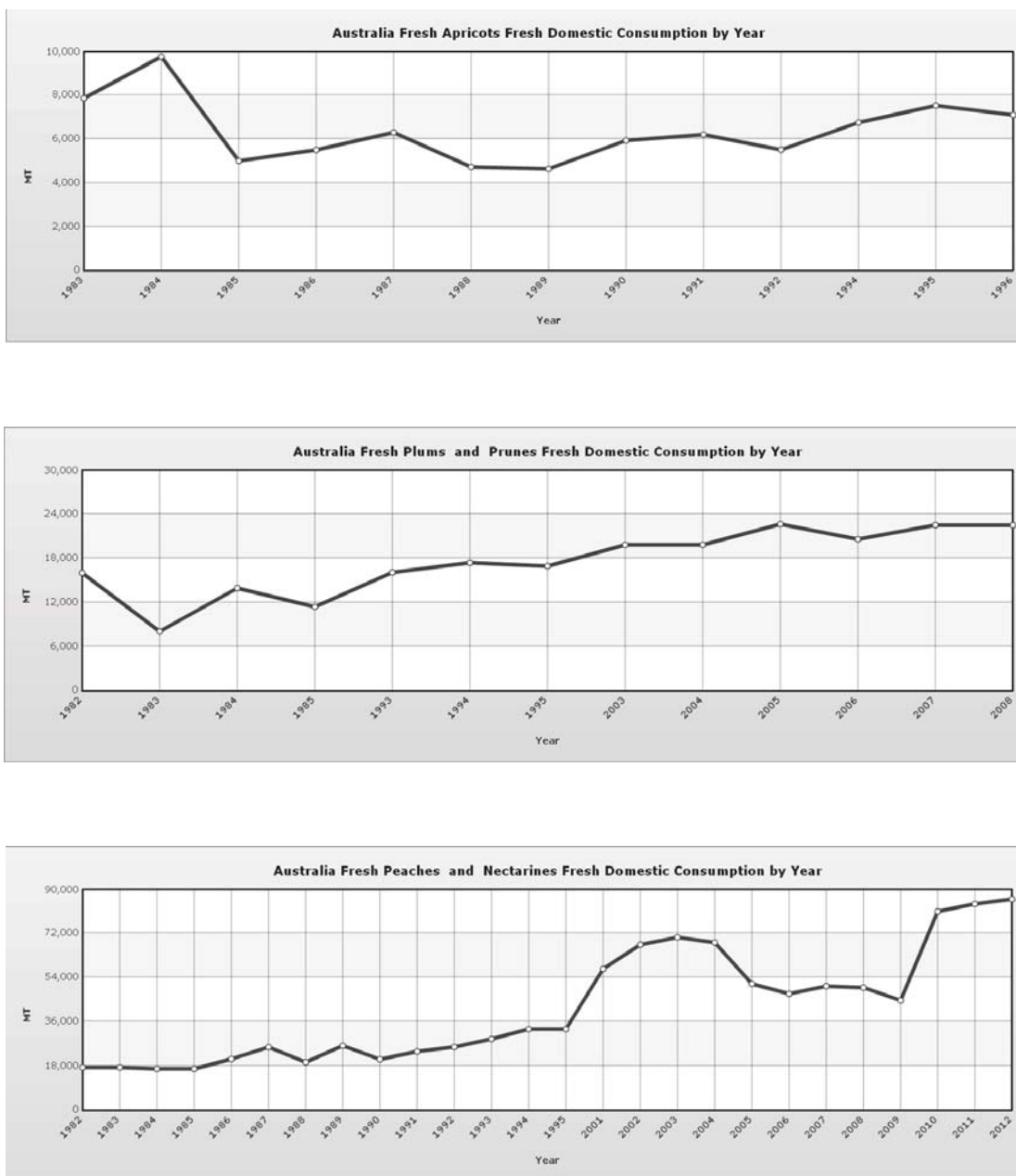
All Australian fresh summerfruit have seen increases in consumption (Figure 20) since collection of data however consumption data are difficult to find. Estimates of around 7 kg per capita per annum were put forward. In the 2010/11 season an average weight of 3.0–4.7 kg nectarine, 2.0–2.4 kg peach, 2–4.5 kg plum and 1.1–1.9 kg apricot were purchased (HAL 2012).

Summerfruit (stonefruit) is grown for both the processing and the fresh fruit market with the majority of fresh summerfruit consumed domestically and a large proportion of the processed fruit being exported. Australia is a small player on the world stage and produces less than 1% of the world production of stone fruit. The dried apricot sector continues to be under pressure from cheaper imported product, particularly from Turkey.

Summerfruit are seasonal and consumption is limited to the summer months. Total consumption of the various summerfruits in the two countries is shown in Figures 20 and 21 (1983–1996 data).

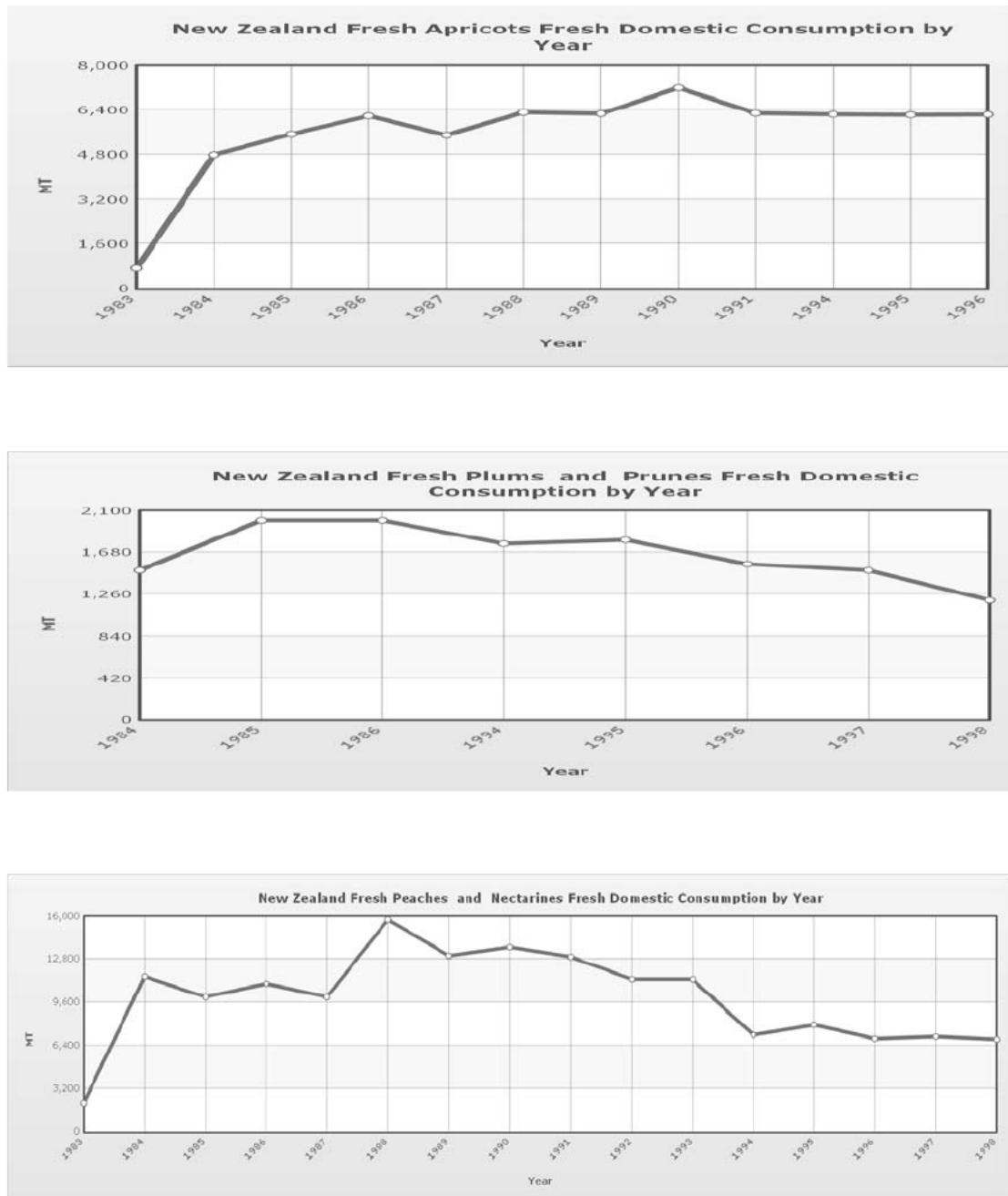
In Australia, the consumption of fresh apricots appeared to have levelled while fresh plums, prunes, peaches and nectarines have increased in that period. During the same period, total consumption of fresh plums, prunes, peaches and nectarines declined while fresh apricots increased and remained constant.

Figure 20: Total Australian consumption of fresh summerfruit by commodity.



Source: IndexMundi <http://www.indexmundi.com/> viewed 29th May 2013

Figure 21: Total New Zealand consumption of fresh summerfruit by commodity.



Source: IndexMundi <http://www.indexmundi.com/> viewed 3rd July 2013

APRICOT

Apricot Structure and production

The Australian apricot has an estimated gross value of production of \$20.5 million for the 2010/11 season (HAL 2012). A snapshot of the industry is presented in Table 41 by Rettke *et al.* (no date). (See summerfruit section for comparison with peach, nectarine and plum)

Table 41: Industry snapshot of the apricot industry in Australia.

Industry Snapshot	
Total Australian production (tonnes)	13 372
Total value (\$'million) of Australian Industry	32
Top three production states (in order, highest first)	VIC, SA, TAS
Percentage of production exported (%)	10
Top three export destinations for dried fruit (in order, largest destination first)	New Zealand, UAE, Netherlands,

(Source: ABS Catalogue 75030, ABS International Trade Data extracted from Rettke *et al.*, no date)

All six mainland states in Australia produce apricots, with production concentrated mainly in Victoria and South Australia (Tables 42 and 43). Apricots are produced in Australia for processing, drying and the fresh market. High proportions of the fruit crop from these two states are utilised for processing and drying, respectively. Apricots grown or processed in Australia are predominately sold on the domestic market. In New Zealand, stone fruit is mainly grown in Hawke's Bay and Central Otago.

Table 42: Apricot production by state across Australia (ABS 2008).

	NSW	QLD	SA	TAS	VIC	WA	Total
Production (tonnes)	268	214	4187	371	11545	332	16,917
Area (ha)	78	57	371	129	702	68	1405

In Victoria, apricots are grown mainly around the Goulburn Valley region, along the Murray River in Swan Hill and Sunraysia. In South Australian fruit is grown in the Riverland region. Areas of apricot production within Australia are shown in Figure 22.

Table 43: Australian apricot production, production location and value for the years ended 30 June 2004, 2005 2006, 2007 and 2009.

Year	Production (tonnes)							Total
	NSW	VIC	QLD	SA	WA	TAS	NT	
2003/4	308	3132	186	6021	321	691	0	10 658
2004/5	439	11 605	249	6391	294	721	0	19 698
2005/6	268	11 545	214	4188	333	371	0	16 920
2006/7	569	11 689	393	3827	395	453	0	17 327
2007/8							0	
2008/9	384	8758	301	2653	396	1180	0	13 672

(Source: ABS Catalogue 7121.0, for the relevant year, extracted from Rettke *et al.*, no date)

Figure 22: Apricot production regions within Australia (ABS 2008).

In the past decade, both processing and dried fruit sectors have declined, which has impacted particularly heavily in South Australia. It seems likely that production for the processing and dried fruit sectors have bottomed and production volumes are not expected to increase but remain fairly stable.

Major export markets were Hong Kong and the Middle East with over 320 tonnes of apricots being exported to these areas in 2008/09. Dominant players in the world export market for apricots include France (US\$47 mil) and Spain (US\$38 million) with the world export market worth some US\$180 mil (180,000Mt) (RIRDC 2010b).

Major export markets were the Middle East and Hong Kong with over 310 tonnes of apricots being exported to these areas in 2010/11. Overall Australian apricot exports were valued at \$1.47 million for the 2010/11 season, with exports to UAE (\$0.74 mil), Hong Kong (\$0.29 mil) and France (\$0.13mil). 858 tonnes apricots, worth approximately \$3.85 mil, were imported from New Zealand in 2010/11 (HAL 2012). The world export market for apricots is worth approximately US\$180 mil and Australia is a minor exporter for

apricots. Dominant players in the world export market for apricots include France (US\$47 mil) and Spain (US\$38 mil).

Few restrictions or impediments to global trade expose the dried apricot sector to global competitive forces on both the domestic and export markets, with the domestic dried apricot sector continuing to be under pressure from cheaper imported product. However, this is unlikely to impact on the supply of fresh apricot fruit trade.

Similar to Australia, most of the fruit produced in New Zealand is sold in domestic markets but sales overseas are increasing. Fruit is sold to Australia, Taiwan, the United States, Europe, Thailand and Japan. Zealand imports some out of season stone fruit from the United States and Chile.

Turkey ranks first in the world for apricot production (376 163 tonnes), Australia 36th (13 283 tonnes) and New Zealand at 47th (2995 tonnes) (Table 44).

Table 44: World apricot production estimates for 2011.

Country	Tonnes	Ranking
Turkey	676 138	1
Iran (Islamic Republic of)	452 988	2
Uzbekistan	356 000	3
Italy	263 132	4
Algeria	205 000	5
Pakistan	189 420	6
France	154 980	7
Morocco	132 523	8
Ukraine	119 900	9
Japan	106 900	10
Australia	13 283	36
New Zealand	2995	47
World Total	3834475	

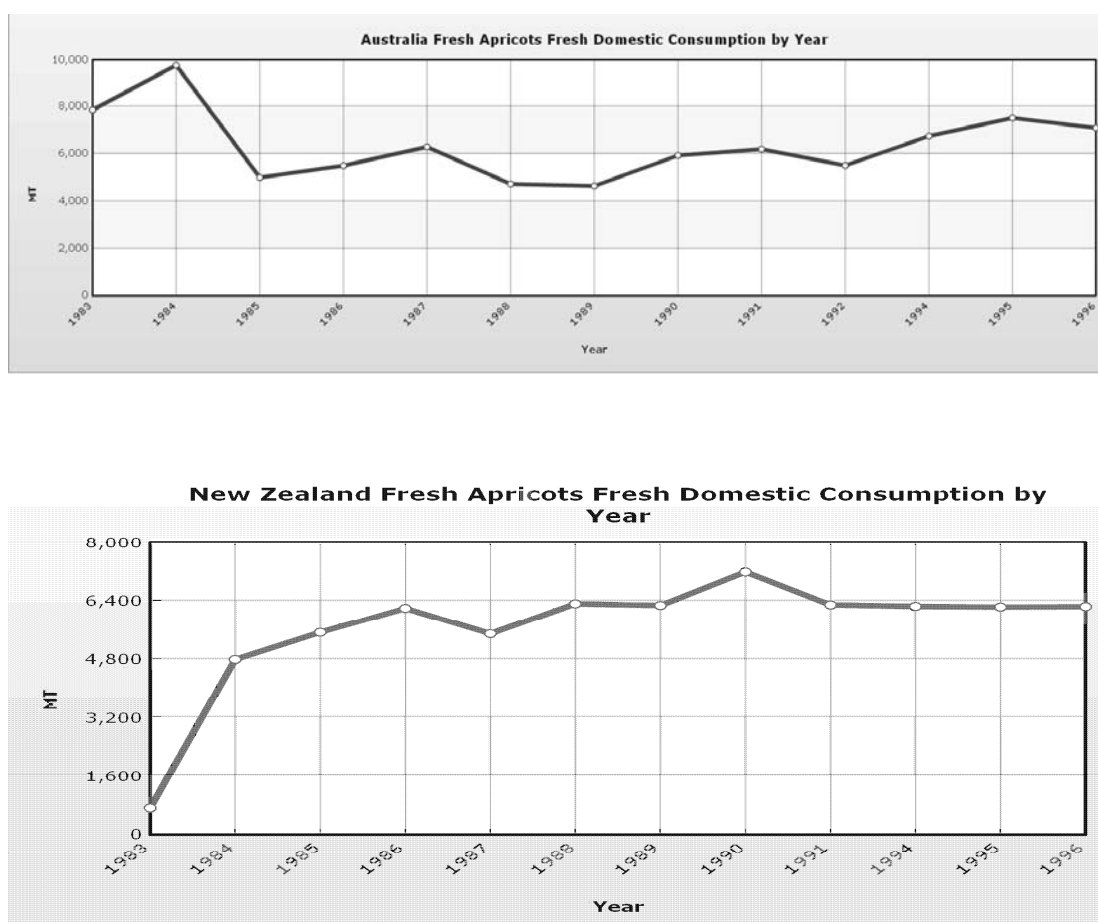
Source: FAOSTAT | © FAO Statistics Division 2013 | 13 June 2013
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
 may include official, semi-official or estimated data

Apricot consumption

There is little data available for apricot consumption. Apricots produced in Australia are destined for processing, drying and the fresh market. High proportions of the crop from the two major production states, Victoria and South Australia, are utilised for processing and drying respectively.

Consumption data for Australia between 1983 and 1996 is shown in Figure 23, relatively stable.

Figure 23: Domestic consumption for fresh apricots in Australia and New Zealand.



Source: IndexMundi <http://www.indexmundi.com/> viewed 29th May 2013

ZUCCHINI

Zucchini structure and production

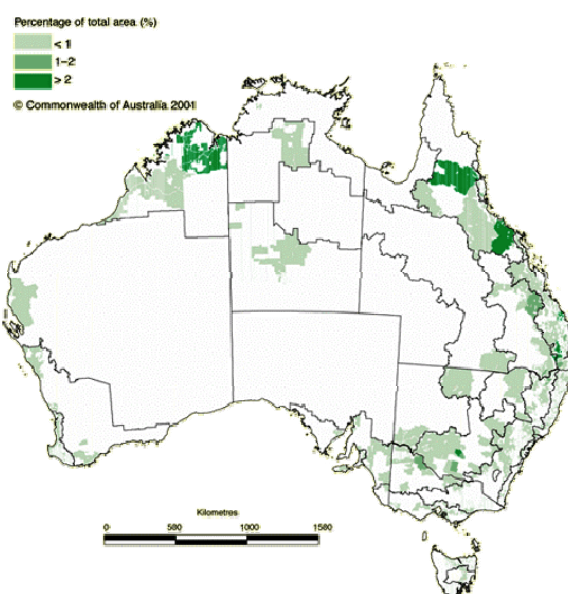
Vegetable growing is concentrated in Queensland and New South Wales but vegetable farms in New South Wales on average are smaller than in the other States. The top ten vegetable crops by value and in order in 2010/11 were potatoes, tomatoes, mushrooms, onions, melons, lettuces, carrots, beans, capsicums and broccoli.

Cucurbits (mainly pumpkin, cucumber, zucchini, gherkins, marrow and squash) was worth \$75 mil (GVP) in 1996/97 (ANRA site decommissioned 31st May 2013), representing about 2% of the total gross value of Australia's horticultural production in that year. Cucurbits in Australia are produced largely for the domestic market although opportunities for overseas export have shown potential. (Cucumbers are currently exported to New Zealand, Hong Kong, Singapore and Papua New Guinea, whilst pumpkins are regularly exported to Japan).

Zucchini production is almost exclusively for the domestic market. Zucchini is traditionally a summer vegetable widely used in Mediterranean cuisine.

Zucchini is grown in all horticultural production areas, in Victoria, New South Wales, Queensland, South Australia, Western Australia, the Northern Territory and Tasmania (Figure 24, combined cucurbit).

Figure 24: Cucurbit production areas.



Source: Australian Natural Resources Atlas

<http://www.anra.gov.au/topics/agriculture/pubs/national/cucurbits.html>

Combined production of zucchini and butter squash are presented in Table 45. Annual production is around the 22 000 tonne mark with a gross value of approximately 65–72 mil. Farmgate value however has dropped slightly.

Table 45: Australian zucchini and butter squash production details.

	2005–06	2006–07	2007–08	2008–09
Number of growers	607	572	552	621
Area planted (hectares)	2707	2438	1858	2220
Production (tonnes)	22 761	23 704	20 382	23 989
Yield (tonnes/hectares)	8.4	9.7	11.0	10.8
Gross value (\$m)	71.7	68.3	55.7	65.2
Gross unit value (\$/tonne)	3151	2879	2733	2718
Farm gate value (\$m)	61.2	59.1	47.0	56.1

Source: AusVeg <http://ausveg.businesscatalyst.com/resources/statistics/domestic-industry/detailed-data.htm> (Vegetables grown in field)

Queensland is the largest zucchini and butter squash producing state (Table 46), and accounted for over 60% of the total Australian production (2008 data).

Table 46: Production of cucumbers, pumpkins and zucchini (ABS 2008 data).

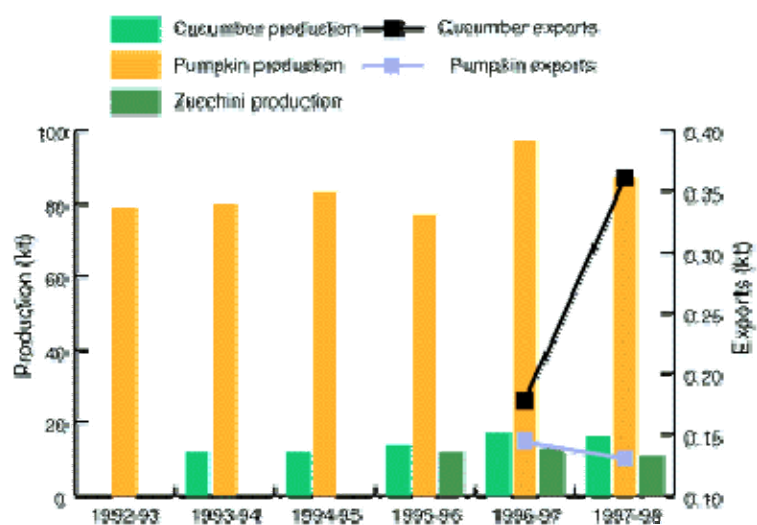
	NSW	NT	QLD	SA	TAS	VIC	WA	Total
Zucchini and button squash (t)	2225	67	12 980	279	129	6775	1136	20 382

Zucchini Trade

Records for zucchini export and imports were difficult to find.

Figure 26 shows the production of cucurbit production and exports from 1992 to 1998. Zucchini production was around the 10 kilotonnes but no exports were recorded for the same period between 1995 and 1998.

Figure 25: Cucumber, pumpkin and zucchini production and exports.



Source: Australian Natural Resources Atlas

<http://www.anra.gov.au/topics/agriculture/pubs/national/cucurbits.html> (site decommissioned 30 May 2013).

APPENDIX 2. NUTRITIONAL VALUE AND FRUIT QUALITY

A2.1 Nutritional Value of Apple

Apples are one of the most consumed fresh fruit in both Australia and second in New Zealand. Fresh apples are the first most consumed fruit by adult Australians (ABS 1999) and figures released by Statistics New Zealand (SNZ) show that an average Kiwi household spends \$88 a year on bananas, compared with \$61 for apples and \$26 for oranges (Otago Daily Times 2013).

Table 47 provides key nutritional data for fresh raw red apple, unpeeled and one reference for green apple. Values were extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). Differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Apples have high water content (83–85%) and therefore the macronutrient and energy levels are low relative to many other foods. Carbohydrate accounts for about 11–13%. Apples contain little protein (0.3 g/100g) and total lipid (0.5 g/100g). From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will come from foods other than apples.

Data extracted from both FSANZ and NZMOH are compared against quoted FSANZ Reference Values with carbohydrate representing the largest percentage intake per serving (Table 48).

The percentage daily intake per serve of fresh apple, which is 150 g fresh fruit accounts for about 4% energy, 0.9% protein, 6% available carbohydrate, 11% total dietary fibre, 19% total sugars and 0.1% sodium (Table 48). Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available per 100 g carbohydrate is between 196–223 kJ (Table 49). A major proportion of the energy value comes from carbohydrate with small amounts from protein and dietary fibre.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). Apples provide a source of Vitamin C and β -carotene. Apple fruit is also good source of B-complex vitamins such as riboflavin, thiamin, and pyridoxine (vitamin B-6) and contains a small amount of minerals like potassium, phosphorus, and calcium (Table 47).

Apples are a popular part of the average consumer's diet although their contribution to overall micronutrient intake will not be pre-dominant (comparison of values in Table 7). Although apples are a useful source of micronutrients, their nutritional profile suggests that they will not be a significant contributor to overall daily micronutrient intake.

Table 47: Nutritional data for raw green and red apple, unpeeled per 100g edible portion.

Nutrient	value	Red Apple			Green Apple
		USDA 2011	MOH 2009	FSANZ 2010	FSANZ 2010
Water	g	85.56	83.25	83.8	85
Energy	KJ	218	215.57	236	204
Protein	g	0.26	0.26	0.3	0.3
Nitrogen	g		0.04	0.05	0.05
Total lipid (fat)	g	0.17	0.49	0	0
Malic acid	g			0.3	0.6
Citric acid	g			0	0
Carbohydrate	g	13.81	11.56	13.1	10.6
Total Dietary Fibre	g	2.4	2	2.2	2.4
Ash	g	0.19	0.22	0.2	0.2
Total sugars	g	10.39	10.5	12.4	10.4
Fructose	g	5.9	5.8	6.9	5.8
Glucose	g	2.43	2.8	3.3	2.7
Sucrose	g	2.07	1.9	2.1	1.9
Ascorbic Acid, Vit C	mg	4.6	4.5	6	5
Thiamin, Vit B1	mg	0.017	0.02	0.019	0.028
Riboflavin, Vit B2	mg	0.026		0.01	0.01
Niacin	mg	0.091		0.1	0.1
Niacin equivalents	mg		0.14	0.13	0.14
Vit B6	mg	0.041	0	0.02	0.05
Folate, Vit B9 total	µg	3		0	0
Vit A (retinol equiv.)	µg	3	7.52	2	1
Alpha carotene	µg	0		0	0
Beta carotene	µg	27		10	3
Beta cryptoxanthin	µg	11			3
Cryptoxanthin	µg			10	10
Vit E	mg	0.18	0.4	0.23	0.47
Vit K	µg	2.2			
Calcium	mg	6	4.68	5	4
Iron	mg	0.12	0.14	0.16	0.16
Magnesium	mg	5	4.19	5	4
Phosphorus	mg	11	7	9	9
Potassium	mg	107	73.8	106	107
Sodium	mg	1	0.85	1	2
Zinc	mg	0.04	0.03	0.06	0.06
Copper	mg	0.027	0.01	0.042	0.024
Manganese	mg	0.035	21.2	0.03	0.041
Selenium	µg	0	0.09	0	0
Iodine	µg		0.2	0	0
Molybdenum	µg				0.1
Nickel	µg				0
Tin	µg				0

Table 48: Nutrient values are per 100 g edible portion of fresh apple.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	83.8	83.25	125.7	124.875			
Energy (kJ)	236	215.57	354	323.355	4.1	3.7	8700
Protein (g)	0.3	0.26	0.45	0.39	0.9	0.8	50
Total lipid (fat) (g)	0	0.49	0	0.735	0.0	1.1	70
Fatty acids, total saturated (g)	0	0	0	0	0.0	0.0	24
Available Carbohydrate (g)	13.1	11.56	19.65	17.34	6.3	5.6	310
Sugar (g)	12.4	10.5	18.6	15.75	20.7	17.5	90
Total dietary fibre (g)	2.2	2	3.3	3	11.0	10.0	30
Sodium (mg)	1	0.85	1.5	1.275	0.1	0.1	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>.

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 49: Calculation of energy value of the major* food components per 100 g apple.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ	Average quantity	Approximate calculation of energy value kJ
Protein	17	0.3	5.1	0.26	4.42
Total lipid (fat)	37	0	0	0.49	18.13
Fatty acids, total saturated		0	0	0	0
Available Carbohydrate	17	13.1	222.7	11.56	196.52
Total sugars		12.4		10.5	
Total dietary fibre	8	2.2	17.6	2	16

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of apple

QLD DAFF (2013) recently conducted nutritional and fruit quality evaluations on red apple (*Malus domestica*) fruit, variety 'Red Delicious', after being treated with gamma irradiation and following a recommended cold (1°C) storage period of 28 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gray (Gy), with fruit evaluations conducted before and after storage (Attachment). The results of the study are in agreement with data from previous research on various apple varieties.

The nutrition study found apple can tolerate 1 kGy radiation; irradiation applications of up to 1 kGy did not significantly impact on the nutritional quality of apple fruit. No significant dose by time interactions were reported in ash, carbohydrates, total dietary fibre, total sugars, fructose, glucose, sucrose, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene). The nutritional components tested were responsive to storage time and not to irradiation. The changes observed in total carbohydrates and individual sugar components and the loss in beta-carotene were primarily associated with the biological ripening processes that can normally occur during storage.

The Postharvest Technology Centre UC Davis (UC Davis website) recommendations for maintaining postharvest quality for apple reports a range of damage during storage - water loss, respiration, metabolism and microbial spoilage – all of these can affect the overall nutritional quality of apple during storage.

Similar results were found by Drake *et al.* (2003) in two different apple varieties. Total carbohydrate, sucrose, glucose, fructose and sorbitol concentrations in Fuji and Granny Smith apples were unaffected by irradiation treatment but these components were affected by storage time. Sucrose decreased while concentrations of total carbohydrate, glucose, fructose and sorbitol increased as storage progressed. An earlier study by Wang *et al.* (1993) showed that there was no significant effect of irradiation with 0.3–2.0 kGy on the nutritional qualities of apples.

Specifically, a main effect of dose was not detected in Vitamin C (total ascorbic acid) and in Vitamin A (beta-carotene) in apple cv. 'Red Delicious' after irradiation. Storage for 28 days resulted in reduced Vitamin C (total ascorbic acid), with the greater decline in samples treated at ≥ 600 Gy (QLD DAFF 2013).

The amount of Vitamin C (total ascorbic acid) in apple is typically low as reported elsewhere (FSANZ 2010, Iordanescu 2012, MOH 2009, USDA 2011b) and it is well documented that Vitamin C in fruits can be influenced by cultivar, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures (Carbone *et al.* 2011, Jan *et al.* 2012, Iordanescu 2012, Lee and Kader 2000, Wu 2007). Other fruits such as capsicum, tropical fruits and summerfruit have greater Vitamin C concentrations than the popular apple (Table 7).

Apple fruit treated with doses up to 1.0 kGy showed little or no loss in nutritional quality (QLD DAFF 2013, Drake *et al.* 1998, 2003). Application of gamma irradiation treatments of ≤ 1 kGy therefore can be considered a suitable phytosanitary / disinfestation method without inducing significant deleterious effects to the chemical and proximate components of apple. Compared with other fruit and vegetables, apple is reported to have a high tolerance to irradiation doses below 1 kGy (Kader 1986). Hussain *et al.* (2008) reported no detrimental changes in fruit quality in apple irradiated < 0.5 kGy and showed that 0.4 kGy gamma irradiation was effective in extending shelf life by 30 days under ambient temperature.

Apple fruit exhibited no symptoms of disease and no disorders occurred as a result of the irradiation or storage treatments.

The postharvest fruit quality study found that apple fruit quality was affected by both irradiation and storage time. Apple flesh colour properties were also affected by both irradiation and storage duration. Fruit firmness decreased significantly with increasing irradiation dose. Slightly firmer fruit found after storage was attributed to using different batches of fruit at each storage time assessment. Apple firmness was reduced when irradiated, however this varied with dose and storage temperature (Al-Bachir 1999, Drake *et al.* 1998).

A slight decrease in titratable acidity was detected after storage but no effects in total soluble solids were reported. There was no change with irradiated Fuji or Granny Smith apples (Drake *et al.* 1998).

Irradiation and storage duration had no impact on total soluble solids content (mean 12.2° Brix) although storage duration did cause a slight decrease in titratable acidity, decreasing from 0.17 to 0.16% malic acid.

Overall, by the end of the trial fruit from all treatments were considered to be of a quality that was commercially saleable, despite the slight decrease in firmness and a change in flesh colour in the higher dose treatments.



Effect of irradiation on the nutritional profile and postharvest quality of fresh apple (*Malus domestica*) fruit.

Final Report
January 2013



Project Title

Effect of irradiation on the nutritional profile and postharvest fruit quality of apple fruit.
Part of MT10057 Phase 2 Final Report (includes apple, apricot, cherry, peach, plum and table grapes).

The Report is presented in two parts.

Part A: Nutritional analysis
Part B: Postharvest fruit quality

Project Leaders

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Market Access Focus Team Leader
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

[REDACTED] Research Scientist, DAFF
[REDACTED] Research Scientist, DAFF
[REDACTED] Senior Biometrician, DAFF
[REDACTED] Market Access Focus Team Leader, DAFF

Technical Personnel

[REDACTED] Technical Officer, DAFF

Funding Sources

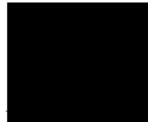
Horticulture Australia Limited (HAL)
Queensland Department of Agriculture, Fisheries and Forestry
Australian Government, Department of Agriculture, Fisheries and Forestry

Date of Report

January 2013

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.



Leader, Radiation Technology
Senior Technical Officer, Radiation Technology
Technical Officer, Radiation Technology
Technical Officer, Radiation Technology

© State of Queensland, 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Contents

Contents	4
Executive Summary	5
Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of apple (<i>Malus domestica</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis	11
Statistical analysis of chemical components	18
Results and Discussion	19
Irradiation treatment – dosimetry	19
Nutritional components	20
Recommendation	33
References	34
Part B. Effect of gamma irradiation on the postharvest quality of apple (<i>Malus domestica</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Executive Summary

Nutrition and fruit quality evaluations were conducted on apple (*Malus domestica*) fruit, variety 'Red Delicious', after being treated with gamma irradiation and following a recommended cold storage period of up to 28 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gray (Gy), with fruit evaluations conducted before and after storage.

The nutrition study found irradiation applications of up to 1 kGy did not significantly impact on the nutritional quality of apple fruit. Storage time rather than irradiation had a greater effect on many of the apple nutritional components, with most of these changes being associated with the ripening process. Application of gamma irradiation treatments of ≤ 1 kGy was therefore considered a suitable phytosanitary / disinfestation method without inducing significant deleterious effects to the chemical and proximate components of apple.

In the fruit quality study, applications of gamma irradiation treatments on apple fruit were found to not cause any deleterious effects on fruit quality. Fruit softness and changes in flesh colour did occur with higher irradiation doses although the effects were minor. The results are in keeping with previous studies that suggest that irradiated 'Red Delicious' apple fruit treated with similar doses as in this study remained at a commercially acceptable standard.

Part A. Effect of low dose gamma (γ)– irradiation on the nutritional profile of apple (*Malus domestica*) fruit.

Contents

Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of apple (<i>Malus domestica</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis.....	11
Moisture. Method VL298 Version 6.2	11
Ash. Method VL286 Ver. 5.1	12
Protein. Method VL299 Protein	12
Dietary Fibre.....	13
Fat. Method VL302_Fat by Mojonnier	13
Fatty Acid Profile. Method VL 289 Fatty Acid Profile.....	14
Sugars. Method VL295_Common Sugars.....	14
Sodium. Method VL247.....	15
Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages	15
Calculation of Energy and Carbohydrates in Food. Method VL 412	16
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs.....	16
Limits of Reporting	17
Statistical analysis of chemical components	18
Results and Discussion	19
Irradiation treatment – dosimetry	19
Nutritional components	20
Recommendation.....	33
References	34

Summary

This report examines the radio-tolerance of apple (*Malus domestica*) cv. 'Red Delicious' at doses at and below 1 kGy for the purpose of quarantine disinfestation. The effects of low dose gamma (γ)–irradiation on the proximate and nutritional quality of untreated and irradiated apple fruit were investigated.

The study provides an analysis of data on the nutritional profile of apple that have been irradiated at 0, 150, 600 and 1000 Gy and assessed on two occasions. The first assessment was one day after irradiation treatment and the second was after 28 days storage at 0°C.

The nutritional profile of each produce was analysed and included ash, energy, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and beta-carotene.

Overall, our results show that apple can tolerate 1 kGy radiation. Generally, fruit nutritional quality was primarily impacted more by storage time than by irradiation. The changes in total carbohydrates and individual sugar components along with loss in beta-carotene were primarily associated with the biological ripening processes that can normally occur during storage.

Specifically, a main effect of dose was not detected in Vitamin C (total ascorbic acid) and beta-carotene in apple cv. 'Red Delicious' after irradiation. Storage for 28 days resulted in lowered Vitamin C (total ascorbic acid), with the greater decline in samples treated at ≥ 600 Gy.

A significant main effect of dose was found in mean fructose, with irradiated samples (6.27–6.37 g/100g) showing a higher concentration than the control sample (6.00 g/100g). Protein values were also affected by dose but the results are not consistent.

In this study, the fresh season apple fruit are low in protein and fat with moisture contents frequently greater than 84%. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of apple.

Introduction

There is an increasing trend to centrally process fresh fruits, suitably packaged, for distribution and marketing. Irradiation technology proved to be effective in reducing postharvest losses, delaying ripening and prolonging fruit shelf life. Fruit maturity, cultivar, environmental conditions, postharvest handling, storage temperature, and the use of controlled atmosphere storage have all been reported to influence such fruit responses to irradiation (Lee and Kader 2000, Maxie and Abdel-Kader 1966, Miller and McDonald 1999, Mitchell *et al.* 1992) but few reports are available on the effects of irradiation on the nutritional and proximate qualities.

Compared with other fruit and vegetables, apple is reported to have a high tolerance to irradiation doses below 1 kGy (Kader 1986). Hussain *et al.* (2008) reported no detrimental changes in fruit quality in apple irradiated < 0.5 kGy and showed that 0.4 kGy gamma irradiation was effective in extending shelf life by 30 days under ambient temperature. Irradiation at doses between 0.30 and 0.90 kGy reduced apple firmness with the amount of firmness lost due to irradiation being cultivar dependent (Drake and Neven 1998). Titratable acidity (TA) of 'Gala' apples was reduced at irradiation levels ≥ 0.60 kGy and with no loss of TA in 'Fiji' and 'Granny Smith' apple. In another study, irradiation at < 1.00 kGy did not result in external colour of apples while high dose rate initially resulted in less softening compared to low dose rate of fresh-cut apples irradiated at doses up to 5 kGy but dose rate became insignificant upon storage (Gunes *et al.*, 2001).

The Interstate Certification Assurance (ICA) scheme is a national system of plant health certification which provides for a harmonised approach to the audit and accreditation of businesses throughout Australia and the mutual recognition of plant health assurance certificates accompanying consignments of produce moving intrastate or interstate. ICA-55 in the state of Queensland was developed to meet the requirements of State and Territory governments in Australia for the certification of irradiated fruit fly host produce for interstate and intrastate quarantine purposes. However, only fresh fruit and vegetables approved in the Food Standard Australia New Zealand (FSANZ) Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) can be certified under this Operational Procedure. There are currently ten commodities that are approved to be irradiated for pest disinfection purposes and the minimum and maximum doses permitted are 150 Gy and the maximum is 1 kGy respectively. The 150 Gy minimum dose is a generic dose for fruit fly which is an internationally approved treatment (International Standard for Phytosanitary Measures ISPM No.28, Annex 7 2009).

The effects of low dose irradiation and cold storage were investigated on the apple variety 'Red Delicious', in order to assess their effects on fruit nutritional quality. Export quality fresh whole produce were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation on apple. This work will also compliment current findings from the postharvest fruit quality component of this study described later in this report.

Materials and Methods

Cultivar

Whole, fresh red apples were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of apples was carried out on 26th March 2012. The apple (*Malus domestica*) variety tested was 'Red Delicious'. It is a crimson to dark red apple, with five distinct crowns on the base of the fruit.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 0°C. The apples were randomly selected but not graded and packed into cardboard boxes which fitted into the stainless steel irradiation chamber for treatment.

Irradiation treatment

The apple samples were exposed to target irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy from a Co^{60} source of gamma irradiation. One box of apple was treated for each dose. For proximate and nutritional analyses 10 fruit were used at each assessment time.

There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 23.0 – 24.0°C. The boxes of fruit were positioned on a rig parallel (Figure 2, pg 24, this document) to the plaque source.

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing (ANSTO 2011).

The irradiation doses were measured by placing Fricke dosimeters throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front and between fruits within the carton. Additional dosimeters were attached to the outside of each package for monitoring and to provide references to the minimum and maximum doses.

The effects of irradiation were measured at two stages: after irradiation treatment (Time 1; one day after irradiation treatment) and after 28 days of cold storage at storage 0°C (Time 2).

Following irradiation treatment, the fruit were sorted, packed and sent for chemical analysis and fruit quality assessment. Time 2 fruit were placed in cold storage until testing commenced.

Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the two occasions, after treatment and after a period in cold storage at 0°C. The first assessment was a day after mean irradiation treatment and the second analysis was at the end of a storage period of 28 days.

Edible portions of each fruit were blended at each time point. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s): AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1 mg.

2 to 5 gram of sample is weighed, to nearest 0.1 mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1 mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1 mg, into the dish. The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s): AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to 525°C ± 25°C until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2 g) is accurately weighed into a Kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20 ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50 ml distilled water is added. The tube is placed in a Kjeltac distillation unit and the mixture is steam distilled into a beaker containing 50ml of saturated boric acid solution. The distilled solution is titrated with

standardised 0.1 N sulphuric acid solution using a mixed indicator of bromocresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre.

Reference Method: AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s): AS 2300.1.3. AOAC 16th Edition 954.02, 948.15, 922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2 g) is accurately weighed into a beaker.

10 ml of approx. 10 % hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10 ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25 ml of diethyl ether and a further minute with each of 25 ml of petroleum ether and 50 ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102°C until constant weight is achieved.

Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish X 100}}{\text{Weight of sample}}$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", Can. J. Biochem. Physiol. 37: 911-917.

Badings and Dejong (1983). J. Chrom. 279: 493-506.

McCance and Widdowson (1991). The Composition of Foods. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10 g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2 g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and re-extracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s): AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45 µm filter into a 2 ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s):

1. USEPA (United States Environmental Protection Agency) Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2–0.5 g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase.

Absorbance is measured by PDA detection at 245 nm, the PDA spectra (220 to

350 nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL 412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code (2011).

Carbohydrate Calculation:

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation:

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference Method: CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5 g of sample is accurately weighed into a 250 ml flask and 60 ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500 ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes; each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10 ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450 nm, the PDA spectra (250 to 650 nm) is used as confirmation. Determination is made against a known β - Carotene standard, whose concentration is determined by absorbance measurements.

Limits of Reporting

The laboratory standard normally only contains the compound or compounds of interest, in the optimal calibration range. It is also in a medium that does not interfere with and/or enhance the performance of the analytical instrument. It is under these ideal conditions that the lowest concentration can be reported, while minimising uncertainty due to matrix effects. This concentration is the limit of detection of the method. Other non-targeted compounds and constituents can interfere with the sample analysis, and the corrected concentration is reported (limit of reporting).

Limits of reporting for the various components tested are tabled below.

Analysis / Analyte	Limit of reporting; LOR (generally 1–5 times the limit of detection)
Vitamin C (L-ascorbic acid)	1 mg/100g
Beta-carotene	5 µg/100g
Ash	0.1 g/100g
Carbohydrates	2 g/100g (calculated by difference)
Dietary fibre	0.05 g/100g
Energy	Calculation
Fat	0.2 g/100g
Moisture	0.2 g/100g
Saturated fat	0.10 %
Trans fat	0.10 %
Mono-saturated fat	0.10 %
Polysaturated fat	0.10 %
Protein	0.2 g/100g
Sodium	10 mg/kg
Total sugars	1 g/100g
Fructose	0.2 g/100g
Glucose	0.2 g/100g
Lactose	0.2 g/100g
Maltose	0.2 g/100g
Sucrose	0.2 g/100g

If the limit of reporting, say for example, for beta-carotene in the methodology used is 5 µg/100g that value means that the laboratory can measure with reasonable accuracy at this level. Any level below the accuracy is not that good and the measurement of uncertainty below the limit of reporting, for example for beta-carotene in the methodology used is 26%.

Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level using GenStat for Windows 14th Edition (VSN International 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed by analysis of variance (ANOVA) separately, as well as a 2-way factorial ANOVA to investigate the time by dose interaction. Where a significant dose or time effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD).

Where all or the majority of data was censored (below the level of reporting) the data could not be analysed. For total ascorbic acid there were a minority of values censored and the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not underestimated.

Results and Discussion

Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required; 0, 150, 600 and 1000 Gy. The average irradiation dose absorbed complies with the required specifications of the study. The Irradiation Report is presented in the section below and reports minimum, maximum and average absorbed doses.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke.

The dose rate was approximately 9.7 Gy/min. Irradiation temperature was 23.0–24.0°C.



20 April 2012

ANSTO Reference	12-2040 A (Apples) & B (Nectarines)
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	

ANSTO Ref: 12-2040

SRT F 004

Prepared: [REDACTED] Authorised: [REDACTED] Date: 26.10.12 Page 1 of 5

Page 1 of 5

Product Details	
Product	Red Delicious Apples and White Flesh Nectarines
Quantity	7 × boxes Apples 3 × 10kg boxes Nectarines
Irradiation Conditions	
Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	26 - 27 March 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 9.7 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F228
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	23.0 to 24.0 °C
ANSTO Ref: 12-2040	
SRT F 004	
Prepared	Authorised
Date	26 - 27 March
Page 2 of 5	

The apples and nectarines that were received for processing were repacked into boxes. The boxes for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited within the boxes at the front of apples and nectarines (Figure 1). Additional dosimeters were attached to the outside of one tray to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R2) samples from the first lot were used to carry out a dose mapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dose mapping repeated twice with dosimeters at those locations. This dose mapping information was used to process the remaining boxes of apples and nectarines to their target doses.



Figure 1: Dosimeter positioned on apple.

ANSTO Ref: 12-2040		SRT F 004	
Prepared	<div></div>	Authorised	<div></div>
	<div></div>	Date	26.4.12
Page 3 of 5			



Figure 2: Boxes positioned for irradiation.

Results for Apples and Nectarines

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	143 ± 7	158 ± 7	151 ± 5
600	Replicate 1	573 ± 7	631 ± 7	602 ± 5
1000	Replicate 1	953 ± 21	1049 ± 21	1001 ± 15
150	Replicate 2	144 ± 7	158 ± 7	151 ± 5
600	Replicate 2	541 ± 18	595 ± 19	568 ± 13
1000	Replicate 2	921 ± 23	1014 ± 23	967 ± 16
150	Replicate 3	139 ± 7	153 ± 7	146 ± 5
600	Replicate 3	562 ± 19	618 ± 19	590 ± 14
1000	Replicate 3	937 ± 23	1032 ± 24	985 ± 17

ANSTO Ref: 12-2040

SRT F 004

Prepared [redacted] Authorised [redacted] Date 26-7-20 Page 4 of 5

[redacted]

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref 12-2040

SRT F 004

Prepared

Authorised

Date 26-04-12

Page 5 of 5

Nutritional components

New season red-skin apples, cultivar 'Red Delicious' were treated and analysed for nutritional components at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2), after 28 days storage in a cold room set at 0°C.

There were no significant dose by time interactions detected in any of the nutritional components measured (Table 1). The nutrient components tested were generally more responsive to storage time than gamma irradiation.

Significant main effects of time were detected in ash, carbohydrates, total dietary fibre, total sugars, fructose, glucose, sucrose, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) while dose effects were observed in energy, carbohydrates, moisture, total sugars, fructose and protein.

Moisture was the largest component in apples, >84 g/100g. Although the moisture content decreased significantly from 0 to 150 Gy, a decrease of <0.75 g/100g is not considered biologically significant. Mostafavi *et al.* (2012) reported that moisture in cv. 'Red Delicious' apple was more responsive to irradiation at 900 Gy to 1.2 kGy than storage time. In this study, the reduction in moisture was small in the 600 and 1000 Gy samples.

Alak and Goswami (2006) reported water loss, respiration, metabolism and microbial spoilage affected the overall quality of apple during storage. The use of controlled atmosphere storage (CAS) is discussed in their review.

There was no significant main effect of dose in beta-carotene. Overall, there was a decrease observed in beta-carotene, from a mean of 17.25 µg/100g to 9.11 µg/100g after a storage period of 28 days. The reported beta-carotene content by FSANZ (2010) is 10 µg/100g for cv. 'Red Delicious' apple and 27 µg/100g for raw apple by USDA (2011).

In this study, Vitamin C (total ascorbic acid) was at or below the reporting level of 1 mg/100g, measured in control and irradiated fruit and, at both assessment times (after irradiation and after storage). The reported FSANZ (2010) value is 6 mg/100g and 4.5 mg/100g in the New Zealand FoodFiles (2010) for cv. 'Red Delicious' apple. A report found 12.49 mg/100g ascorbic acid in 'Red Delicious' grown in Peshawar (Jan *et al.* 2012) while contents between 2.00 – 5.00 mg/100 were reported for different apple varieties (Iordanescu 2012).

The results for Vitamin C (total ascorbic acid) were lower than reported elsewhere. Our fruit handling procedures during fruit preparation before and after irradiation treatment and temperature variation during transportation between facilities may have contributed to the lower levels detected as losses are accelerated at higher temperatures (Lee and Kader 2000). No error in analysis was detected by the independent laboratory undertaking the testing and all duplicates, controls and spike recoveries were found within the acceptable criteria. Additional Vitamin C analysis was tested for 'Red Delicious' and 'Fuji' apples purchased from the supermarket. The results were between 1–3 mg/100g. Although content of Vitamin C in fruits can be influenced by cultivar, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures, temperature management after harvest is the most important factor to maintain Vitamin C in fruits (Lee and Kader, 2000).

The mean Vitamin C (total ascorbic acid) in the untreated sample was 0.90 mg/100g and the irradiated samples contained between 0.83 and 1.00 mg/100 g. Storage time had a stronger effect than dose (Table1). A decrease in mean Vitamin C (total ascorbic acid) was found after 28 days in cold storage, from a mean of 0.91 mg/100g to 0.53 mg/100g over all samples.

It has been reported that the genotype is the main factor that determines the composition of bioactive compounds in apples (Carbone 2011, Jan *et al* 2012, Iordanescu 2012, Lee and Kader 2000, Wu 2007) and that the content of Vitamin C decreases with fruit maturation, being maximum at the beginning of preripening stage and minimum in full ripening (Iordanescu 2012). Cultivar 'Red Delicious' had the highest ascorbic acid (12.49 mg/100g) compared to 'Royal Gala', Mondial Gala and 'Golden Delicious' (Jan *et al.* 2012).

Harvesting stages also significantly affected the ascorbic acid content of apple fruit and decreased with storage during 150 days storage at 5±1.0°C (Jan *et al.* 2012). Ascorbic acid was lowest in apple harvested at the early maturity stage, which increased accordingly in apple harvested at mid and over mature stages (Jan *et al.* 2012). Apples tested in this study were immature and may have contributed to the low Vitamin C (total ascorbic acid) content measured.

Fan *et al.* (2006) investigated the quality of fresh-cut cv. 'Gala' apple slices by low-dose irradiation (0.5 and 1.0 kGy) and calcium ascorbate treatment, a common anti-browning agent, under modified atmosphere packing. The researchers reported values of 2.1, 1.8 and 1.9 mg/100g ascorbic acid in fresh-cut 'Gala' apple slices in 0, 0.5 and 1.0 kGy irradiated samples. Irradiation at doses of 0.5 and 1.0 kGy had no significant effect on ascorbic acid levels and did not affect the ascorbic acid loss during storage on any given day. Ascorbic acid content of both untreated and irradiated apple slices decreased during storage although the ascorbic acid content was not statistically different after 3 weeks, with more of the loss observed in the first week.

Hussain *et al.* (2012) found that ascorbic acid recorded a decreasing trend after 90 days in storage, however, at each 30 day time interval, the ascorbic acid was higher in the irradiated sample than in the control. After 90 days of storage, the control samples recorded a decrease from a mean of 3.8 mg/100g to 2.6 mg/100 while the irradiated 0.4 kGy sample decreased from mean of 4.1 mg/100g to 3.1 mg/100g. The loss in ascorbic acid during storage is recognized to be due to its antioxidant activity especially under postharvest storage conditions (Davey *et al.* 2000).

Mostafavi *et al.* (2012) showed a strong association between phenolic content and antioxidant activity in 'Red Delicious' apples; a dose range of 900 Gy and 1.2 kGy significantly decreased phenolic content and antioxidant activity (Mostafavi *et al.* 2012) while the results from Hussain *et al.* (2012) revealed significant retention in firmness, juice yield and ascorbic acid content in samples treated with combination of calcium chloride at 2.0% w/v and gamma irradiation (0.4 kGy) during storage.

Mean ash levels decreased significantly with storage in this study; mean ash content was 0.26 g/100g at Time 1 and was 0.19 g/100g at Time 2 and was likely a consequence of general fruit senescence.

Podsedeck *et al.* (2004) found in different apple varieties the percentage of water was 84.1, carbohydrate 14.9, protein 0.3, ash 0.29 and fat 0.4 while Mukhtar *et al.* (2010) reported moisture contents between 83.34-85.97%, with the largest variation from 'Red Delicious' apples. In this study, carbohydrate varied between 8.44–9.46 g/100g, protein varied between 2.18–2.33 g/100g, fat 1.00–2.21 mg/100g and ash was 1.50–3.18 g/100g. The differences in these reports with the results of the present study could be due to difference in varieties, availability periods and environmental factors.

No loss of either total or individual carbohydrates was associated with irradiation treatment of apples. While mean carbohydrates increased with storage, the main dose effect was observed only with the 150 Gy sample. Drake *et al.* (2003) reported that irradiation treatment did not influence the total carbohydrate or individual sucrose, glucose and fructose in both apples and pear, irrespective of the cultivar. Apple fruit were irradiated at doses <1.0 kGy (150, 300, 600 and 900 Gy) and stored for 30, 60 and 90 days at 1°C. Carbohydrate concentrations changed in both apples and pears as storage time progressed and these changes were cultivar dependent. Total carbohydrates and glucose, fructose and sorbitol concentrations increased, and sucrose decreased in apples as storage progressed (Drake *et al.*, 2003). The individual concentrations for these components were similar to the concentrations reported in this study.

Total sugars increased slightly with storage from a mean of 11.1 g/100g to 11.5 g/100g; glucose and fructose increased while sucrose decreased with time in storage. The increase in total sugars may be attributed to the enzymatic conversion of higher polysaccharides such as starches and pectins in to simple sugars during ripening (Hussain *et al.* 2008).

Wang *et al.* (1993) and Fan and Mattheis (2001) also reported that irradiation inhibited production of many volatile compounds after storage at 0°C, and inhibition also increased with radiation dose. It appears that some responses of apple fruit to gamma radiation are influenced by ethylene action and post-irradiation storage temperature.

Hussain *et al.* (2012) attributed the delayed increase in total sugars in samples with combination treatments to the synergistic effect of CaCl₂ dip and gamma irradiation. Both CaCl₂ and gamma irradiation delay the natural physiological processes like ripening, senescence and respiration; responsible for increase as well as decrease of total soluble solids (TSS) and total sugars, which is due to inhibitory effect on the activities of enzymes involved in hydrolysis (Izumi and Watada 1994, Agar *et al.* 1999, Rosen and Kader 1989, Kader 1986, Artes *et al.* 1999).

To determine the effect of irradiation on the nutritional components for apple at Time 1 and Time 2, each time has been analysed separately (Tables 2 and 3). A significant main effect of dose was observed in fructose and protein in Time 1 but not in Time 2. Fructose was significantly lower in the control sample (6.00 g/100g) than the irradiated samples (6.23 – 6.37 g/100g) however there was no notable trend observed with the doses applied. Protein was higher in the control sample but the results appeared inconsistent across the irradiated samples. Mean protein one day after irradiation treatment was 0.7 g/100g for the control, and ranged between 0.37 and 0.60 g/100g in the irradiated samples.

This study showed that low irradiation doses (150 Gy – 1 kGy) (combined with cold storage) overall, does not result in significant apple nutritional quality losses one day after treatment and after the storage period studied.

The studies by Wang *et al.* (1993) showed that there was no significant effect of irradiation with 0.3 – 2.0 kGy on the nutritional qualities of apples.

The absorbed dose, commodity maturity and physiological state at harvest, pre and posthandling, transportation, presence of microorganisms, storage environment and storage time all interact to affect product quality and shelf life. Different outcomes in nutritional quality after similar treatments can occur between different varieties of the same fruit, as noted by Thomas (1988), Morris and Jessup (1994) and Lee and Kader (2000). It is a well-known fact that the nutritional components measured depends upon the degree of ripeness of the fruit, and quite different results would no doubt have been obtained had unripe or over-ripe fruits been analysed.

Table 1. A factorial analysis investigating the interactive effects of time and dose (2-way ANOVA) on the nutritional profile of 'Red Delicious' apple fruit.

Component	Dose (Gy)	Time			Factor	ANOVA's	
		1	2	Mean		P-value	SED
Total Ascorbic Acid* (mg/100g)	0	0.90	0.67	0.78 ^a	Time	<0.001	0.050
	150	1.00	0.63	0.82 ^a	Irrad Dose	0.042	0.071
	600	0.83	0.50	0.67 ^{ab}	Time x Irrad.	0.169	0.100
	1000	0.90	0.33	0.62 ^b			
	Mean	0.91 ^a	0.53 ^b				
Ash (g/100g)	0	0.27	0.20	0.23	Time	0.015	0.024
	150	0.23	0.20	0.22	Irrad Dose	0.519	0.034
	600	0.23	0.17	0.20	Time x Irrad.	0.813	0.048
	1000	0.30	0.20	0.25			
	Mean	0.26 ^a	0.19 ^b				
Beta Carotene (ug/100g)	0	17.00	9.83	13.42	Time	<0.001	0.888
	150	18.67	9.83	14.25	Irrad Dose	0.453	1.256
	600	17.00	8.57	12.78	Time x Irrad.	0.921	1.776
	1000	16.33	8.20	12.27			
	Mean	17.25 ^a	9.11 ^b				
Carbohydrates (g/100g)	0	11.3	12.0	11.7 ^b	Time	0.015	0.18
	150	12.7	13.0	12.8 ^a	Irrad Dose	0.003	0.26
	600	11.7	12.3	12.0 ^b	Time x Irrad.	0.837	0.36
	1000	12.0	12.3	12.2 ^b			
	Mean	11.9 ^b	12.4 ^a				
Energy (kJ/100g)	0	220.0	226.7	223.3 ^b	Time	0.260	3.55
	150	236.7	240.0	238.3 ^a	Irrad Dose	0.041	5.02
	600	223.3	226.7	225.0 ^b	Time x Irrad.	0.982	7.10
	1000	226.7	230.0	228.3 ^{ab}			
	Mean	226.7	230.8				
Fructose (g/100g)	0	6.00	6.47	6.23 ^b	Time	<0.001	0.057
	150	6.27	6.67	6.47 ^a	Irrad Dose	0.040	0.081
	600	6.23	6.67	6.45 ^a	Time x Irrad.	0.200	0.115
	1000	6.37	6.50	6.43 ^a			
	Mean	6.22 ^b	6.58 ^a				
Glucose (g/100g)	0	2.73	2.87	2.80	Time	0.028	0.058
	150	2.80	3.03	2.92	Irrad Dose	0.514	0.082
	600	2.73	2.97	2.85	Time x Irrad.	0.349	0.115
	1000	2.83	2.80	2.82			
	Mean	2.78 ^b	2.92 ^a				

Means in treatment followed by the same letter are not significantly different

C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Table 1 contd. A factorial analysis investigating the interactive effects of time and dose (2-way ANOVA) on the nutritional profile of 'Red Delicious' apple fruit.

Component	Dose (Gy)	Time		Mean	Factor	ANOVA's	
		1	2			P-value	SED
Moisture (g/100g)	0	85.53	85.40	85.47 ^a	Time	0.525	0.166
	150	84.73	84.73	84.73 ^b	Irrad Dose	0.047	0.235
	600	85.33	85.17	85.25 ^d	Time x Irrad.	0.229	0.332
	1000	84.77	85.50	85.13 ^{ab}			
	Mean	85.09	85.20				
Protein (g/100g)	0	0.70	0.63	0.67 ^a	Time	0.528	0.052
	150	0.37	0.50	0.43 ^b	Irrad Dose	0.040	0.073
	600	0.60	0.40	0.50 ^b	Time x Irrad.	0.191	0.103
	1000	0.53	0.53	0.53 ^{ab}			
	Mean	0.55	0.52				
Sodium (mg/100g)	0	0.480	0.510	0.495	Time	0.886	0.1648
	150	0.707	0.977	0.842	Irrad Dose	0.450	0.2331
	600	0.757	0.877	0.817	Time x Irrad.	0.635	0.3297
	1000	0.837	0.513	0.675			
	Mean	0.695	0.719				
Sucrose (g/100g)	0	2.17	1.77	1.97	Time	<0.001	0.067
	150	2.17	2.00	2.08	Irrad Dose	0.373	0.095
	600	2.33	1.73	2.03	Time x Irrad.	0.169	0.134
	1000	2.27	2.00	2.13			
	Mean	2.23 ^a	1.88 ^b				
Total Dietary Fibre (g/100g)	0	2.03	1.77	1.90	Time	<0.001	0.056
	150	1.97	1.73	1.85	Irrad Dose	0.851	0.080
	600	2.07	1.73	1.90	Time x Irrad.	0.830	0.113
	1000	2.03	1.67	1.85			
	Mean	2.03 ^a	1.73 ^b				
Total Sugars (g/100g)	0	10.7	11.0	10.8 ^b	Time	0.023	0.16
	150	11.3	12.0	11.7 ^a	Irrad Dose	0.022	0.23
	600	11.0	11.7	11.3 ^a	Time x Irrad.	0.443	0.33
	1000	11.3	11.3	11.3 ^a			
	Mean	11.1 ^b	11.5 ^a				

Time and dose means within a component followed by the same letter are not significantly different.

Table 2. Mean chemical measurements in 'Red Delicious' apple fruit after irradiation treatment (Time1).

Time 1	Dose (Gy)				p-value	SED
Component	0	150	600	1000		
Ascorbic Acid* (mg/100g)	0.90 (0.100)	1.00 (0.173)	0.83 (0.153)	0.90 (0.173)	0.164	0.006
Ash (g/100g)	0.27 (0.058)	0.23 (0.058)	0.23 (0.058)	0.30 (0.100)	0.189	0.030
Beta Carotene (ug/100g)	17.0 (3.46)	18.7 (3.79)	17.0 (2.65)	16.3 (0.58)	0.783	2.34
Carbohydrates (g/100g)	11.3 (0.58)	12.7 (0.58)	11.7 (0.58)	12.0 (1.00)	0.106	0.45
Energy (kJ/100g)	220.0 (10.00)	236.7 (5.77)	223.3 (11.55)	226.7 (15.28)	0.285	8.05
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	6.00 ^b (0.100)	6.27 ^{ab} (0.115)	6.23 ^a (0.058)	6.57 ^a (0.208)	0.037	0.093
Glucose (g/100g)	2.73 (0.153)	2.80 (0.100)	2.73 (0.058)	2.83 (0.306)	0.843	0.135
Moisture (g/100g)	85.53 (0.208)	84.73 (0.231)	85.33 (0.611)	84.77 (0.709)	0.103	0.317
Protein (g/100g)	0.70 ^b (0.100)	0.37 ^b (0.058)	0.60 ^a (0.173)	0.53 ^{ab} (0.115)	0.042	0.087
Sodium (mg/100g)	0.480 (0.0721)	0.707 (0.0586)	0.757 (0.4782)	0.837 (0.5745)	0.552	0.2467
Sucrose (g/100g)	2.17 (0.208)	2.17 (0.208)	2.33 (0.058)	2.27 (0.058)	0.603	0.141
Total Dietary Fibre (g/100g)	2.03 (0.058)	1.97 (0.115)	2.07 (0.153)	2.03 (0.208)	0.887	0.130
Total Sugars (g/100g)	10.7 (0.58)	11.3 (0.58)	11.0 (0.00)	11.3 (0.58)	0.338	0.385

Standard deviations are presented in brackets below each mean. Means in a row followed by the same letter are not significantly different. C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Table 3. Mean chemical measurements in untreated and irradiated 'Red Delicious' apple fruit after 28 days cold storage at 0°C (Time 2).

Time 2	Dose (Gy)				p-value	SED
Component	0	150	600	1000		
Ascorbic Acid* (mg/100g)	0.67 (0.058)	0.63 (0.252)	0.50 (0.100)	0.33 (0.058)	0.104	0.119
Ash (g/100g)	0.20 (0.100)	0.20 (0.000)	0.17 (0.058)	0.20 (0.000)	0.893	0.053
Beta Carotene (ug/100g)	9.83 (2.255)	9.83 (1.201)	8.57 (1.504)	8.20 (0.954)	0.330	1.015
Carbohydrates (g/100g)	12.0 (0.00)	13.0 (0.00)	12.3 (0.58)	12.3 (0.58)	0.050	0.67
Energy (kJ/100g)	226.7 (5.77)	240.0 (0.00)	226.7 (11.55)	230.0 (10.00)	0.262	6.80
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	6.47 (0.115)	6.67 (0.058)	6.67 (0.404)	6.50 (0.200)	0.351	0.131
Glucose (g/100g)	2.87 (0.058)	3.03 (0.208)	2.97 (0.252)	2.80 (0.173)	0.250	0.110
Moisture (g/100g)	85.40 (0.100)	84.73 (0.462)	85.17 (0.493)	85.50 (0.529)	0.213	0.340
Protein (g/100g)	0.63 (0.252)	0.50 (0.173)	0.40 (0.100)	0.53 (0.252)	0.309	0.111
Sodium (mg/100g)	0.510 (0.1493)	0.97 (0.3868)	0.877 (0.7145)	0.513 (0.1563)	0.454	0.343 5
Sucrose (g/100g)	1.77 (0.115)	2.00 (0.265)	1.73 (0.058)	2.00 (0.173)	0.183	0.137
Total Dietary Fibre (g/100g)	1.77 (0.153)	1.73 (0.115)	1.73 (0.115)	1.67 (0.058)	0.688	0.083
Total Sugars (g/100g)	11.0 (0.00)	12.0 (0.00)	11.7 (0.58)	11.3 (0.58)	0.070	0.30

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different. C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Recommendation

The overall findings of this study showed that an irradiation application of up to 1 kGy will not result in any significant detrimental damage to the nutritional quality of apple. The effect of storage time had a greater impact than irradiation on many of the apple nutritional components and the changes generally appeared to be associated with the ripening process during storage.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of apple.

References

- Agar I.T., Massantini R., Hess-Pierce B. and Kader A.A.. (1999). Post harvest CO₂ and ethylene production and quality maintenance of fresh cut kiwi fruit slices. *Journal of Food Science* 64:433–440.
- Alak, K.S. and Goswami, T.K. (2006). Controlled atmosphere storage of fruits and vegetables: a review. *Journal of Food Science and Technology* 43 (1): 1-7.
- Artes, F., Conesa, M.A., Hernandez, S. and Gill, M.I. (1999). Keeping quality of fresh-cut tomato. *Postharvest Biology and Technology* 17: 153–162.
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Carbone, K., Giannini, B., Picchi, V., Scalzo, R. L. and Cecchini, F. (2011). Phenolic composition and free radical scavenging activity of different apple varieties in relation to the cultivar, tissue type and storage. *Food Chemistry* 127 (2): 493–500.
- Davey, M.W., Montagu, M.V., Inze, D., Sanmartin, M., Kanellis, A., Smirnoff, N., Benzie, I.J.J., Strain, J.J., Favell, D. and Fletcher, J. (2000). Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *Journal of the Science of Food and Agriculture* 80: 825–860.
- Dickson, J.S. (2012). Radiation meets food. *Physics Today* 65 (2): 66–67.
- Diehl J.F. (1990). *Safety of irradiated foods*. 1st ed. New York: Marcel Dekker Inc. 196 p.
- Drake, S.R., Neven, L.G. and Sanderson, P.G. (2003). Carbohydrate concentrations of apples and pears as influenced by irradiation as a quarantine treatment. *Journal of Food Processing and Preservation* 27 (3): 165–172.
- Drake, S. R., Neven, L.G. and Sanderson, P.G. (1998). Quality of apples and pears after exposure to irradiation as a quarantine treatment. USDA, ARS-TFRL 1104 N. Western Ave., Wenatchee, WA 98801. <http://www.mbao.org/1998airc/079drake.pdf>
- Fan, X. and Mattheis, J.P. (2001). 1-Methylcyclopropene and storage temperature influence responses of 'Gala' apple fruit to gamma irradiation. *Postharvest Biology and Technology* 23 (2): 143–151.
- Fan, X.T., Niemera, B.A., Mattheis, J.P., Zhuang, H. and Olson, D.W. (2005). Quality of fresh-cut apple slices as affected by low-dose ionizing radiation and calcium ascorbate treatment. *Journal of Food Science* 70 (2): S143-S148.
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database. <http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>

- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339.
<http://www.comlaw.gov.au/Details/F2010C00339>
- Gunes, G., Hotchkiss, J.H. and Watkins, C.B. (2001). Effects of Gamma Irradiation on the Texture of Minimally Processed Apple Slices. *Journal of Food Science* 66 (1) 63-67.
- Horak, C., Di Giorgio, M and Kairiyama, E. (2009). Identification of irradiated apples for phytosanitary purposes. *Radiation Physics and Chemistry* 78 (7-8): 707-709.
- Hussain P.R., Dar M.A., Meena R.S., Mir M.A., Shafi F. and Wani A.M. (2008). Changes in quality of apple (*Malus domestica*) cultivars due to gamma irradiation and storage conditions. *Journal of Food Science and Technology* 45 (1): 44-449.
- Hussain, P.R., Meena R.S., Dar M.A. and Wani A.M. (2012). Effect of post-harvest calcium chloride dip treatment and gamma irradiation on storage quality and shelf-life extension of Red delicious apple. *Journal of Food Science and Technology* 49 (4): 415-426.
- Iordanescu, O., Alexa, E., Micu, R. and Poiana, M-At (2012). Bioactive compounds and antioxidant properties at different maturity stages of apple cultivars from Romania. *Journal of Food, Agriculture and Environment* Vol.10 (1): 147-151. 2012
- ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009).
https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Izumi, H. and Watada, A.E. (1994). Calcium treatments affect storage quality of shredded carrots. *Journal of Food Science* 59:106-109.
- Jan, I., Rab, A. and Sajid, M. (2012). Storage performance of apple cultivars harvested at different stages of maturity. *The Journal of Animal and Plant Sciences* 22 (2): 438-447.
- Jooste, M.M. (1999) Optimum harvest maturity and cold-storage duration for *Prunus armeniaca* L. cvs. Supergold and Imperial cultivated in South Africa.
http://webcache.googleusercontent.com/search?q=cache:ZwQEYJXvx4YJ:http://fruitgro.krazyboyz.co.za/media/uploads/documents/document/file/mariana_ca_pespan_-_apricots_pdf.pdf%2Bjooste+apricot&hl=en&safe=active&gbv=2&qsl=serp.3...27259.27259.0.28617.1.1.0.0.0.250.250.2-1.1.0...0.0...1c.FVMd3idbtJo&ct=clnk
- Jooste, M.M. and Taylor, M.A. (1999). Effect of harvest maturity and cold storage period on the overall quality of Bebeco apricots, with special reference to gel

- breakdown and variates used to accurately establish harvest maturity. *Deciduous Fruit Grower* 49 (Sept): 39-44.
- Kader, A.A. (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 6:117–121.
- Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207–220.
- Maxie, E. C. and Abdel-Kader A. (1966). Food irradiation — physiology of fruits as related to feasibility of the technology. *Advances in Food Resesearch* 15: 05–145.
- Miller, W.R. and McDonald, R.E. (1999). Irradiation, storage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience* 24: 1112–1115.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291–311.
- Morris, S.C. and Jessup, A.J. (1994). Irradiation. In: *Insect Pests and Fresh Horticultural Products: Treatments and responses*. (Editors, R.E. Paull and J.W. Armstrong). CABI International, Wallingford, U.K., pp. 163-190.
- Mostafavi, H., Ahari, M., Seyed, M.M., Seyed, M., Fathollahi, H. and Askari, H. (2012). Gamma radiation effects on physico-chemical parameters of apple fruit during commercial post-harvest preservation. *Radiation Physics and Chemistry* 81 (6): 666-671.
- Mukhtar, P., Gilani, A. H. and Bhatti, N. (2010). Some nutritional and microbiological aspects of apples of common varieties available for household consumption. *The Journal of Animal and Plant Sciences*. 20 (4): 253–257.
- New Zealand FOOD File 2010 Version 2. <http://www.foodcomposition.co.nz/foodfiles>
- Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Podsedek, A., Wilska-Jsezka, J., Anders, B. and Markowski, J. (2004). Compositional characterization of some apple varieties. *Journal European Food Research and Technology* 210(4): 268–272.
- Rajkowski, K.T. and Thayer, D.W. (2000). Reduction of *Salmonella* spp. and Strains of *Escherichia coli* O157:H7 by Gamma Radiation of Inoculated Sprouts. *Journal of Food Protection* 63(7): 871–875.
- Rosen, J.C. and Kader, A.A. (1989). Postharvest Physiology and quality maintenance of sliced pear and strawberry fruits. *Journal of Food Science* 54:656–659.

- Soopaya, R., Stringer, L. D., Woods, B, Stephens, A. E. A., Butler, R.C., Lacey, I., Kaur, A. and Suckling, D.M. (2001). Radiation Biology and Inherited Sterility of Light Brown Apple Moth (Lepidoptera: Tortricidae): Developing a Sterile Insect Release Program. *Journal of Economic Entomology* 104 (6): 1999-2008.
- Taylor, J. (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35-43.
- Thomas, P. (1988). Radiation preservation of foods of plant origin. Part VI. Mushrooms, tomatoes, minor fruits and vegetables, dried fruits, and nuts. *CRC Critical Reviews in Food Science and Nutrition*. 26 (4): 313-358.
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website, <http://www.nal.usda.gov/fnic/foodcomp/search/>
- Viškelis, P., Rubinskienė, M., Sasnauskas, A., Bobinas, C. and Kviklienė, N. (2011). Changes in apple fruit quality during modified atmosphere storage. *Journal of Fruit and Ornamental Plant Research* 19 (1): 155-165.
- VSN International. (2011). *GenStat for Windows 14th Edition*. VSN International, Hemel Hempstead, UK. Web Page: [GenStat.co.uk](http://www.genstat.co.uk)
- Wajea, C.K., Junb, S.Y., Leeb, Y.K., Kimc, B.N., Hanc, D.H., Jod, C. and Kwon, J.H. (2009). Microbial quality assessment and pathogen inactivation by electron beam and gamma irradiation of commercial seed sprouts. *Food Control* 20 (3): 200-204.
- Wang, C.Y., Jiang, M.Y., Gao, M.X., Ma, X.Y., Zhang, S.F. and Liu, S.C. (1993). A study of the physiological-changes and the nutritional qualities of irradiated apples and the effect of irradiation on apples stored at room temperature. *Radiation Physics and Chemistry* 42 (1-3): 347-350.
- Wu, J., Gao, H., Zhao, L., Liao, X., Chen, F., Wang, Z. and Hu, X. (2007). Chemical compositional characterization of some apple cultivars. *Food Chemistry* 103(1): 88-93.

Part B. Effect of gamma irradiation on the postharvest quality of apple (*Malus domestica*) fruit.

Contents

Part B. Effect of gamma irradiation on the postharvest quality of apple (<i>Malus domestica</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Fruit colour	41
Moisture loss and whole fruit softness	41
Biochemical analyses	42
Fruit disease and disorders	42
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Summary

Fruit quality evaluations were conducted on apple (*Malus domestica*) fruit, variety 'Red Delicious', after being treated with gamma irradiation and following a recommended cold storage period of up to 28 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that apple fruit quality was affected by both irradiation and storage time. Fruit firmness decreased significantly with increasing irradiation dose, declining from 29.1 N (Control) to 24 N (1000 Gy). Fruit after storage were slightly firmer (by 0.9 N) which was likely due to the use of different batches of fruit at each storage time assessment. Fruit moisture loss by the end of the trial however was not affected by irradiation. Apple flesh colour properties, comprising lightness, chroma and hue angle, were affected by both irradiation and cold storage duration. Generally, fruit flesh became a deeper shade of yellow with increasing irradiation dose and storage time as indicated primarily by a shift in hue angle values from 106.4° (Control) to 104.4° (1000 Gy) and 105.7 (Day 1) to 105.0 (Day 28). Lightness before and after storage changed from 82.3 to 81.1 and chroma from 20.1 to 22.1, respectively.

Irradiation and storage duration had no impact on total soluble solids content (mean 12.2° Brix) although storage duration did cause a slight decrease in titratable acidity, decreasing from 0.17 to 0.16% malic acid. Fruit exhibited no symptoms of disease and no disorders occurred as a result of the irradiation or storage treatments. Overall, by the end of the trial fruit from all treatments were considered to be of a quality that was commercially saleable, despite the slight decrease in firmness and a change in flesh colour in the higher dose treatments.

Introduction

The present study aims to investigate the effects of gamma irradiation on the postharvest quality of apple (*Malus domestica*) fruit. Gamma irradiation is regularly used not only for disinfestation purposes but also to control for decay and extend the storage and shelf life of perishable commodities (Mitchell *et al.* 1992). Past work has shown that apple fruit generally have a "high" tolerance to ionizing irradiation below 1 kGy compared with other fruit and vegetables (Kader 1986). Generally, reports of apple fruit being gamma-irradiated with up to 500 Gy have shown little to no detrimental effects on fruit quality (Hussain *et al.* 2008). However, as dose and also cold storage time increase, some fruit varieties have been reported to be more prone to a decrease in firmness (Mostafavi *et al.* 2012), titratable acidity levels (Fan and Mattheis 2001) and in some cases developing internal disorders (Fan *et al.* 2000). Several authors (Kader 1986, Mitchell *et al.* 1992, Al-Bachir 1999) have also reported that responses to irradiation can vary widely as a result of not only variety but also harvest maturity, growing conditions and or geographic location.

In the present study, the effects of irradiation and cold storage duration were therefore examined on a familiar apple variety grown in Australia, namely 'Red Delicious', in order to assess their effects on fruit quality. Assessments entailed measurements of physico-chemical changes in fruit properties. The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation (at and below 1 kGy) on a variety grown and marketed under Australian conditions. This work will also compliment current findings from the nutritional component of this study described earlier in this report, which also incorporated fruit that underwent the same irradiation and cold storage treatments as in this study.

Materials and methods

Experimental layout

Apple (*Malus domestica*) fruit, variety 'Red Delicious', were sourced from the Sydney Markets, NSW in late March 2012. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where ca. 20 fruit per carton were irradiated over three sequential times (blocking factor) with target doses of 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group and remained under the same conditions as treated fruit. Replication consisted of a random selection of 10 individual fruit from each tray, comprising one of three blocks per irradiation treatment per assessment time (two times).

Following the irradiation treatment, fruit were packed and immediately transported by air to the Queensland Department of Agriculture, Fisheries and Forestry Postharvest Laboratory in Cairns. Within 24 hours, half the fruit were destructively assessed for quality determination (Day 1) while the second half was transferred into cold storage ($0 \pm 0.5^\circ\text{C}$ at 85% RH) and held for 28 days before being destructively assessed. Storage condition and duration requirements were based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2012). During storage, ambient air temperature and relative humidity conditions were also monitored to ensure they remained within the specifications of the trial.

Fruit quality assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, flesh colour, biochemical analyses (soluble solids and titratable acidity), and a record of the incidence and severity of disorders and disease types. A description of each assessment method is described as follows:

Fruit colour

Fruit internal colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8 mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L^* , C^* , h° units). Fruit external colour was not able to be measured due to the extensive and variable blush coverage on fruit.

Moisture loss and whole fruit softness

Fruit were weighed before and after cold storage. Percent moisture loss was calculated by determining the proportion of moisture lost after storage compared with the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the equatorial region of each fruit was

undertaken using a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newton (N).

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were measured in fruit before and after storage. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

Fruit disease and disorders

If present, the incidence and severity of disease and or disorders were scored on individual fruit before and after storage. Incidence was based on the proportion of fruit within a treatment expressing symptoms and severity as the proportion (%) of fruit surface (or internal cut section) area affected.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A general ANOVA's was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a Fisher's Least Square Difference (LSD) test at 5%.

Results and Discussion

The following study contributes towards further enhancing our baseline knowledge of the potential effects of irradiation on the quality of apple fruit. In this study, apple firmness decreased significantly and almost linearly with increasing irradiation dose, declining from 29.1 N (0 Gy) to 24 N (1000 Gy) (Table 1). Similar responses have been reported in other apple fruit trials, although the sensitivity of fruit to irradiation-induced softening is often cultivar specific (Drake *et al.* 1998). Drake *et al.* (1998), for example, reported that a significant decrease in firmness in 'Granny Smith', 'Gala' and 'Fuji' fruit only occurred following a dose greater than 300, 600 and 900 Gy, respectively. In the present study, fruit were slightly firmer after storage although this was likely due to a statistical anomaly as different batches of fruit were assessed before and after storage.

A number of studies have reported changes in apple flesh colour as a result of irradiation (Drake *et al.* 1998, Al-Bachir 1999). In this study, 'Red Delicious' flesh colour became a deeper shade of yellow with increasing irradiation dose and following storage, as indicated primarily by a shift in hue angle from 106.4° (control fruit) to 104.4° (1000 Gy) and 105.7 (Day 1) to 105.0 (Day 28). Lightness before and after storage also changed from 82.3 to 81.1 and chroma from 20.1 to 22.1, respectively. The changes in flesh colour properties overall was relatively small and likely not noticeable by a consumer (Plate 1). A past survey of 228 consumers found little difference between irradiated (570 – 990 Gy) and non-irradiated Washington 'Red Delicious' in terms of appearance and colour (Terry and Tabor, 1990).

In the present study, factors that impact on flavour such as total soluble solids content (mean 12.2° Brix) and titratable acidity (mean 0.17% malic acid) were not affected by irradiation. Percent titratable acidity however decreased from 0.17 to 0.16% as a result of the storage treatment. Interestingly, findings by Terry and Tabor (1990) reported that a slightly higher proportion of consumers (31%) preferred the flavour of irradiated apples compared to the non-irradiated samples (16%), while the rest (53%) thought the fruit tasted the same or could not distinguish between the treatments.

In conclusion, by the end of the trial fruit quality overall was high despite a slight decrease in firmness and a small change in flesh colour properties as irradiation dose increased. Fruit also exhibited no symptoms of disease nor developed any disorders as a result of the irradiation or storage treatments.

Table 1. Effect of irradiation dose and storage duration on the quality attributes of apple fruit. Fruit were gamma irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and then assessed within 24 hours (Day 1) and after 28 days in cold storage (0.5°C) (Day 28).

Variable	Day	Irradiation dose (Gy)					ANOVA's	
		0	150	600	1000	Mean	Factor	P-value
Moisture Loss (%)	28	0.25	0.24	0.3	0.3	0.3	Irradiation	ns
Firmness	1	28.9	27.0	25.0	23.3	26.1 ^a	Storage	<0.05
N	28	29.3	27.6	26.0	24.7	26.9 ^b	Irradiation	<0.001
	Mean	29.1 ^a	27.3 ^b	25.5 ^c	24.0 ^d		Day x Irradiation	ns
Flesh	1	82.3	82.2	82.4	82.3	82.3 ^a	Storage	<0.001
lightness	28	80.8	81.1	81.3	80.9	81.1 ^b	Irradiation	ns
	Mean	81.6	81.7	81.9	81.6		Day x Irradiation	ns
Flesh	1	20.4	20.2	19.7	20.3	20.1 ^a	Storage	<0.001
chroma	28	22.7	22.5	21.0	22.2	22.1 ^b	Irradiation	<0.001
	Mean	21.5 ^a	21.3 ^a	20.4 ^b	21.2 ^a		Day x Irradiation	ns
Flesh	1	106.6	106.3	105.0	104.8	105.7 ^a	Storage	<0.05
hue angle	28	106.2	105.4	104.6	103.9	105.0 ^b	Irradiation	<0.001
	Mean	106.4 ^a	105.9 ^b	104.8 ^c	104.4 ^c		Day x Irradiation	ns
TSS	1	12.2	12.1	12.2	11.9	12.1	Storage	ns
(°Brix)	28	12.2	12.2	12.2	12.1	12.2	Irradiation	ns
	Mean	12.2	12.1	12.2	12.0		Day x Irradiation	ns
TA	1	0.17	0.17	0.17	0.17	0.17 ^a	Storage	<0.01
(% malic acid)	28	0.16	0.17	0.16	0.15	0.16 ^b	Irradiation	ns
	Mean	0.16	0.17	0.16	0.16		Day x Irradiation	ns


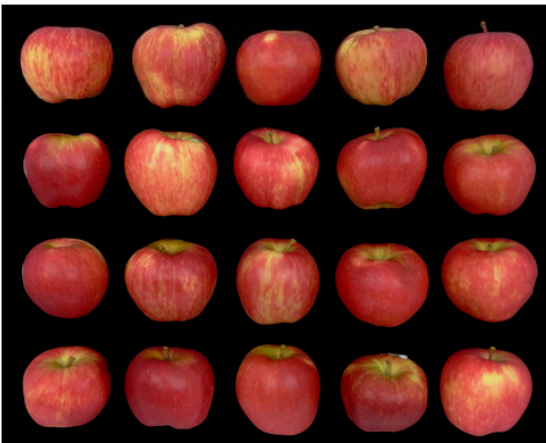
Apples (var. Red Delicious)		
Day 1		0Gy
		150Gy
		600Gy
		1000Gy
Day 28		0Gy
		150Gy
		600Gy
		1000Gy

Plate 1. Photographs of a representative sample of apple fruit ('Red Delicious') irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and taken before and after a subsequent 28 day cold storage (0.5°C) period.

Recommendations

In this study, applications of gamma irradiation treatments can be safely used as a phytosanitary or disinfestation measure on apple fruit without causing any deleterious effects on fruit quality. Fruit softness and changes in flesh colour did occur with higher irradiation doses although the effects were minor. The results are in keeping with previous studies that suggest that irradiated 'Red Delicious' apple fruit treated with a similar dose as in this study remained at a commercially acceptable standard.

References

- Al-Bachir, M. 1999. Effect of gamma irradiation on storability of apples (*Malus domestica* L.). *Plant Foods for Human Nutrition* 54: 1–11.
- Drake, S.R., Sanderson, P.G., Neven, L.G. (1998) Quality of apples and pears after exposure to irradiation as a quarantine treatment. Annual Int. Res. Conference on Methyl Bromide Alternatives and Emission Reductions. December 7–9, Orlando, Florida.
- Fan, X., Buchanan, D., Argenta, L., Mattheis, J. (2000) Ethylene mediates responses of 'Gala' apple fruit to ionizing irradiation. *HortScience* 35: 408.
- Fan, X., Mattheis, J.P. (2001) 1-Methylcyclopropene and storage temperature influence responses of 'Gala' apple fruit to gamma irradiation. *Postharvest Biology and Technology* 23: 143–151.
- Hussain, P.R., Dar, M.A., Meena, R.S., Mir, M.A., Shari, F., Wani, A.M. (2008) Changes in quality of apple (*Malus domestica*) cultivars due to gamma-irradiation and storage conditions. *Journal of Food Science and Technology-Mysore* 45: 44–49.
- Kader, A.A. (1986) Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40 (6): 117–121.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291–311.
- Mostafavi, H.A., Mirmajlessi, S.M., Mirjalili, S.M., Fathollahi, H., Askari, H. (2012) Gamma radiation effects of physico-chemical parameters of apple fruit during commercial post-harvest preservation. *Radiation Physics and Chemistry* 81 (6): 666–671.
- Terry, D.E., Tabor, R.L. (1990) Consumer acceptance of irradiated food products: an apple marketing study. *Journal of Food Distribution Research* 21: 63–73.
- UC Davis (2011) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 01 January, 2012, <<http://postharvest.ucdavis.edu/producefacts/>>

A2.2 Nutritional value of Apricot

Key nutritional data for fresh raw apricot is presented in Table 50. Values are extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). Differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Fresh apricots have high water contents (approximately 85–87%) and are a source of vitamins A, C and E, potassium and dietary fibre. A large portion of the calories in this produce comes from sugars. The fruit's season is short and this produce is often consumed as a snack food.

The values in Table 50 are used to derive the average nutrient content per single (150g) serve and the percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived. The percentage of the daily intake from a single serve of apricot is approximately 2.9% energy, 2.4% protein, 3.8% available carbohydrate, 11.3% total dietary fibre, 12.5% total sugar and 0.2% sodium (Table 51).

Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available carbohydrate is approximately 132kJ/100g, almost entirely from sugars. The rest of the energy value comes from total dietary fibre and protein and a small amount from total lipid (Table 52).

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will not come from fresh apricot fruit. Apricots are not a significant part of the average consumer's diet. Although apricots are a useful source of micronutrients they are consumed generally as snack foods, and in amounts equivalent to that of many other fresh produce crops and to lesser amounts than many popular fruits. They will not be a significant contributor to overall micronutrient intake (see Table 7 for comparison of values across several fruits and vegetables). It is also not known that any sub-populations have a higher than average consumption of fresh apricot and is unlikely to contribute a significant part of the average consumer's diet.

The nutrients will come from a range of foods other than apricot. Pro-vitamin A (carotenes) and vitamin C are present in other fresh produce. Much of the vitamin A will come from foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables, grains, dairy and egg products generally are an excellent source of vitamin K. Vitamin K is not measured here. Nuts, seeds, many fresh vegetables and vegetable oils are good sources of vitamin E.

Table 50: Nutritional data for raw apricot per 100g edible portion.

Nutrient	value	Raw Apricot *		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	86.35	86.1	85.4
Energy	KJ	201	170	171
Protein	g	1.4	0.8	0.8
Nitrogen	g			0.13
Total lipid (fat)	g	0.39	0.4	0.1
Malic acid	g			0.6
Citric acid	g			
Carbohydrate	g	11.12	8.4	7.1
Total Dietary Fibre	g	2	2	2.5
Ash	g	0.75		0.5g
Total sugars	g	9.24	8.4	6.6
Fructose	g	0.94		0.4
Glucose	g	2.37		1.5
Sucrose	g	5.87		4.8
Ascorbic Acid, Vit C	mg	10	7.3	12
Thiamin, Vit B1	mg	0.03	0.03	0.02
Riboflavin, Vit B2	mg	0.04	0.08	0.035
Niacin	mg	0.6	0.92	1.25
Niacin equivalents	mg			1.38
Vit B6	mg	0.054	0.1	
Folate, Vit B9 total	µg	9	8.6	6
Vit A (retinol equiv.)	µg	9	863	60
Alpha carotene	µg	19		
Beta carotene	µg	1094	5170	197
Beta cryptoxanthin	µg	104		
Cryptoxanthin	µg			32
Vit E	mg	0.89	1.2	
Vit K	µg	3.3		
Calcium	mg	13	14	15
Iron	mg	0.39	0.4	0.3
Magnesium	mg	10	0.2	9
Phosphorus	mg	23	22	
Potassium	mg	259	240	335
Sodium	mg	1	2.6	2
Zinc	mg	0.2		0.15
Copper	mg	0.078		
Manganese	mg	0.077		
Selenium	µg	0.1	trace	
Iodine	µg			
Molybdenum	µg			
Nickel	µg			
Tin	µg			

*raw with skin

Table 51: Nutrient values are per 150 g edible portion of fresh apricot.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	85.4	86.1	128.1	129.15			
Energy (kJ)	171	170	256.5	255	2.9	2.9	8700
Protein (g)	0.8	0.8	1.2	1.2	2.4	2.4	50
Total lipid (fat) (g)	0.1	0.4	0.15	0.6	0.2	0.9	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	7.1	8.4	10.65	12.6	3.4	4.1	310
Sugar (g)	6.6	8.4	9.9	12.6	11.0	14.0	90
Total dietary fibre (g)	2.5	2	3.75	3	12.5	10.0	30
Sodium (mg)	2	2.6	3	3.9	0.1	0.2	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 52: Calculation of energy value of the major* food components per 100 g apricot.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ	Average quantity	Approximate calculation of energy value kJ
Protein	17	0.8	13.6	0.8	13.6
Total lipid (fat)	37	0.1	3.7	0.4	14.8
Fatty acids, total saturated			0		0
Available Carbohydrate	17	7.1	120.7	8.4	142.8
Total sugars		6.6		8.4	
Total dietary fibre	8	2.5	20	2	16

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of apricot

QLD DAFF (2013) recently conducted nutritional and fruit quality evaluations on apricot (*Prunus armeniaca*) fruit, variety 'Rival', after being treated with gamma irradiation and following a recommended cold (1°C) storage period of 14 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gray (Gy), with fruit evaluations conducted before and after storage. (Attachment)

The nutrition study found irradiation applications of up to 1 kGy did not significantly impact on the nutritional quality of apricot fruit. No significant dose by time interactions in ash, carbohydrates, total dietary fibre, total sugars, fructose, glucose, sucrose, Vitamin C (total ascorbic acid), Vitamin A (beta-carotene), energy, carbohydrates, moisture, total sugars, fructose and protein were found. The nutritional status was affected more by the changes that occurred during the ripening process while in cold storage, in Vitamin C (total ascorbic acid), Vitamin A (beta carotene) and soluble solid contents (soluble sugars).

The study by Lee *et al.* (2008a) found no significant effect of gamma irradiation in Vitamin C, total sugar and reducing sugar in apricot fruit treated up to 2 kGy and stored at 20°C over a two week period. Treatment with electron beam (1 kGy and 2 kGy) also did not affect total sugar and Vitamin C content in apricot (Lee *et al.* 2008b).

After 14 days the Vitamin C (total ascorbic acid) content in all treatments declined from a mean of 0.44 mg/100g to 0.27 mg/100g. Vitamin C (total ascorbic acid) in untreated apricot fruit reduced from 0.47 mg/100g to 0.27 mg/100g while treated samples dropped from between 0.37 – 0.47mg/100g to 0.23 – 0.30 mg/100g.

The QLD DAFF (2013) study reported lower levels of Vitamin C (total ascorbic acid) than reported elsewhere. Cultivar, season, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures, temperature management can affect Vitamin C level in fruits (e.g. Lee and Kader 2000). The contribution of Vitamin C from consumption of fresh apricot to total dietary intake however is unlikely to be significant.

Vitamin A (beta-carotene) in raw apricot was also unaffected by irradiation treatments up to 1 kGy after irradiation treatment and after 14 days cold storage (QLD DAFF 2013). The same results were found by Egea *et al.* (2005) in 'Bulida' apricot irradiated at 0.5 kGy and 1 kGy. Beta-carotene in apricot juice treated between 0.5 kGy and 3.0 kGy was also unaffected (Agneessens *et al.* 1989).

Results from the QLD DAFF nutritional study (2013) agree with data found in other studies. The nutritional quality of apricot fruit was not adversely impacted by irradiation up to 1.0 kGy (Egea *et al.* 2005, Lee *et al.* 2008a, Lee *et al.* 2008b). Application of gamma irradiation treatments of ≤1 kGy therefore can be considered a suitable phytosanitary treatment without inducing significant deleterious effects to the chemical and proximate components of apricot.

The QLD DAFF postharvest fruit quality (2013) study found that apricot fruit were not impacted by irradiation treatments of up to 1000 Gy but entirely by the effects of storage. Fruit quality remained relatively high by the end of the 14 day storage period. Therefore irradiation up to 1 kGy can therefore be safely used as a phytosanitary or disinfestation method without causing any deleterious effects on fruit quality. Cold storage for up to 14 days resulted in partial ripening of fruit as indicated by a slight reduction in fruit firmness and titratable acidity levels, and minor changes in skin colour properties.

Past work has shown that apricot fruit generally have a “moderate” tolerance to irradiation at doses of <1 kGy compared with other fruit and vegetables (Kader 1986). Drake and Neven (1998) and Egea *et al.* (2007) found no differences in skin colour, soluble solids or titratable acidity levels although with an increase in internal breakdown and a decrease in firmness following an irradiation dose of up to 900 Gy was detected (Drake and Neven 1998). As noted by several authors (Kader 1986, Mitchell *et al.* 1992) responses to irradiation can vary widely between variety, harvest maturity, growing conditions and other factors associated with geographic location.



Effect of irradiation on the nutritional profile and postharvest quality of apricot (*Prunus armeniaca*) fruit.

Final Report
January 2013



Australian Government
Department of Agriculture, Fisheries and Forestry

Department of **Agriculture, Fisheries and Forestry**

Project Title

Effect of irradiation on the nutritional profile and postharvest fruit quality of apricot fruit.

Part of MT10057 Phase 2 Final Report (includes apple, apricot, cherry, peach, plum and table grapes).

This report investigates the effects of low doses of gamma (γ) irradiation on the nutrition and postharvest quality of apricot fruit, both before and after a recommended cold storage period of 14 days.

The Report is presented in two parts.

Part A: Nutritional analysis

Part B: Postharvest fruit quality

Project Leaders

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Market Access Focus Team Leader
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

[REDACTED] Research Scientist, DAFF
[REDACTED], Research Scientist, DAFF
[REDACTED] Senior Biometrician, DAFF
[REDACTED] Market Access Focus Team Leader, DAFF

Technical Personnel

[REDACTED] Technical Officer, DAFF

Funding Sources

Horticulture Australia Limited (HAL)
Queensland Department of Agriculture, Fisheries and Forestry
Australian Government, Department of Agriculture, Fisheries and Forestry

Date of Report

January 2013

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.



Leader, Radiation Technology
, Senior Technical Officer, Radiation Technology
Technical Officer, Radiation Technology
Technical Officer, Radiation Technology

© State of Queensland, 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/4ed/en>

Contents

Executive Summary.....	5
Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of apricot (<i>Prunus armeniaca</i>) fruit.	6
Summary	7
Introduction.....	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis.....	12
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components.....	21
Recommendation.....	33
References	34
Part B. Effect of gamma irradiation on postharvest quality of apricot (<i>Prunus armeniaca</i>) fruit.	38
Summary	39
Introduction.....	40
Materials and methods	41
Experimental layout.....	41
Fruit quality assessments.....	41
Statistical analysis	42
Results and Discussion	43
Recommendations.....	46
References	47

Executive Summary

Nutrition and fruit quality evaluations were conducted on apricot (*Prunus armeniaca*) fruit, variety 'Rival', after being treated with gamma irradiation and following a recommended cold storage period of up to 14 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy, with fruit evaluations conducted one day after irradiation treatment and after storage.

In the nutrition study, irradiation applications of up to 1 kGy did not cause any detrimental damage to the nutritional quality of apricot fruit. Instead, the nutritional status was affected more by the changes that occurred during the ripening process while in cold storage. This included changes in ascorbic acid, beta carotene and soluble solid contents (soluble sugars). Treatment of up to 1 kGy was therefore considered safe to use on apricot without causing any adverse effects on nutrition.

This fruit quality study found that apricot fruit were not impacted by irradiation but entirely by the effects of storage. Cold storage for up to 14 days resulted in partial ripening of fruit as indicated by a slight reduction in fruit firmness and titratable acidity levels, and minor changes in skin colour properties. Applications of gamma irradiation treatments of up to 1000 Gy can therefore be safely used as a phytosanitary or disinfestation measure without causing any deleterious effects on fruit quality.

Part A. Effect of low dose gamma (γ)– irradiation on the nutritional profile of apricot (*Prunus armeniaca*) fruit.

Contents

Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of apricot (<i>Prunus armeniaca</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis	12
Moisture. Method VL298 Version 6.2	12
Ash. Method VL286 Ver. 5.1	13
Protein. Method VL299 Protein	13
Dietary Fibre	14
Fat. Method VL302_Fat by Mojonnier	14
Fatty Acid Profile. Method VL 289 Fatty Acid Profile	15
Sugars. Method VL295_Common Sugars	15
Sodium. Method VL247	16
Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages	16
Calculation of Energy and Carbohydrates in Food. Method VL 412	17
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs	17
Limits of Reporting	18
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation	33
References	34

Summary

This report examines the radio-tolerance of apricot (*Prunus armeniaca*) cv. 'Rival' treated at doses at and below 1 kGy for the purpose of quarantine disinfestation.

The effects of low dose gamma (γ)-irradiation on the proximate and nutritional quality of untreated and irradiated apricot fruit were investigated.

Export quality apricots were irradiated at 0, 150, 600 and 1000 Gy and assessed on two occasions. The first assessment is one day after irradiation treatment and the second is after 14 days storage set at 0°C. The nutritional profile was analysed and included ash, energy, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

Little or no nutritional quality loss was detected in 'Rival' apricot treated with ≤ 1 kGy gamma-irradiation treatments. There were no interactions between dose level and storage time detected in all of the components measured between irradiated and untreated apricot fruit. Overall, storage time had a greater effect than irradiation dose. No main dose effects were detected except in protein, with mean protein being higher in untreated apricot fruit than in irradiated samples.

Overall, storage time had a greater effect than irradiation treatment itself. Cold storage for 14 days resulted in higher beta-carotene level, moisture and sucrose in 'Rival' apricots while decreases in ash, energy level, fat, fructose, glucose, protein and total ascorbic acid were detected.

The changes in these components including individual sugar components and beta-carotene were primarily associated with the biological ripening processes that can normally occur during storage.

Specifically, low dose irradiation did not affect the beta-carotene content and total ascorbic acid content in apricot irradiated a low doses (150 –1000 Gy).

In this study, the fresh season apricot fruit tested are high water content (>89%), and low in protein and fat. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also can change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of apricot.

Introduction

There is an increasing trend to centrally process fresh fruits, suitably packaged, for distribution and marketing. Irradiation technology proved to be effective in reducing postharvest losses, delaying ripening and prolonging fruit shelf life. Fruit maturity, cultivar, environmental conditions, postharvest handling, storage temperature, and the use of controlled atmosphere storage have all been reported to influence such fruit responses to irradiation (Lee and Kader 2000, Maxie and Abdel-Kader 1966, Miller and McDonald 1999, Mitchell *et al.* 1992) but few reports are available on the effects of irradiation on the nutritional and proximate qualities.

Studies treating apricot fruit with ionising gamma irradiation (Lee *et al.* 2008a) and with electron beam (Lee *et al.* 2008b) up to 2 kGy did not affect Vitamin C content and total sugars while carotenoid content in 'Bulida' apricot was not impacted at irradiation doses of 0.5 kGy and 1 kGy (Egea *et al.* 2005). The electron beam treatment on apricots at 1 and 2 kGy did not affect pH and hydrogen donating activity but improved microbial safety (Lee *et al.*, 2008b). Beta-carotene and ascorbic acid levels were retained in dried apricots treated at doses 2.5 and 3.0 kGy without any detrimental effects to colour and taste (Hussain 2011).

The Interstate Certification Assurance (ICA) scheme is a national system of plant health certification which provides for a harmonised approach to the audit and accreditation of businesses throughout Australia and the mutual recognition of plant health assurance certificates accompanying consignments of produce moving intrastate or interstate. ICA-55 in the state of Queensland was developed to meet the requirements of State and Territory governments in Australia for the certification of irradiated fruit fly host produce for interstate and intrastate quarantine purposes. However, only fresh fruit and vegetables approved in the Food Standard Australia New Zealand (FSANZ) Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) can be certified under this Operational Procedure. There are currently ten commodities that are approved to be irradiated for pest disinfection purposes and the minimum and maximum doses permitted are 150 Gy and the maximum is 1 kGy respectively. The 150 Gy minimum dose is a generic dose for fruit fly which is an internationally approved treatment (International Standard for Phytosanitary Measures ISPM No.28, Annex 7 2009).

The effects of low dose irradiation and cold storage were investigated on the apple variety 'Red Delicious', in order to assess their effects on fruit nutritional quality. Export quality fresh whole produce were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation on apricot. This work will also compliment current findings from the postharvest fruit quality component of this study described later in this report.

Materials and Methods

Cultivar

Whole, fresh apricot fruits were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of apricots was carried out on 4th January 2012. The apricot (*Prunus armeniaca*) variety tested is 'Rival'. The fruit size was medium to large (48–50mm) and oval in shape. The fruit skin was slightly light green to orange in colour and sometimes with a slight red blush colouring before ripe. 'Rival' is a freestone variety. Unlike many other fruits, the colour of an apricot is not an indication of flavour or quality.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 0°C. The fruits were sorted but not graded and carefully placed in plastic bags and packed into 5 kg cardboard boxes which fitted into the stainless steel irradiation chamber for treatment. Diseased and damaged fruit were discarded. The produce did not receive any sanitizing or washing before treatment.

Irradiation treatment

Apricots and plums were treated at the same time. Previous dose mapping experiments indicated that the two similar sized fruits could be treated together (ANSTO, pers comm.). Dose mapping was conducted to ensure the doses specified were indeed applied.

The samples were exposed to target irradiation doses of 0, 150, 600 and 1000 Gy from a Co^{60} source of gamma irradiation. One box of fruit was treated for each dose. For proximate and nutritional analyses 20 fruit per sample were blended and measured at each assessment time.

There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 22.7–23.3°C. The boxes of fruits were positioned on a rig parallel to the plaque source (Figure 1).

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing.

The irradiation doses were measured by placing Fricke dosimeters throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front and between fruits within the carton (Figure 1). Additional dosimeters were attached to the outside of each cardboard package for monitoring and to provide references to the minimum and maximum absorbed doses.

The effects of irradiation were measured at two stages: after irradiation treatment (Time 1; one day after irradiation treatment) and after 14 days of cold storage set at 0°C (Time 2).

Following irradiation treatment, the fruit were repacked and sent for chemical analysis and postharvest fruit quality assessment. They were packed into ice coolers and lined with ice packs prior to transport. Time 2 fruit were placed in cold storage until testing commenced.



Figure 1. Apricot and plum fruits packed in plastic bags and placed in a cardboard carton ready for irradiation treatment. Dosimeter(s) attached to bags of fruit inside the carton and on outside of cartons for monitoring doses received within the box.
Source: Radiation Technology, ANSTO.

Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the two occasions, after treatment and after a period in cold storage at 0°C. The first assessment was a day after mean irradiation treatment and the second analysis was at the end of the recommended storage period, which was 14 days for apricot.

Edible portions of each fruit were blended at each time point. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s): AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1 mg.

2 to 5 gram of sample is weighed, to nearest 0.1 mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1 mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1 mg, into the dish. The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s): AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to 525°C ± 25°C until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2 g) is accurately weighed into a Kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20 ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50 ml distilled water is added. The tube is placed in a Kjeltac distillation unit and the mixture is steam distilled into a beaker containing 50ml of saturated boric acid solution. The distilled solution is titrated with standardised 0.1 N sulphuric acid solution using a mixed indicator of bromocresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre.

Reference Method: AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s): AS 2300.1.3. AOAC 16th Edition 954.02, 948.15, 922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2 g) is accurately weighed into a beaker.

10 ml of approx. 10 % hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10 ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25 ml of diethyl ether and a further minute with each of 25 ml of petroleum ether and 50 ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102°C until constant weight is achieved.

Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish}}{\text{Weight of sample}} \times 100$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", *Can. J. Biochem. Physiol.* 37: 911-917.

Badings and Dejong (1983). *J. Chrom.* 279: 493-506.

McCance and Widdowson (1991). *The Composition of Foods*. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10 g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2 g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and re-extracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s): AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45 µm filter into a 2 ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s):

1. USEPA (United States Environmental Protection Agency) Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2–0.5 g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase. Absorbance is measured by PDA detection at 245 nm, the PDA spectra (220 to

350 nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code (2011).

Carbohydrate Calculation:

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation:

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference Method: CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5 g of sample is accurately weighed into a 250 ml flask and 60 ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500 ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes; each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10 ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450 nm, the PDA spectra (250 to 650 nm) is used as confirmation. Determination is made against a known β - Carotene standard, whose concentration is determined by absorbance measurements.

Limits of Reporting

The laboratory standard normally only contains the compound or compounds of interest, in the optimal calibration range. It is also in a medium that does not interfere with and/or enhance the performance of the analytical instrument. It is under these ideal conditions that the lowest concentration can be reported, while minimising uncertainty due to matrix effects. This concentration is the limit of detection of the method. Other non-targeted compounds and constituents can interfere with the sample analysis, and the corrected concentration is reported (limit of reporting).

Limits of reporting for the various components tested are tabled below.

Analysis / Analyte	Limit of reporting; LOR (generally 1–5 times the limit of detection)
Vitamin C (L-ascorbic acid)	1 mg/100g
Beta-carotene	5 μ g/100g
Ash	0.1 g/100g
Carbohydrates	2 g/100g (calculated by difference)
Dietary fibre	0.05 g/100g
Energy	Calculation
Fat	0.2 g/100g
Moisture	0.2 g/100g
Saturated fat	0.10 %
Trans fat	0.10 %
Mono-saturated fat	0.10 %
Polysaturated fat	0.10 %
Protein	0.2 g/100g
Sodium	10 mg/kg
Total sugars	1 g/100g
Fructose	0.2 g/100g
Glucose	0.2 g/100g
Lactose	0.2 g/100g
Maltose	0.2 g/100g
Sucrose	0.2 g/100g

If the limit of reporting, say for example, for beta-carotene in the methodology used is 5 μ g/100g that value means that the laboratory can measure with reasonable accuracy at this level. Any level below the accuracy is not that good and the measurement of uncertainty below the limit of reporting, for example for beta-carotene in the methodology used is 26%.

Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level using GenStat for Windows 14th Edition (VSN International 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed by ANOVA separately, as well as a 2-way factorial ANOVA to investigate the time by dose interaction. Where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD).

For some components, where all or the majority of data was censored (below the level of detection) the data could not be analysed. Where there were a minority of values censored, the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. A \log_{10} transformation was required for Sodium to improve the assumptions underlying the ANOVA and ensure sensible estimates of the censored values were obtained. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not underestimated.

Results and Discussion

Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received in the study were as required; 0, 150, 600 and 1000 Gy. The average irradiation dose absorbed complies with the required specifications of the study. The Irradiation Report is presented in the section below.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke.

The dose rate was approximately 15.2 Gy/min. Irradiation temperature was 22.7–23.3°C.

Apricot and plums

Ansto
Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9335
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

8 February 2012

Irradiation Report

ANSTO Reference 12-1964
A (Apricots) & B (Plums)

Customer QLD DEEDI

Address 21-23 Redden Street,
Portsmith, QLD – 4870
[REDACTED]

ANSTO Ref. 12-1964 SRT F 004

Prepared [REDACTED] Authorised [REDACTED] Date 8. 2. 2012 Page 1 of 5

Product Details	
Product	Apricots and Plums
Quantity	10 x 5 kg boxes Apricots 10 x 5 kg boxes plums
Irradiation Conditions	
Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	4 January 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 15.2 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F227
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	22.7 to 23.3 °C
<div style="display: flex; justify-content: space-between;"> ANSTO Ref. 12-1564 SRT F 004 </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="display: flex; align-items: center;"> <div style="border: 1px solid black; width: 100px; height: 20px; background-color: black;"></div> <div style="margin: 0 5px;">Prepared</div> <div style="border: 1px solid black; width: 100px; height: 20px; background-color: black;"></div> <div style="margin: 0 5px;">Authorised</div> <div style="border: 1px solid black; width: 100px; height: 20px; background-color: black;"></div> <div style="margin: 0 5px;">Date</div> <div style="margin: 0 5px;">8.2.2012</div> <div style="margin: 0 5px;">Page 2 of 5</div> </div> </div>	

The apricots and plums that were received for processing were repacked into trays. The trays for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited with in the trays at the front and in between apricots and plums (Figure 1). Additional dosimeters were attached to the outside of one tray to provide a reference to the minimum and maximum doses (the monitoring position). The trays were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R2) samples from the first lot were used to carry out a dosemapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dosemapping repeated twice with dosimeters at those locations. This dosemapping information was used to process the remaining trays of apricots and plums to their target doses.



Figure 1: Dosimeters positioned on bags of apricots and plums.

ANSTO Ref: 12-1964		SRT F 004	
Prepared	Authorised	Date	Page 3 of 5
[Redacted]		8.2.2012	



Figure 2: Trays positioned for irradiation.

Results for Apricots and Plums

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	140 ± 9	157 ± 7	149 ± 6
600	Replicate 1	546 ± 27	612 ± 21	579 ± 17
1000	Replicate 1	912 ± 32	1022 ± 25	967 ± 20
150	Replicate 2	138 ± 9	154 ± 7	146 ± 6
600	Replicate 2	574 ± 7	644 ± 7	609 ± 5
1000	Replicate 2	937 ± 29	1051 ± 22	994 ± 18
150	Replicate 3	141 ± 10	158 ± 7	149 ± 6
600	Replicate 3	556 ± 27	623 ± 21	590 ± 17
1000	Replicate 3	922 ± 32	1034 ± 25	978 ± 20

ANSTO Ref: 12-1964

SRT F 004

Prepared

Authorised

Date

Page 4 of 5

8.2.2012

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of
Radiation Technology, ANSTO.

ANSTO Ref: 12-1964

SRT F004

Prepared

Authorised

Date

8.2.2012

Page 5 of 5

Nutritional components

Firm light green to orange apricot fruit, variety 'Rival' was treated and the samples were analysed on two occasions; the first analysis (Time 1) one day after irradiation treatment and the second analysis (Time 2), after 14 days storage in a cold room set at 0°C.

No significant time by dose interactions were found in any of the chemical components tested (Table 1). Overall, storage time had a greater effect than irradiation dose. Apricots are low in protein, varying between 1.20–1.53 mg/100g.

Studies on different fruits showed that certain physiological and biochemical changes are induced by exposure to low temperatures (Wang 1990), and the responses may be related to an accumulation or a decrease in specific mRNAs and proteins (Watkins *et al.* 1990), suggesting a general decrease in metabolic activity of fruit during low temperature storage. On the other hand, hot water treatment arrested loss of several proteins during room temperature fruit ripening (Yimyoung *et al.* 2011).

Irradiation did not affect any nutritional components one day after irradiation except for the energy value of the fruit, with reduced levels ≥ 600 Gy irradiation doses (Table 2). There was no significant main effect of dose on any of the components in apricot after 14 days storage (Table 3). Irradiation had no significant effect on ash, carbohydrates, dietary fibre, fat, moisture, sodium, protein, total sugar, fructose, glucose, sucrose, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

A significant decline in Vitamin C (total ascorbic acid) was observed after 14 days, from a mean of 0.44 mg/100g to 0.27 mg/100g (Table 1). Vitamin C (total ascorbic acid) in untreated fruit reduced from 0.47 mg/100g to 0.27 mg/100g while treated samples dropped from between 0.37 – 0.47 mg/100g to 0.23 – 0.30 mg/100g. Lee *et al.* (2008a) showed no significant effect of gamma irradiation in Vitamin C contents, total sugar and reducing sugar in apricot when exposed to irradiation treatment up to 2 kGy and stored at 20°C over a two week period. However, in that study, the Vitamin C content increased after the storage period for all samples while total sugars were not affected. Treatment with electron beam (1 kGy and 2 kGy) also did not affect total sugar and Vitamin C content in apricot (Lee *et al.* 2008b).

In this study, mean Vitamin C (total ascorbic acid) in the control is 0.47 mg/100g and ranged between 0.37 and 0.47 mg/100g in the irradiated samples one day after treatment. The level of ascorbic acid in apricot reported in NUTTAB (Food Standards Australia New Zealand (FSANZ) 2010) is 12 mg/100g and a value of 10.0 g/100g is reported in the USDA database (2010).

The Vitamin C (total ascorbic acid) levels in apricot in this study were lower than reported elsewhere. Our handling procedures and temperature variation during transportation between facilities may have contributed to the lower levels detected as losses are accelerated at higher temperatures (Lee and Kader 2000). No error in analysis was detected by the independent laboratory undertaking the testing and all duplicates, controls and spike recoveries were found within the acceptable criteria. Although content of Vitamin C in fruits can be influenced by cultivar, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures, temperature management after harvest is the most important factor to maintain Vitamin C in fruits (Lee and Kader, 2000).

Wahid *et al.* (1987) treated dried apricots between 0 Gy and 1 kGy. They found loss in ascorbic acid in dried apricots was significant over a 12 month storage period when stored at room temperature and was reduced by irradiation treatment at higher doses. The dried control contained 9.47 mg/100g ascorbic acid just after treatment declining to about 2.5 mg/100g after 12 months.

No main effect of dose was found for beta-carotene after irradiation treatment (Table 2) and after 14 days storage (Table 3). This result is similar to the results from Egea *et al.* (2005) in carotenoid content in 'Bulida' apricot irradiated at 0.5 kGy and 1 kGy. Agneessens *et al.* (1989) reported that irradiation had no effect on beta-carotene in apricot juice treated between 0.5 kGy and 3.0 kGy.

In this study 14 days in storage at 0°C affected beta-carotene levels. Mean beta-carotene ranged between 536.7 and 690.0 µg/100g before storage and increased levels were observed across all irradiated samples (706.7–880.0 µg/100g) and the control sample (660.0 µg/100g) after 14 days storage (Table 1). Mean beta-carotene increased significantly from 625.8 µg/100g to 746.2 µg/100g, with the increase in 150 Gy sample being largest, an increase of 27.5% (Table 1). The increase was 23% in the control while increases were less than 20% in the 600 Gy and 1000 Gy sample.

Ampomah-Dwamena (2009) found that beta-carotene concentration in kiwifruit increased with developmental stage; beta-carotene concentration was 24% of total carotenoid in mature green kiwifruit, and increased during ripening to 40% at the stage when the colour change appeared complete. The apricots used in this study were not fully ripe and the beta-carotene content increased while in storage. Ripening in the 600 Gy and 1000 Gy samples may have been further delayed at 0°C after 14 days than the 150 Gy and control samples, thereby giving a lower measure. Beta-carotene in the 150 Gy sample increased by 27% and in the control by 23% compared with 9% in the 600 Gy sample and 18% in the 1000 Gy sample. Katayama *et al.* (1971) showed that beta-carotene in apricots increased rapidly in the ripening period, from green stage to ripe stage.

Mean beta-carotene of the control just after irradiation was 536.7 µg/100g compared to 197.0 µg/100g reported in NUTTAB (FSANZ 2010) while the irradiated samples were 690.0, 680.0 and 596.7 µg/100g for the 150 Gy, 600 Gy and 1000 Gy samples respectively. Vedralina-Dragojevic *et al.* (1997) recorded an extraordinary large value of 10,754 µg/100g beta-carotene in fresh apricots, and reported that in general a significant loss in beta-carotene occurred irrespective of blanching, drying and freezing with storage.

In sundried apricots however, Hussain *et al.* (2011) found a strong positive correlation between irradiation treatment and beta-carotene content irradiated at doses ≥ 1 kGy. The authors attributed the increase in beta-carotene contents in irradiated samples to the increased extractability of carotenoids because of the changes in cellular structure (Boylston *et al.*, 2002, Moreno *et al.* 2007).

Total sugars was not affected after 14 days cold storage however changes in reducing sugars were observed as an increase in sucrose (from 0.87 g/100g to 1.36 g/100g) and a decrease in glucose (from 1.87 g/100g to 1.52 g/100g) and fructose (from 0.98 g/100g to 0.78 g/100g) levels. The changes in reducing sugars were most likely the result of the acid hydrolysis of disaccharides to monosaccharides as seen in other fruits (Davies and Kempton 1975, Montalvo *et al.* 2009).

Effect of irradiation on the nutritional profile and postharvest quality of apricot fruit.

- 27 -

Mean ash, energy value and fat declined following storage while moisture increased. The moisture content of control and irradiated 'Rival' apricot just after irradiation treatment and 14 days later varied between 89.87 g/100g and 90.43 g/100g. The small change seen in Table 1 has no biological significance and is a normal response in the ripening process.

Table 1. A factorial analysis investigating the interactive effect of time and dose (2-way ANOVA) on the nutritional profile of 'Rival' apricot fruit.

Component	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Ascorbic Acid* (mg/100g)	0	0.47	0.27	0.37	Time	<0.001	0.021
	150	0.47	0.23	0.35	Irrad Dose	0.627	0.029
	600	0.37	0.30	0.33	Time x Irrad.	0.056	0.041
	1000	0.47	0.27	0.37			
	Mean	0.44 ^a	0.27 ^b				
Ash (g/100g)	0	1.00	0.97	0.98	Time	0.008	0.030
	150	0.97	0.83	0.90	Irrad Dose	0.094	0.042
	600	0.93	0.83	0.88	Time x Irrad.	0.690	0.059
	1000	0.93	0.83	0.88			
	Mean	0.96 ^a	0.87 ^b				
Beta Carotene (ug/100g)	0	536.7	660.0	598.3	Time	0.032	50.67
	150	690.0	880.0	785.0	Irrad Dose	0.103	71.66
	600	680.0	738.3	709.2	Time x Irrad.	0.835	101.34
	1000	596.7	706.7	651.7			
	Mean	625.8 ^a	746.2 ^a				
Carbohydrates (g/100g)	0	4.3	4.7	4.5	Time	1.000	0.16
	150	5.3	4.7	5.0	Irrad Dose	0.060	0.23
	600	5.0	5.3	5.2	Time x Irrad.	0.150	0.33
	1000	5.0	5.0	5.0			
	Mean	4.9	4.9				
Energy (kJ/100g)	0	133.3	130.0	131.7	Time	0.007	2.89
	150	153.3	130.0	141.7	Irrad Dose	0.121	4.08
	600	140.0	136.7	138.3	Time x Irrad.	0.082	5.77
	1000	143.3	136.7	140.0			
	Mean	142.5 ^a	133.3 ^b				
Fat (g/100g)	0	0.50	0.37	0.43	Time	<0.001	0.022
	150	0.53	0.33	0.43	Irrad Dose	0.757	0.031
	600	0.50	0.33	0.42	Time x Irrad.	0.757	0.043
	1000	0.53	0.37	0.45			
	Mean	0.52 ^a	0.35 ^b				
Fructose (g/100g)	0	0.90	0.77	0.83	Time	<0.001	0.039
	150	1.00	0.77	0.88	Irrad Dose	0.533	0.356
	600	0.97	0.80	0.88	Time x Irrad.	0.474	0.079
	1000	1.07	0.77	0.92			
	Mean	0.98 ^a	0.78 ^b				

Means in treatment followed by the same letter are not significantly different.

*Total ascorbic acid data presented are at limits of detection.

Table 1 contd. A factorial analysis investigating the interactive effect of time and dose (2-way ANOVA) on the nutritional profile of 'Rival' apricot fruit.

Component	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Glucose (g/100g)	0	1.70	1.43	1.57	Time	<0.001	0.058
	150	1.90	1.53	1.72	Irrad Dose	0.133	0.083
	600	1.83	1.60	1.72	Time x Irrad.	0.303	0.117
	1000	2.03	1.50	1.77			
	Mean	1.87 ^a	1.52 ^b				
Moisture (g/100g)	0	90.23	90.33	90.28	Time	0.019	0.091
	150	89.87	90.43	90.15	Irrad Dose	0.660	0.129
	600	90.20	90.17	90.18	Time x Irrad.	0.146	0.182
	1000	89.97	90.30	90.13			
	Mean	90.07 ^a	90.31 ^a				
Protein (g/100g)	0	1.53	1.27	1.40 ^a	Time	0.025	0.057
	150	1.37	1.27	1.32 ^{ab}	Irrad Dose	0.041	0.080
	600	1.27	1.07	1.17 ^b	Time x Irrad.	0.397	0.113
	1000	1.20	1.20	1.20 ^b			
	Mean	1.34 ^a	1.20 ^b				
Sodium # (mg/100g)	0	0.393	0.386	0.389	Time	0.900	0.0836
	150	0.372	0.272	0.318	Irrad Dose	0.466	0.1183
	600	0.403	0.558	0.474	Time x Irrad.	0.704	0.1673
	1000	0.345	0.314	0.329			
	Mean	0.378	0.368				
Sucrose (g/100g)	0	0.70	1.20	0.95	Time	<0.001	0.900
	150	0.93	1.50	1.22	Irrad Dose	0.232	0.127
	600	0.90	1.40	1.15	Time x Irrad.	0.931	0.180
	1000	0.93	1.33	1.13			
	Mean	0.87 ^b	1.36 ^a				
Total Dietary Fibre (g/100g)	0	2.27	2.43	2.35	Time	0.707	0.065
	150	2.30	2.20	2.25	Irrad Dose	0.664	0.092
	600	2.30	2.37	2.33	Time x Irrad.	0.514	0.131
	1000	2.37	2.33	2.35			
	Mean	2.31	2.33				
Total Sugars (g/100g)	0	3.30	3.40	3.35	Time	0.411	0.148
	150	3.83	3.80	3.82	Irrad Dose	0.138	0.209
	600	3.70	3.53	3.62	Time x Irrad.	0.674	0.295
	1000	4.00	3.60	3.80			
	Mean	3.71	3.58				

Means in treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values are censored and have been analysed using the method of Taylor (1973).

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

Table 2. Mean chemical measurements in 'Rival' apricot fruit after irradiation treatment (Time1).

Time 1 Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid* (mg/100g)	0.47 (0.058)	0.47 (0.058)	0.37 (0.058)	0.47 (0.058)	0.183	0.047
Ash (g/100g)	1.00 (0.000)	0.97 (0.058)	0.93 (0.058)	0.93 (0.058)	0.455	0.045
Beta Carotene (ug/100g)	536.7 (118.46)	690.0 (87.18)	680.0 (98.49)	596.7 (225.46)	0.636	132.34
Carbohydrates (g/100g)	4.3 (0.58)	5.3 (0.58)	5.0 (0.00)	5.0 (0.00)	0.138	0.36
Energy (kJ/100g)	133.3 ^c (5.77)	153.3 ^a (5.77)	140.0 ^{bc} (0.00)	143.3 ^b (5.77)	0.015	4.08
Fat (g/100g)	0.50 (0.000)	0.53 (0.058)	0.50 (0.000)	0.53 (0.058)	0.654	0.036
Fructose (g/100g)	0.90 (0.000)	1.00 (0.173)	0.97 (0.115)	1.07 (0.115)	0.433	0.095
Glucose (g/100g)	1.70 (0.000)	1.90 (0.173)	1.83 (0.231)	2.03 (0.252)	0.246	0.146
Moisture (g/100g)	90.23 (0.058)	89.87 (0.351)	90.20 (0.173)	89.97 (0.503)	0.330	0.213
Protein (g/100g)	1.53 (0.208)	1.37 (0.153)	1.27 (0.231)	1.20 (0.173)	0.259	0.156
Sodium (mg/100g)	0.410 (0.1473)	0.383 (0.1185)	0.407 (0.0681)	0.353 (0.0902)	0.920	0.0928
Sucrose (g/100g)	0.70 (0.265)	0.93 (0.153)	0.90 (0.265)	0.93 (0.321)	0.714	0.231
Total Dietary Fibre (g/100g)	2.27 (0.252)	2.30 (0.100)	2.30 (0.000)	2.37 (0.115)	0.882	0.128
Total Sugars (g/100g)	3.30 (0.265)	3.83 (0.252)	3.70 (0.1000)	4.00 (0.361)	0.092	0.227

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

*Total ascorbic acid data presented are at limits of detection.

Table 3. Mean chemical measurements in untreated and irradiated 'Rival' apricot fruit after 14 days cold storage at 0°C (Time 2).

Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid (mg/100g)	0.27 (0.058)	0.23 (0.058)	0.30 (0.000)	0.27 (0.058)	0.104	0.119
Ash (g/100g)	0.97 (0.115)	0.83 (0.153)	0.83 (0.058)	0.83 (0.115)	0.105	0.053
Beta Carotene (ug/100g)	660.0 (50.00)	880.0 (115.33)	738.3 (30.14)	706.7 (102.14)	0.084	70.37
Carbohydrates (g/100g)	4.7 (0.58)	4.7 (0.58)	5.3 (0.58)	5.0 (0.00)	0.189	0.30
Energy (kJ/100g)	130.0 (10.00)	130.0 (10.00)	136.7 (11.55)	136.7 (5.77)	0.686	7.58
Fat (g/100g)	0.37 (0.058)	0.33 (0.058)	0.33 (0.058)	0.37 (0.058)	0.859	0.054
Fructose (g/100g)	0.77 (0.058)	0.77 (0.115)	0.80 (0.000)	0.77 (0.058)	0.931	0.062
Glucose (g/100g)	1.43 (0.115)	1.53 (0.153)	1.60 (0.100)	1.50 (0.000)	0.238	0.072
Moisture (g/100g)	90.33 (0.451)	90.43 (0.208)	90.17 (0.321)	90.30 (0.200)	0.213	0.110
Protein (g/100g)	1.27 (1.153)	1.27 (0.115)	1.07 (0.058)	1.20 (0.000)	0.087	0.071
Sodium (mg/100g)#	0.386 (0.0306)	0.255 (0.1559)	0.558 [®] (0.9844)	0.314 (0.0503)	0.470	0.2097
Sucrose (g/100g)	1.20 (0.100)	1.50 (0.173)	1.40 (0.265)	1.33 (0.153)	0.316	0.147
Total Dietary Fibre (g/100g)	2.43 (0.153)	2.20 (0.100)	2.37 (0.208)	2.33 (0.208)	0.153	0.087
Total Sugars (g/100g)	3.40 (0.100)	3.80 (0.400)	3.53 (0.764)	3.60 (0.200)	0.749	0.366

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different. Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

*Total ascorbic acid data presented are at limits of detection.

®Contains a sodium reading of 2.00

Recommendation

The overall findings of this study show that an irradiation application of up to 1 kGy will not result in any significant detrimental damage to the nutritional quality of apricot. The effect of storage time was greater than by irradiation itself and the changes seen after storage generally appeared to be associated with the ripening/senescence process during storage.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of apricot.

References

- Abushita, A.A., Daood, H.G. and Biacs, P.A. (2000). Change in carotenoids and antioxidant vitamins in tomato as a function of varietal and technological factors. *Journal of Agricultural and Food Chemistry* 48: 2075–2081.
- Agneessens, R., Nangiot, P., Lacroix, J.P. and Muri, D. (1989). Estimation of beta-carotene in irradiated fruits by high-performance liquid chromatography with amperometric detection. *Bulletin des Recherches Agronomiques de Gembloux* 24: 85–90.
- Ampomah-Dwamena, C., McGhie, T., Wibisono, R., Montefiori, M., Hellens, R.P. and Allan, A.C. (2009). The kiwifruit lycopene beta-cyclase plays a significant role in carotenoid accumulation in fruit. *Journal of Experimental Botany Advance Access published July 2, 2009* 15pages
- AOAC. Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Badings, H.T. and de Jong, C. (1983). Glass capillary gas chromatography of fatty acid methyl esters: a study of conditions for the quantitative analysis of short- and long-chain fatty acids in lipids. *Journal of Chromatography* 279: 493506.
- Bligh, E.G. and Dwyer, W.J. (1959). A Rapid Method of Total Lipid Extraction and Purification", *Canadian Journal of Biochemistry and Physiology* 37: 911–917.
- Boylston, T.D., Reitmeier, C. A., Moy, J.H., Mosher, G.A. and Taladriz, L. (2002). Sensory quality and nutrient composition of three Hawaiian fruits treated by X-irradiation. *Journal of Food Quality* 25: 419-433.
- Brubacher, G., Muller-Mulot, W. and Southgate, W.A.T. (eds). *Methods for the Determination of Vitamins in Food* (1985). Elsevier Applied Science Publishers Ltd Ch 5.
- CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251. 92nd edition link online <http://www.hbcpnetbase.com/>
- Davey, M.W., Montagu, M.V., Inze, D., Sanmartin, M., Kanellis, A., Smirnoff, N., Benzie, I.J.J., Strain, J.J., Favell, D. and Fletcher, J. (2000). Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *Journal of the Science of Food and Agriculture* 80: 825–860.
- Davies, J.N. and Kempton, R.J. (1975). Changes in the individual sugars of tomato fruit during ripening. *Journal of the Science of Food and Agriculture* 26 (8): 1103–1110.

- Dewanto, V., Wu, X., Adom K.K. and Liu, R.H. (2002). Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *Journal of Agricultural and Food Chemistry* 50: 3010–3014.
- Dickson, J.S. (2012). Radiation meets food. *Physics Today* 65 (2): 66–67.
- Egea, M.I., Murcia, M.A., Sánchez-Bel, P., Romojaro, F. and Martínez-Madrid, M.C. (2005). Effect of electron beam ionization on shelf life of apricot. *ISHS Acta Horticulturae* 682: V International Postharvest Symposium.
- Elkins, E.R. (1979). Nutrient content of raw and canned green beans, peaches, and sweet potatoes. *Journal of Food Technology* 33: 66–70.
- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339. <http://www.comlaw.gov.au/Details/F2010C00339>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database. <http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>
- Howard, L.A., Wong, A.D., Perry, A.K. and Klein, B.P. (1999). β -Carotene and ascorbic acid retention in fresh and processed vegetables. *Journal of Food Science* 64: 929–936.
- Hussain, P.R., Meena, R.S., Dar, M.A. and Wani, A.M. (2011). Gamma irradiation of sun-dried apricots (*Prunus armeniaca* L.) for quality maintenance and quarantine purposes. *Radiation Physics and Chemistry* 80 (7): 817–827.
- ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009). https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Jooste, M.M. (1999) Optimum harvest maturity and cold-storage duration for *Prunus armeniaca* L. cvs. Supergold and Imperial cultivated in South Africa. http://webcache.googleusercontent.com/search?q=cache:ZwQEvJXvx4YJ:http://fruitgro.krazyboyz.co.za/media/uploads/documents/document/file/mariana_ca_pespan_-_apricots_pdf.pdf%2Bjooste+apricot&hl=en&safe=active&gbv=2&gs_l=serp.3...27259.27259.0.28617.1.1.0.0.0.0.250.250.2-1.1.0...0.0...1c.FVMd3idbtJo&ct=clink
- Jooste, M.M. and Taylor, M.A. (1999). Effect of harvest maturity and cold storage period on the overall quality of Bebeco apricots, with special reference to gel breakdown and variates used to accurately establish harvest maturity. *Deciduous Fruit Grower* 49 (Sept): 39–44.
- Kader, A.A. (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Journal of Food Technology* 40: 117–121.

Materials and Methods

Cultivar

Whole, fresh apricot fruits were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of apricots was carried out on 4th January 2012. The apricot (*Prunus armeniaca*) variety tested is 'Rival'. The fruit size was medium to large (48–50mm) and oval in shape. The fruit skin was slightly light green to orange in colour and sometimes with a slight red blush colouring before ripe. 'Rival' is a freestone variety. Unlike many other fruits, the colour of an apricot is not an indication of flavour or quality.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 0°C. The fruits were sorted but not graded and carefully placed in plastic bags and packed into 5 kg cardboard boxes which fitted into the stainless steel irradiation chamber for treatment. Diseased and damaged fruit were discarded. The produce did not receive any sanitizing or washing before treatment.

- Montalvo, E., Adame, Y. Garcia, H.S., Tovar, A.B. and Mata, M. (2009). Changes of sugars, β -carotene and firmness of refrigerated Ataulfo mangoes treated with exogenous ethylene. *Journal of Agricultural Science* 147: 193–199.
- Rajkowski, K.T. and Thayer, D.W. (2000). Reduction of *Salmonella* spp. and Strains of *Escherichia coli* O157:H7 by Gamma Radiation of Inoculated Sprouts. *Journal of Food Protection* 63(7): 871–875.
- Taylor, J. (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35–43.
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website, <http://www.nal.usda.gov/fnic/foodcomp/search/>
- USEPA (United States Environmental Protection Agency). Method 6010b. Inductively coupled plasma-atomic emission spectrometry (ICP-MS). <http://www.epa.gov/region8/water/biosolids/analyticalmethods.html>
- USEPA (United States Environmental Protection Agency). Method 6020. Inductively coupled plasma-mass spectrometry (ICP-MS). <http://www.epa.gov/region8/water/biosolids/analyticalmethods.html>
- Vedrinar-Dragojevic, I., Sebecic, B. and Horvatic, M. (1997). Effect of blanching, drying, freezing and storage on degradation of β -carotene in different fruits. *Food / Nahrung* 41 (6): 355–358.
- VSN International. (2011). GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK. Web Page: GenStat.co.uk
- Wahid, M., Sattar, A., Neelofar, Atta, S., Khan, I and Ehlerman, D.A. (1987). Radiation disinfestation and quality of dried fruits. *Acta alimentaria* (Budapest) 16 (2): 159–166.
- Wajea, C.K., Junb, S.Y., Leeb, Y.K., Kimc, B.N., Hanc, D.H., Jod, C. and Kwon, J.H. (2009). Microbial quality assessment and pathogen inactivation by electron beam and gamma irradiation of commercial seed sprouts. *Food Control* 20 (3):200–204.
- Wang, C.Y. (1990). Physiological and biochemical effects of controlled atmosphere on fruits and vegetables. In: M. Calderon and R. Barkai-Golan (eds.), p. 197–223. *Food preservation by modified atmospheres*. CRC Press, Boca Raton, Fla.
- Watkins, C.B., Picton, S. and Grierson, D. (1990). Stimulation and inhibition of expression of ripening-related mRNAs in tomatoes as influenced by chilling temperatures. *Journal of Plant Physiology* 136 (3): 318–323.
- Yimyong, S., Datsenka, T.U., Handa, A.K. and Seraypheap, K. (2011). Hot Water Treatment Delays Ripening-associated Metabolic Shift in 'Okrong' Mango Fruit during Storage. *Journal of The American Society For Horticultural Science*. 136(6): 441–451.

Part B. Effect of gamma irradiation on postharvest quality of apricot (*Prunus armeniaca*) fruit.

Contents

Part B. Effect of gamma irradiation on postharvest quality of apricot (<i>Prunus armeniaca</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Fruit colour	41
Moisture loss and whole fruit softness	41
Biochemical analyses	42
Fruit disease and disorders	42
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Summary

Fruit quality evaluations were conducted on apricot (*Prunus armeniaca*) fruit, variety 'Rival', after being treated with gamma irradiation and following a recommended cold storage period of 14 days. Gamma irradiation treatments consisted of a dose of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that fruit quality of apricot fruit was impacted by storage time but not by irradiation. Fruit lost approximately 0.4% of their fresh weight over the 14 day storage period, irrespective of any irradiation treatment. Fruit after storage were softer (decline from 10 to 8 N), had lower titratable acidity scores (1.8 to 1.5% citric acid) and had attained a brighter orange skin colour (chroma from 48 to 49.5; hue angle values from 83° to 80°); indicating that fruit had partially ripened during storage. Across all treatments, there was no difference in Brix levels (mean 8°) and fruit were free of disease and disorders by the end of the trial.

In conclusion, by the end of the 14 day storage period, fruit quality remained relatively high. As a result, the changes that did occur in fruit quality were entirely influenced by storage and not by the irradiation treatment.

Introduction

The present study aims to investigate the effects of gamma irradiation on the postharvest quality of apricot (*Prunus armeniaca*) fruit. Gamma irradiation is regularly used not only for disinfestation purposes but also to control for decay and extend the storage and shelf life of perishable commodities (Mitchell *et al.* 1992). Past work has shown that apricot fruit generally have a "moderate" tolerance to irradiation at doses of <1 kGy compared with other fruit and vegetables (Kader 1986). In a past study, apricot varieties 'Perfection' and 'Rival' exhibited an increase in internal breakdown and a decrease in firmness following an irradiation dose of up to 900 Gy, although little to no differences were detected in skin colour, soluble solids or titratable acidity levels (Drake and Neven 1998). Similarly, Egea *et al.* (2007) also found no differences in a range of physico-chemical attributes in the variety 'Búlida', such as skin colour, total soluble solids content, titratable acidity and carotenoid levels between control and irradiated (0.5 and 1 kGy) fruit, although a decrease in firmness was recorded. As noted by several authors (Kader 1986, Mitchell *et al.* 1992) responses to irradiation can vary widely between variety, harvest maturity, growing conditions and or other factors associated with geographic location.

In the present study, the effects of irradiation and cold storage duration were therefore examined on an Australian grown apricot fruit (var. 'Rival') to assess their effects on fruit quality following irradiation and a subsequent cold storage period. Fruit assessments entailed measurements of physico-chemical changes in fruit quality. The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation (at and below 1 kGy) on a variety grown and marketed under Australian conditions. This work will also compliment current findings from the nutritional component of this study described earlier in this report, which also incorporated fruit selected from the same irradiation and cold storage treatments as in this study.

Materials and methods

Experimental layout

Apricot (*Prunus armeniaca*) fruit, variety 'Rival', were sourced from the Sydney Markets, NSW in early January 2012. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where 20 fruit packed in polyethylene bags per cartons were irradiated over three sequential times (blocking factor) with target doses of 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group and remained under the same conditions as treated fruit. Replication consisted of a random selection of 10 individual fruit from each carton bag, comprising one of three blocks per irradiation treatment per assessment time (two times).

Following the irradiation treatment, fruit were packed and immediately transported by air to the Queensland Department of Agriculture, Fisheries and Forestry Postharvest Laboratory in Cairns. Within 24 hours, half the fruit were destructively assessed for quality determination (Day 1) while the second half was transferred into cold storage ($0.5 \pm 0.5^\circ\text{C}$ at 85% RH) and held for 14 days before being destructively assessed. Storage condition and duration requirements were based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2012). During storage, ambient air temperature and relative humidity conditions were also monitored to ensure they remained within the specifications of the trial.

Fruit quality assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, skin colour, biochemical analyses (determination of soluble solids and titratable acidity), and a record of the incidence and severity of disorders and disease types. A description of each assessment method is described as follows:

Fruit colour

Fruit skin colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8 mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L^* , C^* , H° units).

Moisture loss and whole fruit softness

Fruit were weighed before and after cold storage. Percent moisture loss was calculated by determining the proportion of moisture lost compared with the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the equatorial region of each fruit was undertaken

using a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newton (N).

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were assessed on fruit before and after storage. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

Fruit disease and disorders

If present, the incidence and severity of disease and or disorders were scored on individual fruit before and after storage. Incidence was based on the proportion of fruit within a treatment expressing symptoms and severity as the proportion (%) of affected skin (or cut flesh) surface area.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A general ANOVA's was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a Fisher's Least Square Difference (LSD) test at 5%.

Results and Discussion

The following study contributes towards furthering our baseline knowledge of the potential effects of irradiation on fruit quality in apricot. In this study, the effects of cold storage duration rather than gamma irradiation had a significant effect on several quality attributes in apricot fruit (Table 1). In this case, fruit firmness and titratable acidity changed significantly over the 14 day cold storage period, despite there being no effect of the irradiation treatment. Specifically, fruit firmness and titratable acidity both decreased over time from 10 to 8 N and from 1.8 to 1.5%, respectively. Fruit colour properties also changed during the cold storage period, with fruit becoming a brighter orange colour after storage as indicated by a significant shift in chroma from 48 to 49.5 and hue angle from 83° to 80° (Plate 1).

Although the Brix levels in apricot fruit did not differ before and after storage (Table 1), the changes observed in fruit firmness, titratable acidity, flesh colour properties would indicate that fruit underwent partial ripening during this storage period. The fact that irradiation had no effect on these fruit quality parameters is not surprising, given that similar results have been observed in other studies. Egea *et al.* (2007), for example, found that irradiation (0.5 and 1 kGy) applied to Búlida apricot fruit had little to no effect on soluble solids content, titratable acidity or on skin colour properties. Similarly, Drake and Neven (1998) also reported a similar response with varieties 'Perfection' and 'Rival', using a dose range similar to our study, from 150 to 900 Gy. Both studies, however, did report a significant decrease in firmness with increasing irradiation, and an increase in internal breakdown in 'Rival' and 'Perfection'. Interestingly, the variety 'Rival' was also examined in our study, although neither of these responses were observed as a result of irradiation. This may suggest that some other variable such as growing environment or maturity may have played a role in their sensitivity to irradiation.

In conclusion, by the end of the 14 day storage period, fruit quality remained relatively high. As a result, the changes that did occur in fruit quality were entirely influenced by the storage treatment, and not by irradiation itself.

Table 1. Effect of irradiation dose and storage duration on the quality attributes of apricot fruit. Fruit were gamma irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and then assessed within 24 hours (Day 1) and after 14 days in cold storage (0.5°C) (Day 14).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVA's	
		0	150	600	1000		Factor	P-value
Moisture loss (%)	14	0.34	0.34	0.4	0.4	0.4	Irradiation	ns
Firmness	1	10.9	10.0	11.0	8.5	10.1 ^a	Storage	<0.001
	14	8.2	7.9	8.2	7.6	8.0 ^b	Irradiation	ns
	Mean	9.5	9	9.6	8.1		Storage x Irradiation	ns
Skin lightness	1	62.3	62.7	61.8	61.6	62.1	Storage	ns
	14	61.8	61.5	61.1	62.3	61.7	Irradiation	ns
	Mean	62	62.1	61.4	61.9		Storage x Irradiation	ns
Skin chroma	1	47.9	48.3	47.5	48.2	48.0 ^b	Storage	<0.001
	14	48.8	49.7	49.8	49.9	49.5 ^a	Irradiation	ns
	Mean	48.3	49	48.6	49.1		Storage x Irradiation	ns
Skin hue angle	1	83.9	84.0	83.4	81.9	83.3 ^a	Storage	<0.001
	14	79.9	79.8	79.8	81.2	80.2 ^b	Irradiation	ns
	Mean	81.9	81.9	81.6	81.5		Storage x Irradiation	ns
TSS (°Brix)	1	8.5	7.4	7.4	8.0	7.8	Storage	ns
	14	8.5	7.9	8.1	7.9	8.1	Irradiation	ns
	Mean	8.5	7.6	7.7	7.9		Storage x Irradiation	ns
TA (% citric acid)	1	1.77	1.75	1.74	1.73	1.75 ^a	Storage	<0.001
	14	1.47	1.45	1.57	1.50	1.50 ^b	Irradiation	ns
	Mean	1.62	1.6	1.65	1.61		Storage x Irradiation	ns

Effect of irradiation on the nutritional profile and postharvest quality of apricot fruit.

- 44 -

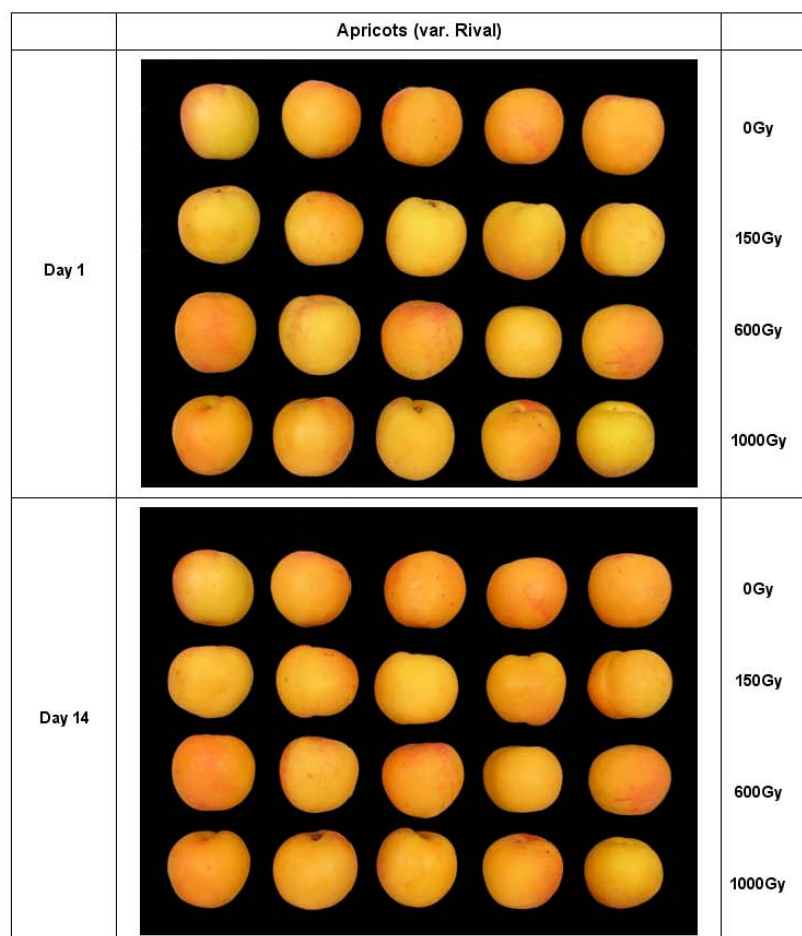


Plate 1. Photographs of a representative sample of apricot fruit ('Rival') irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and taken before and after a subsequent 14 day cold storage (0.5°C) period.

Recommendations

In this study, applications of gamma irradiation treatments of up to 1000 Gy can be safely used as a phytosanitary or disinfestation measure on apricot fruit without causing any deleterious effects on fruit quality. Cold storage for up to 14 days did however result in partial ripening of fruit as indicated by a slight reduction in fruit firmness and titratable acidity levels, and changes in skin colour properties.

References

- Drake, S.R., Neven L.G. (1998) Irradiation as an alternative to methyl bromide for quarantine treatment of stone fruits. *Journal of Food Quality* 22: 529-538.
- Egea, M.I., Martínez-Madrid, M.C., Sánchez-Bel, P., Murcia, M.A., Romojaro, F. (2007) The influence of electron-beam ionization on ethylene metabolism and quality parameters in apricot (*Prunus armeniaca* L., cv Búlida). *Food Science and Technology* 40: 1027-1035.
- Kader, A.A. (1986) Potential applications of Ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology*, 40 (6): 117-121.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291-311.
- UC Davis (2012) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 01 January, 2012, <<http://postharvest.ucdavis.edu/producefacts/>>

A2.3 Nutritional Value of Cherry

Cherries are a seasonal fruit, low in calories and provide a source of vitamin C, calcium, potassium and fibre. The concentration of vitamin A is low in sweet cherries.

There are 250–263 kJ of energy in a 100 g serve of cherry (Table 53). Current per capita sweet cherry consumption in Australia is low. Sweet cherry is considered an occasional special treat by consumers and not everyday enjoyment. Sweet cherry is not eaten for food but for pure enjoyment and would unlikely contribute significant amounts to the daily nutritional intake (Tables 53, 54, 55).

Key nutritional data for fresh sweet cherry are shown in Table 53, the values are extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). The differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Water is the major component, approximately 80%. 100 g cherry contains about 250–260 kJ energy, 1g protein, 14 g carbohydrate and about 1.6 g dietary fibre. Vitamin C ranges between 9 and 20 mg/100 g and beta-carotene between 26 – 56 µg/100g. Glucose and fructose are the main reducing sugars.

The percentage contributions to daily intake of nutrients based on FSANZ Reference Values are derived and shown in Table 54. The percentage of the daily intake from a single serve of sweet cherry is approximately 4.4 % energy, 2.6 % protein, 6.5% available carbohydrate, 7% total dietary fibre, 21% total sugar and 0.1% sodium.

Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available carbohydrate is approximately 219–238 kJ/100g for sweet cherry. Majority of the energy value comes from carbohydrate, mainly sugar, with the rest from protein, dietary fibre and fat (Table 55).

The vitamin C content of sweet cherry is much lower than most other fruit and vegetables such as melons, strawberry and capsicum. The β-carotene content (26–56 µg/100g) is below the range found for other fruits. A comparison of vitamin values against the 10 tropical fruits, tomatoes and capsicums approved for irradiation by FSANZ is provided in Table 7 (average values).

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will not come from sweet cherry. It is also not known that any sub-populations have a higher than average consumption of sweet cherries and therefore is unlikely to contribute a significant part of the average consumer's diet. Cherry contribution to overall micronutrient intake will not be significant and they are consumed as a very occasional snack food.

Pro-vitamin A (carotenes) and vitamin C are present in other fresh produce. Overall, much of the vitamin A will come from foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables, grains, dairy and egg products generally are an excellent source of vitamin K. Vitamin K is not measured here. Nuts, seeds, many fresh vegetables and vegetable oils are good sources of vitamin E.

Table 53: Nutritional data for raw cherry (*Prunus avium*) per 100g edible portion.

Nutrient	value	Sweet Cherry *		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	82.25	79.6	82.8
Energy	KJ	263	258	250
Protein	g	1.06	0.9	0.8
Nitrogen	g			0.12
Total lipid (fat)	g	0.2	0.3	0.2
Malic acid	g			1.1
Citric acid	g			0
Carbohydrate	g	16.01	14	12.9
Total Dietary Fibre	g	2.1	1.3	1.5
Ash	g	0.48		0.5
Total sugars	g	12.82	13.9	10.9
Fructose	g	5.37		4.7
Glucose	g	6.59		6.2
Sucrose	g	0.15		0
Ascorbic Acid, Vit C	mg	7	20.2	19
Thiamin, Vit B1	mg	0.027		0.033
Riboflavin, Vit B2	mg	0.033		0.025
Niacin	mg	0.154		0.5
Niacin equivalents	mg			0.63
Vit B6	mg	0.049		
Folate, Vit B9 total	µg	4		5
Vit A (retinol equiv.)	µg			9
Alpha carotene	µg	0		
Beta carotene	µg	38	26	56
Beta cryptoxanthin	µg	0		
Cryptoxanthin	µg			
Vit E	mg	0.07		
Vit K	µg	2.1		
Calcium	mg	13		22
Iron	mg	0.36		0.28
Magnesium	mg	11		8
Phosphorus	mg	21		
Potassium	mg	222		230
Sodium	mg	0	3.4	0
Zinc	mg	0.07		0.1
Copper	mg	0.060		
Manganese	mg	0.070		
Selenium	µg	0		
Iodine	µg			
Molybdenum	µg			
Nickel	µg			
Tin	µg			

*raw with skin

Table 54: Nutrient values are per 100 g edible portion of fresh cherry.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	82.8	79.6	124.2	119.4			
Energy (kJ)	250	258	375	387	4.3	4.4	8700
Protein (g)	0.8	0.9	1.2	1.35	2.4	2.7	50
Total lipid (fat) (g)	0.2	0.3	0.3	0.45	0.4	0.6	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	12.9	14	19.35	21	6.2	6.8	310
Sugar (g)	10.9	13.9	16.35	20.85	18.2	23.2	90
Total dietary fibre (g)	1.5	1.3	2.25	1.95	7.5	6.5	30
Sodium (mg)	0	3.4	0	5.1	0.0	0.2	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 55: Calculation of energy value of the major* food components per 100 g cherry.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ/g	Average quantity	Approximate calculation of energy value kJ/g
Protein	17	0.8	13.6	0.9	15.3
Total lipid (fat)	37	0.2	7.4	0.3	11.1
Fatty acids, total saturated				0	0
Available Carbohydrate	17	12.9	219.3	14	238
Total sugars		10.9		13.9	
Total dietary fibre	8	1.5	12.0	1.3	10.4

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of cherry

A report of irradiation studies of Australian sweet cherry conducted in 2012 is provided in full in the Attachment 4 to this application. The cultivar studied was fresh ripe cherry (*Prunus avium*), variety 'Stella'. The research investigated the effect of low dose gamma (γ)–irradiation on the nutritional profile and postharvest quality of sweet cherry irradiated at pest disinfection doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

Analyses included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. Time by dose interactions, at the four doses and measured on the two occasions, one day after irradiation and after 14 days cold storage at 0°C were completed. Each time was analysed separately and where a significant dose effect was found, pair-wise comparisons were made using the 95% least significant difference (LSD).

That study (QLD DAFF 2013) showed that low irradiation doses (150 Gy–1 kGy) combined with cold storage overall, does not result in significant cherry nutritional quality and postharvest fruit losses after treatment and after the 14-day storage period studied. Low dose irradiation (≤ 1 kGy) did not cause any detrimental impact for all the nutritional components tested. Storage treatment had a greater impact on sweet cherry nutrition than that of irradiation.

After storage for 14 days, reduced Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) levels and increased protein and ash content were reported. The responses were reported as changes associated with senescence response. After 14 days, only minor changes occurred as a result of irradiation, with a slight decline measured in beta-carotene levels at 600 Gy. Same results were found in a previous study by Akbudak *et al.* (2008), ascorbic acid levels in untreated sweet cherry were no different from fruit irradiated at 300 Gy. In that study which investigated storage at six different atmosphere combinations for up to 60 days after being exposed to gamma irradiation, the highest ascorbic acid value was recorded in fruit stored under controlled atmosphere and gamma irradiation.

The QLD DAFF study (2013) reported a mean of 20.3 $\mu\text{g}/100\text{g}$ beta-carotene for untreated sweet cherry and the irradiated samples ranged between 19.0 $\mu\text{g}/100\text{g}$ and 21.3 $\mu\text{g}/100\text{g}$ just after irradiation. These levels are lower compared to the 56 $\mu\text{g}/100\text{g}$ beta-carotene in NUTTAB (FSANZ 2010) and 38 $\mu\text{g}/100\text{g}$ in USDA (2010). This may be due to different variety tested, fruit maturity, growing conditions and management practices.

In an early study, quality of 'Ron's Seedling', 'American Bing', and 'Lambert' sweet cherry was not affected by irradiation doses of 1 kGy (Jessup 1990) and similarly Drake *et al.* (1994) reported that sweet cherry showed minimal quality loss after being irradiated for disinfection. Parveen and Mir (2011) reported that the quality of the cherry variety 'Misri' or 'Double', shrink-wrapped and gamma irradiated at 1.2 kGy showed little quality loss compared to untreated cherry after 28 days of refrigerated storage ($3\pm 1^\circ\text{C}$, RH $85\pm 5\%$). Moreover, Drake *et al.* (1997) stated that quality loss in irradiated sweet cherry is small compared to the more conventional means of methyl bromide (MeBr) disinfection that can result in considerable quality loss.

Protein levels were within the levels reported by reported by FSANZ (2010) and USDA (2010). There were little or no changes in carbohydrates, glucose and fructose across all samples and after 14 days cold storage. Drake and Neven (1997) found that

carbohydrates (sucrose, glucose, fructose and sorbitol) were not influenced by irradiation treatment in 'Rainer' cherry, irradiated between 0.15 and 0.90 kGy. The reducing sugars, glucose and fructose detected in 'Germersdorfi' cherry were not affected by increasing irradiation doses up to 5 kGy although during storage fructose increased while glucose decreased (Kovacs *et al.* 1995).

In the postharvest quality study, sweet cherry fruit quality was impacted only by storage time and not by irradiation. Storage time had a small impact on the skin colour (lightness values) of sweet cherry with fruit becoming slightly darker shade during storage. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit. The findings suggest that an application of up to 1 kGy would not result in any detrimental damage to the quality of sweet cherry fruit

These results concur with several other studies examining the effects of irradiation and subsequent cold storage on sweet cherry quality, whereby fruit integrity was unaffected (Drake *et al.* 1994, Kovacs *et al.* 1995). Drake *et al.* (1994), for example, demonstrated that fruit treated to doses of up to 1kGy and stored for up to 21 days exhibited no significant changes in various fruit quality attributes, such as in fruit and stem colour, soluble solids, titratable acidity or sensory characteristics. Even at a dose between 1 and 2.5 kGy, fruit quality attributes such as skin colour, sugar contents were unaffected (Kovacs *et al.* 1995). Fruit firmness, however, was found in several studies to be impacted by irradiation, with firmness levels decreasing significantly above 0.4 kGy (Drake *et al.* 1994, Kovacs *et al.* 1995).



Effect of irradiation on the nutritional profile and postharvest quality of sweet cherry (*Prunus avium* L.) fruit.

Final Report
January 2013



Australian Government
Department of Agriculture, Fisheries and Forestry



Know-how for Horticulture™

Department of Agriculture, Fisheries and Forestry

Project Title

Effect of irradiation on the nutritional profile and postharvest fruit quality of sweet cherry fruit.
Part of MT10057 Phase 2 Final Report (includes apple, apricot, cherry, peach, plum and table grapes).

The Report is presented in two parts.

Part A: Nutritional analysis
Part B: Postharvest fruit quality

Project Leaders

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF), Queensland
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF), Queensland
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Market Access Focus Team Leader
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF), Queensland
P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

[REDACTED] Research Scientist, DAFF Qld
[REDACTED], Research Scientist, DAFF Qld
[REDACTED] Senior Biometrician, DAFF Qld
[REDACTED] Market Access Focus Team Leader, DAFF Qld

Technical Personnel

[REDACTED] Technical Officer, DAFF Qld

Funding Sources


Horticulture Australia Limited (HAL)
Queensland Department of Agriculture, Fisheries and Forestry
Australian Government, Department of Agriculture, Fisheries and Forestry

Date of Report

January 2013

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.

 Leader, Radiation Technology
Senior Technical Officer, Radiation Technology
Technical Officer, Radiation Technology
Technical Officer, Radiation Technology

© State of Queensland, 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Contents

Executive Summary	5
 Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of sweet cherry (<i>Prunus avium</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis	12
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation	32
References	34
 Part B. Effect of gamma irradiation on the postharvest quality of sweet cherry (<i>Prunus avium</i>) fruit.	37
Summary	38
Introduction	39
Materials and methods	40
Experimental layout	40
Fruit Quality Assessments	40
Statistical analysis	41
Results and Discussion	42
Recommendations	45
References	46

Executive Summary

Nutrition and fruit quality evaluations were conducted on sweet cherry (*Prunus avium*) fruit, variety 'Stella', after being treated with gamma irradiation and following a recommended cold storage period of 14 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy, with fruit evaluations conducted after irradiation treatment and after cold storage.

The nutritional study found that the storage treatment had a greater impact on sweet cherry nutrition than that of irradiation. As a result, storage for 14 days reduced ascorbic acid and beta carotene levels and increased protein and ash content which were associated with a senescence response. Only minor changes occurred as a result of irradiation, with a slight decline measured in ascorbic acid and beta carotene levels, particularly only at 600 Gy. Overall, low dose irradiation did not cause any detrimental impact on nutritional quality.

In the postharvest quality study, sweet cherry fruit quality was impacted only by storage time and not by irradiation. In this case, storage time had a small impact on the skin colour (lightness values) of sweet cherry with fruit becoming slightly darker shade during storage. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit. The findings suggest that an application of up to 1 kGy would not result in any detrimental damage to the quality of sweet cherry fruit

Part A. Effect of low dose gamma (γ)– irradiation on the nutritional profile of sweet cherry (*Prunus avium*) fruit.

Contents

Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of sweet cherry (<i>Prunus avium</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis.....	12
Moisture. Method VL298 Version 6.2	12
Ash. Method VL286 Ver. 5.1	13
Protein. Method VL299 Protein	13
Dietary Fibre.....	14
Fat. Method VL302_Fat by Mojonnier	14
Fatty Acid Profile. Method VL 289 Fatty Acid Profile.....	15
Sugars. Method VL295_Common Sugars.....	15
Sodium. Method VL247.....	16
Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages	16
Calculation of Energy and Carbohydrates in Food. Method VL 412	17
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs.....	17
Limits of Reporting	18
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation.....	32
References	34

Summary

This report examines the radio-tolerance of sweet cherry (*Prunus avium* L.) at doses at and below 1 kGy for the purposes of quarantine disinfestation. The study provides an analysis of data on the nutritional profile of sweet cherry, variety 'Stella' irradiated with 0, 150, 600 and 1000 Gy and assessed on two occasions.

The nutritional profile analysed included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

In this study, fresh sweet cherry fruits are high in moisture (>86%), and low in protein and fat. Compositions of fruit can vary according to variety, cultivation practices, environment and weather, but also change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

The nutritional quality of sweet cherry fruit was affected by storage rather than by irradiation itself. The changes observed were attributed to processes associated with ripening or senescence during cold storage. The study shows that sweet cherry can be treated with gamma irradiation ≤ 1 kGy with little or no nutritional quality loss. There were no interactions between dose level and storage time detected in any of the proximate and chemical components tested. Specifically, a main effect of dose was not detected in beta-carotene just after irradiation and mean Vitamin C (total ascorbic acid). Storage for 14 days resulted in lower beta-carotene level in 'Stella' cherries while increases in ash and protein were detected.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of sweet cherry.

Introduction

There is an increasing trend to centrally process fresh fruits, suitably packaged, for distribution and marketing. Irradiation technology proved to be effective in reducing postharvest losses, delaying ripening and prolonging fruit shelf life. Fruit maturity, cultivar, environmental conditions, postharvest handling, storage temperature, and the use of controlled atmosphere storage have all been reported to influence such fruit responses to irradiation (Lee and Kader 2000, Maxie and Abdel-Kader 1966, Miller and McDonald 1999, Mitchell *et al.* 1992) but few reports are available on the effects of irradiation on the nutritional and proximate qualities.

Quality loss in irradiated sweet cherry is small compared to the more conventional means of methyl bromide (MeBr) disinfestation that can result in considerable quality loss (Drake *et al.* 1991). Parveen and Mir (2011) reported that the quality of the cherry variety 'Misri' or 'Double' shrink-wrapped and gamma irradiated at 1.2 kGy showed little quality loss compared to untreated cherry after 28 days of refrigerated storage ($3\pm 1^{\circ}\text{C}$, RH $85\pm 5\%$). The reducing sugars glucose and fructose detected in cherry were not affected by increasing irradiation doses up to 5 kGy although during storage fructose increased while glucose decreased (Kovacs *et al.* 1995). Jessup (1990) and Drake *et al.* (1994) reported that sweet cherry showed minimal quality loss after being irradiated for disinfestation.

The Interstate Certification Assurance (ICA) scheme is a national system of plant health certification which provides for a harmonised approach to the audit and accreditation of businesses throughout Australia and the mutual recognition of plant health assurance certificates accompanying consignments of produce moving intrastate or interstate. ICA-55 in the state of Queensland was developed to meet the requirements of State and Territory governments in Australia for the certification of irradiated fruit fly host produce for interstate and intrastate quarantine purposes. However, only fresh fruit and vegetables approved in the Food Standard Australia New Zealand (FSANZ) Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) can be certified under this Operational Procedure. There are currently ten commodities that are approved to be irradiated for pest disinfestation purposes and the minimum and maximum doses permitted are 150 Gy and the maximum is 1 kGy respectively. The 150 Gy minimum dose is a generic dose for fruit fly which is an internationally approved treatment (International Standard for Phytosanitary Measures ISPM No.28, Annex 7 2009).

The effects of low dose irradiation and cold storage were investigated on the sweet cherry variety 'Stella', in order to assess their effects on fruit nutritional quality. Export quality fresh whole produce were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation on apple. This work will also compliment current findings from the postharvest fruit quality component of this study described later in this report.

Materials and Methods

Cultivar

Whole, fresh cherry fruit were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of cherries was carried out on 5th December 2011. The sweet cherry (*Prunus avium* L.) variety tested is the mid-season variety 'Stella'. The fruit is red-dark red, large and heart-shaped. The flesh is black, moderately firm and the variety is fairly susceptible to cracking (New South Wales Agriculture 2004).

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 0°C. Prior to treatment fruit were visually inspected to ensure only cherries with intact stem and no damage were treated. The fruit were randomly selected and carefully packed, with liners, in 2 kg cherry cardboard boxes which fitted into the stainless steel irradiation chamber for treatment (Fig 1).

Irradiation treatment

The samples were exposed to target irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy from a Co^{60} source of gamma irradiation. One 2 kg box of cherries was treated for each dose. For proximate and nutritional analyses 0.5 kg fruit was used at each assessment time.

There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 21.6–22.0°C. The boxes of cherry were positioned on a rig parallel to the plaque source (Figure 1).

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing (ANSTO, 2011).

The irradiation doses were measured by placing Fricke dosimeters throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front and between fruits within the carton (Figure 1). Additional dosimeters were attached to the outside of each package for monitoring and to provide references to the minimum and maximum doses.

The effects of irradiation were measured at two stages: after irradiation treatment (Time 1; one day after irradiation treatment) and after 14 days of cold storage set at 0°C (Time 2).

Following irradiation treatment, the fruit were repacked into 0.5 kg bags and sent for chemical analysis and fruit quality assessment. Time 2 fruit were placed in cold storage at the recommended storage temperature until testing commenced.



Figure 1. Cherry fruit packed in a lined 2 kg cardboard cherry carton ready for irradiation treatment. Dosimeter(s) situated inside the carton of fruit and on outside of cartons for monitoring doses received within the box.
Source: Radiation Technology, ANSTO.

Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat profile, moisture, sodium, protein, total sugars, Vitamin C (ascorbic acid) and Vitamin A (beta-carotene) by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the two occasions, after treatment and after a period in cold storage at 0°C. The first assessment was a day after mean irradiation treatment and the second analysis at the end of the recommended storage period of 14 days.

Edible portions of each fruit were blended at each time point. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s): AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1 mg.

2 to 5 gram of sample is weighed, to nearest 0.1 mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1 mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1 mg, into the dish. The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s): AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to 525°C ± 25°C until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2 g) is accurately weighed into a Kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20 ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50 ml distilled water is added. The tube is placed in a Kjelttec distillation unit and the mixture is steam distilled into a beaker containing

50ml of saturated boric acid solution. The distilled solution is titrated with standardised 0.1 N sulphuric acid solution using a mixed indicator of bromcresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre.

Reference Method: AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s): AS 2300.1.3. AOAC 16th Edition 954.02, 948.15, 922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2 g) is accurately weighed into a beaker.

10 ml of approx. 10 % hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10 ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25 ml of diethyl ether and a further minute with each of 25 ml of petroleum ether and 50 ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102°C until constant weight is achieved.

Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish}}{\text{Weight of sample}} \times 100$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", Can. J. Biochem. Physiol. 37: 911-917.

Badings and Dejong (1983). J. Chrom. 279: 493-506.

McCance and Widdowson (1991). The Composition of Foods. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10 g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2 g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and re-extracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s): AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45 µm filter into a 2 ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s):

1. USEPA (United States Environmental Protection Agency) Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2–0.5 g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase.

Absorbance is measured by PDA detection at 245 nm, the PDA spectra (220 to

350 nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL 412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code (2011).

Carbohydrate Calculation:

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation:

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference Method: CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5 g of sample is accurately weighed into a 250 ml flask and 60 ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500 ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes; each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10 ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450 nm, the PDA spectra (250 to 650 nm) is used as confirmation. Determination is made against a known β - Carotene standard, whose concentration is determined by absorbance measurements.

Limits of Reporting

The laboratory standard normally only contains the compound or compounds of interest, in the optimal calibration range. It is also in a medium that does not interfere with and/or enhance the performance of the analytical instrument. It is under these ideal conditions that the lowest concentration can be reported, while minimising uncertainty due to matrix effects. This concentration is the limit of detection of the method. Other non-targeted compounds and constituents can interfere with the sample analysis, and the corrected concentration is reported (limit of reporting).

Limits of reporting for the various components tested are tabled below.

Analysis / Analyte	Limit of reporting; LOR (generally 1–5 times the limit of detection)
Vitamin C (L-ascorbic acid)	1 mg/100g
Beta-carotene	5 µg/100g
Ash	0.1 g/100g
Carbohydrates	2 g/100g (calculated by difference)
Dietary fibre	0.05 g/100g
Energy	Calculation
Fat	0.2 g/100g
Moisture	0.2 g/100g
Saturated fat	0.10 %
Trans fat	0.10 %
Mono-saturated fat	0.10 %
Polysaturated fat	0.10 %
Protein	0.2 g/100g
Sodium	10 mg/kg
Total sugars	1 g/100g
Fructose	0.2 g/100g
Glucose	0.2 g/100g
Lactose	0.2 g/100g
Maltose	0.2 g/100g
Sucrose	0.2 g/100g

If the limit of reporting, say for example, for beta-carotene in the methodology used is 5 µg/100g that value means that the laboratory can measure with reasonable accuracy at this level. Any level below the accuracy is not that good and the measurement of uncertainty below the limit of reporting, for example for beta-carotene in the methodology used is 26%.

Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level using GenStat for Windows 14th Edition (VSN International 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed by analysis of variance (ANOVA) separately, as well as a 2-way factorial ANOVA to investigate the time by dose interaction. Where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD).

Where all or the majority of data was censored (below the level of reporting) the data could not be analysed. For total ascorbic acid there were a minority of values censored and the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not underestimated.


Results and Discussion

Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required; 0, 150, 600 and 1000 Gy. The average irradiation dose absorbed complies with the required specifications of the study. The Irradiation Report is presented in the section below and reports minimum, maximum and average absorbed doses.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke.

The applied dose rate was approximately 13.1 Gy/min. Irradiation temperature was 21.6–22.0°C.


Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>


1 February 2012


Irradiation Report

ANSTO Reference	11-1942
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	PO 4550048627

ANSTO Ref: 11-1942

SRT F 004

Prepared 

Authorised 

Date 1.2.2012

Page 1 of 5

Product Details	
Product	Cherries
Quantity	32 Boxes
Irradiation Conditions	
Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	5 December 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 13.1 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F226
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	21.6 to 22.0 °C

ANSTO Ref: 11-1942		SRT F 004	
Prepared	Authorised	Date	Page 2 of 5
[Redacted]	[Redacted]	1.2.2012	

The boxes of cherries that were received for processing were divided into four lots and identified for each target dose of 0, 150, 600 & 1000Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited within the boxes at the front and in between the cherries, refer to Figure 1. Additional dosimeters were attached to the outside of one tray to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600Gy & 1000Gy samples from the first lot (R1) were used to carry out a dose mapping exercise at approximately 200Gy. The locations of minimum and maximum doses were found and dose mapping was repeated twice with dosimeters at those locations, for 200Gy dose each irradiation. This dose mapping information was used to process these samples and the remaining boxes of cherries to their target doses. Fricke dosimeters were used in the reference position at the appropriate dose levels to monitor each irradiation.

Figure 1



Box showing dosimeters in between the cherries and on top of cherries.

ANSTO Ref: 11-1942

SRT F 004

Prepared

Authorised

Date

Page 3 of 5

1.2.2012

Figure 2



Boxes positioned for irradiation and dosimeters in monitoring position.

Results for Replicate 1

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	150 ± 8	153 ± 7	151 ± 5
600	598 ± 7	610 ± 7	604 ± 5
1000	996 ± 23	1017 ± 22	1006 ± 16

Results for Replicate 2

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	149 ± 7	152 ± 7	150 ± 5
600	587 ± 21	600 ± 20	594 ± 14
1000	984 ± 25	1004 ± 24	994 ± 18

ANSTO Ref: 11-1942

SRT F 004

Prepared

Authorised

Date

Page 4 of 5

1.2.2012

Results for Replicate 3

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	151 ± 8	154 ± 7	152 ± 5
600	594 ± 21	606 ± 20	600 ± 15
1000	992 ± 26	1013 ± 24	1003 ± 18

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 % for Fricke. The above results include the uncertainties in the dose mapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both product complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: 11-1942

SRT F 004

Prepared

Authorised

Date

Page 5 of 5

1.2.2012

Nutritional components

High quality, sweet cherry, variety 'Stella' were treated with gamma irradiation and the samples were analysed at two occasions; the first analysis (Time 1) was one day after irradiation treatment and the second analysis (Time 2), after 14 days storage in a cold room set at 0°C.

There were no significant dose by time interactions detected in any of the nutritional components measured (Table 1). Of the nutrient components tested that were affected, these changes were more responsive to storage time than gamma irradiation. Significant dose effects were detected in beta-carotene and protein content while a significant effect of time was found in beta-carotene, protein and ash.

Overall, irradiation at all test doses did not affect the nutritional quality of cherry. The nutritional components of fresh whole cherry were not negatively affected by low dose irradiation (150 Gy, 600 Gy and 1000 Gy) compared with the control sample after irradiation treatment.

After 14 days cold storage, the responses in changes in beta-carotene, protein and ash varied. A decrease in beta-carotene was observed after storage while increases were found in ash and protein.

The effects of irradiation dose on the components at each time are summarised in Table 2 and Table 3.

No significant dose effects were found at Time 1 (Table 2) for all the nutritional components tested. Irradiation had no significant effects on ash, carbohydrates, dietary fibre, energy, fat profile, moisture, sodium, protein, total sugar, fructose, glucose and Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene). With the exception of beta-carotene, no significant dose effects were found in all the nutritional components at Time 2 (14 days cold storage) (Table 3). Drake and Neven (1997) reported that irradiation reduced storage rot and delayed ripening in sweet cherry fruit.

While no significant main effect of dose in beta-carotene was detected at Time 1 (Table 2), a significant dose effect was found in beta-carotene at Time 2 (Table 3). The responses however were not consistent and did not appear to have any biological effect. A significant time effect was observed, with beta-carotene decreasing by around 12%, from a mean of 20.3 µg/100g at Time 1 down to 17.8 µg/100g at Time 2 (Table 1). The decrease was smallest in the 1000 Gy sample and largest in the 600 Gy sample.

In apricots (Katayama *et al.* 1971), honeydew melon (Reid *et al.* 1970) and papaya (Wilberg and Rodriguez-Amaya, 1995), ripening is accompanied by carotenoid biosynthesis. Beta-carotene levels in peppers (*Capsicum annuum* L.) were also found to increase with maturity, at the green and red stages of maturity (Howard *et al.* 1994). In contrast, storage of mango at 7 to 20°C for 16 to 43 days caused a substantial reduction in the total carotenoid content even when the fruits were subsequently ripened at optimal conditions (Thomas and Janave 1975).

The major cause of carotenoid loss is enzymatic and non-enzymatic oxidation and is stimulated by light, heat, some metals, enzymes and peroxides and is inhibited by antioxidants. Carotenoid degradation is known to increase with the destruction of the food cellular structure, severity of the processing conditions, storage time and temperature, transmission of light and permeability to oxygen of the packaging (Rodriguez-Amaya and Kimura 1999, Rodriguez-Amaya 2010)

Fresh untreated cherry contained a mean of 20.3 µg/100g beta-carotene and the irradiated samples ranged between 19.0 µg/100g and 21.3 µg/100g at Time 1 (Table 2). After 14 days storage at 0°C, a mean of 18.0 µg/100g beta-carotene was found in the control sample and the irradiated samples ranged between 15.0 µg/100g and 20.7 µg/100g at Time 2 (Table 3). A mean of 56 µg/100g beta-carotene is reported in NUTTAB (Nutrient Tables for Use in Australia) (Food Standards Australia New Zealand 2010). The USDA reports a mean of 38 µg/100g in raw sweet cherry. The lower level of beta-carotene reported in this study may be due to different variety tested, the degree of stage of maturity of the fruit, the condition of ripeness, cultivation practices, postharvest handling, transport and storage conditions.

Vitamin C (total ascorbic acid), fat and sucrose were below the reporting levels at both assessment times. We report a mean Vitamin C (total ascorbic acid) of 0.91 mg/100 for all treatments after irradiation treatment, which declined to a mean of 0.53 mg/100g after 14 days cold storage. The level of ascorbic acid in cherry reported in NUTTAB (FSANZ 2010) is 19 mg/100 g and 7 mg/100g in the USDA database (2010). Our fruit handling procedures and temperature variation during transportation between facilities may have contributed to the lower levels detected as losses are accelerated at higher temperatures (Lee and Kader 2000). Review of analytical records found no error in analysis and all duplicates, controls and spike recoveries were found within the acceptable criteria. Although content of Vitamin C in fruits can be influenced by cultivar, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures, temperature management after harvest is the most important factor to maintain Vitamin C in fruits (Lee and Kader, 2000).

In other studies, no significant differences in ascorbic acid were found between control sweet cherry fruit and fruit irradiated at 300 Gy (Akbulak *et al.* 2008). On the other hand, the highest ascorbic acid value was recorded in fruit stored under controlled atmosphere and gamma irradiation in a study investigating storage at six different atmosphere combinations for up to 60 days after being exposed to gamma irradiation (Akbulak *et al.* 2008).

In this study, the ash content in untreated cherry fruit was 0.43 g/100g and between 0.43 and 0.50 g/100g in irradiated fruit after treatment which is in the normal range reported elsewhere. A mean of 0.5 g/100g ash is reported in NUTTAB (FSANZ 2010) and a mean of 0.48 g/100g in raw sweet cherry by the USDA (2010). Ash content increased with storage time, with the largest increase (almost doubled) observed in the untreated sample (Table 1), from 0.43 g/100g to 0.80 g/100g. The irradiated samples increased between 15–50%, between 0.50 and 0.67 g/100g.

Overall, protein increased from a mean of 0.87 g/100g just after irradiation to 1.00 g/100g after 14 days cold storage (Table 1) in the untreated sample and from 0.97, 0.93 and 0.77 g/100g to 1.20, 1.03 and 0.87 g/100g in the 150, 600 and 1000 Gy

samples respectively. The protein levels are within the levels reported by FSANZ (2010) which is 0.8 g/100g and 1.06 g/100g by the USDA (2010).

There were little or no changes in carbohydrates, glucose and fructose across all samples and after 14 days cold storage.

All sodium samples were less than 0.65 mg/100g, except for one 150 Gy sample which contained nearly 10 times the sodium content compared to the mean. The differing sample could have been caused by anomalies of measurement or sampling.

No dose and time interactions or main effects of irradiation dose and time were found for carbohydrates, fructose and glucose in this study. Similarly, carbohydrates (sucrose, glucose, fructose and sorbitol) were not influenced by irradiation treatment in 'Rainier' cherry, irradiated at 0 Gy, 0.15 Gy, 0.30 Gy, 0.60 Gy and 0.90 Gy using a linear accelerator (Drake and Neven 1997). Kovacs *et al.* (1995) irradiated 'Germersdorfi' cherry at 1 kGy, 2.5 kGy and 5 kGy and found that the quantity of the sugars, glucose and fructose, did not change with increasing dose. During storage at 3–5°C for 19 days fructose concentration decreased while glucose concentration increased.

In this study, the changes in mean values are thought to be responses from general fruit senescence. Ripening in cherry harvested when mature is accompanied by a rapid rise in respiration rate, followed by a slowing down as the fruit ripens and develops good eating quality. Ripeness is followed by senescence and breakdown of the fruit, which is the normal aging of produce. Different outcomes in nutritional quality after similar treatments can occur between different varieties of the same fruit, as noted by Thomas (1988), Morris and Jessup (1994) and Lee and Kader (2000). The overall postharvest fruit quality of irradiated cherry was reported to be better than methyl bromide treated cherry (Neven and Drake 2000).

This study showed that low irradiation doses (150 Gy–1 kGy) (combined with cold storage) overall, does not result in significant cherry nutritional quality losses one day after treatment and after the storage period studied.

The quality of 'Ron's Seedling', 'American Bing', and 'Lambert' sweet cherry was not affected by irradiation doses of 1 kGy (Jessup 1990). The author also demonstrated that a dose of 75 Gy prevented adult eclosion of more than 1300 Queensland fruit fly (*B. tryoni*, Froggatt) with the third instar larvae being the least susceptible to gamma irradiation. The results indicate that a dose of 75 Gy could provide quarantine security against eggs and larvae of *B. tryoni* in cherries. Toba and Moffitt (1996) reported that a dose of 233 Gy prevented pupation of fifth instar larvae of codling moth (*Cydia pomonella* L.) while Burditt and Hungate (1988) showed that a dose of 97 Gy controlled western cherry fruit fly (*Rhagoletis indifferens* L.).

Table 1. A factorial analysis investigating the time by dose interaction 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Ascorbic Acid* (mg/100g)	0	0.77	0.53	0.65 ^a	Time	0.003	0.051
	150	0.67	0.53	0.60 ^a	Irrad Dose	0.008	0.072
	600	0.47	0.30	0.38 ^b	Time x Irrad.	0.908	0.101
	1000	0.73	0.53	0.63 ^a			
	Mean	0.66 ^a	0.47 ^b				
Ash (g/100g)	0	0.43	0.80	0.62	Time	0.003	0.052
	150	0.50	0.57	0.53	Irrad Dose	0.284	0.074
	600	0.43	0.67	0.55	Time x Irrad.	0.168	0.104
	1000	0.43	0.50	0.47			
	Mean	0.45 ^b	0.63 ^a				
Beta Carotene (ug/100g)	0	20.3	18.0	19.2 ^{ab}	Time	0.015	1.87
	150	20.3	17.7	19.0 ^{ab}	Irrad Dose	0.043	2.64
	600	19.0	15.0	17.0 ^b	Time x Irrad.	0.614	3.74
	1000	21.3	20.7	21.0 ^a			
	Mean	20.3 ^a	17.8 ^b				
Carbohydrates (g/100g)	0	11.3	11.0	11.2	Time	1.000	0.313
	150	11.3	11.3	11.3	Irrad Dose	0.056	0.443
	600	10.0	10.3	10.2	Time x Irrad.	0.902	0.627
	1000	11.3	11.3	11.3			
	Mean	11.0	11.0				
Energy (kJ/100g)	0	210.0	210.0	210.0	Time	0.349	6.02
	150	213.3	220.0	216.7	Irrad Dose	0.120	8.51
	600	190.0	200.0	195.0	Time x Irrad.	0.946	12.04
	1000	206.7	213.3	210.0			
	Mean	205.0	210.8				
Fructose (g/100g)	0	3.87	3.90	3.88	Time	1.000	0.188
	150	4.03	4.07	4.05	Irrad Dose	0.235	0.265
	600	3.77	3.80	3.78	Time x Irrad.	0.931	0.375
	1000	3.93	3.83	3.88			
	Mean	3.90	3.90				
Glucose (g/100g)	0	6.27	6.13	6.20	Time	0.247	0.138
	150	6.43	6.27	6.35	Irrad Dose	0.194	0.195
	600	5.97	5.93	5.95	Time x Irrad.	0.891	0.276
	1000	6.50	6.17	6.33			
	Mean	6.29	6.13				
Moisture (g/100g)	0	86.83	86.47	86.65	Time	0.388	0.722
	150	86.43	86.27	86.35	Irrad Dose	0.196	1.021
	600	87.60	87.23	87.42	Time x Irrad.	0.996	1.444
	1000	86.90	86.60	86.75			
	Mean	86.94	86.64				

Time and dose means within a component followed by the same letter are not significantly different.

*Total ascorbic acid data presented are at limits of detection.

Table 1 contd. A factorial analysis investigating the time by dose interaction using a 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Protein (g/100g)	0	0.87	1.00	0.93 ^{bc}	Time	0.009	0.047
	150	0.97	1.20	1.08 ^a	Irrad Dose	0.010	0.066
	600	0.93	1.03	0.98 ^{ab}	Time x Irrad.	0.719	0.094
	1000	0.77	0.87	0.82 ^c			
	Mean	0.88 ^b	1.03 ^b				
Sodium# (mg/100g)	0	0.470	0.369	0.416	Time	0.062	0.0814
	150	0.971	0.369	0.599	Irrad Dose	0.329	0.1151
	600	0.468	0.465	0.467	Time x Irrad.	0.344	0.1627
	1000	0.426	0.314	0.366			
	Mean	0.549	0.376				
Total Dietary Fibre (g/100g)	0	0.70	0.80	0.75	Time	0.187	0.066
	150	0.83	0.90	0.87	Irrad Dose	0.546	0.093
	600	0.83	0.90	0.87	Time x Irrad.	0.981	0.132
	1000	0.73	0.87	0.80			
	Mean	0.78	0.87				
Total Sugars (g/100g)	0	10.20	10.03	10.12	Time	0.718	0.226
	150	10.23	10.27	10.25	Irrad Dose	0.369	0.320
	600	9.73	9.73	9.73	Time x Irrad.	0.977	0.452
	1000	10.33	10.13	10.23			
	Mean	10.12	10.04				

Time and dose means within a component followed by the same letter are not significantly different.

C = majority of the data is censored.

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

Table 2. Mean chemical measurements in 'Stella' sweet cherry fruit after irradiation treatment (Time1).

Time 1 Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid (mg/100g)	0.77 (0.153)	0.67 (0.289)	0.47 (0.058)	0.73 (0.153)	0.164	0.006
Ash (g/100g)	0.43 (0.058)	0.50 (0.173)	0.43 (0.058)	0.43 (0.058)	0.802	0.082
Beta Carotene (ug/100g)	20.3 (0.58)	20.3 (0.58)	19.0 (2.65)	21.3 (2.52)	0.497	1.43
Carbohydrates (g/100g)	11.3 (0.58)	11.3 (1.53)	10.0 (0.00)	11.3 (0.58)	0.318	0.782
Energy (kJ/100g)	210.0 (10.00)	213.3 (25.17)	190.0 (0.00)	206.7 (11.55)	0.403	13.68
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	3.87 (0.208)	4.03 (0.351)	3.77 (0.058)	3.93 (0.058)	0.535	0.177
Glucose (g/100g)	6.27 (0.379)	6.43 (0.513)	5.97 (0.115)	6.50 (0.000)	0.302	0.273
Moisture (g/100g)	86.83 (0.569)	86.43 (1.290)	87.60 (0.173)	86.90 (0.600)	0.472	0.701
Protein (g/100g)	0.87 (0.115)	0.97 (0.058)	0.93 (0.058)	0.77 (0.058)	0.070	0.062
Sodium (mg/100g) #	0.470 (0.0200)	0.971 (1.7871) [®]	0.468 (0.0851)	0.426 (0.1222)	0.416	0.2233
Sucrose (g/100g)	C	C	C	C		
Total Dietary Fibre (g/100g)	0.70 (0.173)	0.83 (0.153)	0.83 (0.306)	0.73 (0.231)	0.634	0.125
Total Sugars (g/100g)	10.20 (0.700)	10.23 (0.681)	9.73 (0.153)	10.33 (0.577)	0.571	0.442

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

[®]Contains a sodium value of 3.6

*Total ascorbic acid data presented are at limits of detection.

Table 3. Mean chemical measurements in untreated and irradiated 'Stella' sweet cherry fruit after 14 days cold storage at 0°C (Time 2).

Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid (mg/100g)	0.53 (0.208)	0.53 (0.252)	0.30 (0.100)	0.53 (0.115)	0.210	0.115
Ash (g/100g)	0.80 (0.300)	0.57 (0.058)	0.67 (0.153)	0.50 (0.100)	0.097	0.101
Beta Carotene (ug/100g)	18.0 ^{ab} (1.00)	17.7 ^{ab} (2.89)	15.0 ^b (1.00)	20.1 ^a (2.89)	0.023	1.26
Carbohydrates (g/100g)	11.0 (1.00)	11.3 (0.58)	10.3 (0.58)	11.3 (0.58)	0.285	0.53
Energy (kJ/100g)	210.0 (20.00)	220.0 (10.00)	200.0 (10.00)	213.3 (15.28)	0.455	11.79
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	3.90 (0.361)	4.07 (0.289)	3.80 (0.100)	3.83 (0.153)	0.577	0.198
Glucose (g/100g)	6.13 (0.551)	6.27 (0.404)	5.93 (0.115)	6.17 (0.379)	0.768	0.318
Moisture (g/100g)	86.47 (1.332)	86.27 (0.777)	87.23 (0.231)	86.60 (0.700)	0.585	0.705
Protein (g/100g)	1.00 (0.000)	1.20 (0.173)	1.03 (0.153)	0.87 (0.153)	0.179	0.128
Sodium (mg/100g)	0.377 (0.0961)	0.370 (0.0300)	0.477 (0.1301)	0.317 (0.0473)	0.331	0.0797
Sucrose (g/100g)	C	C	C	C		
Total Dietary Fibre (g/100g)	0.80 (0.000)	0.90 (0.100)	0.90 (0.173)	0.87 (0.115)	0.745	0.103
Total Sugars (g/100g)	10.03 (0.907)	10.27 (0.643)	9.73 (0.208)	10.13 (0.757)	0.776	0.525

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Recommendation

The overall findings of this study show that an irradiation application of up to 1 kGy will not result in any significant detrimental damage to the nutritional quality of sweet cherry fruit cv. 'Stella'. The effect of storage time was greater than by irradiation itself and where significant responses were observed and the changes generally appeared to be associated with the senescence process during storage.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of cherry.

References

- Akbudak, B., Tezcan, H. and Eris, A. (2008). Effect of low dose irradiation on the quality of sweet cherry during storage. *Italian Journal of Food Science* 20: 381–390.
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Burditt, A.K. and Hungate, F.P. (1988). Gamma irradiation as a quarantine treatment for cherries infested by western cherry fruit fly (Diptera: Tephritidae). *Journal of Economic Entomology* 81: 859–862.
- Drake, S.R. and Neven, L.G. (1997). Quality response of 'Bing' and 'Rainier' sweet cherries to low dose electron beam irradiation. *Journal of Food Processing and Preservation* 21: 345–351.
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database. <http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339. <http://www.comlaw.gov.au/Details/F2010C00339>
- Howard, L.R., Smith, R.T., Wagner, A.B., Villalon, B. and Burns, E.E. (1994). Provitamin A and Ascorbic Acid Content of Fresh Pepper Cultivars (*Capsicum annuum*) and Processed Jalapenos. *Journal of Food Science* 59 (2): 362–365.
- ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009). https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Jessup, A.J. (1990). Gamma Irradiation as a Quarantine Treatment for sweet cherries against Queensland Fruit Fly. *HortScience* 25 (4): 456–458.
- Kader, A. A. (1988). Influence of preharvest and postharvest environment on nutritional composition of fruits and vegetables. In: B. Quebedeaux, & F. A. Bliss (Eds.), *Horticultural and human health: Contributions of fruits and vegetables*. Proceedings of the first International Symposium on Horticulture and Human Health (pp. 18–32). Englewood Cliffs, NJ: Prentice-Hall.
- Kamali, A.R., Maxie, E.C. and Rae, H.L. (1972). Effect of Gamma Irradiation on 'Fuerte avocado fruits. *HortScience* 4 (2): 125–126.
- Katayama, T., Najayama, T., Lee T.H. and Chichester C.O. (1971). Carotenoid transformations in ripening apricots and peaches. *Journal of Food Science* 36: 804–806.

- Kovacs, E., Balla, G and Nessinger, A. (1995). The effect of irradiation on sweet cherries. *Acta Alimentaria*, Vol.24 (4), pp. 331–343.
- Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207–220.
- Maxie, E. C. and Abdel-Kader, A. (1966). Food irradiation — physiology of fruits as related to feasibility of the technology. *Advances in Food Research* 15: 05–145.
- Miller, W.R. and McDonald, R.E. (1999). Irradiation, storage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience* 24: 1112–1115.
- New Zealand FOODFile 2010 Version 2. <http://www.foodcomposition.co.nz/foodfiles>
- Neven, L.G. and Drake, S.R. (2000). Comparison of alternative postharvest quarantine treatments for sweet cherries. *Postharvest Biology and Technology* 20: 107–114.
- Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Reid, M. S., Lee, T.H., Pratt, H.K. and Chichester, C.O. (1970). Chlorophyll and carotenoid changes in developing muskmelons. *Journal of the American Society for Horticultural Science* 95: 814–815.
- Rodriguez-Amaya, D. B. (2010). Critical review. Quantitative analysis, in vitro assessment of bioavailability and antioxidant activity of food carotenoids—A review. *Journal of Food Composition and Analysis* 23: 726–740.
- Rodriguez-Amaya, D.B. and Kimura, M. (1999). Harvest Plus Handbook for carotenoid analysis. HarvestPlus Technical Monograph 2. Washington, DC and Cali: International Food Policy Research Institute (IFPRI) and International Center for Tropical Agriculture (CIAT). 63pp.
- Taylor, J. (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35–43.
- Toba, H.H. and Moffitt, H.R. (1996). Post treatment development and fertility of nondiapausing codling moth (Lepidoptera: Tortricidae) larvae and their progeny following gamma irradiation. *Journal of Economic Entomology* 89: 56–62.
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website, <http://www.nal.usda.gov/fnic/foodcomp/search/>
- VSN International. (2011). GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK. Web Page: GenStat.co.uk

Wilberg, V. C. and Rodriguez-Amaya, D.B. (1995). HPLC quantitation of major carotenoids of fresh and processed guava, mango and papaya. *Lebensmittel-Wissenschaft und-Technologie* 28:474-480.

Part B. Effect of gamma irradiation on the postharvest quality of sweet cherry (*Prunus avium*) fruit.

Contents

Part B. Effect of gamma irradiation on the postharvest quality of sweet cherry (<i>Prunus avium</i>) fruit.	37
Summary	38
Introduction	39
Materials and methods	40
Experimental layout	40
Fruit Quality Assessments	40
Fruit colour	40
Moisture loss and whole fruit softness	40
Biochemical analyses	41
Fruit disease and disorders	41
Statistical analysis	41
Results and Discussion	42
Recommendations	45
References	46

Summary

Fruit quality evaluations were conducted on sweet cherry (*Prunus avium*), variety 'Stella', after being treated with gamma irradiation and following a recommended cold storage period of up to 14 days. Gamma irradiation treatments consisted of a dose of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that quality of sweet cherry fruit was impacted more by storage time than by irradiation itself. In this case, irradiation had no effect on the amount of moisture fruit lost during storage, averaging less than 1% over the 14 day cold storage period. Similarly, there were also no differences in fruit firmness (mean 2.2 N), total soluble solids (mean 13.3%), titratable acidity (0.49% citric acid), and several skin colour values (mean chroma: 24.7, hue angle: 14.6) before and after cold storage or between any of the irradiation doses (including control fruit). There was however a slight trend, although not significant, towards increased stem (peduncle) browning with higher doses of irradiation. Storage time also had a small impact on the skin colour (lightness values) of sweet cherry with fruit becoming slightly darker shade following storage. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit. In conclusion, the findings of study suggest that an application of up to 1 kGy did not result in any detrimental damage to the quality of sweet cherry fruit.

Introduction

The present study aims to investigate the effects of gamma irradiation on the postharvest quality of sweet cherry (*Prunus avium*) fruit. Gamma irradiation is regularly used not only for disinfestation purposes but also to control for decay and extend the storage and shelf life of perishable commodities (Mitchell *et al.* 1992). Past work has shown that in general sweet cherry fruit have a relatively high tolerance to ionizing radiation below 1 kGy in comparison with other fruit and vegetable types (Kader 1986). Drake *et al.* (1994), for example, demonstrated that fruit treated to doses of up to 1 kGy and stored for up to 21 days exhibited no significant changes in various fruit quality attributes, such as in fruit and stem colour, soluble solids, titratable acidity or sensory characteristics. Even at a dose between 1 and 2.5 kGy, fruit quality attributes such as skin colour, sugar contents were unaffected (Kovacs *et al.* 1995). Fruit firmness, however, was found in several studies to be impacted by irradiation, with firmness levels decreasing significantly above 0.4 kGy (Drake *et al.* 1994, Kovacs *et al.* 1995). However, as noted by several authors (Kader 1986, Mitchell *et al.* 1992), responses to irradiation can vary widely between variety, harvest maturity, growing conditions and or geographic location.

In the present study, the effects of irradiation and cold storage duration were therefore examined on Australian grown sweet cherry fruit (var. 'Stella') to assess their effects on fruit quality following irradiation and a subsequent cold storage period. Fruit assessments entailed measurements of physico-chemical changes in fruit quality. The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation (at and below 1 kGy) on a variety grown and marketed under Australian conditions. This work will also compliment current findings from the nutritional component of this study described earlier in this report, which also incorporated fruit selected from the same irradiation and cold storage treatments as in this study.

Materials and methods

Experimental layout

Sweet cherry (*Prunus avium*) fruit, variety 'Stella', were sourced from the Sydney Markets, NSW in early August 2011. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where 24 5kg cartons of fruit were irradiated over three sequential times (blocking factor) with target doses of 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group and remained under the same conditions as treated fruit. Replication consisted of a random selection of 15 individual fruit from each carton, represented by one of three blocks per irradiation treatment per assessment time (two times).

Following the irradiation treatment, fruit were packed and immediately transported by air to the Queensland Department of Agriculture, Fisheries and Forestry Postharvest Laboratory in Cairns. Within 24 hours, half the fruit were destructively assessed for quality determination (Day 1) while the second half was transferred into cold storage (0°C at RH 85%) and held for 14 days before being destructively assessed. Storage condition and duration requirements were based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2012). During storage, ambient air temperature and relative humidity conditions were also monitored to ensure they remained within the specifications of the trial.

Fruit Quality Assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, skin colour, biochemical analyses (soluble solids and titratable acidity), and a record of the incidence and severity of disorders and disease types. A description of each assessment method is described below.

Fruit colour

Fruit skin colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8 mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L^* , C^* , h° units).

Moisture loss and whole fruit softness

Fruit were weighed before and after cold storage. Percent moisture loss was calculated by determining the proportion of moisture lost after storage compared with the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the equatorial region of each fruit was

undertaken using a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newton (N).

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were assessed before and after storage. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

Fruit disease and disorders

If present, the incidence and severity of diseases and or disorders were scored on individual fruit based. Incidence was based on the proportion of fruit within a treatment expressing symptoms and severity as the proportion (%) of fruit surface area affected. Browning on fruit stems was measured based on the proportion of stem area affected, using a 0 to 3 rating scale, where 0 = no browning, 1 = up to 25%, 2 = 25-50%, 3 = greater than 50%.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A general ANOVA's was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a Fisher's Least Square Difference (LSD) test at 5%.

Results and Discussion

The following study contributes towards further enhancing our baseline knowledge of the effects of irradiation on fruit quality in sweet cherry. In this study, gamma irradiation applied up to 1 kGy in addition to 14 days of cold storage overall had little to no effect on a range of fruit quality attributes (Table 1 and Plate 1). There was no difference in the amount of moisture fruit lost during storage, averaging less than 1% over the 14 days cold storage period. Similarly, there was also no differences in fruit firmness (mean 2.2 N), total soluble solids (mean 13.3%), titratable acidity (0.49% citric acid), and several skin colour values (mean chroma: 24.7, hue angle: 14.6) before and after cold storage or between the irradiation dose treatments. These results concur with several other studies examining the effects of irradiation and subsequent cold storage on sweet cherry quality, whereby fruit integrity was unaffected (Drake *et al.* 1994, Kovacs *et al.* 1995). Previous workers have however reported a reduction in fruit firmness levels at a dose of 0.4 kGy and above, although this response did not occur in the present study, at least not in the variety 'Stella'.

Storage time did have a slight affect on sweet cherry quality. Fruit progressed towards a slightly darker red colour with storage time as indicated by a small change in lightness values from 29 (day 1) to 27.5 (day 7) (Table 1). This could be described as a typical senescence response that can occur in fruit while in storage. After 7 days in storage, there was also a slight trend, although not significant, towards increased stem (peduncle) browning with higher doses of irradiation. Overall, however, fruit quality was found to remain high irrespective of the imposed storage and irradiation treatments.

Table 1. Effect of irradiation dose and storage duration on sweet cherry quality attributes. Fruit were gamma irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and then assessed within 24 hours (Day 1) and after 14 days (Day 14) in cold (0°C) storage.

Variable	Day	Irradiation dose (Gy)					ANOVA's	
		0	150	600	1000	Mean	Factor	P-value
Moisture loss (%)	14	1.1	0.2	0.5	1.1	0.7	Irradiation	ns
Firmness (N)	1	2.4	2.2	2.1	1.9	2.1	Storage	ns
	14	2.3	2.3	2.3	2.4	2.3	Irradiation	ns
	Mean	2.4	2.2	2.2	2.2		Storage x Irradiation	ns
TSS (°Brix)	1	13.1	13.9	13.2	14.2	13.6	Storage	ns
	14	12.7	13.1	12.9	13.4	13.1	Irradiation	ns
	Mean	12.9	13.5	13.1	13.8		Storage x Irradiation	ns
TA (% citric acid)	1	0.52	0.48	0.5	0.52	0.51	Storage	ns
	14	0.44	0.49	0.46	0.49	0.47	Irradiation	ns
	Mean	0.48	0.48	0.48	0.51		Storage x Irradiation	ns
Skin lightness	1	29.6	28.6	28.5	29.2	29.0 ^a	Storage	<0.001
	14	27.2	26.5	27.5	27.7	27.2 ^b	Irradiation	ns
	Mean	28.4	27.6	28	28.4		Storage x Irradiation	ns
Skin chroma	1	26.0	24.2	26.0	25.0	25.3	Storage	ns
	14	24.5	23.3	23.5	25.5	24.2	Irradiation	ns
	Mean	25.2	23.7	24.8	25.2		Storage x Irradiation	ns
Skin hue angle	1	15.0	13.5	14.5	14.5	14.4	Storage	ns
	14	15.4	14.0	14.6	15.2	14.8	Irradiation	ns
	Mean	15.2	13.7	14.5	14.9		Storage x Irradiation	ns
Stem Browning (0-3)	14	0.8	0.9	0.8	1.3	0.9	Irradiation	ns



	Cherries (var. Stella)	
Day 1		0Gy 150Gy 600Gy 1000Gy
Day 14		0Gy 150Gy 600Gy 1000Gy

Plate 1. Photographs of a representative sample of sweet cherry fruit ('Stella') irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and taken before and after a subsequent 14 day cold storage (0°C) period.

Recommendations

In this study, applications of gamma irradiation treatments of up to 1000 Gy can be safely used as a disinfestation or phytosanitary measure on sweet cherry without inducing any deleterious effects on fruit quality. Storage up to 14 days following irradiation also had no deleterious effects on fruit quality.

References

- Drake, S.R., Moffitt, H.R., Eakin, D.E. (1994) Low dose irradiation of 'Rainier' sweet cherries as a quarantine treatment. *Journal of Food Processing and Preservation*, 18, 473-481.
- Kader, A.A. (1986) Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology*, 40 (6), 117-121.
- Kovacs, E., Balla, G., Nessinger, A. (1995) The effect of irradiation on sweet cherries. *Acta Alimentaria*, 24 (4), 331-343.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis*, 5, 291-311.
- UC Davis (2012) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 01 January, 2012, <<http://postharvest.ucdavis.edu/producefacts/>>

A2.4 Nutritional Value of Peach

Not unlike other varieties of summerfruit, peaches are a source of Vitamins A, C and E and dietary fibre. Key nutritional data for fresh raw peaches are shown Table 56. Values are extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). Significant differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Peaches have high water content (approximately 85–89%). Nutritional data for 100 g per fresh fruit is shown in Table 56. 100 g peach provides approximately 173 kJ of energy, 1 g protein, 8.6 g carbohydrate (8.1 total sugars) and 1.9 g dietary fibre. Vitamin C ranges from 6.6 – 9.6mg/100g and beta carotene is more variable, between 147–477 µg/100g. There is very little lipid and sodium.

The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived (Table 57). The percentage of the daily intake from a single serve of peach is approximately 2.7–3.4 % energy, 3.0 % protein, 3.5–4.1 % available carbohydrate, 9.5–11.5 % total dietary fibre, 12.2–14.2 % total sugar and 0.1–0.3% sodium.

Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available carbohydrate is approximately 124–153 kJ/100g with just over 70% of the energy value coming from carbohydrate with the rest from protein, fats and dietary fibre (Table 58).

In Australia and New Zealand, there are other more commonly eaten fresh fruits than peaches. Summerfruit are seasonal and consumption is limited to the summer months extending from October to March. The five most commonly eaten fruits are apples > oranges > grapes (inc. wine) > banana > pear. It is not known if there are sub-populations that may have a higher than average consumption of peach. Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011) although it is also unlikely that peach will make major contribution to daily dietary intake of macronutrients. Peaches are not a significant part of the average consumer's diet. Although a useful source of micronutrients they are consumed in amounts equivalent to that of many other fresh produce crops and to lesser amounts than many popular fruits. They will not be a significant contributor to overall micronutrient intake.

Pro-vitamin A (carotenes) and vitamin C are found in other fresh produce and vitamin A in foods such as organ meats, dairy products, eggs and ready-to-eat cereals. In addition to green vegetables, grains and dairy and egg products are excellent sources of vitamin K. Nuts, seeds and vegetable oils, and many fresh vegetables are good sources of vitamin E. Folate can be found in small amounts in many foods with a major dietary source being enriched and fortified foods.

Table 56: Nutritional data for raw peach (*Prunus persica*) per 100g edible portion.

Nutrient	value	Peach *		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	88.87	87.6	85.7
Energy	KJ	165	159	195
Protein	g	0.91	1	1
Nitrogen	g			0.16
Total lipid (fat)	g	0.25	0.5	0.1
Malic acid	g			0.4
Citric acid	g			0.4
Carbohydrate	g	9.54	7.3	9
Total Dietary Fibre	g	1.5	1.9	2.3
Ash	g	0.43		0.5
Total sugars	g	8.39	7.3	8.5
Fructose	g	1.53		1.5
Glucose	g	1.95		1.3
Sucrose	g	4.75		5.7
Ascorbic Acid, Vit C	mg	6.6	9.6	9
Thiamin, Vit B1	mg	0.024	0.01	0.006
Riboflavin, Vit B2	mg	0.031	0.02	0.023
Niacin	mg	0.806	0.74	1.01
Niacin equivalents	mg			1.21
Vit B6	mg	0.025	0.08	0.02
Folate, Vit B9 total	µg	4	3	0
Vit A (retinol equiv.)	µg	16	80	25
Alpha carotene	µg	0		2
Beta carotene	µg	162	477	147
Beta cryptoxanthin	µg	67		
Cryptoxanthin	µg			0
Vit E	mg	0.73	1.3	0.7
Vit K	µg	2.6		
Calcium	mg	6	6.5	7
Iron	mg	0.25	0.4	0.3
Magnesium	mg	9		9
Phosphorus	mg	20	21	21
Potassium	mg	190	220	241
Sodium	mg	0	4.1	2
Zinc	mg	0.17	0.2	0.12
Copper	mg	0.068		0.067
Manganese	mg	0.061		0.041
Selenium	µg	0.1	trace	0
Iodine	µg			1.8
Molybdenum	µg			1.1
Nickel	µg			8
Tin	µg			0.6

*raw with skin

Table 57: Nutrient values are per 100 g edible portion of fresh peach.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	85.7	87.6	128.55	131.4			
Energy (kJ)	195	159	292.5	238.5	3.4	2.7	8700
Protein (g)	1	1	1.5	1.5	3.0	3.0	50
Total lipid (fat) (g)	0.1	0.5	0.15	0.75	0.21	1.07	70
Fatty acids, total saturated (g)			0	0	0	0.0	24
Available Carbohydrate (g)	9	7.3	13.5	10.95	4.4	3.5	310
Sugar (g)	8.5	7.3	12.75	10.95	14.2	12.2	90
Total dietary fibre (g)	2.3	1.9	3.45	2.85	11.5	9.5	30
Sodium (mg)	2	4.1	3	6.15	0.1	0.3	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 58: Calculation of energy value of the major* food components per 100 g peach.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ	Average quantity	Approximate calculation of energy value kJ
Protein	17	1	17	1	17
Total lipid (fat)	37	0.1	3.7	0.5	18.5
Fatty acids, total saturated					
Available Carbohydrate	17	9	153	7.3	124.1
Total sugars		8.5		7.3	
Total dietary fibre	8	2.3	18.4	1.9	15.2

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of peach

A report of irradiation studies in Australian fresh peach conducted in 2012 is provided in full in the Attachment in this section. The cultivar studied was raw yellow flesh peach (*Prunus persica*), variety 'Elegant Lady'. The research investigated the effect of low dose gamma (γ)–irradiation on the nutritional profile and postharvest quality of fresh raw peach irradiated at pest disinfection doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The proximate and chemical measurements for peach were analysed using analysis of variance at Time 1 (one day after irradiation) and at Time 2 (after 28 days cold storage at 0°C) after receiving irradiation. Each time was analysed separately and where a significant dose effect was found, pair-wise comparisons were made using the 95% least significant difference (LSD). Nutritional analyses included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and Vitamin A (beta-carotene).

That study (QLD DAFF 2013) showed that low irradiation doses (150 Gy–1 kGy) combined with cold storage overall, did not result in significant deleterious effects on peach nutritional quality and overall fruit quality remained high and did not detract from the integrity or overall visual appeal of peach fruit.

Overall the nutritional study (QLD DAFF 2013) found no significant effects of low dose irradiation for all the nutritional components tested in peach. The peach variety 'Elegant Lady' has a relatively high tolerance to ionizing-radiation stress at doses ≤ 1 kGy as was indicated by Kader (1986) in his review of the potential applications of ionising energy in fruits and vegetables.

No significant dose effects in mean Vitamin C (total ascorbic acid) levels were reported between irradiated and untreated peaches. Overall, storage time resulted in lower mean Vitamin C (total ascorbic) levels across all treatments, which was the result of general fruit ripening. The Vitamin C concentrations reported in the QLD DAFF study (2013) were lower than reported by MOH, FSANZ and USDA, which could have been due to differences in varieties, growing conditions, fruit maturity and post harvest handling.

Irradiation and storage time did not affect beta-carotene in peaches (QLD DAFF 2013) although the values were lower than the values from MOH, FSANZ and USDA (147-477 $\mu\text{g}/100\text{g}$). The QLD DAFF study (2013) reported mean range between of 50.7 and 59.3 $\mu\text{g}/100\text{g}$ in irradiated peach and 60.0 $\mu\text{g}/100\text{g}$ in untreated peach. The lower values were attributed to the differences in varieties, growing conditions, fruit maturity and post harvest handling. The trend has been to harvest summerfruit at an earlier maturity stage nowadays compared to 20 years ago for longer market shelf life, and particularly for fruit destined for export markets.

In the postharvest quality study, peach fruit quality was impacted by storage time and less so by irradiation. Fruit firmness decreased with increasing irradiation dose, which was also observed in other studies (Braddock *et al.* 1966, Drake and Neven 1998, McDonald *et al.* 2012). Changes that occurred in titratable acidity and total soluble solids during storage indicated fruit ripening during this 28 day storage period. Overall fruit quality remained high despite a slight decrease in firmness and flesh colour at higher irradiation doses (≥ 600 Gy). By the end of the 28 day storage period, fruit quality remained relatively high irrespective of any irradiation dose treatment.



Effect of irradiation on the nutritional profile and postharvest quality of peach (*Prunus persica*) fruit.

Final Report
January 2013



Australian Government
Department of Agriculture, Fisheries and Forestry



Know-how for Horticulture™

Department of **Agriculture, Fisheries and Forestry**

Project Title

Effect of irradiation on the nutritional profile and postharvest fruit quality of peach fruit.

Part of MT10057 Phase 2 Final Report (includes apple, apricot, cherry, peach, plum and table grapes).

The Report is presented in two parts.

Part A: Nutritional analysis

Part B: Postharvest fruit quality

Project Leaders

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Market Access Focus Team Leader
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

[REDACTED] Research Scientist, DAFF
[REDACTED] d, Research Scientist, DAFF
[REDACTED] Senior Biometrician, DAFF
[REDACTED] Market Access Focus Team Leader, DAFF

Technical Personnel

[REDACTED], Technical Officer, DAFF

Funding Sources

Horticulture Australia Limited (HAL)
Queensland Department of Agriculture, Fisheries and Forestry
Australian Government, Department of Agriculture, Fisheries and Forestry

Date of Report

January 2013

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.

Leader, Radiation Technology
Senior Technical Officer, Radiation Technology
Technical Officer, Radiation Technology
Technical Officer, Radiation Technology

© State of Queensland, 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Contents

Executive Summary	5
 Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of peach (<i>Prunus persica</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis	12
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation	32
References	34
 Part B. Effect of gamma irradiation on postharvest quality of peach (<i>Prunus persica</i>) fruit.	37
Summary	38
Introduction	39
Materials and methods	40
Experimental layout	40
Fruit quality assessments	40
Statistical analysis	41
Results and Discussion	42
Recommendations	45
References	46

Executive Summary

Nutrition and fruit quality evaluations were conducted on peach (*Prunus persica*) fruit, variety 'Elegant Lady', after being treated with gamma irradiation and following a recommended cold storage period of up to 28 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 gray (Gy), with fruit evaluations conducted before and after storage.

In the nutritional study, no nutritional loss was found in peach fruit treated with ≤ 1 kGy gamma-irradiation treatments. Storage was found to have a greater impact with changes in various sugar components, dietary fibre and Vitamin C (total ascorbic acid) associated with a senescence response as a result of storage for 28 days.

Similarly, peach fruit quality was impacted by storage time and less so by irradiation. Storage time for 28 days caused reductions in fruit moisture which appeared to be enhanced in fruit irradiated at >600 Gy. The minor decreases in titratable acidity and total soluble solids after storage are associated with normal biological changes associated with ripening in storage. Overall, fruit quality remained high and did not detract from the integrity or overall visual appeal of peach fruit.

Gamma irradiation treatments of up to 1000 Gy can be applied to fresh peach fruit, variety 'Elegant Lady' without inducing any significant deleterious effects on the nutritional quality and postharvest fruit quality.

Part A. Effect of low dose gamma (γ)– irradiation on the nutritional profile of peach (*Prunus persica*) fruit.

Contents

Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of peach (<i>Prunus persica</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis.....	12
Moisture. Method VL298 Version 6.2	12
Ash. Method VL286 Ver. 5.1	13
Protein. Method VL299 Protein	13
Dietary Fibre.....	14
Fat. Method VL302_Fat by Mojonnier	14
Fatty Acid Profile. Method VL 289 Fatty Acid Profile.....	15
Sugars. Method VL295_Common Sugars.....	15
Sodium. Method VL247.....	16
Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages	16
Calculation of Energy and Carbohydrates in Food. Method VL 412	17
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs.....	17
Limits of Reporting	18
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation.....	32
References	34

Summary

This report examines the radio-tolerance of peach (*Prunus persica*) fruit cv. 'Elegant Lady' treated at doses at and below 1 kGy for the purpose of quarantine disinfestation. The effects of low dose gamma (γ)–irradiation on the proximate and nutritional quality of untreated and irradiated peach fruit using doses of 0, 150, 600 and 1000 Gy and assessed on two occasions. The first assessment is one day after irradiation treatment and the second is after 28 days storage at 0°C.

The nutritional profile was analysed and included ash, energy, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

No nutritional quality loss was detected in 'Elegant Lady' peach fruit treated with ≤ 1 kGy gamma-irradiation treatments. With the exception of sodium content, there were no interactions between dose level and storage time found in any of the components measured between irradiated and untreated peach fruit.

Overall, storage time had a greater effect than irradiation treatment itself. Cold storage for 28 days resulted in significantly higher glucose and fructose in peach fruit while decreases in Vitamin C (total ascorbic acid), sucrose and total dietary fibre were detected. These minor changes including individual sugar components and Vitamin C were primarily associated with the biological ageing processes that can normally occur during storage. Stone fruits like peaches, nectarines and apricots are often picked early and are firm or hard, so they will still be fresh by the time they get to the retail outlets. Fruit picked when they are still immature would likely have different nutritional levels to mature ripe fruit.

Specifically, low dose irradiation at doses between 150–1000 Gy did not affect the beta-carotene content and total ascorbic acid in peach just after irradiation and after 28 days storage at 0°C.

In this study, the fresh season peach fruit tested are high in moisture (>88%), and low in protein and fat. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also can change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

The study shows that applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the nutritional and proximate components of peach.

Introduction

There is an increasing trend to centrally process fresh fruits, suitably packaged, for distribution and marketing. Irradiation technology proved to be effective in reducing postharvest losses, delaying ripening and prolonging fruit shelf life. Fruit maturity, cultivar, environmental conditions, postharvest handling, storage temperature, and the use of controlled atmosphere storage have all been reported to influence such fruit responses to irradiation (Lee and Kader 2000, Maxie and Abdel-Kader 1966, Miller and McDonald 1999, Mitchell *et al.* 1992) but few reports are available on the effects of irradiation on the nutritional and proximate qualities.

Quality changes in peaches irradiated at low doses between 0.29 and 0.90 kGy were evaluated in a study by McDonald *et al.* (2012). There was no dose effect on titratable acidity (TA), Brix and weight loss due to irradiation but 0.69 and 0.90 kGy peaches were softer, had darker flesh colour and more juicy. Kim *et al.* (2010) investigated the effect of gamma irradiation (0.5–2 kGy) on the physiochemical properties of peach during a 6-day storage at 20±3°C. The authors reported a similar loss in firmness in peach with increasing dose whereas soluble solid and polyphenol contents increased. Kim *et al.* (2010) reported that gamma irradiation of peaches at doses between 0.5–2 kGy improved antioxidant activity. After storage over six days at 20±3°C, radical-scavenging activity of the irradiated peach was higher than that of the control and its activity increased with increasing irradiation dose level.

The Interstate Certification Assurance (ICA) scheme is a national system of plant health certification which provides for a harmonised approach to the audit and accreditation of businesses throughout Australia and the mutual recognition of plant health assurance certificates accompanying consignments of produce moving intrastate or interstate. ICA-55 in the state of Queensland was developed to meet the requirements of State and Territory governments in Australia for the certification of irradiated fruit fly host produce for interstate and intrastate quarantine purposes. However, only fresh fruit and vegetables approved in the Food Standard Australia New Zealand (FSANZ) Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) can be certified under this Operational Procedure. There are currently ten commodities that are approved to be irradiated for pest disinfection purposes and the minimum and maximum doses permitted are 150 Gy and the maximum is 1 kGy respectively. The 150 Gy minimum dose is a generic dose for fruit fly which is an internationally approved treatment (International Standard for Phytosanitary Measures ISPM No.28, Annex 7 2009).

The effects of low dose irradiation and cold storage were investigated on the peach (*Prunus persica*) variety 'Elegant Lady', in order to assess their effects on fruit nutritional quality. Export quality fresh whole produce were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation on apple. This work will also compliment current findings from the postharvest fruit quality component of this study described later in this report.

Materials and Methods

Cultivar

Whole, fresh peach fruits were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of peach was carried out on 30th January 2012. The peach (*Prunus persica*) variety tested was 'Elegant Lady'. It is a yellow-fleshed freestone variety. The fruit is large with a round shape.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 0°C. Prior to treatment fruit were visually inspected to ensure only undamaged fruit were treated. Forty-one fruit were packed into 5 kg cardboard boxes which fitted into the stainless steel irradiation chamber for treatment (Figure 1).

Irradiation treatment

The boxed samples were exposed to target irradiation doses of 0, 150, 600 and 1000 Gy from a Co^{60} source of gamma irradiation. One box of 41 fruit was treated for each dose. For proximate and nutritional analyses 10 fruit per sample were blended and measured at each assessment time.

There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 21.8–23.0°C. The boxes of fruits were positioned on a rig parallel to the plaque source (Figure 1).

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing.

The irradiation doses were measured by placing Fricke dosimeters throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front and between fruits within the carton (Figure 1). Additional dosimeters were attached to the outside of each package for monitoring and to provide references to the minimum and maximum doses.

The effects of irradiation were measured at two stages: after irradiation treatment (Time 1; one day after irradiation treatment) and after 28 days in cold storage at 0°C (Time 2).

Following irradiation treatment, the fruit repacked and sent for chemical analysis and postharvest fruit quality assessment. They were packed into ice coolers and lined with ice packs prior to transport. Time 2 fruit were placed in cold storage until testing commenced.



Figure 1. Peaches in a cardboard carton ready for irradiation treatment. Dosimeter(s) attached to fruit inside the carton and on outside of cartons.
Source: Radiation Technology, ANSTO.

Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, total ascorbic acid (Vitamin C) and beta-carotene (Vitamin A) by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the two occasions, after treatment and after a period in cold storage at 0°C. The first assessment was a day after mean irradiation treatment and the second analysis was at the end of the recommended storage period, which was 28 days for peach.

Fruit were blended at each time point. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s): AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1 mg.

2 to 5 gram of sample is weighed, to nearest 0.1 mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1 mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1 mg, into the dish. The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s): AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to 525°C ± 25°C until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2 g) is accurately weighed into a Kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20 ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50 ml distilled water is added. The tube is placed in a Kjeltac distillation unit and the mixture is steam distilled into a beaker containing 50ml of saturated boric acid solution. The distilled solution is titrated with

standardised 0.1 N sulphuric acid solution using a mixed indicator of bromocresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre.

Reference Method: AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s): AS 2300.1.3. AOAC 16th Edition 954.02, 948.15, 922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2 g) is accurately weighed into a beaker.

10 ml of approx. 10 % hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10 ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25 ml of diethyl ether and a further minute with each of 25 ml of petroleum ether and 50 ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102°C until constant weight is achieved.

Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish X 100}}{\text{Weight of sample}}$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", Can. J. Biochem. Physiol. 37: 911-917.

Badings and Dejong (1983). J. Chrom. 279: 493-506.

McCance and Widdowson (1991). The Composition of Foods. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10 g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2 g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and re-extracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s): AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45 µm filter into a 2 ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s):

1. USEPA (United States Environmental Protection Agency) Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2–0.5 g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase. Absorbance is measured by PDA detection at 245 nm, the PDA spectra (220 to

350 nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL 412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code (2011).

Carbohydrate Calculation:

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation:

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference Method: CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5 g of sample is accurately weighed into a 250 ml flask and 60 ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500 ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes; each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10 ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450 nm, the PDA spectra (250 to 650 nm) is used as confirmation. Determination is made against a known β - Carotene standard, whose concentration is determined by absorbance measurements.

Limits of Reporting

The laboratory standard normally only contains the compound or compounds of interest, in the optimal calibration range. It is also in a medium that does not interfere with and/or enhance the performance of the analytical instrument. It is under these ideal conditions that the lowest concentration can be reported, while minimising uncertainty due to matrix effects. This concentration is the limit of detection of the method. Other non-targeted compounds and constituents can interfere with the sample analysis, and the corrected concentration is reported (limit of reporting).

Limits of reporting for the various components tested are tabled below.

Analysis / Analyte	Limit of reporting; LOR (generally 1–5 times the limit of detection)
Vitamin C (L-ascorbic acid)	1 mg/100g
Beta-carotene	5 μ g/100g
Ash	0.1 g/100g
Carbohydrates	2 g/100g (calculated by difference)
Dietary fibre	0.05 g/100g
Energy	Calculation
Fat	0.2 g/100g
Moisture	0.2 g/100g
Saturated fat	0.10 %
Trans fat	0.10 %
Mono-saturated fat	0.10 %
Polysaturated fat	0.10 %
Protein	0.2 g/100g
Sodium	10 mg/kg
Total sugars	1 g/100g
Fructose	0.2 g/100g
Glucose	0.2 g/100g
Lactose	0.2 g/100g
Maltose	0.2 g/100g
Sucrose	0.2 g/100g

If the limit of reporting, say for example, for beta-carotene in the methodology used is 5 μ g/100g that value means that the laboratory can measure with reasonable accuracy at this level. Any level below the accuracy is not that good and the measurement of uncertainty below the limit of reporting, for example for beta-carotene in the methodology used is 26%.

Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level using GenStat for Windows 14th Edition (VSN International, 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed by ANOVA separately, as well as a 2-way factorial ANOVA to investigate the time by dose interaction. Where a significant dose or time effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD).

Where all or the majority of data was censored (below the level of reporting) the data could not be analysed. For sodium there were a minority of values censored and the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not under-estimated. A \log_{10} transformation was also required for sodium to improve the assumptions underlying the ANOVA and ensure sensible estimates of the censored values were obtained.


Results and Discussion

Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required; 0, 150, 600 and 1000 Gy. Table grapes and peaches were treated at the same time. The average irradiation dose absorbed complies with the required specifications of the study. The Irradiation Report is presented in the section below and reports minimum, maximum and average absorbed doses.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke.

The dose rate was approximately 14.7 Gy/min. Irradiation temperature was 21.8–23.0°C.


Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

9 February 2012

Irradiation Report

ANSTO Reference	12-1985 A (Grapes) & B (Peaches)
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]

ANSTO Ref: 12-1985

SRT F 004

Prepared
[REDACTED]
[REDACTED]

Authorised
[REDACTED]

Date 9.2.2012

Page 1 of 6

Product Details

Product	Grapes and Peaches
Quantity	12 × 6 kg boxes Grapes 12 × 5 kg boxes Peaches

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	30 - 31 January 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 14.7 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F227
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	21.8 to 23.0 °C

ANSTO Ref: 12-1985

SRT F 004

Prepared

Authorised

Date

7.2.2012

Page 2 of 6

The samples of grapes and peaches that were received for processing were repacked into trays. The trays for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited at the front and in between grapes and in front of peaches (Figure 1 & Figure 2). Additional dosimeters were attached to the outside of one box to provide a reference to the minimum and maximum doses (the monitoring position). The trays were positioned on a rig parallel to the plaque source (Figure 3).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R1) samples from the first lot were used to carry out a dosemapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dosemapping repeated twice with dosimeters at those locations. This dosemapping information was used to process the remaining trays of grapes and peaches to their target doses.



Figure 1: Trays of grapes for irradiation showing dosimeter position (circled).

ANSTO Ref: 12-1985

SRTF 004

Prepared

Authorised

Date

9.2.2012

Page 3 of 6



Figure 2: Tray of peaches for irradiation showing dosimeter position.



Figure 2: Trays positioned for irradiation.

ANSTO Ref: 12-1985

SRT F 004

Prepared

Authorised

Date

Page 4 of 6

9.2.2012

Results for Grapes and Peaches

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	137 ± 7	162 ± 7	149 ± 5
600	Replicate 1	544 ± 6	642 ± 7	593 ± 5
1000	Replicate 1	908 ± 21	1071 ± 22	990 ± 15
150	Replicate 2	136 ± 7	161 ± 7	148 ± 5
600	Replicate 2	550 ± 20	649 ± 21	600 ± 14
1000	Replicate 2	916 ± 25	1080 ± 25	998 ± 18
150	Replicate 3	139 ± 7	164 ± 7	151 ± 5
600	Replicate 3	545 ± 20	643 ± 20	594 ± 14
1000	Replicate 3	913 ± 25	1077 ± 25	995 ± 17

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

ANSTO Ref. 12-1985

SRT F 004

Prepared

Authorised

Date

9.2.2012

Page 5 of 6

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: 12-1985

SRT F 004

Prepared

Authorised

Date 9.2.2012

Page 6 of 6

Nutritional components

Yellow flesh peaches, variety 'Elegant Lady' were analysed at two occasions; the first analysis (Time 1) one day after irradiation treatment and the second analysis (Time 2), after 28 days storage in a coldroom set at 0°C.

The results of this study demonstrates that the peach variety 'Elegant Lady' has a relatively high tolerance to ionizing-radiation stress at doses ≤ 1 kGy. The data supports the summation by Kader (1986) that peach fruit has a high tolerance to irradiation doses below 1 kGy in his review of the potential applications of ionising energy in fruits and vegetables.

There was no time by dose interaction in all nutritional components except for sodium content, with the 150 Gy sample showing odd results. Sodium ranged between 0.151 mg/100g and 0.328 mg/100g just after irradiation treatment. Interestingly, mean sodium in the 150 Gy sample increased after 28 days storage by 3-fold compared to the other samples which decreased after storage (Table 1). One 150 Gy sample gave a reading of about 10 times greater than the other readings. The reported mean for sodium in NUTTAB (Food Standards Australia New Zealand (FSANZ) 2010) for raw unpeeled peach is 2 mg/100g while the reported value is 0mg/100g raw peaches in the USDA nutrient database (USDA 2010).

Storage time affected the levels in fructose, glucose, sucrose and total dietary fibre. Storage time had a significant effect in total dietary fibre, with a decrease from a mean of 1.66 g/100g to 1.33 g/100g after 28 days; the untreated control decreased from 1.70 g/100g to 1.40 g/100g while the irradiated samples decreased from 1.53–1.80 g/100g to 1.23–1.37 g/100g. There was no significant effect of irradiation on dietary fibre. Total sugars did not change significantly however significant increases were observed in both fructose and glucose with a corresponding decrease in sucrose.

There were no significant dose effects in mean Vitamin C (total ascorbic acid) levels reported between irradiated peach samples and the untreated control at both assessment times. At Time 1 mean Vitamin C (total ascorbic acid) in the control sample was 0.83 mg/100g compared to 0.83 mg/100g, 0.83 mg/100g and 0.93 mg/100g in the 150 Gy, 600 Gy and 1000 Gy samples, respectively (Table 2). Overall storage time resulted in a decrease in mean Vitamin C (total ascorbic) levels. At Time 2 the level of Vitamin C (total ascorbic acid) was 0.83, 0.57, 0.60 and 0.50 mg/100g for the control, 150, 600 and 1000 Gy peach fruit respectively.

Vitamin C (total ascorbic acid) levels in this study were lower than reported elsewhere. The reported value for total ascorbic acid in raw unpeeled peach in NUTTAB is 9 mg/100g (FSANZ 2010). The level reported in the USA database (USDA 2010) is 6.6 mg/100g. Our fruit handling procedures and temperature variation during transportation between facilities may have contributed to the lower levels detected as losses are accelerated at higher temperatures (Lee and Kader 2000). Sample preparation records, analytical data and chromatograms were reviewed and no error in analysis was detected by the independent laboratory undertaking the testing. The level of ascorbic acid was found to vary with cultivar, ranging from 3–10 mg/100g in peaches (Gil *et al.* 2002). Although content of Vitamin C in fruits can be influenced by cultivar, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures, temperature management after

harvest is the most important factor to maintain Vitamin C in fruits (Lee and Kader, 2000).

Vitamin C is known to decrease with increasing maturity in some fruit species (Spencer *et al.* 1955). The peaches investigated in this study were very firm and not fully mature, possibly giving a lower Vitamin C (total ascorbic acid) content compared to previously reported values. Peaches (and other fruit types like honeydew and rockmelon) can ripen in appearance but not in sweetness after picking and commercial fruit are often delivered in the less mature stage for longer shelf life.

No main effect of dose or storage time was detected in beta-carotene. Beta-carotene decreased slightly but these were not statistically significant. Mean values ranged between 50.7 and 59.3 µg/100g in irradiated peach fruits and 60.0 µg/100g in untreated peach fruit after irradiation treatment, and after 28 days in storage were between 47.0 and 57.7 µg/100g in treated samples and 50.0 µg/100g in the control fruit. The result for beta-carotene in this study is lower than reported in other records. A mean of 147 µg/100g beta-carotene was reported in NUTTAB (FSANZ 2010) and 162 µg/100g in the USDA (2010) database.

The beta-carotene content of fruits and vegetables can vary depending on the season and degree of ripening. Ampomah-Dwamena (2009) found that beta-carotene concentration in kiwifruit increased with developmental stage; beta-carotene concentration was 24% of total carotenoid in mature green kiwifruit, and increased during ripening to 40% at the stage when the colour change appeared complete. The peach fruit used in this study was not fully ripe and could have reported the lower beta-carotene values observed and remained low while in storage until it ripened further if at all. Katayama *et al.* (1971) showed that beta-carotene in apricots increased rapidly in the ripening period, from green stage to ripe stage.

Another factor affecting beta-carotene content in fruits may be due to orchard soil management. Yellow plums (*Prunus domestica*) grown in orchards where the natural meadow covered the soil accumulated more beta-carotene than fruit grown in tilled soil or in soil covered with *Trifolium* (Lombardi-Boccia *et al.* 2004).

Each time was analysed separately to determine the effect of irradiation on the nutritional components (Tables 2 and 3). No main effect of irradiation dose was detected in Time 1 (Table 2). At Time 2 (Table 3) only ash showed a significant dose effect with ash decreasing as dose increased. Irradiation did not affect the levels in carbohydrates, dietary fibre, energy, fat, moisture, sodium, protein, total sugar, fructose, glucose, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) when measured at these two times.

The small changes in mean contents in the chemical components observed in this study are thought to be responses from general fruit ripening although very slowly as the samples were stored at 0°C. At 0°C, respiration is reduced to a level that is just enough to maintain cell function. Ripening in peach harvested when mature is accompanied by a rise in respiration rate, followed by a slowing down as the fruit ripens and develops good eating quality. Ripeness is followed by senescence and breakdown of the fruit, which is the normal aging of produce.

This study shows that peach can be irradiated at doses ≤1 kGy without any significant loss to the nutritional quality and can be considered as a method for phytosanitary disinfestation.

Table 1. A factorial analysis investigating the time by dose interaction 2-way ANOVA with time and dose as the main factors.

Variable	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Ascorbic Acid* (mg/100g)	0	0.83	0.83	0.83	Time	0.038	0.102
	150	0.83	0.57	0.70	Irrad Dose	0.778	0.144
	600	0.83	0.60	0.72	Time x Irrad.	0.530	0.203
	1000	0.93	0.50	0.72			
	Mean	0.86 ^a	0.62 ^b				
Ash (g/100g)	0	0.60	0.63	0.62	Time	0.131	0.057
	150	0.63	0.60	0.62	Irrad Dose	0.938	0.081
	600	0.70	0.57	0.63	Time x Irrad.	0.404	0.114
	1000	0.70	0.47	0.58			
	Mean	0.66	0.57				
Beta Carotene (ug/100g)	0	60.0	50.0	55.0	Time	0.292	4.11
	150	58.3	57.7	58.0	Irrad Dose	0.401	5.81
	600	59.3	55.7	57.5	Time x Irrad.	0.875	8.21
	1000	50.7	47.0	48.8			
	Mean	57.1	52.6				
Carbohydrates (g/100g)	0	8.7	8.7	8.7	Time	0.767	0.28
	150	8.3	7.7	8.0	Irrad Dose	0.397	0.39
	600	8.0	8.7	8.3	Time x Irrad.	0.397	0.55
	1000	8.3	8.0	8.2			
	Mean	8.3	8.3				
Energy (kJ/100g)	0	176.7	173.3	175.0	Time	0.737	4.87
	150	166.7	153.3	160.0	Irrad Dose	0.174	6.89
	600	160.0	173.3	166.7	Time x Irrad.	0.317	9.74
	1000	163.3	160.0	161.7			
	Mean	166.7	165.0				
Fat (g/100g)	0	C	C		Time		
	150	C	C		Irrad Dose		
	600	C	C		Time x Irrad.		
	1000	C	C				
	Mean						
Fructose (g/100g)	0	1.03	1.30	1.17	Time	0.002	0.061
	150	1.13	1.27	1.20	Irrad Dose	0.916	0.086
	600	1.03	1.37	1.20	Time x Irrad.	0.644	0.122
	1000	1.07	1.23	1.15			
	Mean	1.07 ^b	1.29 ^a				
Glucose (g/100g)	0	1.03	1.13	1.08	Time	0.005	0.047
	150	1.10	1.17	1.13	Irrad Dose	0.446	0.067
	600	1.00	1.30	1.15	Time x Irrad.	0.348	0.095
	1000	0.97	1.13	1.05			
	Mean	1.03 ^b	1.18 ^a				

Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Table 1 contd. A factorial analysis investigating the time by dose interaction using a 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time		Mean	Factor	ANOVA's	
		1	2			P-value	SED
Moisture (g/100g)	0	88.47	88.73	88.60	Time	0.123	0.264
	150	88.47	89.43	88.95	Irrad Dose	0.4	0.374
	600	88.83	88.53	88.68	Time x Irrad.	0.354	0.528
	1000	88.83	89.63	89.23			
	Mean	88.65	89.08				
Protein (g/100g)	0	0.80	0.77	0.78	Time	0.410	0.039
	150	0.73	0.80	0.77	Irrad Dose	0.523	0.056
	600	0.80	0.83	0.82	Time x Irrad.	0.782	0.078
	1000	0.70	0.77	0.73			
	Mean	0.76	0.79				
<i>Sodium</i> (mg/100g)#	0	0.328	0.238	0.279	Time	0.928	0.1076
	150	0.151	0.651 [®]	0.313	Irrad Dose	0.205	0.1521
	600	0.229	0.102	0.153	Time x Irrad.	0.030	0.2151
	1000	0.225	0.177	0.200			
	Mean	0.225	0.230				
<i>Sodium</i> (mg/100g)#	0	ab	abc				
	150	bc	a				
	600	abc	c				
	1000	abc	bc				
Sucrose (g/100g)	0	5.43	4.97	5.20	Time	<0.001	0.164
	150	5.23	4.33	4.78	Irrad Dose	0.142	0.232
	600	5.13	4.63	4.88	Time x Irrad.	0.370	0.329
	1000	5.23	4.03	4.63			
	Mean	5.26 ^a	4.49 ^b				
Total Dietary Fibre (g/100g)	0	1.70	1.40	1.55	Time	0.002	0.083
	150	1.80	1.33	1.57	Irrad Dose	0.418	0.117
	600	1.60	1.37	1.48	Time x Irrad.	0.782	0.166
	1000	1.53	1.23	1.38			
	Mean	1.66 ^a	1.33 ^b				
Total Sugars (g/100g)	0	7.50	7.40	7.45	Time	0.121	0.499
	150	7.47	6.77	7.12	Irrad Dose	0.339	0.705
	600	7.17	7.30	7.23	Time x Irrad.	0.401	0.997
	1000	7.27	6.40	6.83			
	Mean	7.35	6.97				

Means in treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values are censored and have been analysed using the method of Taylor (1973).

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

®One reading of 2.7 mg/100g

Table 2. Mean chemical measurements in 'Elegant Lady' peach fruit after irradiation treatment (Time1).

Time 1	Dose (Gy)				p-value	SED
Component	0	150	600	1000		
<i>Ascorbic Acid*</i> (mg/100g)	0.83 (0.289)	0.83 (0.379)	0.83 (0.289)	0.83 (0.404)	0.966	0.244
Ash (g/100g)	0.60 (0.173)	0.63 (0.231)	0.70 (0.173)	0.70 (0.173)	0.638	0.091
Beta Carotene (ug/100g)	60.0 (19.08)	58.3 (5.51)	59.3 (4.73)	50.7 (4.51)	0.723	9.08
Carbohydrates (g/100g)	8.7 (1.53)	8.3 (0.58)	8.0 (0.00)	8.3 (0.58)	0.793	0.65
Energy (kJ/100g)	176.7 (25.17)	166.7 (11.55)	160.0 (0.00)	163.3 (5.77)	0.510	10.97
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	1.03 (0.058)	1.13 (0.058)	1.03 (0.058)	1.07 (0.058)	0.216	0.047
Glucose (g/100g)	1.03 (0.153)	1.10 (0.100)	1.00 (0.100)	0.97 (0.058)	0.540	0.090
Moisture (g/100g)	88.47 (1.405)	88.47 (0.681)	88.83 (0.306)	88.83 (0.058)	0.868	0.616
Protein (g/100g)	0.80 (0.173)	0.73 (0.115)	0.80 (0.100)	0.70 (0.100)	0.678	0.097
<i>Sodium</i> (mg/100g)#	0.328 (0.0458)	0.154 (0.2394)	0.233 (0.2438)	0.225 (0.1803)	0.528	0.2096
Sucrose (g/100g)	5.43 (0.666)	5.23 (0.404)	5.13 (0.321)	5.23 (0.153)	0.836	0.334
Total Dietary Fibre (g/100g)	1.70 (0.100)	1.80 (0.100)	1.60 (0.436)	1.53 (0.306)	0.595	0.200
Total Sugars (g/100g)	7.50 (0.062)	7.47 (0.230)	7.17 (0.257)	7.27 (0.190)	0.854	0.447

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

*Total ascorbic acid data presented are at limits of detection.

Table 3. Mean chemical measurements in untreated and irradiated 'Elegant Lady' peach fruit after 28 days cold storage at 0°C (Time 2).

Time 2 Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid* (mg/100g)	0.83 (0.231)	0.57 (0.058)	0.60 (0.100)	0.50 (0.200)	0.230	0.148
Ash (g/100g)	0.63 ^a (0.058)	0.60 ^a (0.100)	0.57 ^a (0.058)	0.47 ^b (0.058)	0.022	0.039
Beta Carotene (ug/100g)	50.0 (14.93)	57.7 (7.02)	55.7 (10.50)	47.0 (1.00)	0.497	7.39
Carbohydrates (g/100g)	8.7 (0.58)	7.7 (0.58)	8.7 (0.58)	8.0 (0.00)	0.117	0.408
Energy (kJ/100g)	173.3 (11.55)	153.3 (11.55)	173.3 (11.55)	160.0 (0.00)	0.117	8.16
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	1.30 (0.100)	1.27 (0.058)	1.37 (0.321)	1.23 (0.208)	0.829	0.148
Glucose (g/100g)	1.13 (0.115)	1.17 (0.058)	1.30 (0.173)	1.13 (0.058)	0.320	0.093
Moisture (g/100g)	88.73 (0.451)	89.43 (0.321)	88.53 (0.416)	89.63 (0.493)	0.086	0.398
Protein (g/100g)	0.77 (0.058)	0.80 (0.000)	0.83 (0.058)	0.77 (0.058)	0.455	0.045
Sodium (mg/100g)#	0.213 (0.1851)	0.651 [@] (1.3742)	0.078 (0.1256)	0.162 (0.1008)	0.079	0.2794
Sucrose (g/100g)	4.97 ^a (0.379)	4.33 ^b (0.321)	4.63 ^{ab} (0.351)	4.03 ^b (0.462)	0.040	0.246
Total Dietary Fibre (g/100g)	1.40 (0.000)	1.33 (0.115)	1.37 (0.115)	1.23 (0.058)	0.226	0.073
Total Sugars (g/100g)	7.40 (0.171)	6.77 (0.536)	7.30 (0.066)	6.40 (0.052)	0.160	0.422

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

*Total ascorbic acid data presented are at limits of detection.

@One reading of 2.7 mg/100g

Recommendation

The overall findings of this study showed that an irradiation application of up to 1 kGy will not result in any significant detrimental damage to the nutritional quality of 'Elegant Lady' peach. The effect of storage time was greater in the chemical components tested than by irradiation itself and the changes generally appeared to be associated with the ripening/senescence process during storage.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of peach.

References

- Ampomah-Dwamena, C., McGhie, T., Wibisono, R., Montefiori, M., Hellens, R.P. and Allan, A.C. (2009). The kiwifruit lycopene beta-cyclase plays a significant role in carotenoid accumulation in fruit. *Journal of Experimental Botany Advance*. Access published July 2, 2009 15pages.
- AOAC. Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Badings, H.T. and de Jong, C. (1983). Glass capillary gas chromatography of fatty acid methyl esters: a study of conditions for the quantitative analysis of short- and long-chain fatty acids in lipids. *Journal of Chromatography* 279: 493506.
- Bligh, E.G. and Dwyer, W.J. (1959). A Rapid Method of Total Lipid Extraction and Purification". *Canadian Journal of Biochemistry and Physiology* 37: 911–917.
- Brubacher, G., Muller-Mulot, W. and Southgate, W.A.T. (eds). *Methods for the Determination of Vitamins in Food* (1985). Elsevier Applied Science Publishers Ltd Ch 5.
- CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251. 92nd edition link online <http://www.hbcpnetbase.com/>
- Dickson, J.S. (2012). Radiation meets food. *PhysicsToday* 65 (2): 66–67.
- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339. <http://www.comlaw.gov.au/Details/F2010C00339>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database. <http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>
- Gil, M.I., Tomas-Barberan, F.A. Hess-Pierce, B. and Kader A.A. (2002). Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and peach cultivars from California. *Journal of Agricultural and Food Chemistry* 50: 4975–4982.
- ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009). https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Jooste, M.M. (1999) Optimum harvest maturity and cold-storage duration for *Prunus armeniaca* L. cvs. Supergold and Imperial cultivated in South Africa.

http://webcache.googleusercontent.com/search?q=cache:ZwQEJXvx4YJ:http://fruitgro.krazyboyz.co.za/media/uploads/documents/document/file/mariana_ca_pespan_-_apricots_pdf.pdf%2Bjooste+apricot&hl=en&safe=active&gbv=2&gs_l=serp.3...27259.27259.0.28617.1.1.0.0.0.0.250.250.2-1.1.0...0.0...1c.FVMd3idbtJo&ct=clink

- Jooste, M.M. and Taylor, M.A. (1999). Effect of harvest maturity and cold storage period on the overall quality of Bebeco apricots, with special reference to gel breakdown and varieties used to accurately establish harvest maturity. *Deciduous Fruit Grower* 49 (Sept): 39–44.
- Kader, A.A. (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40: 117–121.
- Katamaya, T., Nakayama, T.O.M., Lee, T.H. and Chichester, C.O. (1971). Carotenoid transformations in ripening apricots and peaches. *Journal of Food Science* 36:804–806.
- Kim, K-H, Kim, M-S, Kim, H-G and Yook, H-S (2010). Inactivation of contaminated fungi and antioxidant effects of peach (*Prunus persica* L. Batsch cv Dangeumdo) by 0.5–2 kGy gamma irradiation. *Radiation Physics and Chemistry* 79 (4): 495–501.
- Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207–220.
- Lombardi-Boccia, G., Lucarini, M., Lanzi, S., Aguzzi, A. and Cappelloni, M. (2004). Nutrients and antioxidant molecules in yellow peaches (*Prunus domestica* L.) from conventional and organic productions: a comparative study. *Journal of Agricultural and Food Chemistry* 52: 90–94.
- Maxie, E. C. and Abdel-Kader A. (1966). Food irradiation — physiology of fruits as related to feasibility of the technology. *Advances in Food Research* 15: 05–145.
- McCance, R.A. and Widdowson, E.M. (2004). *The Composition of Foods: Summary Edition (6th Edition)*. Royal Soc Chemistry, Cambridge and Food Standards Agency, London.
- McDonald, H., McCulloch, M., Caporaso, F., Winborne, I., Oubichon, M. and Prakash, A. (2012). Commercial scale irradiation for insect disinfestation preserves peach quality. *Radiation Physics and Chemistry* 81 (6): 697–704.
- Miller, W.R. and McDonald, R.E. (1999). Irradiation, storage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience* 24: 1112–1115.
- Rajkowski, K.T. and Thayer, D.W. (2000). Reduction of *Salmonella* spp. and Strains of *Escherichia coli* O157:H7 by Gamma Radiation of Inoculated Sprouts. *Journal of Food Protection* 63 (7): 871–875.

- Spencer, J.L., Morris, M.P. and Kennard, W.C. (1956). Vitamin C concentration in developing and mature fruits of mango (*Mangifera indica* L.). *Plant Physiology* 31 (1): 79–80.
- Taylor, J. (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35-43.
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website, <http://www.nal.usda.gov/fnic/foodcomp/search/>
- USEPA (United States Environmental Protection Agency). Method 6010b. Inductively coupled plasma-atomic emission spectrometry (ICP-MS). <http://www.epa.gov/region8/water/biosolids/analyticalmethods.html>
- USEPA (United States Environmental Protection Agency). Method 6020. Inductively coupled plasma-mass spectrometry (ICP-MS). <http://www.epa.gov/region8/water/biosolids/analyticalmethods.html>
- VSN International. (2011). GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK. Web Page: GenStat.co.uk
- Wajea, C.K., Junb, S.Y., Leeb, Y.K., Kimc, B.N., Hanc, D.H., Jod, C. and Kwon, J.H. (2009). Microbial quality assessment and pathogen inactivation by electron beam and gamma irradiation of commercial seed sprouts. *Food Control* 20 (3):200–204.

Part B. Effect of gamma irradiation on postharvest quality of peach (*Prunus persica*) fruit.

Contents

Part B. Effect of gamma irradiation on postharvest quality of peach (<i>Prunus persica</i>) fruit.	37
Summary	38
Introduction	39
Materials and methods	40
Experimental layout	40
Fruit quality assessments	40
Fruit colour	40
Moisture loss and whole fruit softness	40
Biochemical analyses	41
Fruit disease and disorders	41
Statistical analysis	41
Results and Discussion	42
Recommendations	45
References	46

Summary

Fruit quality evaluations were conducted on peach (*Prunus persica*) fruit, variety 'Elegant Lady', after being treated with gamma irradiation and following a recommended cold storage period of up to 28 days. Gamma irradiation treatments consisted of a dose of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that peach fruit quality was impacted by storage time and less so by irradiation. Irradiation had no effect on fruit moisture loss, decreasing by 2.0% following 28 days in cold storage. Fruit irradiated >600 Gy were comparatively softer (mean 6.0 N) than control fruit (mean 7.3 N). Flesh colour was affected by the storage treatment and less so by irradiation, becoming a slighter darker yellow colour after 28 days storage (mean chroma values from 39 to 35 units; lightness: 78 to 79 units) and being slightly lighter in shade in the 150 Gy treatment.

Both titratable acidity and total soluble solids content decreased following cold storage although was unaffected by irradiation. Titratable acidity and total soluble solids levels decreased from 10° to 9° Brix and 0.45 to 0.37% (citric acid), respectively, following cold storage. These biochemical changes would likely suggest that fruit underwent ripening while in storage. Overall fruit quality in this study remained high despite a slight decrease in firmness and flesh colour at higher irradiation doses (≥ 600 Gy).

Introduction

The present study aims to investigate the effects of gamma irradiation on the postharvest quality of peach (*Prunus persica*) fruit. Gamma irradiation is regularly used not only for disinfestation purposes but also to control for decay and extend the storage and shelf life of perishable commodities (Mitchell *et al.* 1992). Past work has shown that peach fruit generally have a "high" tolerance to ionizing irradiation below 1 kGy compared with other fruit and vegetables (Kader 1986). Nonetheless, several studies have reported irradiation induced softening in peach fruit. Braddock *et al.* (1966), for example, observed that flesh softening in 'Maygold', 'Southland', 'Loring' and 'Dixiland' varieties was positively correlated with dose amount, with all varieties exhibiting changes in texture at a dose of 1kGy and above. Similarly, six other varieties of peach treated between 290 and 900 Gy also exhibited softening with increasing dose level, although no differences in titratable acidity, Brix and weight loss were observed as a result of the treatments (McDonald *et al.* 2012). Several authors (Kader 1986, Mitchell *et al.* 1992) have reported however that these responses to irradiation can vary widely between variety, harvest maturity, growing conditions and or geographic location.

In the present study, the effects of irradiation and cold storage duration were therefore examined on Australian grown peach variety ('Elegant Lady') in order to assess their effects on fruit quality following irradiation and subsequent cold storage. Fruit assessments entailed measurements of physico-chemical changes in fruit quality. The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation (at and below 1 kGy) on a variety grown and marketed under Australian conditions. This work will also compliment current findings from the nutritional component of this study described earlier in this report, which also incorporated fruit selected from the same irradiation and cold storage treatments as in this study.

Materials and methods

Experimental layout

Peach (*Prunus persica*) fruit, variety 'Elegant Lady', were sourced from the Sydney Markets, NSW in early February 2012. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where ca. 40 fruit in cardboard trays were irradiated over three sequential times (blocking factor) with a target dose of 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group and remained under the same conditions as treated fruit. Replication consisted of a random selection of 10 individual fruit from each tray, comprising one of three blocks per irradiation treatment per assessment time (two times).

Following the irradiation treatment, fruit were packed and immediately transported by air to the Queensland Department of Agriculture, Fisheries and Forestry Postharvest Laboratory in Cairns. Within 24 hours, half the fruit were destructively assessed for quality determination (Day 1) while the second half was transferred into cold storage ($1.5 \pm 0.5^\circ\text{C}$ at 85% RH) and held for 28 days before being destructively assessed. Storage condition and duration requirements were based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2012). During storage, ambient air temperature and relative humidity conditions were also monitored to ensure they remained within the specifications of the trial.

Fruit quality assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, flesh colour, biochemical analyses (soluble solids and titratable acidity), and a record of the incidence and severity of disorders and disease types. A description of each assessment method is described as follows:

Fruit colour

Fruit internal colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8 mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L^* , C^* , h° units). Fruit external colour was not able to be measured due to the extensive and variable blush coverage on fruit.

Moisture loss and whole fruit softness

Fruit were weighed before and after cold storage. Percent moisture loss was calculated by determining the proportion of moisture lost after storage compared with the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the equatorial region of each fruit was

undertaken using a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newton (N).

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were assessed before and after storage. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

Fruit disease and disorders

If present, the incidence and severity of diseases and or disorders were scored on individual fruit before and after storage. Incidence was based on the proportion of fruit within a treatment expressing symptoms while severity was based as the proportion (%) of skin (or cut flesh) surface area affected.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A general ANOVA's was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a Fisher's Least Square Difference (LSD) test at 5%.

Results and Discussion

The following study contributes towards further enhancing our baseline knowledge of the potential effects of irradiation on fruit quality in peach. In this study, the primary effect of the irradiation treatment was on fruit firmness. As a result, fruit firmness in 'Elegant Lady' decreased with increasing irradiation, a symptom also observed in a number of other studies (Braddock *et al.* 1966, Drake and Neven 1998, McDonald *et al.* 2012). Specifically, peaches in this study treated to 1000 Gy and stored for 28 days were approximately 1.3 N softer than control fruit (7.3 N) (Table 1). Interestingly, fruit after storage were slightly firmer than those before storage, although this was likely a statistical anomaly since separate sets of fruit were assessed during each assessment time.

In regards to fruit colour properties, the effect of storage had a more significant impact on peach internal colour than irradiation (Table 1). Based on the changes that occurred in the lightness and chroma values, peach flesh transitioned to a slightly darker yellow colour after 28 days in cold storage. Mean flesh chroma properties of control fruit was 39.4 before storage and 34.9 after storage. For some unexplained reason, the flesh colour of 150 Gy-treated fruit after storage was slightly lighter than those of Control or the 600 and 1000 Gy-treated fruit. In contrast, McDonald *et al.* (2012) described a more pronounced response in terms of flesh darkening in peach fruit following a dose of 690 or 900 Gy. They noted however that the response overall was not perceived negatively by a consumer evaluation panel.

Both titratable acidity and total soluble solids content decreased after the cold storage treatment, despite there being no effect of irradiation (Table 1). Drake and Neven (1998) and McDonald *et al.* (2012) also showed that irradiation had no effect on these variables in several other peach varieties, in spite of using a similar irradiation treatment regime (up to 900 Gy) to the present study. Nonetheless, the decreases in titratable acidity and total soluble solids level as a result of the storage treatment would suggest that fruit underwent partial ripening during this period.

In conclusion, by the end of the 28 day storage period, fruit quality remained relatively high irrespective of any irradiation dose treatment (Plate 1). The changes in firmness and flesh colour have been documented in previous studies although these symptoms only appeared with doses at or above 600 Gy.

Table 1. Effect of irradiation dose and storage duration on the quality attributes of peach fruit. Fruit were gamma irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and then assessed within 24 hours (Day 1) and after 28 days (Day 28) in cold (1.5°C) storage.

Variable	Day	Irradiation dose (Gy)				Mean	ANOVA's	
		0	150	600	1000		Factor	P-value
Moisture loss (%)	28	2.2	1.6	1.7	2.6	2.0	Irradiation	ns
Firmness (N)	1	6.7	6.1	6.1	5.6	6.1 ^b	Storage	<0.001
	28	7.9	7.1	6.9	6.5	7.1 ^a	Irradiation	<0.05
	Mean	7.3 ^a	6.6 ^{ab}	6.5 ^{ab}	6.0 ^b		Day x Irradiation	ns
Flesh lightness	1	77.9	78.3	78.2	77.9	78.1 ^b	Storage	<0.001
	28	79.4	78.5	79.7	79.9	79.4 ^a	Irradiation	ns
	Mean	78.7	78.4	79	78.9		Day x Irradiation	ns
Flesh chroma	1	40.1 ^a	39.0 ^a	39.4 ^a	39.0 ^a	39.4	Storage	<0.001
	28	34.4 ^c	36.2 ^b	34.3 ^c	34.5 ^c	34.9	Irradiation	ns
	Mean	37.2	37.6	36.9	36.7		Day x Irradiation	<0.05
Flesh hue angle	1	93.2	93.1	93.0	93.9	93.3	Storage	ns
	28	93.4	93.0	93.3	93.5	93.3	Irradiation	ns
	Mean	93.3	93	93.2	93.7		Day x Irradiation	ns
TSS (°Brix)	1	10.0	9.9	10.0	9.9	10.0 ^a	Storage	<0.01
	28	8.7	8.7	9.3	9.1	9.0 ^b	Irradiation	ns
	Mean	9.3	9.3	9.7	9.5		Day x Irradiation	ns
TA (% citric acid)	1	0.47	0.44	0.44	0.45	0.45 ^a	Storage	<0.001
	28	0.39	0.37	0.34	0.39	0.37 ^b	Irradiation	ns
	Mean	0.43	0.4	0.39	0.42		Day x Irradiation	ns

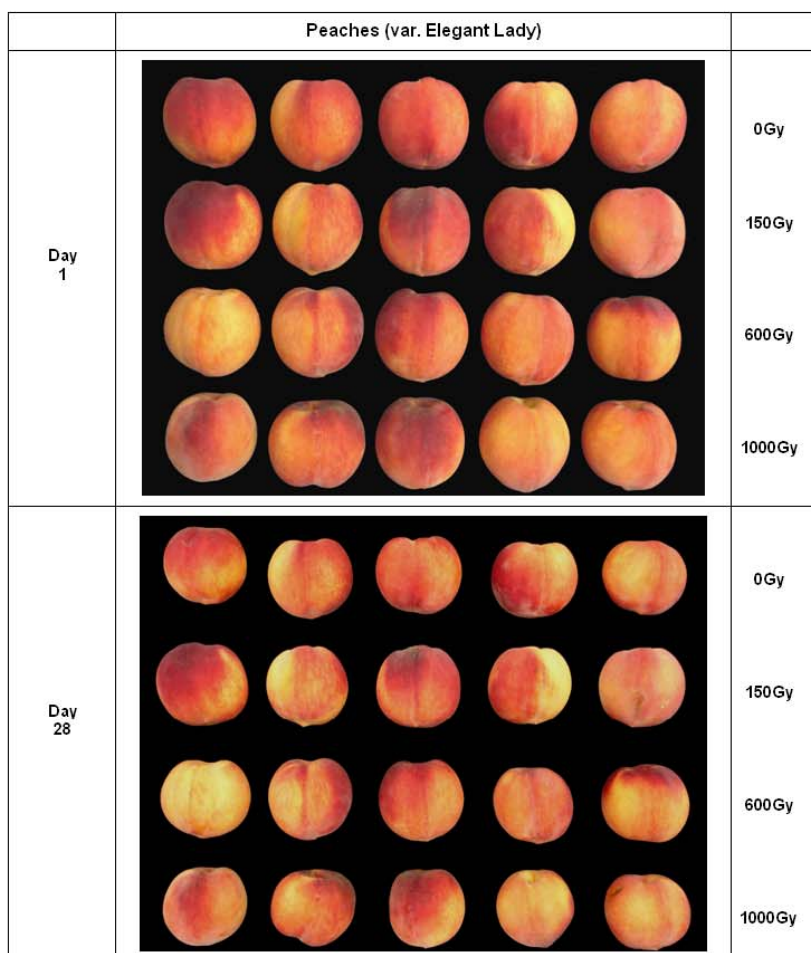


Plate 1. Photographs of a representative sample of peach fruit ('Elegant Lady') irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and taken before and after a subsequent 28 day cold (1.5°C) storage period.

Recommendations

In this study, applications of gamma irradiation treatments of up to 1000 Gy can be safely used as a phytosanitary or disinfestation measure on peach fruit without causing any deleterious effects on fruit quality. At ≥ 600 Gy fruit softness and flesh darkening increased slightly, although similar studies noted that these effects were not sufficient enough to class the fruit as commercially unacceptable.

References

- Braddock, R.J., Dennison, R.A., Ahmed, E.M. (1966) The influence of gamma irradiation on textural changes in peaches. *Florida Agricultural Experiment Stations Journal Series 2554*: 281-284.
- Drake, S.R., Neven L.G. (1998) Irradiation as an alternative to methyl bromide for quarantine treatment of stone fruits. *Journal of Food Quality* 22: 529-538.
- Kader, A.A. (1986) Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40 (6): 117-121.
- McDonald, H., McCulloch, M., Caporaso, F., Winborne, I., Oubichon, M., Rakovski, C., Prakash, A. (2012) Commercial scale irradiation for insect disinfestation preserves peach quality. *Radiation Physics and Chemistry* 81 (6): 697-704.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291-311.
- UC Davis (2012) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 01 January, 2012, <http://postharvest.ucdavis.edu/producefacts/>

A2.5 Nutritional value of Plum

Key nutritional data for fresh raw plum extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b) are collated in Table 59. Significant differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Like many other fresh fruits, plums have high water content (approximately 85–88 %). Nutritional data (100 g fresh fruit) is shown in Table 59. 100 g plum provides between 162–267 kJ of energy, < 1 g protein, 7.1–13.9 g carbohydrate (6.5–13.8 g total sugars) and 1.4–2 g dietary fibre. Vitamin C ranges is low, ranging between 3.2 and 9.5 mg/100g. Beta carotene is more variable, between 147–477 µg/100g. There is very little lipid and sodium.

The average nutrient content per single serve (150g for fresh fruit) is presented in Table 60. Percentage of the daily intake from a single serve of plum is approximately 2.8–4.6 % energy, 1.8–2.7 % protein, 3.4–6.7 % available carbohydrate, 8.5–10.0 % total dietary fibre, 10.8–23.0 % total sugar and 0.1–0.2 % sodium.

The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived. The energy value from available carbohydrate is approximately 120–236 kJ/100g for plum, approximately 13 kJ from protein and 15 kJ from total dietary fibre (Table 61).

Summerfruit or stonefruit are seasonal and consumption is limited to the summer months extending from October to March. Plums are not known to be consumed in higher amounts by any subpopulations. From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears plums are unlikely to make major contributions to daily dietary intake of macronutrients.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). Plums, for example, provide a source of vitamin C, vitamin A precursors (mainly β -carotene), potassium and other trace elements and are similar to concentrations in other fruits such as peaches and nectarines.

The Vitamin C content of plums is between 3.2–9.5 mg/100g and the β -carotene content is not high, about 147–417 µg per 100g. Other fruits such as peaches and nectarine contain similar levels of Vitamin C and β -carotene while papaya contains higher levels for both the micronutrients. Micronutrients can be supplied from other fresh produce other than plums.

Pro-vitamin A (carotenes) and vitamin C can be obtained from other fresh produce and vitamin A from foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables are an excellent source of vitamin K, as are grains and dairy and egg products and nuts, seeds and vegetable oils and many fresh vegetables provide good sources of vitamin E. Folate can be found in small amounts in many foods with a major dietary source being enriched and fortified foods.

Plums are not a significant part of the average consumer's diet and their contribution to overall micronutrient intake will be minimal. The fruit are consumed in much smaller amounts than many other fresh and popular fruits available. They will not be a significant contributor to overall micronutrient intake.

Table 59: Nutritional data for raw plum (*Prunus domestica*) per 100g edible portion.

Nutrient	value	Raw Plum *		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	87.23	85.4	87.8
Energy	KJ	192	267	162
Protein	g	0.7	0.9	0.6
Nitrogen	g			0.1
Total lipid (fat)	g	0.28	0.6	0.1
Malic acid	g			1.6
Citric acid	g			
Carbohydrate	g	11.42	13.9	7.1
Total Dietary Fibre	g	1.4	1.7	2
Ash	g	0.37		0.3
Total sugars	g	9.92	13.8	6.5
Fructose	g	3.07		1.8
Glucose	g	5.07		2.1
Sucrose	g	1.57		2.6
Ascorbic Acid, Vit C	mg	9.5	3.2	5
Thiamin, Vit B1	mg	0.028	0.01	0.035
Riboflavin, Vit B2	mg	0.026	0.01	0.045
Niacin	mg	0.417	0.8	0.58
Niacin equivalents	mg			0.72
Vit B6	mg	0.029	0.06	
Folate, Vit B9 total	µg	5µg	5µg	0
Vit A (retinol equiv.)	µg	17	70	25
Alpha carotene	µg	0		5
Beta carotene	µg	190	417	147
Beta cryptoxanthin	µg	35		
Cryptoxanthin	µg			
Vit E	mg	0.26	0.82	0
Vit K	µg	6.4		
Calcium	mg	6	6.8	7
Iron	mg	0.17	0.4	0.22
Magnesium	mg	7		6
Phosphorus	mg	16	20	21
Potassium	mg	157	190	153
Sodium	mg	0	3.6	2
Zinc	mg	0.1	0.1	0.1
Copper	mg	0.057		
Manganese	mg	0.052		
Selenium	µg	0		
Iodine	µg			1.8
Molybdenum	µg			
Nickel	µg			
Tin	µg			

*raw with skin

Table 60: Nutrient values are per 100 g edible portion of fresh plum.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	87.8	85.4	131.7	128.1			
Energy (kJ)	162	267	243	400.5	2.8	4.6	8700
Protein (g)	0.6	0.9	0.9	1.35	1.8	2.7	50
Total lipid (fat) (g)	0.1	0.6	0.15	0.9	0.2	1.3	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	7.1	13.9	10.65	20.85	3.4	6.7	310
Sugar (g)	6.5	13.8	9.75	20.7	10.8	23.0	90
Total dietary fibre (g)	2	1.7	3	2.85	10.0	9.5	30
Sodium (mg)	2	3.6	3	5.4	0.1	0.2	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>.

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 61: Calculation of energy value of the major* food components per 100 g plum.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ	Average quantity	Approximate calculation of energy value kJ
Protein	17	0.6	10.2	0.9	15.3
Total lipid (fat)	37	0.1	3.7	0.6	22.2
Fatty acids, total saturated			0		0
Available Carbohydrate	17	7.1	120.7	13.9	236.3
Total sugars		6.5		13.8	
Total dietary fibre	8	2	16	1.7	13.6

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of plum

Irradiation studies (QLD DAFF, 2013) of Australian raw plum (*Prunus domestica*), conducted in 2012 is provided in full in the Attachment 5 to this application. The cultivar studied was 'Black Amber'. The research investigated the effect of low dose gamma (γ)–irradiation on the nutritional profile and postharvest quality of fresh raw peach irradiated at pest disinfection doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The study showed that low irradiation doses up to 1 kGy) did not result in significant deleterious effects in nutritional quality and postharvest fruit quality in plum. Storage had a greater effect than irradiation treatment itself. The changes in nutrition and fruit quality were associated with ripening during storage.

The study showed that plum is tolerant to ionising-radiation stress at doses ≤ 1 kGy. There was no nutritional quality loss in plum treated with ≤ 1 kGy gamma-irradiation. Ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) were not affected. Low dose irradiation treatment was considered a safe disinfection method for plum.

No significant dose effects in mean Vitamin C (total ascorbic acid) levels were reported between irradiated and untreated plums, decreased levels were observed after 35 days in cold storage in all treatments. Mean values for Vitamin C (total ascorbic acid) reported were 1.12 and 0.34 mg/100g after treatment and after 35 days, respectively. Lee *et al.* (2008a) found no significant effect of gamma irradiation and treatment with electron beam (Lee *et al.* 2008b) in Vitamin C in the stone fruit, apricot, at doses up to 2 kGy.

Although there was no dose effect detected, the irradiated samples recorded higher increases in beta-carotene after 35 days (QLD DAFF 2013). A strong positive correlation between irradiation treatment and beta-carotene content in sundried apricots irradiated at doses ≥ 1 kGy was reported by Hussain *et al.* (2011). The increase may be attributed to the increased extractability of carotenoids resulting from the changes in cellular structure (Boylston *et al.* 2002, Moreno *et al.* 2007).

Fruit maturity may have impacted the beta-carotene content. The increase in beta-carotene over the 35 days was due to the test fruit being at a less mature stage when treated (Katayama *et al.* 1971, Ampomah-Dwamena 2009). The immaturity of the fruit may also have been responsible for the lower Vitamin C content recorded, compared with reported values from MOH, FSANZ and USDA.

Past work has shown that plum fruit generally have a “moderate” tolerance to irradiation at doses of <1 kGy compared with other fruit and vegetables (Kader 1986). Several studies have reported that ionizing radiation can cause softening in plum fruit. South African grown 'Songold' plums, for example, became significantly softer when irradiated with between 600 to 800 Gy compared to untreated fruit (Viljoen 2011). QLD DAFF fruit quality evaluations (2013) found that plum fruit were impacted more by storage time than by irradiation itself. Plum fruit quality remained comparatively high over the 35 day storage period with minor changes in fruit quality associated with ripening during storage, as indicated by a reduction in firmness and titratable acidity levels.

Storage duration caused a significant reduction in fruit firmness, decreasing from 5.4 to 3.4 N before and after removal from cold storage. After the storage period, Brix levels remained similar to pre-storage levels (mean 11°) whereas titratable acidity values decreased significantly from 1.3 to 1.0%. Additionally, fruit became a slightly darker red colour over this period, which was partially enhanced by higher irradiation doses (≥ 600

Gy). In contrast, Moy (1983) found differences in colour at 0.5 kGy and texture at 0.5 kGy and 1.0 kGy treated plum. Kader (1986) reported that applications of ionizing radiation above 150 Gy may cause undesirable side effects such as tissue darkening in various fruit types. The overall extent of darkening in plum skin in this study was small (< 2 lightness units between irradiation doses), with the differences not visibly discernable with the naked eye.

Applications of gamma irradiation treatments of up to 1 k Gy can therefore be safely used as a phytosanitary or disinfestation measure without causing any deleterious effects on nutritional and fruit quality.



Effect of irradiation on the nutritional profile and postharvest quality of plum (*Prunus domestica*) fruit.

Final Report
January 2013



Australian Government
Department of Agriculture, Fisheries and Forestry



Know-how for Horticulture™

Department of **Agriculture, Fisheries and Forestry**

Project Title

Effect of irradiation on the nutritional profile and postharvest fruit quality of plum fruit.

Part of MT10057 Phase 2 Final Report (includes apple, apricot, cherry, peach, plum and table grapes).

The Report is presented in two parts.

Part A: Nutritional analysis

Part B: Postharvest fruit quality

Project Leaders

Research Scientist

Horticulture and Forestry Science

Department of Agriculture, Fisheries and Forestry (DAFF), Queensland

P.O. Box 652 Cairns, Queensland, Australia 4870.

Research Scientist

Horticulture and Forestry Science

Department of Agriculture, Fisheries and Forestry (DAFF), Queensland

P.O. Box 652 Cairns, Queensland, Australia 4870.

Market Access Focus Team Leader

Horticulture and Forestry Science

Department of Agriculture, Fisheries and Forestry (DAFF), Queensland

P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

Research Scientist, DAFF Qld

l, Research Scientist, DAFF Qld

Senior Biometrician, DAFF Qld

arket Access Focus Team Leader, DAFF Qld

Technical Personnel

Technical Officer, DAFF Qld

Funding Sources

Horticulture Australia Limited (HAL)

Queensland Department of Agriculture, Fisheries and Forestry

Australian Government, Department of Agriculture, Fisheries and Forestry

Date of Report

January 2013

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.

Justin Davies, Leader, Radiation Technology
Connie Banos, Senior Technical Officer, Radiation Technology
Sohil Sheth, Technical Officer, Radiation Technology
Allan Perry, Technical Officer, Radiation Technology

© State of Queensland, 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Contents

Executive Summary	5
 Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of plum (<i>Prunus domestica</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis	12
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation	33
References	34
 Part B. Effect of gamma irradiation on the postharvest quality of plum (<i>Prunus domestica</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Executive Summary

Nutrition and fruit quality evaluations were conducted on plum (*Prunus domestica*) fruit, variety 'Black Amber', after being treated with gamma irradiation and following a recommended cold storage period of up to 35 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 gray (Gy), with fruit evaluations conducted prior to and after storage.

Irradiation applications of up to 1 kGy did not cause any detrimental damage to the nutritional quality of plum fruit. The nutritional status of plum was affected more by the changes that occurred during the ripening process while in cold storage. This included increases in beta-carotene, carbohydrates, total sugars and fructose and decreases in total ascorbic acid, ash, total dietary fibre and protein. Irradiation treatment of up to 1 kGy was therefore considered safe to use on plum without causing any adverse affects on nutrition.

Fruit quality evaluations found that plum fruit were impacted more by storage time than by irradiation itself. Plum fruit quality remained comparatively high over the 35 day storage period with minor changes in fruit quality associated with ripening during storage, as indicated by a reduction in firmness and titratable acidity levels. Additionally, fruit became a slightly darker red colour over this period, which was partially enhanced by higher irradiation doses (≥ 600 Gy). Applications of gamma irradiation treatments of up to 1 k Gy can therefore be safely used as a phytosanitary or disinfestation measure without causing any deleterious effects on fruit quality.

Part A. Effect of low dose gamma (γ)– irradiation on the nutritional profile of plum (*Prunus domestica*) fruit.

Contents

Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of plum (<i>Prunus domestica</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	9
Cultivar	9
Irradiation treatment	10
Chemical analysis.....	12
Moisture. Method VL298 Version 6.2	12
Ash. Method VL286 Ver. 5.1	13
Protein. Method VL299 Protein	13
Dietary Fibre.....	14
Fat. Method VL302_Fat by Mojonnier	14
Fatty Acid Profile. Method VL 289 Fatty Acid Profile.....	15
Sugars. Method VL295_Common Sugars.....	15
Sodium. Method VL247.....	16
Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages	16
Calculation of Energy and Carbohydrates in Food. Method VL 412	17
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs.....	17
Limits of Reporting	18
Statistical analysis of chemical components	19
Results and Discussion	20
Irradiation treatment – dosimetry	20
Nutritional components	21
Recommendation.....	33
References	34

Summary

This report examines the radio-tolerance of plum (*Prunus domestica*) cv. 'Black Amber' treated at doses at and below 1 kGy for the purpose of quarantine disinfestation. The effects of low dose gamma (γ)-irradiation on the proximate and nutritional quality of untreated and irradiated plum fruit were investigated.

The study provides an analysis of data on the nutritional profile of 'Black Amber' plum that have been irradiated at 0, 150, 600 and 1000 Gy and assessed on two occasions. The first assessment is one day after irradiation treatment and the second is after 35 days storage at 0°C. The nutritional profile was analysed and included ash, energy, dietary fibre, fat, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

No nutritional quality loss was detected in 'Black Amber' plum treated with ≤ 1 kGy gamma-irradiation treatments. There were no interactions between dose level and storage time found in any of the components measured between irradiated and untreated plum fruit.

Overall, storage time had a greater effect than irradiation treatment itself. Cold storage for 35 days resulted in higher beta-carotene level, carbohydrates, total sugars and fructose in plum fruit while decreases in total ascorbic acid, ash, total dietary fibre and protein were detected.

These changes including individual sugar components, beta-carotene and total ascorbic acid detected were primarily associated with the biological ripening processes that can normally occur during storage.

Specifically, low dose irradiation did not affect the Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) content in plum just after irradiation and after 35 days storage at 0°C.

In this study, the fresh season plum fruit tested are high in moisture content (>88%), and low in protein and fat. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also can change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

The study shows that applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of plum.

Introduction

There is an increasing trend to centrally process fresh fruits, suitably packaged, for distribution and marketing. Irradiation technology proved to be effective in reducing postharvest losses, delaying ripening and prolonging fruit shelf life. Fruit maturity, cultivar, environmental conditions, postharvest handling, storage temperature, and the use of controlled atmosphere storage have all been reported to influence such fruit responses to irradiation (Lee and Kader 2000, Maxie and Abdel-Kader 1966, Miller and McDonald 1999, Mitchell *et al.* 1992) but few reports are available on the effects of irradiation on the nutritional and proximate qualities.

No differences in sensory qualities were detected between plum fruit irradiated at 0.3 kGy and the untreated control fruit while differences in colour at 0.5 kGy and texture at 0.5 kGy and 1.0 kGy were found (Moy 1983). Irradiated plum (400, 600 and 800 Gy) were firmer than the control and generally flesh firmness decreased with increasing dose (Viljoen 2011). In a very early study, irradiation was found to extend the shelf- and storage-life plum with a dose of 2 kGy giving the best results while 3kGy dose induced skin damage (Mercier and MacQueen 1966).

The Interstate Certification Assurance (ICA) scheme is a national system of plant health certification which provides for a harmonised approach to the audit and accreditation of businesses throughout Australia and the mutual recognition of plant health assurance certificates accompanying consignments of produce moving intrastate or interstate. ICA-55 in the state of Queensland was developed to meet the requirements of State and Territory governments in Australia for the certification of irradiated fruit fly host produce for interstate and intrastate quarantine purposes. However, only fresh fruit and vegetables approved in the Food Standard Australia New Zealand (FSANZ) Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) can be certified under this Operational Procedure. There are currently ten commodities that are approved to be irradiated for pest disinestation purposes and the minimum and maximum doses permitted are 150 Gy and the maximum is 1 kGy respectively. The 150 Gy minimum dose is a generic dose for fruit fly which is an internationally approved treatment (International Standard for Phytosanitary Measures ISPM No.28, Annex 7 2009).

The effects of low dose irradiation and cold storage were investigated on plum (*Prunus domestica*) variety 'Black Amber', in order to assess their effects on fruit nutritional quality. Export quality fresh whole produce were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation on apple. This work will also compliment current findings from the postharvest fruit quality component of this study described later in this report.

Materials and Methods

Cultivar

Whole, fresh plum fruits were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of plum was carried out on 4th January 2012. The plum (*Prunus domestica*) variety tested was 'Black Amber', a medium to small (~ 50 mm diameter) sized plum. It was a clingstone variety. The fruit was firm, had a rounded shape, purple black in skin colour and the flesh colour was amber.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 0°C. Prior to treatment fruit were visually inspected to ensure only undamaged fruit were treated. Fruit were carefully placed in plastic bags and packed into 5 kg cardboard boxes which fitted into the stainless steel irradiation chamber for treatment (Figure 1).

Irradiation treatment

Plums and apricots were treated at the same time. Previous dose mapping experiments indicated that the two similar sized fruits could be treated together (ANSTO, pers comm.). Dose mapping was conducted to ensure the doses specified were indeed applied.

The fruit samples were exposed to target irradiation doses of 0, 150, 600 and 1000 Gy from a Co^{60} source of gamma irradiation. One box of fruit was treated for each dose. For proximate and nutritional analyses 20 fruit per sample were blended and measured at each assessment time.

There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 22.7–23.3°C. The boxes of fruits were positioned on a rig parallel to the plaque source (Figure 1).

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing.

The irradiation doses were measured by placing Fricke dosimeters throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front and between fruits within the carton (Figure1). Additional dosimeters were attached to the outside of each cardboard package for monitoring and to provide references to the minimum and maximum doses.

The effects of irradiation were measured at two stages: after irradiation treatment (Time 1; one day after irradiation treatment) and after 35 days of cold storage set at 0°C (Time 2).

Following irradiation treatment, the fruit were sent for chemical analysis and postharvest fruit quality assessment. They were packed into ice coolers and lined with ice packs prior to transport. Time 2 fruit were placed in cold storage until testing commenced.



Figure 1. Plum and apricot fruits packed in plastic bags and placed in a cardboard carton ready for irradiation treatment. Dosimeter(s) attached to bags of fruit inside the carton and on outside of cartons.

Source: Radiation Technology, ANSTO.

Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat profile, moisture, sodium, protein, total sugars, Vitamin C (ascorbic acid) and Vitamin A (beta-carotene) by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the two occasions, after treatment and after a period in cold storage at 0°C. The first assessment was a day after mean irradiation treatment and the second analysis at the end of the recommended storage period of 14 days.

Edible portions of each fruit were blended at each time point. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s): AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1 mg.

2 to 5 gram of sample is weighed, to nearest 0.1 mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1 mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1 mg, into the dish. The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s): AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to 525°C ± 25°C until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2 g) is accurately weighed into a Kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20 ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50 ml distilled water is added. The tube is placed in a Kjelttec distillation unit and the mixture is steam distilled into a beaker containing

50ml of saturated boric acid solution. The distilled solution is titrated with standardised 0.1 N sulphuric acid solution using a mixed indicator of bromcresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre.

Reference Method: AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s): AS 2300.1.3. AOAC 16th Edition 954.02, 948.15, 922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2 g) is accurately weighed into a beaker.

10 ml of approx. 10 % hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10 ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25 ml of diethyl ether and a further minute with each of 25 ml of petroleum ether and 50 ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102°C until constant weight is achieved.

Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish X 100}}{\text{Weight of sample}}$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", Can. J. Biochem. Physiol. 37: 911-917.

Badings and Dejong (1983). J. Chrom. 279: 493-506.

McCance and Widdowson (1991). The Composition of Foods. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10 g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2 g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and re-extracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s): AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45 µm filter into a 2 ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s):

1. USEPA (United States Environmental Protection Agency) Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2–0.5 g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase. Absorbance is measured by PDA detection at 245 nm, the PDA spectra (220 to

350 nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL 412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code (2011).

Carbohydrate Calculation:

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation:

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference Method: CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5 g of sample is accurately weighed into a 250 ml flask and 60 ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500 ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes; each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10 ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450 nm, the PDA spectra (250 to 650 nm) is used as confirmation. Determination is made against a known β - Carotene standard, whose concentration is determined by absorbance measurements.

Limits of Reporting

The laboratory standard normally only contains the compound or compounds of interest, in the optimal calibration range. It is also in a medium that does not interfere with and/or enhance the performance of the analytical instrument. It is under these ideal conditions that the lowest concentration can be reported, while minimising uncertainty due to matrix effects. This concentration is the limit of detection of the method. Other non-targeted compounds and constituents can interfere with the sample analysis, and the corrected concentration is reported (limit of reporting).

Limits of reporting for the various components tested are tabled below.

Analysis / Analyte	Limit of reporting; LOR (generally 1–5 times the limit of detection)
Vitamin C (L-ascorbic acid)	1 mg/100g
Beta-carotene	5 μ g/100g
Ash	0.1 g/100g
Carbohydrates	2 g/100g (calculated by difference)
Dietary fibre	0.05 g/100g
Energy	Calculation
Fat	0.2 g/100g
Moisture	0.2 g/100g
Saturated fat	0.10 %
Trans fat	0.10 %
Mono-saturated fat	0.10 %
Polysaturated fat	0.10 %
Protein	0.2 g/100g
Sodium	10 mg/kg
Total sugars	1 g/100g
Fructose	0.2 g/100g
Glucose	0.2 g/100g
Lactose	0.2 g/100g
Maltose	0.2 g/100g
Sucrose	0.2 g/100g

If the limit of reporting, say for example, for beta-carotene in the methodology used is 5 μ g/100g that value means that the laboratory can measure with reasonable accuracy at this level. Any level below the accuracy is not that good and the measurement of uncertainty below the limit of reporting, for example for beta-carotene in the methodology used is 26%.

Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level using GenStat for Windows 14th Edition (VSN International 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed by analysis of variance (ANOVA) separately, as well as a 2-way factorial ANOVA to investigate the time by dose interaction. Where a significant dose or time effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD).

Where all or the majority of data was censored (below the level of reporting) the data could not be analysed. For total ascorbic acid there were a minority of values censored and the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not underestimated.

Results and Discussion

Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required; 0, 150, 600 and 1000 Gy. The average irradiation dose absorbed complies with the required specifications of the study. The Irradiation Report is presented in the section below and reports minimum, maximum and average absorbed doses.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke.

The dose rate was approximately 15.2 Gy/min. Irradiation temperature was 22.7–23.3°C.

Apricot and plums



Ansto
Nuclear-based science benefiting all Australians



ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

8 February 2012

Irradiation Report

ANSTO Reference	12-1964 A (Apricots) & B (Plums)
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay

ANSTO Ref: 12-1964		SRT F 004	
Prepared 	Authorised 	Date 8.2.2012	Page 1 of 5
Sohil Sheth	Connie Banos		

Product Details	
Product	Apricots and Plums
Quantity	10 × 5 kg boxes Apricots 10 × 5 kg boxes plums
Irradiation Conditions	
Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	4 January 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 15.2 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F227
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	22.7 to 23.3 °C
ANSTO Ref: 12-1964 SRT F 004	
Prepared 	Authorised  Date 8.2.2012 Page 2 of 5
Sohil Sheth	Connie Banos

The apricots and plums that were received for processing were repacked into trays. The trays for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited with in the trays at the front and in between apricots and plums (Figure 1). Additional dosimeters were attached to the outside of one tray to provide a reference to the minimum and maximum doses (the monitoring position). The trays were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R2) samples from the first lot were used to carry out a dose mapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dose mapping repeated twice with dosimeters at those locations. This dose mapping information was used to process the remaining trays of apricots and plums to their target doses.



Figure 1: Dosimeters positioned on bags of apricots and plums.

ANSTO Ref: 12-1964

SRT F 004

Prepared

SH

Sohil Sheth

Authorised

CB

Connie Banos

Date

8.2.2012

Page 3 of 5



Figure 2: Trays positioned for irradiation.

Results for Apricots and Plums

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	140 ± 9	157 ± 7	149 ± 6
600	Replicate 1	546 ± 27	612 ± 21	579 ± 17
1000	Replicate 1	912 ± 32	1022 ± 25	967 ± 20
150	Replicate 2	138 ± 9	154 ± 7	146 ± 6
600	Replicate 2	574 ± 7	644 ± 7	609 ± 5
1000	Replicate 2	937 ± 29	1051 ± 22	994 ± 18
150	Replicate 3	141 ± 10	158 ± 7	149 ± 6
600	Replicate 3	556 ± 27	623 ± 21	590 ± 17
1000	Replicate 3	922 ± 32	1034 ± 25	978 ± 20

ANSTO Ref: 12-1964

SRT F 004

Prepared

Sh

Sohil Sheth

Authorised

CB

Connie Banos

Date

8.2.2012

Page 4 of 5

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of
Radiation Technology, ANSTO.

ANSTO Ref: 12-1964

SRT F 004

Prepared



Sohil Sheth

Authorised



Connie Banos

Date

8. 2. 2012

Page 5 of 5

Nutritional components

High quality firm 'Black Amber' plums were treated and the samples were analysed at two occasions; the first analysis (Time 1) was one day after irradiation treatment and the second analysis (Time 2), after 35 days storage in a cold room set at 0°C.

There were no significant time by dose interactions detected in any of the nutritional components tested (Table 1) in 'Black Amber' plum however, storage time affected the levels in ash, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene), carbohydrates, fructose, protein, total dietary fibre and total sugars.

Each time was analysed separately to determine the effect of irradiation on the nutritional components (Tables 2 and 3). No main effect of irradiation dose was detected in Time 1 (Table 2) and at Time 2 (Table 3). Irradiation did not affect the levels in ash, carbohydrates, dietary fibre, energy, fat, moisture, sodium, protein, total sugar, fructose, glucose and Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

Irradiation did not affect the Vitamin C (total ascorbic acid) concentrations after irradiation (Table 2) and after 35 days (Table 3). There were no significant differences in mean Vitamin C (total ascorbic acid) levels reported between irradiated plum samples and the untreated control. At Time 1 mean Vitamin C (total ascorbic acid) was 1.10 mg/100g in the control sample compared to 1.23 mg/100g, 1.30 mg/100g and 0.83 mg/100g in the 150 Gy, 600 Gy and 1000 Gy samples, respectively (Table 2). After 35 days storage the total ascorbic acid reduced significantly to an overall mean of 0.34 mg/100g. The untreated control gave a measure of 0.37 mg/100g Vitamin C (total ascorbic acid) while 0.30, 0.37 and 0.33 mg/100g were detected in the 150, 600 and 1000 Gy samples respectively.

Vitamin C (total ascorbic acid) levels in plum fruit detected here were lower than reported, but positive. A value of 5 mg/100g is found in NUTTAB (Food Standards Australia New Zealand database (FSANZ) 2010) and the USA database reports a level of 9.5 mg/100g (USDA 2010). The level of ascorbic acid is known to vary with cultivar, ranging from 3–10 mg/100g in different plums (Gil *et al.* 2002). Lee *et al.* (2008a) found no significant effect of gamma irradiation and treatment with electron beam (Lee *et al.* 2008b) in Vitamin C in the stone fruit, apricot, at doses up to 2 kGy.

Our fruit handling procedures and temperature variation during transportation between facilities may have contributed to the lower levels detected since Vitamin C losses are accelerated at higher temperatures (Lee and Kader 2000). No error in analysis was detected by the independent laboratory undertaking the testing and all duplicates, controls and spike recoveries were found within the acceptable criteria. While pre-harvest conditions, harvesting, and postharvest handling procedures can influence the Vitamin C content of fruits, temperature management after harvest is considered to be the most important factor to maintain Vitamin C in fruit (Lee and Kader 2000).

Fresh untreated plum contained a mean of 36.7 µg/100g beta-carotene at Time 1 and the irradiated samples ranged between 32.7 and 39.3 µg/100g (Table 1). In all cases, mean beta-carotene increased in all samples with storage. At Time 2, a significant increase in mean beta carotene was observed; from a mean of 36.4 µg/100g before storage to 48.9 µg/100g after 35 days (Table 1). Although there was

no dose effect detected, the irradiated samples recorded higher increases in beta-carotene after 35 days. The levels reported in this study are lower than the values reported in NUTTAB (147 µg/100g FSANZ 2010) and the USDA nutrient database (190 µg/100g USDA 2010).

Hussain *et al.* (2011) found a strong positive correlation between irradiation treatment and beta-carotene content in sundried apricots irradiated at doses ≥ 1 kGy. The increase in beta-carotene in irradiated samples was attributed to the increased extractability of carotenoids resulting from the changes in cellular structure (Boylston *et al.* 2002, Moreno *et al.* 2007).

The beta-carotene content of fruits and vegetables can also vary depending on the season and degree of ripening. Ampomah-Dwamena (2009) found that beta-carotene concentration in kiwifruit increased with developmental stage; beta-carotene concentration was 24% of total carotenoid in mature green kiwifruit, and increased during ripening to 40% at the stage when the colour change appeared complete. The plum fruit used in this study was not fully ripe and could have given the lower beta-carotene values observed and then rose while in storage. Katayama *et al.* (1971) showed that beta-carotene in other stone fruits (apricots) increased rapidly in the ripening period, from green stage to ripe stage.

Immaturity in the fruit tested may also have attributed to the lower total ascorbic acid content discussed previously.

Another factor affecting beta-carotene content in fruits is orchard soil management. Yellow plums grown in orchards where the natural meadow covered the soil apparently accumulated more beta-carotene than fruit grown in tilled soil or soil covered with *Trifolium* (Lombardi-Boccia *et al.* 2004).

Storage time significantly affected ash content, carbohydrates, total dietary fibre, protein and total sugars. Ash, protein and dietary fibre decreased after 35 days while carbohydrates and total sugars increased. At initial testing, the main sugars are glucose and fructose. Sucrose was not detected. Ripening of plum resulted in significantly increased fructose (overall mean increase in all samples from 3.15 g/100g to 3.57 g/100g) and increased concentration of total sugars after 35 days storage at 0°C. Mean overall total sugars in all samples increased from 7.11 to 7.57 g/100g while in cold storage. Glucose was found to be highest (ranging from 3.90 to 4.13 g/100g at Time 2), followed by fructose (3.50–3.63 g/100g at Time 2). The mean glucose level in all plum fruit remained statistically unchanged, around 4.0 g/100g.

In a study with apricot, total sugar and reducing sugar were not affected when exposed to gamma irradiation treatment up to 2 kGy and stored at 20°C over a two week period Lee *et al.* (2008a). Similarly, treatment with electron beam at 1 kGy and 2 kGy also did not affect total sugar (Lee *et al.* 2008b).

The minor changes in mean values in the chemical components are thought to be responses from general fruit ripening although very slowly as the samples were stored at 0°C. At 0°C, respiration is reduced to a level that is just enough to maintain cell function. Ripening in plum harvested when mature is accompanied by a rise in respiration rate, followed by a slowing down as the fruit ripens and develops good eating quality. Ripeness is followed by senescence and breakdown of the fruit, which is the normal aging of produce.

No significant dose and storage time interactions were found in protein in plum. The protein level in all plum fruit, treated and untreated, decreased from an overall mean of 0.54 g/100g to 0.47 g/100g between Time 1 and Time 2 (Table 1). No statistically significant dose effect was found at either assessment times although the decrease observed was greatest in the untreated sample. Certain physiological and biochemical changes are induced by exposure to low temperatures (Wang 1990), and the responses may be related to an accumulation or a decrease in specific mRNAs and proteins (Watkins *et al.* 1990), suggesting a general decrease in metabolic activity of fruit. In contrast, hot water treatment impeded loss of several proteins during room temperature fruit ripening (Yimyong *et al.* 2011).

The moisture content of control and irradiated 'Black Amber' plum just after irradiation treatment and 35 days later varied between 88.57 g/100g and 89.33 g/100g. There was no statistical moisture loss as a result of irradiation treatment and after 35 days in storage at 0°C.

Viljoen (2011) irradiated plums up to 800 Gy and found that as cell membranes become more permeable with ripening, fluids from cells are released into the intra-cellular regions of the flesh tissue, thereby reversing shrivel symptoms. Higher levels of shrivel were associated with higher irradiation dosages. He also found that decay, total soluble solids and acid levels were not affected by the irradiation.

The small changes noted here are thought to be normal responses in the ripening process and not biologically significant. It is also known that the nutritional qualities will vary depending on cultivar, production location, maturity stage, season and processing methods (Davey, 2000; Dewanto *et al.* 2002, Elkins 1979, Howard *et al.* 1999, Korus *et al.* 2002, Lee *et al.* 1976, Martin-Belloso and Llanos-Barriobero 2001, Abushita *et al.* 2000).

This study shows that plum can be irradiated at doses <1 kGy without any significant loss to the nutritional quality and can be considered as a method for phytosanitary disinfestation.

Table 1. A factorial analysis investigating the time by dose interaction 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time		Mean	Factor	ANOVA's	
		1	2			P-value	SED
Ascorbic Acid* (mg/100g)	0	1.10	0.37	0.73	Time	<0.001	0.060
	150	1.23	0.30	0.77	Irrad Dose	0.060	0.085
	600	1.30	0.37	0.83	Time x Irrad.	0.068	0.120
	1000	0.83	0.33	0.58			
	Mean	1.12 ^a	0.34 ^b				
Ash (g/100g)	0	0.37	0.37	0.37	Time	0.033	0.025
	150	0.33	0.27	0.30	Irrad Dose	0.127	0.035
	600	0.33	0.23	0.28	Time x Irrad.	0.553	0.049
	1000	0.33	0.27	0.30			
	Mean	0.34 ^a	0.28 ^b				
Beta Carotene (ug/100g)	0	36.7	41.0	38.8	Time	<0.001	2.12
	150	39.3	51.3	45.3	Irrad Dose	0.208	2.99
	600	32.7	55.0	43.8	Time x Irrad.	0.063	4.23 ^{cd}
	1000	37.0	48.3	42.7			
	Mean	36.4 ^b	48.9 ^a				
Carbohydrates (g/100g)	0	9.0	9.3	9.2	Time	0.015	0.27
	150	8.3	9.3	8.8	Irrad Dose	0.789	0.38
	600	8.7	9.3	9.0	Time x Irrad.	0.789	0.54
	1000	8.7	9.7	9.2			
	Mean	8.7 ^b	9.4 ^a				
Energy (kJ/100g)	0	176.7	173.3	175.0	Time	0.117	4.00
	150	163.3	173.3	168.3	Irrad Dose	0.453	5.65
	600	163.3	173.3	168.3	Time x Irrad.	0.570	7.99
	1000	170.0	180.0	175.0			
	Mean	168.3	175.0				
Fat (g/100g)	0	C	C		Time		
	150	C	C		Irrad Dose		
	600	C	C		Time x Irrad.		
	1000	C	C				
	Mean						
Fructose (g/100g)	0	3.27	3.57	3.42	Time	<0.001	0.064
	150	3.17	3.57	3.37	Irrad Dose	0.537	0.090
	600	3.07	3.50	3.28	Time x Irrad.	0.642	0.127
	1000	3.10	3.63	3.37			
	Mean	3.15 ^c	3.57 ^a				

Means in treatment followed by the same letter are not significantly different

C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Table 1 contd. A factorial analysis investigating the time by dose interaction using a 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Glucose (g/100g)	0	4.23	3.97	4.10	Time	0.689	0.102
	150	3.97	4.00	3.98	Irrad Dose	0.295	0.144
	600	3.73	3.90	3.82	Time x Irrad.	0.352	0.204
	1000	3.90	4.13	4.02			
	Mean	3.96	4.00				
Moisture (g/100g)	0	88.70	88.77	88.73	Time	0.309	0.229
	150	89.17	88.90	89.03	Irrad Dose	0.607	0.324
	600	89.17	89.17	89.17	Time x Irrad.	0.576	0.458
	1000	89.33	88.57	88.95			
	Mean	89.09	88.85				
Protein (g/100g)	0	0.57	0.47	0.52	Time	0.032	0.060
	150	0.53	0.50	0.52	Irrad Dose	0.948	0.085
	600	0.53	0.47	0.50	Time x Irrad.	0.870	0.120
	1000	0.53	0.47	0.50			
	Mean	0.54 ^a	0.47 ^b				
Sodium (mg/100g)	0	C	C		Time		
	150	C	C		Irrad Dose		
	600	C	C		Time x Irrad.		
	1000	C	C				
	Mean						
Sucrose (g/100g)	0	C	C		Time		
	150	C	C		Irrad Dose		
	600	C	C		Time x Irrad.		
	1000	C	C				
	Mean						
Total Dietary	0	1.57	1.00	1.28	Time	<0.001	0.066
Fibre (g/100g)	150	1.70	0.93	1.32	Irrad Dose	0.268	0.093
	600	1.37	0.93	1.15	Time x Irrad.	0.193	0.131
	1000	1.37	1.00	1.18			
	Mean	1.50 ^a	0.97 ^b				
Total Sugars (g/100g)	0	7.50	7.53	7.52	Time	0.012	0.160
	150	7.13	7.57	7.35	Irrad Dose	0.351	0.226
	600	6.80	7.40	7.10	Time x Irrad.	0.436	0.320
	1000	7.00	7.77	7.38			
	Mean	7.11 ^d	7.57 ^a				

Means in treatment followed by the same letter are not significantly different.
C = majority of the data is censored.

Table 2. Mean chemical measurements in 'Black Amber' plum fruit after irradiation treatment (Time1).

Time 1	Dose (Gy)				p-value	SED
Component	0	150	600	1000		
<i>Ascorbic Acid*</i> (mg/100g)	1.10 (0.100)	1.23 (0.306)	1.30 (0.100)	0.83 (0.153)	0.095	0.159
Ash (g/100g)	0.37 (0.058)	0.33 (0.115)	0.33 (0.115)	0.33 (0.058)	0.802	0.041
Beta Carotene (ug/100g)	36.7 (6.51)	39.3 (5.69)	32.7 (3.79)	37.0 (2.00)	0.442	3.85
Carbohydrates (g/100g)	9.0 (0.00)	8.3 (0.58)	8.7 (0.58)	8.7 (1.15)	0.793	0.65
Energy (kJ/100g)	176.7 (5.77)	163.3 (5.77)	163.3 (11.55)	170.0 (17.32)	0.563	10.45
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	3.27 (0.058)	3.17 (0.115)	3.07 (0.153)	3.10 (0.200)	0.412	0.118
Glucose (g/100g)	4.23 (0.115)	3.97 (0.115)	3.73 (0.306)	3.90 (0.400)	0.262	0.224
Moisture (g/100g)	88.70 (0.529)	89.17 (0.115)	89.17 (0.874)	89.33 (0.808)	0.624	0.487
Protein (g/100g)	0.57 (0.058)	0.53 (0.058)	0.53 (0.058)	0.53 (0.058)	0.893	0.053
Sodium (mg/100g)	C	C	C	C		
Sucrose (g/100g)	C	C	C	C		
Total Dietary Fibre (g/100g)	1.57 (0.252)	1.70 (0.173)	1.37 (0.153)	1.37 (0.306)	0.135	0.139
Total Sugars (g/100g)	7.50 (0.173)	7.13 (0.231)	6.80 (0.458)	7.00 (0.600)	0.308	0.341

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

*Total ascorbic acid data presented are at limits of detection.

Table 3. Mean chemical measurements in untreated and irradiated 'Black Amber' plum fruit after 35 days cold storage at 0°C (Time 2).

Time 2 Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid* (mg/100g)	0.37 (0.058)	0.30 (0.000)	0.37 (0.058)	0.30 (0.115)	0.666	0.061
Ash (g/100g)	0.37 (0.153)	0.27 (0.115)	0.23 (0.058)	0.27 (0.115)	0.117	0.047
Beta Carotene (ug/100g)	41.0 (6.08)	51.3 (9.29)	55.0 (1.00)	48.3 (8.14)	0.111	4.77
Carbohydrates (g/100g)	9.3 (0.58)	9.3 (0.58)	9.3 (0.58)	9.7 (0.58)	0.859	0.47
Energy (kJ/100g)	173.3 (5.77)	173.3 (5.77)	173.3 (5.77)	180.0 (10.00)	0.538	5.27
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	3.57 (0.058)	3.57 (0.058)	3.50 (0.200)	3.63 (0.208)	0.800	0.133
Glucose (g/100g)	3.97 (0.153)	4.00 (0.100)	3.90 (0.265)	4.13 (0.321)	0.736	0.210
Moisture (g/100g)	88.77 (0.153)	88.90 (0.520)	89.17 (0.351)	88.57 (0.473)	0.393	0.327
Protein (g/100g)	0.47 (0.058)	0.50 (0.000)	0.47 (0.115)	0.47 (0.058)	0.942	0.067
Sodium (mg/100g)	C	C	C	C		
Sucrose (g/100g)	C	C	C	C		
Total Dietary Fibre (g/100g)	1.00 (0.000)	0.93 (0.058)	0.93 (0.058)	1.00 (0.173)	0.738	0.083
Total Sugars (g/100g)	7.53 (0.208)	7.57 (0.153)	7.40 (0.458)	7.77 (0.451)	0.738	0.326

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

Recommendation

The overall findings of this study showed that an irradiation application of up to 1 kGy will not result in any significant detrimental damage to the nutritional quality of 'Black Amber' plum. The effect of storage time was greater in the chemical components tested than by irradiation itself and the changes generally appeared to be associated with the ripening/senescence process during storage.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of plum fruit.

References

- Abushita, A.A., Daood, H.G. and Biacs, P.A. (2000). Change in carotenoids and antioxidant vitamins in tomato as a function of varietal and technological factors. *Journal of Agricultural and Food Chemistry* 48: 2075–2081.
- Ampomah-Dwamena, C., McGhie, T., Wibisono, R., Montefiori, M., Hellens, R.P. and Allan, A.C. (2009). The kiwifruit lycopene beta-cyclase plays a significant role in carotenoid accumulation in fruit. *Journal of Experimental Botany Advance Access published July 2, 2009* 15pages.
- AOAC. Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Badings, H.T. and de Jong, C. (1983). Glass capillary gas chromatography of fatty acid methyl esters: a study of conditions for the quantitative analysis of short- and long-chain fatty acids in lipids. *Journal of Chromatography* 279: 493–506.
- Bligh, E.G. and Dwyer, W.J. (1959). A Rapid Method of Total Lipid Extraction and Purification". *Canadian Journal of Biochemistry and Physiology* 37: 911–917.
- Boylston, T.D., Reitmeier, C. A., Moy, J.H., Mosher, G.A. and Taladriz, L. (2002). Sensory quality and nutrient composition of three Hawaiian fruits treated by X-irradiation. *Journal of Food Quality* 25: 419-433.
- Brubacher, G., Muller-Mulot, W. and Southgate, W.A.T. (eds). *Methods for the Determination of Vitamins in Food* (1985). Elsevier Applied Science Publishers Ltd Ch 5.
- CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251. 92nd edition link online <http://www.hbcpnetbase.com/>
- Davey, M.W., Montagu, M.V., Inze, D., Sanmartin, M., Kanellis, A., Smirnoff, N., Benzie, I.J.J., Strain, J.J., Favell, D. and Fletcher, J. (2000). Plant Lascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *Journal of the Science of Food and Agriculture* 80: 825–860.
- Dewanto, V., Wu, X., Adom K.K. and Liu, R.H. (2002). Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *Journal of Agricultural and Food Chemistry* 50: 3010–3014.
- Dickson, J.S. (2012). Radiation meets food. *Physics Today* 65 (2): 66–67.
- Elkins, E.R. (1979). Nutrient content of raw and canned green beans, peaches, and sweet potatoes. *Food Technology* 33: 66–70.

- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339.
<http://www.comlaw.gov.au/Details/F2010C00339>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database.
<http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>
- Gil, M.I., Tomas-Barberan, F.A. Hess-Pierce, B. and Kader A.A. (2002). Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and plum cultivars from California. *Journal of Agricultural and Food Chemistry* 50: 4975–4982.
- Hallman, G.J. (2003). Ionizing Irradiation Quarantine Treatment Against Plum Curculio (Coleoptera: Curculionidae). *Journal of Economic Entomology* 96 (5): 1399–1404.
- Hallman, G.J. (2004). Ionizing irradiation quarantine treatment against oriental fruit moth (Lepidoptera: Tortricidae) in ambient and hypoxic atmospheres. *Journal of Economic Entomology* 97 (3): 824–827.
- Howard, L.A., Wong, A.D., Perry, A.K. and Klein, B.P. (1999). β -Carotene and ascorbic acid retention in fresh and processed vegetables. *Journal of Food Science* 64: 929–936.
- Hussain, P.R., Meena, R.S., Dar, M.A. and Wani, A.M. (2011). Gamma irradiation of sun-dried apricots (*Prunus armeniaca* L.) for quality maintenance and quarantine purposes. *Radiation Physics and Chemistry* 80 (7): 817–827.
- ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009).
https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Jooste, M.M. (1999) Optimum harvest maturity and cold-storage duration for *Prunus armeniaca* L. cvs. Supergold and Imperial cultivated in South Africa.
http://webcache.googleusercontent.com/search?q=cache:ZwQEJXvx4YJ:http://fruitgro.krazyboyz.co.za/media/uploads/documents/document/file/mariana_ca_pespan_-_apricots_pdf.pdf%2Bjooste+apricot&hl=en&safe=active&gbv=2&gs_l=serp.3...27259.27259.0.28617.1.1.0.0.0.250.250.2-1.1.0...0.0...1c.FVMd3idbtJo&ct=clink
- Jooste, M.M. and Taylor, M.A. (1999). Effect of harvest maturity and cold storage period on the overall quality of Bebeco apricots, with special reference to gel breakdown and varieties used to accurately establish harvest maturity. *Deciduous Fruit Grower* 49 (Sept): 39-44.
- Kader, A.A. (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40: 117–121.

- Katamaya, T., Nakayama, T.O.M., Lee, T.H. and Chichester, C.O. (1971). Carotenoid transformations in ripening apricots and peaches. *Journal of Food Science* 36: 804-806.
- Korus, A., Lisiewska, Z. and Kmiecik, W. (2002). Effect of freezing and canning on the content of selected vitamins and pigments in seeds of two grass pea (*Lathyrus sativus* L.) cultivars at the not fully mature stage. *Nahrung/Food* 46: 233–237.
- Lee, C.Y., Downing, D.L., Iredale, H.D. and Chapman, J.A. (1976). The variations of ascorbic acid content in vegetable processing. *Food Chemistry* 1: 15–22.
- Lee, J.O., Lee, S.A., Kim, M.S. Hwang, H.R., Kim, K.H. Chun, J.P. and Yook, H.S. (2008a). The effects of low-dose electron beam irradiation on quality characteristics of stored apricots. *Journal of the Korean Society of Food Science and Nutrition* 37 (7): 934–941.
- Lee, S.A., Lee, J.O., Kim, K.H., Kwon, J.S., Kim, H.G., Byun, M.W., Lee, J.W. and Yook, H.S. (2008b). Influence gamma irradiated on microbial and physicochemical changes of apricot. *Journal of the Korean Society of Food Science and Nutrition* 37 (6): 767–774.
- Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207–220.
- Lombardi-Boccia, G., Lucarini, M., Lanzi, S. Aguzzi, A. and Cappelloni, M. (2004). Nutrients and antioxidant molecules in yellow plums (*Prunus domestica* L.) from conventional and organic productions: a comparative study. *Journal of Agricultural and Food Chemistry* 52: 90–94.
- Mareno, M.A., Castell-Perez, M.E., Gomes, C., Da Silva, P.F. and Moreira, R.G. (2007). Quality of electron beam irradiation of blueberries (*Vaccinium corymbosum* L.) at medium dose levels (1.0-3.3 kGy). *LWT-Swiss Society for Food Science and Technology* 40: 1123–1132.
- Martin-Belloso, O. and Llanos-Barriobero, E. (2001). Proximate composition, minerals and vitamins in selected canned vegetables. *European Food Research and Technology* 212: 182–187.
- Maxie, E. C. and Abdel-Kader A. (1966). Food irradiation — physiology of fruits as related to feasibility of the technology. *Advances in Food Research* 15: 05–145.
- Mercier, R.G. and MacQueen, K.F. (1966). Gamma-irradiation to extend postharvest life of fruits and vegetables. Report Ontario Horticultural Experimental Statistics Station Production Laboratory 1965, pages 57-72.
- Miller, W.R. and McDonald, R.E. (1999). Irradiation, storage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience* 24: 1112–1115.

- Moy, J.H., Kaneshiro, K.Y., Mila, A.T. and Nagai, N. (1983). Radiation Disinfestation of California Stone Fruits Infested by Medfly – Effectiveness and Fruit Quality. *Journal of Food Science* 48: 928-931.
- Rajkowski, K.T. and Thayer, D.W. (2000). Reduction of *Salmonella* spp. and Strains of *Escherichia coli* O157:H7 by Gamma Radiation of Inoculated Sprouts. *Journal of Food Protection* 63 (7): 871–875.
- Taylor, J. (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35–43.
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website, <http://www.nal.usda.gov/fnic/foodcomp/search/>
- USEPA (United States Environmental Protection Agency). Method 6010b. Inductively coupled plasma-atomic emission spectrometry (ICP-MS). <http://www.epa.gov/region8/water/biosolids/analyticalmethods.html>
- USEPA (United States Environmental Protection Agency). Method 6020. Inductively coupled plasma-mass spectrometry (ICP-MS). <http://www.epa.gov/region8/water/biosolids/analyticalmethods.html>
- VSN International. (2011). GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK. Web Page: [GenStat.co.uk](http://www.genstat.co.uk)
- Wajea, C.K., Junb, S.Y., Leeb, Y.K., Kimc, B.N., Hanc, D.H., Jod, C. and Kwon, J.H. (2009). Microbial quality assessment and pathogen inactivation by electron beam and gamma irradiation of commercial seed sprouts. *Food Control* 20 (3):200–204.
- Wang, C.Y. (1990). Physiological and biochemical effects of controlled atmosphere on fruits and vegetables. In: M. Calderon and R. Barkai-Golan (eds.), p. 197–223. *Food preservation by modified atmospheres*. CRC Press, Boca Raton, Fla.
- Watkins, C.B., Picton, S. and Grierson, D. (1990). Stimulation and inhibition of expression of ripening-related mRNAs in tomatoes as influenced by chilling temperatures. *Journal of Plant Physiology* 136 (3): 318–323.
- Yimyong, S., Datsenka, T.U., Handa, A.K. and Seraypheap, K. (2011). Hot Water Treatment Delays Ripening-associated Metabolic Shift in 'Okrong' Mango Fruit during Storage. *Journal of the American Society for Horticultural Science* 136 (6): 441–451.
- Viljoen, H.W. (2011). Effect of gamma irradiation as a mitigation treatment on storage quality of plums. The South African Stone Fruit Producers Association, 7 pages.

Part B. Effect of gamma irradiation on the postharvest quality of plum (*Prunus domestica*) fruit.

Contents

Part B. Effect of gamma irradiation on the postharvest quality of plum (<i>Prunus domestica</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Fruit colour	41
Moisture loss and whole fruit softness	41
Biochemical analyses	42
Fruit disease and disorders	42
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Summary

Fruit quality evaluations were conducted on plum (*Prunus domestica*) fruit, variety 'Black Amber', after being treated with gamma irradiation and following a recommended cold storage period of 35 days. Gamma irradiation treatments consisted of a dose of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that plum fruit quality was impacted more by storage time than by irradiation itself. Fruit lost approximately 1.1% of their fresh weight over the 35 day storage period, irrespective of any irradiation treatment. Storage duration caused a significant reduction in fruit firmness, decreasing from 5.4 to 3.4 N before and after removal from cold storage. After the storage period, Brix levels remained similar to pre-storage levels (mean 11°) whereas titratable acidity values decreased significantly from 1.3 to 1.0%. Flesh colour represented by hue angle (mean 126°) and chroma (mean 5.8) values was not affected by irradiation dose or cold storage. However, skin lightness was affected by the interaction of the storage and irradiation treatment, with fruit from the 600 and 1000 Gy treatments being slightly darker in colour than the 0 (control) and 150 Gy-treated fruit by the end of the storage period. Irradiation and storage time had no effect on the development of any disorders and fruit from all treatments were free of disease. In conclusion, fruit quality overall remained relatively high over the storage duration, with the effect of storage having a greater impact on quality than that of irradiation.

Introduction

The present study aims to investigate the effects of gamma irradiation on the postharvest quality of plum (*Prunus domestica*) fruit. Gamma irradiation is regularly used not only for disinfestation purposes but also to control for decay and extend the storage and shelf life of perishable commodities (Mitchell *et al.* 1992). Past work has shown that plum fruit generally have a "moderate" tolerance to irradiation at doses of <1 kGy compared with other fruit and vegetables (Kader 1986). Several studies have reported that ionizing radiation can cause softening in plum fruit. South African grown 'Songold' plums, for example, became significantly softer when irradiated with between 600 to 800 Gy compared to untreated fruit (Viljoen 2011). However, this effect was negated when fruit were pretreated with 1-MCP. 'Songold' plums treated to the higher dose of irradiation (800 Gy) were also prone to developing gel breakdown, although apart from this disorder, the quality of fruit from all treatments was considered acceptable after 45 days of cold storage (Viljoen 2011). Moy *et al.* (1983) also observed changes in plum fruit colour between treated and untreated fruit at 0.5 kGy, and in fruit texture between 0.5 and 1 kGy, although no internal disorders were reported. As noted by several authors (Kader 1986, Mitchell *et al.* 1992), responses to irradiation can vary widely between variety, harvest maturity, growing conditions and or geographic location.

In the present study, the effects of irradiation and cold storage duration were therefore examined on Australian grown plum fruit (var. 'Black Amber') to assess their effects on fruit quality following irradiation and a subsequent cold storage period. Fruit assessments entailed measurements of physico-chemical changes in fruit quality. The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation (at and below 1 kGy) on a variety grown and marketed under Australian conditions. This work will also compliment current findings from the nutritional component of this study described earlier in this report, which also incorporated fruit selected from the same irradiation and cold storage type treatments as in this study.

Materials and methods

Experimental layout

Plum (*Prunus domestica*) fruit, variety 'Black Amber', were sourced from the Sydney Markets, NSW in early January 2012. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where ca. 40 fruit in cardboard trays were irradiated over three sequential times (blocking factor) with target doses of 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group and remained at all times under the same environmental conditions as treated fruit. Replication consisted of a random selection of 10 individual fruit from each tray, comprising one of three blocks per irradiation treatment per assessment time (two times).

Following the irradiation treatment, fruit were packed and immediately transported by air to the Queensland Department of Agriculture, Fisheries and Forestry Postharvest Laboratory in Cairns. Within 24 hours, half the fruit were destructively assessed for quality determination (Day 1) while the second half was transferred into cold storage ($0.5 \pm 0.5^\circ\text{C}$ at 85% RH) and held for 35 days before being destructively assessed. Storage condition and duration requirements were based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2012). During storage, ambient air temperature and relative humidity conditions were also monitored to ensure they remained within the specifications of the trial.

Fruit quality assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, skin and / or flesh colour, biochemical analyses (determination of soluble solids and titratable acidity), and a record of the incidence and severity of disorders and disease types. A description of each assessment method is described below.

Fruit colour

Fruit skin colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8 mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L^* , C^* , h° units).

Moisture loss and whole fruit softness

Fruit were weighed before and after cold storage. Percent moisture loss was calculated by determining the proportion of moisture lost by the end of the storage period compared with the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the

equatorial region of each fruit was undertaken using a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newton (N).

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were assessed before and after storage. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

Fruit disease and disorders

If present, the incidence and severity of disease and or disorders were scored on individual fruit before and after storage. Incidence was based on the proportion of fruit within a treatment expressing symptoms and severity on the proportion (%) of skin (or cut flesh) surface area affected.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A general ANOVA's was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a Fisher's Least Square Difference (LSD) test at 5%.

Results and Discussion

The following study contributes towards further enhancing our baseline knowledge of the effects of irradiation on fruit quality in plum. In this study, gamma irradiation applied up to 1 kGy in addition to 35 days of cold storage had only a minor effect on several fruit quality attributes (Table 1). Although there was no significant difference in percent moisture loss between irradiation treatments during storage (mean 1.1% moisture lost), there was a significant reduction in fruit firmness. Initial mean fruit firmness levels (5.4 N) decreased by 1.6 N after 35 days cold storage. In contrast, fruit softening or changes in texture due to the effects of irradiation have been reported in several other plum varieties. Viljoen (2011), for example, observed increased softening in 'Songold' plums grown in South Africa when subjected to target doses of between 400 to 800 Gy, although this effect was negated when used with 1-MCP. Sensory evaluation panels were also able to detect a difference in flesh texture of a Californian grown plum fruit (var. 'Casselman') when treated with a dose of around 500 Gy compared with untreated fruit.

In this study, plum fruit exhibited minor changes in quality associated with ripening during storage. Fruit not only became softer but titratable acidity levels decreased from 1.3 to 1.0% citric acid over the 35 days storage period (Table 1). Additionally, fruit became a slightly darker red colour over this period, which was partially enhanced by higher irradiation doses (≥ 600 Gy). Kader (1986) also reported that applications of ionizing radiation above 150 Gy may cause undesirable side effects such as tissue darkening in various fruit types. The overall extent of darkening in plum skin in this study was small (< 2 lightness units between irradiation doses), with the differences not being visibly discernable with the naked eye (Plate 1).

Several other fruit quality attributes were not affected by any of the treatments included several fruit colour properties (eg. skin hue angle and chroma values) and Brix levels, and no disease or disorders were detected on any of the fruit samples. Fruit quality overall was therefore found to remain relatively high with the storage rather than irradiation treatment component having a greater impact on quality.

Table 1. Effect of irradiation dose and storage duration on the quality attributes of plum fruit. Fruit were gamma irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and then assessed within 24 hours (Day 1) and after 35 days (Day 35) in cold (0.5°C) storage.

Variable	Day	Irradiation dose (Gy)				Mean	ANOVA's	
		0	150	600	1000		Factor	P-value
Moisture loss (%)	35	0.9	1.1	1.3	1.0	1.1	Irradiation	ns
Firmness	1	4.3	5.1	5.5	5.0	5.0 ^a	Storage	<0.001
(N)	35	3.8	3.1	3.2	3.5	3.4 ^o	Irradiation	ns
	Mean	4.1	4.1	4.4	4.3		Storage x Irradiation	ns
Skin	1	26.1 ^a	25.9 ^{ab}	26.1 ^a	26.4 ^a	26.1	Storage	<0.001
lightness	35	25.5 ^{bc}	25.1 ^{cd}	24.4 ^e	24.9 ^{de}	25	Irradiation	<0.05
	Mean	25.8	25.5	25.3	25.7		Storage x Irradiation	<0.05
Skin	1	6.3	5.5	5.5	5.7	5.7	Storage	ns
chroma	35	6.4	5.4	5.1	6.6	5.9	Irradiation	ns
	Mean	6.3	5.4	5.3	6.2		Storage x Irradiation	ns
Skin	1	98.9	168.9	133.0	99.3	123.8	Storage	ns
hue angle	35	145.1	155.8	143.8	68.5	127.9	Irradiation	ns
	Mean	122	162.3	138.4	80.7		Storage x Irradiation	ns
TSS	1	10.8	10.9	10.8	11.0	10.9	Storage	ns
("Brix)	35	11.0	10.6	10.8	11.4	10.9	Irradiation	ns
	Mean	10.9	10.7	10.8	11.1		Storage x Irradiation	ns
TA	1	1.21	1.27	1.27	1.26	1.25 ^a	Storage	<0.001
(% citric acid)	35	1.04	1.00	0.98	0.92	0.98 ^b	Irradiation	ns
	Mean	1.12	1.13	1.12	1.09		Storage x Irradiation	ns



	Plums (var. Black Amber)	
Day 1		0Gy 150Gy 600Gy 1000Gy
Day 35		0Gy 150Gy 600Gy 1000Gy

Plate 1. Photographs of a representative sample of plum fruit ('Black Amber') irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and taken before and after a subsequent 35 day cold (0.5°C) storage period.

Recommendations

In this study, applications of gamma irradiation treatments of up to 1000 Gy may be safely used as a phytosanitary or disinfestation measure on plum fruit without inducing any deleterious effects on fruit quality. Cold storage for up to 35 days did however cause a slight reduction in fruit firmness and titratable acidity levels.

References

- Drake, S.R., Moffitt, H.R., Eakin, D.E. (1994) Low dose irradiation of 'Rainier' sweet cherries as a quarantine treatment. *Journal of Food Processing and Preservation* 18: 473-481.
- Kader, A.A. (1986) Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40 (6): 117-121.
- Kovacs, E., Balla, G., Nessinger, A. (1995) The effect of irradiation on sweet cherries. *Acta Alimentaria* 24 (4): 331-343.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291-311.
- UC Davis (2012) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 01 January, 2012, <<http://postharvest.ucdavis.edu/producefacts/>>

A2.6 Nutritional value of Table Grape

Table 62 provides key nutritional data for fresh red table grape. Values are extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). The significant differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Table grapes have a high water content, of approximately 80 %, with macronutrient levels and energy content low relative to many other foods. 100 g table grape provides 277–288 kJ energy, carbohydrate is 15–18 g/ 100g, total sugars 15–16 g/100g and vitamin and mineral contents are low.

The average nutrient values per single serve (150g for fresh fruit) can be derived and is presented in Table 63. The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived and shown in the same table. A single serve of table grapes accounts for approximately 4.8–5.6 % energy, 2.3–2.7 % protein, 7.5–7.9 % available carbohydrate, 0–17.5 % total dietary fibre, 25.8–27.2 % total sugar and 0.1–0.3 % sodium.

Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the major energy value comes from available carbohydrate at approximately 263–277 kJ/100g. Minute amounts come from protein, fats and dietary fibre (Table 64).

The Vitamin C content of red table grapes (3.2–10.8 mg/100g) is low and comparable to other more commonly eaten fruits such as apples (5 mg/100g) and banana (4 mg/100g). The β -carotene content of red table grape is in the range found for many other fruits however, the values vary with variety.

Table 7 compares vitamin values for the nine tropical fruits, persimmon, tomato and capsicum approved for irradiation by FSANZ. Generally the pattern of vitamin content of table grape is not too different and within ranges of the particular component of the foods in the table.

In addition to fresh fruits, the main sources of pro-vitamin A (carotenes) and Vitamin C are found in other fresh produce and vitamin A in foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables generally are an excellent source of vitamin K, as are grains and dairy and egg products. Nuts, seeds and vegetable oils, as well as many fresh vegetables are good sources of vitamin E. Folate can be found in small amounts in many foods with a major dietary source being enriched and fortified foods

Table grape is not a significant part of the average consumer's diet and the nutrient values show that its contribution to overall micronutrient intake is therefore also not significant. Table grape is a popularly consumed fruit in Australia and New Zealand, ranked third in the most commonly eaten fruits - apples > oranges > grapes (inc. wine) > banana > pear (MOH 1999). It is not known that there are any sub-populations who may have a higher than average consumption of table grapes. From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will come from foods other than table grapes. Contribution to micronutrient intake will not be significant as well. There are other fresh fruits and vegetables and foods that contribute greater amounts of nutrition to daily dietary intake.

Table 62: Nutritional data for table grape (*Vitis vinifera*) per 100 g edible portion.

Nutrient	value	Table grape *		
		USDA 2011	MOH 2009	FSANZ 2010 (red globe)
Water	g	80.54	80.54	80.7
Energy	KJ	288	277	322
Protein	g	7.2	0.75	0.9
Nitrogen	g		0.12	0.14
Total lipid (fat)	g	0.16	0.16	0.2
Malic acid	g			1
Citric acid	g			0
Carbohydrate	g	18.1	15.48	16.3
Total Dietary Fibre	g	0.9	0	3.5
Ash	g	0.48	0.48	0.7
Total sugars	g	15.48	15.48	16.3
Fructose	g	8.13	8.13	9.2
Glucose	g	7.2	7.2	7.1
Sucrose	g	0.15	0.15	0
Ascorbic Acid, Vit C	mg	3.2	10.8	0
Thiamin, Vit B1	mg	0.069	0.07	0.03
Riboflavin, Vit B2	mg	0.07	0.07	0
Niacin	mg	0.188	0.19	0
Niacin equivalents	mg			0.15
Vit B6	mg	0.086	0.09	0.03
Folate, Vit B9 total	µg	2		0
Vit A (retinol equiv.)	µg	3		0
Alpha carotene	µg	1		0
Beta carotene	µg	39		0
Beta cryptoxanthin	µg	0		
Cryptoxanthin	µg			0
Vit E	mg	0.19	0.2	0.5
Vit K	µg	14.6		
Calcium	mg	10	10	10
Iron	mg	0.36	0.36	0.42
Magnesium	mg	7	7	8
Phosphorus	mg	20		19
Potassium	mg	191	191	270
Sodium	mg	2	2	5
Zinc	mg	0.07	0.07	0.22
Copper	mg	0.127		0.1
Manganese	mg	0.071		0.08
Selenium	µg	0.1	0.1	0
Iodine	µg		0.49	0
Molybdenum	µg			1.3
Nickel	µg			0
Tin	µg			

*raw with skin

Table 63: Nutrient values are per 100 g edible portion of table grape.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	80.7	80.54	121.05	120.81			
Energy (kJ)	322	277	483	415.5	5.6	4.8	8700
Protein (g)	0.9	0.75	1.35	1.125	2.7	2.3	50
Total lipid (fat) (g)	0.2	0.16	0.3	0.24	0.4	0.3	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	16.3	15.48	24.45	23.22	7.9	7.5	310
Sugar (g)	16.3	15.48	24.45	23.22	27.2	25.8	90
Total dietary fibre (g)	3.5	0	5.25		17.5	0.0	30
Sodium (mg)	5	2	7.5	3	0.3	0.1	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 64: Calculation of energy value of the major* food components per 100 g table grape.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ/g	Average quantity	Approximate calculation of energy value kJ/g
Protein	17	0.9	15.3	0.75	12.75
Total lipid (fat)	37	0.2	7.4	0.16	5.92
Fatty acids, total saturated			0		0
Available Carbohydrate	17	15.48	277.1	15.48	263.16
Total sugars		15.48	0	15.48	0
Total dietary fibre	8	0	28	0	0

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of table grapes

QLD DAFF (2013) recently conducted nutritional and fruit quality evaluations of fresh red table grape (*Vitis vinifera*) fruit, variety 'Flame Seedless', after being treated with gamma irradiation and following a recommended cold (0°C) storage period of 50 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gray (Gy), with fruit evaluations conducted before and after storage (See Attachment in this section).

The QLD DAFF study found that applications of gamma irradiation treatments of up to 1000 Gy can be safely applied on fresh table grape fruit without inducing any significant damaging effects on the nutritional quality and postharvest fruit quality. No nutritional quality loss in table grape fruit was found after irradiation applications of up to 1 kGy. Energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) were not affected. Similar results were found in the study by Kang *et al.* (2012) who found that X-ray irradiation up to 1.0 kGy had no negative effect on the physical and chemical quality of fresh American 'Red Globe' grape. Kang *et al.* (2012) found no significant effect of irradiation on weight loss, total soluble solids, titratable acidity, protein, mineral content and sensory assessments of 'Red Globe' table grapes irradiated at 0.2, 0.4, 0.6 and 1.0 kGy.

The nutritional status was affected more by the changes that occurred during the ripening process while in cold storage for 50 days. Cold storage for 50 days after treatment resulted in significantly lower Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) levels, the largest decrease observed in the 600 Gy sample (0.80 mg/100g). No significant dose effects were detected in beta-carotene in the control samples and the treated fruit one day after irradiation treatment (24.7–29.7 µg/100g) and after 50 days storage (17.7–24.7 µg/100g). The reported mean is 0 µg/100g in 'Red Globe' grapes (FSANZ 2010). A significant decrease was noted after 50 days, with the largest decrease seen in the untreated sample, from 29.7 µg/100g down to 18.0 µg/100g. Significant increases were observed in fructose, sodium and total dietary fibre. These minor changes were attributed primarily to changes associated with senescence.

The QLD DAFF postharvest fruit quality study found that table grape fruit were not impacted by irradiation treatments of up to 1000 Gy but entirely by the effects of storage. Fruit quality remained relatively high by the end of the 50 day storage period and it appeared that irradiation of up to 1 kGy can be beneficial for shelf life extension, as evidenced by the absence of disease or disorders, and by the presence of the natural bloom on the berries before and after storage. Similar results were shown in earlier studies, with gamma irradiation at doses up to 1.0 kGy (Al-Bachir 1998, Kang *et al.* 2012) and at 2 kGy (Donini and Pansolli 1970). Paek (2011) found that irradiation did not affect the shelf life of grapes and that age (or storage time) had a greater effect on the quality of the grapes than irradiation at doses up to 800 Gy and held at 3°C.

Table grapes in this study did not exhibit any symptoms of decay or disease expression, and the natural bloom was present on the fruit before and after storage. Fruit irradiated up to 1 kGy followed by cold storage of up to 50 days had little to no detrimental effects on fruit quality.

Overall, the nutritional and postharvest quality of table grapes in this study following irradiation and cold storage was relatively high before and after storage. Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method for table grape.



Effect of irradiation on the nutritional profile and postharvest quality of fresh table grape (*Vitis vinifera*) fruit.

Final Report
January 2013

Chay P., Henriod R., Wright C. & Leach P.



Australian Government
Department of Agriculture, Fisheries and Forestry



Know-how for Horticulture™
Department of Agriculture, Fisheries and Forestry

Project Title

Effect of irradiation on the nutritional profile and postharvest fruit quality of fresh table grape (*Vitis vinifera*) fruit.
Part of MT10057 Phase 2 Final Report (includes apple, apricot, cherry, peach, plum and table grapes).

The Report is presented in two parts.

Part A: Nutritional analysis
Part B: Postharvest fruit quality

Project Leaders

Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF), Queensland
P.O. Box 652 Cairns, Queensland, Australia 4870.

Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF), Queensland
P.O. Box 652 Cairns, Queensland, Australia 4870.

Market Access Focus Team Leader
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF), Queensland
P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

Research Scientist, DAFF Qld
I, Research Scientist, DAFF Qld
Senior Biometrician, DAFF Qld
Market Access Focus Team Leader, DAFF Qld

Technical Personnel

Technical Officer, DAFF Qld

Funding Sources

Horticulture Australia Limited (HAL)
Queensland Department of Agriculture, Fisheries and Forestry
Australian Government, Department of Agriculture, Fisheries and Forestry

Date of Report

January 2013

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.

..... Leader, Radiation Technology
....., Senior Technical Officer, Radiation Technology
..... echnical Officer, Radiation Technology
..... echnical Officer, Radiation Technology

© State of Queensland, 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

For more information on this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Contents

Executive Summary	5
 Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of table grapes (<i>Vitis vinifera</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	10
Cultivar	10
Irradiation treatment	11
Chemical analysis	13
Statistical analysis of chemical components	20
Results and Discussion	21
Irradiation treatment – dosimetry	21
Nutritional components	22
Recommendation	34
References	35
 Part B. Effect of gamma irradiation on postharvest quality of table grape (<i>Vitis vinifera</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Executive Summary

In this study, applications of gamma irradiation treatments of up to 1000 Gray (Gy) can be safely applied on fresh table grape (*Vitis vinifera*) fruit without inducing any significant damaging effects on the nutritional quality and postharvest fruit quality.

Fruit nutritional and quality evaluations were conducted on table grape (*V. vinifera*) fruit, variety 'Flame Seedless', after being treated with gamma irradiation and following a recommended cold storage period of up to 50 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy.

In the nutritional study, irradiation did not significantly affect all the components tested; these were ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene). Irradiation showed no significant effect on the nutritional quality of table grape fruit although storage time after 50 days at 0°C induced some significant changes, which were considered as part of the biological senescence process. Specifically, cold storage for 50 days after treatment resulted in significantly lower Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) levels but these were not affected by irradiation dose.

In the fruit quality study, changes observed in skin colour as a result of irradiation and 50 days cold storage were minor. While fruit was less firm after storage the natural bloom was present before and after storage and the fruit showed no symptoms of disease and decomposition. While irradiation showed no effect on firmness, doses at 600 and 1000 Gy appeared to have inhibited moisture loss of the stored fruit.

In conclusion, fruit irradiated up to 1 kGy followed by cold storage of up to 50 days had little to no detrimental effects on the nutritional quality and postharvest fruit quality of table grape fruit although it appears to be beneficial for shelf life extension.

Part A. Effect of low dose gamma (γ)– irradiation on the nutritional profile of table grapes (*Vitis vinifera*) fruit.

Contents

Executive Summary	5
Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of table grapes (<i>Vitis vinifera</i>) fruit.	6
Summary	7
Introduction	8
Materials and Methods	10
Cultivar	10
Irradiation treatment	11
Chemical analysis	13
Moisture. Method VL298 Version 6.2	13
Ash. Method VL286 Ver. 5.1	14
Protein. Method VL299 Protein	14
Dietary Fibre	15
Fat. Method VL302_Fat by Mojonnier	15
Fatty Acid Profile. Method VL 289 Fatty Acid Profile	16
Sugars. Method VL295_Common Sugars	16
Sodium. Method VL247	17
Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages	17
Calculation of Energy and Carbohydrates in Food. Method VL 412	18
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs	18
Limits of Reporting	19
Statistical analysis of chemical components	20
Results and Discussion	21
Irradiation treatment – dosimetry	21
Nutritional components	22
Recommendation	34
References	35

Summary

This study shows that fresh 'Flame Seedless' table grapes (*Vitis vinifera*) has a high tolerance to irradiation doses up to 1 kGy. No main effect of dose was detected in all the nutritional components tested (ash, energy, dietary fibre, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and Vitamin A (beta-carotene)). Storage time had a greater effect on the nutritional quality of grapes than irradiation itself.

Table grapes were treated at doses at and below 1 kGy for the purpose of quarantine disinfestation. The study provides an analysis of data on the nutritional profile of 'Flame Seedless' table grapes that have been irradiated at 0, 150, 600 and 1000 Gy and assessed on two occasions. The first assessment is one day after irradiation treatment and the second assessment is after 50 days cold storage set at 0°C

No nutritional quality loss was detected in 'Flame Seedless' table grape fruit treated with ≤ 1 kGy gamma-irradiation treatments. There were no interactions between dose level and storage time found in any of the components measured between gamma irradiated and untreated table grapes.

Storage time showed a significant effect compared with irradiation treatment, which had not affected any of the nutritional components and proximates tested. Cold storage at 0°C for 50 days after treatment resulted in significantly lower Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) levels, while significant increases were observed in fructose, sodium and total dietary fibre. These minor changes observed were primarily associated with senescence (biological aging processes) that normally occurs during long term storage.

Specifically, low dose irradiation did not affect the beta-carotene content in table grapes and total ascorbic acid just after irradiation and after 50 days storage at 0°C.

In this study, the fresh season table grape fruit tested are high in moisture (>80%) and low in protein and nil fat. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also can change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

The study shows that applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant negative effects to the chemical and proximate components of 'Flame Seedless' table grape fruit.

Introduction

There is an increasing trend to centrally process fresh fruits, suitably packaged, for distribution and marketing. Irradiation technology proved to be effective in reducing postharvest losses, delaying ripening and prolonging fruit shelf life. Fruit maturity, cultivar, environmental conditions, postharvest handling, storage temperature, and the use of controlled atmosphere storage have all been reported to influence such fruit responses to irradiation (Lee and Kader 2000, Maxie and Abdel-Kader 1966, Miller and McDonald 1999, Mitchell *et al.* 1992) but few reports are available on the effects of irradiation on the nutritional and proximate qualities.

While gamma irradiation at doses up to 1.0 kGy (Al-Bachir 1998, Kang *et al.* 2012) and at 2 kGy (Domini and Pansolli 1970) have been shown to extend the shelf life of fresh grapes (*Vitis vinifera*) another report (Paek 2011) found that irradiation did not affect the shelf life of grapes and that age (or storage time) had a greater effect on the quality of the grapes than irradiation at doses up to 800 Gy and held at 3°C. Kang *et al.* (2012) found no significant effect of irradiation on weight loss, total soluble solids, titratable acidity, protein, mineral content and sensory assessments of 'Red Globe' table grapes irradiated at 0.2, 0.4, 0.6 and 1.0 kGy.

In February 2012, the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS) approved an irradiation facility in South Africa following a request by the quarantine organization of South Africa. Table grapes is anticipated to be the first commodity to be irradiated (Irradiation T105-a-2) and shipped to the United States. Export consignments were unlikely to take place during the 2012 season but one producer exported a single container and despite the short notice the consignment reached its export destination "in perfect condition" Basson and Labuschagne (2012). The minimum absorbed dose required is 400 Gy and the consignment inspected and found free of the mite *Eutetranychus orientalis* (USDA-APHIS, 2013).

The Interstate Certification Assurance (ICA) scheme is a national system of plant health certification which provides for a harmonised approach to the audit and accreditation of businesses throughout Australia and the mutual recognition of plant health assurance certificates accompanying consignments of produce moving intrastate or interstate. ICA-55 in the state of Queensland was developed to meet the requirements of State and Territory governments in Australia for the certification of irradiated fruit fly host produce for interstate and intrastate quarantine purposes. However, only fresh fruit and vegetables approved in the Food Standard Australia New Zealand (FSANZ) Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) can be certified under this Operational Procedure. There are currently ten commodities that are approved to be irradiated for pest disinfection purposes and the minimum and maximum doses permitted are 150 Gy and the maximum is 1 kGy respectively. The 150 Gy minimum dose is a generic dose for fruit fly which is an internationally approved treatment (International Standard for Phytosanitary Measures ISPM No.28, Annex 7 2009).

The effects of low dose irradiation and cold storage were investigated on the table grape variety 'Flame Seedless', in order to assess their effects on fruit nutritional quality. Export quality fresh whole produce were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation on table grape. This work will also compliment current findings from the postharvest fruit quality component of this study described later in this report.

Materials and Methods

Cultivar

Fresh, firm seedless red table grapes were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of table grapes was carried out on 30th January 2012. The red table grape (*V. vinifera*), variety tested was 'Flame Seedless'. The variety has large clusters of medium–large well-coloured red, round-shaped grapes with firm crisp flesh that are firmly attached to the stem.

Table grapes are usually picked ripe, as they will not continue to ripen after they are picked from the vine.

Control produce and treatment produce were stored pre and post irradiation in a cold room set at 0°C. Fruit packed into the original 6 kg cardboard cartons fitted into the stainless steel irradiation chamber for treatment. Fruit were carefully re-packed into plastic bags after treatment for further analyses.

Irradiation treatment

The fruit samples were exposed to target irradiation doses of 0, 150, 600 and 1000 Gy from a Co^{60} source of gamma irradiation. One 6 kg box of table grapes was treated for each dose. For proximate and nutritional analyses, a random sample of clusters of fruit, 1.5 kg weight, was used at each assessment time.

There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 21.8–23.0°C. The boxes of fruits were positioned on a rig parallel to the plaque source (Figure 1).

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing (ANSTO, 2011).

The irradiation doses were measured by placing Fricke dosimeters throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front and between fruits within the carton (Figure 1). Additional dosimeters were attached to the outside of each package for monitoring and to provide references to the minimum and maximum doses

The effects of irradiation were measured at two stages: after irradiation treatment (Time 1 is one day after irradiation treatment) and after 50 days cold storage at 0°C (Time 2).

Following irradiation treatment, the fruits were re-packed and sent for chemical analysis and fruit quality assessment. Time 2 fruits were placed in cold storage until testing commenced.



Figure 1. Table grapes packed in a plastic bag and placed in a cardboard carton ready for irradiation treatment. Dosimeter(s) were attached to bunches of berries inside the carton and on outside of the plastic bag for monitoring doses received within the box.
Source: Radiation Technology, ANSTO.

Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat profile, moisture, sodium, protein, total sugars, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the two occasions, after treatment and after a period in cold storage at 0°C. The first assessment was a day after mean irradiation treatment and the second analysis at the end of the recommended storage period of 50 days.

Fruit were blended at each time point for analysis. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s): AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1 mg.

2 to 5 gram of sample is weighed, to nearest 0.1 mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1 mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1 mg, into the dish. The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s): AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to 525°C ± 25°C until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2 g) is accurately weighed into a Kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20 ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50 ml distilled water is added. The tube is placed in a Kjelttec distillation unit and the mixture is steam distilled into a beaker containing

50ml of saturated boric acid solution. The distilled solution is titrated with standardised 0.1 N sulphuric acid solution using a mixed indicator of bromcresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre.

Reference Method: AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s): AS 2300.1.3. AOAC 16th Edition 954.02, 948.15, 922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2 g) is accurately weighed into a beaker.

10 ml of approx. 10 % hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10 ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25 ml of diethyl ether and a further minute with each of 25 ml of petroleum ether and 50 ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102°C until constant weight is achieved.

Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish}}{\text{Weight of sample}} \times 100$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", Can. J. Biochem. Physiol. 37: 911-917.

Badings and Dejong (1983). J. Chrom. 279: 493-506.

McCance and Widdowson (1991). The Composition of Foods. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10 g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2 g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and re-extracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s): AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45 µm filter into a 2 ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s):

1. USEPA (United States Environmental Protection Agency) Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2–0.5 g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic Acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase. Absorbance is measured by PDA detection at 245 nm, the PDA spectra (220 to

350 nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL 412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code (2011).

Carbohydrate Calculation:

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation:

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference Method: CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5 g of sample is accurately weighed into a 250 ml flask and 60 ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500 ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes; each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10 ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450 nm, the PDA spectra (250 to 650 nm) is used as confirmation. Determination is made against a known β - Carotene standard, whose concentration is determined by absorbance measurements.

Limits of Reporting

The laboratory standard normally only contains the compound or compounds of interest, in the optimal calibration range. It is also in a medium that does not interfere with and/or enhance the performance of the analytical instrument. It is under these ideal conditions that the lowest concentration can be reported, while minimising uncertainty due to matrix effects. This concentration is the limit of detection of the method. Other non-targeted compounds and constituents can interfere with the sample analysis, and the corrected concentration is reported (limit of reporting).

Limits of reporting for the various components tested are tabled below.

Analysis / Analyte	Limit of reporting; LOR (generally 1–5 times the limit of detection)
Vitamin C (L-ascorbic acid)	1 mg/100g
Beta-carotene	5 μ g/100g
Ash	0.1 g/100g
Carbohydrates	2 g/100g (calculated by difference)
Dietary fibre	0.05 g/100g
Energy	Calculation
Fat	0.2 g/100g
Moisture	0.2 g/100g
Saturated fat	0.10 %
Trans fat	0.10 %
Mono-saturated fat	0.10 %
Polysaturated fat	0.10 %
Protein	0.2 g/100g
Sodium	10 mg/kg
Total sugars	1 g/100g
Fructose	0.2 g/100g
Glucose	0.2 g/100g
Lactose	0.2 g/100g
Maltose	0.2 g/100g
Sucrose	0.2 g/100g

If the limit of reporting, say for example, for beta-carotene in the methodology used is 5 μ g/100g that value means that the laboratory can measure with reasonable accuracy at this level. Any level below the accuracy is not that good and the measurement of uncertainty below the limit of reporting, for example for beta-carotene in the methodology used is 26%.

Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level using GenStat for Windows 14th Edition (VSN International 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed by analysis of variance (ANOVA) separately, as well as a 2-way factorial ANOVA to investigate the time by dose interaction. Where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD).

Where all or the majority of data was censored (below the level of reporting) the data could not be analysed. For total ascorbic acid there were a minority of values censored and the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not underestimated.

Results and Discussion



Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required; 0, 150, 600 and 1000 Gy. The average irradiation dose absorbed complies with the required specifications of the study. The Irradiation Report is presented in the section below and reports minimum, maximum and average absorbed doses.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2% for Fricke.

The dose rate was approximately 14.7 Gy/min. Irradiation temperature was 21.8–23.0°C.

Product Details	
Product	Grapes and Peaches
Quantity	12 × 6 kg boxes Grapes 12 × 5 kg boxes Peaches
Irradiation Conditions	
Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	30 - 31 January 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 14.7 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F227
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	21.8 to 23.0 °C

ANSTO Ref: 12-1985		SRT F 004	
Prepared	Authorised	Date	Page 2 of 6
		7.2.2012	
Sohil Sheth	Connie Banos		

The samples of grapes and peaches that were received for processing were repacked into trays. The trays for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited at the front and in between grapes and in front of peaches (Figure 1 & Figure 2). Additional dosimeters were attached to the outside of one box to provide a reference to the minimum and maximum doses (the monitoring position). The trays were positioned on a rig parallel to the plaque source (Figure 3).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R1) samples from the first lot were used to carry out a dose mapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dose mapping repeated twice with dosimeters at those locations. This dose mapping information was used to process the remaining trays of grapes and peaches to their target doses.



Figure 1: Trays of grapes for irradiation showing dosimeter position (circled).

ANSTO Ref: 12-1985

SRT F 004

Prepared

gus

Sohil Sheth

Authorised

CB

Connie Banos

Date

9.2.2012



Page 3 of 6



Figure 2: Tray of peaches for irradiation showing dosimeter position.



Figure 2: Trays positioned for irradiation.

ANSTO Ref: 12-1985		SRT F 004	
Prepared	Authorised	Date	Page 4 of 6
		9.2.2012	
Sohail Sheth	Connie Banos		

Results for Grapes and Peaches

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	137 ± 7	162 ± 7	149 ± 5
600	Replicate 1	544 ± 6	642 ± 7	593 ± 5
1000	Replicate 1	908 ± 21	1071 ± 22	990 ± 15
150	Replicate 2	136 ± 7	161 ± 7	148 ± 5
600	Replicate 2	550 ± 20	649 ± 21	600 ± 14
1000	Replicate 2	916 ± 25	1080 ± 25	998 ± 18
150	Replicate 3	139 ± 7	164 ± 7	151 ± 5
600	Replicate 3	545 ± 20	643 ± 20	594 ± 14
1000	Replicate 3	913 ± 25	1077 ± 25	995 ± 17

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dose mapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

ANSTO Ref: 12-1985

SRT F 004

Prepared



Sohail Sheth

Authorised



Connie Banos

Date 9.2.2012 Page 5 of 6

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: 12-1985

SRT F 004

Prepared


Sohail Sheth

Authorised


Connie Banos

Date 9.2.2012

Page 6 of 6

Nutritional components

Seedless red table grapes variety 'Flame Seedless' were treated and analysed for nutritional components at two occasions; the first analysis (Time 1) one day after irradiation treatment and the second analysis (Time 2), after 50 days storage in a coldroom set at 0°C.

Results from this study show that fresh 'Flame Seedless' table grapes can tolerate up to 1 kGy irradiation without negative effects on the nutritional attributes investigated.

However a significant effect of storage time was detected in Vitamin C (total ascorbic acid), Vitamin A (beta-carotene), fructose, total dietary fibre and sodium (Table 1). Mean values for Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) decreased after 50 days whereas there were significant increases in fructose, total dietary fibre and sodium observed.

Each time was analysed separately to determine the effect of irradiation on the nutritional components (Tables 2 and 3). No main effect of irradiation dose was detected in any of the chemical components tested in Time 1 (Table 2). Irradiation did not affect the levels in ash, carbohydrates, dietary fibre, energy, fat, moisture, sodium, protein, total sugar, fructose, glucose and Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene).

There were no significant differences in mean Vitamin C (total ascorbic acid) levels detected between irradiated table grape samples and the untreated control. At Time 1 mean Vitamin C (total ascorbic acid) in the control sample was 1.37 mg/100g compared to 1.00 mg/100g, 1.30 mg/100g and 1.17 mg/100g in the 150 Gy, 600 Gy and 1000 Gy samples, respectively (Table 2). A reduction in total ascorbic acid was observed after 50 days cold storage, with the largest decrease observed in the 600 Gy sample (0.80 mg/100g) (Table 3).

In this study, the results for Vitamin C (total ascorbic acid) were lower than reported elsewhere. The reported value for the seeded cultivar, 'Red Globe' table grapes is 5 mg/100g in NUTTAB (Food Standards Australia New Zealand (FSANZ) 2010). The level reported in the USA database (USDA 2010) in raw grapes, red or green (European type such as Thompson seedless) is 3.2 mg/100g. Our handling procedures and temperature variation during transportation of fruit between facilities may have contributed to the lower levels detected as losses are accelerated at higher temperatures (Lee and Kader 2000). No error in analysis was detected by the independent laboratory undertaking the testing and all duplicates, controls and spike recoveries were found within the acceptable criteria. Although content of Vitamin C in fruits can be influenced by cultivar, pre-harvest conditions, fruit maturity, harvesting and postharvest handling procedures, temperature management after harvest is the most important factor to maintain Vitamin C in fruits (Lee and Kader, 2000).

No significant dose effects were detected in beta-carotene in the control samples and the treated fruit one day after irradiation treatment (24.7–29.7 µg/100g) and after 50 days storage (17.7–24.7 µg/100g). The reported mean is 0 µg/100g in 'Red Globe' grapes (FSANZ 2010). A significant decrease was noted after 50 days, with

the largest decrease seen in the untreated control, from 29.7 µg/100g down to 18.0 µg/100g.

Mean protein in this study was between 0.70 and 0.87 g/100g just after irradiation. After 50 days in cold storage at 0°C, protein levels were not significantly different, 0.80–0.93 g/100g (Tables 1, 2, 3). Kang *et al.* (2012) found no significant effect of irradiation in weight loss, total soluble solids, titratable acidity, protein, mineral content and sensory assessments of fresh American Red Globe grapes. In that study, the measured protein ranged between 0.6 and 0.7 g/100g after X-ray irradiation and declined after 21 days in storage at 1.5°C ± 0.5 to 0.4–0.6 g/100g.

The protein levels in table grapes in this study are within the range of the reported values, between 0.70 and 0.93 g/100g. The mean protein content reported in NUTTAB (FSANZ 2010) for the seeded cultivar, 'Red Globe' table grapes is 0.9 g/100g. The level reported in the USA database (USDA 2010) in raw grapes, red or green (European type such as Thompson seedless) is 0.72 g/100g.

Of the reducible sugars, only fructose showed a significant but small increase with storage time (Table 1) from a mean of 7.42 g/100g to 8.03 g/100g. Overall there was a minor but insignificant decrease in glucose while total sugars slightly increased with storage.

Two of the values for sodium in Time 2 were ten times larger the other values and may have contributed to the significant increase noted after storage. Mean sodium was 0.286 mg/100g just after irradiation treatment. Nevertheless, the sodium contents are lower than the reported sodium mean for 'Red Globe' (5 mg/100 g) in NUTTAB (FSANZ 2010) and 2 mg/100 g in the USA database (USDA 2010) in raw grapes, red or green (European type such as Thompson seedless). There is no explanation for the high values detected.

The minor changes in mean values in the chemical components are thought to be responses from general fruit aging while in storage. At 0°C, respiration is reduced to a level that is just enough to maintain cell function.

There was no statistical moisture loss as a result of irradiation treatment and after 50 days in storage at 0°C. The moisture content of control and irradiated 'Flame Seedless' table grapes was >81.00 g/100g just after irradiation treatment and after 50 days. Viljoen (2011) reported similar lack of shrivel in his study; cell membranes of grapes irradiated at 800 Gy become more permeable with ripening as fluids from cells are released into the intra-cellular regions of the flesh tissue, thereby reversing shrivel symptoms (Viljoen 2011).

This study shows that table grapes can be irradiated at doses ≤1 kGy without deleterious effects to the nutritional quality. Irradiation up to 1.0 kGy may be considered as a method for phytosanitary disinfestation. This study result is in agreement with Kang *et al.* (2012) who found that X-ray irradiation up to 1.0 kGy had no negative effect on the physical and chemical quality of fresh American 'Red Globe' grape.

Table 1. A factorial analysis investigating the time by dose interaction 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time			ANOVA's		
		1	2	Mean	Factor	P-value	SED
Ascorbic Acid* (mg/100g)	0	1.37	1.0	1.18	Time	<0.001	0.065
	150	1.00	0.93	0.97	Irrad Dose	0.175	0.092
	600	1.30	0.80	1.05	Time x Irrad.	0.155	0.130
	1000	1.17	0.93	1.05			
	Mean	1.21 ^a	0.92 ^b				
Ash (g/100g)	0	0.50	0.60	0.55	Time	0.877	0.053
	150	0.50	0.63	0.57	Irrad Dose	0.963	0.075
	600	0.67	0.50	0.58	Time x Irrad.	0.167	0.105
	1000	0.63	0.53	0.58			
	Mean	0.58	0.57				
Beta Carotene (ug/100g)	0	29.7	18.0	23.8	Time	<0.001	2.75
	150	27.0	19.3	23.2	Irrad Dose	0.081	3.89
	600	24.7	17.7	21.2	Time x Irrad.	0.198	5.50
	1000	28.0	24.7	26.3			
	Mean	27.3 ^a	19.9 ^b				
Carbohydrates (g/100g)	0	17.0	16.3	16.7	Time	0.360	0.44
	150	16.0	15.3	15.7	Irrad Dose	0.118	0.62
	600	15.3	15.0	15.2	Time x Irrad.	0.940	0.88
	1000	16.3	16.3	16.3			
	Mean	16.2	15.8				
Energy (kJ/100g)	0	303.3	300.0	301.7	Time	0.595	7.66
	150	290.0	280.0	285.0	Irrad Dose	0.107	10.83
	600	276.7	273.3	275.0	Time x Irrad.	0.972	15.31
	1000	296.7	296.7	296.7			
	Mean	291.7	287.5				
Fructose (g/100g)	0	7.47	8.47	7.97	Time	0.002	0.211
	150	6.90	7.83	7.37	Irrad Dose	0.157	0.299
	600	7.07	7.73	7.40	Time x Irrad.	0.865	0.422
	1000	7.53	8.10	7.82			
	Mean	7.24 ^b	8.03 ^a				
Glucose (g/100g)	0	7.77	7.53	7.65	Time	0.413	0.198
	150	7.13	7.20	7.17	Irrad Dose	0.105	0.280
	600	7.33	7.00	7.17	Time x Irrad.	0.905	0.396
	1000	7.83	7.67	7.75			
	Mean	7.52	7.35				

Means in treatment followed by the same letter are not significantly different

*Total ascorbic acid data presented are at limits of detection.

Table 1 (contd.). A factorial analysis investigating the time by dose interaction using a 2-way ANOVA with time and dose as the main factors.

Component	Dose (Gy)	Time			Factor	ANOVA's	
		1	2	Mean		P-value	SED
Moisture (g/100g)	0	81.43	81.43	81.43	Time	1.000	0.422
	150	82.53	82.50	82.52	Irrad Dose	0.130	0.597
	600	82.73	82.90	82.82	Time x Irrad.	0.995	0.844
	1000	82.90	81.77	81.83			
	Mean	82.15	82.15				
Protein (g/100g)	0	0.70	0.90	0.8	Time	0.071	0.073
	150	0.83	0.87	0.85	Irrad Dose	0.218	0.103
	600	0.83	0.80	0.82	Time x Irrad.	0.150	0.146
	1000	0.87	0.93	0.90			
	Mean	0.81	0.88				
Sodium (mg/100g)#	0	0.213	0.665	0.376	Time	<0.001	0.0862
	150#	0.297	0.968	0.536	Irrad Dose	0.205	0.1219
	600#	0.362	1.397	0.711	Time x Irrad.	0.963	0.1724
	1000	0.292	0.846	0.497			
	Mean	0.286 ^b	0.934 ^a				
Total Dietary Fibre (g/100g)	0	0.33	0.77	0.55	Time	<0.001	0.058
	150	0.30	0.70	0.50	Irrad Dose	0.859	0.082
	600	0.40	0.70	0.55	Time x Irrad.	0.706	0.115
	1000	0.37	0.63	0.50			
	Mean	0.35 ^b	0.70 ^b				
Total Sugars (g/100g)	0	15.3	16.0	15.7	Time	0.190	0.91
	150	14.3	15.0	14.7	Irrad Dose	0.133	1.29
	600	14.3	14.7	14.5	Time x Irrad.	0.989	1.82
	1000	15.3	16.0	15.7			
	Mean	14.8	15.4				

Means in treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

#One sodium reading of 3.0 and 3.1 respectively, for the dose applied at Time 2.

Table 2. Mean chemical measurements in 'Flame Seedless' table grapes after irradiation treatment (Time1).

Time 1	Dose (Gy)				p-value	SED
Component	0	150	600	1000		
<i>Ascorbic Acid*</i> (mg/100g)	1.37 (0.351)	1.00 (0.000)	1.30 (0.300)	1.17 (0.314)	0.170	0.150
Ash (g/100g)	0.50 (0.173)	0.50 (0.100)	0.67 (0.153)	0.63 (0.153)	0.528	0.137
Beta Carotene (ug/100g)	29.7 (2.08)	27.0 (1.73)	24.7 (1.15)	28.0 (4.00)	0.282	2.33
Carbohydrates (g/100g)	17.0 (1.00)	16.0 (1.73)	15.3 (0.58)	16.3 (0.58)	0.476	1.009
Energy (kJ/100g)	303.3 (15.28)	290.0 (34.64)	276.7 (11.55)	296.7 (11.55)	0.580	19.10
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	7.47 (0.473)	6.90 (0.985)	7.07 (0.208)	7.53 (0.208)	0.589	0.522
Glucose (g/100g)	7.77 (0.404)	7.13 (0.961)	7.33 (0.058)	7.83 (0.153)	0.452	0.477
Moisture (g/100g)	81.43 (0.950)	82.53 (1.963)	82.73 (0.306)	81.90 (0.173)	0.589	1.011
Mono Trans Fat	C	C	C	C		
Protein (g/100g)	0.70 (0.000)	0.83 (0.115)	0.83 (0.115)	0.87 (0.058)	0.150	0.065
<i>Sodium</i> (mg/100g)	0.230 (0.0985)	0.297 (0.0058)	0.373 (0.1185)	0.303 (0.1002)	0.243	0.061
Sucrose (g/100g)	C	C	C	C		
Total Dietary Fibre (g/100g)	0.33 (0.153)	0.30 (0.100)	0.40 (0.100)	0.37 (0.115)	0.703	0.087
Total Sugars (g/100g)	15.3 (0.58)	14.3 (2.08)	14.3 (0.58)	15.3 (0.58)	0.621	1.027

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

*Total ascorbic acid data presented are at limits of detection.

Table 3. Mean chemical measurements in untreated and irradiated 'Flame Seedless' table grapes after 50 days cold storage set at 0°C (Time 2).

Time 2 Component	Dose (Gy)				p-value	SED
	0	150	600	1000		
Ascorbic Acid (mg/100g)	1.00 ^b (0.0000)	0.93 ^b (0.115)	0.80 ^a (0.0000)	0.93 ^b (0.115)	0.050	0.054
Ash (g/100g)	0.60 (0.000)	0.63 (0.153)	0.50 (0.100)	0.53 (0.153)	0.285	0.068
Beta Carotene (ug/100g)	18.0 (1.00)	19.3 (4.04)	17.7 (2.08)	24.7 (5.03)	0.175	3.02
Carbohydrates (g/100g)	16.3 (1.15)	15.3 (1.15)	15.0 (1.00)	16.3 (0.58)	0.356	0.85
Energy (kJ/100g)	300.0 (17.32)	280.0 (17.32)	273.3 (15.28)	296.7 (11.55)	0.233	13.26
Fat (g/100g)	C	C	C	C		
Fructose (g/100g)	8.47 (0.351)	7.83 (0.551)	7.73 (0.306)	8.10 (0.458)	0.283	0.365
Glucose (g/100g)	7.53 (0.351)	7.20 (0.600)	7.00 (0.173)	7.67 (0.503)	0.319	0.358
Moisture (g/100g)	81.43 (0.971)	82.50 (1.212)	82.90 (0.700)	81.77 (0.586)	0.306	0.772
Mono Trans Fat	C	C	C	C		
Protein (g/100g)	0.90 (0.173)	0.87 (0.058)	0.80 (0.100)	0.93 (0.115)	0.385	0.073
Sodium (mg/100g)	0.707 (0.2901)	1.370# (1.4136)	1.750# (1.2816)	1.013 (0.7720)	0.262	0.4860
Sucrose (g/100g)	C	C	C	C		
Total Dietary Fibre (g/100g)	0.77 (0.153)	0.70 (0.173)	0.70 (0.173)	0.63 (0.058)	0.547	0.087
Total Sugars (g/100g)	16.0 (1.00)	15.0 (1.00)	14.7 (0.58)	16.0 (1.00)	0.297	0.78

Standard deviations are presented in brackets below each mean. Means in treatment followed by the same letter are not significantly different.

C = majority of the data is censored.

*Total ascorbic acid data presented are at limits of detection.

#One sodium reading of 3.0 and 3.1 respectively, for the dose applied.

Recommendation

The overall findings of this study showed that an irradiation application of up to 1 kGy will not result in any significant detrimental damage to the nutritional quality of fresh 'Flame Seedless' table grapes. The effect of storage time was greater in the nutritional components tested than by irradiation and the changes generally appeared to be associated with the senescence process during storage.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing negative effects to the chemical and proximate components of table grapes and to the overall postharvest fruit quality.

References

- Al-Bachir, M. (1998). Use of gamma-irradiation and sulfur dioxide to improve storability of two Syrian grape cultivars (*Vitis vinifera*). *International Journal of Food Science & Technology* 33: 521–526.
- AOAC. Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Basson, R. and Labuschagne, J. (2012). Grape exports to US set to increase, thanks to new irradiation system. *Farmer's Weekly Magazine*, South Africa. <http://www.farmersweekly.co.za/article.aspx?id=25863&h=Grape-exports-to-US-set-to-increase,-thanks-to-new-irradiation-system>
- Badings, H.T. and de Jong, C. (1983). Glass capillary gas chromatography of fatty acid methyl esters: a study of conditions for the quantitative analysis of short- and long-chain fatty acids in lipids. *Journal of Chromatography* 279: 493–506.
- Bligh, E.G. and Dwyer, W.J. (1959). A Rapid Method of Total Lipid Extraction and Purification. *Canadian Journal of Biochemistry and Physiology* 37: 911–917.
- Brubacher, G., Muller-Mulot, W. and Southgate, W.A.T. (eds). *Methods for the Determination of Vitamins in Food* (1985). Elsevier Applied Science Publishers Ltd Ch 5.
- CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251. 92nd edition link online <http://www.hbcpnetbase.com/>
- Dickson, J.S. (2012). Radiation meets food. *Physics Today* 65 (2): 66–67.
- Domini, M.L.B. and Pansolli, P. (1970). Gamma irradiation of table grapes of the 'Hoanes' variety. *Food Irradiation* 10 (4): 15–21.
- Fan, X. (2005). Formation of furan from carbohydrates and ascorbic acid following exposure to ionising radiation and thermal processing. *Journal of Agricultural and Food Chemistry* 53: 7826–7832.
- Fan, X. and Sokorai, K.J.B. (2008). Effect of Ionizing Radiation on Furan Formation in Fresh-Cut Fruits and Vegetables. *Journal of Food Science* 73: C79–83.
- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339. <http://www.comlaw.gov.au/Details/F2010C00339>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database.

<http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>

ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009).

https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc

Jooste, M.M. (1999) Optimum harvest maturity and cold-storage duration for *Prunus armeniaca* L. cvs. Supergold and Imperial cultivated in South Africa.

http://webcache.googleusercontent.com/search?q=cache:ZwQEJXvx4YJ:http://fruitgro.krazyboyz.co.za/media/uploads/documents/document/file/mariana_ca_pespan_-_apricots_pdf.pdf%2Bjooste+apricot&hl=en&safe=active&gbv=2&gs_l=serp.3...27259.27259.0.28617.1.1.0.0.0.250.250.2-1.1.0...0.0...1c.FVMd3idbtJo&ct=clnk

Jooste, M.M. and Taylor, M.A. (1999). Effect of harvest maturity and cold storage period on the overall quality of Bebeco apricots, with special reference to gel breakdown and varieties used to accurately establish harvest maturity. *Deciduous Fruit Grower* 49 (Sept): 39-44.

Kader, A.A. (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40: 117–121.

Kang, F., Hallman, G. J., Wei, Y., Zhang, F and Li, Z. (2012). Effect of X-ray irradiation on the physical and chemical quality of America Red Globe grape. *African Journal of Biotechnology* 11 (31): 7966-7972.

Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207–220.

Maxie, E. C. and Abdel-Kader A. (1966). Food irradiation — physiology of fruits as related to feasibility of the technology. *Advances in Food Research* 15: 05–145.

McCance, R.A. and Widdowson, E.M. (1991). *The Composition of Foods*. 5th Ed, p 9. Published by Royal Society of Chemistry / Ministry of Agriculture Fisheries and Food.

Miller, W.R. and McDonald, R.E. (1999). Irradiation, storage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience* 24: 1112–1115.

Paek, G.C. (2011). Effects of low dose irradiation on the quality of fresh table grapes. Presentation. Chapman University. Marshall Cleland Award.

Rajkowski, K.T. and Thayer, D.W. (2000). Reduction of *Salmonella* spp. and Strains of *Escherichia coli* O157:H7 by Gamma Radiation of Inoculated Sprouts. *Journal of Food Protection* 63 (7): 871–875.

Summary

Fruit quality evaluations were conducted on table grape (*Vitis vinifera*) fruit, variety 'Flame Seedless', after being treated with gamma irradiation and following a recommended cold storage period of up to 50 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that storage environment significantly affected the firmness of table grape berries, being approximately 1.5 N softer after 50 days in cold storage (mean 3.5 N) (Table 1). The irradiation treatment alone had no effect on firmness, although it did significantly inhibit moisture loss (by around 4-fold) in fruit dosed at 600 and 1000 Gy compared with untreated control fruit (mean 4%) following 50 days in cold storage.

Berry skin colour was affected by irradiation and storage environment, becoming a significantly darker but less intense red colour as a result of the storage environment. Berry colour intensity was significantly higher in irradiated fruit compared with control fruit.

Neither irradiation nor storage treatment affected fruit total soluble solids content. Fruit acidity however was significantly affected by the interaction of storage environment and irradiation treatment, with mean tartaric acid levels (0.41% in Control berries at Day 1) decreasing with increasing irradiation dose and after a 50 day storage period (0.33% for 1 kGy-treated berries).

Table grapes in this study did not exhibit any symptoms of decay or disease expression, and the natural bloom was present on the fruit before and after storage. In conclusion, fruit irradiated up to 1 kGy followed by cold storage of up to 50 days had little to no detrimental effects on fruit quality.

Part B. Effect of gamma irradiation on postharvest quality of table grape (*Vitis vinifera*) fruit.

Contents

Part B. Effect of gamma irradiation on postharvest quality of table grape (<i>Vitis vinifera</i>) fruit.	38
Summary	39
Introduction	40
Materials and methods	41
Experimental layout	41
Fruit quality assessments	41
Fruit berry colour	41
Moisture loss and whole fruit softness	41
Biochemical analyses	42
Fruit disease and disorders	42
Statistical analysis	42
Results and Discussion	43
Recommendations	46
References	47

Summary

Fruit quality evaluations were conducted on table grape (*Vitis vinifera*) fruit, variety 'Flame Seedless', after being treated with gamma irradiation and following a recommended cold storage period of up to 50 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy applied at three separate times, each representing a replicate block. Fruit evaluations consisting of physico-chemical measurements were conducted on fruit immediately after treatment (within 24 hours) and after subsequent cold storage.

This study found that storage environment significantly affected the firmness of table grape berries, being approximately 1.5 N softer after 50 days in cold storage (mean 3.5 N) (Table 1). The irradiation treatment alone had no effect on firmness, although it did significantly inhibit moisture loss (by around 4-fold) in fruit dosed at 600 and 1000 Gy compared with untreated control fruit (mean 4%) following 50 days in cold storage.

Berry skin colour was affected by irradiation and storage environment, becoming a significantly darker but less intense red colour as a result of the storage environment. Berry colour intensity was significantly higher in irradiated fruit compared with control fruit.

Neither irradiation nor storage treatment affected fruit total soluble solids content. Fruit acidity however was significantly affected by the interaction of storage environment and irradiation treatment, with mean tartaric acid levels (0.41% in Control berries at Day 1) decreasing with increasing irradiation dose and after a 50 day storage period (0.33% for 1 kGy-treated berries).

Table grapes in this study did not exhibit any symptoms of decay or disease expression, and the natural bloom was present on the fruit before and after storage. In conclusion, fruit irradiated up to 1 kGy followed by cold storage of up to 50 days had little to no detrimental effects on fruit quality.

Introduction

The present study aims to investigate the effects of gamma irradiation on the postharvest quality of table grape (*Vitis vinifera*) fruit. Gamma irradiation is regularly used not only for disinfestation purposes but also to control for decay and extend the storage and shelf life of perishable commodities (Mitchell *et al.* 1992). Past work by Al-Bachir (1998) on table grape varieties 'Baladi' and 'Helwani' showed that ionizing irradiation (1 and 1.5 kGy) to be a relatively effective method for controlling postharvest diseases. Sulphur dioxide applied in combination with irradiation not only significantly reduced spoilage rates but also fruit moisture loss in fruit stored (at 1-2°C) up to 12 weeks. Other studies examining the effects of irradiation on postharvest quality have shown positive results on fruit quality. Kang *et al.* (2012), for example, treated 'Red Globe' fruit to a maximum dose of 1 kGy, applied in 0.2 kGy increments, and found no negative impact on weight loss, total soluble solids, titratable acidity or various biochemical properties. Several reports have suggested that relatively high doses of irradiation (> 1 kGy) can cause fruit and stems to become darker or discoloured (Kader 1986, Santillo *et al.* 2009). As noted by several prominent authors, however, differences in responses to irradiation can vary widely within a species and may be attributed to a number of factors, including variety, harvest maturity, growing conditions and or geographic location (Kader 1986, Mitchell *et al.* 1992).

In the present study, the effects of irradiation and cold storage duration were therefore examined on the table grape variety 'Flame Seedless' grown under Australia conditions in order to assess their effects on fruit quality. Assessments entailed measurements of physico-chemical changes in fruit properties. The findings of this study are anticipated to contribute to our overall understanding of the impact of low dose gamma irradiation (at and below 1 kGy) on a variety grown and marketed under Australian conditions. This work will also compliment current findings from the nutritional component of this study described earlier in this report, which also incorporated fruit selected from the same irradiation and cold storage treatments as in this study.

Materials and methods

Experimental layout

Table grapes (*Vitis vinifera*), variety 'Flame Seedless', were sourced from the Sydney Markets, NSW in early February 2012. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where ca. 6 to 8 table grape bunches per carton were irradiated over three sequential times (blocking factor) with target doses of 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group and remained under the same conditions as treated fruit. Replication consisted of a random cutting from the rachis of each bunch, with each cutting containing approximately 10 individual berries. Each of the three blocks per irradiation treatment per assessment time (two times) was represented by a cutting of these fruit.

Following the irradiation treatment, fruit were packed within closed cartons along with sulphur dioxide generator pads placed on top of fruit bunches and immediately transported by air to the Queensland Department of Agriculture, Fisheries and Forestry Postharvest Laboratory in Cairns. Within 24 hours, half the fruit were destructively assessed for quality determination (Day 1) while the second half was transferred into cold storage ($1.5 \pm 0.5^{\circ}\text{C}$ at 85% RH) along with sulphur dioxide generator pads and held for 50 days before being destructively assessed. Storage condition and duration requirements were based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2012). During storage, ambient air temperature and relative humidity conditions were also monitored to ensure they remained within the specifications of the trial.

Fruit quality assessments

Fruit quality assessments were conducted on 10 individual berries per bunch both before and after storage. This comprised a measure of fresh weight, berry firmness, skin colour, biochemical analyses (soluble solids and titratable acidity), and when present a record of the incidence and severity of disorders and disease types. A description of each assessment method is described below:

Fruit berry colour

Berry skin colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8 mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L^* , C^* , h° units).

Moisture loss and whole fruit softness

The cutting containing 10 berries were weighed before and after cold storage. Percent moisture loss was calculated as the proportion of moisture lost over the 50

day storage period. A measure of fruit firmness was also conducted for each berry fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the equatorial region of each berry was undertaken using a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newton (N).

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were determined by destructively assessing fruit from each cutting before and after storage. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

Fruit disease and disorders

If present, the incidence and severity of diseases and or disorders were scored for each berry and averaged for the bunch cutting. Incidence was based on the proportion of fruit within a treatment expressing symptoms and severity as the proportion (%) of fruit surface area affected.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). A general ANOVA's was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a Fisher's Least Square Difference (LSD) test at 5%.

Results and Discussion

The following study contributes towards further enhancing our baseline knowledge of the potential effects of irradiation on the quality of table grapes. In this study, storage environment significantly affected the firmness of table grape berries, being approximately 1.5 N softer after 50 days in cold storage (mean 3.5 N) (Table 1). Although the irradiation treatment itself had no effect on firmness, it did significantly inhibit moisture loss (by around 4-fold) in fruit dosed at 600 and 1000 Gy compared with the untreated fruit (mean 4%) by the end of the 50 day storage period. Al-Bachir (1998) also reported a similar finding, whereby fruit treated to a dose of 1 kGy and stored with sulphur dioxide for up to 12 or 26 weeks, lost less weight (ca. 22% less) than untreated control fruit. Al-Bachir (1998) attributed this response to a decline in respiration and enzyme activity later during storage as a result of the initial irradiation treatment.

Small although significant changes in berry skin colour were directly affected by the irradiation and storage environment treatments. Based on changes in skin lightness and chroma, berries became a significantly darker but less intense red colour as a result of the storage environment. Red berry colour intensity also increased significantly in irradiated berries compared with control berries. Changes in berry colour properties as a result of ionizing irradiation exposure are suggested to be due to an increase in phenolic compounds such as anthocyanins (Ayed *et al.* 1999, Santillo *et al.* 2009).

Neither the irradiation nor the storage treatment affected total soluble solids content (Table 1). Fruit acidity however was affected by the interaction of these two treatments, with mean tartaric acid levels (0.41% for Control berries at Day 1) decreasing as irradiation dose increased and following 50 days in storage (0.33% for 1kGy berries at Day 52). Similar responses have been reported in irradiated 'Thompson', 'Sonaka' and 'Tas-A-Ganesh' grape varieties although at a higher irradiation dose range (1 to 3.5 kGy) (Thomas *et al.* 1995) than the present study. Kang *et al.* (2012) also noted a slight decrease in titratable acidity (from 1.3% to 1.1%) in 'Red Globe' in comparison with untreated fruit following a treatment dose of either 0.2 or 1 kGy.

Overall, the quality of table grapes in this study following irradiation and cold storage was relatively high as further evidenced by the absence of disease or disorders, and by the presence of the natural bloom on the berries before and after storage (Plate 1). Despite minor changes in berry colour and firmness levels, fruit lost less moisture with higher doses of irradiation; a factor suggested to extend the shelf life of table grape berries (Al-Bachir 1998). Moreover, sensory evaluations have purported to find that irradiated 'Red Globe' grape berries (up to 1 kGy) were indistinguishable in terms of taste and appearance compared with untreated fruit (Kang *et al.* 2012). In conclusion, irradiation of up to 1 kGy had little to no detrimental effects on fruit quality but rather appears to be beneficial for shelf life extension.

Table 1. Effect of irradiation dose and storage duration on the quality attributes of table grapes. Fruit were gamma irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and then assessed within 24 hours (Day 1) and after 50 days (Day 50) in cold (1.5°C) storage.

Variable	Day	Irradiation dose (Gy)				Mean	ANOVA's	
		0	150	600	1000		Factor	P-value
Moisture loss (%)	50	4.0 ^a	2.6 ^a	0.4 ^b	1.0 ^{ab}	2.0	Irradiation	<0.05
Firmness (N)	1	4.9	4.7	5.3	4.7	4.9 ^a	Day	<0.001
	50	3.3	3.2	3.7	3.7	3.5 ^a	Irradiation	ns
	Mean	4.1	4	4.5	4.2		Day x Irradiation	ns
Skin lightness	1	29.8	31.0	31.8	30.9	30.9 ^a	Day	<0.001
	50	27.7	29.0	29.1	28.6	28.6 ^a	Irradiation	ns
	Mean	28.8	30	30.4	29.8		Day x Irradiation	ns
Skin chroma	1	8.6	10.5	12.1	11.0	10.6 ^a	Day	<0.05
	50	8.2	10.1	10.6	9.3	9.5 ^b	Irradiation	<0.01
	Mean	8.4 ^a	10.3 ^b	11.3 ^b	10.2 ^b		Day x Irradiation	ns
Skin hue angle	1	34.7	36.5	27.1	27.9	31.6	Day	ns
	50	27.7	33.0	20.8	17.7	24.8	Irradiation	ns
	Mean	31.2	34.7	23.9	22.8		Day x Irradiation	ns
TSS (°Brix)	1	17.4	16.8	16.9	17.1	17	Day	ns
	50	17.8	16.7	16.9	17.1	17.1	Irradiation	ns
	Mean	17.6	16.8	16.9	17.1		Day x Irradiation	ns
TA (% Tartaric acid)	1	0.41 ^{ab}	0.42 ^a	0.38 ^{cd}	0.39 ^{bcd}	0.40	Day	<0.001
	50	0.40 ^{abc}	0.37 ^d	0.33 ^e	0.33 ^e	0.36	Irradiation	<0.001
	Mean	0.4	0.39	0.36	0.36		Day x Irradiation	<0.05

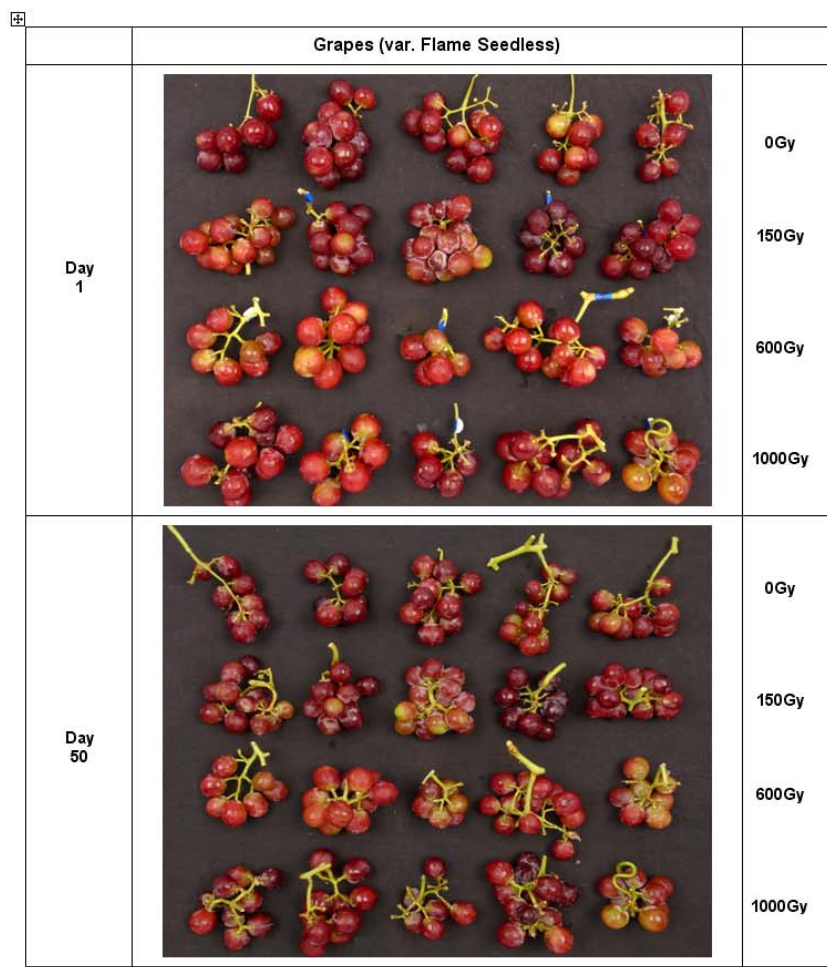


Plate 1. Photographs of a representative sample of table grapes ('Flame Seedless') irradiated with a target dose of 0 (control) 150, 600 and 1000 Gy and taken before and after a subsequent 50 day cold (1.5°C) storage period.

Recommendations

In this study, applications of gamma irradiation treatments may be safely used as a phytosanitary or disinfestation measure on table grapes without causing any deleterious effects on fruit quality. Changes observed in skin colour as a result of irradiation and cold storage were minor and the addition of sulphur dioxide generator pads provided protection against disease development. Fruit treated up to 1 kGy and cold-stored for up to 50 days would be considered commercially acceptable.

References

- Al-Bachir, M. (1998) Use of gamma-irradiation and sulphur dioxide to improve storability of two Syrian grape cultivars (*Vitis vinifera*). *International Journal of Food Science and Technology* 33: 521-526.
- Ayed, N., Yu, H.L., Lacroix, M. (1999) Improvement of anthocyanin yield and shelf-life extension of grape pomace by gamma irradiation. *Food Research International* 32: 539-543.
- Kader, A.A. (1986) Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40 (6): 117-121.
- Kader, A., Cantwell, M. (2008) Produce quality rating scales and colour charts. *Postharvest Technology Research and Information Center, University of California, Davis, CA*. Pg 34.
- Kang, F., Hallman, G.J., Wei, Y., Zhang, F., Li, Z. (2012). Effect of x-ray irradiation on the physical and chemical quality of America red globe grape. *African Journal of Biotechnology* 11: 7966-7972.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J., Nottingham, S.M. (1992) Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291-311.
- Santillo, A.G., Rogovschi, V.D., Araujo, M.M., Silva, P.V., Silveira, P.M., Villavicencio, A.L. C.H. (2009) Influence of gamma radiation on grapes colour during storage period. *Proceedings from: 2009 International Nuclear Atlantic Conference – INAC 2009. Rio de Janeiro, Brazil. Sept. 27 – Oct 2, 2009. ABEN. Pp 4.*
- Thomas, P., Bhushan, B., Joshi, M.R. (1995) Comparison of the effect of gamma irradiation, heat-radiation combination, and sulphur dioxide generating pads on decay and quality of grapes. *Journal of Food Science and Technology – Mysore* 32: 477-481.
- UC Davis (2012) *Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA*, viewed 01 January, 2012, <<http://postharvest.ucdavis.edu/producefacts/>>

A2.7 Nutritional value of Strawberry

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). Strawberry is a good source of folate and potassium, and a source of dietary fibre, Vitamin C and manganese although a large portion of the calories in this food come from sugars. The fruit is also very low in saturated fat, cholesterol and sodium. Some other vitamins provided from this fruit are Vitamin B2, Vitamin B5, Vitamin B6 and Vitamin K.

Table 65 shows key nutritional data for fresh strawberry fruit. Values are extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). The significant differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Water contents in strawberries are high, ranging between 89 and 92 %. The macronutrient levels and energy content are also reported. 100 g strawberry provides approximately 127 kJ of energy, < 1 g protein, 3.9–7.7 g carbohydrate (3.8–6.6 g total sugars) and 1.3–2.5 g dietary fibre. Vitamin C content is between 45 and 59 mg/100g. Beta carotene is low, between nil and 7 µg/100g. There is very little lipid and sodium.

Table 66 shows the average nutrient values per single serve of strawberry (150g for fresh fruit), and Table 67 shows the energy value from the food components. A serve of strawberries provides for approximately 1.8–2.4 energy, 2.1–2.4 % protein, 1.9–3.2 % available carbohydrate, 6.5–12.5 % total dietary fibre, 6.3–11% total sugar and 0.1–0.2 % sodium of the daily intake. The energy value from available carbohydrate ranges between 66–114 kJ/100g, with the majority coming from total sugars. The rest of the energy value comes from protein 11.9–13.6 kJ/100g, fats (7.4–17.9 kJ/100g) and dietary fibre (20–30 kJ/100g).

From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will come from foods other strawberries. There are a wide variety of fresh fruits and vegetables available in Australia and New Zealand that are more commonly eaten that provide similar levels of nutrients. The five most commonly eaten fruits are apples > oranges > grapes (inc. wine) > banana > pear, while potatoes > tomato > carrot > onion > pumpkin are the five most commonly eaten vegetables (MOH 1999). A positive aspect for the industry is that strawberry is gaining market penetration but this will not change its contribution to daily intake of macro and micronutrients.

Other fresh produce provide pro-vitamin A (carotenes) and vitamin C and vitamin A can be found in foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables, grains and dairy and egg products are great sources of vitamin K while nuts, seeds and vegetable oils and other fresh vegetables are good sources of vitamin E. While folate can be found in small amounts in many foods a major dietary source is enriched and fortified foods.

Strawberries are not a significant part of the average consumer's diet and their contribution to overall micronutrient intake will not be significant. There is no known sub-population that consumes greater amounts of strawberries.

Table 65: Nutritional data for strawberry (*Fragaria* sp.), variety 'Albion' per 100g edible portion.

Nutrient	value	Strawberry *		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	90.95	89	92.1
Energy	KJ	136	137	108
Protein	g	0.67	0.8	0.7
Nitrogen	g			0.11
Total lipid (fat)	g	0.3	0.4	0.2
Malic acid	g			0.1
Citric acid	g			0.6
Carbohydrate	g	7.68	6.7	3.9
Total Dietary Fibre	g	2	1.3	2.5
Ash	g	0.4		0.5
Total sugars	g	4.89	6.6	3.8
Fructose	g	2.44		2.1
Glucose	g	1.99		1.8
Sucrose	g	0.47		0
Ascorbic Acid, Vit C	mg	58.8	46	45
Thiamin, Vit B1	mg	0.024	0.01	0.02
Riboflavin, Vit B2	mg	0.022		0.05
Niacin	mg	0.386		0.1
Niacin equivalents	mg		0.5	0.22
Vit B6	mg	0.047	0.05	0.02
Folate, Vit B9 total	µg	24	19	39
Vit A (retinol equiv.)	µg		1	0
Alpha carotene	µg	0		0
Beta carotene	µg	7		0
Beta cryptoxanthin	µg	0		0
Cryptoxanthin	µg			0
Vit E	mg	0.29		0.32
Vit K	µg	2.2		
Calcium	mg	16	21	18
Iron	mg	0.41	0.4	0.58
Magnesium	mg	13		8
Phosphorus	mg	24	18	24
Potassium	mg	153	151	158
Sodium	mg	1	2	3
Zinc	mg	0.14	0.2	0.18
Copper	mg	0.048		0.065
Manganese	mg	0.386		0.328
Selenium	µg	0.4	0.1	1
Iodine	µg		0.2	0
Molybdenum	µg			8.6
Nickel	µg			1
Tin	µg			

*raw with skin

Table 66: Nutrient values are per 100 g edible portion of fresh strawberry.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	92.1	89	138.15	133.5			
Energy (kJ)	108	137	162	205.5	1.86	2.36	8700
Protein (g)	0.7	0.8	1.05	1.2	2.1	2.4	50
Total lipid (fat) (g)	0.2	0.4	0.3	0.6	0.43	0.86	70
Fatty acids, total saturated (g)							24
Available Carbohydrate (g)	3.9	6.7	5.85	10.05	1.89	3.24	310
Sugar (g)	3.8	6.6	5.7	9.9	6.3	11	90
Total dietary fibre (g)	2.5	1.3	3.75	1.95	12.5	6.5	30
Sodium (mg)	3	2	3	3	0.13	0.13	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>.

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 67: Calculation of energy value of the major* food components per 100 g strawberry.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ/g	Average quantity	Approximate calculation of energy value kJ/g
Protein	17	0.7	11.9	1.05	17.85
Total lipid (fat)	37	0.2	7.4	0.3	11.1
Fatty acids, total saturated					
Available Carbohydrate	17	3.9	66.3	5.85	99.45
Total sugars		3.8		5.7	
Total dietary fibre	8	2.5	20	3.75	30

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of fresh strawberry

Fresh strawberries have a relatively short shelf life after harvesting because of rapid ripening and microbial spoilage. Its high content of sugar allows for the development of the micro-organisms and the rate of rot of the fruit and doses up to 3000 Gy have been approved for strawberry irradiation (ICGFI 2002) to control spoilage. Irradiation of strawberries as a means of prolonging shelf and storage life is a potentially profitable procedure, and the cost may be compensated by the saving achieved from the reduction in losses. The effect of ionising radiation has produced contrasting results and have been reported to be attributed to differences in commodity, variety, postharvest handling, storage, production system, maturity, environmental conditions, soil type, growing and weather conditions during growth.

A report of irradiation studies of Australian strawberry conducted in 2011/12 is provided in full (Attachment in this section) in this application. The study examines the radio-tolerance of strawberry at doses between 0 and 3 kGy. The cultivar studied was fresh strawberry (*Fragaria* sp.), variety 'Albion'. The nutritional profile and postharvest fruit quality of fresh strawberry and microbiological aspects in shelf life extension in strawberry fruit irradiated at doses of 0 Gy, 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy were investigated.

This section reports mainly on the results in strawberry treated at doses ≤ 1 kGy. Proximate and chemical measurements analysed after irradiation treatment and after a period of 14 days in cold storage at 0°C after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy are considered in this discussion on nutritional quality.

Overall, the findings of the study showed that cold storage duration but not irradiation had a significant effect on whole fruit quality. Ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) were not impacted by low dose irradiation with favourable postharvest fruit quality. The changes were attributed to processes resulting from general ripening of fruit during storage and the extent of nutrient changes may be comparable or insignificant with losses often seen during handling, storage and microbial degradation, as they do during the accepted freezing, canning, heat treatment and pickling processes.

In the nutritional study, applications of gamma irradiation treatments of ≤ 1 kGy can be used as a phytosanitary treatment without inducing significant deleterious effects to the nutritional quality of fresh strawberry. Fresh strawberry fruit is high in moisture content ($>90\%$), low in protein (0.57–0.73 g/100g) and contain no fats. In fact, the nutritional components of fresh strawberries were not negatively impacted by irradiation doses up to 2500 Gy.

The nutritional components of fresh strawberry were not negatively affected by 150 Gy, 400 Gy and 1 kGy irradiation compared with the control sample immediately after irradiation treatment and after 14 days cold storage, with values ranging between 43.3–51.0 mg/100g. Mean beta-carotene decreased with storage time from 3.50 μ g/100g to 2.59 μ g/100g over 14 days, and the strawberry samples irradiated at ≥ 1 kGy declined further to a mean of 1.97 μ g/100g after another 14 days, although this second decline was not significant.

Vitamin C was not affected at doses ≤ 1 kGy in the QLD DAFF study (2012). Vitamin C levels were reported to decline in untreated strawberries from the beginning to the end of the storage (Perez *et al.* 1998, Sanz *et al.* 1999). Graham and Stevenson (1997)

observed that the radiation-induced Vitamin C concentration change in different varieties was small compared to the large variations observed between the varieties. The authors concluded that the contribution made by strawberries to vitamin C intake would be more dependent on the variety consumed than the effects of irradiation or storage.

Irradiation of strawberry at doses between 2–3 kGy, combined with refrigeration (6°C) extended shelf life (Graham and Stevenson 1997). Vitamin C content of irradiated strawberries at doses of >1 kGy was determined including measurements of total ascorbic acid (TAA), ascorbic acid (AA) and dehydroascorbic acid (DHAA) concentrations, and their contribution to vitamin C content (Graham and Stevenson 1997). In the study, the authors found that DHAA increased with increased dose while TAA concentration and AA decreased in strawberries assayed immediately after treatment. During storage total Vitamin C and AA increased while DHAA decreased. The researchers found that overall irradiation resulted in some loss in total Vitamin C which increased during storage. In contrast, Herregods and Defroost (1963) reported Vitamin C in untreated samples reduced more rapidly than 1 kGy, 2.5 kGy and 5 kGy samples in 2–15°C storage. Saluhnke *et al.* (1959) found significant reductions in ascorbic acid content in irradiated strawberries while others have found only minor changes (Maxie *et al.* 1964).

Storage impacted on some macro and micronutrient levels and the changes generally appeared to be associated with the ripening process during storage. Although irradiation is known to destroy vitamins in pure and unadulterated systems, in food the damage may not be significant due the mutually protective action or shielding effect of various chemical constituents on each other (Diehl 1990, 1995).

Several pre- and postharvest factors are responsible for the wide variation in Vitamin C content in fruits at harvest and include factors such as genotypic variation (Kader 1988, Lee and Kader 2000), climatic, environmental and cultural practices (Somers and Beeson 1948, Lee 1974, Mozafar 1994). Kader (1988) reported that maturity at harvest, the method of harvesting, and postharvest handling contribute to the variation, as do cooking and various processing methods can also affect the Vitamin C content (Fennema 1977).

Strawberries contain low levels of beta-carotene. Beta-carotene of untreated and irradiated fresh strawberries was not significantly different after treatment and after storage. Beta-carotene levels however were significantly lower after 14 days in cold storage. Fresh untreated strawberry, variety 'Albion' had a mean of 3.13 µg/100g of beta-carotene, the 150 Gy, 400 Gy and 1000 Gy irradiated samples had means of 3.57, 3.63 and 4.27 µg/100g beta-carotene, respectively. The value recorded in the FSANZ nutrient database is 0 µg/100g. As discussed previously, the different nutritive values reported between studies can be attributed to differences in commodity, variety, postharvest handling, storage, production system, maturity, environmental conditions, soil type, growing and weather conditions during growth.

Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher in untreated and irradiated strawberry samples after 14 days. Schubert *et al.* (1973) and Beyers *et al.* (1979) have found no significant changes after irradiation.

Whole fruit quality decreased significantly with storage time but was not affected by the irradiation treatment. Fruit removed from cold storage resulted in development of water-soaked symptoms on individual fruit irrespective of any irradiation dose, with symptoms only occurring after 14 and 21 days of storage. During each shelf-life environment, fruit quality deteriorated further, with symptoms of water soaking occurring across most fruit irrespective of its irradiation treatment.

At 7 days storage, there was little to no difference between treatments (mean <25% browning), but after 14 days calyx browning in fruit irradiated with ≥ 2.5 kGy was approximately twice the severity compared with non-irradiated fruit (~25%). The shelf life environment also exacerbated calyx discoloration across all treatments (including non-irradiated fruit) suggesting chilling injury may have played a role in its expression.

Increasing doses of irradiation but shorter storage times corresponded to an increased suppression of fruit mould growth. Mould was present but in low levels (less than 10% of fruit with infections $<1\text{ cm}^2$ in size) after 7 days storage and primarily only in fruit treated to a dose of <1 kGy. After 14 days storage, mould was present in all irradiated fruit except those subjected to 3 kGy, with the proportion of fruit affected ranging from 3.3% (2 – 2.5 kGy) to 25% (≤ 1 kGy) and 50% for control fruit.

Fruit firmness levels were significantly affected by irradiation, with higher doses resulting in softer fruit. Immediately after treatment, firmness levels in non-irradiated fruit (mean 2.6 N) were 0.6 N firmer than those treated to 1 kGy. These findings are consistent with other studies on strawberry that reported a softening response due to irradiation (Thomas 1986c, D'Amour *et al.* 1993, Yu *et al.* 1996, Vachon *et al.* 2003). The subsequent loss in fruit firmness has been attributed to changes in cell wall composition and structure, particularly in the degradation of cell wall polysaccharides (D'Amour *et al.* 1994, Yu *et al.* 1995). Irradiated strawberries were softer with fruit firmness decreasing as dose increased (Yu *et al.* 1995, 1996), and intensity of the red colour decreased as irradiation dosage increased from 0 to 2 kGy (Yu *et al.* 1995).

The presence of decay on fruit was generally considered as an unacceptable quality trait. The study showed that a dose of between 1 – 2 kGy and a storage time of 7 days would likely result in the optimum treatment combination for producing “acceptable” fruit at out-turn. Doses above 2 kGy resulted in fruit being considerably softer and having extensive browning on their calyxes, whilst below 1 kGy fruit decay would be a significant issue.

In conclusion, the overall findings of this study suggest that an application of up to 1 kGy will not result in any significant detrimental damage to the nutritional and postharvest quality of strawberry. Irradiation treatment < 1 kGy can be used as an alternative option for a phytosanitary purpose for fresh strawberry.

Shelf life extension and nutritional profile of irradiated strawberry.

Final report

Horticulture and Forestry Science
Agri-Science Queensland
a service of the Department of Employment, Economic Development
and Innovation

March 2012



Project Title

Shelf life extension and nutritional profile of irradiated strawberry.
Final Report.

This report is separated into three parts.

Part A – provides the results of gamma (γ)-irradiation on the nutritional profile of strawberry assessed after treatment and after fourteen and twenty-eight days in cold storage at 0°C.

Part B – provides the fruit quality evaluations and shelf life of strawberry after being treated with gamma irradiation over several cold storage and shelf life periods.

Part C – provides an assessment of the changes in microbiota associated with the irradiation treatments.

Project Leaders

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Employment, Economic Development and Innovation (DEEDI)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Employment, Economic Development and Innovation (DEEDI)
P.O. Box 652 Cairns, Queensland, Australia 4870.

[REDACTED]
Market Access Focus Team Leader
Senior Entomologist
Horticulture and Forestry Science
Department of Employment, Economic Development and Innovation (DEEDI)
P.O. Box 652 Cairns, Queensland, Australia 4870.

Report Authors

[REDACTED] Research Scientist, DEEDI
[REDACTED] Research Scientist, DEEDI
[REDACTED] Microbiologist, DEEDI
[REDACTED] Senior Biometrician, DEEDI
[REDACTED] Market Access Focus Team Leader, DEEDI

Other Personnel

[REDACTED] Technical Officer, DEEDI
[REDACTED] Technical Officer, DEEDI
[REDACTED] Technical Officer, DEEDI
[REDACTED] Senior Technical Officer, Radiation Technology
[REDACTED] Senior Technical Officer, Radiation Technology
[REDACTED] Senior Technical Officer, Radiation Technology

Funding Sources

Horticulture Australia Limited (HAL)
Queensland Department of Employment, Economic Development and Innovation
Steritech Pty Ltd.

Date of Report

March 2012

Acknowledgements:

Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.

© State of Queensland, Department of Employment, Economic Development and Innovation, 2011.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek permission from DEEDI, to use this publication in accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland, Department of Employment, Economic Development and Innovation as the source of the publication.

For more information on this licence visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Shelf life extension and nutritional profile of irradiated strawberry. Final Report.

4

Contents

Contents	5
Report Summary	8
Nutritional Quality Study	8
Postharvest Quality Study	9
Microbiology Study	9
Part A. Effect of gamma (γ)–irradiation on the nutritional profile of strawberry	10
Summary	10
Introduction	11
Materials and methods	12
Irradiation Treatment	12
Chemical analysis	13
Moisture. Method VL298 Version 6.2	14
Ash. Method VL286 Ver. 5.1	14
Protein. Method VL299 Protein	15
Dietary Fibre. Reference Method AOAC 985.29	15
Fat. Method VL302_Fat by Mojonnier	15
Fatty Acid Profile. Method VL 289 Fatty Acid Profile	16
Sugars. Method VL295_Common Sugars	16
Sodium. Method VL247	17
Total Ascorbic acid. Method VL301_Total Ascorbic Acid in Food and Beverages	17
Calculation of Energy and Carbohydrates in Food. Method VL 412	18
Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs	18
Statistical analysis of chemical components	19
Results	20
Irradiation treatment– Dosimetry	20
Nutritional and chemical components	20
Discussion	29
Recommendations	32
References	33
Appendix. Dosimetry Results	36

Part B. Phytosanitary irradiation effects on the postharvest quality of strawberry fruit.	41
Summary	41
Introduction	43
Materials and methods	44
Experimental layout	44
Fruit Quality Assessments	44
Fruit firmness	44
Fruit quality and disease expression	44
Biochemical analyses	45
Statistical analysis	45
Results	46
Storage quality	46
Shelf-life quality	50
Discussion	53
Recommendations	55
References	56
Appendix	57

Part C. Irradiation effects on the microbiological quality of strawberry fruit	66
Summary	66
Introduction	67
Methods	68
Microbiological analyses	68
Irradiation	68
Sampling	68
Sample preparation	68
Total counts	68
Yeasts	68
Enterobacteriaceae	69
Statistical methods	69
Results	70
Effect of irradiation on initial microbial populations in strawberries	70
Effect of irradiation on microbial populations in strawberries during storage	71
Discussion	74
Recommendation	75
References	76

Report Summary

The effects of irradiation (0 – 3 kGy) were investigated on the nutritional profile, postharvest quality and disease pathology in strawberry fruit (*Fragaria* sp) var. 'Albion' following cold storage (0, 7, 14 and 21 days) and a subsequent shelf life period (up to 72 hours).

Overall, the findings of the nutritional and postharvest quality studies showed that cold storage duration but not irradiation had a significant effect on whole fruit quality. The microbiological quality of the non-irradiated and irradiated strawberries generally mirrored the assessments in the postharvest quality study.

The recommended treatment combination that provided the best trade-off in terms of fruit quality, with little or no impact on proximates and nutrition, favourable fruit quality attributes with minimal mould and, microbiological quality was an irradiation dose of between 1 and 2 kGy and a storage period of up to 7 days.

Nutritional Quality Study

The radio-tolerance in strawberry was investigated one day, 14 days and 28 days after irradiation treatment at doses between 0 to 3 kGy. The study provides an analysis of data on the nutritional profile of strawberry that had been irradiated with 0, 150, 400, 1000, 2000, 2500 and 3000 Gy. Assessment at day 28 was conducted on the surviving strawberry fruit, that is, fruit that were irradiated at ≥ 1 kGy.

The nutritional profile analysed includes ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene.

Fresh strawberry fruit is high in moisture content (>90%), low in protein (0.57–0.73 g/100g) and contain no fats.

In this study irradiation treatment up to 2.5 kGy provided the least significant deleterious changes in strawberry over the assessment period. Applications of γ -irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method with minimal nutritional changes to the chemical and proximate components in strawberry. Results from the 3 kGy sample varied a little but the effect of time on the components was significant. However, applications >1 kGy will need to be considered with the overall effects these doses have on postharvest fruit quality and shelf life extension.

In particular, one day after irradiation treatment, Vitamin C (ascorbic acid) in strawberries decreased with doses >2 kGy. No significant dose effect was observed after 14 days between untreated and irradiated strawberry samples (T2 mean of 49.3 mg/100g). Of the remaining strawberries which survived to 28 days, Vitamin C (ascorbic acid) in the samples ≥ 1 kGy decreased significantly (25.7 mg/100g – 44.0 mg/100g). No significant dose effects were detected in beta-carotene in the three assessment times.

The effect of storage time was greater than by irradiation itself in several components; ash, protein, sodium, total sugars, fructose, glucose, sucrose, Vitamin C (ascorbic acid) and beta-carotene. The changes that were observed appeared to be associated with the general ripening process of fruit during storage. The extent of nutrient changes may be comparable or insignificant with losses often seen during handling, storage and microbial degradation, as they do during the accepted freezing, canning, heat treatment and pickling processes.

Postharvest Quality Study

The findings of the postharvest quality study showed that cold storage duration but not irradiation had a significant effect on whole fruit quality. In this case, the removal of fruit from cold storage resulted in development of water-soaked symptoms on individual fruit irrespective of any irradiation dose, with symptoms only occurring following 14 and 21 days of cold storage. Calyx browning was positively related to the level of irradiation and storage duration. Specifically, with 7 days storage, there was little to no difference in calyx browning between treatments (mean <25% browning) but after 14 days calyx browning in those treated to ≥ 2.5 kGy was twice that of control fruit (~25%).

Fruit firmness levels were significantly affected by irradiation, with higher doses resulting in softer fruit evident immediately after storage. Mean firmness levels of non-irradiated fruit (2.6 N) was 0.6 N firmer than those treated to 1 kGy and almost twice of those treated to 3 kGy (1.5 N). Brix levels showed no consistent pattern across the different storage times or irradiation treatments, except after 21 days when levels in non-irradiated fruit were significantly lower (mean 6.8°) compared to fruit treated to ≥ 2 kGy (mean 8.7°). Titratable acidity levels were similar across irradiation and storage duration treatments (mean 0.84% for ascorbic acid).

Increasing doses of irradiation but shorter cold storage times corresponded to an increased suppression of fruit mould growth. Generally, mould was present but in low levels in fruit treated to a dose of <1 kGy following 7 days of cold storage (less than 10% of fruit with infections <1 cm² in size). After 14 days storage, mould was present in all irradiated fruit except those subjected to 3 kGy, with the proportion of fruit affected ranging from 3.3% (2.5 – 2 kGy) to 25% (≤ 1 kGy) and 50% for control (0 Gy) fruit.

During each shelf life environment, fruit quality deteriorated further, with presence of water soaked symptoms occurring across most fruit irrespective of its irradiation treatment. The shelf life environment also exacerbated the development of mould, particularly in fruit treated to lower doses of irradiation (<1 kGy), whereas both irradiation and extended cold storage hastened calyx discoloration.

In this study, the recommended treatment combination that provided the best trade-off in terms of fruit with little to no mould and with favourable quality attributes, such as maintenance of relatively high firmness levels, no water-soaked spots and little calyx discoloration, was an irradiation dose of between 1 – 2 kGy and a storage time of up to 7 days. This is inline with recommendations provided by other authors for producing "acceptable" fruit at out-turn.

Microbiology Study

Strawberry fruit (*Fragaria* sp. Cv. 'Albion') were irradiated at doses from 0 to 3 kGy and stored at 0°C for up to 28 days. Samples were analysed for total counts, yeasts and Enterobacteriaceae. Fruit with visible mould were excluded from the analysis. The trials were replicated three times for statistical analysis and determination of significant differences between treatments.

Enterobacteriaceae were detected in some non-irradiated fruit and only at low levels. All irradiation treatments caused significant decreases in the mean total counts compared to the control at day 0. Mean yeast counts in strawberries treated with at least 1 kGy were significantly less than those for the control at day 0. Yeasts dominated the microflora of stored strawberries, irrespective of irradiation treatment. Analysis of stored strawberries treated with 0, 150 and 400 Gy doses ceased after 21 days because of mould development. Strawberries irradiated at 3 kGy were not greatly affected by mould even after 28 days storage.

Part A. Effect of gamma (γ)–irradiation on the nutritional profile of strawberry

Summary

The effect of irradiation on the nutritional quality of strawberry was studied. Strawberry fruit (*Fragaria* sp. cv 'Albion') were irradiated at doses from 0 to 3 kGy and stored at 0°C to verify whether irradiation at these doses could delay postharvest ripening while causing minimal damage to the nutritional composition.

This report examines the radio-tolerance in strawberry at doses between 0 and 3 kGy for the purposes of quarantine disinfestation and shelf life extension. The study provides an analysis of data on the nutritional profile of strawberry that had been irradiated with 0, 150, 400, 1000, 2000, 2500 and 3000 Gy. The assessments were made after irradiation, 14 days after irradiation and 28 days after irradiation stored at 0°C. Assessment at day 28 was conducted on the surviving strawberry fruit, that is, fruit that were irradiated at ≥ 1 kGy.

The nutritional profile analysed includes ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. In this study, the fresh strawberry fruit is high in moisture content (>90%), low in protein (0.57–0.73 g/100g) and contain no fats. The nutritional components of fresh strawberries were not negatively affected by irradiation doses up to 2500 Gy. Results from the 3 kGy sample varied a little.

The results in this part of the study suggest that it may be possible to use irradiation at a 2.5 kGy in strawberry while causing only minimal nutritional changes. Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components in strawberry. Applications > 1 kGy will need to be considered with the overall effects the doses have on postharvest fruit quality and shelf life extension.

The proximate and chemical measurements for strawberry at each assessment time were analysed using analysis of variance. Each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% Fishers protected least significant difference (LSD). Time by dose interactions, at the seven doses and measured on the three occasions were also investigated.

Vitamin C (ascorbic acid) in strawberries decreased with doses >2 kGy immediately following irradiation. While irradiation affected Vitamin C (ascorbic acid) at these higher doses, the Vitamin C (ascorbic acid) content in these samples rose to levels comparable to the untreated control after 14 days. No significant dose effect was observed after 14 days between untreated and irradiated strawberry samples. After 28 days storage, only the remaining strawberry samples were those irradiated ≥ 1 kGy. Vitamin C (ascorbic acid) in these samples decreased significantly to a range of 25.7 mg/100g – 44.0 mg/100g.

The effect of storage time was greater than by irradiation itself in many of the chemical components measured in the study. Where there were small changes, these generally appeared to be associated with the ripening process during storage. The extent of nutrient changes may be comparable or insignificant with losses during handling, storage and microbial degradation, as they do during the accepted freezing, canning, heat treatment and pickling processes.

Research studies and simulated transport studies are recommended with irradiation treatment included as part of the supply chain system.

Introduction

Irradiation of strawberries as a means of prolonging shelf and storage life is a potentially profitable procedure, and the cost may be compensated by the saving achieved from the reduction in losses.

Fresh strawberries have a relatively short shelf life after harvesting because of rapid senescence and microbial spoilage. Doses up to 3000 Gy have been approved for strawberry irradiation (ICGFI, 2002). Its high content of sugar allows for the development of the micro-organisms and the rate of rot of the fruit.

The few available reports on irradiation-induced changes in chemical components of nutritional significance appear to be contradictory. The effect of ionising radiation has produced contrasting results and have been reported to be attributed to differences in commodity, variety, postharvest handling, storage, production system, maturity, environmental conditions, soil type, growing and weather conditions during growth.

The objective of this study is to investigate the effects of low dose gamma (γ)-irradiation for disinfestation purposes and shelf life extension, particularly on the nutritional components and fruit quality attributes of fresh ripe strawberry and the effects on spoilage organisms.

Fresh whole strawberry, variety 'Albion' was sourced for this study. Treatment doses were 0 Gy, 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy.

The Australia New Zealand Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) permits irradiation of food for the purposes of pest disinfestation.

Irradiation treatment for fruit flies of the family Tephritidae (generic) (ISPM No.28, Annex 7, 2009) provides for the irradiation of fruits and vegetables at 150 Gy minimum absorbed dose to prevent the emergence of adults of fruit flies at the stated efficacy. Approved new minimum doses for certain fruit flies are reviewed and re-evaluated as required and would facilitate the use of irradiation to neutralise more pests at lower doses, potentially minimising any adverse affects on commodity quality.

The effect of low dose γ -irradiation was also examined after a period of cold storage following treatment and after storage for 14 and 28 days at 0°C. This approach provides data on the effect of irradiation treatment however, limited to only the particular variety.

Materials and methods

Whole, fresh strawberry fruits were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of strawberry (*Fragaria* sp. cv 'Albion') was carried out in November 2011.

Control produce and treatment fruit were stored pre and post irradiation in a coldroom set at 0°C. 15 x 250 g punnet strawberries were carefully placed in cardboard boxes which fitted into the stainless steel irradiation chamber for treatment. The produce did not receive any sanitizing or washing before treatment. The fruits were not graded.

There were three replications for each dose treatment: 0 Gy, 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy. Irradiation treatments were applied at three separate times each representing a replicate block. After treatment, the strawberry punnets were packed into eskies with frozen ice and transported to the Laboratory for assessment. Fruit were then placed into cold storage at 0°C based on the postharvest storage conditions recommended by the University of California, Davis Postharvest Technology Center, California (UC Davis, 2011).

The effect of irradiation were measured at three assessment times: before storage (Time 1; one day after mean irradiation treatment), after 14 days (Time 2) and after 28 days (Time 3) cold storage set at 0°C. Time 3 assessments were only made from existing fruit. All deteriorated fruit were discarded.

Each replicate consisted of 2 punnets of fruit per treatment dose per assessment time.

Irradiation Treatment

The samples were exposed to target irradiation doses : 0 Gy, 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy from a Co⁶⁰ source of gamma irradiation. There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 21–23°C. The boxes of produce were positioned on a rig parallel to the plaque source (Figure 1). Control and treatment produce were stored pre and post irradiation in a coldroom set at 0°C.



Figure 1. Boxes of strawberry positioned for irradiation. Dosimeters attached on the outside of boxes of packed punnets of strawberries. Source photo: ANSTO.

Radiation Technology, ANSTO maintains a quality management system that complies with ISO 9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing (ANSTO, 2011).

The irradiation doses were confirmed by dosimeters. Dosimeters (Fricke) were placed throughout the array of punnets of strawberry at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were inside punnets between fruits (Figure 2). Additional dosimeters were attached to the outside of punnets for monitoring and to provide references to the minimum and maximum doses (Figure 1).



Figure 2. Punnets of strawberries in a cardboard box ready for irradiation. Dosimeter inside punnet and attached on the outside for monitoring doses received within the box. Source photos: ANSTO.

Chemical analysis

Control and irradiated strawberry were analysed for ash, energy, carbohydrates, dietary fibre, fat profile, moisture, sodium, protein, total sugars, Vitamin C (ascorbic acid) and beta-carotene by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at the three occasions, after treatment and after a period in cold storage. The first assessment was a day after mean irradiation treatment, the second analysis at 14 days and the third on strawberries existing after 28 days in cold storage.

Edible portions of each fruit were blended at each time point. A summary of the method of analysis for determining the component is described. Reference methods are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

Moisture. Method VL298 Version 6.2

Reference Method(s) AOAC 16th Ed. 934.06, 964.22, AS2300.1.1

Samples are homogenised.

Moisture determination is made, according to sample matrix type, using either, sand and vacuum drying (Method A) or no sand and conventional drying (Method B).

Method A (Using Sand);

A moisture dish with sand, lid and glass rod is oven dried at 102°C and cooled before all dried components are weighed together to the nearest 0.1mg.

2 to 5 gram of sample is weighed, to nearest 0.1mg, into the moisture dish. Water is added to the dish to aid mixing of the sample and sand. The moisture dish is placed on a steam bath until visible dryness of the sand/sample mix is achieved.

The dish and components are placed in a vacuum oven and dried under vacuum (approx. 5kpa) at between 70 and 100°C, depending on sugar content of the sample. Drying time is a minimum of 4 hours depending on the sample matrix. After the required initial drying period the moisture dish and components are removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until constant weight is obtained.

Calculation (Method A):

Subtract the mass of the dish (plus components) from the mass of dried sample and dish (plus components). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Method B (Without Sand);

A moisture dish and lid is oven at 102°C dried and cooled. The dried components are weighed together to the nearest 0.1mg.

A portion of sample (2 to 5 grams) is weighed, to nearest 0.1mg, into the dish.

The sample in the dish is then placed in a conventional oven at 102°C for a minimum of 4 hours depending on the sample matrix.

The dish and lid are then removed, cooled, re-weighed and returned for a further 1 hour drying. The weighing and drying process is repeated until a constant weight is obtained.

Calculation (Method B):

Subtract the mass of the dish (plus lid) from the mass of dried sample and dish (plus lid). Divide the figure obtained by the sample mass and multiply by 100 to obtain a result as % moisture or g/100g.

Ash. Method VL286 Ver. 5.1

Determination of ash in food.

Reference Method(s) AOAC 16th Edn. 1995, 923.03 and 900.02

Sample must be homogenous.

Weigh an appropriate weight of sample into a prepared weighed dish, beaker or crucible. Disperse sample on bottom of container, remove excess moisture on a water bath.

Transfer container to muffle furnace and slowly heat to $525^{\circ}\text{C} \pm 25^{\circ}\text{C}$ until all organic matter is destroyed. It may be necessary to dissolve salts in water to allow destruction of occluded carbon particles.

Weigh container and ash. Calculate ash content.

Protein. Method VL299 Protein

Protein determination based on Total Nitrogen content.

Reference Method: AOAC 16th Ed. 981.10, 920.152, 990.03, 920.87 AS2300.1.2.1

Preparation:

Sample is homogenised and a sub sample (approx. 2g) is accurately weighed into a kjeldahl digestion tube. A digestion aid of potassium sulphate and a catalyst, copper sulphate is added to the sample, followed by 20ml of concentrated sulphuric acid. The tube is slowly heated to 400°C and then the temperature is maintained until the mixture in the tube is clear. The clear solution is digested for 1 hour and the tube allowed to cool.

Determination:

Once the tube has cooled 50ml distilled water is added. The tube is placed in a Kjeltec distillation unit and the mixture is steam distilled into a beaker containing 50ml of saturated boric acid solution. The distilled solution is titrated with standardised 0.1N sulphuric acid solution using a mixed indicator of bromcresol green and methyl red.

Calculations:

Total N (g/100g) = $0.14 \times (\text{titre-blank}) / \text{sample mass}$

Conversion from Total N to protein is made using a Factor related to the food matrix type.

For most foods a factor of 6.25 applies.

Dietary Fibre. Reference Method AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.

The residue is corrected for protein and ash and calculated as dietary fibre.

Fat. Method VL302_Fat by Mojonnier

Fat Determination in non-dairy samples by Mojonnier.

Reference Method(s) AS 2300.1.3. AOAC 16th Edition 95402,948.15,922.08

Preparation & Procedure:

Samples are homogenised and a sub sample (approx. 2g) is accurately weighed into a beaker. 10ml of approx. 10% hydrochloric acid is added and the mixture is heated at 80°C until hydrolysis is complete (approx. 0.5 hours).

The mixture is cooled and transferred quantitatively to a Mojonnier tube. 10ml of ethanol is added and the fat is extracted by shaking for 1 minute with 25ml of diethyl ether and a further minute with each of 25ml of petroleum ether and 50ml petroleum and diethyl ether mix. (The petroleum and diethyl ether mix extract is conducted twice).

After each solvent addition, and subsequent shaking, the organic layer is decanted from the Mojonnier tube into a pre-weighed glass dish. Once all extractions are complete the organic extract in the glass dish is evaporated.

The dish is then dried in an oven at 102 C until constant weight is achieved.
Calculation: % Fat = $\frac{\text{Weight of dish} - \text{Weight of dish X 100}}{\text{Weight of sample}}$

Fatty Acid Profile. Method VL 289 Fatty Acid Profile

Determination of Fatty Acid Profile in Foodstuffs by GC-FID.

Reference Method(s):

Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", Can. J. Biochem. Physiol., 37, 911-917.

Badings & Dejong (1983). J. Chrom., 279, 493-506.

McCance & Widdowson (1991). The Composition of Foods. 5th Ed, p 9.

Preparation:

The sample is homogenised and a sub sample taken (usually 1 to 10g, depending on sample type). Fat is extracted from the sample using either Chloroform/Methanol or Petroleum ether/iso-propyl alcohol. The extract is evaporated under nitrogen. A minimum extracted mass of 0.2g fat is required. The extracted fat is esterified using a methanolic sodium methoxide solution and treatment with sulphuric acid in methanol. The solution is neutralised and reextracted using n-hexane. The hexane layer is removed, dried using anhydrous sodium sulphate and made to volume, with hexane.

Determination:

The relative proportion of each fatty acid methyl ester in the prepared sample is determined using gas chromatography with flame ionisation detection. Identification of the individual fatty acids is made by retention time against a standard of known fatty acid methyl esters including both cis and trans isomers. The amount of Conjugated Linoleic Acid (CLA) can be also determined from the FAME's chromatogram.

Calculation:

Integration and calculation of proportional methyl ester concentrations is made using instrument software. CLA is quantitated using a six point external standard calibration. CLA is usually expressed as mg CLA/g fat.

Sugars. Method VL295_Common Sugars

Determination of Common Sugars in Foods by HPLC.

Reference Method(s) AOAC 13th Ed. 31.138-31.142

Preparation:

Sample is homogenised and a sub sample is accurately weighed. Sugars are extracted with 25 ml water at 60°C for 30 minutes. The extract is clarified with 25 ml acetonitrile and filtered through a 0.45µm filter into a 2ml vial, suitable for HPLC.

Determination for common sugars:

Filtered solution is analysed by HPLC using amino column with an acetonitrile/water mobile phase containing salt and refractive index detection. Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Determination for low level sugars:

Filtered solution is analysed by HPLC using carbohydrate ES column with an acetonitrile/water mobile phase and evaporative light scattering detector (ELSD). Quantitation is made against a standard solution containing known amounts of fructose, glucose, sucrose, maltose and lactose.

Calculation:

Result calculation is performed by HPLC software and a report generated.

Sodium. Method VL247

Determination of trace elements in food and biota by inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled atomic emission spectrometry (ICP-AES).

Reference Method(s)

1. USEPA Method 6010B & 6020
2. NMI NSW Method 2.46

Sample is homogenised and a sub-sample (0.2-0.5g) is digested with re-distilled nitric acid on a DigiPrep block for one hour until vigorous reaction is complete. Samples are then transferred to a Milestone microwave to be further digested. After making up to appropriate volume with Milli-Q (high purity) water, the digest is analysed for trace elements using ICP-MS and / or ICP-AES.

Total Ascorbic acid. Method VL301_Total Ascorbic Acid in Food and Beverages

Determination by HPLC.

Reference Method: Various publications. Principally; G. Brubacher, W. Muller-Mulot and D.A.T. Southgate (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.

Preparation & Extraction:

Solid/Liquid samples:

The acids are extracted from solid homogenised samples with metaphosphoric acid solution and the extract made to known volume. The extract is purified and diluted with dithiothreitol solution, which reduces the dehydro forms to their parent acids and stabilises the reduced state.

Filtration:

Extracts or sample solutions are filtered through an appropriate pore size filter to obtain a clean filtrate.

Determination:

The ascorbic acid content of the filtrate is determined by normal phase HPLC on an Amino column using a phosphate buffer and acetonitrile mobile phase. Absorbance is measured by PDA detection at 245nm, the PDA spectra (220 to 350nm) is used as confirmation. Determination is made against known L-ascorbic acid and Disoascorbic acid standards.

Calculation of Energy and Carbohydrates in Food. Method VL 412

Carbohydrate is calculated by difference and energy is calculated based on published energy factors for each food component from section 1.2.8 of the Australia New Zealand Food Standards Code.

Carbohydrate Calculation

Carbohydrate is calculated by subtracting from 100 the quantity expressed as a percentage of moisture, protein, fat, ash, and if quantified, total dietary fibre (TDF), alcohol and organic acids (i.e. acetic acid).

$$\text{Carbohydrate (g/100g)} = 100 - (\text{Moisture} + \text{Fat} + \text{Protein} + \text{Ash} + \text{TDF})$$

Energy Calculation

Energy is calculated by multiplying published energy factors from section 1.2.8 of the Australia New Zealand Food Standards Code by the determined quantity of food components.

$$\text{Energy (kJ/100g or kJ/100ml)} = (37 \times \text{Fat}) + (17 \times \text{Protein}) + (17 \times \text{Carbohydrates}) + (8 \times \text{TDF})$$

Alpha and Beta-carotene. Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Reference method CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235. Ibid, page C251

Preparation & Saponification:

Approximately 5g of sample is accurately weighed into a 250ml flask and 60ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.

Extraction:

The saponified sample is cooled. The solution is transferred to a 500ml separating funnel containing brine. Extraction is made using petroleum ether with 5 aqueous washes, each shake and wash followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10ml in a volumetric flask with methanol.

Determination:

α - and β -Carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450nm, the PDA spectra (250 to 650nm) is used as confirmation. Determination is made against a known β -Carotene standard, whose concentration is determined by absorbance measurements.

Statistical analysis of chemical components

The chemical measurements for each commodity at time 1, time 2 and time 3 after receiving irradiation doses of 0 Gy, 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy were analysed using analysis of variance (ANOVA). No data was collected at time 3 for doses 0 Gy, 150 Gy and 400 Gy due to severe degradation of the fruit. All statistical tests were performed at the 5% significance level and using GenStat 14 edition (VSN International, 2011).

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% Fishers protected least significant difference (LSD). An 2-way ANOVA investigating the time by dose interaction has also been made. Due to not all irradiation doses having nutritional components measured at time 3, the combined data is unbalanced. This has resulted in two standard error of the differences (SED) between the means for the 3 time measurements. There is one SED for differences between the time 1 mean and the time 2 mean which both had data collected for all doses, and a second SED for differences between time 1 and time 3 means, and between time 2 and time 3 means.

A \log_{10} transformation was required for the 2-way ANOVA for sodium to improve the assumptions underlying the ANOVA. The pairwise comparisons are made on the \log_{10} scale and all SED are reported on the \log_{10} scale. However the means for sodium presented in the tables have been back-transformed and are in mg/100g.

For some components, where all or the majority of data was censored (below the level of detection) the data have not been analysed. Where there were a minority of values censored, the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment.

There is no mean for dose when we combine the three times into one because the third time point doesn't have all doses present. If there is a time effect the means for dose will be biased. The interaction term is now interpreted as a test of whether there is a dose effect within each time (effectively this is testing whether there is a dose effect).

There were no strawberry samples for the control, 150 Gy and 400 Gy at time 3 assessment time since the strawberries had deteriorated.

For some components, where all or the majority of data was censored (below the level of detection) the data have not been analysed. Where there were a minority of values censored, the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment.

The components which were below the level of detection are fat, mono-unsaturated fat, omega 6 fats, omega 3 fats, poly-unsaturated fat, saturated fat, trans fat, poly trans fat and mono trans fats and alpha-carotene. These are not shown in the following tables. Lactose and maltose were also below detection levels and not listed.

The lower limits of detection were: for fat, saturated fat, mono-unsaturated fat, poly-unsaturated fat and trans fat <0.1 g/100g; for dietary fibre <0.1 g/100g; for sucrose <0.2 mg/100g and; maltose and lactose <0.5 g/100g.

Results

Irradiation treatment– Dosimetry

The results of dosimetry indicate that the doses received by the fruit were as required. The average irradiation dose absorbed complies with the required specifications. The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2%.

Treatment details are attached in the Appendix.

Nutritional and chemical components

Overall, irradiation at low doses did not affect the nutritional quality of strawberry. The nutritional components of fresh strawberry were not negatively affected by 150 Gy, 400 Gy and 1 kGy irradiation compared with the control sample immediately after irradiation treatment (Table 1) and after 14 days cold storage (Table 2).

With the exception of Vitamin C (ascorbic acid), no significant dose effects on the nutritional components tested were found at time 1. Significantly lower levels of Vitamin C (ascorbic acid) were detected in strawberry samples irradiated at doses ≥ 2 kGy (before storage) (Table 1). Mean Vitamin C (ascorbic acid) were lower at doses 2 kGy, 2.5 kGy and 3 kGy, ranging between 36.7 and 41.0 mg/100 g compared to samples irradiated at the low doses (47.7–49.7 mg/100g). In the control sample, mean Vitamin C (ascorbic acid) detected after irradiation was 49.7 mg/100g.

Table 1. Mean chemical measurements in 'Albion' strawberry after irradiation treatment (Time 1).

Time 1 Variable	Dose (Gy)							p-value	SED
	0	150	400	1000	2000	2500	3000		
<i>Ash (g/100g)</i>	0.27 (0.153)	0.30 (0.100)	0.27 (0.173)	0.27 (0.058)	0.27 (0.153)	0.37 (0.208)	0.30 (0.200)	0.961	0.109
<i>Carbohydrates (g/100g)</i>	7.0 (0.00)	7.0 (0.00)	6.3 (0.58)	7.0 (0.00)	7.7 (0.58)	7.3 (1.16)	7.0 (0.00)	0.221	0.45
<i>Dietary Fibre (g/100g)</i>	1.80 (0.100)	1.87 (0.153)	1.97 (0.115)	1.63 (0.306)	1.33 (0.493)	1.33 (0.208)	1.77 (0.416)	0.126	0.245
<i>Energy (kJ/100g)</i>	140.0 (0.00)	143.3 (5.77)	136.7 (11.55)	140.0 (0.00)	146.7 (5.77)	143.3 (20.82)	143.3 (5.77)	0.898	7.80
<i>Moisture (g/100g)</i>	90.43 (0.289)	90.40 (0.265)	90.87 (0.321)	90.60 (0.458)	90.27 (0.416)	90.53 (0.603)	90.50 (0.100)	0.645	0.315
<i>Protein (g/100g)</i>	0.57 (0.058)	0.63 (0.058)	0.60 (0.100)	0.60 (0.000)	0.57 (0.058)	0.57 (0.058)	0.60 (0.000)	0.746	0.047
<i>Sodium (mg/100g)</i>	0.550 (0.0436)	0.707 (0.1222)	0.587 (0.0208)	0.577 (0.0833)	0.613 (0.0551)	0.623 (0.1401)	0.647 (0.0929)	0.448	0.0716
<i>Total Sugars (g/100g)</i>	5.37 (0.306)	4.97 (0.404)	4.97 (0.351)	5.17 (0.321)	5.20 (0.346)	5.07 (0.208)	5.13 (0.153)	0.641	0.235
<i>Fructose (g/100g)</i>	2.60 (0.100)	2.53 (0.058)	2.47 (0.153)	2.50 (0.100)	2.57 (0.153)	2.43 (0.058)	2.47 (0.058)	0.349	0.076
<i>Glucose (g/100g)</i>	2.30 (0.100)	2.13 (0.058)	2.10 (0.173)	2.17 (0.058)	2.20 (0.100)	2.07 (0.115)	2.10 (0.173)	0.394	0.104
<i>Sucrose (g/100g)</i>	0.47 (0.116)	0.35 (0.208)	0.40 (0.100)	0.50 (0.173)	0.43 (0.153)	0.57 (0.058)	0.57 (0.058)	0.143	0.082
<i>Beta-carotene (µg/100g)</i>	3.13 (0.577)	3.57 (1.266)	3.63 (1.550)	4.27 (1.935)	2.87 (0.321)	3.80 (0.624)	3.20 (0.173)	0.344	0.592
<i>Ascorbic Acid</i>	49.7a (2.89)	49.3a (3.06)	49.3a (6.03)	47.7ab (3.22)	39.7c (2.31)	41.0bc (9.64)	36.7c (5.51)	0.009	3.49

Means in treatment followed by the same letter are not significantly different.

Variable labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Standard deviations are presented in brackets below each mean.

Table 2. Mean chemical measurements in 'Albion' strawberry after 14 days cold storage (Time 2).

Time 2 Variable	0	150	400	Dose (Gy)				p-value	SED
Ash (g/100g)	0.57 (0.058)	0.53 (0.058)	0.53 (0.058)	0.53 (0.058)	0.57 (0.058)	0.57 (0.058)	0.67 (0.208)	0.468	0.067
Carbohydrates (g/100g)	6.7 (0.58)	6.3 (0.58)	6.0 (1.00)	7.3 (0.58)	6.7 (0.58)	7.3 (0.58)	7.0 (0.00)	0.080	0.44
Dietary Fibre (g/100g)	1.93a (0.058)	1.83a (0.058)	1.67ab (0.231)	1.40b (0.000)	1.73ab (0.153)	1.90a (0.100)	2.03a (0.451)	0.046	0.169
Energy (kJ/100g)	136.7 (5.77)	133.3 (5.77)	126.7 (15.28)	146.7 (11.55)	136.7 (5.77)	150.0 (10.00)	143.3 (5.77)	0.074	7.09
Moisture (g/100g)	90.27 (0.473)	90.70 (0.656)	91.20 (0.721)	90.13 (0.451)	90.37 (0.493)	89.73 (0.764)	90.03 (0.351)	0.119	0.460
Protein (g/100g)	0.67 (0.116)	0.67 (0.058)	0.73 (0.058)	0.70 (0.000)	0.67 (0.058)	0.70 (0.100)	0.63 (0.116)	0.818	0.067
Sodium (mg/100g)	0.587 (0.0208)	0.593 (0.1069)	0.570 (0.0889)	0.663 (0.0252)	0.633 (0.0503)	0.687 (0.0379)	0.620 (0.0964)	0.386	0.0556
Total Sugars (g/100g)	5.57 (0.513)	5.40 (0.361)	5.37 (0.379)	5.90 (0.200)	5.70 (0.436)	6.13 (0.603)	5.90 (0.100)	0.254	0.327
Fructose (g/100g)	2.93 (0.289)	2.83 (0.252)	2.77 (0.208)	3.13 (0.208)	2.97 (0.208)	3.17 (0.252)	3.00 (0.100)	0.213	0.160
Glucose (g/100g)	2.40 (0.265)	2.37 (0.252)	2.27 (0.208)	2.63 (0.208)	2.47 (0.208)	2.63 (0.306)	2.50 (0.100)	0.313	0.166
Sucrose (g/100g)	0.28 (0.100)	0.24 (0.058)	0.33 (0.058)	0.22 (0.116)	0.27 (0.058)	0.33 (0.058)	0.40 (0.100)	0.069	0.054
Beta-carotene (µg/100g)	2.70 (0.872)	2.33 (0.208)	2.33 (0.289)	2.57 (0.404)	2.73 (0.351)	2.73 (0.874)	2.73 (0.231)	0.916	0.465
Ascorbic Acid	48.0 (4.36)	56.3 (5.51)	46.0 (3.00)	51.0 (5.29)	50.7 (4.51)	50.0 (3.46)	43.3 (5.03)	0.123	4.00

Means in treatment followed by the same letter are not significantly different.

Variable labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Standard deviations are presented in brackets below each mean.

After 14 days storage, mean Vitamin C (ascorbic acid) were not significantly different amongst all treatments. The levels ranged between 43.3–51.0 mg/100g (Table 2). In fact the Vitamin C (ascorbic acid) in samples irradiated 2 kGy, 2.5 kGy and 3 kGy increased to levels similar to the untreated sample and samples irradiated at 150 Gy, 400 Gy and 1 kGy.

No significant dose effect was detected in mean beta-carotene in strawberry samples tested after dose treatment (Table 1) and after storage for 14 days (Table 2). After 28 days cold storage no significant dose effects in beta-carotene were found in strawberry irradiated at the higher doses (Table 3). Before storage, fresh untreated strawberry, variety 'Albion' contained a mean of 3.13 µg/100g of beta-carotene while irradiated strawberry samples contained means of between 2.87 µg/100g (2 kGy) to a mean of 4.27 µg/100g (1 kGy) (Table 1). After 14 days cold storage, beta-carotene levels decreased across all samples, and declined further after 28 days for the remaining samples irradiated at ≥1 kGy.

At time 2, no significant dose effects were found in ash, carbohydrates, energy, moisture, sodium, protein, total sugars, fructose, glucose, sucrose and beta-carotene. There was a small difference

detected for dietary fibre, with mean dietary fibre slightly lower in strawberry irradiated at 400 Gy, 1 kGy and 2 kGy, although only 1 kGy was significantly lower than the control.

After 28 days cold storage, no significant dose effects were found in all the components tested for the remaining strawberry samples. These were reported only for doses ≥ 1 kGy due to spoilage and deterioration at the lower doses and untreated samples.

Table 3. Mean chemical measurements in 'Albion' strawberry after 28 days cold storage (Time 3).

Time 3 Variable	0	150	400	Dose (Gy)				p-value	SED
Ash (g/100g)				0.57 (0.252)	0.57 (0.115)	0.57 (0.208)	0.53 (0.058)	0.993	0.139
Carbohydrates (g/100g)				6.3 (0.58)	6.3 (0.58)	6.0 (1.00)	7.0 (1.00)	0.138	0.36
Dietary Fibre (g/100g)				1.53 (0.153)	1.60 (0.100)	1.60 (0.173)	1.67 (0.058)	0.671	0.105
Energy (kJ/100g)				130.0 (10.00)	133.3 (5.77)	123.3 (15.28)	140.0 (0.00)	0.102	5.44
Moisture (g/100g)				90.53 (0.321)	90.77 (0.802)	91.13 (0.651)	90.20 (0.265)	0.158	0.353
Protein (g/100g)				0.67 (0.115)	0.67 (0.153)	0.63 (0.058)	0.67 (0.058)	0.942	0.067
Sodium (mg/100g)				2.500 (3.0312)	1.463 (1.2447)	1.113 (0.7681)	0.917 (0.1850)	0.495	1.0527
Total Sugars (g/100g)				4.47 (0.503)	4.90 (1.054)	5.03 (0.850)	5.47 (0.404)	0.121	0.340
Fructose (g/100g)				2.43 (0.208)	2.57 (0.416)	2.57 (0.252)	2.70 (0.000)	0.654	0.204
Glucose (g/100g)				1.93 (0.153)	2.03 (0.351)	2.10 (0.173)	2.13 (0.058)	0.468	0.127
Beta-carotene (μ g/100g)				1.30 (1.015)	2.53 (1.976)	1.70 (1.044)	2.33 (0.551)	0.203	0.557
Ascorbic Acid				25.7 (22.86)	32.0 (19.93)	37.3 (9.07)	44.0 (5.57)	0.385	10.04

Means in treatment followed by the same letter are not significantly different.

Standard deviations are presented in brackets below each mean.

A full analysis investigating the time by dose interaction has also been made using a 2-way ANOVA with time and dose as the main factors, comparing the full set of components for time 1 and time 2, and for the partial set involving time 3.

No significant time by dose interactions were found, with the effect of storage time being greater than by irradiation itself in all cases.

Specifically for Vitamin C (ascorbic acid), no significant dose effects were found but there was a significant time effect ($p < 0.001$) between time 1 and time 3, and between time 2 and time 3. Overall, mean Vitamin C (ascorbic acid) in untreated and irradiated strawberry samples remained unchanged after 14 days in cold storage. Mean Vitamin C (ascorbic acid) at time 1 (44.8 mg/100g) and Time 2 (49.3 mg/100g) were significantly higher than the mean at time 3 (34.8 mg/100g). For doses ≥ 1 kGy, mean Vitamin C (ascorbic acid) declined considerably except for strawberry irradiated at 3 kGy (Table 4).

Table 4. Mean Vitamin C (ascorbic acid) in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time 3	Factor	P-value	Av. SED
Vitamin C		mg/100g	mg/100g	mg/100g			
	0	49.7	48.0		Time	<0.001	2.72 ¹
	150	49.3	56.3				3.19 ²
	400	49.3	46.0		Time x Irrad.	0.319	7.19
	1000	47.7	51.0	25.7			
	2000	39.7	50.7	32.0			
	2500	41.0	50.0	37.3			
	3000	36.7	43.3	44.0			
	Mean	44.8a	49.3a	34.8b			

Means in treatment followed by the same letter are not significantly different. ¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

There were no significant time by dose interactions found for beta-carotene, with the effect of storage time being greater than by irradiation dose. No significant dose effects were detected but there was a significant time effect ($p < 0.001$) between time 1 and time 2, and between time 1 and time 3. Mean beta-carotene decreased with storage time from 3.50 µg/100g to 2.59 µg/100g over 14 days, and the strawberry samples irradiated at ≥ 1 kGy declined further to a mean of 1.97 µg/100g after another 14 days, although this second decline was not significant.

Table 5. Mean beta-carotene in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time3	Factor	P-value	Av. SED
Beta-carotene	0	3.13	2.70		Time	<0.001	0.306 ¹
	150	3.57	2.33				0.358 ²
	400	3.63	2.33		Time x Irrad.	0.917	0.809
	1000	4.27	2.57	1.30			
	2000	2.87	2.73	2.53			
	2500	3.80	2.73	1.70			
	3000	3.20	2.73	2.33			
	Mean	3.50a	2.59b	1.97b			

Means in treatment followed by the same letter are not significantly different. ¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

Significant time effects were also detected in ash, protein, sodium and total sugars including fructose, glucose and sucrose.

After water, carbohydrates are the main components of strawberry. Mean moisture was around 90g/100g for all strawberry samples whilst carbohydrates ranged between 6.0 g/100g and 7.3 g/100g.

The mean energy value of untreated and irradiated samples is shown in Table 6. No dose or time effects were found in untreated and irradiated strawberries initially after treatment and 14 days cold storage, however, strawberry samples treated at doses ≥ 1 kGy showed a significantly lower mean energy value after 28 days storage. Untreated strawberry contains 140.0 kJ energy and irradiated strawberries contain 136.7–146.7 kJ at time 1.

Table 6. Mean energy value in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time 3	Factor	P-value	Av. SED
Energy	0	140.0	136.7		Time	0.020	2.96 ¹
	150	143.3	133.3				3.47 ²
	400	136.7	126.7		Time x Irrad.	0.251	7.83
	1000	140.0	146.7	130.0			
	2000	146.7	136.7	133.3			
	2500	143.3	150.0	123.3			
	3000	143.3	143.3	140.0			
	Mean	141.9a	139.0a	131.7b			

Means followed by the same letter are not significantly different. ¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

Mean total sugars increased significantly after 14 days from 5.12 g/100g to 5.71 g/100g and after 28 days a significant loss was found in samples irradiated ≥ 1 kGy to a mean of 4.97 g/100g (Table 7)

The main monosaccharides are glucose and fructose; their concentration may change depending on the degree of maturation of the fruit. Overall, strawberry fruit contain higher amounts of free fructose and glucose to sucrose just after treatment at time 1. These levels remained unchanged between untreated and irradiated strawberry including samples irradiated at the higher doses of

irradiation. However, there was a significant time effect detected, with increases after 14 days. The same trend was observed for both fructose and glucose. Mean fructose increased from 2.51 g/100g to 2.97 g/100g in 14 days and decreased to 2.57 g/100 g for the ≥ 1 kGy samples after 28 days. Mean glucose increased from 2.15 g/100g to 2.47 g/100g after 14 days cold storage and declined to 2.05 g/100g for the ≥ 1 kGy samples after 28 days. Sucrose declined over the whole study period.

Table 7. Mean total sugars, fructose, glucose and sucrose in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time3	Factor	P-value	Av. SED
Total Sugars	0	5.37	5.57		Time	<0.001	0.125 ¹
	150	4.97	5.40				0.147 ²
	400	4.97	5.37		Time x Irrad.	0.228	0.332
	1000	5.17	5.90	4.47			
	2000	5.20	5.70	4.90			
	2500	5.07	6.13	5.03			
	3000	5.13	5.90	5.47			
	Mean	5.12b	5.71a	4.97b			
Fructose	0	2.60	2.93		Time	<0.001	0.053 ¹
	150	2.53	2.83				0.062 ²
	400	2.47	2.77		Time x Irrad.	0.277	0.140
	1000	2.50	3.13	2.43			
	2000	2.57	2.97	2.57			
	2500	2.43	3.17	2.57			
	3000	2.47	3.00	2.70			
	Mean	2.51b	2.97a	2.57b			
Glucose	0	2.30	2.40		Time	<0.001	0.054 ¹
	150	2.13	2.37				0.063 ²
	400	2.10	2.27		Time x Irrad.	0.360	0.142
	1000	2.17	2.63	1.93			
	2000	2.20	2.47	2.03			
	2500	2.07	2.63	2.10			
	3000	2.10	2.50	2.13			
	Mean	2.15b	2.47a	2.05b			
Sucrose	0	0.47	0.27		Time	<0.001	0.040 ¹
	150	0.34	0.24				
	400	0.40	0.33		Time x Irrad.	0.445	0.107
	1000	0.50	0.19	C			
	2000	0.43	0.27	C			
	2500	0.57	0.33	C			
	3000	0.57	0.40	C			
	Mean	0.47a	0.29b				

Means in treatment followed by the same letter are not significantly different.

Variable labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

C= majority of the data is censored.

Mean dietary fibre, the most common components being celluloses, hemicelluloses and pectins ranged between 1.33 g/100g and 2.03 g/100g however, the levels found between each treatment sample were variable (Table 8). Within each dose, only 2 kGy and 2.5 kGy showed significant differences between times, with both increasing from time 1 to time 2.

Table 8. Mean dietary fibre in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time3	Factor	P-value	Av. SED
Dietary Fibre	0	1.80	1.93		Time	0.075	0.070 ¹
	150	1.87	1.83				0.083 ²
	400	1.97	1.67		Time x Irrad.	0.013	0.186
	1000	1.63	1.40	1.53			
	2000	1.33	1.73	1.60			
	2500	1.33	1.90	1.60			
	3000	1.77	2.03	1.67			
	Mean	1.67	1.79	1.60			
Dietary Fibre*	0	abc	ab				
	150	abc	abc				
	400	ab	abcde				
	1000	bcde	de	cde			
	2000	e	abcd	bcde			
	2500	e	abc	bcde			
	3000	abcd	a	abcde			

* The letters correspond the dose by time means above. Treatment means followed by the same letter are not significantly different.

¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

The limit of reporting for fat (Mojonnier extraction) is <0.2 g/100g; saturated fat, mono trans fats, mono-unsaturated fat, omega 3 fats, omega 6 fats, poly trans fat poly-unsaturated fat and trans fat <0.1 g/100g. This means that the component can be measured with reasonable accuracy at this level. There is no fat in strawberry.

Strawberries contain a small amount of protein, with a mean of 0.57–0.67 g/100 g (untreated control). A significant time effect was observed; protein increased after 14 days in cold storage and the samples irradiated at doses ≥ 1 kGy remained relatively unchanged up to 28 days.

Table 9. Mean protein in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time 3	Factor	P-value	Av. SED
Protein	0	0.57	0.67		Time	0.002	0.024 ¹
	150	0.63	0.67				0.028 ²
	400	0.60	0.73		Time x Irrad.	0.982	0.064
	1000	0.60	0.70	0.67			
	2000	0.57	0.67	0.67			
	2500	0.57	0.70	0.63			
	3000	0.60	0.63	0.67			
	Mean	0.59b	0.68a	0.66a			

Means followed by the same letter are not significantly different. ¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

Ash is a measure of the inorganic residue remaining after the water and organic matter have been removed. It provides a measure of the total mineral content. Overall, mean ash content in strawberry significantly increased after 14 days in cold storage from 0.29 mg/100g to 0.57 g/100g; for the remaining strawberries irradiated at doses ≥ 1 kGy, the mean ash content remained unchanged in the following 14 days (Table 10).

Mean sodium content was not significantly different from the control samples across all doses one day after treatment and 14 days later. Mean sodium was 0.609 mg/100 g at time 1 and the mean was 0.618 g/100g at time 2. After another 14 days cold storage, of the remaining strawberries, i.e. all the samples treated ≥ 1 kGy, mean sodium increased by about 50% or doubled.

Table 10. Mean ash and sodium in 'Albion' strawberry after treatment (Time 1), 14 days in cold storage (Time 2) and 28 days cold storage (Time 3).

Variable	Dose (Gy)	Time 1	Time 2	Time 3	Factor	P-value	Av. SED
<i>Ash</i>	0	0.27	0.57		Time	<0.001	0.044 ¹
	150	0.30	0.53				0.052 ²
	400	0.28	0.53		Time x Irrad.	0.999	0.116
	1000	0.27	0.53	0.57			
	2000	0.27	0.57	0.57			
	2500	0.37	0.57	0.57			
	3000	0.30	0.67	0.53			
	Mean	0.29b	0.57a	0.56a			

Means in treatment followed by the same letter are not significantly different. Variable labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

Variable	Dose (Gy)	Time 1	Time 2	Time 3	Factor	P-value	Av. SED
<i>Sodium#</i>	0	0.549	0.586		Time	<0.001	0.050
	150	0.700	0.586				0.059
	400	0.586	0.565		Time x Irrad.	0.990	0.133
	1000	0.573	0.663	1.500			
	2000	0.612	0.632	1.171			
	2500	0.613	0.686	0.964			
	3000	0.642	0.615	0.904			
	Mean	0.609b	0.618b	1.112a			

Means in treatment followed by the same letter are not significantly different. # Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale. ¹ SED is for comparisons between Time 1 v Time 2. ² SED is for comparisons involving Time 3.

Discussion

The chemical measurements for each commodity at time 1 (one day after mean irradiation treatment), at time 2 (14 days cold storage at 0°C) and time 3 (28 days) for the remaining fruit that had not deteriorated after receiving irradiation doses of 0 Gy, 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy were analysed. Irradiation treatments were applied at three separate times each representing a replicate block.

Ripe fresh strawberries, variety 'Albion' was used in this study. The fruit is typically long, conical in shape and symmetrical. Albion is the currently the most planted variety in Victoria. The fruit is sweet and has an attractive internal and external fruit colour.

The nutritional profile analysed included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. Each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% Fishers protected least significant difference (LSD). Time and dose interactions, at the seven doses and measured on the first two occasions were also investigated. Due to not all irradiation doses having nutritional components measured at time 3, the combined data is unbalanced.

The results show that at time 1, low dose irradiation (≤ 1 kGy) had no statistical effect on the range of nutritional and proximate components measured in fresh ripe strawberry. Overall, 'Albion' strawberry can tolerate low doses of irradiation without significant negative effects on the nutritional measurements reported.

These components were analysed again at time 2, after 14 days in cold storage. No significant main effect of dose was found in the nutritional components in strawberry except for dietary fibre. However, differences in response to the main effect of dose were not damaging.

In general, after a period in cold storage, fresh ripe strawberry tolerated low irradiation dose (≤ 1 kGy) without significant losses in nutritional composition. At doses between 2 – 3 kGy, Vitamin C (ascorbic acid) initially decreased and after 14 days increased to levels comparable with untreated samples. No significant dose effects were found after 14 days in storage. In particular, no significant main effect of dose was detected in Vitamin C (ascorbic acid) and beta-carotene at time 2 and for doses between 1 – 3 kGy at time 3.

All other chemical components investigated showed no deleterious effects at the higher doses as well.

Vitamins

Particularly, no significant main effect of dose was detected in Vitamin C (ascorbic acid) in strawberry at time 1 at low doses (≤ 1 kGy). At the 2 kGy, 2.5 kGy and 3 kGy samples mean Vitamin C (ascorbic) were significantly lower than the untreated sample and the samples treated at low doses one day after irradiation treatment.

However, after 14 days in cold storage at 0°C the Vitamin C (ascorbic acid) content levelled for the samples irradiated at 2 kGy, 2.5 kGy and 3 kGy and were not significantly different to the other samples and the untreated control sample. Although the responses during the 14 days were variable, depending on the dose, no main effect of dose was detected at time 2. After 28 days cold storage at 0°C, the remaining strawberry samples irradiated at >1 kGy showed lower mean Vitamin C (ascorbic acid) compared to time 2 except for the 3 kGy sample.

Some researchers found Vitamin C levels decreased in untreated strawberries from the beginning to the end of the storage (Perez *et al*, 1998; Sanz *et al*, 1999). Graham and Stevenson (1997) observed that the radiation-induced vitamin C concentration change in different varieties was small compared to the large variations observed between the varieties.

An early study by Kim *et al* (1968) reported that the level of reduced ascorbic acid decreased with increasing dose (1 kGy, 2 kGy, and 3 kGy) soon after irradiation. After 23 days storage at $4^{\circ} \pm 2^{\circ}\text{C}$, samples irradiated at 1 kGy and 2 kGy retained twice the ascorbic acid content than the untreated sample. On the other hand, the reverse was found in a study by Herregods and Defroost (1963) where Vitamin C in untreated samples reduced more rapidly than 1 kGy, 2.5 kGy and 5 kGy samples in $2\text{--}15^{\circ}\text{C}$ storage.

In a very early study, Zegota (1988) found losses in ascorbic acid after 7 days and after 14 days stored at $2 - 4^{\circ}\text{C}$ in strawberry irradiated at 2.5 kGy and 3 kGy, however, the rate of decrease was less than the untreated strawberry. The researcher found that in Dukat strawberries irradiated with a dose of 2.5 kGy and 3 kGy, the ascorbic acid levels decreased in proportion to the absorbed dose and storage time and inferred that irradiation had caused the oxidation of ascorbic acid to dehydroascorbic acid.

Salunke *et al* (1959) reported significant reductions in ascorbic acid content in irradiated strawberries while others have found minor (Maxie *et al*, 1964; Lopez *et al* 1967) or no effect on ascorbic acid content (DeZeeuw, 1961).

Mean Vitamin C (ascorbic acid) in the control sample one day after irradiation was 49.7 mg/100g while the means for the irradiated samples ranged between 36.7 – 49.3 mg/100g. These figures are comparable with the reference data in the Food Standard Australia New Zealand (FSANZ) nutrient database of 45 mg/100g (FSANZ, 2011 website) and 58.8 mg/100g in the United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference (US Dept Agric, 2011 website). In the FSANZ database, Vitamin C refers to total Vitamin C activity: to ascorbic acid and dehydroascorbic acid while the USDA database refers to total ascorbic acid.

Nelson *et al*. (1972) found that ascorbic acid in the six varieties they tested ranged from 19.3 to 71.5 mg/100g. Agar *et al*. (1997) reported ascorbic acid levels in fresh strawberries declined from 60 mg/100 g to 27 mg/100g after storage for 20 days at 1°C and 20% CO_2 but dehydroascorbic acid increased during storage from 5.0 mg/100g to 34.0 mg/100g.

Although irradiation is known to destroy vitamins in pure and unadulterated systems, in food the damage may not be significant due the mutually protective action or shielding effect of various chemical constituents on each other (Diehl 1990).

It is well known that many pre and postharvest factors are responsible for the wide variation in Vitamin C content in fruits at harvest. These are genotypic variation (Stevens, 1974; Harris, 1975), climatic, environmental and cultural practices (Somers and Beeson, 1948; Lee, 1974; Harris, 1975; Mozafar, 1994; Weston and Barth, 1997). Kader (1988) reported that maturity at harvest, the method of harvesting, and postharvest handling contribute to the variation, as do cooking and various processing methods can also affect the Vitamin C content (Fennema, 1977).

Carotenoid

There was also no main effect of dose detected in beta-carotene at time 1. Overall, mean beta-carotene levels were significantly lower after 14 days in cold storage and decreased further when measured at 28 days.

At 28 days, for the remaining strawberry samples which were irradiated at doses ≥ 1 kGy, no main effect of dose was found in all the chemical components investigated.

Fresh untreated strawberry, variety 'Albion' had a mean of 3.13 $\mu\text{g}/100\text{g}$ of beta-carotene, the 150 Gy, 400 Gy, 1000 Gy, 2000 Gy, 2500 Gy and 3000 Gy irradiated samples had means of 3.57, 3.63, 4.27, 2.87, 3.80 and 3.20 $\mu\text{g}/100\text{g}$ beta-carotene, respectively. The value recorded in the FSANZ nutrient database is 0 $\mu\text{g}/100\text{g}$.

Reyes and Cisneros-Zevallos (2007) observed no major effect of irradiation treatments (1 – 3.1 kGy) on the total carotenoid content in mango just after irradiation. While other components of the carotenoid profile changed after 18 days storage, beta-carotene did not.

Reducing sugars

Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher in untreated and irradiated strawberry samples after 14 days. Wall (2007) observed these changes in bananas as dose increased to 800 Gy and attributed these differences to an acceleration of sucrose hydrolysis in treated bananas. Strawberry treated at doses ≥ 1000 Gy showed a decline in all three profiles at 28 days.

A decrease in total sugars and sucrose with increasing radiation dose has been reported by some researchers (Kim *et al.*, 1968; Tencheva and Todorov, 1975) while Schubert *et al.* (1973) and Beyers *et al.* (1979) have found no significant changes after irradiation.

Doses of 1.5 kGy and 3 kGy produced no significant changes in the content of fructose, glucose, and sucrose after irradiation treatment from fresh whole berries or after vacuum drying (Schubert *et al.*, 1973). The same conclusion was reached by Beyers *et al.* (1979) who found no significant changes in the amount of total sugars between control and 2 kGy treated fruits in two varieties of strawberry determined 24 hr after irradiation. However, these results may not necessarily reflect the changes that might occur during storage of irradiated fruits.

The effect of storage time was greater than by irradiation itself in many of the chemical components measured and the changes generally appeared to be associated with the ripening process during storage.

It is a well-known fact that the nutritional components measured depends upon the degree of ripeness of the fruit, and quite different results would no doubt have been obtained had unripe or over-ripe fruits been analysed. Their nutritional content and quality can be affected by variety, storage conditions, handling and presence of microorganism.

Ripening in strawberry harvested when mature is accompanied by a rapid rise in respiration rate, followed by a slowing down as the fruit ripens and develops good eating quality. Ripeness is followed by senescence and breakdown of the fruit, which is the normal aging of produce. These changes in mean values are considered to be responses from general fruit senescence

Recommendations

Applications of gamma irradiation treatments of 1 kGy can be considered as a phytosanitary method for strawberry. While components responded differently when exposed to ionising low dose γ -irradiation the overall findings of this study show that an application of up to 1 kGy will not induce any significant detrimental effects to the chemical and proximate components of strawberry measured.

No significant main effect of dose was detected in the components measured in strawberry samples irradiated up to 3 kGy except for Vitamin C (ascorbic acid) in samples irradiated at 2 kGy, 2.5 kGy and 3 kGy one day after irradiation treatment.

Treatment with doses >1 kGy could be safely applied without inducing any deleterious effects in strawberry when overall time effects are considered, particularly when considering the effect of irradiation on Vitamin C (ascorbic acid) content. After 14 days in cold storage at 1°C the Vitamin C (ascorbic acid) levels for strawberry treated at the higher doses (2 – 3 kGy) were not significantly different from the untreated sample and were in the same range as the levels observed one day after treatment. Untreated strawberries and strawberries irradiated at doses <1 kGy perished after 14 days.

No deleterious effects were detected in the nutritional components measured when strawberry samples were irradiated at doses 2 – 3 kGy over the period in the study.

References

- Agar, I.T., Streif, J., Bangerth, F. (1997). Effect of high CO₂ and controlled atmosphere on the ascorbic and dehydroascorbic acid content of some berry fruits. *Postharvest Biol. Technol.* 11: 47–55.
- AOAC 16th Ed. Official Methods of Analysis of AOAC INTERNATIONAL (OMA) 18th Ed., AOAC INTERNATIONAL. Gaithersburg, MD. USA. Online <http://www.eoma.aoac.org/>
- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895. <http://www.comlaw.gov.au/Details/F2009C00895>
- Badings & Dejong (1983). *J. Chrom.*, 279, 493-506.
- Beyers, M., Thomas, A. C., and Van Tender, A. J., y irradiation of subtropical fruits. I. Compositional tables of mango, papaya, strawberry, and litchi fruits at the edible-ripe stage, *Agric. Food Chem.*, 27, 37, 1979.
- Bligh & Dwyer, "A Rapid Method of Total Lipid Extraction and Purification", *Can. J. Biochem. Physiol.*, 37, 911-917.
- Brubacher, G., Muller-Mulot, W. and Southgate, D.A.T. (eds), 'Methods for the Determination of Vitamins in Food', (1985) Elsevier Applied Science Publishers Ltd Ch 5.
- CRC Handbook of Chemistry and Physics, 56th Edition (1975-76), page C235 Ibid, page C251
- De Zeeuw, D. (1961). Experiments on the preservation of fresh fruits by irradiation, *Food Irradiat.*, 1(3), 5.
- Diehl J.F. (1990). Safety of irradiated foods. 1st ed. New York: Marcel Dekker Inc. 196 p.
- Fennema, O.,(1977). Loss of vitamins in fresh and frozen foods. *Food Technol.* 31 (12), 32–38.
- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database. <http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010onlinesearchabledatabase/onlineversion.cfm>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339. <http://www.comlaw.gov.au/Details/F2010C00339>
- Graham W.D, Stevenson M.H. 1997. Effect of irradiation on vitamin C content of strawberries and potatoes in combination with storage and with further cooking in potatoes. *J Sci Food Agric* 75(3):371-377.
- Harris, R.S. (1975). Effects of agricultural practices on the composition of foods. In: Harris, R.S., Karmas, E. (Eds.), *Nutritional Evaluation of Food Processing*, 2nd edn. AVI.
- Herregods, M. and DeProost, M. (1963). The effect of gamma irradiation on the preservation of strawberries. *Food Irradiat.*, 4(1): 35.

- International Consultative Group on Food Irradiation (2002). <http://www.iaea.org/icgfi>
- ISPM No. 28 Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009). https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Kader, A.A. (1988). Influence of preharvest and postharvest environment on nutritional composition of fruits and vegetables. In: Quebedeaux, B., Bliss, F.A. (Eds.), *Horticulture and Human Health: Contributions of Fruits and Vegetables*. Proceedings of the 1st International Symposium on Horticulture and Human Health. Prentice-Hall, Englewood Cliffs, NJ, pp. 18–32.
- Kim, H. S., Choi, Y. R., and Byung, S. M. (1968). Studies on the preservation of fruits. I. Effects of γ -ray radiation on the chemical composition of strawberries, *J. Nucl. Sci. (Seoul)*, 8(2):147.
- Lee, C.Y. (1974). Effect of cultural practices on chemical composition of processing vegetables. A review. *J. Food Sci.* 39, 1075–1079. content of horticultural crops. *Postharvest Biology and Technology* 20 (3): 207–220.
- Lopez, G. M., Rivas, G. A., Ortin, S. N., and del Val Cob, M. (1967). Preservation of food by irradiation. VI. Preliminary investigation on strawberries, in *Symp. Application of Radioisotopes*, Madrid, 1967.
- Maxie, E. C., Sommer, N. F. and Rae, H. L. (1964). Effect of gamma irradiation on Shasta strawberries under marketing conditions, *Isot., Radiat. Technol.*, 2(1): 50.
- Mozafar, A. (1994). *Plant Vitamins: Agronomic, Physiological and Nutritional Aspects*. CRC Press, Boca Raton, FL.
- Nelson, J.W., Barritt, B.H. and Wolford, E.R. (1972). Influence of location and cultivar on color and chemical composition of strawberry fruit. *Wash. Agric. Exp. Stn. Tech. Bull.* 74: 1–7.
- Perez, A. G., R. Olias, J. M. Olias and C. Sanz (1998). Strawberry quality as a function of the “high pressure fast cooling” design. *Food Chemistry* 62(2): 161–168.
- Reyes, F. L. and Cisneros-Zevallos, L. (2007). Electron-Beam Ionizing Radiation Stress Effects on Mango Fruit (*Mangifera indica* L.) Antioxidant Constituents before and during Postharvest Storage. *J. Agric. Food Chem.* 55: 6132–6139.
- Saluhnke, D.K., Gerber, R.K. and Pollard, L.H. (1959). Physiological and Chemical Effects of Gamma Radiation on Certain Fruits, Vegetables and Their Products. *Proc. Am. Soc. Hort. Sci.*, 74, 423–429.
- Sanz, C., Perez, A.G., Olias, R. and Olias, J.M. (1999). Quality of strawberries packed with perforated polypropylene. *Journal of Food Science* 64(4): 748–752.
- Schubert, J., Sanders, E. B., Pan, S. F., and Wald, N. (1973). Irradiated strawberries - chemical, cytogenetic and antibacterial properties, *Agric. Food Chem.* 21:684.
- Somers, G.F. and Beeson, K.C. (1948). The influence of climate and fertilizer practices upon the vitamin and mineral content of vegetables. *Adv. Food Res.* 1, 291–324.
- Stevens, M.A. (1974). Varietal influence on nutritional value. In: White, P.L., Selvey, N. (Eds.), *Nutritional Qualities of Fresh Fruits and Vegetables*. Futura, Mt. Kisco, NY, pp.87–110.

- Taylor, J. (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35–43.
- Tancheva, S. and Todorov, S. (1975). Effect of gamma irradiation on the storage life extension of fresh strawberries and raspberries, *Nauchni Tr. Nauchnoizsled. Inst. Radiobiol. Radiats. Kbig*, 5(2): 271.
- UC Davis (2011) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 15 January, 2012, <http://postharvest.ucdavis.edu/producefacts/>
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website, <http://www.nal.usda.gov/fnic/foodcomp/search/>
- VSN International (2011) GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK. Web page: GenStat.co.uk
- Wall, M.M. (2007) Postharvest quality and ripening of Dwarf Brazilian bananas (*Musa* sp.) after x-ray irradiation quarantine treatment. *Hort Sci.* 42: 130-134.
- Zegota, H. (1988). Suitability of Dukat strawberries for studying effects on shelf life of irradiation combined with cold storage. *Z Lebensm Unters Forsch* 187:111-114.

Appendix. Dosimetry Results



Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

22 November 2011

Irradiation Report

ANSTO Reference 11-1915
Customer QLD DEEDI
Address 21-23 Redden Street,
Portsmith, QLD – 4870
Contact [REDACTED]



ANSTO Ref: 11-1915

SRT F 004

Prepared [REDACTED]

Authorised [REDACTED]

Date

22.11.2011

Page 1 of 6

Product Details

Product Strawberries
Quantity 42 trays (15 punnets per tray)

Irradiation Conditions

Irradiation Facility Gamma Technology Research Irradiator (GATRI)
Radiation type Gamma radiation (cobalt-60)
Irradiation Dates 14 November 2011 to 16 November 2011
Required Doses 0, 150, 400, 1000, 2000, 2500 & 3000 Gy
Dose rate Approx. 15.4 Gy.min⁻¹
Dosimeter Type Fricke & Low dose Ceric Cerous
Dosimeter Batches F225 & CCAB
Storage Conditions Pre & post irradiation 1 °C
Irradiation temperature 21.0 to 23.0 °C

ANSTO Ref: 11-1915

SRT F 004

Prepared

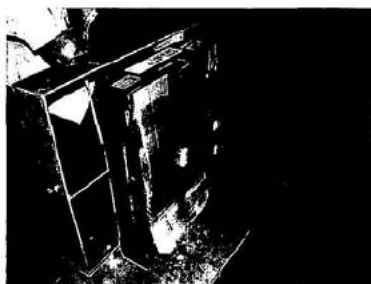
Authorised

Date

Page 2 of 6

20-11-2011

Figure 2



Trays positioned for irradiation and dosimeters in monitoring position.

Results for Replicate 1

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	139 ± 4	155 ± 4	147 ± 3
400	378 ± 7	420 ± 7	399 ± 5
1000	933 ± 12	1038 ± 12	985 ± 9
2000	1910 ± 110	2130 ± 120	2020 ± 80
2500	2380 ± 110	2660 ± 120	2520 ± 80
3000	2820 ± 130	3150 ± 150	2980 ± 100

ANSTO Ref: 11-1915

SRT F 004

Prepared

Authorised

Date

22.11.2011

Page 4 of 6

Results for Replicate 2

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	142 ± 4	158 ± 4	150 ± 3
400	375 ± 7	417 ± 7	396 ± 5
1000	947 ± 100	1056 ± 120	1000 ± 80
2000	1910 ± 120	2130 ± 130	2020 ± 90
2500	2320 ± 120	2590 ± 140	2460 ± 90
3000	2810 ± 120	3130 ± 140	2970 ± 90

Results for Replicate 3

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	143 ± 4	159 ± 4	151 ± 3
400	380 ± 7	423 ± 7	401 ± 5
1000	936 ± 13	1041 ± 13	988 ± 9
2000	1940 ± 100	2160 ± 100	2050 ± 100
2500	2390 ± 100	2660 ± 100	2530 ± 100
3000	2840 ± 100	3170 ± 200	3010 ± 100

ANSTO Ref: 11-1915

SRT F 004

Prepared

Author

Date

22.11.2011

Page 5 of 6

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 % for Fricke and 3.0% for Ceric Cerous. The above results include the uncertainties in the dose mapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: 11-1915

SRT F 004

Authorise

Date

22.11.2011

Page 6 of 6

Part B. Phytosanitary irradiation effects on the postharvest quality of strawberry fruit.

Summary

Fruit quality evaluations were conducted on strawberry fruit (*Fragaria* sp) var. 'Albion' after being treated with gamma irradiation and following a cold (0°C) storage period of either 0, 7, 14 or 21 days. Gamma irradiation treatments consisted of a dose of either 0, 150, 400, 1000, 2000, 2500 or 3000 Gy, applied separately to three sets of fruit with each set representing a replicate block. Mould development and physico-chemical changes in quality were measured on fruit within 24 hours after treatment with irradiation and after removal from each cold storage treatment. An additional set of fruit after storage were held for 24 or 72 hours at ambient temperature (24°C) to replicate a shelf-life environment with similar assessments conducted for mould development and fruit quality.

The findings of this study showed that cold storage duration but not irradiation had a significant effect on whole fruit quality. In this case, the removal of fruit from cold storage resulted in development of water-soaked symptoms on individual fruit irrespective of any irradiation dose, with symptoms only occurring after 14 and 21 days of storage. During each shelf-life environment, fruit quality deteriorated further, with symptoms of water soaking occurring across most fruit irrespective of its irradiation treatment.

The extent of calyx browning was positively related to the level of irradiation and storage duration, with higher levels of both factors resulting in increased browning after removal from storage and at the end of each shelf life period. At 7 days storage, there was little to no difference between treatments (mean <25% browning), but after 14 days calyx browning in fruit irradiated with ≥ 2.5 kGy was approximately twice the severity compared with non-irradiated fruit (~25%). The shelf life environment also exacerbated calyx discoloration across all treatments (including non-irradiated fruit), suggesting chilling injury may have played a role in its expression.

Other organoleptic properties such as fruit firmness levels were significantly affected by irradiation, with higher doses resulting in softer fruit. Immediately after treatment, firmness levels in non-irradiated fruit (mean 2.6 N) were 0.6 N firmer than those treated to 1 kGy and almost twice as firm as those treated to 3 kGy (1.5 N). From a biochemical perspective, Brix levels showed no consistent pattern across the different storage times or irradiation treatments, except after 21 days when levels in un-irradiated fruit were significantly lower (mean 6.8°) compared to fruit treated to ≥ 2 kGy (mean 8.7°). Titratable acidity levels measured immediately after removal from storage were not affected by any cold storage duration or irradiation treatment (mean 0.84% for ascorbic acid).

Increasing doses of irradiation but shorter storage times corresponded to an increased suppression of fruit mould growth. Mould was present but in low levels (less than 10% of fruit with infections <1 cm² in size) after 7 days storage and primarily only in fruit treated to a dose of <1 kGy. After 14 days storage, mould was present in all irradiated fruit except those subjected to 3 kGy, with the proportion of fruit affected ranging from 3.3% (2 – 2.5 kGy) to 25% (≤ 1 kGy) and 50% for control fruit. A similar pattern was present after 21 days storage, despite slightly higher levels of mould across all treatments. During each shelf life environment, mould appeared in fruit across almost all irradiation treatments, which was exacerbated with longer storage times.

The recommended treatment combination that provided the best trade-off in terms of fruit with little to no mould and with favourable quality attributes, such as maintenance of relatively high firmness levels, no water-soaked spots and little calyx discoloration, was an irradiation dose of between 1 –

2 kGy and a storage time of up to 7 days. This is inline with recommendations provided by other authors for producing "acceptable" fruit at out-turn.

Introduction

Strawberry (*Fragaria* sp) is a temperate non-climacteric fruit and once harvested is considered a highly perishable commodity, particularly under warmer ambient conditions. Even under refrigerated conditions fruit are highly susceptible to breakdown, particularly from fungal infections (Sommer et al. 1968, Aziz and Moussa 2002) which can often result in excessive losses of up to 20% or more during commercial storage and transport conditions (Thomas 1986). Studies have shown that cold storage or transport temperatures at 0°C can slow but not entirely stop fungal growth although applied in combination with radiation, it can be an effective method for decreasing microbial contamination and improving shelf life (Hussain et al. 2007, Amrani 2008). Compared with most other fruit crops, strawberry fruit has a relatively high tolerance to irradiation and an upper dose of 2 kGy has generally been found to be the most effective treatment without causing significant deleterious effects on fruit quality (Thomas 1986). Above 2 kGy, fruit have reported to experience softening and development of water-soaked spots (Thomas 1986, D'Amour et al. 1993), although as noted by several authors (Kader 1986, Hussain 2007) responses to irradiation can vary between variety, harvest maturity, growing conditions and other factors associated with geographic location.

In the present study, the effects of irradiation and cold storage duration were therefore examined on Australian grown strawberry fruit (var. 'Albion') to assess their effects on fruit quality following cold storage and a subsequent ambient shelf life. Fruit assessments entailed measurements of mould development and physico-chemical changes in fruit quality. The findings of this study are anticipated to contribute to our overall understanding of the impact of a range of gamma irradiation doses (0 – 3 kGy) on an Australian grown and marketed variety. This work will also compliment the findings from the nutritional component of this study (described earlier in this report) which incorporated the same irradiation dose and cold storage treatments as in this study.

Materials and methods

Experimental layout

Strawberry fruit (var. 'Albion') were sourced from the Sydney Markets, NSW in November 2011. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, and gamma irradiated with a target dose of 150, 400, 1000, 2000, 2500 and 3000 Gy. Fruit were divided into three blocks per irradiation dose with each block consisting of a separate irradiation event. A corresponding set of untreated fruit served as a control group (0 Gy). Replication consisted of 250 g standard plastic (PET) clamshell punnets containing between 10 – 15 individual strawberry fruit per block per irradiation treatment per assessment time. Assessment times were immediately after storage and then at the end of a shelf life period.

After being irradiated, the strawberry punnets were packed in Styrofoam containers with frozen Techni-Ice dry ice packs (Techni Ice Australia) and transported overnight by air to the Department of Employment, Economic Development and Innovation (DEEDI) postharvest laboratory in Cairns, Queensland. Fruit were then immediately placed into cold storage at 0°C based on the postharvest storage conditions recommended by the University of California, Davis Postharvest Technology Center, California (UC Davis, 2011). Fruit were held in storage for a treatment duration of either 0, 7, 14 or 21 days and then transferred to evaluation room held at ambient temperature (24°C, ~RH 65%). An initial set of fruit were assessed immediately after storage (0 hours) and a second set after 24 hours in the shelf life evaluation room. These two respective assessment times are referred to as the "storage" and "shelf life" periods.

Note, a shelf life duration of 72 hours was initially planned for the experiment and was undertaken on fruit from the first "0 day" treatment, however, due to excessive decay that developed on these fruit the shelf life duration was subsequently scaled down to 24 hours. Hence, the data for the 0 day storage treatment is presented in this study after a shelf life duration of 72 hours, whereas all subsequent evaluations (7, 14 and 21 storage days) were conducted using the revised 24 hour shelf life duration.

Fruit Quality Assessments

Fruit quality was assessed immediately after storage using 10 randomly selected fruit per punnet. This included measurements of fruit firmness, scores of calyx and whole fruit quality, biochemical analyses (soluble solids and titratable acidity) and an incidence and severity measure of disease. Assessments at the end of the shelf life period comprised a measure of calyx and whole fruit quality, and disease incidence and severity.

Fruit firmness

Fruit firmness measurements were conducted using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12 mm spherical probe. Compression on the equatorial region of each fruit was undertaken at a rate of 20 mm per minute until 2 mm of fruit tissue was displaced, with results expressed in Newtons (N).

Fruit quality and disease expression

Fruit quality comprised a measurement of calyx quality, whole fruit quality and disease expression on 10 randomly selected fruit per punnet. Calyx quality was scored based on the degree of colour change in the calyx, where 0 = fully green, no brown tissue; 1 = <25% browning; 2 = up to 50%

browning; and 3 = >50% browning. Whole fruit quality was scored based on a modified method described Jeff Brecht within Kader and Cantwell (2010) (Table 1). Fruit decay (fungal disease) was scored based on the percent fruit surface area affected, where 0 = nil, 1 = slight, incipient decay spot, <1 cm²; 2 = Moderate, <20%; 3 = Moderate severe, 20-50%; and 4 = Severe, >50%.

Table 1. Rating scale for whole fruit quality in strawberry.

Rating	Definition
0	Shiny and turgid appearance.
1	Slightly dull appearance.
2	Lacks sheen, has some water soaked spots.
3	Serious water loss, softening and water-soaking appearance.
4	Total fruit collapse.

Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) assessment were conducted on up to 10 randomly selected fruit per punnet. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed in degree (°) Brix. Selected fruit samples were also blended to a fine slurry with an extracted juice sample used to determine TA. Samples were titrated to pH 8.1 with 0.1 N NaOH (Mettler Toledo T50 autotitrator) and expressed as % citric acid.

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package GenStat version 11.1 (VSN International Ltd.). Two-way ANOVA's were performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute recorded immediately after storage. Shelf life quality analyses were conducted separately for fruit from each storage duration time, using a one-way ANOVA to compare quality attributes recorded immediately after storage with those at the end of the shelf life period. In all analyses, the blocking factor represented each of the three irradiation events per treatment. Mean differences were separated by the least square difference (LSD) test at the 5% level and non-significant results were reported as "ns".

Results

Storage quality

The effects of irradiation and storage duration on strawberry fruit quality traits such as firmness, calyx colour and fruit quality are shown in Figure 1A – C and the Appendix. Treatment with irradiation had a significant and immediate effect on fruit firmness, with higher doses of irradiation generally resulting in significantly softer fruit (Figure 1A). Control fruit (0 Gy) were initially 1 N firmer than those treated to 3 kGy. However, firmness levels in the control and low-dosed fruit (<1 kGy) decreased over successive storage times, becoming equivalent to 3 kGy-treated fruit after 21 days storage.

Calyx quality decreased with both the storage time and irradiation treatments (Figure 1B). Differences in calyx quality between the irradiation treatments were evident after 7 day storage, although by 14 days storage fruit dosed with 2.5 and 3 kGy exhibited the highest rates of browning (up to 50%) compared with control fruit (< 25%). The control fruit also had the lowest rate of calyx browning across the entire storage period, reaching a score of 1.5 (mean 38% browning) after 21 days storage.

Whole fruit quality decreased significantly with storage time but was not affected by the irradiation treatment (Figure 1C). Symptoms of water-soaking on fruit were first evident following 14 days of cold storage, which continued to increase in severity with further storage time. On day 14, this equated to fruit displaying a lack of sheen on their skin surface with the presence of some water-soaked spots (mean score: 2) which became more severe by day 21 (mean score: 2.5).

Disease expression in strawberry was inversely related to the level of irradiation, with higher doses incurring a lower incidence and severity of decay (Figure 2A and B, and Appendix). Differences between treatments occurred from 14 days after storage onwards. By day 21 in storage, 50% or more of the fruit expressed disease when dosed with ≤ 400 Gy, while intermediate (33%) and low (<10%) incidences occurred at 1 kGy and at ≥ 2 kGy, respectively. After 21 days, a similar pattern was also observed with respect to disease severity, with fruit in the low dose treatments (≤ 400 Gy) exhibiting up to 20% of their surface area with mould (disease scores: 1.4 to 2.0) compared to <1 cm² area for ≥ 2 kGy-treated fruit (scores below 0.3) (Figure 2B). An intermediate response in disease severity was observed in fruit treated to 1 kGy (score: 0.7).

Fruit brix levels changed little over the storage durations except for a significant difference on day 21 (Figure 3). On this day, Brix levels in fruit treated to ≥ 2 kGy were approximately 1.5° higher than those treated ≤ 1 kGy (mean 7.2°). Titratable acidity levels did not differ between treatment doses and remained relatively constant over the entire storage period (mean 0.84% for ascorbic acid).

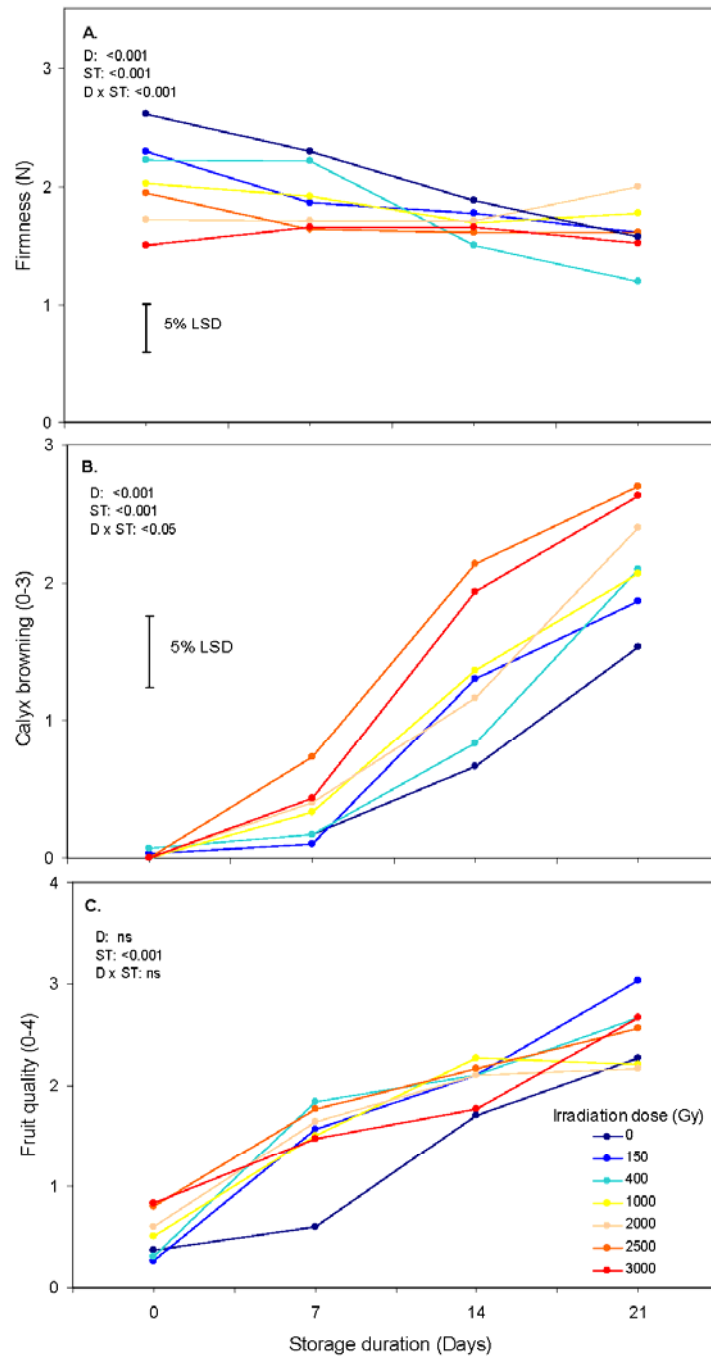


Figure 1 A - C. Effect of irradiation dose and subsequent cold (0°C) storage duration on strawberry (A) firmness, (B) calyx browning and (C) whole fruit quality measured immediately after removal from storage.

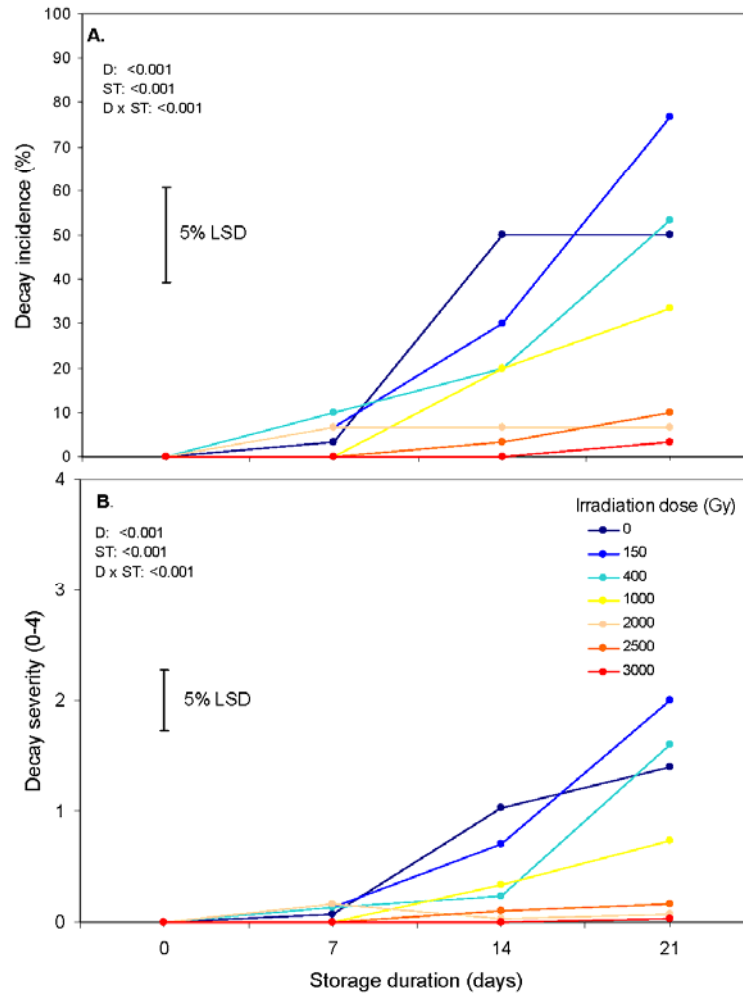


Figure 2 A- B. Effect of irradiation dose and subsequent cold (0°C) storage duration on the (A) incidence and (B) severity of pathogenic decay in strawberry fruit measured immediately after removal from storage.

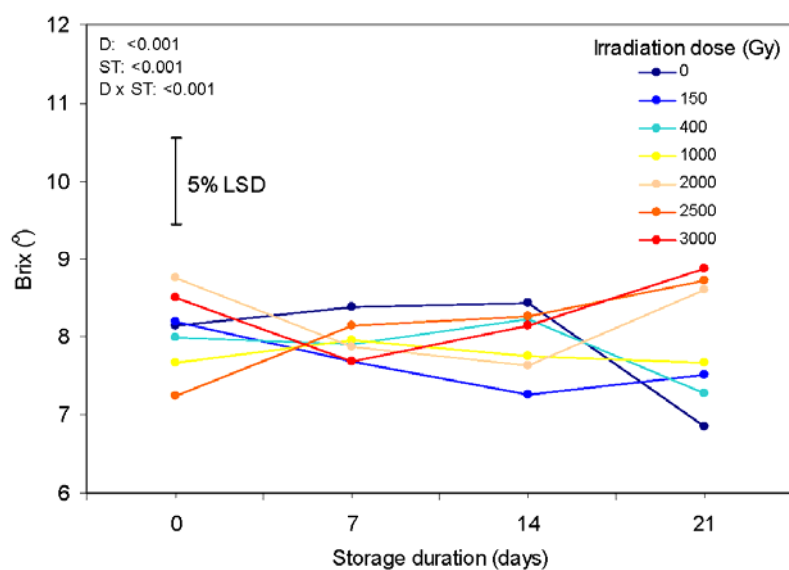


Figure 3. Effect of irradiation dose and subsequent cold (0°C) storage duration on Brix levels in strawberry fruit measured immediately after removal from storage.

Shelf-life quality

Whole fruit and calyx quality were evaluated at the end of each shelf life period, being 72 hours after the first storage time (0 days) and 24 hours for each subsequent storage period (Tables 2 and 3). Whole fruit quality over each storage period was generally more affected by the shelf-life environment than by irradiation itself. At the end of each shelf life period, almost all fruit exhibited water-soaked symptoms (equivalent to scores of ≥ 2) (Table 2).

Calyx quality was affected by both irradiation dose and the shelf life period (Table 3). Generally, calyx browning increased significantly during each shelf-life period, and from day 7 onwards, was more severe in treatments treated to higher doses of irradiation. By day 21, the extent of calyx browning was not able to be determined due to the high incidence of pathogenic decay across most treatments.

The incidence and severity of fruit disease or decay increased within each shelf life period and over each storage duration (Table 4 and 5). At the end of the 72 hour shelf life assessment (Day 0), over 70% of fruit in the control treatment (0 Gy) had symptoms of decay compared with $\leq 20\%$ of fruit in the ≥ 2 kGy treatments. Observations over each consecutive 24 hour shelf life period (after 7, 14, and 21 days storage) showed that the incidence of decay increased between 2 to 4-fold across all the irradiation treatments, except for the 3 kGy treatment where fruit decay was absent at 7 and 14 day after cold storage.

Table 2. Effect of irradiation dose and shelf life time on strawberry fruit quality after each cold (0°C) storage duration (0 – 21 days). Fruit quality variables ranged from 0 to 4 as listed in Table 1. Abbreviations: SL = Shelf life time; ID = Irradiation dose; ns = not significant.

Storage duration (days)	Shelf life time (hours)	Irradiation dose (Gy)							Mean	ANOVA's	
		0	150	400	1000	2000	2500	3000		Factor	P-value
0	0	0.4	0.3	0.3	0.5	0.6	0.8	0.8	0.5 ^a	SL	<0.001
	72	3.3	3.5	3.1	3.0	2.7	3.1	3.1	3.1 ^b	ID	ns
	Mean	1.8	1.9	1.7	1.8	1.7	2.0	2.0		SL x ID	ns
7	0	0.6	1.6	1.8	1.5	1.6	1.8	1.5	1.5 ^a	SL	<0.001
	24	1.8	2.7	2.9	2.5	2.6	2.9	2.8	2.6 ^b	ID	<0.01
	Mean	1.2 ^b	2.1 ^a	2.4 ^a	2.0 ^a	2.1 ^a	2.3 ^a	2.1 ^a		SL x ID	ns
14	0	1.7	2.1	2.1	2.3	2.1	2.2	1.8	2.0 ^a	SL	<0.001
	24	3.0	3.3	3.0	3.0	2.4	2.9	2.7	2.9 ^b	ID	ns
	Mean	2.4	2.7	2.6	2.6	2.3	2.5	2.3		SL x ID	ns
21	0	2.3	3.0	2.7	2.2	2.2	2.6	2.7	2.5 ^a	SL	<0.001
	24	4.0	4.0	4.0	3.6	3.5	3.4	3.3	3.7 ^b	ID	ns
	Mean	3.1	3.5	3.3	2.9	2.8	3.0	3.0		SL x ID	ns

Table 3. Effect of irradiation dose and shelf life time on strawberry calyx browning after each cold (0°C) storage duration (0 – 21 days). Calyx browning scores ranged from 0 to 3, where 0 = fully green, no brown tissue; 1 = <25% browning; 2 = up to 50% browning; and 3 = >50% browning. Abbreviations: SL = Shelf life time; ID = Irradiation dose; ns = not significant; n/a = not available.

Storage duration (days)	Shelf life time (hours)	Irradiation dose (Gy)							Mean	ANOVA's	
		0	150	400	1000	2000	2500	3000		Factor	P-value
0	0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1 ^a	SL	<0.001
	72	3.3	3.5	3.1	3.0	2.7	3.1	3.1	3.1 ^b	ID	ns
	Mean	1.7	1.8	1.6	1.5	1.4	1.6	1.6		SL x ID	ns
7	0	0.2	0.1	0.2	0.3	0.4	0.7	0.4	0.3 ^a	SL	<0.001
	24	1.8	2.7	2.9	2.5	2.6	2.9	2.8	2.6 ^b	ID	<0.05
	Mean	1.0 ^b	1.4 ^{ab}	1.6 ^a	1.4 ^{ab}	1.5 ^a	1.8 ^a	1.6 ^a		SL x ID	ns
14	0	0.7 ^f	1.3 ^{ef}	0.8 ^f	1.4 ^{ef}	1.2 ^{ef}	2.1 ^{cd}	1.9 ^{de}	1.3 ^a	SL	<0.001
	24	3.0 ^{ab}	3.3 ^a	3.0 ^{ab}	3.0 ^{ab}	2.4 ^{bcd}	2.9 ^{ab}	2.7 ^{abc}	2.9 ^b	ID	ns
	Mean	1.9	2.3	1.9	2.2	1.8	2.5	2.3		SL x ID	<0.05
21	0	1.5	1.9	2.1	2.1	2.4	2.7	2.6	2.2	SL	n/a
	24	n/a	n/a	n/a	n/a	n/a	2.9	2.8	n/a	ID	n/a
	Mean	n/a	n/a	n/a	n/a	n/a	2.8	2.7		SL x ID	n/a

Table 4. Effect of irradiation dose and shelf life time on the incidence of decay (%) on strawberry fruit after each cold (0°C) storage duration (0 – 21 days). Abbreviations: SL = Shelf life time; ID = Irradiation dose; ns = not significant.

Storage duration (days)	Shelf life time (hours)	Irradiation dose (Gy)							Mean	ANOVA's	
		0	150	400	1000	2000	2500	3000		Factor	P-value
0	0	0	0	0	0	0	0	0			
	72	73.3 ^a	86.7 ^a	66.7 ^a	26.7 ^b	20.0 ^b	26.7 ^b	10.0 ^b		ID	<0.001
7	0	3.3	6.7	10.0	0.0	6.7	0.0	0	3.8 ^a	SL	<0.01
	24	10.0	23.3	36.7	13.3	20.0	3.3	0	15.2 ^b	ID	ns
	Mean	6.7	15.0	23.3	6.7	13.3	1.7	0		SL x ID	ns
14	0	50.0	30.0	20.0	20.0	6.7	3.3	0	18.1 ^a	SL	<0.001
	24	76.7	76.7	66.7	50.0	16.7	26.7	0	44.8 ^b	ID	<0.001
	Mean	63.3 ^a	53.3 ^{ab}	43.3 ^{ab}	35.0 ^{bc}	10.0 ^c	15.0 ^c	0		SL x ID	ns
21	0	46.7	76.7	53.3	33.3	6.7	10.0	3.3	32.9 ^a	SL	<0.001
	24	100.0	100.0	100.0	80.0	56.7	56.7	20.0	73.3 ^b	ID	<0.001
	Mean	73.3 ^{ab}	88.3 ^a	76.7 ^a	56.7 ^b	31.7 ^c	33.3 ^c	11.7 ^d		SL x ID	ns

Table 5. Effect of irradiation dose and shelf life time on the severity of decay (0-4) on strawberry fruit after each cold (0°C) storage duration (0 – 21 days). Fruit decay ranged from 0 to 4, where 0 = nil, 1 = slight, incipient decay spot <1 cm²; 2 = Moderate, <20%; 3 = Moderate severe, 20-50%; and 4 = Severe; >50%. Abbreviations: SL = Shelf life time; ID = Irradiation dose; ns = not significant.

Storage duration (days)	Shelf life time (hours)	Irradiation dose (Gy)							Mean	ANOVA's	
		0	150	400	1000	2000	2500	3000		Factor	P-value
0	0	0	0	0	0	0	0	0			
	72	2.2 ^{ab}	2.8 ^a	1.7 ^b	0.6 ^c	0.3 ^c	0.7 ^c	0.1 ^c		ID	<0.001
7	0	0.1	0.1	0.1	0	0.2	0	0	0.1 ^a	SL	<0.01
	24	0.3	0.6	0.6	0.3	0.5	0	0	0.3 ^b	ID	ns
	Mean	0.18	0.35	0.38	0.13	0.32	0.02	0		SL x ID	ns
14	0	1.0	0.7	0.2	0.3	0	0.1	0	0.4 ^a	SL	<0.001
	24	2.5	2.5	1.7	1.1	0.2	0.5	0	1.3 ^b	ID	<0.001
	Mean	1.8 ^a	1.6 ^{ab}	1.0 ^{bc}	0.7 ^{cd}	0.1 ^{de}	0.3 ^{de}	0 ^e		SL x ID	ns
21	0	1.4	2.0	1.6	0.7	0.1	0.2	0	0.9 ^a	SL	<0.001
	24	4.0	4.0	4.0	2.3	1.7	1.4	0.2	2.5 ^b	ID	<0.001
	Mean	2.7 ^a	3.0 ^a	2.8 ^a	1.5 ^b	0.9 ^{bc}	0.8 ^{bc}	0.1 ^c		SL x ID	ns

Discussion

The following study examined the interaction of both ionising radiation and storage duration on subsequent strawberry quality. Interestingly, irradiation itself had little to no effect on our measure of whole fruit quality, both after storage and over each shelf-life period. Rather, the physiological deterioration of fruit was more affected by storage duration itself. Initially, after 7 days of cold storage, fruit generally had a duller appearance although it was not until day 14 onwards that symptoms of water soaking became evident which was only exacerbated with further storage time. The results were consistent with other studies highlighting the perishable nature of strawberry fruit, hence the reason a cold storage duration of less than 2 weeks has often been recommended (Kader 1993).

Organoleptic properties of fruit such as sugars and acids are important components that impart flavour (Pelayo et al. 2003). In the present study, titratable acidity neither varied significantly between irradiation treatments nor across the different storage durations. Similarly, there was also no consistent pattern in Brix levels, except after 21 days storage when levels in fruit treated to a dose of ≥ 2 kGy remained higher than non-irradiated fruit. These findings would suggest that there was likely very little difference in flavour between the treatments, a response often reported in other studies (Thomas 1986). The results overall are probably not surprising given that cold temperature and irradiation are both known to reduce fruit respiration rates and consequently limit the reduction in sugars and other storage products (Hussain et al. 2007).

Interestingly, irradiation had a direct effect on other organoleptic properties of strawberry. In the present study, treatment with irradiation resulted in an immediate decrease in fruit firmness levels, with the extent of softening being positively related to the dose level. A dose at 1 kGy, for instance, was sufficient to cause a 0.6 N reduction in fruit firmness compared with non-irradiated fruit (2.6 N), whereas a 3 kGy dose resulted in firmness levels that decreased by half (1.5 N). These findings are consistent with other studies on strawberry that reported a softening response due to irradiation (Thomas 1986, D'Amour et al. 1993, Yu et al. 1996, Vachon et al. 2003). The subsequent loss in fruit firmness has been attributed to changes in cell wall composition and structure, particularly in the degradation of cell wall polysaccharides (D'Amour et al. 1994, Yu et al. 1995).

The effect of irradiation on strawberry calyx quality would likely be an important criterion affecting the sale of fruit. Findings from this study suggest that the extent of calyx browning was very much dependent on the irradiation dose level and storage duration, with increasing levels of both factors resulting in greater browning severity immediately after removal from storage. For example, our study showed that with only 7 days storage there was little to no difference between treatments. After 14 days storage, however, fruit treated to ≥ 2.5 kGy had approximately twice the amount of calyx browning (~50%) than non-irradiated control fruit (~25%). Moreover, during each shelf life period, irradiation and shelf life time itself also enhanced calyx discoloration. As browning also occurred on the calyxes of non-irradiated fruit, it suggests that a chilling related injury as a result of extended cold storage may have also contributed to its overall expression.

As shown in past studies, strawberry decay due to mould growth has been the primary causal factor affecting the postharvest life of strawberry fruit (Thompson 1959, Sommer et al. 1968, Aziz and Moussa 2002). However, the level of fruit decay is typically found to be inversely proportional to the dose of irradiation (Vachon et al. 2003, Hussain et al. 2007); a pattern also exhibited in the present study. Specifically, significant differences in the incidence and severity of decay were observed on fruit with 14 or more days of cold storage, with the lowest and highest levels of decay occurring in the ≥ 2 kGy and ≤ 1 kGy treatments, respectively. A similar experiment conducted by Hussain et al. (2007) also found that their highest treatment dose of 2 kGy was most effective in reducing mould appearance, which extended the life of strawberries by 8 days compared with non-

irradiated fruit. However, as shown in the present study, when fruit were held for an extended period (24 hours or greater) within the warmer shelf life environment, mould growth increased in severity at a faster rate.

In conclusion, both cold storage and gamma irradiation contributed to extending the storage life of strawberry fruit. However, devising of a recommended treatment combination has to be considered in light of consumer tolerance levels to any fruit physiological breakdown and pathological decay. Generally, strawberry fruit with a slight dull appearance (score of 1 in this study) would likely be marketable although, less so, when some water soaked spots become apparent (score of 2 or greater). According to Hussain et al. (1996), the presence of decay on fruit was generally considered as an unacceptable quality trait. Thus, applying the following criteria for the present study, a dose of between 1 – 2 kGy and a storage time of 7 days would likely result in the optimum treatment combination for producing “acceptable” fruit at out-turn. This is because a dose above 2 kGy would likely result in fruit being considerably softer and having extensive browning on their calyxes, whilst below 1 kGy fruit decay would be a significant issue. Moreover, a 24 hour shelf-life period after a 7 day cold storage treatment would likely be unacceptable given the significant amount of decay that developed over this period. In all, these findings are therefore in line with recommendations put forth by Kader (1993), suggesting that a maximum storage time of less than 14 days for irradiated strawberry fruit would be important for ensuring optimum outturn quality.

Recommendations

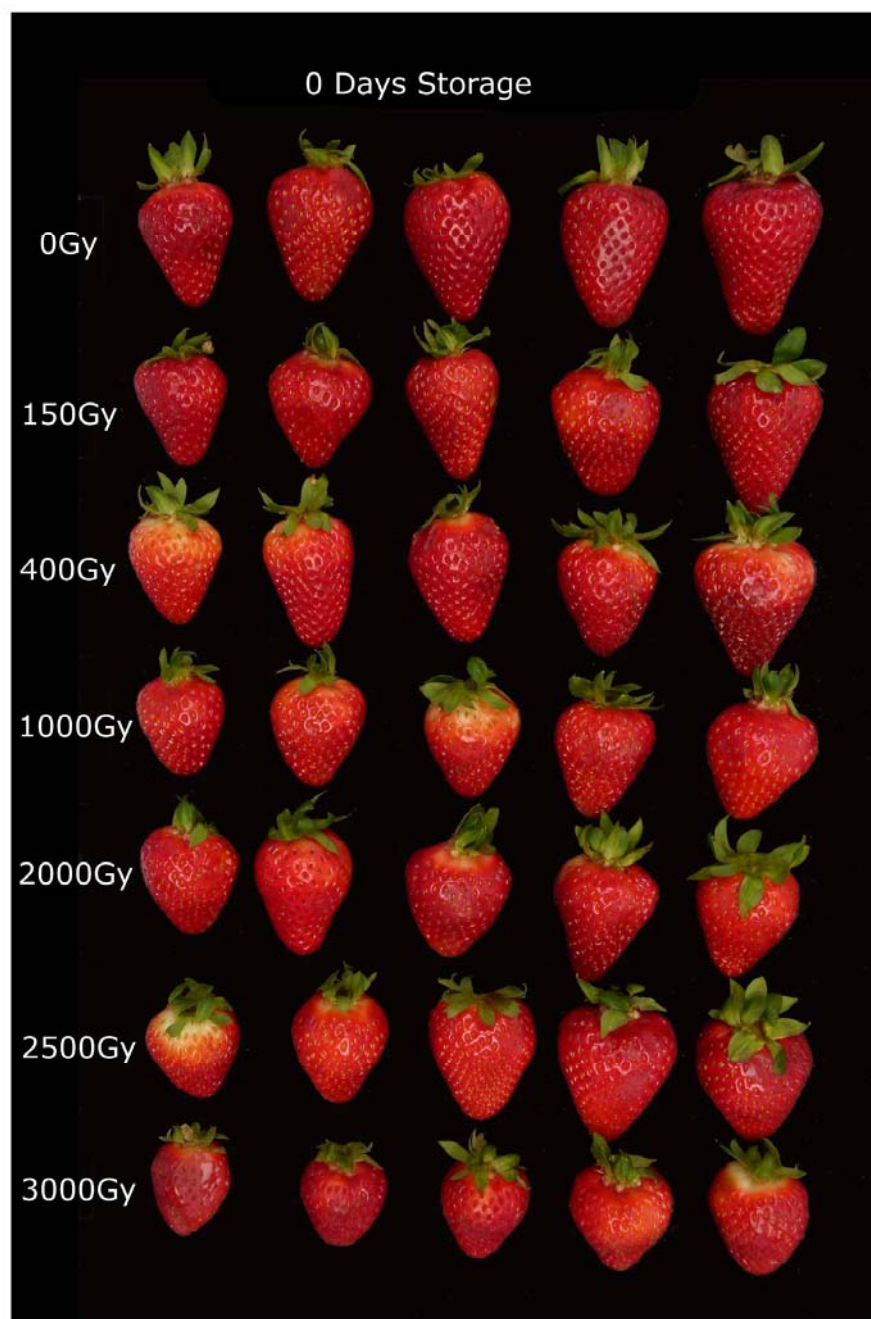
The recommended treatment combination that provided the best trade-off in terms of fruit with little to no mould and with favourable quality attributes, such as maintenance of relatively high firmness levels, no water-soaked spots and little calyx discoloration, was an irradiation dose of between 1 – 2 kGy and a storage time of up to 7 days. This is inline with recommendations provided by other authors for producing "acceptable" fruit at out-turn.

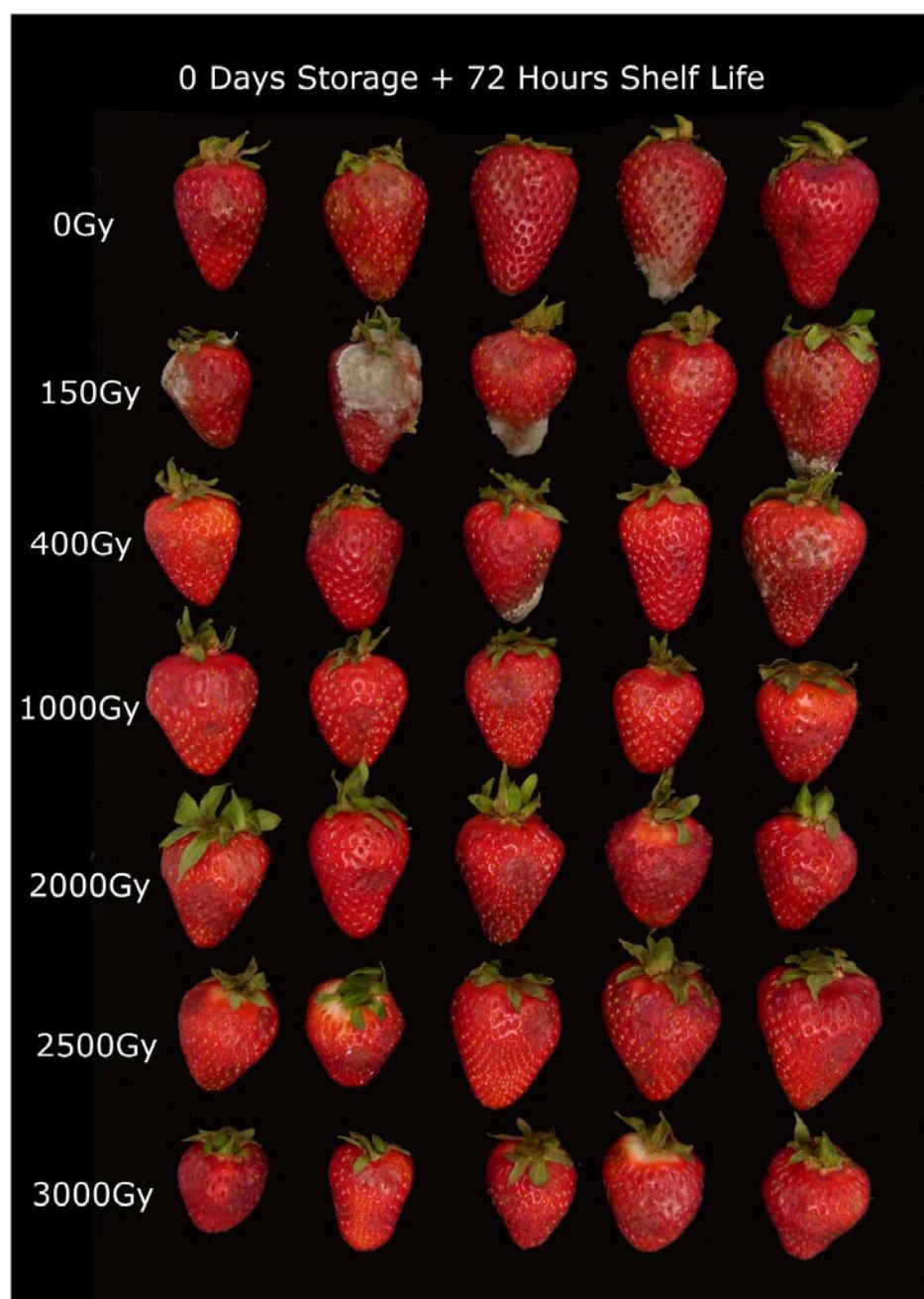
References

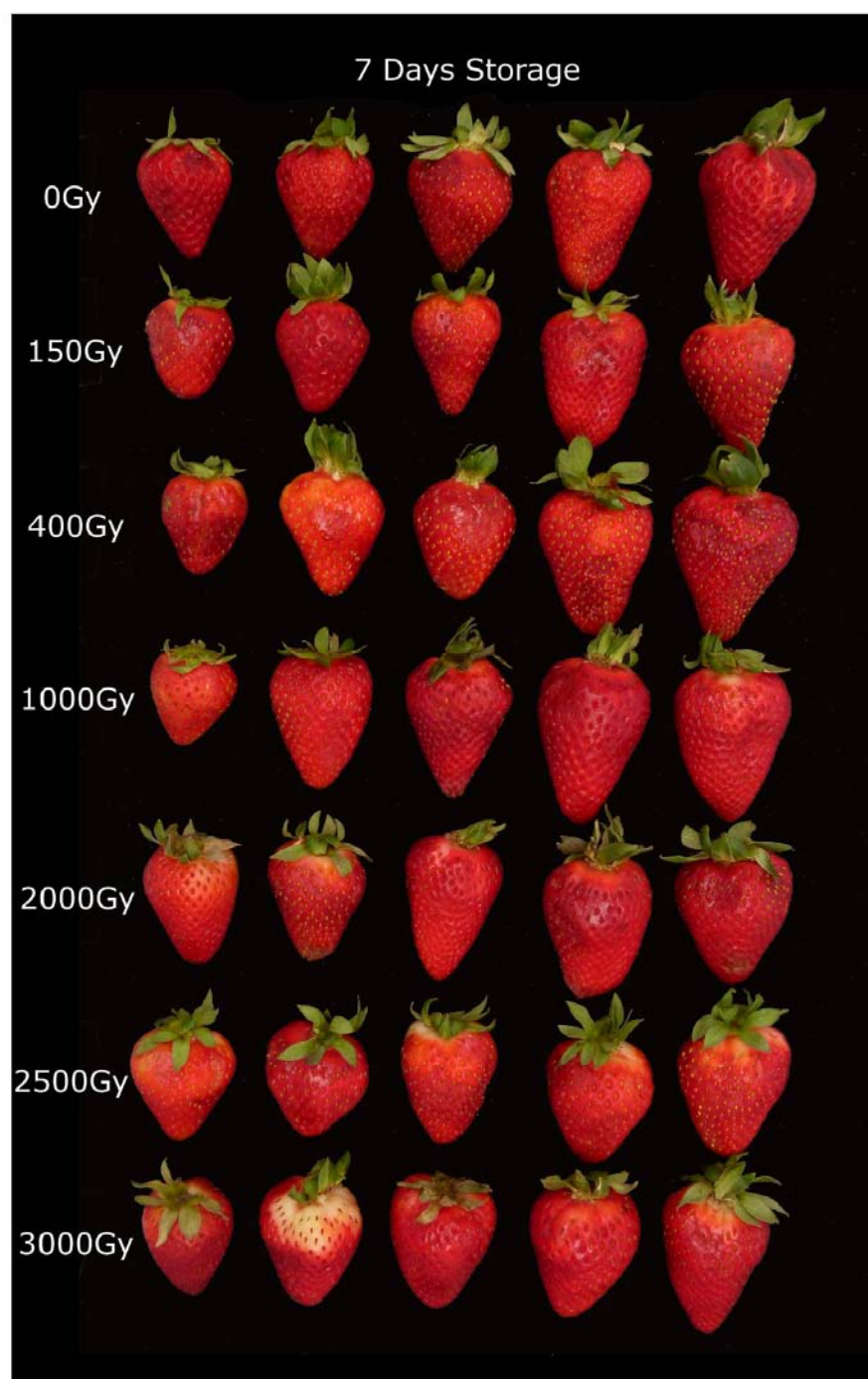
- Amrani, M. (2008) Increasing shelf life of strawberries using an irradiation-cooling process. *International Journal of Food Engineering*, 4: 1-11.
- Aziz, N.H., Moussa, L.A.A. (2002) Influence of gamma-radiation on mycotoxin producing moulds and mycotoxins in fruits. *Food Control*, 13: 281-288.
- D'Amour J., Gosselin C., Arul J., Castaigne F., Willemot C. (1993) Gamma-radiation affects wall composition of strawberries. *Journal of Food Science*, 58: 182-185.
- Hussain, P.R., Meena, R.S., Dar, M.A., Mir, M.A., Shafi, F., Wani, A.M. (2007) Effect of gamma-irradiation and refrigerated storage on mould growth and keeping quality of strawberry (*Fragaria* sp) cv 'Confitura'. *Journal of Food Science and Technology*, 44: 513-516.
- Kader, A.A. (1993) Postharvest handling. In: Preece, J.E. and Read, P.E. *The Biology of Horticulture – An Introductory Textbook*. New York: John Wiley & Sons. Pp. 353-377.
- Kader, A. and Cantwell, M. (2010) Produce quality rating scales and colour charts. Postharvest Technology Center, University of California, Davis. Postharvest Horticulture Series No. 23, 2nd Edition. Pp 116.
- Pelayo, C., Ebeler, S.E., Kader, A.A. (2003) Postharvest life and flavour quality of three strawberry cultivars kept at 5°C in air or air+20 kPa CO₂. *Postharvest Biology and Technology*, 27: 171-183.
- Sommer, N.F., Buckley, P.M. Fortlage, R.J., Coon, D.A., Maxie, E.C., Mitchell, F.G. (1968) Heat sensitization for control of grey mould of strawberry fruits by gamma irradiation. *Radiation Botany*, 8: 441-448.
- Thompson, B.D. (1959) Post-harvest treatments of strawberries and radishes with cobalt-60 irradiation. *Florida Agricultural Experiment Stations Journal Series*, 975: 114-123.
- Thomas, P. (1986) Radiation preservation of foods of plant origin. Part V. Temperate fruits: Pome fruits, stone fruits, and berries. *CRC – Critical reviews in food science and nutrition*, 24: 357-400.
- UC Davis (2011) Postharvest Technology Produce Fact Sheets, Agriculture and Natural Resources, University of Southern California, USA, viewed 15 January, 2012, <http://postharvest.ucdavis.edu/producefacts/>
- Vachon, C., D'Aprano, G., Lacroix, M., Letendre, M. (2003) Effect of edible coating process and irradiation treatment of strawberry *Fragaria* spp. on storage-keeping quality. *Food Microbiology and Safety*, 68: 608-612.
- Yu, L., Reitmeier, C.A., Love, M.H. (1996) Strawberry texture and pectin content as affected by electron beam irradiation. *Journal of Food Science*, 61: 844-846.

Appendix

Photographic plates of strawberry fruit irradiated with a dose of either 0, 150, 400, 1000, 2000, 2500 or 3000 Gy and then held in cold (0°C) storage for either 0, 7, 14 or 21 days. Plates comprise photographs taken of a representative sample of fruit immediately after removal from storage and after a 24 or 72 hour shelf life period.







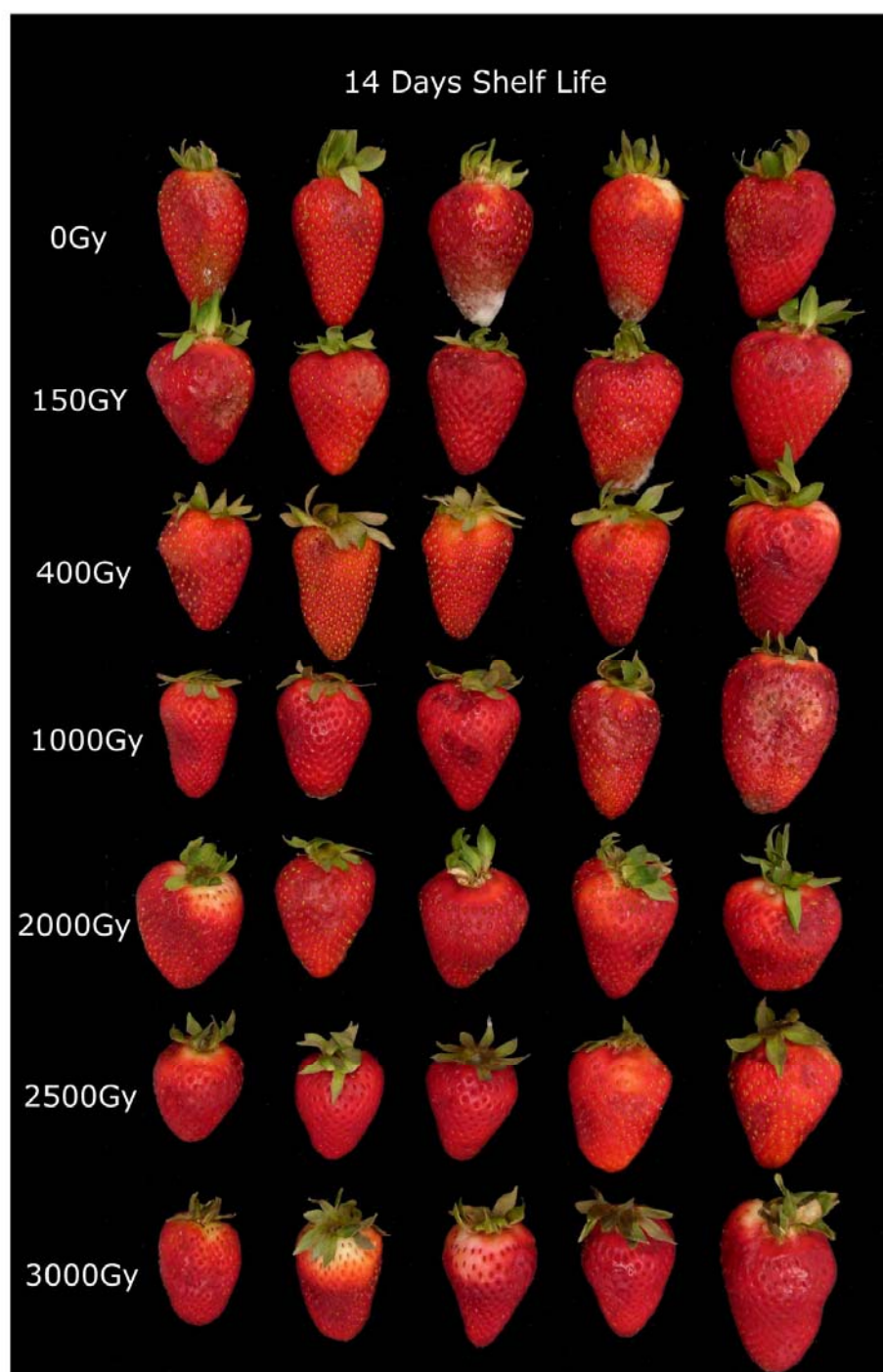
Shelf life extension and nutritional profile of irradiated strawberry. Final Report.

60



Shelf life extension and nutritional profile of irradiated strawberry. Final Report.

61

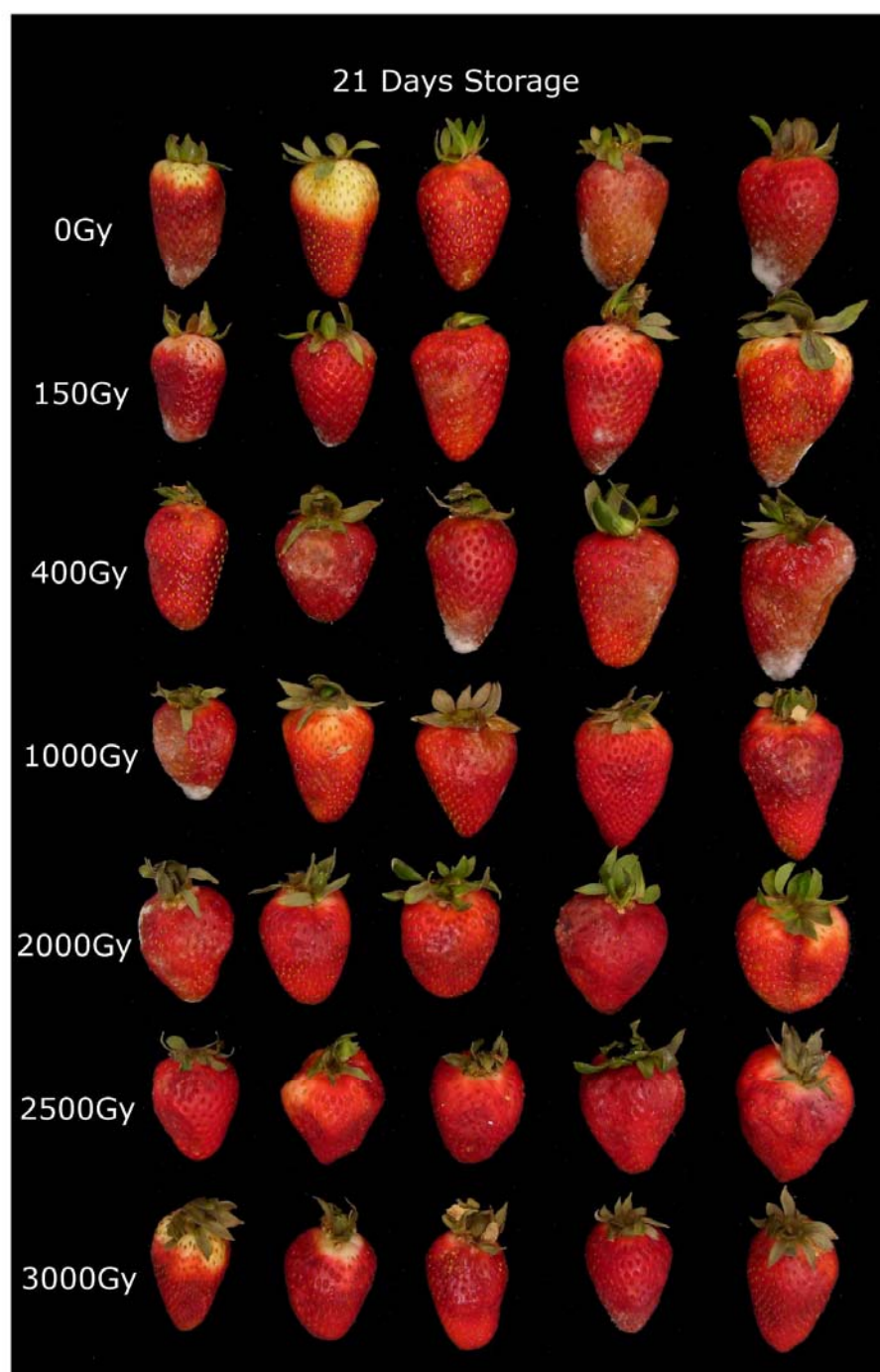


Shelf life extension and nutritional profile of irradiated strawberry. Final Report.

62



Shelf life extension and nutritional profile of irradiated strawberry. Final Report.



Shelf life extension and nutritional profile of irradiated strawberry. Final Report.



Shelf life extension and nutritional profile of irradiated strawberry. Final Report.

Part C. Irradiation effects on the microbiological quality of strawberry fruit

Summary

Strawberry fruit (*Fragaria* sp. var 'Albion') were irradiated at doses from 0 to 3 kGy and stored at 0°C for up to 28 days. Samples were analysed for total counts, yeasts and Enterobacteriaceae. Fruit with visible mould were excluded from the analysis. The trials were replicated three times for statistical analysis and determination of significant differences between treatments.

Enterobacteriaceae were detected in some non-irradiated fruit and only at low levels. All irradiation treatments caused significant decreases in the mean total counts compared to the control at day 0. Mean yeast counts in strawberries treated with at least 1 kGy were significantly less than those for the control at day 0. Yeasts dominated the microflora of stored strawberries, irrespective of irradiation treatment. Analysis of stored strawberries treated with 0, 150 and 400 Gy doses ceased after 21 days because of mould development. Strawberries irradiated at 3 kGy were not greatly affected by mould even after 28 days storage.

Introduction

It has been suggested that irradiation is potentially an effective control measure to eliminate pathogenic bacteria from the surface of fruits (Molins et al., 2001) but, more importantly, it has been proposed as a treatment which can extend the shelf life of fruit, in particular strawberries (Aziz and Moussa, 2002; Yu et al., 1995; Zegota, 1998).

Fungi are the main microorganisms associated with the spoilage of strawberries during storage. Irradiation doses ranging from 1 to 2.5 kGy significantly decreased the initial mould counts in the fruit (Van Calenberg et al., 1999) and inhibited their growth during refrigerated storage for varying times from one to four weeks (Aziz and Moussa, 2002; Yu et al., 1995; Zegota, 1998). The fungal flora was completely inhibited at 5 kGy radiation dose (Aziz and Moussa, 2002).

An Australian study (O'Connor and Mitchell 1991) found that the microflora of irradiated strawberries primarily consisted of yeasts and spore-forming bacteria prior to and after refrigerated storage for five days.

Nguyen and Carlin (1994) reviewed the literature on effects of irradiation on the microbiology of fruit and vegetables. They concluded that the efficiency of irradiation varies according to the products and the susceptibilities of the microorganisms initially present in the product. Generally, at doses lower than 2 kGy, total counts are reduced 10^3 - to 10^4 - fold; yeast counts are only reduced 10- to 100- fold and bacterial spores are resistant to 1 kGy. The lower counts achieved through irradiation persist during subsequent storage.

In this study, the effect of irradiation doses ranging from 0 Gy to 3 kGy on the microflora of strawberries after irradiation treatment and during storage at 0°C was examined.

Methods

Microbiological analyses

Irradiation

The strawberries and irradiation treatments were as described in Part A of this report.

Sampling

The control and irradiated strawberries were sampled for microbiological analyses at up to 11 different times during storage: 0 days (one day after mean irradiation treatment), and subsequently after 4, 7, 10, 14, 17, 21, 24, and 28 days.

At each sampling time, a punnet of strawberries from each of the treatments was randomly selected. The total number of strawberries in each punnet was recorded along with the number of strawberries showing visible mould, which were then discarded. The percentage of mould affected strawberries was calculated for each irradiation treatment.

Sampling was ceased for an irradiation treatment when there was insufficient sample for microbiological analysis (usually about 50%) in one or more of the three replicates.

Sample preparation

The hulls on the remaining strawberries were removed and approximately 125 g of strawberries were weighed into a sterile stomacher bag. An equivalent weight of 0.1% peptone diluent was added and this was stomached for 1 minute. A 20 g sample of the homogenate was stomached for 1 minute with 80 g of 0.1% peptone diluent. This was the initial 1:10 dilution. Further decimal dilutions were made in 0.1% peptone.

Total counts

The total count was determined using standard plate count agar (Oxoid) with the pour-plate technique, with an overlay of 1.5% agar (Oxoid) and aerobic incubation at 30°C for 3 days.

Yeasts

Yeasts were counted using dichloran rose bengal chloramphenicol agar (Scharlau), spread-plated and incubated at 25°C for 5 days.

Enterobacteriaceae

Enterobacteriaceae were enumerated in violet red bile glucose agar (Oxoid) using the pour plate technique with an agar overlay, and incubation at 37°C for 1 day.

Statistical methods

The total counts and the yeast counts at each sampling time point were transformed to the \log_{10} values which were analysed using analysis of variance (ANOVA). Where a significant effect of irradiation dose was found, (p-value <0.05), pairwise comparisons were made using the 95% Fishers protected least significant difference (LSD). The estimations of mould contamination of strawberries during storage were not statistically analysed. All statistical analyses were performed in GenStat 14th Edition (VSN International, 2011).

Results

Effect of irradiation on initial microbial populations in strawberries

All irradiation treatments caused significant decreases in the mean total microbial count of strawberries as compared to the non-irradiated strawberries (Figure 1). Irradiation treatments at 150 Gy and 400 Gy had similar effects on the mean total count. Further increases in irradiation dose to 3 kGy caused further decreases in total count. While a decrease in the total count was caused by the 1 kGy treatment, the difference was not significantly different to the 150 Gy or 400 Gy treatments (Table 1). Irradiation doses to 3 kGy caused further decreases in total counts, but the differences between 1, 2, 2.5 and 3 kGy were not significantly different for the mean total counts (Table 1).

On average, yeasts comprised approximately one-quarter of the microflora of non-irradiated strawberries, as determined by microbial counts (Table 1). In the irradiated strawberries, the yeast counts were actually higher than the 'total' counts.

Initial mean yeast counts in the strawberries were significantly decreased by irradiation treatments of 1 kGy and higher compared to the non-irradiated samples (Figure 1, Table 1). The slight decreases in the yeast counts caused by the 150 Gy and 400 Gy treatments were not significantly different to the counts in the non-irradiated samples. There was a further slight decrease in the mean yeast counts from 1 kGy to 3 kGy (Figure 1), but this difference was not statistically significant (Table 1).

Table 1. The effect of irradiation dose on the initial mean total counts and yeast counts in strawberries.

Irradiation dose (Gy)	Total count		Yeast count	
	Mean (cfu/g)	log ₁₀ mean ¹	Mean (cfu/g)	log ₁₀ mean ¹
0	4.5x10 ⁵	5.65 a	1.2x10 ⁵	5.08 a
150	1.3x10 ⁴	4.11 b	2.6x10 ⁴	4.41 abc
400	1.3x10 ⁴	4.10 b	4.8x10 ⁴	4.68 ab
1000	1.4x10 ³	3.15 bc	9.9x10 ³	4.00 bcd
2000	6.8x10 ²	2.84 c	3.7x10 ³	3.57 cd
2500	3.3x10 ²	2.51 c	3.8x10 ³	3.58 cd
3000	8.8x10 ¹	1.94 c	2.1x10 ³	3.31 d
P-value		<0.001		0.009
SED		0.58		0.42

¹ Means within columns followed by the same letter are not significantly different.

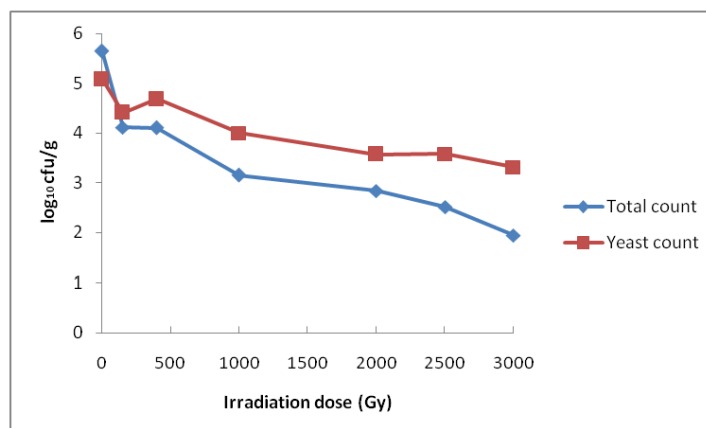


Figure 1. Effect of irradiation dose on the initial mean total counts and mean yeast counts.

The visual estimations of mould contamination on the strawberries were not analysed statistically. At day 0, less than about 10% of the individual strawberries in a punnet had some level of visible mould contamination (less than 10% of an individual fruit). There was no apparent effect of irradiation dose on this level of contamination.

The Enterobacteriaceae were an insignificant component of the microbial population of the strawberries. Detectable levels were found in about one-third of the total punnets of non-irradiated strawberries examined. They were not detected in any of the irradiated samples. When detected, counts were less than 1000/g. They were not detected in non-irradiated strawberries after 14 days of storage.

Effect of irradiation on microbial populations in strawberries during storage

The mean total counts, for both non-irradiated and irradiated strawberries, did not change appreciably from the initial total counts during storage at 0°C (Figure 2). The differences in total counts at day 0 as a result of the irradiation treatments were generally maintained during the storage periods.

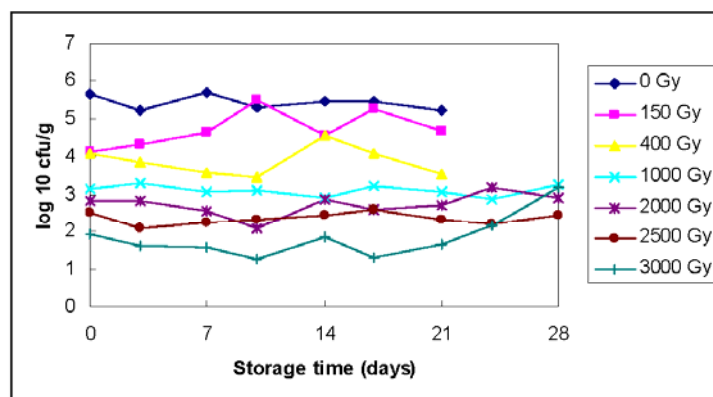


Figure 2. Total counts in strawberries stored at 0°C after irradiation treatments from 0 Gy (control) to 3000 Gy.

In contrast, the yeast counts in the strawberries generally increased during storage (Figure 3). The differences in yeast counts at day 0 as a result of the irradiation treatments were maintained until about 14 days storage, especially for the irradiation doses of 1 kGy and above as compared to the control.

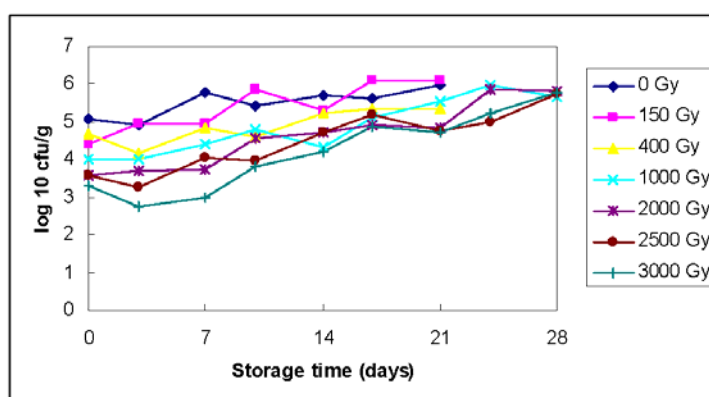


Figure 3. Yeast counts in strawberries stored at 0°C after irradiation treatments from 0 Gy (control) to 3 kGy.

Figure 4 demonstrates that after the seven day storage period, the visual appearance of mould started to become a problem. There are some indications that irradiation doses above 1 kGy before storage may have some effect on the proportion of strawberries affected by mould contamination. As these results were not statistically analysed, it is not known whether this is a

significant effect. These results were only a gross estimation because individual fruits had varying levels of contamination. Part B of this report addresses the quality of the fruits in relation to fungal disease by the percent fruit surface area affected.

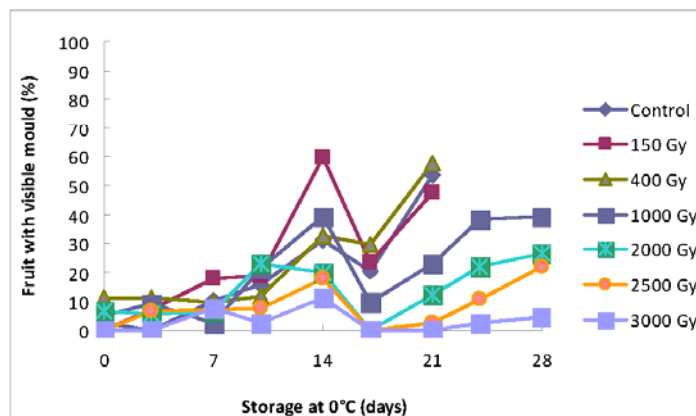


Figure 4. Effect of irradiation dose on the average proportion of strawberries in a punnet affected by visible mould during refrigerated storage.

Discussion

O'Connor & Mitchell (1991) was an Australian study on the effect of irradiation on microorganisms in strawberries. The average total count in non-irradiated strawberries in that study was 2.7×10^5 cfu/g which is a similar level in the current study (4.5×10^5 cfu/g). O'Connor & Mitchell (1991) reported that irradiation of strawberries at 2 kGy resulted in approximately a one-log reduction in the average total count. However, in the current study, greater reductions in total count were found (2.8 log reduction at 2 kGy).

The yeast counts reported by O'Connor & Mitchell (1991) were quite variable and ranged from <50 cfu/g to 1.4×10^5 cfu/g in non-irradiated strawberries. The mean yeast count on non-irradiated strawberries in the current study was 1.2×10^5 cfu/g and replicate counts were similar.

In this current study, yeasts comprised, on average, approximately one-quarter of the initial total count in non-irradiated strawberries, as determined by microbial counts. Yeasts dominated the initial microflora of irradiated strawberries. Yeasts were the main microorganism in both control and irradiated fruit during storage. Using the data published by O'Connor & Mitchell (1991), the proportion of the total count comprised of yeasts ranged from <1% to nearly 50%. O'Connor & Mitchell (1991) used fruit from seven different growers which may account for the variability in the counts reported in their study. They found that spore-forming bacteria were the major component of the initial microflora of irradiated strawberries. Yeasts were isolated from fruit stored at 8°C obtained from only one of the seven growers. The reduction in total count caused by irradiation treatments will depend on the types of microorganisms present on the fruit prior to irradiation and the relative resistances to irradiation treatments of the microorganisms.

In this study, the yeast counts on the irradiated strawberries were higher than the total counts. This means that the types of yeasts that survived irradiation and grew at 0°C were either not able to grow on plate count agar or were not able to grow at 30°C.

Tamminga et al (1975) suggested that if Enterobacteriaceae and *Pseudomonas* are not found on strawberries, then irradiation is likely to have taken place. O'Connor and Mitchell (1991) suggested that an absence of Enterobacteriaceae (<5 cfu/g) in strawberries may indicate that strawberries have been irradiated, at least to a dose of 1.2 kGy. The initial populations of Enterobacteriaceae in those studies ranged from 120 to 6.5×10^5 cfu/g and 100 to 8.5×10^4 cfu/g, respectively. However, in this study, Enterobacteriaceae were not a significant component of the microflora of untreated strawberries. As reported by O'Connor and Mitchell (1991), this group of microorganisms was not found in any of the irradiated fruit in the current study.

It was the appearance of visible mould on the strawberries after seven days storage that would have limited the shelf life, irrespective of irradiation treatments. The data in Figure 4 indicates that the higher levels of irradiation treatment may delay the growth of mould to some extent. However, the results are variable, possibly because the assessment of mould contamination in this section of the study was subjective, or post-irradiation contamination of the strawberries may have occurred.

Recommendation

The microbiological quality of the non-irradiated and irradiated strawberries generally mirrored the fruit quality evaluations reported in Part B of this report. In terms of consumer acceptance the appearance and texture of the fruit would be the major attributes which should determine the shelf life.

References

- Aziz, N.H. and Moussa, L.A.A. (2002). Influence of gamma-radiation on mycotoxin producing moulds and mycotoxins in fruits. *Food Control* 3: 281–288.
- Molins, R.A., Motarjemi, Y. and Kaferstein, F.K. (2001). Irradiation: a critical control point in ensuring the microbiological safety of raw foods. *Food Control* 2: 347–356.
- Nguyen-the, C. and Carlin, F. (1994). The microbiology of minimally processed fresh fruit and vegetables. *Critical Reviews in Food Science and Nutrition*: 34: 371–401.
- O'Connor, R.E. and Mitchell, G.E. (1991). Effect of irradiation on microorganisms in strawberries. *International Journal of Food Microbiology* 12: 247–255.
- Tamminga, S.K., Beumer, R.R., van Kooij, J.G. and Kampelmacher, E.H. (1975). Microbiological possibilities to demonstrate that strawberries have been irradiated. *European Journal of Applied Microbiology* 1: 79–93.
- Van Calenberg, S., Van Cleemput, O., Mondelaers, W. and Huyghebaert, A. (1999). Comparison of the effect of X-ray and electron beam irradiation on the microbiological quality of foodstuffs. *Lebensmittel-Wissenschaft und-Technologie* 32: 372–376.
- VSN International (2011) GenStat for Windows 14th Edition. VSN International, Hemel Hempstead, UK. Web page: GenStat.co.uk
- Yu, L., Reitmeier, C.A., Gleason, M.L., Nonnecke, G.R., Olson, D.G. and Gladon, R.J. (1995). Quality of electron beam irradiated strawberries. *Journal of Food Science* 60: 1084–1087.
- Zegota, H. (1988). Suitability of Dukat strawberries for studying effects on shelf life of irradiation combined with cold storage. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung A*, 187: 111–114.

A2.8 Nutritional Value of Honeydew melon

Key nutritional data for fresh yellow skin and white skin honeydew melons are presented in Table 68, with values extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). Significant differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems. The differences are apparent between yellow skin and white skin varieties.

Honeydew melon fruit is very high in water content, ranging between 88–93%. The macronutrient levels and energy content are accordingly, low. Energy values range between 107 and 192 kJ, carbohydrate is 4.4–9.8 g/100g, total dietary fibre (0.9–1.0 g/100g) and protein (0.5–1.25 g/100g) are low. The Vitamin C range is 12–50 mg/100g and beta-carotene at 30–50 µg/100g.

The percentage contributions to daily intake of nutrients for yellow skin honeydew melon based on FSANZ Reference Values can be derived (Table 69) and the energy values are provided in Table 59. The percentage of the daily intake from a single serve of honeydew melon is approximately 2.6–3.3 % energy, 2.1–3.8 % protein, 3.4–4.7 % available carbohydrate, 3–5 % total dietary fibre, 11.8–16.3 % total sugar and 2.1–2.9 % sodium. The energy value from available carbohydrate from 100 g honeydew melon is between 120–166 kJ/g, with the rest from protein, fats and dietary fibre. The majority energy value comes from total sugars and the rest from total dietary fibre, protein and lipids (Table 70).

Honeydew melon is not a staple purchase. The fruit is available throughout the year with purchase being more active but low in the summer months. Honeydew melon is not one of the more popularly consumed fruit and there are no known sub-populations that may have a higher than average consumption of this fruit. From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that honeydew melon is not a major contributor to the daily dietary intake of macronutrients.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). Honeydew melon provides some amounts of Vitamins A and C and potassium (150–436mg/100g) is comparable to the potassium content found in bananas (approximately 322–346 mg/100g) (FSANZ 2010). Both vitamin contents are also comparable with the more popular banana fruit. The vitamins are well known antioxidants that protect the body from free radical damage and boost the immune system.

β-carotene concentrations range between 30–50 g/100g, which is a little higher than bananas (23–35 g/100g) but significantly lower than from vegetables such as carrots (6000µg /100g). The vitamin C content (approximately 12–50 mg/100g) is within the range of most other fresh produce. Table 7 compares vitamin values for the eight tropical fruits, persimmon, tomato and capsicum approved for irradiation by FSANZ. Generally the pattern of vitamin content is similar across these foods. Honeydew melon fruit is not expected to significantly affect daily nutrient intake.

Other fresh produce contain Pro-vitamin A (carotenes) and vitamin C and foods such as organ meats, dairy products, eggs and ready-to-eat cereals are excellent sources of vitamin A. Green vegetables, grains and dairy and egg products generally are excellent sources of vitamin K. Nuts, seeds and vegetable oils and many fresh vegetables are good sources of vitamin E. Folate can be found in small amounts in many foods with a major dietary source being enriched and fortified foods.

Table 68: Nutritional data for honeydew melon (*Cucumis melo*), variety 'Galaxy' per 100g edible portion.

Nutrient	value	Honeydew melon Yellow skin *			Honeydew melon White skin *
		USDA 2011	MOH 2009	FSANZ 2010	FSANZ 2010
Water	g	89.82	88.5	89.8	92.7
Energy	KJ	150	192	149	107
Protein	g	0.54	1.25	0.7	0.8
Nitrogen	g		0.2	0.11	0.13
Total lipid (fat)	g	0.14	0.2	1.3	0.3
Malic acid	g			0.1	0.1
Citric acid	g			0.4	0.4
Carbohydrate	g	9.09	9.8	7.1	4.4
Total Dietary Fibre	g	0.8	0.6	1	0.9
Ash	g	0.41	0.7	0.6	0.6
Total sugars	g	8.12	9.8	7.1	4.4
Fructose	g	2.96	2.9	1.9	1.9
Glucose	g	2.68	2	1.3	1.5
Sucrose	g	2.48	4.9	3.9	1
Ascorbic Acid, Vit C	mg	18	50	20	12
Thiamin, Vit B1	mg	0.038	0.03	0.02	0.02
Riboflavin, Vit B2	mg	0.012	0.06	0.02	0.01
Niacin	mg	0.418		0.2	0.2
Niacin equivalents	mg		18	0.32	0.33
Vit B6	mg	0.088	0.06		
Folate, Vit B9 total	µg	19	19		
Vit A (retinol equiv.)	µg		5.85	5	9
Alpha carotene	µg	0		0	10
Beta carotene	µg	30		30	50
Beta cryptoxanthin	µg	0			
Cryptoxanthin	µg			0	0
Vit E	mg	0.02	0.1		
Vit K	µg	2.9			
Calcium	mg	6	28	39	38
Iron	mg	0.17	0.4	0.3	0.4
Magnesium	mg	10	12	16	9
Phosphorus	mg	11			
Potassium	mg	228	436	160	150
Sodium	mg	18	32	44	40
Zinc	mg	0.09		0.2	0.1
Copper	mg	0.024	0.08		
Manganese	mg		173		
Selenium	µg	0.7	0.1		
Iodine	µg		0.1		
Molybdenum	µg				
Nickel	µg				
Tin	µg				

Table 69: Nutrient values are per 100 g edible portion of yellow skin honeydew melon.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	89.8	88.5	134.7	132.75			
Energy (kJ)	149	191.94	223.5	287.91	2.6	3.3	8700
Protein (g)	0.7	1.25	1.05	1.875	2.1	3.8	50
Total lipid (fat) (g)	1.3	0.2	1.95	0.3	2.8	0.4	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	7.1	9.8	10.65	14.7	3.4	4.7	310
Sugar (g)	7.1	9.8	10.65	14.7	11.8	16.3	90
Total dietary fibre (g)	1	0.6	1.5	0.9	5.0	3.0	30
Sodium (mg)	44	32	66	48	2.9	2.1	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 70: Calculation of energy value of the major* food components per 100 g yellow skin honey dew melon.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ	Average quantity	Approximate calculation of energy value kJ
Protein	17	0.7	11.9	1.25	21.25
Total lipid (fat)	37	1.3	48.1	0.2	7.4
Fatty acids, total saturated					
Available Carbohydrate	17	7.1	120.7	9.8	166.6
Total sugars		7.1		9.8	
Total dietary fibre	8	1	8	0.6	4.8

Honeydew melons are a useful source of micronutrients but not a significant part of the average consumer's diet and, their contribution to overall micronutrient intake will therefore not be significant. Many other more popular fresh fruits such as apples, bananas and citrus fruits, and vegetables, for example, tomato provide equivalent amounts of micronutrients to overall micronutrient intake.

Effects of irradiation on nutritional content and postharvest fruit quality of honeydew melon

QLD DAFF (2012) recently conducted nutritional and fruit quality evaluations on honeydew melon (*Cucumis melo*) fruit, variety 'Galaxy', after being treated with gamma irradiation and following a recommended cold (7°C) storage period of 14 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gy, with fruit evaluations conducted before and after storage. (See Attachment - Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at end of section).

The nutrition study found honeydew melon fruit can tolerate up to 1 kGy irradiation. With the exception of beta-carotene there were no significant dose effects on ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars and Vitamin C (ascorbic acid) either before storage or after cold storage for 14 days. The nutritional status was affected more by the changes that occurred during the ripening process while in cold storage than by irradiation.

Honeydew melon however, was less tolerant to doses ≥ 600 Gy with respect to beta-carotene after irradiation treatment. No differences in beta-carotene were found after 14 days. Beta-carotene was initially affected by irradiation immediately after treatment, being significantly lower in the ≥ 600 Gy treatment (12 $\mu\text{g}/100\text{g}$) compared with control fruit (17 $\mu\text{g}/100\text{g}$), although by the end of the 14-day storage period no differences were detected across all of the treatments (mean 12.3 $\mu\text{g}/100\text{g}$). In a study with rockmelon, a *Cucumis melo* produce, Castell-Perez *et al.* (2004) found no changes in beta-carotene content of whole melon fruits irradiated at 1000 Gy over the storage period at 10°C.

Application of irradiation treatment impacted the postharvest fruit quality of honeydew melon, with irradiation damage only expressed by the end of the storage period and at doses ≥ 600 Gy. The incidence and severity of symptoms (skin browning and pitting) increased with dose level. Symptoms in honeydew melon fruit occurred only when treated to a dose of 600 Gy and above, with up to 51% of the skin surface area being affected.

Reports on melon fruit have also shown that treatment with gamma irradiation at or below 1000 Gy resulted in little to no damage to fruit (Kader 1986; Castell-Perez *et al.* 2004). According to Kader (1986), melon fruit are generally regarded as having a relatively high stress tolerance to ionizing radiation (up to 1kGy), although acknowledges that various pre and postharvest factors can influence their susceptibility, including climatic growing conditions, cultural field practices, and handling and storage conditions.

A2.9 Nutritional value of Rockmelon

Table 71 shows key nutritional data for fresh raw rockmelon, with values extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). Significant differences in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Rockmelon fruit is high in water contents (approximately 83–90%). The macronutrient levels and energy content are low. 100 g rockmelon fruit provides 107–141 kJ energy, contains 0.6–1.2 g protein, 5.2–8.2 g carbohydrate, 0.8–1.2 g total dietary fibre, 0.7–0.8 g ash and minute amounts of lipid (0.1–0.2 g) and, small amounts of vitamins and other micronutrients.

The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can be derived (Table 72) and energy value in Table 73.

The percentage of the daily intake from a single serve of rockmelon is approximately 1.8–2.1 % energy, 1.8–3.7 % protein, 2.5–2.8 % available carbohydrate, 4–6 % total dietary fibre, 8.7–9.5 % total sugar and 0.9–1.1 % sodium. Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available carbohydrate from 100 g rockmelon is approximately 88–97kJ/g, the rest from protein, fats and dietary fibre.

From the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients does not come from rockmelon. There are no known sub-populations that may have a higher than average consumption of rockmelon.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). Rockmelon is a good source of Vitamins A and C and is high in potassium. Both vitamins are well known antioxidants that protect the body from free radical damage and boost the immune system. Consumption of rockmelon is steady and is a popular fruit consumed in the summer period Australia and New Zealand.

In rockmelons, β -carotene concentrations range between 836–2020 $\mu\text{g}/100\text{ g}$, which is higher than the concentrations found in fruits such as apples and bananas but lower than vegetables such as carrots (6000 $\mu\text{g}/100\text{g}$). The vitamin C content (approximately 25–41 mg/100g) is similar to other fruits. Table 7 compares vitamin values for fresh produce approved for irradiation by FSANZ. Generally the pattern of vitamin content is similar across these foods and consumption of irradiated rockmelon is expected not to significantly affect daily nutrient intake. In addition, daily intake will more commonly be from a range of foods and therefore is not expected to significantly affect daily nutrient intake.

Other fresh produce contain Pro-vitamin A (carotenes) and vitamin C and foods such as organ meats, dairy products, eggs and ready-to-eat cereals are excellent sources of vitamin A. Green vegetables, grains and dairy and egg products generally are excellent sources of vitamin K. Nuts, seeds and vegetable oils and many fresh vegetables are good sources of vitamin E. Folate can be found in small amounts in many foods with a major dietary source being enriched and fortified foods.

Rockmelons are a useful source of micronutrients but not a significant part of the average consumer's diet and, their contribution to overall micronutrient intake will therefore not be significant. There are many other more popular fresh fruits and vegetables that provide equivalent amounts of micronutrients to overall micronutrient intake.

Table 71: Nutritional data for rockmelon (*Cucumis melo*), variety 'Triumph' per 100g edible portion.

Nutrient	value	Rockmelon		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	90.15	83.2	90.7
Energy	KJ	141	107.24	120
Protein	g	0.84	1.23	0.6
Nitrogen	g		0.16	0.1
Total lipid (fat)	g	0.19	0.1	0.1
Malic acid	g			0.1
Citric acid	g			0.3
Carbohydrate	g	8.16	5.2	5.7
Total Dietary Fibre	g	0.9	0.8	1.2
Ash	g	0.65	0.7	0.8
Total sugars	g	7.86	5.2	5.7
Fructose	g	1.87	2.5	2.7
Glucose	g	1.54	1.4	1.6
Sucrose	g	4.35	1.3	1.4
Ascorbic Acid, Vit C	mg	36.7	25	41
Thiamin, Vit B1	mg	0.041	0.05	0.024
Riboflavin, Vit B2	mg	0.019	0.03	0.024
Niacin	mg	0.734		0.24
Niacin equivalents	mg		0.5	0.34
Vit B6	mg	0.072	0.07	0.03
Folate, Vit B9 total	µg	21	21	19
Vit A (retinol equiv.)	µg	0		142
Alpha carotene	µg	16		6
Beta carotene	µg	2020		836
Beta cryptoxanthin	µg	1		
Cryptoxanthin	µg			24
Vit E	mg	0.05	0.1	0
Vit K	µg	2.5		
Calcium	mg	9	0.04	9
Iron	mg	0.21	0.3	0.28
Magnesium	mg	12	12	10
Phosphorus	mg	15		14
Potassium	mg	267	320	251
Sodium	mg	16	14	17
Zinc	mg	0.18		0.13
Copper	mg	0.041		0.024
Manganese	mg	0.041	30	0.044
Selenium	µg	0.4		0
Iodine	µg		0.1	0
Molybdenum	µg			
Nickel	µg			
Tin	µg			0

Table 72: Nutrient values are per 100 g edible portion of rockmelon.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	90.7	83.2	136.05	124.8			
Energy (kJ)	120	107.24	180	160.86	2.1	1.8	8700
Protein (g)	0.6	1.23	0.9	1.845	1.8	3.7	50
Total lipid (fat) (g)	0.1	0.1	0.15	0.15	0.2	0.2	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	5.7	5.2	8.55	7.8	2.8	2.5	310
Sugar (g)	5.7	5.2	8.55	7.8	9.5	8.7	90
Total dietary fibre (g)	1.2	0.8	1.8	1.2	6.0	4.0	30
Sodium (mg)	17	14	25.5	21	1.1	0.9	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 73: Calculation of energy value of the major* food components per 100 g rockmelon.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ/g	Average quantity	Approximate calculation of energy value kJ/g
Protein	17	0.6	10.2	1.23	20.91
Total lipid (fat)	37	0.1	3.7	0.1	3.7
Fatty acids, total saturated					0
Available Carbohydrate	17	5.7	96.9	5.2	88.4
Total sugars		5.7		5.2	
Total dietary fibre	8	1.2	9.6	0.8	6.4

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of rockmelon

QLD DAFF (2012) recently conducted nutritional and fruit quality evaluations on rockmelon (*Cucumis melo*) fruit, variety 'Triumph', after being treated with gamma irradiation and following a recommended cold (7°C) storage period of 14 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gray (Gy), with fruit evaluations conducted before and after storage. (See Attachment - Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at end of section).

The nutrition study found rockmelon fruit can tolerate up to 1 kGy irradiation without significant dose effects on the nutritional attributes tested. Irradiation had no significant effect on ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars and Vitamin C (ascorbic acid) either before storage or after cold storage for 14 days. The nutritional status was affected more by the changes that occurred during the ripening process while in cold storage in Vitamin C (total ascorbic acid), Vitamin A (beta carotene) and soluble solid contents (soluble sugars). Mean Vitamin C (ascorbic acid) ranged from 17.60–27.33mg/100g one day after irradiation treatment and between 17.80–23.07mg/100g after 14 days in storage. No significant dose effects were detected in beta-carotene in the control samples and the treated rockmelon fruit one day after irradiation treatment (986.7–1600.0µg/100g) and after 14 days storage (1026.7–1266.7µg/100g).

The Castell-Perez *et al.* study (2004) found no significant effect on the sugars content of whole cantaloupe (rockmelon) fruits irradiated at 1000Gy but sugars content decreased significantly by the fourth day of storage at 10°C. No changes in beta-carotene content of whole cantaloupes over the storage period were also reported.

The QLD DAFF postharvest fruit quality (2012) study found no effect of irradiation on the overall visual appearance and fruit quality of rockmelon fruit and no significant effect on the internal flesh colour. Total soluble solids and titratable acidity were unaffected by any of the irradiation treatments, although storage time did result in a small but significant decline in Brix levels and a slight increase in citric acid levels.

Rockmelon fruit became softer during storage but was unaffected by the irradiation treatment. By Day 14, fruit had lost approximately 5% of their initial mean fresh weight (1.7kg), although this was not influenced by the irradiation treatment.

Results from the QLD DAFF study (2012) and the Castell-Perez *et al.* study (2004) show that rockmelon fruit treated at doses ≤ 1 kGy are not significantly impacted. Low dose (≤ 1 kGy) irradiation treatment can be used as an effective phytosanitary method. An application of up to 1kGy will not result in any significant detrimental damage to the nutritional and postharvest quality of rockmelon fruit.

A2.10 Nutritional value of Nectarine

Table 74 shows key nutritional data for fresh raw nectarine, with values extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). There are some differences in values for a few micronutrients which may be the result of testing different varieties and different growing conditions or crop management systems.

Water content in nectarine is highest at approximately 87%. 100 g nectarine provides on average about 165 kJ of energy, 1.2 g protein, 8.8 g carbohydrate, 1.8 g dietary fibre and very little total lipid and sodium. Vitamin C is approximately 4.3–12 mg/100g and the range in beta-carotene is large, between 65 and 362 µg/100g. There is no one nutritional component that stands out as a major contributor to daily nutritional intake.

Average nutrient values per single serve (150g for fresh fruit) is shown in Table 75. The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived (Table 75). The percentage of the daily intake from a single serve of nectarine is approximately 2.8–3.2 % energy, 3.3–3.6 % protein, 3.7–3.9 % available carbohydrate, 8.0–10.5 % total dietary fibre, about 13 % total sugar and 0.13 % sodium.

Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available carbohydrate is approximately 138–207 kJ from 100g nectarine. The balance energy value comes from protein and total lipid (Table 76).

In Australia and New Zealand, there are other more commonly eaten fresh fruits than nectarine although as a stonefruit group, production and consumption is slightly increasing in market penetration. There are other more commonly eaten fruits, apples > oranges > grapes (including wine) > banana > pear. It is not known if there are sub-populations in Australia and New Zealand that may have a higher than average consumption of nectarine however, the fruit is not likely a major contributor to daily macro and micronutrient intakes.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011) but it is unlikely that the major contribution to daily dietary intake of macronutrients will come from nectarine. Nectarines are not a significant part of the average consumer's diet in Australia and New Zealand. Although a useful source of micronutrients nectarine are consumed in amounts equivalent to that of many other fresh produce crops and to lesser amounts than many popular vegetables. They will not be a significant contributor to overall micronutrient intake.

Pro-vitamin A (carotenes) and vitamin C can be found in other fresh produce and vitamin A in foods such as organ meats, dairy products, eggs and ready-to-eat cereals. Green vegetables, grains and dairy and egg products generally provide good sources of vitamin K and nuts, seeds, vegetable oils and many fresh vegetables are good sources of vitamin E. Folate is found in small amounts in many foods with a major dietary source being enriched and fortified foods.

Table 74: Nutritional data for nectarine (*Prunus persica*), variety 'Arctic Snow' per 100g edible portion.

Nutrient	value	Nectarine *		
		USDA 2011	MOH 2009	FSANZ 2010
Water	g	87.59	87.2	87
Energy	KJ	145	165	184
Protein	g	1.06	1.1	1.2
Nitrogen	g			0.19
Total lipid (fat)	g	0.32	0.4	0.1
Malic acid	g			
Citric acid	g			
Carbohydrate	g	10.55	7.8	8.1
Total Dietary Fibre	g	1.7	1.6	2.1
Ash	g	0.48		0.3
Total sugars	g	7.89	7.8	8.1
Fructose	g	1.37		1.3
Glucose	g	1.57		1.4
Sucrose	g	4.87		5.5
Ascorbic Acid, Vit C	mg	5.4	4.3	12
Thiamin, Vit B1	mg	0.034	0.01	0.02
Riboflavin, Vit B2	mg	0.027	0.01	0.038
Niacin	mg	1.125	0.52	1.21
Niacin equivalents	mg			
Vit B6	mg			
Folate, Vit B9 total	µg	0.025	0.04	0.02
Vit A (retinol equiv.)	µg	17	60	11
Alpha carotene	µg			3
Beta carotene	µg	150	362	65
Beta cryptoxanthin	µg	98		
Cryptoxanthin	µg			
Vit E	mg		1.9	0.8
Vit K	µg	2.2		
Calcium	mg	6	5	9
Iron	mg	0.28	0.3	0.14
Magnesium	mg	9		7
Phosphorus	mg	26	20	26
Potassium	mg	201	210	242
Sodium	mg		2	
Zinc	mg	0.17	0.1	0.11
Copper	mg	0.086		0.073
Manganese	mg	0.054		0.092
Selenium	µg	0	trace	0
Iodine	µg			
Molybdenum	µg			
Nickel	µg			
Tin	µg			

*raw with skin

Table 75: Nutrient values are per 100 g edible portion of fresh nectarine.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	87	87.2					
Energy (kJ)	184	165	276	247.5	3.17	2.84	8700
Protein (g)	1.2	1.1	1.8	1.65	3.6	3.3	50
Total lipid (fat) (g)	0.1	0.4	0.15	0.6	0.20	0.86	70
Fatty acids, total saturated (g)	0	0	0	0	0	0	24
Available Carbohydrate (g)	8.1	7.8	12.15	11.7	3.92	3.77	310
Sugar (g)	8.1	7.8	12.15	11.7	13.5	13.0	90
Total dietary fibre (g)	2.1	1.6	3.15	2.4	10.5	8.0	30
Sodium (mg)	0	2	0	3	0	0.13	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>.

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 76: Calculation of energy value of the major* food components per 100 g nectarine.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ/g	Average quantity	Approximate calculation of energy value kJ/g
Protein	17	1.2	20.4	1.1	18.7
Total lipid (fat)	37	0.1	3.7	0.4	14.8
Fatty acids, total saturated		0	0	0	0
Available Carbohydrate	17	8.1	137.7	7.8	132.6
Total sugars		8.1		7.8	
Total dietary fibre	8	2.1	16.8	1.6	12.8

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of nectarine

QLD DAFF (2012) recently conducted nutritional and fruit quality evaluations on white flesh nectarine (*Prunus persica*) fruit, variety 'Arctic Snow', after being treated with gamma irradiation and following a recommended cold (4°C) storage period of 21 days. Gamma irradiation treatments consisted of doses of 0, 150, 600 and 1000 Gray (Gy), with fruit evaluations conducted before and after storage. (See Attachment - Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at end of section).

Overall, the results showed that applications of gamma irradiation of $\leq 1\text{kGy}$ did not significantly impact on the majority of nutritional components in nectarine one day after treatment, except for fat, poly-unsaturated fat and sugar profile (fructose, glucose and sucrose). Fat, poly-unsaturated fat and sucrose at the 1000 Gy dose was significantly lower than the control dose (0 Gy) and lower doses. On the other hand, mean glucose and fructose was significantly higher for fruit treated at 1000Gy than untreated nectarine and the lower doses.

Storage time impacted the values of some nutrients and they were associated with the ripening process during storage. Minor changes were reported in fructose, sucrose and glucose. Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher with irradiated nectarine after 21 days. Wall (2007) observed these changes in bananas as dose increased to 800Gy and attributed these differences to an acceleration of sucrose hydrolysis.

There was a significant time effect detected in Vitamin C (total ascorbic acid). Untreated and treated nectarines contained 1.37–2.00mg/100g Vitamin C (total ascorbic acid) before storage and increased levels were detected (4.37–6.33mg/100g) after 21 days. However, no significant differences were detected between untreated and irradiated samples within each assessment time.

The irradiation treatment had a small but significant effect on the postharvest fruit quality of nectarine fruit, with the incidence and severity of skin browning and pitting increasing with dose level. These symptoms were observed only at the end of the 21-day storage period. The overall severity of symptoms in nectarine fruit was very low across all treatment doses ($< 1\text{cm}^2$ skin area affected), with only a few (3%) fruit expressing very mild symptoms at 150Gy. However, this increased significantly to greater than 13% of fruit affected at a dose of 600 Gy and above. Mitchell *et al.* (1992) also assessed the effects irradiation on nectarine, yet found no effects on fruit physico-chemical properties up to 300Gy. According to Kader (1986), nectarine fruits are generally regarded as having a relatively high stress tolerance to ionizing radiation, up to 1kGy, although acknowledges that various pre and postharvest factors can influence their susceptibility, including climatic growing conditions, cultural field practices, and handling and storage conditions.

The QLD DAFF study (2012) did not define the threshold between 150 and 600 Gy where these disorders could be expressed.

An irradiation treatment of $\leq 1\text{kGy}$ is safe to apply on nectarine fruit as a phytosanitary method, no detrimental effects were found in the nutritional profile.

A2.11 Nutritional value of Zucchini

Zucchini is a summer vegetable widely used in traditional Mediterranean cuisine. Total national production is about 15% of pumpkin production (2008 data).

Table 77 shows key nutritional data for fresh raw zucchini, with values extracted from FSANZ (2010), the New Zealand Ministry of Health (MOH 2009) and the USDA (2011b). Significant differences reported in values for a few micronutrients may be the result of testing different varieties and different growing conditions or crop management systems.

Zucchini has a high water content of approximately 94%. Macronutrient levels and energy content are, therefore, low relative to many other foods. Zucchini is one of the very low calorie vegetables; provide only 61–70 kJ per 100 g and is a good source of potassium (191–439 mg/100g). Its peel provides a source of dietary fibre. Zucchini is a relatively moderate source of folates, provides of 18–24 µg or around 5% of RDA per 100 g (Power Your Diet no date)

The average nutrient content per single serve of zucchini (75g for fresh vegetables) can be derived and presented in Table 78. A single serve of zucchini provides approximately 1.2 % energy, 2.4–5.9 % protein, 0.8 % available carbohydrate, 6–8 % total dietary fibre, 2.7–2.9 % total sugar and 0.1 % sodium of the average daily intake.

The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived. Using standard energy factors for carbohydrate, protein, fats and fibre, the energy value from available carbohydrate is approximately 27–30 kJ/100g for zucchini. The rest of the energy values come from protein, fats and dietary fibre (Table 79).

A wide variety of fresh produce is available in Australia and New Zealand. The five most commonly eaten vegetables are potatoes > tomato > carrot > onion > pumpkin (MOH 1999). Sub-populations, for example of Mediterranean origin, may have a higher than average consumption of zucchini. However, from the dietary consumption patterns (ABS 1998, 1999, MOH 1999) and the nutrient tables (MOH 2009, FSANZ 2010, USDA 2011b), it appears that the major contribution to daily dietary intake of macronutrients will come from foods other than zucchini.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). In zucchini, β -carotene concentrations are similar to concentrations in other vegetables such as broccoli and tomato but lower than green capsicum (200µg per 100g), red capsicum (1400µg per 100g) and carrot (6000µg/100g). Vitamin C concentrations are similar to those found in broccoli and cauliflower but much lower than capsicums. Majority of micronutrients can be found in foods other than zucchini. Pro-vitamin A (carotenes) and Vitamin C are present in other fresh produce and Vitamin A in organ meats, dairy products, eggs and ready-to-eat cereals. Nuts, seeds and vegetable oils, as well as many fresh vegetables are good sources of Vitamin E. A major dietary source of folates is from enriched and fortified foods.

Zucchini is a useful source of micronutrients, but they are consumed in amounts equivalent to or less than that of many other fresh produce crops and to lesser amounts than many popular vegetables. They will not be a significant contributor to overall micronutrient intake.

Table 77: Nutritional data for zucchini (*Cucurbita pepo*), variety 'Blackjack' per 100g edible portion.

Nutrient	value	Zucchini raw with skin *		
		USDA+ 2011	MOH 2009	FSANZ 2010
Water	g	94.79	93.13	94.8
Energy	KJ	70	70.1	61
Protein	g	1.21	1.96	0.8
Nitrogen	g		0.31	0.13
Total lipid (fat)	g	0.32	0.22	0.3
Malic acid	g			0.2
Citric acid	g			0
Carbohydrate	g	3.11	1.75	1.6
Total Dietary Fibre	g	1	1.6	1.2
Ash	g	0.58	1.06	0.4
Total sugars	g	2.5	1.75	1.6
Fructose	g	1.38	0.9	0.8
Glucose	g	1.07	0.85	0.7
Sucrose	g	0.05	0	0
Ascorbic Acid, Vit C	mg	17.9	0	22
Thiamin, Vit B1	mg	0.045	0.06	0.028
Riboflavin, Vit B2	mg	0.094	0.09	0.056
Niacin	mg	0.451	0.85	0.56
Niacin equivalents	mg			0.71
Vit B6	mg	0.163	0.04	0.03
Folate, Vit B9 total	µg	24	18	18
Vit A (retinol equiv.)	µg			45
Alpha carotene	µg	0		1
Beta carotene	µg	120		243
Beta cryptoxanthin	µg	0		
Cryptoxanthin	µg			
Vit E	mg	0.12	0	0.55
Vit K	µg	4.3		
Calcium	mg	16	21.3	17
Iron	mg	0.37	0.55	0.49
Magnesium	mg	18	26.1	16
Phosphorus	mg	38		36
Potassium	mg	261	439	191
Sodium	mg	8	0.97	1
Zinc	mg	0.32	0.57	0.33
Copper	mg	0.053	0.06	0.071
Manganese	mg	0.177	294.51	16
Selenium	µg	0.2	0	0
Iodine	µg		0.15	0
Molybdenum	µg			
Nickel	µg			
Tin	µg			

*raw with skin

Table 78: Nutrient values are per 100 g edible portion of zucchini.

NUTRITIONAL INFORMATION							
One serve of fruit is 150 grams of fresh fruit (Department of Health and Ageing Go for 2&5 [®] campaign)							
Nutrient	FSANZ ^a	NZ Food ^b	Average quantity per serving (150g)		% Daily Intake per serving ^c		Reference value
	Average quantity per 100g	Average quantity per 100g	FSANZ	NZFA	FSANZ	NZFA	
Water (g)	94.8	93.13	105.15	139.695			
Energy (kJ)	61	70.1	91.5	105.15	1.1	1.2	8700
Protein (g)	0.8	1.96	1.2	2.94	2.4	5.9	50
Total lipid (fat) (g)	0.3	0.22	0.45	0.33	0.6	0.5	70
Fatty acids, total saturated (g)			0	0	0.0	0.0	24
Available Carbohydrate (g)	1.6	1.75	2.4	2.625	0.8	0.8	310
Sugar (g)	1.6	1.75	2.4	2.625	2.7	2.9	90
Total dietary fibre (g)	1.2	1.6	1.8	2.4	6.0	8.0	30
Sodium (mg)	1	0.97	1.5	1.455	0.1	0.1	2300

^a Food Standards Australia New Zealand; FSANZ AUSNUT database (2007) Australian Food, Supplement and Nutrient Database 2007 for estimation of population nutrient intakes.

^b <http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/pages/default.aspx>

^c <http://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand>.

^d Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Your daily intakes may be higher or lower depending on your energy needs.

Table 79: Calculation of energy value of the major* food components per 100 g zucchini.

Nutrient	Energy factor	FSANZ ^a		NZ Food Authority ^b	
		Average quantity	Approximate calculation of energy value kJ/g	Average quantity	Approximate calculation of energy value kJ/g
Protein	17	0.8	13.6	1.96	33.32
Total lipid (fat)	37	0.3	11.1	0.22	8.14
Fatty acids, total saturated					
Available Carbohydrate	17	1.6	27.2	1.75	29.75
Total sugars		1.6		1.75	
Total dietary fibre	8	1.2	9.6	1.6	12.8

*Only carbohydrate (including fibre), fats, proteins, organic acids, polyols and ethanol contain food energy. All foods are made up of a combination of these five nutrients.

Effects of irradiation on nutritional content and postharvest fruit quality of raw zucchini

A report of irradiation studies of Australian zucchini conducted in 2011 is provided in full (Attachment) in this section. The cultivar studied was raw dark skin zucchini (*Cucurbita pepo*), variety 'Blackjack'. The research investigated the effect of low dose gamma (γ)–irradiation on the nutritional profile and postharvest fruit quality of zucchini irradiated at pest disinfection doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy after irradiation treatment and after a recommended period of 7 days in cold storage at 8°C. (See Attachment - Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at end of section).

In the nutritional study, applications of gamma irradiation treatments of ≤ 1 kGy can be used as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of zucchini. No significant dose effects were found in ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars, Vitamin C (ascorbic acid) and Vitamin A (beta-carotene) after treatment. This was also found in an early study by Mitchell *et al.* (1992) where no loss in nutritional composition was found with zucchini irradiated at 300Gy. Significant differences between doses however, were found after seven days for carbohydrates, dietary fibre and total sugars although the mean values were higher for the treated samples than the untreated control.

Vitamin C (ascorbic acid) levels were not significantly different between irradiated zucchini samples and the untreated control. Vitamin C (ascorbic acid) in the untreated control was 6.20mg/100g and 12.60 mg/100g, 8.90 mg/100g and 8.37mg/100g in the 150 Gy, 600 Gy and 1000 Gy samples, respectively. After seven days storage, mean Vitamin C (ascorbic acid) was 7.03 mg/100g for the control sample and varied between 8.53 mg/100g and 11.13 mg/100g in the irradiated zucchini samples.

Beta-carotene of untreated and irradiated zucchini samples was not significantly different after treatment and after storage although storage had a significant impact. In all cases, mean beta-carotene increased, with the greatest increase reported for the 150 Gy sample.


Storage impacted on some macro and micronutrient levels and the changes generally appeared to be associated with the ripening process during storage. Although irradiation is known to destroy vitamins in pure and unadulterated systems, in food the damage may not be significant due the mutually protective action or shielding effect of various chemical constituents on each other (Diehl 1990, 1995). As early as 1965, Bramlage and Lipton reported the use of gamma irradiation in vegetables to extend market life.

The QLD DAFF postharvest fruit quality study showed that irradiation applied up to 1 kGy overall had little to no effect on a range of quality attributes measured in zucchini. The commodity was instead impacted more by storage time than by irradiation itself, undergoing the typical senescent-related processes (e.g. deterioration through aging) often observed under storage conditions, such as changes in skin and/or flesh colour, flesh softening and weight loss.

Zucchini colour properties changed over the seven day storage period, with the skin becoming a lighter green and the flesh a darker yellow colour with time. Only small changes in internal flesh colour (chroma values) were attributed to the effects of irradiation, resulting in flesh tissue becoming slightly duller in colour by Day 7, particularly with doses at and above 600Gy. These changes however were not visually detectable.

The overall findings of the study indicate that an application of up to 1kGy will not result in any significant detrimental damage to the nutritional and postharvest quality of zucchini.

Department of Agriculture, Fisheries and Forestry



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

Final Report
May 2012



Project title: Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon.
MT10057 Final Report

This report investigates the effects of low doses of gamma (γ)-irradiation applied as a quarantine disinfestation method on the nutrition (Part A) and quality (Part B) of a selection of fruit commodities, both before and after a recommended cold storage period.

Project leaders: [REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
PO Box 652
Cairns Qld 4870, Australia
[REDACTED]
Research Scientist
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
Cairns Qld 4870, Australia
[REDACTED]
Market Access Focus Team Leader
Horticulture and Forestry Science
Department of Agriculture, Fisheries and Forestry (DAFF)
Cairns Qld 4870, Australia

Project authors: [REDACTED] Research Scientist, DAFF
[REDACTED], Research Scientist, DAFF
[REDACTED] Senior Biometrician, DAFF
[REDACTED] Market Access Focus Team Leader, DAFF

Key personnel: [REDACTED] Technical Officer, DAFF
[REDACTED] Leader, Radiation Technology
[REDACTED] Senior Technical Officer, Radiation Technology
[REDACTED] Technical Officer, Radiation Technology
[REDACTED] Technical Officer, Radiation Technology

Funding sources: Horticulture Australia Limited (HAL)
Queensland Department of Employment, Economic Development and Innovation
New Zealand Fresh Produce Importers Association Inc.
Vegetable R & D Levy
Summerfruit R & D Levy
Bowen District Growers Association Inc.
Steritech Pty Ltd.

Acknowledgement: Acknowledgement is made to the team at Radiation Technology, Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, for assistance with irradiation procedures.

© State of Queensland, Department of Agriculture, Fisheries and Forestry, May 2012.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.



Under this licence you are free, without having to seek permission from Department of Agriculture, Fisheries and Forestry, to use this publication in accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland, Department of Agriculture, Fisheries and Forestry as the source of the publication.

For more information on this licence visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

2

Contents

1. Report summary	7
2. Part A – Effect of low dose gamma (γ)-irradiation on the nutritional profile of selected fruit commodities	8
2.1 Summary	8
2.2 Introduction	9
2.3 Materials and methods	9
2.3.1 Cultivars	10
2.3.2 Irradiation treatment	10
2.3.3 Chemical analysis	12
2.3.4 Statistical analysis of chemical components	14
2.4 Results	15
2.4.1 Irradiation treatment – dosimetry	15
2.4.2 Tomato	15
2.4.3 Capsicum	20
2.4.4 Zucchini	25
2.4.5 Nectarine	30
2.4.6 Rockmelon	35
2.4.7 Honeydew melon	35
2.5 Discussion	42
2.5.1 Vitamin C and beta-carotene	45
2.6 Recommendations	48
2.7 References	48
2.8 Appendix 1 – Irradiation reports	50
2.9 Appendix 2 – Irradiation reports for beta-carotene analysis	71
3. Part B – Effect of gamma irradiation on postharvest quality of selected fruit commodities	84
3.1 Summary	84
3.2 Introduction	84
3.3 Materials and methods	85
3.3.1 Experimental layout	85
3.3.2 Fruit quality assessments	85
3.3.3 Statistical analysis	86
3.4 Results	86
3.4.1 Tomato	86
3.4.2 Capsicum	88
3.4.3 Zucchini	90
3.4.4 Nectarine	90
3.4.5 Rockmelon	94
3.4.6 Honeydew	94

3.5	Discussion	97
3.6	Recommendations	97
3.7	References	97
3.8	Appendix 3 – Photographs of each fruit type gamma irradiated with a dose between 0Gy to 1000Gy taken before cold storage (Day 1) and up to a maximum of 21 days	98
3.8.1	Tomato (var. Gourmet Swanson).....	98
3.8.2	Capsicum (var. Plato)	99
3.8.3	Zucchini (var. Blackjack)	101
3.8.4	Nectarine (var. Arctic Snow)	102
3.8.5	Honeydew (var. Galaxy)	104
3.8.6	Rockmelons (var. Triumph).....	105

List of Figures

Figure 1.	Boxes of produce positioned for irradiation. Dosimeters attached on the outside of boxes of packed produce.	11
Figure 2.	Rockmelon, zucchini, capsicum, tomato and nectarine arranged in a cardboard box ready for irradiation. Dosimeter(s) attached to a piece of produce for monitoring doses received within the box.	11
Figure 3.	Effect of irradiation dose on fruit moisture content during cold (7.5°C) storage of green capsicum.	88
Figure 4.	Nectarine fruit with symptoms of irradiation damage following treatment to 1kGy occurring after 21 days in cold (1.0°C) storage. Symptoms consisted of mild pitting associated with browning on the skin surface.	90
Figure 5.	Honeydew melon expressing symptoms of irradiation damage following treatment to 1kGy occurring after 14 days in cold (7.0°C) storage. Symptoms consisted of pitting and browning on the skin surface.	94

List of Tables

Table 1.	Storage conditions for tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon.	10
Table 2.	Mean chemical measurements in 'Gourmet Swanson' tomato after irradiation treatment (Time 1).	16
Table 3.	Mean chemical measurements in untreated and irradiated 'Gourmet Swanson' tomato after 14 days cold storage at 10°C (Time 2).	17
Table 4.	Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) 'Gourmet Swanson' tomato before storage (Time 1) and after 14 days cold storage (Time 2).	18
Table 5.	Mean chemical measurements in 'Plato' capsicum after irradiation treatment (Time 1).	21
Table 6.	Mean chemical measurements in untreated and irradiated 'Plato' capsicum after 21 days cold storage at 8°C (Time 2).	22
Table 7.	Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) capsicum, variety 'Plato' before storage and after 14 days cold storage (Time 2).	23
Table 8.	Mean chemical measurements in zucchini, variety 'Blackjack' after irradiation treatment (Time 1).	26
Table 9.	Mean chemical measurements in untreated and irradiated zucchini, variety 'Blackjack' after seven days (Time 2) cold storage at 8°C.	27
Table 10.	Mean chemical measurements in untreated and irradiated zucchini (150Gy, 600Gy and 1000Gy), variety 'Blackjack' before storage (Time 1) and after seven days cold storage (Time 2).	28
Table 11.	Mean chemical measurements in nectarine, variety 'Arctic Snow' one day after irradiation treatment (Time 1).	31
Table 12.	Mean chemical measurements in untreated and irradiated nectarine, variety 'Arctic Snow' after 21 days cold storage (Time 2).	32

Table 13.	Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) nectarine, variety 'Arctic Snow' before storage (Time 1) and after 21 days cold storage (Time 2).....	33
Table 14.	Mean chemical measurements in rockmelon, variety 'Triumph' after irradiation treatment (Time 1).....	36
Table 15.	Mean chemical measurements in untreated and irradiated rockmelon, variety 'Triumph' after 14 days cold storage (Time 2).....	37
Table 16.	Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) rockmelon, variety 'Triumph' before storage (Time 1) and after 14 days cold storage (Time 2).	38
Table 17.	Mean chemical measurements in honeydew melon, variety 'Galaxy' after irradiation treatment (Time 1).....	40
Table 18.	Mean chemical measurements in untreated and irradiated honeydew melon, variety 'Galaxy' after 14 days cold storage (Time 2).....	41
Table 19.	Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) honeydew melon, variety 'Galaxy' before storage (Time 1) and after 14 days cold storage (Time 2).....	43
Table 20.	Description of fruit type and storage conditions applied in the present study.....	85
Table 21.	Effect of irradiation dose and storage duration on tomato quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (10°C) for 14 days (Day 14).....	87
Table 22.	Effect of irradiation dose and storage duration on green capsicum quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.5°C) for 21 days (Day 21).....	89
Table 23.	Effect of irradiation dose and storage duration on zucchini fruit quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for seven days (Day 7).	91
Table 24.	Effect of irradiation dose and storage duration on nectarine fruit quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (1.0°C) for 21 days (Day 21).....	92
Table 25.	Effect of irradiation dose and storage duration on rockmelon quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for 14 days (Day 14).....	95
Table 26.	Effect of irradiation dose and storage duration on honeydew melon quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for 14 days (Day 14).....	96

1. Report summary

This study examines the radio-tolerance of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at doses at and below 1kGy for the purposes of quarantine disinfestation. The effects of low dose gamma (γ)-irradiation on the proximate and nutritional profile and postharvest fruit quality attributes of these selected fruits were investigated.

The study provides an analysis of the six commodities irradiated with 0Gy, 150Gy, 600Gy and 1000Gy and then assessed at two times, being within 24 hours after being irradiated and after a recommended cold storage period of up to 21 days. The nutritional profile of each produce was analysed at these two times for ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, ascorbic acid (vitamin C) and beta-carotene. Fruit physico-chemical measurements were also conducted at the same times.

The results showed that applications of gamma irradiation of $\leq 1\text{kGy}$ did not induce any significant deleterious effects on the chemical and proximate components of tomato, green capsicum, zucchini, nectarine and rockmelon. Beta-carotene levels in honeydew melon however were initially affected by irradiation (within 24 hours), being significantly lower in the $\geq 600\text{Gy}$ treatment ($12\mu\text{g}/100\text{g}$) compared with control fruit ($17\mu\text{g}/100\text{g}$), although by the end of the storage period no differences were detected across any of the treatments (mean $12.3\mu\text{g}/100\text{g}$). Treatment doses at below 600Gy can therefore be applied safely without inducing any deleterious effects on the nutritional components in honeydew melon.

In regards to fruit quality, irradiation applied up to 1kGy overall had little to no effect on a range of quality attributes measured in tomato, capsicum, zucchini and rockmelon. These commodities were instead impacted more by storage time than by irradiation itself, undergoing the typical senescent-related processes (e.g. deterioration through aging) often observed under storage conditions, such as changes in skin and/or flesh colour, flesh softening and weight loss.

The irradiation treatment did however have a significant effect on the quality of honeydew melon and, to a lesser extent, nectarine fruit. In both cases, the incidence and severity of symptoms (namely skin browning and pitting) increased with dose level; being observed only at the end of the recommended storage period. Specifically, symptoms in honeydew melon occurred only when treated to a dose of 600Gy and above, with up to 51% of the skin surface area being affected. In contrast, irradiation damage in nectarine fruit was comparatively low across all the treatments ($< 1\text{cm}^2$ skin area affected), with only a small proportion of fruit (3%) affected at 150Gy. However, this increased significantly to greater than 13% of fruit affected at a dose of 600Gy and above.

In conclusion, the overall findings of this study suggest that an application of up to 1kGy will not result in any significant detrimental damage to the nutritional and postharvest quality of fruit such as tomato, capsicum, zucchini or rockmelon. An irradiation dose of 600Gy or above, however, would not be recommended for honeydew melon or nectarine fruit given the potential for adverse affects on fruit quality. Further studies on both commodities looking at factors such as, postharvest handling, storage, the particular cultivar, production system, maturity and environmental conditions prior to harvest is recommended. All factors listed above have been reported to impact on the radio-tolerance of a wide range of commodities.

2. Part A – Effect of low dose gamma (γ)-irradiation on the nutritional profile of selected fruit commodities

2.1 Summary

This report examines the radio-tolerance of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at doses at and below 1kGy for the purposes of quarantine disinfestation. The study provides an analysis of data on the nutritional profile of the six commodities that have been irradiated with 0Gy, 150Gy, 600Gy and 1000Gy and assessed on two occasions.

The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety 'Gourmet Swanson'; green capsicum (*Capsicum annuum*), variety 'Plato'; dark skin zucchini (*Cucurbita pepo*), variety 'Blackjack'; firm white flesh nectarine (*Prunus persica* var. *nucipersica*), variety 'Arctic Snow'; rockmelon (*Cucumis melo*), variety 'Triumph' and white skin honeydew melon (*Cucumis melo*), variety 'Galaxy'.

The nutritional profile of each produce was analysed and included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. Overall, our results show that tomato, capsicum, zucchini, nectarine and rockmelon can tolerate 1kGy radiation without significant deterioration in the majority of nutrient components investigated. The nutritional components of these fresh commodities tested were not negatively affected by low dose irradiation.

Where there are effects, the extent of nutrient changes is variable and may be comparable or insignificant with losses during handling, storage and microbial degradation, as they do during the accepted freezing, canning, heat treatment and pickling processes.

Specifically, a main effect of dose was not detected in Vitamin C (ascorbic acid) in tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon. No main effect of dose was detected in beta-carotene in tomato, capsicum, zucchini, nectarine and rockmelon. However, beta-carotene content in honeydew melon was significantly affected with doses ≥ 600 Gy immediately after irradiation treatment. An interaction of time and dose was observed in Vitamin C (ascorbic acid) and beta-carotene in honeydew melon.

While each commodity responded differently when exposed to ionising low dose gamma (γ)-irradiation, overall, the effect of storage time was greater than by irradiation itself in many of the nutrients investigated and the changes generally appeared to be associated with the ripening or senescence processes during storage.

In this study, the fresh fruits studied are high in water content, and low in protein and fat with moisture contents frequently greater than 86%. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

Applications of gamma irradiation treatments of ≤ 1 kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of tomato, green capsicum, zucchini, nectarine and rockmelon. Honeydew melon however, was less tolerant to doses > 600 Gy with respect to beta-carotene content just after irradiation treatment. Treatment with 150Gy could be safely applied without inducing any deleterious effects in honeydew melon.

Research studies and simulated transport are still needed in which irradiation is included as part of the supply chain system or combination treatments involving irradiation and modified atmosphere packaging or edible coatings to reduce postharvest rots and extend shelf life.

2.2 Introduction

As soon as fruits are harvested, some undergo higher rates of respiration, in association with moisture loss, deterioration of fruit quality, nutrition and potential microbial spoilage. Fruits will also lose some vitamins quite rapidly and can deteriorate if they are stored in warmth and light. More than likely, fruit will also be picked at a slightly immature stage to reduce mechanical damage during harvesting and transportation. The literature indicates that by the time they are consumed, fresh, frozen and canned fruits may be nutritionally similar, depending on the post harvest handling and processing treatments.

It is known that respiration by fruit and other tissues are affected as a result of exposure to ionising radiation however, these responses can vary. It has also been shown that irradiation can delay the ripening of some fruits or the sprouting of certain bulbs and tubers, thereby extending shelf life.

While there is literature available on the effect of irradiation on the nutrition and quality of tropical fruits in general, there is sometimes discrepancy reported as well. The differences have been reported to be due to the commodity, postharvest handling, storage, the particular cultivar, production system, maturity, environmental conditions, soil type, growing and weather conditions during growth.

The objective of this study is to investigate the effects of low dose gamma (γ)-irradiation for disinfestation purposes on the nutritional components and fruit quality attributes of harvest ready, export quality tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon.

Export quality fresh whole produce were sourced for this study. Treatment doses were 0Gy, 150Gy, 600Gy and 1000Gy.

The Australia New Zealand Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) permits irradiation of food for the purposes of pest disinfestation for a phytosanitary objective; the minimum is 150Gy and the maximum of 1kGy.

Irradiation treatment for fruit flies of the family Tephritidae (generic) (ISPM No.28, Annex 7, 2009) provides for the irradiation of fruits and vegetables at 150Gy minimum absorbed dose to prevent the emergence of adults of fruit flies at the stated efficacy. Approved new minimum doses for certain fruit flies are reviewed and re-evaluated as required and would facilitate the use of irradiation to neutralise more pests at lower doses, potentially minimising any adverse affects on commodity quality.

The effect of low dose gamma (γ)-irradiation was also examined after a period of cold storage following treatment. This approach provides data on the effect of irradiation treatment however, limited to only the particular variety. Other researchers have obtained samples from the supermarket, measuring what the consumer has available, but this can increase nutrient variability due to cultivar, growing conditions, maturity and handling practices.

2.3 Materials and methods

Whole, fresh fruits were purchased from the Sydney Wholesale Market on the day of the treatment. Export quality, fresh produce were transported to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, New South Wales for the irradiation treatments. The radiation type used was gamma radiation (cobalt-60).

Irradiation treatment of tomatoes and capsicum were carried out on 28 February - 2 March 2011. Zucchini and nectarine were treated between 14-16 March 2011 and rockmelon and honeydew melon on 9-10 May 2011.

A second set of produce (tomato, capsicum, zucchini, rockmelon and honeydew melon) were purchased and treated 18 July 2011 and sent for beta-carotene analysis as the previous analysis was done in error. The same varieties were purchased and treated in the same way using the same experimental design. Nectarine for beta-carotene analysis was irradiated 28 March 2012.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 10°C. The fruits were carefully placed in cardboard boxes which fitted into the stainless steel irradiation chamber for treatment. The produce did not receive any sanitizing or washing before treatment. The fruits were not graded.

There were three replications for each dose treatment (0Gy, 150Gy, 600Gy and 1000Gy) and the effects of irradiation were measured at two stages: before storage (Time 1; one day after irradiation treatment) and after a period of storage (Time 2). The storage times and conditions for each commodity are listed in Table 1.

Table 1. Storage conditions for tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon.

Commodity	Set storage temperature	Duration
Tomato (red)	10°C	14 days
Capsicum (green)	8°C	21 days
Zucchini	8°C	7 days
Nectarine	4°C	21 days
Rockmelon	7°C	14 days
Honeydew melon	7°C	14 days

For tomato and nectarine, each replicate consisted of ten pieces of fruit per treatment dose per assessment time. For capsicum, each replicate consisted of five pieces of produce per treatment dose per assessment time. For zucchini, each replicate consisted of eight pieces of fruit per treatment dose per assessment time. For rockmelon and honeydew melon, each replicate consisted of three pieces of fruit per treatment dose per assessment time.

Following irradiation treatment, the fruits were sorted, packed and sent for chemical analysis and fruit quality assessment. Time 2 fruits were placed in cold storage at their respective set conditions until testing commenced (Table 1).

2.3.1 Cultivars

Export quality fresh fruits were selected. The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety 'Gourmet Swanson'; green capsicum (*Capsicum annuum*), variety 'Plato'; dark skin zucchini (*Cucurbita pepo*), variety 'Blackjack'; firm white flesh nectarine (*Prunus persica* var. *nucipersica*), variety 'Arctic Snow'; rockmelon (*Cucumis melo*), variety 'Triumph' and white skin honeydew melon (*Cucumis melo*), variety 'Galaxy'. To minimise variation, each commodity was sourced from only one producer.

2.3.2 Irradiation treatment

The samples were exposed to target irradiation doses of 0Gy, 150Gy, 600Gy and 1000Gy from a Co⁶⁰ source of gamma irradiation. There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 22-25°C, varying with the commodity. The boxes of produce were positioned on a rig parallel to the plaque source (Figure 1). Control and treatment produce were stored pre and post irradiation in a coldroom set at 10°C.



Figure 1. Boxes of produce positioned for irradiation. Dosimeters attached on the outside of boxes of packed produce.

Source: Radiation Technology, ANSTO.

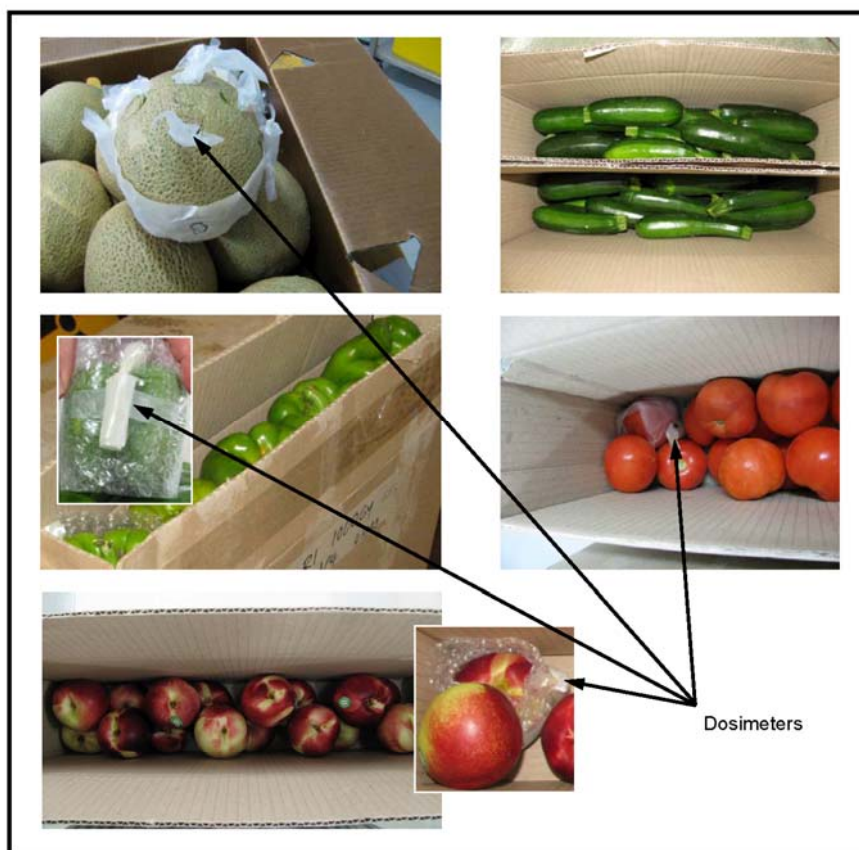


Figure 2. Rockmelon, zucchini, capsicum, tomato and nectarine arranged in a cardboard box ready for irradiation. Dosimeter(s) attached to a piece of produce for monitoring doses received within the box.

Source: Radiation Technology, ANSTO.

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

11

Radiation Technology, ANSTO maintains a quality management system that complies with ISO9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing (ANSTO, 2011).

The irradiation doses were confirmed by dosimeters. Dosimeters (Fricke) were placed throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front, the back and between fruits (Figure 2). Additional dosimeters were attached to the outside of each package for monitoring and to provide references to the minimum and maximum doses (Figure 1).

2.3.3 Chemical analysis

Control and irradiated produce were analysed for ash, energy, carbohydrates, dietary fibre, fat profile, moisture, sodium, protein, total sugars, Vitamin C (ascorbic acid) and beta-carotene by the contracted National Association of Testing Authorities (NATA) accredited Analytical Laboratory.

The samples were analysed at two occasions, after treatment and after a period in cold storage. The first assessment was a day after mean irradiation treatment and the second analysis at the end of the storage period (Table 1).

Edible portions of each fruit were blended at each time point. A summary of the method of analysis for determining the component is described. "Reference methods" are only the basis of the internal method used by the contracted laboratory in the determination of that component and does not necessarily represent every detail of the process followed.

2.3.3.1 Moisture. Reference method AS2300.1.1

The moisture content is the percentage decrease in mass obtained on drying the material. This method is used to determine the percentage of water in a sample by drying the sample to a constant weight.

- Place homogenised sample in pre-dried, weighed dish.
- Include sand and a small rod in the dish, if necessary.
- Add sample. Macerate with the sand, if using.
- Dry at 102°C for 4 hours.
- Cool in a desiccator. Weigh.
- Return to the oven for one hour.
- Cool in a desiccator. Weigh.
- Repeat the drying process until constant weight is obtained.
- Calculate moisture (or total solids).

2.3.3.2 Ash. Reference method AS2300.1.5

Ash is determined as the percentage by mass of residue obtained after thorough ignition.

- Weigh sample into a clean crucible
- Dry and then burn off organic matter
- Ignite to 550°C, to a pale grey ash.
- Cool in a desiccator. Weigh.

2.3.3.3 Protein. Reference method AOAC 928.08

Protein was determined with acid digestion, followed by distillation and titration (Kjeldahl Method).

- Digest sample with sulphuric acid and catalyst.
- Add caustic to neutralise.
- Distil and collect the ammonia.
- Titrate ammonia and calculate as protein.

2.3.3.4 Dietary fibre. Reference Method AOAC 985.29

The sample undergoes sequential enzymatic digestion by heat stable α -amylase, protease and amyloglycosidase to remove starch and protein.

- The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.
- The residue is corrected for protein and ash and calculated as dietary fibre.

2.3.3.5 Fat. Reference method AOAC 922.06

Fat was determined using the acid hydrolysis method. Crude fat was determined by extracting the fat from the sample using a solvent, then determining the weight of the fat recovered.

- Homogenise sample.
- Transfer weighed portion to Mojonnier flask.
- Add 10ml acid and digest to dissolve sample.
- Cool.
- Add 10ml alcohol.
- Extract with diethyl ether and petroleum spirits.
- Decant solvents and evaporate to recover fat.
- Back-wash if necessary.
- Calculate fat result.

2.3.3.6 Fatty acid profile. Reference method AOAC 963.22

The fatty acid composition can contain a complex mixture of saturated, monounsaturated, and polyunsaturated fatty acids, each with a variety of carbon chain lengths. The analysis of fatty acids was performed by gas chromatography following the conversion of the fatty acids into their corresponding Methyl Esters (FAME).

- Cold extract fat from sample.
- Saponify fat.
- Methylate with boron trifluoride.
- Extract into heptane.
- Dry with anhydrous sodium sulphate.
- Inject onto gas chromatograph.
- Compare to standards for peak identification.
- Correct low molecular weight fats, if appropriate.
- Calculate area percent of FAME.

2.3.3.7 Sugars. Reference method AOAC 982.14

Sucrose, glucose, maltose and fructose were analysed by high performance liquid chromatography (HPLC), using refractive index detector.

- Run sugar standards and control.
- Extract sample into water.
- Calculate sugar levels from standards.
- Clarify with Carrez Reagents.
- Filter.
- Inject onto HPLC.
- Calculate sugar levels from standards.

2.3.3.8 Sodium. Reference method AOAC 985.35

Sodium was determined using the Atomic Absorption Spectrophotometer (AAS) Method.

- Homogenise sample.
- Ash sample at 560°C for 8 hours.
- Dissolve ash in 1:1 nitric acid, dry, re-ash.

- Dissolve ash in 1:1 hydrochloric acid.
- Make to volume.
- Run standards on AAS.
- Run samples on AAS.
- Calculate result.

2.3.3.9 Vitamin C (ascorbic acid). Reference method AOAC 985.33

The method used for Vitamin C (ascorbic acid) was by titration with coloured oxidation-reduction indicator 2, 6-Dichloroindophenol.

- Prepare standard.
- Standardise indophenol solution.
- Pipette aliquot of sample into conical flask.
- Complex sulphur dioxide, if necessary, with acetone.
- Add metaphosphoric acid solution and swirl.
- Titrate with the indophenol solution.
- Calculate ascorbic acid level.

2.3.3.10 Carbohydrates. Reference Method Food Standard Code 1.2.8

Carbohydrates are determined by difference.

2.3.3.11 Energy. Reference Method Food Standard Code 1.2.8

By calculation.

- Levels of individual components of the analysis are multiplied by the factors listed in Standard 1.2.8 of the Australian Food Standard code to establish the total energy level.

2.3.3.12 Beta-carotene. Reference Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Carotenes are sensitive to degradation caused by exposure to oxygen, heat and light.

- Preparation and Saponification:
Approximately 5g of sample is accurately weighed into a 250ml flask and 60ml alcoholic KOH is added. The solution is then placed in a water bath at 80°C for 30 minutes.
- Extraction:
The saponified sample is cooled. The solution is transferred to a 500ml separating funnel containing brine. Extraction is made using petroleum ether with five aqueous washes. Each shake and wash is followed by collection and combining of organic phases.

The petroleum ether extract is then reduced under rotary evaporation followed by nitrogen. The sample is then made up to 10ml in a volumetric flask with methanol.

- Determination:
 α - and β -carotene are separated by reverse phase HPLC on a C18 column using a 95:5 methanol:tetrahydrofuran mobile phase. Absorbance is measured by PDA detection at 450nm, the PDA spectra (250 to 650nm) is used as confirmation. Determination is made against a known β -carotene standard, whose concentration is determined by absorbance measurements.

2.3.4 Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0Gy, 150Gy, 600Gy and 1000Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level.

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD). A factorial analysis investigating the time by dose interaction has also been made using a 2-way ANOVA with time and dose as the main factors.

For some components, where all or the majority of data was censored (below the level of detection) the data have not been analysed. Where there were a minority of values censored, the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. A \log_{10} transformation was required for several censored variables to improve the assumptions underlying the ANOVA and ensure sensible estimates of the censored values were obtained. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not under-estimated.

The lower limits of detection were: for fat, saturated fat, mono-unsaturated fat, poly-unsaturated fat and trans fat and dietary fibre < 0.1g/100g; for sucrose < 0.2mg/100g; maltose and lactose were < 0.5g/100g and; beta-carotene was < 0.5µg/100g.

2.4 Results

2.4.1 Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required. The average irradiation dose absorbed complies with the required specifications. The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2%.

Details for the irradiation treatment for the six commodities are provided in Appendices 1 and 2.

2.4.2 Tomato

High quality, oblate and firm tomatoes, variety 'Gourmet Swanson' were treated and the samples were analysed at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 14 days storage in a cold room set at 10°C.

Irradiation at all test doses did not affect the nutritional quality of tomato. The nutritional components of fresh whole tomato were not negatively affected by low dose irradiation (150Gy, 600Gy and 1000Gy) compared with the control sample, before storage and after 14 days storage. The effects of irradiation dose on the components at each time are summarised in Tables 2 and 3.

No significant dose effects on the nutritional components tested were found at either Time 1 (before storage) (Table 2) or Time 2 (fourteen days cold storage) (Table 3). Irradiation had no significant effects on ash, carbohydrates, dietary fibre, energy, fat profile, moisture, sodium, protein, total sugar, fructose, glucose and Vitamin C (ascorbic acid) and beta-carotene.

In the control sample, mean Vitamin C (ascorbic acid) detected after irradiation was 18.3mg/100g while the irradiated samples ranged between 17.0-18.0mg/100g (Table 2). After 14 days storage, mean Vitamin C (ascorbic acid) ranged between 16.3-25.0mg/100g (Table 3).

Fresh untreated tomato, variety 'Gourmet Swanson' contained a mean of 180.0µg/100g of beta-carotene, the 150Gy and 1000Gy irradiated samples contained means of 196.7µg/100g and 600Gy tomato contained a mean of 210.0µg/100g.

Table 2. Mean chemical measurements in 'Gourmet Swanson' tomato after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.57 (0.058)	0.57 (0.058)	0.50 (0.000)	0.53 (0.058)	0.455	0.045
Carbohydrates (g/100g)	3.27 (0.153)	3.07 (0.058)	3.23 (0.321)	3.40 (0.265)	0.426	0.187
Dietary fibre (g/100g)	0.73 (0.208)	1.00 (0.173)	0.93 (0.115)	0.93 (0.153)	0.263	0.125
Energy (kJ/100g)	80.7 (3.22)	79.7 (5.69)	84.0 (4.58)	88.3 (2.08)	0.210	3.87
Moisture (g/100g)	94.43 (0.115)	94.43 (0.208)	94.27 (0.153)	94.07 (0.153)	0.106	0.138
Protein (g/100g)	0.83 (0.058)	0.80 (0.173)	0.83 (0.058)	0.93 (0.058)	0.349	0.071
Sodium (mg/100g)	16.7 (2.89)	18.3 (2.89)	18.3 (2.89)	15.0 (5.00)	0.613	2.81
<i>Fat</i> (g/100g)	0.12 (0.067)	0.17 (0.058)	0.20 (0.000)	0.20 (0.000)	0.188	0.034
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	2.93 (0.058)	2.90 (0.173)	2.97 (0.058)	2.90 (0.173)	0.918	0.112
Fructose (g/100g)	1.57 (0.058)	1.53 (0.058)	1.60 (0.000)	1.53 (0.058)	0.455	0.045
Glucose (g/100g)	1.37 (0.058)	1.37 (0.115)	1.40 (0.000)	1.37 (0.115)	0.950	0.071
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	18.3 (5.03)	18.0 (1.00)	17.7 (1.53)	17.0 (1.73)	0.952	2.45
Beta-carotene (µg/100g)	180.0 (26.46)	196.7 (5.77)	210.0 (26.46)	196.7 (5.77)	0.475	17.85

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore has not been analysed.

Table 3. Mean chemical measurements in untreated and irradiated 'Gourmet Swanson' tomato after 14 days cold storage at 10°C (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.47 (0.058)	0.57 (0.153)	0.53 (0.058)	0.47 (0.058)	0.455	0.071
Carbohydrates (g/100g)	3.07 (0.058)	2.80 (0.173)	2.93 (0.462)	3.17 (0.208)	0.202	0.156
Dietary fibre (g/100g)	0.90 (0.100)	0.90 (0.100)	0.70 (0.173)	0.77 (0.153)	0.133	0.085
Energy (kJ/100g)	84.3 (5.51)	85.7 (3.22)	77.3 (6.11)	77.7 (2.52)	0.065	3.03
Moisture (g/100g)	94.57 (0.153)	94.80 (0.346)	94.87 (0.551)	94.80 (0.173)	0.403	0.174
Protein (g/100g)	0.73 (0.058)	0.93 (0.321)	0.83 (0.058)	0.67 (0.115)	0.379	0.149
Sodium (mg/100g)	18.3 (2.89)	21.7 (2.89)	18.3 (2.89)	20.0 (5.00)	0.613	2.81
Fat (g/100g)	0.33 (0.153)	0.40 (0.173)	0.20 (0.100)	0.17 (0.058)	0.227	0.112
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total Sugars (g/100g)	2.87 (0.115)	2.70 (0.173)	2.70 (0.265)	2.90 (0.100)	0.396	0.139
Fructose (g/100g)	1.53 (0.058)	1.47 (0.115)	1.53 (0.115)	1.53 (0.058)	0.730	0.071
Glucose (g/100g)	1.30 (0.100)	1.23 (0.058)	1.20 (0.200)	1.33 (0.058)	0.482	0.089
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	25.0 (6.00)	19.3 (2.08)	16.3 (2.08)	16.7 (1.53)	0.108	3.19
Beta-carotene (µg/100g)	303.3 (58.60)	336.7 (47.26)	310.0 (17.32)	298.0 (80.57)	0.882	52.27

Standard deviations are presented in brackets below each mean.

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Potentially there could be a time by dose interaction and a full factorial analysis is shown in Table 4. Exploration of the variation of treatment effect over time to partly understand the changes is presented.

Table 4. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) 'Gourmet Swanson' tomato before storage (Time 1) and after 14 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAS		
		0	150	600	1000		Factor	p-value	SED
Ash (g/100g)	1	0.57	0.57	0.50	0.53	0.54	Day	0.288	0.030
	14	0.47	0.57	0.53	0.47	0.51	Irrad.	0.460	0.043
	Mean	0.52	0.57	0.52	0.50		Day x Irrad.	0.416	0.060
Carbohydrates (g/100g)	1	3.27	3.07	3.23	3.40	3.24a	Day	0.025	0.100
	14	3.07	2.80	2.93	3.17	2.99 b	Irrad.	0.136	0.141
	Mean	3.17	2.93	3.08	3.28		Day x Irrad.	0.986	0.199
Dietary fibre (g/100g)	1	0.73	1.00	0.93	0.93	0.90	Day	0.221	0.065
	14	0.90	0.90	0.70	0.77	0.82	Irrad.	0.448	0.092
	Mean	0.82	0.95	0.82	0.85		Day x Irrad.	0.191	0.130
Energy (kJ/100g)	1	80.7abc	79.7 bc	84.0abc	88.3a	83.2	Day	0.302	1.79
	14	84.3abc	85.7ab	77.3 c	77.7 c	81.2	Irrad.	0.794	2.53
	Mean	82.5	82.7	80.7	83.0		Day x Irrad.	0.014	3.58
Moisture (g/100g)	1	94.43	94.43	94.27	94.07	94.30 b	Day	<0.001	0.088
	14	94.57	94.80	94.87	94.80	94.76a	Irrad.	0.502	0.124
	Mean	94.50	94.62	94.57	94.43		Day x Irrad.	0.126	0.176
Protein (g/100g)	1	0.83	0.80	0.83	0.93	0.85	Day	0.346	0.060
	14	0.73	0.93	0.83	0.67	0.79	Irrad.	0.768	0.085
	Mean	0.78	0.87	0.83	0.80		Day x Irrad.	0.163	0.120
Sodium (g/100g)	1	16.7	18.3	18.3	15.0	17.1	Day	0.075	1.30
	14	18.3	21.7	18.3	20.0	19.6	Irrad.	0.502	1.84
	Mean	17.5	20.0	18.3	17.5		Day x Irrad.	0.575	2.60
Vitamin C (ascorbic acid) (mg/100g)	1	18.3	18.0	17.7	17.0	17.8	Day	0.259	1.35
	14	25.0	19.3	16.3	16.7	19.3	Irrad.	0.080	1.90
	Mean	21.7	18.7	17.0	16.8		Day x Irrad.	0.203	2.69
Beta-carotene (µg/100g)	1	180.0	196.7	210.0	196.7	195.8 b	Day	<0.001	18.18
	14	303.3	336.7	310.0	298.0	312.0a	Irrad.	0.758	25.71
	Mean	241.7	266.7	260.0	247.3		Day x Irrad.	0.841	36.36
Total sugars (g/100g)	1	2.93	2.90	2.97	2.90	2.92a	Day	0.042	0.060
	14	2.87	2.70	2.70	2.90	2.79 b	Irrad.	0.566	0.084
	Mean	2.90	2.80	2.83	2.90		Day x Irrad.	0.405	0.119

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

18

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Fructose (g/100g)	1	1.57	1.53	1.60	1.53	1.56	Day	0.169	0.029
	14	1.53	1.47	1.53	1.53	1.52	Irrad.	0.428	0.041
	Mean	1.55	1.50	1.57	1.53		Day x Irrad.	0.818	0.057
Glucose (g/100g)	1	1.37	1.37	1.40	1.37	1.37a	Day	0.016	0.040
	14	1.30	1.23	1.20	1.33	1.27 b	Irrad.	0.758	0.056
	Mean	1.33	1.30	1.30	1.35		Day x Irrad.	0.482	0.079
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.10	0.17	0.20	0.20	0.17 b	Day	0.018	0.040
	14	0.33	0.40	0.20	0.17	0.28a	Irrad.	0.350	0.057
	Mean	0.22	0.28	0.20	0.18		Day x Irrad.	0.055	0.080
Mono- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Energy was the only component that showed a significant time by dose interaction in tomato. No significant differences were found over time for 0Gy, 150Gy and 600Gy samples, but a significant decrease in energy was observed for 1000Gy. However, no dose was significantly different to the control within each time.

Table 4 also presents results where the interaction of time and dose was not significant but there was a significant main effect of time. Significant main effect of time was found for beta-carotene, carbohydrates, moisture, fat, total sugars and glucose.

Mean beta-carotene increased from 195.8µg/100g to 312.0µg/100g after 14 days cold storage at 10°C.

Control and irradiated tomato showed a mean of 3.24g/100g carbohydrate before storage which reduced to 2.99g/100g after 14 days of storage at 10°C.

Tomato fruit contain slightly higher amounts of free fructose to glucose and sucrose was below the detection level. These levels remained unchanged or slightly declined with storage and were not affected by low dose irradiation (Table 4). Mean total sugars decreased from 2.92g/100 g to 2.79g/100g after 14 days cold storage and mean glucose also reduced from 1.37g/100g to 1.27g/100g.

On the other hand, there was a significant increase in the moisture content from 94.30g/100g to 94.76g/100g and mean fat increased from 0.17g/100g to 0.28g/100g.

Ripening in tomato harvested when mature is accompanied by a rapid rise in respiration rate, followed by a slowing down as the fruit ripens and develops good eating quality. Ripeness is followed by senescence and breakdown of the fruit, which is the normal aging of produce. These changes in mean values are thought to be responses from general fruit senescence.

2.4.3 Capsicum

Medium dark green, firm, blocky capsicum fruit, variety 'Plato' were treated on 1 March 2011. The samples were analysed on two occasions; the first analysis (Time 1) one day after irradiation treatment and the second analysis (Time 2) after 21 days storage in a cold room set at 8°C.

Overall, there was no significant effect of dose on all the nutritional components in capsicum one day after irradiation (Table 5). Irradiation had no significant effects on ash, carbohydrates, dietary fibre, energy, fat profile, moisture, sodium, protein, total sugar, fructose, glucose, Vitamin C (ascorbic acid) and beta-carotene.

A significant dose effect at Time 2 was found for moisture, poly-unsaturated fat and fructose after 21 days in cold storage (Table 6). For moisture, the mean after exposure to 1000Gy (93.97g/100g) was significantly lower than the control mean (94.30mg/100g). The mean poly-unsaturated fat content was significantly lower after exposure to 150Gy compared to 600Gy and 1000Gy, but no irradiation treatments were significantly different to the control mean.

Mean Vitamin C (ascorbic acid) in the control sample was 82.7mg/100g one day after irradiation while mean Vitamin C (ascorbic acid) in the irradiated samples ranged between 61.0-76.3mg/100g (Table 5). This decrease in mean Vitamin C in the irradiated samples is not significantly different to the control sample.

Table 7 shows the means for the time by dose interactions for capsicum. Significant interactions were found for carbohydrates, energy, moisture, sodium, total sugars, fructose and glucose. In each case a significant difference was found between the controls at Time 1 and Time 2, but no significant difference was found between the 1000Gy measurements at Time 1 and Time 2. This suggests the mean level of these compounds changed significantly for untreated fruit after storage, but not for capsicums treated with a "higher" dose.

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

20

Table 5. Mean chemical measurements in 'Plato' capsicum after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.37 (0.058)	0.50 (0.100)	0.47 (0.058)	0.50 (0.000)	0.181	0.059
Carbohydrates (g/100g)	3.43 (0.115)	3.30 (0.200)	3.33 (0.058)	3.20 (0.100)	0.339	0.116
Dietary fibre (g/100g)	1.60 (0.100)	1.57 (0.208)	1.57 (0.115)	1.43 (0.058)	0.322	0.087
Energy (kJ/100g)	95.3 (3.06)	91.7 (4.16)	92.7 (1.53)	88.0 (3.00)	0.089	2.29
Moisture (g/100g)	93.43 (0.208)	93.47 (0.379)	93.50 (0.200)	93.77 (0.252)	0.370	0.193
Protein (g/100g)	0.97 (0.058)	0.93 (0.058)	0.87 (0.115)	0.87 (0.058)	0.362	0.062
Sodium (mg/100g)	8.3 (2.89)	16.7 (2.89)	16.7 (2.89)	15.0 (5.00)	0.070	2.81
Fat (g/100g)	0.200 (0.0000)	0.200 (0.0000)	0.220 (0.0346)	0.203 (0.0058)	0.517	0.0147
Mono-unsaturated fat (g/100g)	C	C	C	C		
<i>Poly-unsaturated fat</i> (g/100g)	0.10 (0.000)	0.13 (0.058)	0.12 (0.073)	0.10 (0.000)	0.795	0.039
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	2.93 (0.058)	2.83 (0.115)	2.73 (0.153)	2.60 (0.200)	0.122	0.118
Fructose (g/100g)	1.43 (0.058)	1.40 (0.000)	1.40 (0.100)	1.30 (0.100)	0.349	0.071
Glucose (g/100g)	1.47 (0.058)	1.40 (0.100)	1.37 (0.058)	1.30 (0.100)	0.204	0.068
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	82.7 (35.80)	61.0 (26.85)	62.7 (11.59)	76.3 (0.58)	0.701	21.26
Beta-carotene (µg/100g)	62.0 (19.93)	47.7 (15.28)	48.7 (25.15)	52.0 (17.69)	0.831	17.17

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 6. Mean chemical measurements in untreated and irradiated 'Plato' capsicum after 21 days cold storage at 8°C (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.40 (0.000)	0.40 (0.000)	0.30 (0.100)	0.37 (0.058)	0.216	0.047
Carbohydrates (g/100g)	2.90 (0.100)	3.07 (0.153)	3.00 (0.200)	3.23 (0.153)	0.218	0.141
Dietary fibre (g/100g)	1.27 (0.153)	1.27 (0.058)	1.23 (0.208)	1.27 (0.058)	0.990	0.122
Energy (kJ/100g)	82.7 (3.51)	84.3 (0.58)	86.3 (2.08)	89.7 (5.13)	0.123	2.50
Moisture (g/100g)	94.30a (0.100)	94.20ab (0.100)	94.40a (0.173)	93.97b (0.208)	0.046	0.118
Protein (g/100g)	0.90 (0.000)	0.80 (0.000)	0.83 (0.058)	0.87 (0.058)	0.070	0.030
Sodium (mg/100g) #	18.9 (8.66)	7.3 (3.55)	11.4 (2.89)	11.4 (2.89)	0.122	0.14
Fat (g/100g)	0.243 (0.0351)	0.230 (0.0265)	0.267 (0.0208)	0.270 (0.0361)	0.477	0.0279
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	0.16ab (0.067)	0.10 b (0.000)	0.20a (0.000)	0.20a (0.000)	0.032	0.028
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	1.73 (0.306)	2.37 (0.058)	2.10 (0.608)	2.70 (0.173)	0.057	0.275
Fructose (g/100g)	0.83 c (0.208)	1.27ab (0.058)	1.13 bc (0.379)	1.53a (0.058)	0.022	0.156
Glucose (g/100g)	0.90 (0.100)	1.10 (0.000)	0.97 (0.231)	1.23 (0.058)	0.070	0.105
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	127.7 (39.94)	97.0 (1.73)	109.3 (30.67)	132.0 (21.07)	0.449	22.86
Beta-carotene (µg/100g)	143.3 (15.28)	136.7 (15.28)	130.0 (20.00)	130.0 (10.00)	0.718	13.26

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different ($p > 0.05$).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Analysed on the \log_{10} scale. Reported means are back-transformed. SED is on the \log_{10} scale.

Table 7. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) capsicum, variety 'Plato' before storage and after 14 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Ash (g/100g)	1	0.37	0.50	0.47	0.50	0.46a	Day	0.003	0.025
	14	0.40	0.40	0.30	0.37	0.37 b	Irrad.	0.178	0.035
	Mean	0.38	0.45	0.38	0.43		Day x Irrad.	0.062	0.050
Carbohydrates (g/100g)	1	3.43a	3.30ab	3.33a	3.20abc	3.32a	Day	<0.001	0.061
	14	2.90 d	3.07 bcd	3.00 cd	3.23abc	3.05 b	Irrad.	0.929	0.087
	Mean	3.17	3.18	3.17	3.22		Day x Irrad.	0.038	0.123
Dietary fibre (g/100g)	1	1.60	1.57	1.57	1.43	1.54a	Day	<0.001	0.056
	14	1.27	1.27	1.23	1.27	1.26 b	Irrad.	0.747	0.079
	Mean	1.43	1.42	1.40	1.35		Day x Irrad.	0.688	0.112
Energy (kJ/100g)	1	95.3a	91.7abc	92.7ab	88.0 bcde	91.9a	Day	<0.001	1.35
	14	82.7 e	84.3 de	86.3 cde	89.7abcd	85.8 b	Irrad.	0.885	1.91
	Mean	89.0	88.0	89.5	88.8		Day x Irrad.	0.017	2.70
Moisture (g/100g)	1	93.43 d	93.47 d	93.50 d	93.77 cd	93.54 b	Day	<0.001	0.088
	14	94.30ab	94.20ab	94.40a	93.97 bc	94.22a	Irrad.	0.813	0.126
	Mean	93.87	93.83	93.95	93.87		Day x Irrad.	0.049	0.177
Protein (g/100g)	1	0.97	0.93	0.87	0.87	0.91a	Day	0.041	0.026
	14	0.90	0.80	0.83	0.87	0.85 b	Irrad.	0.157	0.037
	Mean	0.93	0.87	0.85	0.87		Day x Irrad.	0.346	0.052
Sodium (g/100g)	1	8.3 cd	16.7ab	16.7ab	15.0abc	14.2	Day	0.410	1.79
	14	20.0a	7.3 d	11.7 bcd	11.7 bcd	12.6	Irrad.	0.798	2.53
	Mean	14.2	12.0	14.2	13.3		Day x Irrad.	0.005	3.58
Vitamin C (ascorbic acid) (mg/100g)	1	82.7	61.0	62.7	76.3	70.7 b	Day	<0.001	10.31
	14	127.7	97.0	109.3	132.0	116.5a	Irrad.	0.230	14.59
	Mean	105.2	79.0	86.0	104.2		Day x Irrad.	0.926	20.63
Beta-carotene (µg/100g)	1	62.0	47.7	48.7	52.0	52.6 b	Day	<0.001	7.12
	14	143.3	136.7	130.0	130.0	135.0a	Irrad.	0.558	10.07
	Mean	102.7	92.2	89.3	91.0		Day x Irrad.	0.955	14.24
Total sugars (g/100g)	1	2.93a	2.83ab	2.73ab	2.60ab	2.77	Day	<0.001	0.111
	14	1.73 d	2.37 bc	2.10 cd	2.70ab	2.22	Irrad.	0.189	0.157
	Mean	2.33	2.60	2.42	2.65		Day x Irrad.	0.008	0.222

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

23

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Fructose (g/100g)	1	1.43a	1.40ab	1.40ab	1.30ab	1.38a	Day	0.012	0.066
	14	0.83 c	1.27ab	1.13 b	1.53a	1.19 b	Irrad.	0.052	0.093
	Mean	1.13	1.33	1.27	1.42		Day x Irrad.	0.005	0.132
Glucose (g/100g)	1	1.47a	1.40ab	1.37ab	1.30ab	1.38a	Day	<0.001	0.043
	14	0.90 e	1.10 cd	0.97 de	1.23 bc	1.05 b	Irrad.	0.314	0.061
	Mean	1.18	1.25	1.17	1.27		Day x Irrad.	0.008	0.086
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.20	0.20	0.22	0.20	0.21 b	Day	<0.001	0.011
	14	0.24	0.23	0.27	0.27	0.25a	Irrad.	0.252	0.015
	Mean	0.22	0.22	0.24	0.24		Day x Irrad.	0.681	0.021
Mono- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly- unsaturated fat (g/100g)	1	0.10	0.13	0.12	0.10	0.11 b	Day	0.010	0.017
	14	0.16	0.10	0.20	0.20	0.17a	Irrad.	0.274	0.024
	Mean	0.13	0.12	0.16	0.15		Day x Irrad.	0.067	0.034
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 7 also show instances where the interaction of time and dose was not significant, but there was a significant main effect of time.

After 21 days storage, mean dietary fibre, ash and protein were found to be lower while fat, polyunsaturated fat, beta-carotene and Vitamin C (ascorbic acid) increased.

In this study, Vitamin C (ascorbic acid) increased for all capsicum samples after storage. A significant effect of time was found for Vitamin C (ascorbic acid), increasing from a mean of 70.7mg/100g to 116.5g/100g after storage at 8°C for three weeks. The mean Vitamin C (ascorbic acid) in the control increased from 82.7mg/100g to 127.7mg/100g.

Mean beta-carotene ranged between 47.7-62.0µg/100g before storage and increased levels were observed across all irradiated samples (130.0-136.7µg/100g) and the control sample (143.3µg/100g) after three weeks storage (Tables 5 and 6). Mean beta-carotene in capsicum increased in storage from 52.6µg/100g to 135.0µg/100g, with the relative increase in irradiated samples being greater than in the control sample (Table 7).

Overall, our results show that green capsicum can tolerate up to 1000Gy irradiation without significant deterioration in nutritional content.

2.4.4 Zucchini

Green skin zucchini, variety 'Blackjack' were treated and analysed at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2), after seven days storage in a coldroom set at 8°C.

Irradiation at all test doses did not affect the nutritional quality of zucchini. The nutritional components of fresh whole zucchini were not negatively affected by low dose irradiation (150Gy, 600Gy and 1000Gy) compared with the control sample at one day after irradiation. The effects of irradiation dose on the components are summarised in Table 8.

No significant dose effects were found in ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars, Vitamin C (ascorbic acid) and beta-carotene one day after treatment (Table 8). Significant differences between doses however, were found after seven days for carbohydrates, dietary fibre and total sugars (Table 9). In all cases, the mean values were higher for the treated samples than the untreated control.

There were no significant differences in mean Vitamin C (ascorbic acid) levels detected between irradiated zucchini samples and the untreated control. At Time 1 mean Vitamin C (ascorbic acid) was 6.20mg/100g in the control sample compared to 12.60mg/100g, 8.90mg/100g and 8.37mg/100g in the 150Gy, 600Gy and 1000Gy samples, respectively (Table 8). After seven days storage, mean Vitamin C (ascorbic acid) was 7.03mg/100g for the control sample and the values varied between 8.53mg/100g and 11.13mg/100g in the irradiated zucchini samples.

Beta-carotene of the irradiated samples was not significantly different to the control sample just after treatment and after seven days in cold storage (Table 8 and Table 9). Time in storage however did affect these levels. In all cases, mean beta-carotene increased, with the greatest increase observed in the 150Gy sample (Table 10).

Dietary fibre was significantly higher after storage for doses 150, 600 and 1000Gy, and also higher for the control samples but not significantly so.

Table 10 presents results where the interaction of time and dose was significant. Significant interactions were found for dietary fibre, total sugars and fructose. The changes in means of total sugars and fructose were greater for the untreated fruit after storage than for treated zucchini.

Table 8. Mean chemical measurements in zucchini, variety 'Blackjack' after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.57 (0.115)	0.67 (0.058)	0.63 (0.058)	0.60 (0.100)	0.244	0.045
Carbohydrates (g/100g)	1.53 (0.208)	1.57 (0.058)	1.60 (0.100)	2.00 (0.557)	0.255	0.233
Dietary fibre (g/100g)	0.30 (0.100)	0.23 (0.058)	0.30 (0.100)	0.23 (0.058)	0.519	0.059
Energy (kJ/100g)	66.7 (5.86)	64.7 (2.52)	64.7 (3.22)	69.7 (7.37)	0.455	3.34
Moisture (g/100g)	95.73 (0.404)	95.87 (0.153)	95.93 (0.153)	95.63 (0.569)	0.498	0.201
Protein (g/100g)	1.33 (0.058)	1.20 (0.173)	1.13 (0.153)	1.07 (0.058)	0.094	0.087
Sodium (mg/100g)	25.0 (5.00)	25.0 (8.66)	31.7 (10.41)	26.7 (2.89)	0.739	6.80
Fat (g/100g)	0.43 (0.058)	0.43 (0.058)	0.43 (0.058)	0.43 (0.058)	1.000	0.041
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	0.20 (0.000)	0.20 (0.000)	0.17 (0.058)	0.27 (0.058)	0.138	0.036
Saturated fat (g/100g)	0.23 (0.058)	0.20 (0.000)	0.23 (0.058)	0.20 (0.000)	0.455	0.027
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	1.37 (0.058)	1.30 (0.200)	1.33 (0.115)	1.63 (0.231)	0.214	0.152
Fructose (g/100g)	0.77 (0.058)	0.70 (0.100)	0.73 (0.058)	0.87 (0.115)	0.256	0.077
Glucose (g/100g)	0.67 (0.058)	0.60 (0.100)	0.67 (0.058)	0.77 (0.115)	0.297	0.078
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	6.20 (8.404)	12.60 (2.816)	8.90 (2.326)	8.37 (1.210)	0.303	3.052
Beta-carotene (µg/100g)	216.7 (32.15)	200.0 (10.00)	200.0 (30.06)	146.7 (28.87)	0.140	26.28

Standard deviations are presented in brackets below each mean.

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 9. Mean chemical measurements in untreated and irradiated zucchini, variety 'Blackjack' after seven days (Time 2) cold storage at 8°C.

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.67 (0.058)	0.60 (0.000)	0.63 (0.058)	0.60 (0.000)	0.189	0.030
Carbohydrates (g/100g)	0.83 b (0.153)	1.30a (0.100)	1.13a (0.058)	1.10ab (0.173)	0.040	0.119
Dietary fibre (g/100g)	0.37 b (0.058)	0.37 b (0.058)	0.53a (0.058)	0.57a (0.058)	0.015	0.053
Energy (kJ/100g)	46.0 (4.36)	52.0 (2.65)	50.7 (3.22)	49.3 (3.51)	0.366	3.23
Moisture (g/100g)	96.53 (0.289)	96.27 (0.231)	96.23 (0.252)	96.27 (0.231)	0.539	0.222
Protein (g/100g)	1.57 (0.115)	1.37 (0.058)	1.37 (0.153)	1.30 (0.100)	0.129	0.097
Sodium (mg/100g)	18.3 (5.77)	41.7 (17.56)	30.0 (5.00)	31.7 (10.41)	0.237	9.91
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
<i>Total sugars</i> (g/100g)	0.41 b (0.165)	0.90a (0.173)	0.77a (0.115)	0.73a (0.115)	0.042	0.129
Fructose (g/100g)	0.30 (0.100)	0.53 (0.058)	0.43 (0.058)	0.47 (0.058)	0.055	0.065
Glucose (g/100g)	0.16 (0.123)	0.40 (0.100)	0.33 (0.058)	0.30 (0.100)	0.144	0.089
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	7.03 (9.419)	8.53 (2.470)	9.63 (1.124)	11.13 (3.308)	0.850	4.778
Beta-carotene (µg/100g)	230.0 (30.00)	310.0 (52.92)	226.7 (55.08)	176.7 (5.77)	0.062	37.74

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different ($p > 0.05$).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 10. Mean chemical measurements in untreated and irradiated zucchini (150Gy, 600Gy and 1000Gy), variety 'Blackjack' before storage (Time 1) and after seven days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Ash (g/100g)	1	0.57	0.67	0.63	0.60	0.62	Day	0.699	0.021
	14	0.67	0.60	0.63	0.60	0.62	Irrad.	0.644	0.030
	Mean	0.62	0.63	0.63	0.60		Day x Irrad.	0.090	0.042
Carbohydrates (g/100g)	1	1.53	1.57	1.60	2.00	1.67a	Day	<0.001	0.095
	14	0.83	1.30	1.13	1.10	1.09 b	Irrad.	0.095	0.135
	Mean	1.18	1.43	1.37	1.55		Day x Irrad.	0.149	0.191
Dietary fibre (g/100g)	1	0.30 bc	0.23 c	0.30 bc	0.23 c	0.27 b	Day	<0.001	0.027
	14	0.37 b	0.37 b	0.53a	0.57a	0.46a	Irrad.	0.028	0.039
	Mean	0.33 bc	0.30 c	0.42a	0.40ab		Day x Irrad.	0.020	0.055
Energy (kJ/100g)	1	66.7	64.7	67.7	69.7	66.4a	Day	<0.001	1.70
	14	46.0	52.0	50.7	49.3	49.5 b	Irrad.	0.624	2.41
	Mean	56.3	58.3	57.7	59.5		Day x Irrad.	0.257	3.41
Moisture (g/100g)	1	95.73	95.87	95.93	95.63	95.79 b	Day	<0.001	0.111
	14	96.53	96.27	96.23	96.27	96.33a	Irrad.	0.698	0.158
	Mean	96.13	96.07	96.08	95.95		Day x Irrad.	0.410	0.223
Protein (g/100g)	1	1.33	1.20	1.13	1.07	1.18 b	Day	<0.001	0.044
	14	1.57	1.37	1.37	1.30	1.40a	Irrad.	0.005	0.062
	Mean	1.45a	1.28 b	1.25 b	1.18 b		Day x Irrad.	0.930	0.087
Sodium (g/100g)	1	25.0	25.0	31.7	26.7	27.1	Day	0.421	4.02
	14	18.3	41.7	30.0	31.7	30.4	Irrad.	0.243	5.69
	Mean	21.7	33.3	30.8	29.2		Day x Irrad.	0.240	8.04
Vitamin C (ascorbic acid) (mg/100g)	1	6.20	12.60	8.90	8.37	9.02	Day	0.973	1.921
	14	7.03	8.53	9.63	11.13	9.08	Irrad.	0.519	2.716
	Mean	6.62	10.57	9.27	9.75		Day x Irrad.	0.641	3.841
Beta-carotene (µg/100g)	1	216.7	200.0	200.0	146.7	190.8 b	Day	0.010	15.09
	14	230.0	310.0	226.7	176.7	235.8a	Irrad.	0.005	21.34
	Mean	223.3a	255.0a	213.3a	161.7 b		Day x Irrad.	0.144	30.18
Total sugars (g/100g)	1	1.37 cd	1.30 c	1.33 c	1.63 d	1.41a	Day	<0.001	0.066
	14	0.41a	0.90 b	0.77 b	0.73 b	0.70 b	Irrad.	0.046	0.094
	Mean	0.89 b	1.10a	1.05ab	1.18a		Day x Irrad.	0.030	0.133

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

28

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Fructose (g/100g)	1	0.77ab	0.70 b	0.73ab	0.87a	0.77a	Day	<0.001	0.033
	14	0.30 d	0.53 c	0.43 cd	0.47 c	0.43 b	Irrad.	0.075	0.047
	Mean	0.53	0.62	0.58	0.67		Day x Irrad.	0.033	0.066
Glucose (g/100g)	1	0.67	0.60	0.67	0.77	0.68a	Day	<0.001	0.039
	14	0.17	0.40	0.33	0.30	0.30 b	Irrad.	0.247	0.056
	Mean	0.42	0.50	0.50	0.53		Day x Irrad.	0.067	0.078
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.43	0.43	0.43	0.43		Day		
	14	C	C	C	C		Irrad.	1.000	0.041
	Mean						Day x Irrad.		
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	0.20	0.20	0.17	0.27		Day		
	14	C	C	C	C		Irrad.	0.138	0.036
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	0.23	0.20	0.23	0.20		Day		
	14	C	C	C	C		Irrad.	0.455	0.027
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Mean carbohydrates ranged from 1.53-2.00g/100g before storage, decreasing to 0.83-1.30g/100g after seven days in storage. The decrease in carbohydrates was greater in the untreated zucchini sample. The control carbohydrates mean after seven days storage (0.83g/100g) was significantly lower than the means for 150Gy and 600Gy.

While there were no significant differences in mean total sugars between doses before storage (1.30-1.63g/100g), the mean total sugar content for the control (0.41g/100g) after seven days was found to be significantly lower than the means for all other doses (150Gy, 600Gy and 1000Gy). A significant main effect of time on total sugars was observed; decreasing from a mean of 1.41g/100g to 0.70g/100g (Table 10).

Storage time had a significant effect on carbohydrates, dietary fibre, energy, moisture, protein, beta-carotene and total sugars (both fructose and glucose decreased in storage). All components increased with storage except for carbohydrates, total sugars (both fructose and glucose) and energy.

2.4.5 Nectarine

White flesh, medium-large, rounded nectarine, variety 'Arctic Snow' were analysed at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 21 days storage in a coldroom set at 4°C.

Nectarine fruit investigated in this study were very firm. The skin surface was white with a red blush and a hint of green. Nectarine (like honeydew and rockmelon) can ripen in appearance but not in sweetness after picking. The samples were free from defects. The flesh was firm and white, some with a hint of green. Fruit are often delivered in the less mature stage for longer shelf life.

Irradiation had no significant effect on the majority of nutritional components in nectarine analysed in this study one day after treatment, except for fat, poly-unsaturated fat and sugar profile (fructose, glucose and sucrose) (Table 11). For fat, poly-unsaturated fat and sucrose the mean for the 1000Gy was significantly lower than the control dose (0Gy) and lower doses. On the other hand, mean glucose and fructose was significantly higher for fruit treated at 1000Gy than untreated nectarine and the lower doses.

After 21 days storage, no significant differences were detected in ash, carbohydrates, energy, dietary fibre, moisture, protein, fat, total sugars, glucose, sucrose and Vitamin C (ascorbic acid) between untreated nectarine and irradiated nectarine (Table 12). The censored values for mono-unsaturated fat, poly-unsaturated fat and trans fat are <0.1g/100g and < 0.5µg/100g for beta-carotene.

Mean sodium content in untreated nectarine (21.7mg/100g) was significantly lower than the 600Gy (40.0mg/100g) and 1000Gy (43.3mg/100g) irradiated nectarine (Table 12).

Mean fructose was significantly lower in the control fruit compared to all other doses (Table 12).

There was a significant time effect detected in Vitamin C (ascorbic acid). Untreated and treated nectarines contained 1.37-2.00mg/100g Vitamin C (ascorbic acid) before storage whereas after 21 days, increased values for Vitamin C (ascorbic acid) were detected (4.37-6.33mg/100g). However, no significant differences were detected between untreated and irradiated samples within each time.

Table 13 presents the analysis investigating the time by dose interaction using a 2-way ANOVA with time and dose as the main factors.

There was no time by dose interaction, main dose or time effect on total sugars but there were some changes in fructose, sucrose and glucose. Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher with irradiated nectarine after 21 days.

Table 11. Mean chemical measurements in nectarine, variety 'Arctic Snow' one day after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.50 (0.100)	0.50 (0.100)	0.43 (0.058)	0.50 (0.000)	0.538	0.053
Carbohydrates (g/100g)	10.17 (0.723)	10.20 (0.173)	9.97 (0.603)	9.60 (0.361)	0.351	0.339
Dietary fibre (g/100g)	1.67 (0.289)	1.73 (0.115)	1.70 (0.100)	1.57 (0.058)	0.673	0.139
Energy (kJ/100g)	222.3 (13.32)	216.7 (2.89)	214.0 (11.36)	201.1 (7.81)	0.077	6.54
Moisture (g/100g)	86.13 (1.026)	86.37 (0.208)	86.67 (0.777)	87.23 (0.416)	0.222	0.481
Protein (g/100g)	1.10 (0.436)	0.77 (0.058)	0.80 (0.100)	0.70 (0.100)	0.278	0.196
Sodium (mg/100g)	30.0 (8.66)	30.0 (5.00)	33.3 (7.64)	31.7 (7.64)	0.913	5.49
Fat (g/100g)	0.47a (0.058)	0.43a (0.058)	0.47a (0.058)	0.37 b (0.058)	0.016	0.024
Mono-unsaturated fat (g/100g)	C	C	C	C		
<i>Poly-unsaturated fat</i> (g/100g)	0.20a (0.000)	0.17a (0.058)	0.12ab (0.070)	0.05 b (0.043)	0.037	0.038
Saturated fat (g/100g)	0.23 (0.058)	0.20 (0.100)	0.30 (0.173)	0.27 (0.115)	0.742	0.093
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	8.33 (0.451)	8.37 (0.306)	8.43 (0.473)	7.80 (0.100)	0.212	0.290
Fructose (g/100g)	1.03 b (0.153)	1.00 b (0.000)	1.07 b (0.153)	1.50a (0.100)	0.001	0.073
Glucose (g/100g)	0.87 b (0.153)	0.83 b (0.058)	0.93 b (0.115)	1.20a (0.100)	0.005	0.065
Sucrose (g/100g)	6.40a (0.200)	6.53a (0.321)	6.43a (0.208)	5.17 b (0.115)	0.002	0.208
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	1.37 (0.252)	1.67 (0.306)	2.00 (0.854)	2.00 (0.656)	0.594	0.521
Beta-carotene (µg/100g)	C	C	C	C		

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different ($p > 0.05$).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 12. Mean chemical measurements in untreated and irradiated nectarine, variety 'Arctic Snow' after 21 days cold storage (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.50 (0.000)	0.53 (0.115)	0.57 (0.058)	0.53 (0.058)	0.714	0.056
Carbohydrates (g/100g)	9.93 (0.651)	9.90 (1.136)	9.17 (0.551)	9.67 (1.595)	0.842	0.956
Dietary fibre (g/100g)	1.70 (0.100)	1.67 (0.321)	1.57 (0.058)	1.53 (0.231)	0.619	0.141
Energy (kJ/100g)	196.3 (7.23)	199.7 (19.35)	188.7 (11.06)	194.3 (27.47)	0.907	15.44
Moisture (g/100g)	87.17 (0.462)	86.97 (1.210)	87.63 (0.611)	87.43 (1.858)	0.907	0.980
Protein (g/100g)	0.60 (0.346)	0.77 (0.153)	0.90 (0.100)	0.73 (0.058)	0.481	0.181
Sodium (mg/100g)	21.7 c (5.77)	28.3 bc (10.41)	40.0ab (5.00)	43.3a (2.89)	0.017	5.09
<i>Fat</i> (g/100g)	0.049 (0.0449)	0.133 (0.0252)	0.110 (0.0466)	0.118 (0.0598)	0.234	0.0380
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	8.13 (0.764)	8.80 (1.058)	8.37 (0.473)	8.40 (1.229)	0.887	0.856
Fructose (g/100g)	1.40 b (0.100)	1.90a (0.173)	1.80a (0.100)	1.83a (0.115)	0.010	0.103
Glucose (g/100g)	1.17 (0.153)	1.37 (0.153)	1.30 (0.000)	1.33 (0.115)	0.233	0.090
Sucrose (g/100g)	5.57 (0.757)	5.57 (0.907)	5.23 (0.321)	5.23 (1.097)	0.941	0.764
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	4.37 (0.945)	5.57 (1.823)	6.00 (2.138)	6.33 (1.106)	0.518	1.324
Beta-carotene (µg/100g)	C	C	C	C		

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different ($p>0.05$).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 13. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) nectarine, variety 'Arctic Snow' before storage (Time 1) and after 21 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Ash (g/100g)	1	0.50	0.50	0.43	0.50	0.48	Day	0.073	0.026
	14	0.50	0.53	0.57	0.53	0.53	Irrad.	0.935	0.036
	Mean	0.50	0.52	0.50	0.52		Day x Irrad.	0.328	0.052
Carbohydrates (g/100g)	1	10.17	10.20	9.97	9.60	9.98	Day	0.356	0.332
	14	9.93	9.90	9.17	9.67	9.67	Irrad.	0.614	0.469
	Mean	10.05	10.05	9.57	9.63		Day x Irrad.	0.830	0.664
Dietary fibre (g/100g)	1	1.67	1.73	1.70	1.57	1.67	Day	0.463	0.066
	14	1.70	1.67	1.57	1.53	1.62	Irrad.	0.408	0.094
	Mean	1.68	1.70	1.63	1.55		Day x Irrad.	0.843	0.133
Energy (kJ/100g)	1	222.3	216.7	214.0	201.0	213.5a	Day	0.004	5.50
	14	196.3	199.7	188.7	194.3	164.8 b	Irrad.	0.412	7.78
	Mean	209.3	208.2	201.3	197.7		Day x Irrad.	0.582	11.00
Moisture (g/100g)	1	86.13	86.37	86.67	87.23	86.60	Day	0.071	0.358
	14	87.17	86.97	87.63	87.43	87.30	Irrad.	0.462	0.506
	Mean	86.65	86.67	87.15	87.33		Day x Irrad.	0.834	0.716
Protein (g/100g)	1	1.10	0.77	0.80	0.70	0.84	Day	0.334	0.092
	14	0.60	0.77	0.90	0.73	0.75	Irrad.	0.678	0.129
	Mean	0.85	0.77	0.85	0.72		Day x Irrad.	0.126	0.183
Sodium (g/100g)	1	30.0	30.0	33.3	31.7	31.2	Day	0.421	2.51
	14	21.7	28.3	40.0	43.3	33.3	Irrad.	0.013	3.56
	Mean	25.8 c	29.2 bc	36.7ab	37.5a		Day x Irrad.	0.061	5.03
Vitamin C (ascorbic acid) (mg/100g)	1	1.37	1.67	2.00	2.00	1.76 b	Day	<0.001	0.497
	14	4.37	5.57	6.00	6.33	5.57a	Irrad.	0.297	0.702
	Mean	2.87	3.62	4.00	4.17		Day x Irrad.	0.804	0.993
Beta-carotene (µg/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Total sugars (g/100g)	1	8.33	8.37	8.43	7.80	8.23	Day	0.528	0.296
	14	8.13	8.80	8.37	8.40	8.43	Irrad.	0.689	0.419
	Mean	8.23	8.58	8.40	8.10		Day x Irrad.	0.739	0.592

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

33

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Fructose (g/100g)	1	1.03 c	1.00 c	1.07 c	1.50 b	1.15 b	Day	<0.001	0.043
	14	1.40 bc	1.90abc	1.80abc	1.83a	1.73a	Irrad.	<0.001	0.061
	Mean	1.22 c	1.45 b	1.43 b	1.67a		Day x Irrad.	<0.001	0.086
Glucose (g/100g)	1	0.87 c	0.83 c	0.93 c	1.20ab	0.96 b	Day	<0.001	0.039
	14	1.17 b	1.37a	1.30ab	1.33ab	1.29a	Irrad.	0.004	0.055
	Mean	1.02 b	1.10 b	1.12 b	1.27a		Day x Irrad.	0.021	0.078
Sucrose (kJ/100g)	1	6.40	6.53	6.43	5.17	6.13a	Day	0.014	0.261
	14	5.57	5.57	5.23	5.23	5.40 b	Irrad.	0.131	0.369
	Mean	5.98	6.05	5.83	5.20		Day x Irrad.	0.370	0.521
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.467abcd	0.433abc	0.467abcd	0.367 b	0.433a	Day	<0.001	0.0178
	14	0.051 d	0.133 c	0.107 cd	0.123 cd	0.104 b	Irrad.	0.325	0.0252
	Mean	0.259	0.283	0.287	0.245		Day x Irrad.	0.023	0.0357
Mono- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

2.4.6 Rockmelon

Round, firm, green skin rockmelon with brown netting, variety 'Triumph' were treated and analysed for nutritional components at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 14 days storage in a coldroom set at 7°C.

Rockmelon fruit appear to be able to tolerate up to 1000Gy irradiation without significant dose effects on the nutritional attributes investigated.

No significant dose effects were found at either Time 1 or Time 2 (Tables 14 and 15), where each time has been analysed separately. Irradiation had no significant effect on ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars and Vitamin C (ascorbic acid) either before storage or after cold storage for 14 days. The main effect of irradiation on beta-carotene could be considered marginally significant as it was just outside the 0.05 level of significance at Time 1.

Mean Vitamin C (ascorbic acid) ranged from 17.60-27.33mg/100g one day after irradiation treatment and between 17.80-23.07mg/100g after 14 days in storage. No significant dose effects were detected in beta-carotene in the control samples and the treated rockmelon fruit one day after irradiation treatment (986.7-1600.0µg/100g) and after 14 days storage (1026.7-1266.7µg/100g).

Only fructose showed a significant time by dose interaction (Table 16) however, the changes were variable with the control decreasing significantly after storage, 150Gy samples increasing significantly after storage, and 600Gy and 1000Gy showing no significant difference between Time 1 and Time 2.

Where the interaction of time and dose was not significant, a significant main effect of time was detected in ash, carbohydrates, sodium and glucose. Mean values for carbohydrates, glucose and sodium decreased with storage whereas there was a significant increase in ash.

2.4.7 Honeydew melon

Firm, smooth and white skin honeydew melon fruit, variety 'Galaxy' were treated and analysed for nutritional components at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 14 days storage in a coldroom set at 7°C.

There was a significant dose effect detected in beta-carotene and not in the other nutritional components measured at Time 1 (Table 17). In general, beta-carotene was lower in irradiated samples than in the control sample, being significantly lower to the control samples for 600Gy and 1000Gy samples.

Significant differences between the doses were found after 14 days in cold storage (Time 2) for protein, fructose and glucose (Table 18). For each of these components, the mean for dose 600Gy was higher.

Mean protein after 14 days was 0.40-0.57g/100 for the control, 150Gy and 1000Gy fruit and 0.67g/100g for the 600Gy irradiated fruit. No significant differences in protein were found between the control fruit and the treated samples.

One day after irradiation treatment, fructose ranged between 2.27-2.83g/100g while glucose was 2.13-2.60g/100g. After 14 days storage, fructose ranged between 2.57-2.77g/100g for the control, 150Gy and 1000Gy fruit and 3.37g/100g for the 600Gy irradiated fruit. Glucose ranged between 2.30-2.53g/100g for the control, 150Gy and 1000Gy fruit and 3.07g/100g for the 600Gy irradiated fruit.

No significant dose effect was detected in Vitamin C (ascorbic acid) at Time 1 and Time 2 between the irradiated samples and corresponding controls. Vitamin C (ascorbic acid) ranged between 11.90-16.90mg/100g one day after treatment. After 14 days in cold storage mean Vitamin C (ascorbic acid) ranged between 9.20-13.10mg/100g.

Table 14. Mean chemical measurements in rockmelon, variety 'Triumph' after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.60 (0.100)	0.63 (0.115)	0.60 (0.100)	0.63 (0.058)	0.919	0.068
Carbohydrates (g/100g)	5.40 (1.300)	4.03 (0.321)	4.27 (0.551)	4.40 (0.520)	0.255	0.644
Dietary fibre (g/100g)	0.40 (0.100)	0.43 (0.252)	0.37 (0.058)	0.37 (0.058)	0.931	0.119
Energy (kJ/100g)	110.7 (22.01)	91.3 (6.66)	92.3 (8.08)	95.0 (5.57)	0.303	10.36
Moisture (g/100g)	92.80 (1.400)	93.97 (0.462)	93.93 (0.493)	93.70 (0.436)	0.372	0.691
Protein (g/100g)	0.70 (0.100)	0.90 (0.200)	0.77 (0.252)	0.80 (0.200)	0.748	0.183
Sodium (mg/100g)	50.0 (21.79)	36.7 (20.21)	33.3 (11.55)	38.3 (7.64)	0.729	15.35
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	5.07 (1.358)	3.90 (0.458)	3.93 (0.462)	4.13 (0.473)	0.330	0.655
Fructose (g/100g)	2.53 (0.306)	1.97 (0.058)	2.17 (0.058)	2.23 (0.208)	0.083	0.174
Glucose (g/100g)	1.93 (0.651)	1.50 (0.100)	1.50 (0.100)	1.53 (0.208)	0.473	0.307
<i>Sucrose</i> (g/100g) #	0.51 (0.296)	0.36 (0.384)	0.29 (0.322)	0.33 (0.072)	0.734	0.220
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	26.97 (13.353)	27.33 (11.511)	21.73 (3.356)	17.60 (1.609)	0.563	7.604
Beta-carotene (µg/100g)	1333.3 (208.17)	1366.7 (208.17)	1600.0 (100.00)	986.7 (287.29)	0.051	165.04

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

Table 15. Mean chemical measurements in untreated and irradiated rockmelon, variety 'Triumph' after 14 days cold storage (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.90 (0.265)	0.77 (0.058)	0.73 (0.058)	0.77 (0.208)	0.683	0.145
Carbohydrates (g/100g)	4.00 (0.346)	4.23 (0.513)	3.97 (0.569)	3.47 (0.306)	0.369	0.407
Dietary fibre (g/100g)	0.53 (0.058)	0.40 (0.000)	0.37 (0.231)	0.43 (0.058)	0.527	0.112
Energy (kJ/100g)	91.7 (9.29)	94.3 (10.21)	86.7 (8.15)	82.0 (3.61)	0.407	7.25
Moisture (g/100g)	93.63 (0.723)	93.60 (0.529)	94.20 (0.458)	94.27 (0.058)	0.343	0.434
Protein (g/100g)	0.93 (0.208)	0.90 (0.100)	0.73 (0.115)	0.93 (0.115)	0.323	0.113
Sodium (mg/100g)	33.3 (15.28)	18.3 (5.77)	16.7 (12.58)	28.3 (18.93)	0.271	8.74
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	3.73 (0.586)	4.07 (0.551)	3.77 (0.252)	3.37 (0.153)	0.438	0.397
Fructose (g/100g)	2.07 (0.153)	2.30 (0.173)	2.07 (0.115)	2.00 (0.173)	0.245	0.138
Glucose (g/100g)	1.23 (0.115)	1.50 (0.173)	1.27 (0.058)	1.20 (0.173)	0.165	0.124
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	23.07 (3.661)	17.80 (2.800)	20.07 (1.793)	20.27 (5.358)	0.421	2.917
Beta-carotene (µg/100g)	1153.3 (323.32)	1266.7 (208.17)	1103.3 (167.43)	1026.7 (237.56)	0.729	212.93

Standard deviations are presented in brackets below each mean.

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 16. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) rockmelon, variety 'Triumph' before storage (Time 1) and after 14 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Ash (g/100g)	1	0.60	0.63	0.60	0.63	0.62 b	Day	0.008	0.057
	14	0.90	0.77	0.73	0.77	0.79a	Irrad.	0.778	0.080
	Mean	0.75	0.70	0.67	0.70		Day x Irrad.	0.663	0.113
Carbohydrates (g/100g)	1	5.40	4.03	4.27	4.40	4.52a	Day	0.036	0.263
	14	4.00	4.23	3.97	3.47	3.92 b	Irrad.	0.235	0.372
	Mean	4.70	4.13	4.12	3.93		Day x Irrad.	0.196	0.526
Dietary fibre (g/100g)	1	0.40	0.43	0.37	0.37	0.39	Day	0.477	0.057
	14	0.53	0.40	0.37	0.43	0.43	Irrad.	0.666	0.081
	Mean	0.47	0.42	0.37	0.40		Day x Irrad.	0.741	0.114
Energy (kJ/100g)	1	110.7	91.3	92.3	95.0	97.3	Day	0.072	4.45
	14	91.7	94.3	86.7	82.0	88.7	Irrad.	0.219	6.29
	Mean	101.2	92.8	89.5	88.5		Day x Irrad.	0.367	8.90
Moisture (g/100g)	1	92.80	93.97	93.93	93.70	93.60	Day	0.273	0.285
	14	93.63	93.60	94.20	94.27	93.92	Irrad.	0.193	0.403
	Mean	93.22	93.78	94.07	93.98		Day x Irrad.	0.505	0.570
Protein (g/100g)	1	0.70	0.90	0.77	0.80	0.79	Day	0.269	0.072
	14	0.93	0.90	0.73	0.93	0.87	Irrad.	0.508	0.102
	Mean	0.82	0.90	0.75	0.87		Day x Irrad.	0.555	0.145
Sodium (g/100g)	1	50.0	36.7	33.3	38.3	39.6a	Day	0.026	6.19
	14	33.3	18.3	16.7	28.3	24.2 b	Irrad.	0.276	8.76
	Mean	41.7	27.5	25.0	33.3		Day x Irrad.	0.965	12.39
Vitamin C (ascorbic acid) (mg/100g)	1	26.97	27.33	21.73	17.60	23.41	Day	0.311	2.954
	14	23.07	17.80	20.07	20.27	20.30	Irrad.	0.534	4.178
	Mean	25.02	22.57	20.90	18.93		Day x Irrad.	0.546	5.909
Beta-carotene (µg/100g)	1	1333.3	1366.7	1600.0	986.7	1321.7	Day	0.070	94.00
	14	1153.3	1266.7	1103.3	1026.7	1137.5	Irrad.	0.083	132.94
	Mean	1243.3	1316.7	1351.7	1006.7		Day x Irrad.	0.268	188.00
Total sugars (g/100g)	1	5.07	3.90	3.93	4.13	4.26	Day	0.069	0.266
	14	3.73	4.07	3.77	3.37	3.73	Irrad.	0.362	0.377
	Mean	4.40	3.98	3.85	3.75		Day x Irrad.	0.246	0.533

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

38

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Fructose (g/100g)	1	2.53a	1.97 c	2.17 bc	2.23abc	2.23	Day	0.140	0.075
	14	2.07 bc	2.30ab	2.07 bc	2.00 bc	2.11	Irrad.	0.275	0.105
	Mean	2.30	2.13	2.12	2.12		Day x Irrad.	0.014	0.149
Glucose (g/100g)	1	1.93	1.50	1.50	1.53	1.62a	Day	0.013	0.112
	14	1.23	1.50	1.27	1.20	1.30 b	Irrad.	0.496	0.158
	Mean	1.58	1.50	1.38	1.37		Day x Irrad.	0.214	0.224
Sucrose # (kJ/100g)	1	0.51	0.31	0.26	0.33	0.34	Day	0.415	0.181
	14	0.30	0.17	0.34	0.20	0.24	Irrad.	0.836	0.256
	Mean	0.39	0.23	0.30	0.26		Day x Irrad.	0.878	0.362
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Mono- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

Table 17. Mean chemical measurements in honeydew melon, variety 'Galaxy' after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.33 (0.058)	0.40 (0.000)	0.37 (0.115)	0.30 (0.100)	0.507	0.065
Carbohydrates (g/100g)	6.10 (1.375)	5.63 (0.351)	6.73 (1.704)	5.67 (1.940)	0.767	1.166
<i>Dietary fibre</i> (g/100g) #	0.19 (0.448)	0.20 (0.301)	0.25 (0.174)	0.20 (0.301)	0.970	0.294
Energy (kJ/100g)	116.7 (24.01)	108.7 (3.79)	130.0 (31.19)	108.7 (36.75)	0.727	21.23
Moisture (g/100g)	92.80 (1.323)	93.17 (0.153)	92.00 (2.107)	93.27 (2.146)	0.743	1.248
Protein (g/100g)	0.43 (0.153)	0.43 (0.058)	0.50 (0.265)	0.40 (0.265)	0.941	0.167
Sodium (mg/100g)	38.3 (17.56)	26.7 (2.89)	33.3 (2.89)	33.3 (14.43)	0.754	10.61
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	5.50 (1.179)	5.37 (0.351)	6.37 (1.716)	5.27 (1.940)	0.752	1.112
Fructose (g/100g)	2.43 (0.231)	2.57 (0.153)	2.83 (0.404)	2.27 (0.208)	0.233	0.246
Glucose (g/100g)	2.27 (0.252)	2.40 (0.200)	2.60 (0.265)	2.13 (0.252)	0.306	0.229
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	11.90 (3.176)	16.90 (3.381)	14.83 (4.430)	14.00 (1.997)	0.488	3.059
Beta-carotene (µg/100g)	17.0a (2.65)	16.0ab (1.00)	12.0c (1.73)	13.7bc (3.22)	0.027	1.27

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Analysed on the log₁₀ scale. Reported means are back-transformed. SED is on the log₁₀ scale.

Table 18. Mean chemical measurements in untreated and irradiated honeydew melon, variety 'Galaxy' after 14 days cold storage (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.60 (0.000)	0.40 (0.100)	0.57 (0.058)	0.53 (0.115)	0.085	0.065
Carbohydrates (g/100g)	7.30 (1.058)	5.57 (0.473)	8.33 (0.115)	6.83 (2.013)	0.159	1.033
Dietary fibre (g/100g)	0.17 (0.058)	0.33 (0.208)	0.27 (0.058)	0.27 (0.115)	0.455	0.097
Energy (kJ/100g)	138.3 (19.09)	107.7 (6.66)	159.0 (2.00)	129.0 (31.43)	0.108	16.97
Moisture (g/100g)	91.27 (1.210)	93.17 (0.306)	90.13 (0.208)	91.90 (1.931)	0.125	1.056
Protein (g/100g)	0.57ab (0.115)	0.40 b (0.000)	0.67a (0.058)	0.40 b (0.173)	0.024	0.072
Sodium (mg/100g)	33.3 (7.64)	21.7 (2.89)	26.7 (5.77)	25.0 (13.23)	0.315	5.73
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	7.10 (1.044)	5.30 (0.500)	8.13 (0.058)	6.30 (1.682)	0.095	0.923
Fructose (g/100g)	2.77 b (0.351)	2.77 b (0.153)	3.37a (0.153)	2.57 b (0.153)	0.032	0.201
Glucose (g/100g)	2.53 b (0.351)	2.50 b (0.200)	3.07a (0.115)	2.30 b (0.173)	0.050	0.213
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	12.87 (2.454)	7.33 (1.595)	9.20 (2.402)	13.10 (2.651)	0.062	1.939
<i>Beta-carotene</i> (µg/100g)	7.72 (0.075)	9.67 (2.082)	11.67 (2.887)	10.33 (2.309)	0.559	2.677

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different ($p > 0.05$).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Table 19 presents results of the interaction of dose and time. Significant time and dose interactions were detected in ash, Vitamin C (ascorbic acid) and beta-carotene. In each case, there was no significant main effect of dose.

Mean ash levels increased significantly with storage, except in the 150Gy sample where it remained unchanged. Mean ash content was 0.35g/100g at Time 1 and was 0.52g/100g at Time 2.

Mean Vitamin C (ascorbic acid) decreased significantly after 14 days storage for doses 150Gy and 600Gy, while no significant differences were found for the control samples and the 1000Gy samples.

In beta-carotene significant decreases were observed in the control sample and 150Gy honeydew melon sample. Overall, a fall in beta-carotene was observed with time in storage, from 14.7µg/100g to 9.9µg/100g.

Table 19 shows where the interaction of dose and time was not significant but there was a significant main effect of time and/or dose. There was a significant time of storage effect in total sugars and significant dose and time effects on fructose and glucose.

2.5 Discussion

The chemical measurements for each commodity at Time 1 (one day after mean irradiation treatment) and at Time 2 after receiving irradiation doses of 0Gy, 150Gy, 600Gy and 1000Gy were analysed. Time 2 is the number of days in cold storage; 7 days for zucchini, 14 days for tomato, rockmelon and honeydew melon; 21 days for nectarine and capsicum. All irradiation treatments were applied on three separate occasions, representing three replicate blocks.

The cultivars studied were: firm ripe tomato, variety 'Gourmet Swanson'; fresh green capsicum, variety 'Plato'; dark skin zucchini, variety 'Blackjack'; firm white flesh nectarine, variety 'Arctic Snow'; firm rockmelon, variety 'Triumph' and firm white skin honeydew melon, variety 'Galaxy'.

The nutritional profile analysed included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. Each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD). Time and dose interactions, at the four doses and measured on the two occasions were also investigated.

The results show that at Time 1, low dose irradiation ($\leq 1\text{kGy}$) had minor or no statistical effect on the range of nutritional and proximate components measured in tomato, capsicum, zucchini, nectarine and rockmelon. While each commodity responded differently when exposed to ionising low dose gamma (γ)-irradiation, overall, tomato, capsicum, zucchini, nectarine and rockmelon can tolerate low doses without significant negative effects on the nutritional measurements reported.

This was also found in an early study by Mitchell *et al.* (1992) where no loss in nutritional composition was found with zucchini irradiated at 300Gy.

Some of the Vitamin C (ascorbic acid) and beta-carotene levels detected in these varieties were different to published data and will be discussed further. In particular, no significant main effect of dose was detected in Vitamin C (ascorbic acid) in tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at Time 1. There was no main effect of dose detected in beta-carotene in tomato, capsicum, zucchini and rockmelon. Beta-carotene in nectarine was below the detection level ($< 0.5\mu\text{g}/100\text{g}$).

A significant dose effect in beta-carotene in honeydew melon, variety 'Galaxy' was detected at Time 1. Lower mean beta-carotene levels were found in the 600Gy and 1000Gy samples. However, after 14 days in cold storage the beta-carotene levels were higher, although not significantly so, in the 600Gy and 1000Gy samples than in the control and 150Gy honeydew samples.

Table 19. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) honeydew melon, variety 'Galaxy' before storage (Time 1) and after 14 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Ash (g/100g)	1	0.33 b	0.40 b	0.37 b	0.30 b	0.35 b	Day	<0.001	0.030
	14	0.60a	0.40 b	0.57a	0.53a	0.52a	Irrad.	0.315	0.043
	Mean	0.47	0.40	0.47	0.42		Day x Irrad.	0.032	0.060
Carbohydrates (g/100g)	1	6.10	5.63	6.73	5.67	6.03	Day	0.090	0.535
	14	7.30	5.57	8.33	6.83	7.01	Irrad.	0.121	0.756
	Mean	6.70	5.60	7.53	6.25		Day x Irrad.	0.717	1.069
Dietary fibre (g/100g)	1	0.24	0.23	0.27	0.23	0.24	Day	0.810	0.085
	14	0.17	0.33	0.27	0.27	0.26	Irrad.	0.833	0.121
	Mean	0.20	0.28	0.27	0.25		Day x Irrad.	0.839	0.171
Energy (kJ/100g)	1	116.7	108.7	130.0	108.7	116.0	Day	0.082	9.35
	14	138.3	107.7	159.0	129.0	133.5	Irrad.	0.086	13.23
	Mean	127.5	108.2	144.5	118.8		Day x Irrad.	0.704	18.71
Moisture (g/100g)	1	92.80	93.17	92.00	93.27	92.81	Day	0.053	0.563
	14	91.27	93.17	90.13	91.90	91.62	Irrad.	0.101	0.797
	Mean	92.03	93.17	91.07	92.58		Day x Irrad.	0.668	1.127
Protein (g/100g)	1	0.43	0.43	0.50	0.40	0.44	Day	0.335	0.067
	14	0.57	0.40	0.67	0.40	0.51	Irrad.	0.234	0.094
	Mean	0.50	0.42	0.58	0.40		Day x Irrad.	0.662	0.133
Sodium (g/100g)	1	38.3	26.7	33.3	33.3	32.9	Day	0.146	4.06
	14	33.3	21.7	26.7	25.0	26.7	Irrad.	0.287	5.74
	Mean	35.8	24.2	30.0	29.2		Day x Irrad.	0.989	8.12
Vitamin C (ascorbic acid) (mg/100g)	1	11.90abc	16.90a	14.83a	14.00ab	14.41a	Day	0.008	1.231
	14	12.87ab	7.33 c	9.20 bc	13.10ab	10.62 b	Irrad.	0.804	1.741
	Mean	12.38	12.12	12.02	13.55		Day x Irrad.	0.037	2.462
Beta-carotene (µg/100g)	1	17.0a	16.0ab	12.0 bod	13.7abc	14.7a	Day	<0.001	1.03
	14	7.8 d	9.7 cd	11.7 bod	10.3 cd	9.9b	Irrad.	0.902	1.46
	Mean	12.4	12.8	11.8	12.0		Day x Irrad.	0.048	2.07
Total sugars (g/100g)	1	5.50	5.37	6.37	5.27	5.62 b	Day	0.047	0.497
	14	7.10	5.30	8.13	6.30	6.71a	Irrad.	0.083	0.703
	Mean	6.30	5.33	7.25	5.78		Day x Irrad.	0.571	0.995

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

43

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs		
		0	150	600	1000		Factor	p-value	SED
Fructose (g/100g)	1	2.43	2.57	2.83	2.27	2.52 b	Day	0.006	0.105
	14	2.77	2.77	3.37	2.57	2.87a	Irrad.	0.003	0.149
	Mean	2.60 b	2.67 b	3.10a	2.42 b		Day x Irrad.	0.726	0.210
Glucose (g/100g)	1	2.27	2.40	2.60	2.13	2.35 b	Day	0.029	0.103
	14	2.53	2.50	3.07	2.30	2.60a	Irrad.	0.006	0.145
	Mean	2.40 b	2.45 b	2.83a	2.22 b		Day x Irrad.	0.621	0.205
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Mono- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly- unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

These components were analysed again at Time 2, after a recommended period of cold storage. No significant main effect of dose was found in the nutritional components in tomato and rockmelon after 14 days storage however, differences in response to the main effect of dose were detected for various components in capsicum, zucchini, nectarine and honeydew melon.

Overall after a period in cold storage, fresh ripe tomato, green capsicum, zucchini, nectarine and rockmelon tolerated low irradiation dose (≤ 1 kGy) without significant losses in nutritional composition. In particular, no significant main effect of dose was detected in Vitamin C (ascorbic acid) in tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at Time 2. There was no main effect of dose detected in beta-carotene in tomato, capsicum, zucchini, rockmelon and honeydew melon.

In nectarine, there was no interaction of time and dose, or main effect of dose or time on total sugars but there were some changes in fructose, sucrose and glucose. Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher with irradiated nectarine after 21 days. Wall (2007) observed these changes in bananas as dose increased to 800Gy and attributed these differences to an acceleration of sucrose hydrolysis in treated bananas.

Castell-Perez *et al.* (2004) found no significant effect on the sugars content of whole cantaloupe (rockmelon) fruits irradiated at 1000Gy but sugars content decreased significantly by the fourth day of storage at 10°C. They also reported no changes in beta-carotene content of whole cantaloupes over the storage period.

The effect of storage time was greater than by irradiation itself in many of these cases and the changes generally appeared to be associated with the ripening process during storage.

Although irradiation is known to destroy vitamins in pure and unadulterated systems, in food the damage may not be significant due the mutually protective action or shielding effect of various chemical constituents on each other (Diehl 1990).

The absorbed dose, commodity maturity and physiological state at harvest, pre and post handling, transportation, presence of microorganisms, storage environment and storage time all interact to affect product quality and shelf life. Different outcomes in nutritional quality after similar treatments can occur between different varieties of the same fruit, as noted by Thomas (1988) and Morris and Jessup (1994). It is a well-known fact that the nutritional components measured depends upon the degree of ripeness of the fruit, and quite different results would no doubt have been obtained had unripe or over-ripe fruits been analysed.

2.5.1 Vitamin C and beta-carotene

2.5.1.1 Tomato

In tomato, mean Vitamin C (ascorbic acid) in the control sample after irradiation was 18.3mg/100g while the means for the irradiated samples ranged between 17.0-18.0mg/100g. These figures are comparable with the reference data in the Food Standard Australia New Zealand (FSANZ) nutrient database of 18mg/100g (FSANZ, 2011 website) and 13.7mg/100g in the United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference (US Dept Agric, 2011 website). In the FSANZ database, Vitamin C refers to total Vitamin C activity: to ascorbic acid and dehydroascorbic acid while the USDA database refers to total ascorbic acid for red ripe tomato.

Fresh untreated tomato, variety 'Gourmet Swanson' had a mean of 180.0µg/100g of beta-carotene, the 150Gy and 1000Gy irradiated samples had means of 196.7µg/100g and the 600Gy tomato had a mean of 210.0µg/100g. The value recorded in the FSANZ nutrient database is 150µg/100g while the recorded beta-carotene value is 449µg/100g in the USDA database for year round average of red ripe tomatoes.

Time and dose interactions were not detected in Vitamin C (ascorbic acid) or beta-carotene in tomato however, a significant time effect was found in beta-carotene. There was an increase in mean beta-carotene from 195.8µg/100g to 312.0µg/100g after 14 days in cold storage at 8°C.

An increase in mean fat in tomato has no biological significance in this study although Heureux *et al.* (1993) found increasing electrolyte leakage or membrane permeability and fatty acid unsaturation of tomato during storage at 1°C. Yasia *et al.* (1987) studied the loss of firmness of tomatoes and linked this to the breakdown of pectic fractions at doses > 1000Gy.

2.5.1.2 Capsicum

In capsicum, irradiation had no significant effects on Vitamin C (ascorbic acid). The mean Vitamin C (ascorbic acid) in the control sample was 82.7mg/100g one day after irradiation compared to the reference data of 98mg/100g of total Vitamin C activity (ascorbic acid and dehydroascorbic acid) in the FSANZ nutrient database (FSANZ, 2011 website) and 80.4mg/100g total ascorbic acid in the USDA nutrient database (US Dept Agric, 2011 website). Topuz and Ozdemir (2007) reported values for Vitamin C of 63.1-64.9mg/100g in wet basis in two Turkish capsicum varieties.

An early study also showed that irradiation at low doses (≤ 300 Gy) had no significant effects on total Vitamin C (ascorbic acid plus dehydroascorbic acid), Vitamin C as dehydroascorbic acid or sugars in green capsicum shortly after irradiation or after storage at 5°C for 3.5 weeks (Mitchell *et al.* 1992).

In this study, Vitamin C (ascorbic acid) increased for all capsicum samples after storage. A significant effect of time was found for Vitamin C (ascorbic acid), increasing from a mean of 70.7mg/100g to 116.5g/100g after storage at 10°C for three weeks. The mean Vitamin C (ascorbic acid) in the control increased from 82.7mg/100g to 127.7mg/100g. Mitchell *et al.* (1992) also reported increasing total Vitamin C and dehydroascorbic acid with storage. In their study, total Vitamin C for untreated green capsicum increased from 56.5mg/100g to 83.8mg/100g and for dehydroascorbic acid, this increased from 7.7mg/100g to 10.0g/100g after storage at 5°C for 3.5 weeks.

The FSANZ nutrient database (FSANZ, 2011 website) records a mean of 161µg/100g for beta-carotene in green, raw capsicum whereas it is 208µg/100g in the USDA database (US Dept Agric, 2011 website). Our results for beta-carotene were much lower than these immediately at Time 1 (47.7-62.0µg/100g) and increased with storage (130.0-143.3µg/100g).

In a study with red capsicum, the beta-carotene levels were roughly four times higher (Mitchell *et al.* 1990) and increased slightly during three weeks storage at 5°C. The study also showed there was no significant effect of dose (≤ 300 Gy) in beta-carotene in red capsicum.

The increase in Vitamin C (ascorbic acid) and decrease in glucose and fructose found in green capsicum during storage appear to be metabolic events occurring during senescence in fruit. The ratio of fructose to glucose is nearly 1:1. The same results were observed in green capsicum treated at doses ≤ 300 Gy and stored at 5°C for 3.5 weeks (Mitchell *et al.* 1992).

This study supports the data previously established by other studies (Kader 1986; Mitchell *et al.* 1990, 1992). Kader (1986) in his list of relative tolerance of fresh fruit and vegetables to irradiation doses below 1000Gy indicated that tomato suffered minimal detrimental effects.

Although doses were lower, ≤ 300 Gy, in Mitchell *et al.*'s studies (1990, 1992), they reported parallel findings in beta-carotene and Vitamin C activity before and after storage for a period of 3-3.5 weeks. They also showed that time in storage had a greater effect on physio-chemical components in tomato and capsicum than irradiation. Ramamurthy *et al.* (2004) found small reductions in Vitamin C and carotenoids in capsicums at doses between 1000-3000Gy.

2.5.1.3 Zucchini

At Time 1 in zucchini, mean Vitamin C (ascorbic acid) ranged between 6.20-12.60mg/100g and at Time 2 ranged from 7.03-11.13mg/100g. The mean detected in the control sample at Time 1 was low (6.2mg/100g) compared with the reference data in the FSANZ Nutrient Database of 22mg/100g and 17.9mg/100g in the USDA Database.

Lee and Kader (2000) in their review indicated that preharvest and postharvest factors, such as genotypes, climatic conditions, cultural practices, maturity at harvest, harvesting method and postharvest handling can influence Vitamin C content of horticultural crops.

Fresh untreated zucchini contained a mean of 216.7µg/100g of beta-carotene at Time 1. The value recorded in the FSANZ nutrient database is 243µg/100g while the recorded beta-carotene value is 120µg/100g in the USDA database. While there was no time by dose interaction, there was an effect of dose and time in storage in the beta-carotene levels in zucchini.

2.5.1.4 Nectarine

At Time 1 mean Vitamin C (ascorbic acid) in the control nectarine sample (1.37mg/100g) was low compared with the reference data in the FSANZ Nutrient Database of 12mg/100g and 5.4mg/100g in the USDA Database. The irradiated samples ranged from 1.67-2.00mg/100g. There was no significant time and dose interaction but a significant time effect was detected. Mean Vitamin C (ascorbic acid) increased after 21 days in cold storage to 4.37mg/100g in the control and 5.57-6.33mg/100g in the irradiated samples.

The lower Vitamin C (ascorbic acid) may be that the nectarine variety tested was a late-season variety. In a study in grapefruit, Patil *et al.* (2004) found an interaction between harvest season and irradiation dose on production of bioactive compounds of grapefruit irradiated up to 700Gy. The study demonstrated that irradiation doses of up to 700Gy had no significant effect on Vitamin C content of early-season grapefruit while late season fruit showed lower Vitamin C when exposed to doses ≥ 200 Gy after 35 days storage. The authors indicated that this was a result of stress by irradiation above 200Gy, coupled with low temperature stress that may be harmful to the late season crop.

Data for beta-carotene in nectarine was below the detection level of 0.5µg/100g. The value recorded in the FSANZ nutrient database is 65µg/100g while the recorded beta-carotene value is 150µg/100g in the USDA Database.

The lower Vitamin C (ascorbic acid) and beta-carotene values observed in this study may be a result of the nectarine samples being immature. The study by Lester and Dunlap (1985) showed that the major compositional changes in developing and ripening in muskmelon were sucrose, glucose, fructose and beta-carotene; beta-carotene increased from 0.3% (w/w) at 10 days post-pollination to 2.7% (w/w) in 50-day old melons.

Similarly, in a study with tomato, the advance ripening rate of ethylene treated fruit was indicated by increased carotenoid concentrations as the fruit ripened (Boe and Salunkhe 1967).

2.5.1.5 Rockmelon

In this study, no significant dose effect, time or time and dose interaction were observed in Vitamin C (ascorbic acid) and beta-carotene in rockmelon, variety 'Triumph', although the effect of dose at Time 1 on beta-carotene could be considered marginally significant.

The Vitamin C (ascorbic acid) level in the control sample was 26.9 mg/100g compared with a Vitamin C value of 41mg/100g in the FSANZ Nutrient Database, 36.7mg/100g in the USDA Database.

Beaulieu and Lea (2007) found total Vitamin C (combined dehydroascorbic acid and ascorbic acid) in rockmelon peaked at 35 days after anthesis (47.3mg/100g) and started declining independent of fruit maturity. The loss was attributed to transport, handling and natural senescence.

Castell-Perez *et al.* (2004) reported no changes in beta-carotene content of whole cantaloupes over the storage period of 0, 4, 8 and 12 days at 10°C irradiated at 1000Gy.

Fresh untreated rockmelon contained a mean of 1333.3µg/100g of beta-carotene, the irradiated samples contained means of 986.7-1600.0µg/100g. The value recorded in the FSANZ nutrient database is 836µg/100g while the recorded beta-carotene value is 2020µg/100g in the USDA Database.

2.5.1.6 Honeydew melon

No significant main effect of dose was detected in Vitamin C (ascorbic acid) in Time 1 and Time 2. The control sample at Time 1 recorded a value of 11.90mg/100g compared with a value of 20mg/100g in the FSANZ Nutrient Database and 18.0mg/100g in the USDA Database. At Time 2, mean Vitamin C (ascorbic acid) for the control samples was 12.87mg/100g. A significant time and dose interaction was found. Mean vitamin C levels for doses 150 and 600Gy decreased significantly over time, while no significant changes were detected in the mean levels for the control samples and 1000Gy.

For beta-carotene, a significant main effect of dose was detected at Time 1 but not at Time 2. Our results for beta-carotene were lower than the FSANZ Nutrient Database and USDA Database record of 30µg/100g for beta-carotene. A significant time and dose interaction was detected. The mean beta-carotene levels decreased significantly after storage for the control samples and 150Gy. Decreases were also observed for 600 and 1000Gy but the decrease was not significant.

2.6 Recommendations

Tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon are potential fruit fly hosts and are subject by regulation to plant quarantine treatments against fruit fly and other regulated pests as a condition of entry and/or movement into certain plant quarantine jurisdictions. This applies to both domestic and international markets.

In this study, applications of gamma irradiation treatments of ≤ 1kGy can be considered as a phytosanitary method. While components in each commodity responded differently when exposed to ionising low dose gamma (γ)-irradiation the overall findings of this study suggest that an application of up to 1kGy will not induce any significant detrimental effects to the chemical and proximate components of tomato, green capsicum, zucchini, nectarine and rockmelon. Honeydew melon however, showed lower tolerance to doses > 600Gy with respect to beta-carotene content at Time 1. There were no treatments between 150Gy and 600Gy applied in this study. Treatment with 150Gy could be safely applied without inducing any deleterious effects in honeydew melon.

2.7 References

- Australia New Zealand Food Standards Code - Standard 1.5.3 - Irradiation of Food F2009C00895.
<http://www.comlaw.gov.au/Details/F2009C00895>
- Beaulieu JC and Lea JM (2007). Quality changes in cantaloupe during growth, maturation, and in stored fresh-cut cubes prepared from fruit harvested at various maturities. *J. Amer. Soc. Hort. Sci.* 133 (5): 720-728.
- Boe AA and Salunkhe DI (1967). Ripening tomatoes: ethylene, oxygen and light treatments. *Economic Botany* 21 (4): 312-319.
- Castell-Perez E, Moreno M, Rodriguez O and Moreira, RG (2004). Electron beam irradiation treatment of cantaloupes: effect on product quality. *Food Science and Technology International* 10 (6): 383-390.
- Diehl JF (1990). Safety of irradiated foods. 1st ed. New York: Marcel Dekker Inc. 196 p.

- Food Standards Australia New Zealand (FSANZ) (2011) website. Nutrient database for researchers and consumers. NUTTAB 2010 Online Searchable Database.
<http://www.foodstandards.gov.au/consumerinformation/nuttab2010/nuttab2010online searchabledatabase/onlineversion.cfm>
- Food Standards Australia New Zealand (FSANZ) (2011) website. Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements - F2010C00339.
<http://www.comlaw.gov.au/Details/F2010C00339>
- Heureux GP, Bergevin M, Thompson JE and Willemot C (1993). Molecular species profile of membrane lipids of tomato pericarp during chilling. *ACTA Horticulturae* 343: 286-287.
- ISPM No. 28. Phytosanitary treatment for regulated pests, International Standards for Phytosanitary Measures (2009). https://www.ippc.int/file_uploaded/1248880412026_ISPM_28_2009_E.doc
- Kader AA (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technol.* 40 (6): 117-121.
- Lee SK and Kader AA (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* 20: 207-220.
- Lester GE and Dunlap JR (1985). Physiological changes during development and ripening of 'Perlita' muskmelon fruits. *Scientia Horticulturae* 26 (4): 323-331.
- Mitchell GE, McLauchlan RL, Beattie TR, Banos C and Gillen AA (1990). Effect of gamma irradiation on the carotene content of mangos and red capsicums. *J. Food Science* 55 (4): 1185-1186.
- Mitchell GE, McLauchlan L, Isaacs AR, Williams DJ and Nottingham SM (1992). Effect of low dose irradiation on composition of tropical fruits and vegetables. *J. Food Composition and Analysis* 1992 (5): 291-311.
- Morris SC and Jessup AJ (1994). Irradiation. In: *Insect Pests and Fresh Horticultural Products: Treatments and responses*. (Editors: R.E. Paull and J.W. Armstrong). CABI International, Wallingford, UK, pp.163-190.
- Official Methods of Analysis of AOAC International (OMA) 18th Ed., AOAC International, Gaithersburg, MD, USA. Online <http://www.eoma.aoac.org/>
- Patil BS, Vanamala J and Hallman G (2004). Irradiation and storage influence on bioactive components and quality of early and late season 'Rio Red' grapefruit (*Citrus paradisi* Macf.). *Postharvest Biology and Technology* 34 (1): 53-64.
- Ramamurthy MS, Kamat A, Kakatkar A, Ghadge N, Bushan B and Alur NM (2004). Improvement of shelf-life and microbiological quality of minimally processed refrigerated capsicum by gamma irradiation. *Int. J. Food Sci. Nutr.* 55 (4): 291-299.
- Taylor J (1973). The analysis of designed experiments with censored observations. *Biometrics* 29: 35-43.
- Thomas P (1988). Radiation preservation of foods of plant origin. Part VI. Mushrooms, tomatoes, minor fruits and vegetables, dried fruits, and nuts. *CRC Critical Reviews Food Sci. Nutr.* 26 (4): 313-358.
- Topuz A and Ozdemir F (2007). Assessment of carotenoids, capsaicinoids and ascorbic acid composition of some selected pepper cultivars (*Capsicum annuum* L.) grown in Turkey. *J. Food Composition and Analysis* 20 (7): 596-602.
- USDA Agricultural Research Service (2011) National Nutrient Database for Standard Reference website <http://www.nal.usda.gov/fnic/foodcomp/search/>
- Wall MM (2007). Postharvest quality and ripening of Dwarf Brazilian bananas (*Musa* sp.) after x-ray irradiation quarantine treatment. *Hort Science* 42: 130-134.
- Yasia MS, Chachin K and Iwata T (1987). Effects of gamma irradiation on tissue firmness, some cell wall degrading enzymes and pectic substances of tomato fruit. *Bulletin of the Osaka Prefecture B39*: 9-20.

2.8 Appendix 1 – Irradiation reports



15 March 2011

Irradiation Report

ANSTO Reference	G11142
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]
Customer Reference	PO 4550047094

ANSTO Ref: G11142		SRT F 004	
Prepared	[REDACTED]	Authorised	[REDACTED]
		Date	16.3.11
[REDACTED]			

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

50

Product Details

Product	Capsicums and Tomatoes
Quantity	7, 10kg boxes Tomatoes 14, 8kg boxes Capsicums

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	28 February 2011 to 2 March 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Capsicum Approx. 8.3 Gy.min ⁻¹ & Tomatoes Approx. 7.9 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F219
Storage Conditions	Pre & post irradiation 10 °C
Irradiation temperature	22.7 to 24.5 °C

ANSTO Ref: G11142

SRT F 004

Prepared [REDACTED] Authorised [REDACTED] Date 18-3-11 Page 2 of 5

The samples of tomatoes and capsicums that were received for processing were repacked into cardboard boxes. The boxes for each produce were divided into four lots and identified for each target dose of 150, 600 & 1000 Gy.

A pair of dosimeters were sited on the outside of one box at the monitoring position, as per previous dose mapping (ANSTO Ref G11139). The boxes were positioned on a rig parallel to the plaque source for processing.

Results for Capsicums

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Capsicums R1&R2	144 ± 7	152 ± 7	148 ± 5
600	Capsicums R1&R2	560 ± 19	594 ± 19	577 ± 14
1000	Capsicums R1&R2	936 ± 23	993 ± 24	964 ± 17
150	Capsicums R3	146 ± 7	155 ± 7	151 ± 5
600	Capsicums R3	564 ± 19	599 ± 20	582 ± 14
1000	Capsicums R3	941 ± 23	999 ± 24	970 ± 17
150	Capsicums R4	146 ± 7	155 ± 7	150 ± 5
600	Capsicums R4	573 ± 20	609 ± 20	591 ± 14
1000	Capsicums R4	955 ± 24	1013 ± 24	984 ± 17

ANSTO Ref: G11142

SRT F 004

Prepared by [REDACTED] Authorised by [REDACTED] Date 18-3-11 Page 3 of 5

Results for Tomatoes

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Tomatoes R1&R2	148 ± 7	159 ± 8	154 ± 5
600	Tomatoes R1&R2	584 ± 21	628 ± 22	606 ± 15
1000	Tomatoes R1&R2	969 ± 25	1042 ± 26	1006 ± 18
150	Tomatoes R3	147 ± 7	158 ± 8	152 ± 5
600	Tomatoes R3	566 ± 20	609 ± 21	588 ± 15
1000	Tomatoes R3	953 ± 24	1026 ± 26	990 ± 18
150	Tomatoes R4	148 ± 7	159 ± 8	154 ± 5
600	Tomatoes R4	580 ± 20	624 ± 22	602 ± 15
1000	Tomatoes R4	964 ± 25	1037 ± 26	1001 ± 18

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

ANSTO Ref: G11142

SRT F 004

Prepared

Authorised

Date 18.3.11

Page 4 of 5

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: G11142		SRT F 004		
Prepared		Authorised		Date 13.3.11
Page 5 of 5				



Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

24 March 2011

Irradiation Report

ANSTO Reference	G11145
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]
Customer Reference	PO 4550047094

ANSTO Ref: G11145

SRT F 004

Prepared by
[REDACTED]

Authorised
[REDACTED]

Date 29.3.11

Page 1 of 6

Product Details

Product	Nectarines and Zucchini
Quantity	10 × 10 kg boxes Nectarines 9 × 10 kg boxes Zucchini

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	14 March 2011 to 16 March 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Nectarines Approx. 8.1 Gy.min ⁻¹ & Zucchini Approx. 7.8 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F219 & F220
Storage Conditions	Pre & post irradiation 10 °C
Irradiation temperature	23.3 to 24.0 °C

ANSTO Ref: G11145

SRT F 004

Prepared by [REDACTED] Authorised [REDACTED] Date 24-3-11 Page 2 of 6

The samples of nectarines and zucchinis that were received for processing were repacked into cardboard boxes. The boxes for each produce were divided into three lots and identified for each target dose of 150, 600 & 1000 Gy.

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited at the front, the back and in between nectarines and zucchinis. Additional dosimeters were attached to the outside of one box to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy samples from the first lot were used to carry out a dosemapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dosemapping repeated twice with dosimeters at those locations. This dosemapping information was used to process the remaining boxes of nectarines to their target doses. The dosemapping exercise was repeated for the zucchinis.



Figure 1: Boxes of nectarines and zucchinis for irradiation.

ANSTO Ref: G11145		SRT F 004	
Prepared	Authorised	Date 24-3-11	Page 3 of 6



Figure 2: Boxes positioned for irradiation.

Results for Nectarines

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Nectarines R1	145 ± 11	163 ± 13	154 ± 8
600	Nectarines R1	575 ± 7	645 ± 7	610 ± 5
1000	Nectarines R1	953 ± 32	1069 ± 38	1011 ± 25
150	Nectarines R2	139 ± 10	156 ± 12	148 ± 8
600	Nectarines R2	539 ± 29	604 ± 34	572 ± 23
1000	Nectarines R2	911 ± 36	1021 ± 42	966 ± 27
150	Nectarines R3	139 ± 10	155 ± 12	147 ± 8
600	Nectarines R3	545 ± 30	611 ± 35	578 ± 23
1000	Nectarines R3	910 ± 36	1020 ± 42	965 ± 28

ANSTO Ref: G11145

SRT F 004

Prepared

Authorised

Date

24-3-11

Page 4 of 6

Results for Zucchini

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Zucchini R1	145 ± 8	154 ± 7	150 ± 6
600	Zucchini R1	584 ± 7	617 ± 7	600 ± 5
1000	Zucchini R1	972 ± 26	1028 ± 22	1000 ± 17
150	Zucchini R2	148 ± 9	157 ± 8	152 ± 6
600	Zucchini R2	578 ± 24	612 ± 21	595 ± 16
1000	Zucchini R2	968 ± 29	1024 ± 26	996 ± 19
150	Zucchini R3	147 ± 9	155 ± 7	151 ± 6
600	Zucchini R3	576 ± 24	610 ± 21	593 ± 16
1000	Zucchini R3	965 ± 29	1021 ± 26	993 ± 20

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

ANSTO Ref: G11145

SRT F 004

Prepared [REDACTED] Authorised [REDACTED] Date 24.3.11 Page 5 of 6

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: G11145

SRT F 004

Prepared

Authorised

Date

24.2.11

Page 6 of 6



Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-6717 3441
F +61-2-6717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

31 March 2011

Irradiation Report

ANSTO Reference	G11146
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]
Customer Reference	PO 4550047094

ANSTO Ref: G11146

SRT F 004

Prepared [REDACTED]

Authorised [REDACTED]

Date 31-3-11

Page 1 of 6

Product Details

Product	Rockmelons (for dose mapping)
Quantity	6 boxes (8 melons/box)

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	22 March 2011 to 23 March 2011
Required Doses	N/A (dose mapping only)
Dosimeter Type	Fricke
Dosimeter Batch	F220

ANSTO Ref: G11146

SRT F 004

Prepared [REDACTED] Authorised [REDACTED] Date 31.3.11 Page 2 of 6

[REDACTED]

Six boxes each containing 8 rockmelons were received for dose mapping in preparation for targetted irradiations.

An initial experiment (Experiment A) looked at the dose distribution through three melons. Holes were bored into these melons of diameter sufficient to snugly fit a Fricke dosimeter container (approx. 15 mm diameter). Three dosimeters were placed inside each melon; one in the centre, and one behind and one in front through the flesh. These melons were placed in a box with other melons such that the dosimeters lined up with the source. The box was sited such that only one layer of melons faced the source. In this setup the melons were irradiated to approx. 200 Gy. The dosimeters were measured to determine depth dose profiles. This experiment was repeated with the irradiation interrupted to rotate the box 180° at 100 Gy and then irradiated for a further 100 Gy (Experiment B).

In a separate experiment (Experiment C), four boxes of melons were prepared for dose mapping. Dosimeters were sited on the front and back of every melon. A pair of dosimeters were attached to the outside of one melon to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source.

The rockmelons were irradiated to approximately 200 Gy. The locations of minimum and maximum doses were found and dose mapping repeated twice with dosimeters at those locations. Factors were then calculated that relate the dose at the monitoring position to the minimum and maximum doses.

ANSTO Ref: G11146		SRT F 004	
Prepared		Authorised	
		Date	31-3-11
			Page 3 of 6

Results – Experiment A (one-sided irradiation)

Displayed in Figure 1 is a plot of the average depth dose profiles measured in three rockmelons when each melon has been irradiated from one side. This result indicates approximately half of the gamma radiation intensity is attenuated through a rockmelon.

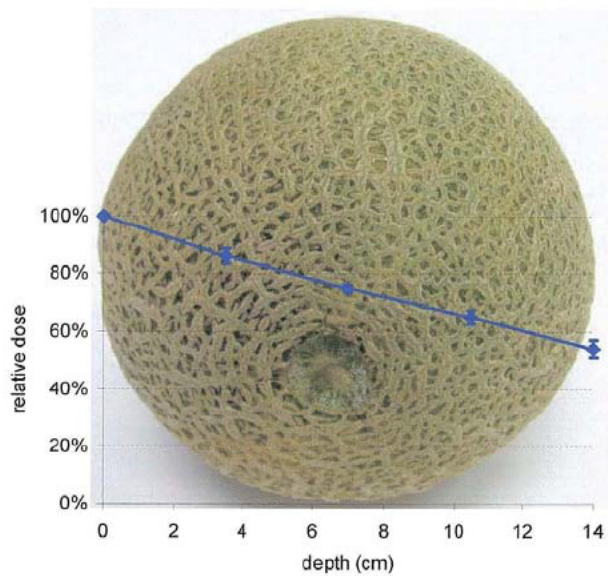


Figure 1: The average of three depth dose profiles from a one-sided irradiation (irradiated from the left-hand side). The doses are relative to the dose measured at the left-hand side. Error bars indicate the precision of the measurement (one standard deviation of three readings).

Results – Experiment B (two-sided irradiation)

Displayed in Figure 2 is a plot of the average depth dose profiles measured in three rockmelons when each melon has been irradiated approximately equally from both sides (i.e. the irradiation was interrupted at 100 Gy, the box of melons rotated 180°, and irradiated for a further 100 Gy). This result indicates that when the rockmelons are given a two-sided irradiation, the dose delivered inside is approximately the same as the outside (within measurement error).

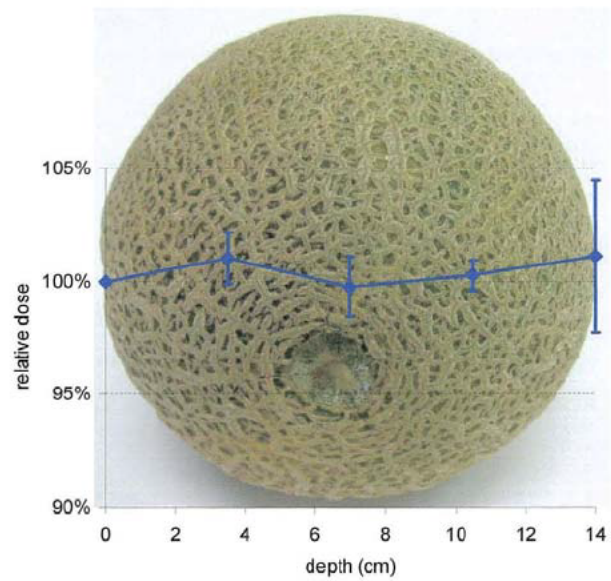


Figure 2: The average of three depth dose profiles from a two-sided irradiation. The doses are relative to the dose measured at the left-hand side. Error bars indicate the precision of the measurement (one standard deviation of three readings).

ANSTO Ref: G11146				SRT F 004	
Prepared		Authorised		Date 21-3-11	Page 5 of 6

Results – Experiment C (dose map)

The factors that relate the dose at the monitoring position to the minimum and maximum doses are the Minimum and Maximum Dose Factors, respectively. The Uniformity Ratio is the ratio of the maximum to minimum doses.

Minimum Dose Factor	0.925 ± 0.039
Maximum Dose Factor	1.014 ± 0.043
Uniformity Ratio	1.096 ± 0.066

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

This dose mapping information may be used in subsequent targeted irradiations.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: G11146		SRT F 004	
Prepared	Authorised	Date	31-3-11
		Page 6 of 6	



Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

23 May 2011

Irradiation Report

ANSTO Reference	G11160
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]
Customer Reference	4550047094

ANSTO Ref: G11160

SRT F 004

[REDACTED] Authorised [REDACTED] Date 23.5.11 Page 1 of 4

Product Details

Product	Honeydew & Rock Melons
Quantity	24, 13 kg boxes Honeydew Melons 24, 15 kg boxes Rock Melons

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	9 May 2011 to 10 May 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 7.5 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batch	F221
Storage Conditions	Pre & post irradiation 7 °C to 8 °C
Irradiation temperature	20.9 to 21.5 °C

ANSTO Ref: G11160

SRT F 004

Prepared

Authorised

Date 23.5.11

Page 2 of 4

The samples of Honeydew and Rock Melons that were received for processing were divided into **four** lots and identified for each target dose of 0 (control), 150, 600 & 1000 Gy.

A pair of dosimeters were sited on a melon inside one box at the pre-determined monitoring position, as per previous dose mapping (ANSTO Ref G11146). The boxes were positioned on a rig parallel to the plaque source for processing. The dose at each replicate represented an irradiation of two boxes of Honeydew and two boxes of Rock Melons.

Results for Honeydew & Rock Melons

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	139 ± 6	152 ± 7	145 ± 5
600	Replicate 1	553 ± 14	607 ± 16	580 ± 11
1000	Replicate 1	915 ± 22	1003 ± 24	959 ± 16
150	Replicate 2	143 ± 6	156 ± 7	150 ± 5
600	Replicate 2	570 ± 18	625 ± 20	598 ± 13
1000	Replicate 2	940 ± 22	1031 ± 24	985 ± 16
150	Replicate 3	144 ± 6	158 ± 7	151 ± 5
600	Replicate 3	561 ± 18	615 ± 20	588 ± 13
1000	Replicate 3	945 ± 22	1036 ± 24	991 ± 17

ANSTO Ref: G11160

SRT F 004

Prepared

Authorised

Date 23.5.11

Page 3 of 4

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref. G11160			SRT F 004	
Prepared	Authorised	Date	23.5.11	Page 4 of 4

2.9 Appendix 2 – Irradiation reports for beta-carotene analysis



3 August 2011

Irradiation Report

ANSTO Reference	11-1806
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]
Customer Reference	4550047974

ANSTO Ref: 11-1806

SRT F 004

Prepared [REDACTED]

Authorised [REDACTED]

Date 3.8.11

Page 1 of 4

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

71

Product Details

Product	Capsicums, Tomatoes & Zucchini
Quantity	12 Boxes Capsicums 12 Boxes Tomatoes 6 Boxes Zucchini

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	18 July 2011 to 19 July 2011
Required Doses	150, 600 & 1000 Gy
Dose rate	Capsicums Approx. 7.8 Gy.min ⁻¹ & Tomatoes & Zucchini Approx. 7.5 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F221
Storage Conditions	Pre & post irradiation 8 °C
Irradiation temperature	20.0 to 21.0 °C

Capsicums and tomatoes were repacked into 12 cardboard boxes, and zucchini into 6 cardboard boxes for processing. The boxes for each produce were divided into three lots and identified for each target dose of 150, 600 & 1000 Gy.

ANSTO Ref: 11-1806

SRT F 004

Prepared [REDACTED] Authorised [REDACTED] Date 3-8-11 Page 2 of 4

Dosimeters were sited in a position that provides reference to the minimum and maximum doses within the irradiated volume based on previous dose mapping (refer to G11139, G11142 & G11145). Two dosimeters were sited at the reference position. The product was then irradiated for a time expected to give the required dose.

Results

Tomatoes

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	147 ± 7	158 ± 8	153 ± 5
600	574 ± 20	618 ± 21	596 ± 15
1000	967 ± 24	1040 ± 25	1004 ± 17

Zucchini

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	148 ± 9	156 ± 8	152 ± 6
600	576 ± 24	609 ± 21	592 ± 16
1000	970 ± 28	1025 ± 25	998 ± 19

Capsicums

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	141 ± 7	150 ± 7	145 ± 5
600	558 ± 19	592 ± 19	575 ± 13
1000	977 ± 24	1038 ± 24	1007 ± 17

ANSTO Ref: 11-1806

SRT F 004

Prepared

Authorised

Date

3 - 8 - 11

Page 3 of 4

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimetry undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of
Radiation Technology, ANSTO.

ANSTO Ref: 11-1806

SRT F 004

Prepared by [Redacted]	Authorised by [Redacted]	Date 25.05.11	Page 4 of 4
---------------------------	-----------------------------	------------------	-------------



Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

9 August 2011

Irradiation Report

ANSTO Reference	11-1826
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]
Customer Reference	4550047974

ANSTO Ref 11-1826

SRT F 004

Prepared

Authorised

Date 9.8.11

Page 1 of 4

Product Details

Product	Honeydew & Rock Melons
Quantity	12 boxes Honeydew Melons 12 boxes Rock Melons

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	8 August 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 7.4 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batch	F222
Storage Conditions	Pre & post irradiation 7 °C to 8 °C
Irradiation temperature	21.2 to 22.7 °C

ANSTO Ref: 11-1826

SRT F 004

Prepared

Authorised

Date 7.8.11

Page 2 of 4

The samples of Honeydew and Rock Melons that were received for processing were divided into four lots and identified for each target dose of 0 (control), 150, 600 & 1000 Gy.

A pair of dosimeters was sited on one box at the pre-determined monitoring position, as per previous dose mapping (ANSTO Ref G11146). The boxes were positioned on a rig parallel to the plaque source for processing. Four boxes were sited on one side and two boxes on other side of the plaque source for each irradiation representing all three replicates for Honeydew and Rock Melons for each dose.

Results for Honeydew & Rock Melons

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	142 ± 6	156 ± 7	149 ± 5
600	556 ± 18	609 ± 19	582 ± 13
1000	935 ± 21	1026 ± 23	980 ± 16

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dose mapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

ANSTO Ref: 11-1826

SRT F 004

Prepared

Authorised

Date 7-8-11

Page 3 of 4

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: 11-1826

SRT F 004

Prepared

Authorised

Date

9.8.11

Page 4 of 4



Nuclear-based science benefiting all Australians

ANSTO – Radiation Technology
Building 23, New Illawarra Road, Lucas Heights NSW 2234, Australia
T +61-2-9717 3441
F +61-2-9717 9325
E radtech@ansto.gov.au
<http://www.ansto.gov.au>

20 April 2012

Irradiation Report

ANSTO Reference	12-2040 A (Apples) & B (Nectarines)
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	[REDACTED]

ANSTO Ref: 12-2040

SRT F 004

Prepared [REDACTED]

Authorised [REDACTED]

Date 26-4-12

Page 1 of 5

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

79

Product Details

Product	Red Delicious Apples and White Flesh Nectarines
Quantity	7 × boxes Apples 3 × 10kg boxes Nectarines

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	26 - 27 March 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 9.7 Gy.min ⁻¹
Dosimeter Type	Fricke
Dosimeter Batches	F228
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	23.0 to 24.0 °C

ANSTO Ref: 12-2040

SRT F 004

Prepared [REDACTED] Authorised [REDACTED] Date 26-4-12 Page 2 of 5

The apples and nectarines that were received for processing were repacked into boxes. The boxes for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited within the boxes at the front of apples and nectarines (Figure 1). Additional dosimeters were attached to the outside of one tray to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R2) samples from the first lot were used to carry out a dose mapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dose mapping repeated twice with dosimeters at those locations. This dose mapping information was used to process the remaining boxes of apples and nectarines to their target doses.

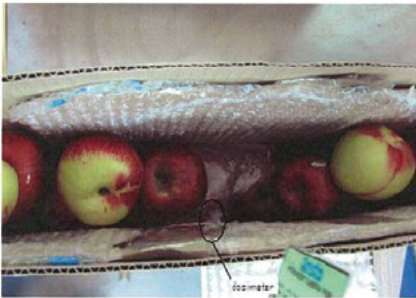


Figure 1: Dosimeter positioned on apple.

ANSTO Ref: 12-2040			SRT F 004	
Prepared		Authorised		Date 26-9-12
Page 3 of 5				



Figure 2: Boxes positioned for irradiation.

Results for Apples and Nectarines

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	143 ± 7	158 ± 7	151 ± 5
600	Replicate 1	573 ± 7	631 ± 7	602 ± 5
1000	Replicate 1	953 ± 21	1049 ± 21	1001 ± 15
150	Replicate 2	144 ± 7	158 ± 7	151 ± 5
600	Replicate 2	541 ± 18	595 ± 19	568 ± 13
1000	Replicate 2	921 ± 23	1014 ± 23	967 ± 16
150	Replicate 3	139 ± 7	153 ± 7	146 ± 5
600	Replicate 3	562 ± 19	618 ± 19	590 ± 14
1000	Replicate 3	937 ± 23	1032 ± 24	985 ± 17

ANSTO Ref: 12-2040

SRT F 004

Prepared

Authorised

Date 26-4-12

Page 4 of 5

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosimapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

This report shall not be reproduced except in full without the written approval of Radiation Technology, ANSTO.

ANSTO Ref: 12-2040

SRT F 004

Prepared

Authorised

Date 26.04.12

Page 5 of 5

3. Part B – Effect of gamma irradiation on postharvest quality of selected fruit commodities

3.1 Summary

Fruit quality evaluations were conducted on six commodities, comprising tomato, capsicum, nectarine, zucchini, honeydew and rockmelon, after being treated with gamma irradiation and following a recommended cold storage period of up to 21 days. For each commodity, treatments consisted of a gamma irradiation dose of 0Gy (control), 150Gy, 600Gy or 1000Gy applied sequentially on up to three sets of fruit with each representing a statistical replicate block. Fruit evaluations consisted of physico-chemical measurements conducted immediately after an irradiation treatment (within 24 hours), during and after removal from their recommended storage period.

For the majority of commodities tested, fruit quality was primarily impacted more by the effects of storage duration than that of irradiation per se. In this case, changes in skin and flesh colour, along with fruit softening and moisture loss rates were primarily associated with the typical senescence or ripening processes that can occur during storage. For some fruit, the use of high doses of irradiation (600-1000Gy) resulted in minor changes in quality, such as a slight increase in moisture loss and Brix levels in capsicum fruit, while in zucchini Brix levels decreased. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit.

Irradiation however had a significant impact on the quality of honeydew melon and to a lesser extent on nectarine fruit, although its effects were not expressed until the end of their recommended storage period. In both cases, the level of skin pitting and browning was related to the intensity of the dose, with initial symptoms first being expressed in nectarine and honeydew melon at 150Gy and 600Gy respectively. In nectarine, the disorder expressed at 150Gy was very low with only 3% of fruit exhibiting skin pitting/browning on < 1cm² of the total fruit surface area. At 1000Gy, this increased to 20% of fruit affected despite the severity remaining low. In contrast, treatment doses from 600-1000Gy in honeydew melon resulted in up to 86% of fruit expressing symptoms of pitting on 26% of their skin surface area.

In conclusion, the overall findings of the study suggest that an application of up to 1000Gy will not result in any detrimental damage to the quality of tomato, capsicum, zucchini or rockmelon fruit. In contrast, the quality of honeydew melon and to a lesser extent nectarine fruit showed little to no defects following a 150Gy irradiation dose. However, a dose of 600Gy or above would not be recommended for either produce type given the severity of irradiation damage expressed.

3.2 Introduction

The current study serves to compliment the nutritional component of this report, where the focus is primarily directed towards an examination of the effects of irradiation on fruit quality in tomato, capsicum, nectarine, zucchini, honeydew melon and rockmelon. The work was undertaken using a similar corresponding set of fruit as used in the nutritional study, which included the same postharvest irradiation treatments and subsequent storage duration conditions.

Fruit quality assessments in this study specifically entailed measurements of physico-chemical properties of each commodity, with evaluations conducted immediately (within 24 hours) after each irradiation event, and after a recommended cold storage period. The findings of this study are therefore anticipated to contribute to our overall understanding of the impact of relatively low to moderate doses of gamma irradiation (≤ 1000 Gy) on fruit storage life and on overall quality maintenance. The study will provide recommendations on the irradiation dose limits for ensuring product integrity.

3.3 Materials and methods

3.3.1 Experimental layout

Six fruit commodities (Table 1) were sourced from the Sydney Markets, NSW between February and May 2011. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where each commodity was irradiated over three sequential times (blocking factor) with target doses of 150Gy, 600Gy and 1000Gy. A corresponding set of untreated fruit (0Gy) served as a control group. For each fruit commodity, replication consisted of ten replicate fruit per block per irradiation treatment per assessment time (two times), except for both melons which consisted of five replicate fruit.

Following the irradiation treatment, each commodity was immediately transported by air to the DAFF postharvest laboratory in Cairns. Within 24 hours, a subset of fruit was destructively assessed for quality determination (Day 1) while a second subset was placed immediately into cold storage and, depending on the commodity type, stored for up to 21 days and then destructively assessed (Table 20). Over the storage period, fruit were also assessed for any visual defects and weighed at seven day intervals. Storage condition and duration for each commodity was based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2011). During storage, ambient conditions (air temperature and relative humidity) were also monitored to ensure they remained within the specifications of the trial.

Table 20. Description of fruit type and storage conditions applied in the present study.

Commodity	Variety	Storage temperature (°C)	Storage relative humidity (%)	Storage duration (days)
Tomato	'Gourmet Swanson'	10.0	90-95%	14
Capsicum (green)	'Plato'	7.5	> 95%	21
Zucchini	'Blackjack'	7.0	95%	7
Nectarine	'Arctic Snow'	1.0	90-95%	21
Honeydew melon	'Galaxy'	7.0	90-95%	14
Rockmelon	'Triumph'	7.0	85-90%	14

3.3.2 Fruit quality assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, skin and/or flesh colour, biochemical analyses (determination of soluble solids and titratable acidity), and record of the incidence and severity of disorders and disease types. Both fruit weight and disorder/disease measurements were recorded every seven days during the storage period. A description of each assessment method is described below.

3.3.2.1 Fruit colour

Fruit skin and/or flesh colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L*, C*, H° units). On some fruit types, an internal colour measurement was taken on the cut flesh surface taken from an equatorial transection of fruit.

3.3.2.2 Moisture loss and whole fruit softness

Fruit were weighed on each specified evaluation day. Percent moisture loss was calculated by determining the proportion of moisture lost from each assessment day compared to the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12mm spherical probe. Compression on the equatorial region of each fruit was undertaken using a rate of 20mm per minute until 2mm of fruit tissue was displaced, with results expressed in Newton (N).

3.3.2.2 Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were determined by destructively assessing a subset of fruit before and after their storage period. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

3.3.2.3 Fruit disorders and pathogens

The incidence and severity of physiological disorders and diseases were scored on individual fruit. Incidence was based on the proportion of fruit within a treatment expressing symptoms. A severity rating scale using a score from 0 to 5 was based on the surface area affected, where 0 = nil, 1 = < 1cm, 2 = 1-2cm, 3 = 2.1-3cm, 4 = 3.1cm to 25% and 5 = > 25%. A severity rating scale on the larger fruit, specifically both melon types, was based on the proportion (%) of surface area affected.

3.3.3 Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). For each crop, a general ANOVAs was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event for a given commodity. A significant result occurred when $p \leq 0.05$, and not significant findings were reported as "ns". Differences between treatment levels were determined using a least square difference (LSD) test at 5%.

3.4 Results

3.4.1 Tomato

The effects of irradiation and storage duration on tomato fruit quality attributes are summarised in Table 21. Over the storage period, tomato fruit firmness decreased significantly by 19% from 3.2N to 2.6N, although it still remained highly saleable in regards to overall fruit firmness. This was associated with an approximate 3% loss in moisture content of individual fruit over this period. The irradiation treatment however had no effect on either fruit firmness or on moisture loss rates.

Small, although significant, changes in tomato skin colour occurred over the 14 day storage period. These were primarily attributed to the time in storage and less so to the effects of irradiation. Skin colour, therefore, over this period transitioned to a slightly deeper shade of red. Visually, irradiation, therefore, had no detrimental effect on skin quality (Appendix 3).

TSS in tomato flesh remained relatively constant over the storage period, showing only a 0.1° difference from the mean (~4.9° Brix) across most of the irradiation levels. Percent citric acid was not affected by irradiation but did increase with storage time, equating to an average increase of 0.04% from an initial value of 0.39% (Day 0).

Table 21. Effect of irradiation dose and storage duration on tomato quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (10°C) for 14 days (Day 14).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVA	
		0	150	600	1000		Factor	p-value
Firmness (N)	1	3.3	3.2	3.1	3.0	3.2a	Day	<0.001
	14	2.8	2.5	2.6	2.5	2.6 b	Irrad.	ns
	Mean	3.1	2.9	2.9	2.8		Day x Irrad.	ns
Skin lightness	1	38.9	38.9	39.3	39.4	39.1a	Day	<0.001
	14	37.2	37.1	37.5	37.0	37.2 b	Irrad.	ns
	Mean	38.1	38.0	38.4	38.2		Day x Irrad.	ns
Skin chroma	1	34.0	32.7	34.0	33.8	33.6a	Day	<0.01
	14	36.1	34.9	35.7	33.6	35.1 b	Irrad.	ns
	Mean	35.1	33.8	34.8	33.7		Day x Irrad.	ns
Skin hue angle	1	44.2	45.7	44.69	45.7	45.0a	Day	<0.001
	14	43.0	43.4	43.20	43.2	43.2 b	Irrad.	<0.05
	Mean	43.6a	44.6 b	43.90ab	44.4 b		Day x Irrad.	ns
TSS (° Brix)	1	4.9	4.8	5.0	4.9	4.9	Day	ns
	14	4.9	4.7	4.9	4.9	4.9	Irrad.	<0.05
	Mean	4.9a	4.8 b	4.9a	4.9a		Day x Irrad.	ns
TA (% citric acid)	1	0.39	0.38	0.40	0.38	0.39 b	Day	<0.001
	14	0.44	0.44	0.43	0.42	0.43a	Irrad.	ns
	Mean	0.42	0.41	0.42	0.40		Day x Irrad.	ns

Means followed by the same letter are not significantly different.
ns = not significant

3.4.2 Capsicum

The effects of irradiation and storage duration on green capsicum quality attributes are summarised in Table 22. Both storage time and irradiation dose independently affected fruit firmness levels, resulting in fruit becoming softer (up to 1.6N) after 21 days of storage and with increasing doses of irradiation. Fruit softening was also associated with significantly higher rates of moisture loss rates in 1kGy treated fruit compared with all other treatments ($p < 0.05$) (Figure 3).

The development of red pigments in capsicum skin (degreening) was not affected by irradiation but did occur over the 21 storage period. Only a mean surface area of 2% per fruit expressed this red pigment. According to skin colour analyses, background green colour also changed as a result of storage time, showing only a slight shift towards a darker green shade by 21 days (Table 22). Fruit treated to 600Gy and above were also slightly darker than 0Gy and 150Gy treated fruit, although this was not visually detectable (Appendix 3).

Internal quality, such as TSS and TA levels, were both affected independently by storage time and irradiation dose (Table 22). TSS levels increased from 4.1° to 4.5° Brix over the 21 day storage period and between the 0Gy and 1kGy irradiation treatment. TA levels exhibited very small but significant changes over the storage period and between irradiation doses. Generally, TA levels decreased (by 0.02 to 0.13%) with storage time, whereas irradiation exposure resulted in a slight increase in TA levels (range 0.13 to 0.15%).

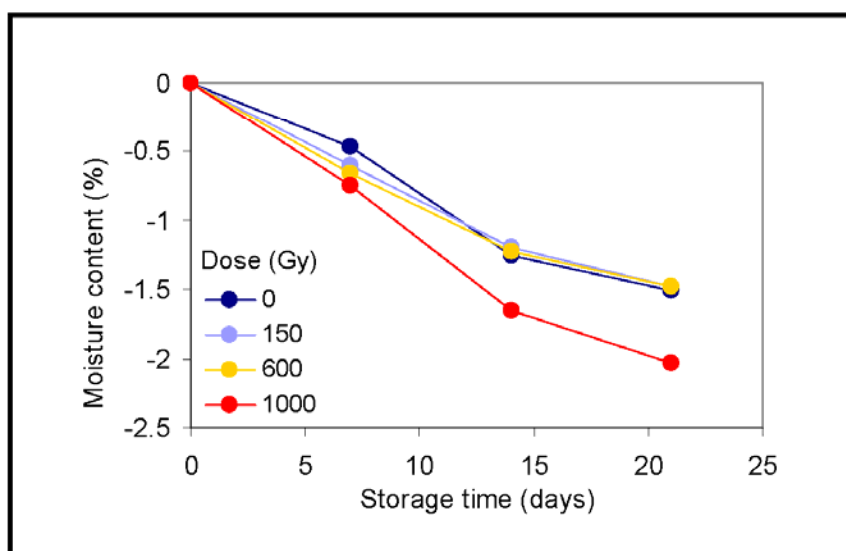


Figure 3. Effect of irradiation dose on fruit moisture content during cold (7.5°C) storage of green capsicum.

Table 22. Effect of irradiation dose and storage duration on green capsicum quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.5°C) for 21 days (Day 21).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVA	
		0	150	600	1000		Factor	p-value
Firmness (N)	1	7.9	7.1	6.6	5.8	6.9a	Day	<0.001
	14	5.8	5.6	5.2	4.8	5.3 b	Irrad.	<0.01
	Mean	6.9a	6.3ab	5.9 bc	5.3 c		Day x Irrad.	ns
Degreen (%)	1	1.0	0.3	0.0	0.3	0.4 b	Day	<0.001
	14	3.0	2.3	7.5	3.3	4.0a	Irrad.	ns
	Mean	2.0	1.3	3.8	1.8		Day x Irrad.	ns
Skin lightness	1	35.9	36.2	36.0	36.4	36.1a	Day	<0.001
	14	33.7	33.4	33.4	34.1	33.7 b	Irrad.	ns
	Mean	34.8	34.8	34.7	35.3		Day x Irrad.	ns
Skin chroma	1	16.2	16.8	17	17.1	16.8a	Day	<0.01
	14	14.9	14.3	14.6	15.2	14.7 b	Irrad.	ns
	Mean	15.5	15.5	15.8	16.2		Day x Irrad.	ns
Skin hue angle	1	129.5	128.2	127.7	128	128.4 b	Day	<0.01
	14	131	130.8	129.5	128.7	130.0a	Irrad.	<0.01
	Mean	130.2a	129.5ab	128.6 b	128.4 b		Day x Irrad.	ns
TSS (° Brix)	1	3.9	3.9	4.2	4.5	4.1 b	Day	<0.001
	14	4.3	4.5	4.6	4.5	4.5a	Irrad.	<0.05
	Mean	4.1 c	4.2 bc	4.4ab	4.5a		Day x Irrad.	ns
TA (% citric acid)	1	0.14	0.15	0.16	0.15	0.15a	Day	<0.001
	14	0.11	0.13	0.14	0.13	0.13 b	Irrad.	<0.001
	Mean	0.13 b	0.14a	0.15a	0.14a		Day x Irrad.	ns

Means followed by the same letter are not significantly different.
ns = not significant

3.4.3 Zucchini

Fruit moisture loss rates between treatments remained unchanged over the seven day storage duration, averaging a 3% loss over that period. Similarly, fruit firmness also remained relatively similar between treatments and evaluation dates (Table 23). Biochemically, TA was not affected by any treatments although fruit TSS increased significantly with storage time (from 2.8° to 3.5° Brix) although decreased with an irradiation dose above 600Gy (mean of 3.3° down to 2.7° Brix).

Zucchini colour properties changed over the seven day storage period, with the skin becoming a lighter green and the flesh a darker yellow colour with time (Table 23). Only small changes in internal flesh colour (chroma values) were attributed to the effects of irradiation, resulting in flesh tissue becoming slightly duller in colour by Day 7, particularly with doses at and above 600Gy. These changes however were not visually detectable (Appendix 3).

3.4.4 Nectarine

Changes in fruit colour properties are shown in Table 24. With exception to skin chroma values, irradiation and storage time had no effect on skin colour properties. Changes in chroma values were associated with a slight decrease in skin colour intensity, particularly in the control and the lowest dose treatment. Small changes in internal flesh colour also occurred, although storage time had more of an effect on colour properties than did the irradiation treatment itself. In this case, fruit flesh colour became a lighter yellow colour with time, with the colour becoming more intense with higher doses of irradiation (Appendix 3).

All fruit lost approximately 1.4% of their initial weight by the end of the 21 day storage period, although there was no effect of irradiation. There was also no significant difference in fruit firmness levels between irradiation doses or assessment times. Internal quality such as TSS and TA were also unaffected by the irradiation treatment, although storage time did affect fruit flavour. Over this period, TSS increased significantly from 11.4° to 12.3° Brix while TA decreased from 0.38 to 0.29% (Table 24).

The irradiation treatments resulted in fruit developing a mild form of pitting along with browning of the skin surface (Figure 4 and Table 24). This was expressed only after 21 days of storage, occurring in a small percentage of fruit (3%) at 150Gy although this increased significantly with higher doses with up to 20% of fruit affected at 1kGy. The severity of symptoms however was low with on average less than 1cm² of their surface area being affected.



Figure 4. Nectarine fruit with symptoms of irradiation damage following treatment to 1kGy occurring after 21 days in cold (1.0°C) storage. Symptoms consisted of mild pitting associated with browning on the skin surface.

Table 23. Effect of irradiation dose and storage duration on zucchini fruit quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for seven days (Day 7).

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Firmness (N)	1	7.1	8.0	8.2	8.1	7.8	Day	ns
	14	7.6	8.2	7.2	6.3	7.3	Irrad.	ns
	Mean	7.4	8.1	7.7	7.2		Day x Irrad.	ns
TSS (° Brix)	1	3.3	2.9	2.7	2.3	2.8 b	Day	<0.01
	14	3.6	3.7	3.6	3.1	3.5a	Irrad.	<0.05
	Mean	3.4a	3.3a	3.2a	2.7 b		Day x Irrad.	ns
TA (% citric acid)	1	0.15	0.16	0.17	0.17	0.16	Day	ns
	14	0.17	0.17	0.17	0.16	0.17	Irrad.	ns
	Mean	0.16	0.16	0.17	0.17		Day x Irrad.	ns
Skin lightness	1	28.1	28.2	27.5	27.2	27.7 b	Day	<0.05
	14	31.5	32.4	32.3	31.0	31.8a	Irrad.	ns
	Mean	29.8	30.3	29.9	29.1		Day x Irrad.	ns
Skin chroma	1	16.2	15.3	14.8	14.6	15.2 b	Day	<0.05
	14	17.0	18.6	18.3	16.7	17.6a	Irrad.	ns
	Mean	16.6	16.9	16.6	15.6		Day x Irrad.	ns
Skin hue angle	1	126.1	126.3	126.9	127	126.6a	Day	<0.05
	14	128.7	128.1	128.5	129	128.6 b	Irrad.	ns
	Mean	127.4	127.2	127.7	128.0		Day x Irrad.	ns
Flesh lightness	1	86.4	87.3	88.0	87.5	87.3a	Day	<0.05
	14	85.3	85.0	85.0	82.5	84.5 b	Irrad.	ns
	Mean	85.8	86.1	86.5	85.0		Day x Irrad.	ns
Flesh chroma	1	23.6a	22.2ab	20.0 bc	22.2ab	22.0	Day	ns
	14	22.1ab	23.1a	21.9abc	20.0 c	21.8	Irrad.	<0.05
	Mean	22.8a	22.6ab	21.0 c	21.1 bc		Day x Irrad.	<0.05
Flesh hue angle	1	102.3	105.5	105.8	104.9	105.4a	Day	<0.001
	14	104.4	103.9	103.8	103.4	103.9 b	Irrad.	ns
	Mean	104.8	104.7	104.8	104.2		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

91

Table 24. Effect of irradiation dose and storage duration on nectarine fruit quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (1.0°C) for 21 days (Day 21).

Variable	Day	Irradiation dose (Gy)					ANOVA	
		0	150	600	1000	Mean	Factor	p-value
Firmness (N)	1	6.4	5.8	6.4	6.1	6.2	Day	ns
	14	6.8	6.2	7.0	7.6	6.9	Irrad.	ns
	Mean	6.6	6.0	6.7	6.8		Day x Irrad.	ns
TSS (° Brix)	1	11.5	11.1	11.6	11.4	11.4 b	Day	<0.05
	14	12.3	12.3	12.6	12.2	12.3a	Irrad.	ns
	Mean	11.9	11.7	12.1	11.8		Day x Irrad.	ns
TA (% citric acid)	1	0.39	0.37	0.36	0.40	0.38a	Day	<0.001
	14	0.3	0.28	0.28	0.29	0.29 b	Irrad.	ns
	Mean	0.35	0.33	0.32	0.35		Day x Irrad.	ns
Skin lightness	1	79.8	79.5	78.5	77.9	78.9	Day	ns
	14	79.3	80.1	80.6	79.3	79.8	Irrad.	ns
	Mean	79.6	79.8	79.5	78.6		Day x Irrad.	ns
Skin chroma	1	29.8ab	30.3a	30.2a	30.5a	30.2	Day	<0.01
	14	26.0 c	28.4 b	30.0a	31.0a	28.8	Irrad.	<0.001
	Mean	27.9	29.3	30.1	30.8		Day x Irrad.	<0.01
Skin hue angle	1	100.1	98.9	92.4	91.4	95.7	Day	ns
	14	99.6	98.5	97.3	97.1	98.1	Irrad.	ns
	Mean	99.8	98.7	94.8	94.2		Day x Irrad.	ns
Flesh lightness	1	78.5	78.1	79.5	78.6	78.7 b	Day	<0.001
	14	79.4	79.8	80.1	80.2	79.9a	Irrad.	ns
	Mean	78.9	79.0	79.8	79.4		Day x Irrad.	ns
Flesh chroma	1	12.3 d	13.4 c	14.6 b	13.9 bc	13.6	Day	ns
	14	12.2 d	13.1 cd	14.5 b	15.9a	13.9	Irrad.	<0.001
	Mean	12.2 c	13.2 b	14.6a	14.9a		Day x Irrad.	<0.05
Flesh hue angle	1	88.1	87.2	93.2	91.2	89.9 b	Day	<0.05
	14	98.0	99.8	99.5	99.2	99.1a	Irrad.	<0.001
	Mean	93.0 b	93.5 b	96.3a	95.2ab		Day x Irrad.	ns

Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

92

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs	
		0	150	600	1000		Factor	p-value
Skin browning/ pitting incidence (%)	1	0 b	0.0 b	0.0 b	0.0 b	9.2a	Day	<0.05
	14	0 b	3.3 b	13.3ab	20.0a	0.0 b	Irrad.	<0.01
	Mean	0 b	1.7 b	6.7ab	10.0a		Day x Irrad.	<0.05
Skin browning/ pitting severity (0-5)	1	0	0.0	0.0	0.0	0.0 b	Day	<0.01
	14	0	0.1	0.4	0.4	0.2a	Irrad.	ns
	Mean	0	0.0	0.2	0.2		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

3.4.5 Rockmelon

The effects of irradiation and storage duration on rock melon quality attributes are summarised in Table 25. Rockmelon fruit became softer during storage but was unaffected by the irradiation treatment. By Day 14, fruit had lost approximately 5% of their initial mean fresh weight (1.7kg), although this was not influenced by the irradiation treatment. Aside from a few small spots of mould on the skin surface (Day 14), there was no affect of irradiation or storage time on the overall visual appearance of the fruit (Appendix 3), nor on the internal flesh colour. TSS and TA were also unaffected by any of the irradiation treatments, although storage time did result in a small but significant decline in Brix levels and a slight increase in citric acid levels.

3.4.6 Honeydew

In Table 26 the effects of irradiation and storage duration on honeydew melon quality attributes are presented. Honeydew melon fruit lost approximately 1.6% in fresh weight during the storage period, although no differences in firmness levels were detected between irradiation treatments and before or after storage. TSS and TA were also unaffected by any of the irradiation treatments, although did decline slightly during storage.

By the end of the 14 day storage period, some honeydew fruit treated with irradiation developed pitting on the skin surface (Table 26; Figure 5; Appendix 3). Those affected were 60% and 80% of fruit treated with 600Gy and 1kGy, respectively. The proportion of skin surface area affected was also associated with the intensity of the dose, increasing from 8% (600Gy) to 51% (1kGy).



Figure 5. Honeydew melon expressing symptoms of irradiation damage following treatment to 1kGy occurring after 14 days in cold (7.0°C) storage. Symptoms consisted of pitting and browning on the skin surface.

Table 25. Effect of irradiation dose and storage duration on rockmelon quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for 14 days (Day 14).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs	
		0	150	600	1000		Factor	p-value
Firmness (kg force)	1	21.9	18.3	17.3	18.8	19.1a	Day	<0.001
	14	14.1	15.1	15.4	15.4	15.0 b	Irrad.	ns
	Mean	18.0	16.7	16.4	17.1		Day x Irrad.	ns
Flesh lightness	1	67.8	68.7	68.2	68.9	68.4	Day	ns
	14	67.6	67.8	68.2	67.9	67.9	Irrad.	ns
	Mean	67.7	68.3	68.2	68.4		Day x Irrad.	ns
Flesh chroma	1	35.5	35.6	36.7	34.7	35.6	Day	ns
	14	35.7	36.1	36.0	36.4	36.1	Irrad.	ns
	Mean	35.6	35.9	36.4	35.6		Day x Irrad.	ns
Flesh hue angle	1	79.1	79.3	77.7	79.4	78.9	Day	ns
	14	77.9	77.7	78.0	78.1	77.9	Irrad.	ns
	Mean	78.5	78.5	77.9	78.7		Day x Irrad.	ns
TSS (° Brix)	1	7.7	7.5	7.1	7.7	7.5a	Day	<0.05
	14	6.7	7.1	7.1	7.0	7.0 b	Irrad.	ns
	Mean	7.2	7.3	7.1	7.3		Day x Irrad.	ns
TA (% citric acid)	1	0.06	0.06	0.07	0.06	0.06 b	Day	<0.001
	14	0.08	0.08	0.07	0.08	0.08a	Irrad.	ns
	Mean	0.07	0.07	0.07	0.07		Day x Irrad.	ns

Means followed by the same letter are not significantly different.
ns = not significant

Table 26. Effect of irradiation dose and storage duration on honeydew melon quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for 14 days (Day 14).

Variable	Day	Irradiation dose (Gy)				Mean	ANOVAs	
		0	150	600	1000		Factor	p-value
Firmness (kg force)	1	21.9	24.4	25.7	24.3	24.1	Day	ns
	14	25.6	26.7	26.5	23.6	25.6	Irrad.	ns
	Mean	23.7	25.5	26.1	24.0		Day x Irrad.	ns
Flesh lightness	1	63.4	62.1	60.5	60.6	61.7 b	Day	<0.001
	14	64.7	63.6	63.4	65.5	64.3a	Irrad.	<0.05
	Mean	64.0a	62.9ab	62.0 b	63.1ab		Day x Irrad.	ns
Flesh chroma	1	25.8	25.4	27.4	26.9	26.4	Day	ns
	14	25.9	25.7	24.9	24.4	25.2	Irrad.	ns
	Mean	25.9	25.5	26.1	25.7		Day x Irrad.	ns
Flesh hue angle	1	117.4	117.1	117.1	117.4	117.2	Day	ns
	14	117.8	117.2	117.1	116.6	117.2	Irrad.	ns
	Mean	117.6	117.2	117.1	117.0		Day x Irrad.	ns
TSS (° Brix)	1	8.5	9.6	9.5	9.6	9.3a	Day	<0.05
	14	8.1	9.2	7.7	7.8	8.2 b	Irrad.	ns
	Mean	8.3	9.4	8.6	8.7		Day x Irrad.	ns
TA (% citric acid)	1	0.10	0.09	0.10	0.10	0.10a	Day	<0.05
	14	0.08	0.09	0.09	0.09	0.09 b	Irrad.	ns
	Mean	0.09	0.09	0.09	0.10		Day x Irrad.	ns
Skin pitting incidence (%)	1	0 c	0 c	0.0 c	0.0 c	0.0 b	Day	<0.001
	14	0 c	0 c	60.0 b	86.7a	40.0a	Irrad.	<0.001
	Mean	0 c	0 c	30.0 b	43.3a		Day x Irrad.	<0.001
Skin pitting severity (%)	1	0 c	0 c	0.0 c	0.0 c	0.0 b	Day	<0.001
	14	0 c	0 c	7.5 b	51.3a	15.2a	Irrad.	<0.001
	Mean	0 c	0 c	3.7 b	25.7a		Day x Irrad.	<0.001

Means followed by the same letter are not significantly different.

ns = not significant

3.5 Discussion

This study contributes towards further enhancing our baseline knowledge of the effects of irradiation on fruit quality. In this study, irradiation applied up to 1kGy overall had little to no effect on a range of fruit quality attributes measured in tomato, capsicum, zucchini and rockmelon. These commodities were instead primarily impacted more by storage time than by irradiation itself. This comprised small changes in skin and flesh colour along with moisture loss and fruit softening; being overall typical ripening or senescence responses that occur while in storage.

As a result of irradiation, capsicum and zucchini fruit, in particular, exhibited small although statistically significant changes in fruit quality. At high doses of irradiation (0.6-1kGy), a slight increase in moisture loss and Brix levels were observed in capsicum fruit, while Brix levels in zucchini decreased. These effects overall were minor and did not visually detract from the integrity or overall appearance of the fruit. Mitchell *et al.* (1992) also reported similar findings in a study which included irradiated green capsicum and zucchini fruit stored at 5°C and 7°C for 3.5 weeks and 3 weeks, respectively. Although they only applied doses up to 300Gy, they found that storage duration had a greater impact on physico-chemical components in these crops than did the effect of irradiation itself. These effects included decreases in soluble solids, acidity and fruit colour properties.

Application of irradiation however had a significant impact on the quality of honeydew melon and, to a lesser extent, nectarine fruit. In both commodities, irradiation damage was only expressed by the end of the storage period, with the development of skin pitting and browning being positively related to the dose intensity. The overall severity of symptoms in nectarine fruit however was very low across all treatment doses, with only a few (3%) fruit expressing very mild symptoms at 150Gy. Mitchell *et al.* (1992) also assessed the effects irradiation on nectarine, yet found no effects on fruit physico-chemical properties up to 300Gy. Similarly, reports on melon fruit have also shown that treatment with gamma irradiation (≤ 1000 Gy) resulted in little to no damage to fruit (Kader 1986; Castell-Perez *et al.* 2004). According to Kader (1986), nectarine and melon fruit are generally regarded as having a relatively high stress tolerance to ionizing radiation (up to 1kGy), although acknowledges that various pre and postharvest factors can influence their susceptibility, including climatic growing conditions, cultural field practices, and handling and storage conditions.

3.6 Recommendations

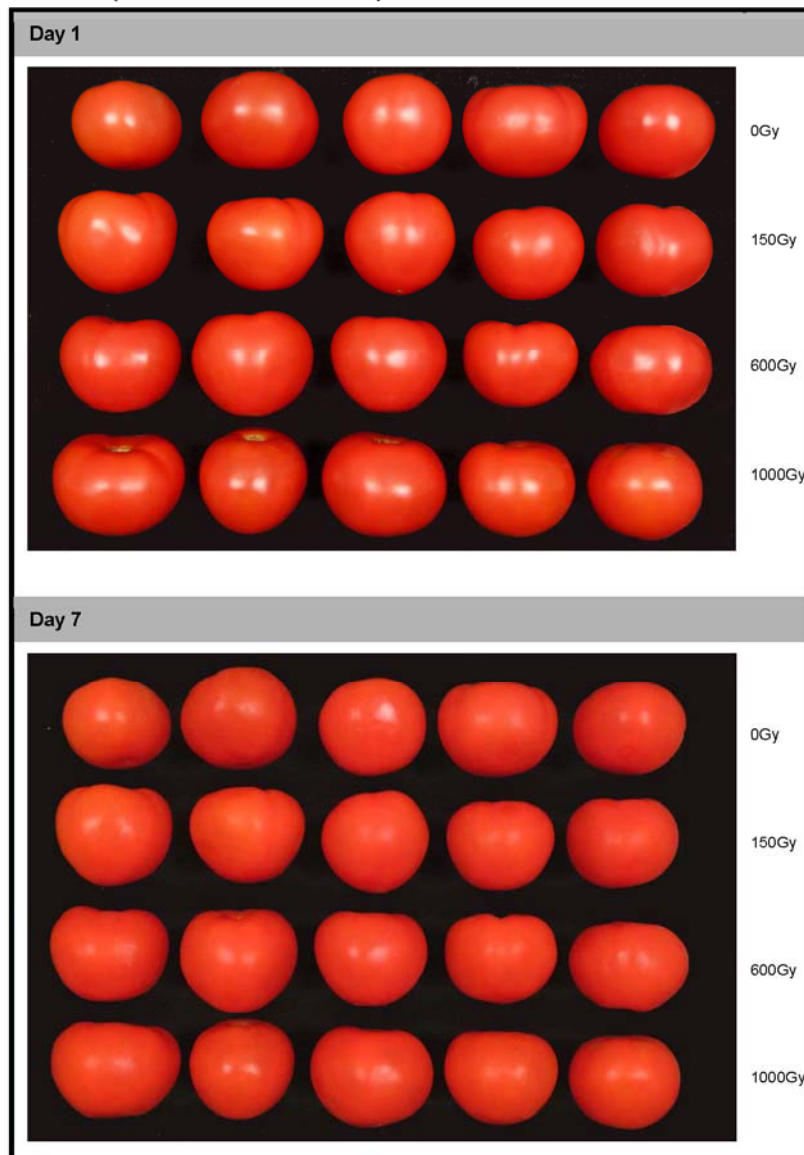
In this study, applications of gamma irradiation treatments of ≤ 1 kGy can be used as a disinfection measure without inducing any deleterious effects on quality in tomato, green capsicum, zucchini and rockmelon fruit. In contrast, honeydew melon, and to a lesser extent, nectarine fruit both expressed a lower tolerance to irradiation, with doses predominately at 600Gy and above resulting in skin pitting and browning. In regards to honeydew melon, as this study did not define the threshold between 150 and 600Gy where these disorders could be expressed, applications of gamma irradiation of up to 150Gy could therefore be safely employed without any negligible impacts on quality. In nectarine, treatment with 150Gy could also be considered a safe limit given the overall incidence and severity of symptoms at this dose level was extremely low.

3.7 References

- Castell-Perez E, Moreno M, Rodriguez O and Moreira RG (2004). Electron beam irradiation treatment of cantaloupes: effect on product quality. *Food Science & Technology International* 10 (6): 383-390.
- Kader AA (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. *Food Technology* 40 (6): 117-121.
- Mitchell GE, McLauchlan RL, Isaacs AR, Williams DJ, Nottingham SM (1992). Effect of low dose irradiation on composition of tropical fruits and vegetables. *Journal of Food Composition and Analysis* 5: 291-311.
- UC Davis (2011). Postharvest Technology Produce Fact Sheets. Agriculture and Natural Resources, University of Southern California, USA website viewed 15 August, 2011. <http://postharvest.ucdavis.edu/producefacts/>

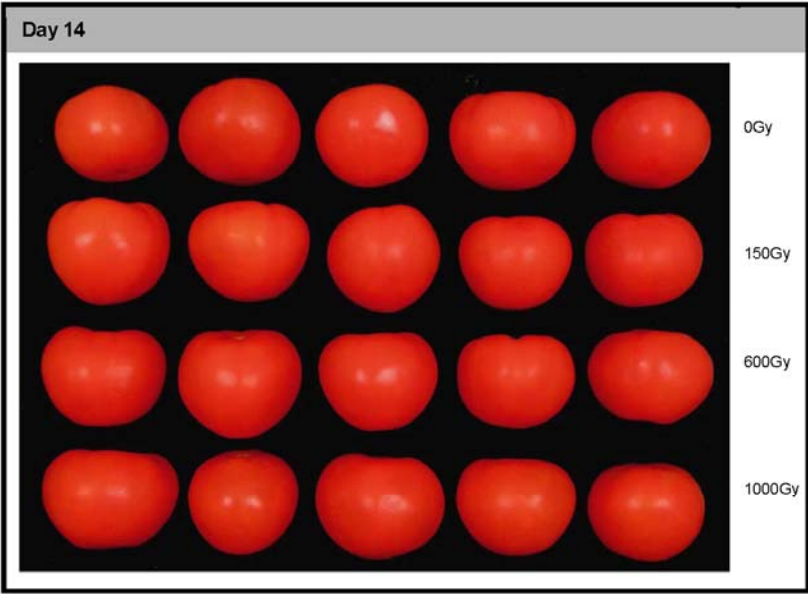
3.8 Appendix 3 – Photographs of each fruit type gamma irradiated with a dose between 0Gy to 1000Gy taken before cold storage (Day 1) and up to a maximum of 21 days

3.8.1 Tomato (var. Gourmet Swanson)



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

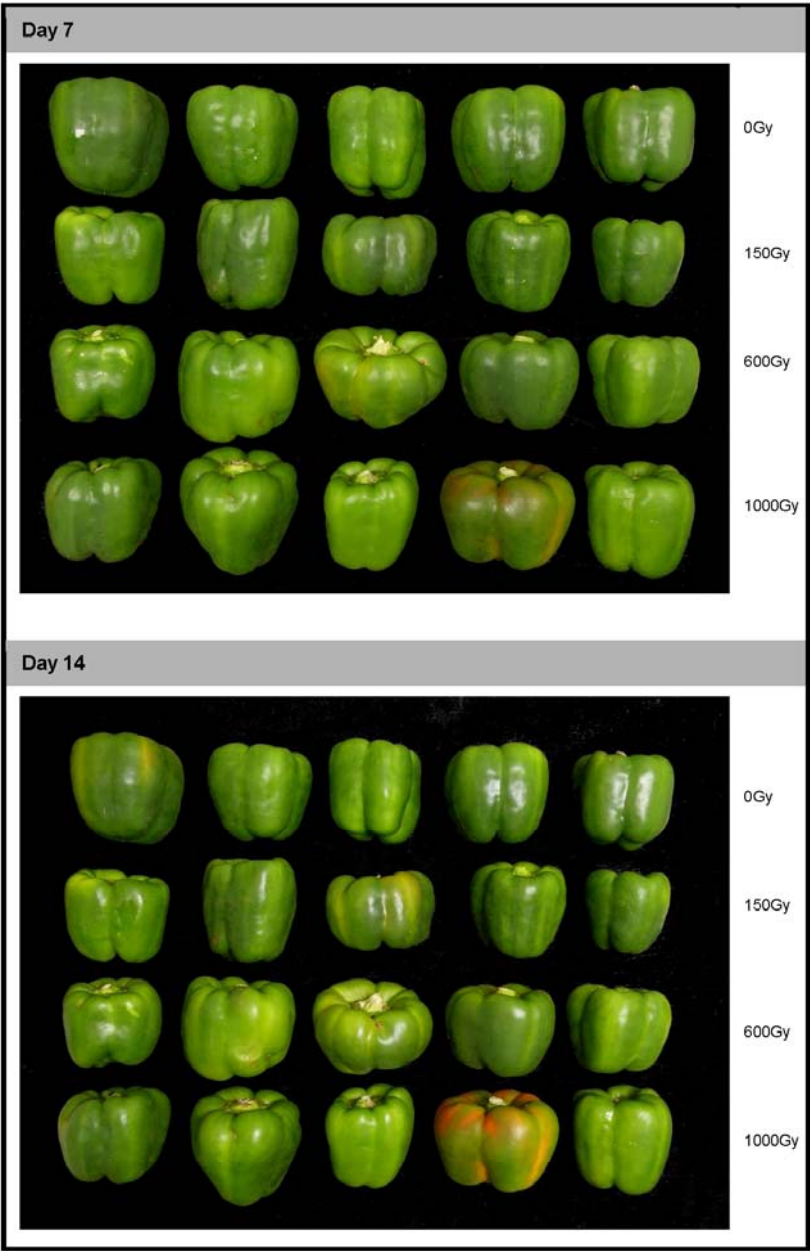
98



3.8.2 Capsicum (var. Plato)



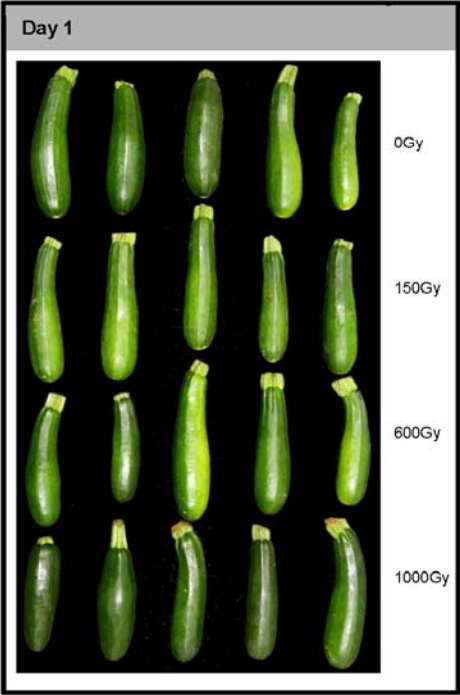
Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon



3.8.3 Zucchini (var. Blackjack)



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

3.8.4 Nectarine (var. Arctic Snow)



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

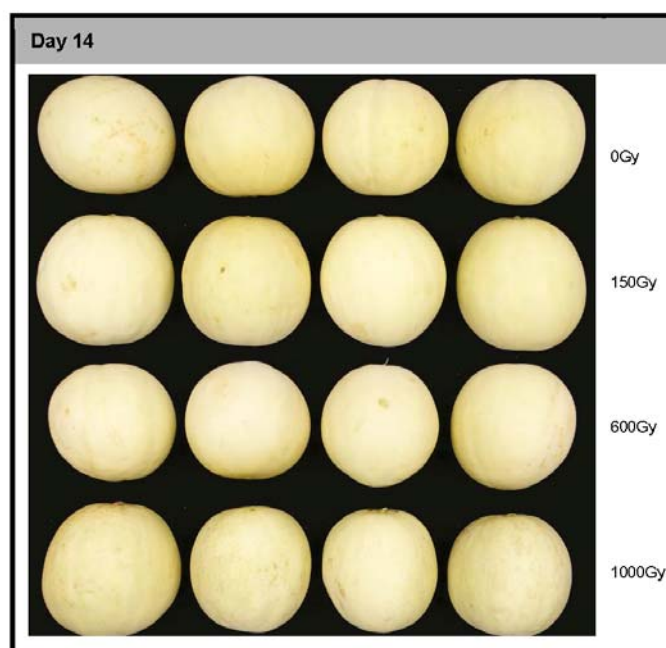


Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

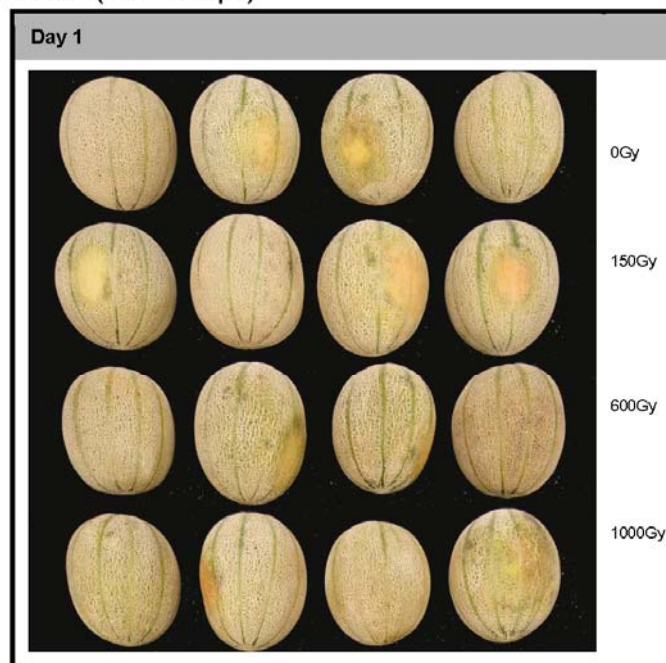
3.8.5 Honeydew (var. Galaxy)



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

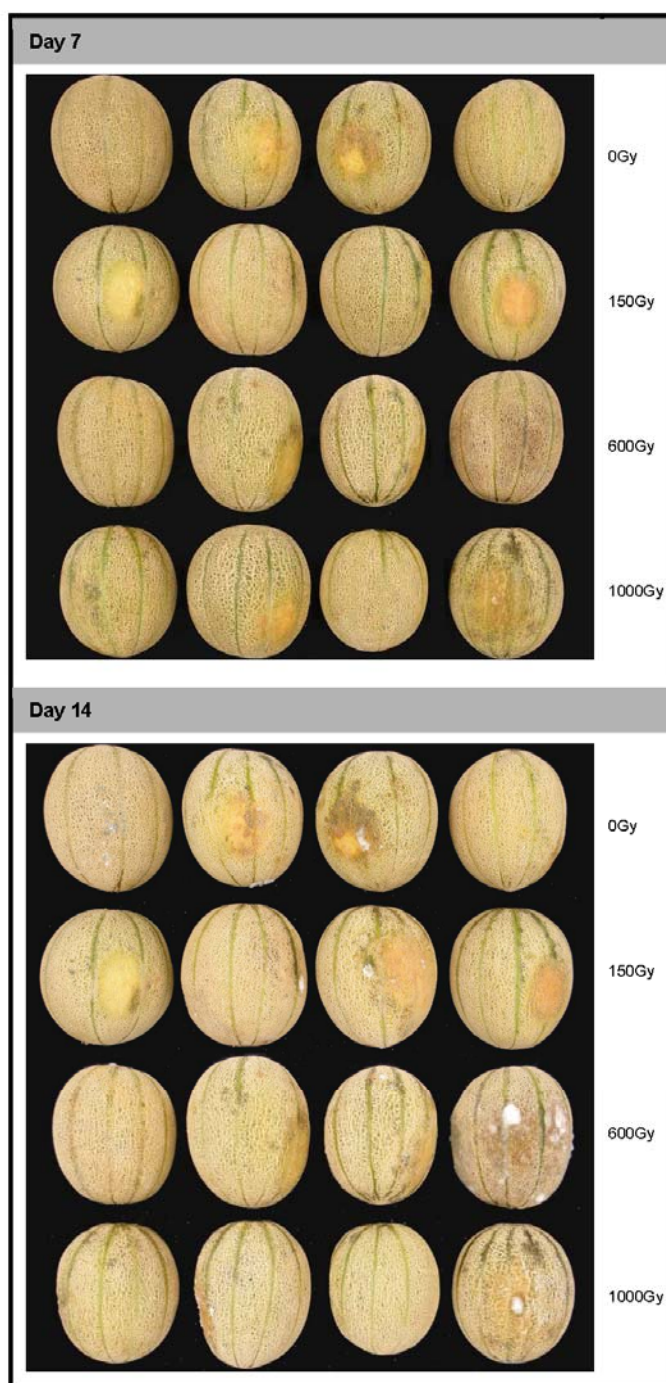


3.8.6 Rockmelons (var. Triumph)



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

105



Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

APPENDIX 3 – LABELLING

Packages containing treated produce (apple, apricot, cherry, honeydew melon, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini) will be unambiguously labelled in accordance with the labelling requirement of FSANZ Food Standards Code Standard 1.5.3. There is no application to vary the labelling requirement.

Standard 1.5.3 states that

(1) The label on the package of irradiated food must include a statement to the effect that the irradiated food has been treated with ionising radiation.

Examples include:

'TREATED WITH IONISING RADIATION'
'IRRADIATED (name of food) '

(2) The label on a package of food containing an irradiated food as an ingredient or component, must include a statement that the ingredient or component has been treated with ionising radiation, either as part of the declaration of that ingredient or component in an ingredient list or elsewhere on the label.

(3) Where an irradiated food, or a food containing an irradiated food as an ingredient or component, is not required to bear a label pursuant to clause 2 (1) of Standard 1.2.1, there must be displayed on or in connection with the display of the food a statement that the food has been treated with ionising radiation, or that it contains an ingredient or component that has been treated with ionising radiation, as the case may be.

APPENDIX 4 – FACILITIES, DOSIMETRY AND RECORD KEEPING

A4.1 Facilities

In accordance with Standard 1.5.3, the operation of irradiation facilities and control of the irradiation process will be undertaken in accordance with any relevant State, Territory and New Zealand law governing radiation control. They will also be undertaken in accordance with the Codex Alimentarius Code of Practice for Radiation Processing of Food (CAC 2003b).

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) regulates all Australian Government entities and the activities of non-Australian Government entities are regulated by the respective state and territory authorities.

The Ministry of Health's Office of Radiation Safety administers the Radiation Protection Act 1965 and the Radiation Protection Regulations 1982 on behalf of the New Zealand Government. This legislation controls the use of ionising radiation. It regulates all radiation facilities and radioactive substances and apparatus in New Zealand. The National Radiation Laboratory (NRL) is a specialist unit of The Institute of Environmental Science & Research Ltd (ESR). NRL provides a resource of expert advice, service provision and research capability on matters concerning public, occupational and medical exposure to radiation, the performance of radiation equipment and the measurement of radiation and radioactivity.

Any facility used to irradiate food will be a licensed and prescribed radiation facility. It is not expected that irradiation of food will be carried out in New Zealand.

In Australia, responsibility for licensing is under the jurisdiction of the relevant state departments:

- ACT Health, Radiation Safety Section
- NSW Environment Protection Authority (EPA)
- NT Department of Health, Radiation Protection
- QLD Health
- SA Environment Protection Authority
- TAS Dept of Health and Human Services, Radiation Protection
- VIC Department of Health
- WA Department of Health, Radiological Council.

Extensive worker training, supervision and regulatory oversight are required. All matters including occupational health safety and welfare regulations are regulated by the relevant regulatory authorities, i.e. all national, state, territory and local government authorities.

The relevant regulatory entities ensure that commercial irradiation facilities are properly designed and operate according to federal and state or territory regulations. The facilities have multiple fail-safe measures and have established extensive and well-documented

safety and training procedures. This will ensure that the irradiation facility operates safely and without posing any significant radiation risk to personnel or the public.

Irradiation treatment facilities will need to abide by requirements of good manufacturing practice and act in accordance with the Codex Alimentarius General Standard for Irradiated Foods (2003a) and its associated Code of Practice for the Operation of Irradiation Facilities Used for the Treatment of Foods (1983).

The Codex General Standard for Irradiated Foods 106-1983, REV.1-2003 (2003a) applies to foods processed by ionizing radiation and is used in conjunction with applicable Codex hygienic codes, food standards and transportation codes. It does not apply to foods exposed to doses imparted by measuring instruments used for inspection purposes.

Any treatments for each specific commodity to be exported from Australia would be required to meet importing country requirements.

There are currently three commercial irradiation facilities in Australia. All three irradiation facilities use gamma radiation from radioactive Cobalt-60. The facility at Narangba is the only facility currently accredited by AQIS for treatment of fruits.

Company name	Location
Steritech Pty Ltd	5 Widemere Road Wetherill Park NSW 2164
Steritech Pty Ltd	180 –186 Potassium Street Narangba QLD 4504
Steritech Pty Ltd	160 South Gippsland Highway Dandenong VIC 3175

There is a commercial irradiation facility in New Zealand – Schering Plough Animal Health Ltd., 33, Whakatiki Street, Upper Hutt, New Zealand. It conducts occasional sterilisation treatments of imported goods at the request of importers and Biosecurity NZ. It is unsuitable for the general irradiation of fruits and vegetables.

The Certificates of Registration, AQIS certification and ICA Arrangement for the Steritech facility are attached.

Plate 1. Certificate of Registration ISO 9001:2008



CERTIFICATE OF REGISTRATION

This is to certify that:

Steritech Pty Ltd
ABN 30 451 935 502

5 Widemere Road WETHERILL PARK NSW 2164 AUSTRALIA
180 - 186 Potassium Street NARANGBA QLD 4504 AUSTRALIA
160 South Gippsland Highway DANDENONG VIC 3175 AUSTRALIA

operates a
QUALITY MANAGEMENT SYSTEM
which complies with the requirements of
ISO 9001:2008
for the following scope

The registration covers the Quality Management System for the gamma irradiation (Wetherill Park, Dandenong and Narangba), ethylene oxide (Wetherill Park), and heat treatment (Wetherill Park) processing service to decontaminate and sterilise a wide range of products and substances for a variety of industries.

Certificate No: QEC11523

Issued: 18 June 2010 Expires: 24 August 2013	Originally Certified: 25 August 1998 Current Certification: 16 May 2010
---	--



General Manager – Certification Services



Global Head – Assurance Services



ISO 9001



WWW.JAS-ANZ.ORG/REGISTER

Registered by:
SAI Global Certification Services Pty Ltd (ACN 108 716 069) 286 Sussex Street Sydney NSW 2000 Australia with SAI Global Limited
286 Sussex Street Sydney NSW 2000 Australia ("SAI Global") and subject to the SAI Global Terms and Conditions for Certification.
While all due care and skill was exercised in carrying out this assessment, SAI Global accepts responsibility only for proven
negligence. This certificate remains the property of SAI Global and must be returned to SAI Global upon its request. To verify that this
certificate is current please refer to SAI Global On-Line Certification register at <http://www.sai-global.com>



SAI GLOBAL
VERITAS IN AERE INVENIETUR

Plate 2. Certificate of Registration ISO 13485:2003



Australian Government

Department of Health and Ageing
Therapeutic Goods Administration

**Quality Management System Certificate
ISO 13485:2003**

Issued to:

Steritech Pty Ltd

This is to certify that the Quality Management System for the manufacture of the devices described below conforms to the relevant provisions of ISO13485:2003.

TGA File Number: 2011/001850
Manufacturer Name: Steritech Pty Ltd
Manufacturer Address: 180-186 Potassium St
Narangba QLD 4504
AUSTRALIA
Scope of Certification: Provision of contract gamma irradiation services, in accordance with ISO11135:2007 and ISO11137:2006.
Special Conditions: Nil

Effective Date: 15 November 2012

Expiry Date: 10 May 2015

*This Certificate is valid for the period indicated
subject to periodic and satisfactory surveillance.*



15 November 12

Inspection Group Manager
Office of Manufacturing Quality
Therapeutic Goods Administration
PO Box 100, Woden ACT 2606 Australia
Phone: +61 (0)2 6232 8790
Fax: +61 (0)2 6232 8426

MI-2011-LI-03848-3

This Certificate is the property of the Office of Manufacturing Quality, TGA, and must be returned upon demand.

Plate 3. Certificate of Registration of an export registered establishment

 Australian Government Department of Agriculture, Fisheries and Forestry Australian Quarantine and Inspection Service		Certificate of Registration of an Export Registered Establishment Registration Number 2997	
Name of Occupier STERITECH PTY LTD ACN 007 308 027 ABN 30 451 935 502		Location of Premises or Name of Ship and Home Port 180 - 186 POTASSIUM ST NARANGBA QLD 4504	
Alternate Trading Names			
Registered Operations Producing : game meat (irradiated) Packing : plants products, prescribed grains Inspecting : fresh fruit, fresh vegetables, plants products, prescribed grains Load in : game meat commodity Load out : game meat commodity, game meat (irradiated) Holding : game meat commodity (frozen)			
Country Listing			
Persons who manage and control <div style="background-color: black; width: 100%; height: 1.2em;"></div>			
Registered subject to the following conditions (if any) <div style="background-color: black; width: 100%; height: 1.2em;"></div>			
<div style="background-color: black; width: 100%; height: 100%;"></div>			
This certificate is issued in accordance the <i>Export Control Act 1982</i> and its subordinate Orders and Regulations Date of Effect 14 Sep 2011 <div style="background-color: black; width: 100%; height: 1.2em;"></div>		Department Seal 	
Secretary or Delegate <div style="background-color: black; width: 100%; height: 1.2em;"></div>		15 Sep 2011 Date	

* denotes a suspended Registered Operation or Country Eligibility

EX23A - 11/03

Plate 3. Certificate of Accreditation for an ICA Arrangement

CERTIFICATE OF ACCREDITATION

FOR AN

INTERSTATE CERTIFICATION ASSURANCE (ICA) ARRANGEMENT



Queensland
Government

Department of
Agriculture, Fisheries
and Forestry

BUSINESS DETAILS

NAME OF ACCREDITED PERSON

Steritech Pty Ltd

TRADING NAME/S OF ACCREDITED PERSON

Steritech

POSTAL ADDRESS OF ACCREDITED PERSON

PO BOX 376
BURPENGARY QLD 4505

STREET ADDRESS OF ACCREDITED FACILITY

180-186 Potassium St
NARANGBA

INTERSTATE PRODUCE (IP) NUMBER

Q 1067

ICA ARRANGEMENT (CAA) NUMBER

Q 1067-01-ICA55

PERIOD OF ACCREDITATION

From 31 May 2013 to 31 May 2014

SCOPE OF ACCREDITATION

The business is accredited under the Plant Protection Act 1989 for an Interstate Certification Assurance arrangement for the following Operational Procedure. The scope of the accreditation covers the produce types, chemicals and other restrictions listed under Restrictions on Accreditation. Accreditation is subject to the conditions specified on the application form.

PROCEDURE CODE

ICA55

OPERATIONAL PROCEDURE TITLE

Irradiation Treatment

RESTRICTIONS ON ACCREDITATION

Produce

Food approved by
FSANZ for Irradiation

Chemical

Chemical Not Specified

Other Restrictions

Not Applicable

AUTHORISATION



Signature

4 June 2013



DPI&F Stamp

A4.2 Dosimetry

Dosimetry is one component of a total quality assurance programme for adherence to good irradiation (manufacturing) practice. Record-keeping (Appendix A4.3), trained staff and adherence to licensing conditions are also obligatory.

Proper dosimetry systems will ensure that the dose required technically for each treatment is given and that it is within the dose range stipulated in Standard 1.5.3. Competence in dosimetry is also required for any approval by federal and state licensing agencies to operate an irradiation facility and by the relevant plant quarantine authorities when a facility treats food for a disinfestation purpose. Authorities require dosimetry to be conducted in accordance with internationally recognized procedures.

The purpose of irradiation as a phytosanitary treatment is to minimize the pest risk and to maximize the safety associated with the movement and use of fresh agricultural produce. The dose range is applied in accordance with ASTM F1355 - 06 Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment.

The requirements for proper dosimetry are laid out in the Codex Recommended Code of Practice for Radiation Processing of Food (CAC 2003b). Internationally recognized guidelines and manuals on how to conduct adequate dosimetry are available ((ISO/ASTM 51275, ISO/ASTM 51276, ISO/ASTM 51538, ISO/ASTM 51607, ISO/ASTM 51631 and ASTM F1355-06). An overview is provided in a report of an IAEA workshop (IAEA 2002b).

The International Consultative Group on Food Irradiation (ICGFI) has issued documents providing overall guidance on Good Irradiation Practice (GIP) for a range of foods and food classes (a list of GIPs and other ICGFI documents can be obtained at <https://apps.who.int/fsf/whopb3.htm>). There is a Code of Good Irradiation Practice for Insect Disinfestation of Fresh Fruits (ICGFI 1991).

The procedure used in commercial food irradiation is that the food package or pallet is exposed to the source for the specified time and then the package or pallet is rotated through 180°, to expose the other side. As the radiation energy is absorbed by the food, the dose absorbed progressively decreases. The food at the outermost part of the package or pallet will receive the maximum dose and the food in the middle the minimum dose.

The minimum dose (D_{min}) must be that set by biosecurity officials to ensure elimination of the pest threat. The maximum dose (D_{max}) may then be the lower of the dose that produces an adverse effect on quality or the regulated maximum dose for fresh produce of 1 kGy. In practice the ratio of D_{max} to D_{min} (the dose uniformity) is set by the fixed engineered features of the plant and the physical dimensions and density of the package or pallet. To ensure that D_{max} and D_{min} are as required, it is necessary to 'map' the dose distribution within the package or pallet. Guidance on dose mapping is available in the standard manuals on dosimetry.

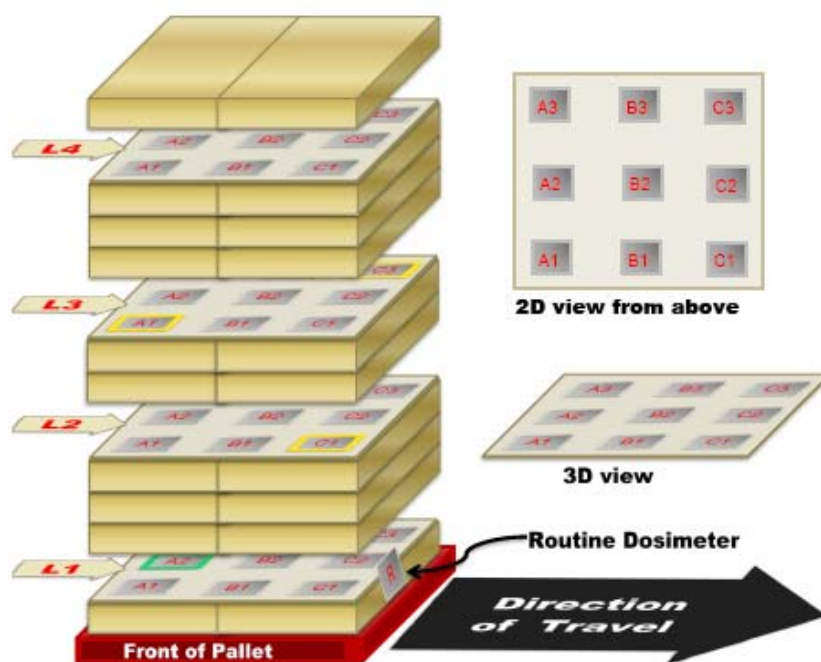
The Irradiation Operator must perform dose mapping to establish the dose distribution within the product in order to demonstrate that the treatment consistently meets the prescribed requirements under defined and controlled conditions. For dose mapping, the Irradiation Operator must place sufficient dosimeters throughout the product that is to be passed through the irradiator.

The positioning of the dosimeters will depend on the composition, density, configuration of the packaging and shape and or size of the product. The variation in dose is determined by mapping the dose distribution in at least three process loads with the same product loading configuration and irradiation conditions. The Irradiation Operator must record dose

mapping using a Dose Mapping Record or records which capture the same information. The dose mapping record shall provide the following –

- (a) the name and address of the accredited Business;
- (b) the time and date when the dose mapping occurred;
- (c) the dimensions and packaging of the product;
- (d) geometric packaging configuration;
- (e) the loading pattern of the dose mapped product;
- (f) the location of the dosimeters within the product;
- (g) the type of dosimeter;
- (h) the duration of irradiation;
- (i) the minimum and maximum absorbed doses in the product; and
- (j) the printed name and signature of the operator that conducted dose mapping.

Likely positions of dosimeters to map dose distribution within a pallet are shown below.



The product dose mapping must be repeated if changes are made, either in the facility or in an operational mode that could affect the magnitudes or locations of the maximum and minimum doses.

Nine dosimeters (A1 – C3) are placed as shown on a horizontal plane at four levels (L) within the pallet load. Dose mapping is carried out on trial shipments prior to any commercial treatments. During commercial treatments, the irradiation operator performs routine dosimetry to ensure that the specified dose is received by the product. Dosimeters are placed in the process load at the predetermined maximum and minimum dose positions, or at a qualified reference dose location (an example is shown in the figure)

above). Routine dosimetry must be performed for each lot and the Irradiation Operator then records the minimum and maximum absorbed dose from the routine dosimetry using the Irradiation Treatment Record or records which capture the same information.

The dosimeters and dosimeter reader system used by Steritech are supplied by Far West Technology, Goleta, USA (<http://fwt.com/racm/fwt70ds.htm>). The dosimeter type is the Radiochromic Optical Waveguide Dosimeter, which uses a dye that changes from clear to deep blue as the absorbed dose increases. The dosimeter model for food irradiation is the FWT-70-40M dosimeter which has a sensitivity range of 10Gy to 10,000Gy. Each new batch of dosimeters is calibrated upon purchase.

The dosimeter reader model used is the FWT-200 in which the dosimeters are read at an optical wavelength of 656nm. This reader is easy to use, providing an automatic zero and PC interface. The reader is easily calibrated using Neutral Density Filters and adjusting the gain on the FWT-200 reader.

The relevant ISO/ASTM standards for use of the dosimetry system are:

ISO/ASTM 51261:2002 – Guide For The Selection And Calibration Of Dosimetry Systems For Radiation Processing

ISO/ASTM 51310:2004 – Practice For Use Of A Radiochromic Optical Waveguide Dosimetry System.

Important standards considered include; ISO / ASTM51204 – 04 Standard Practice for Dosimetry in Gamma Irradiation Facilities for Radiation Processing (2004), ISO / ASTM51431 – 05 Standard Practice for Dosimetry in Electron Beam and X-Ray (Bremsstrahlung) Irradiation Facilities for Radiation Processing (2005) and ASTM E2303 – 03 Standard Guide for Absorbed-Dose Mapping in Radiation Processing Facilities (2003).

Dosimetry is subject to approval by the relevant licensing authority and the plant quarantine authority. Dose mapping will be repeated if the packaging is changed from the original map test conditions approved.

Dosimetry is only one component of a total quality assurance program for adherence to good manufacturing practices.

Aspects of dosimetry related to radiation processing of food at an irradiation facility including dosimetry procedures for process validation and process control (IAEA 2002a) can be used to ensure the compliance of trade in irradiated food with national and international standards.

A4.3 Record-keeping

Approved radiation facilities must keep accurate records as specified by the competent radiation licensing and plant quarantine authorities. The purpose of the records is to establish and document traceability.

Records will be maintained to track the irradiated food product from receiving through shipping. All records must identify the irradiated product and be retained in accordance with requirements by phytosanitary authorities.

Irradiation treatment, however, will not replace good agricultural production practices and the supply chain practices currently in place and employed by Australian and New Zealand growers.

There will be compliance with record keeping requirements, as established in FSANZ Standard 1.5.3:

(1) Records must be kept at a facility where food is irradiated in relation to:

- the nature and quality of the food treated; and
- lot identification; and
- the minimum durable life of the food treated; and
- the process used; and
- compliance with the process used; and
- the minimum and maximum dose absorbed by the food; and
- an indication whether or not the product has been irradiated previously and if so, details of such treatment; and
- date of irradiation.

(2) The records required to be kept by subclause (1) must be kept for a period of time that exceeds the minimum durable life of the irradiated food by one year.

Irradiation treatment does not need to kill the pest immediately to provide quarantine security as it effectively renders pests sterile (IPPC 2003, 2009). As a result, live (but sterile) pests may occasionally accompany shipments. This was initially a cause of some concern among biosecurity officials. However, the successful import of irradiated fruits into the US and New Zealand shows that the issue is being managed and will continue to decrease in importance as further experience is gained. The issue does emphasise the importance of record-keeping and the certification and labelling documents that accompany shipments.

Research has been carried out on radiation-damage to insects at phytosanitary doses with the hope that it would prove possible to identify irradiated insects. Some success has been achieved and Nation (1999) nominated several possible markers to indicate treatment, but the methods are too time-consuming, costly and require expert interpretation. They are not yet useful for confirming that an insect has been irradiated on a rapid, routine basis.

This results in an added level of importance to the certification procedures for irradiation facilities, treatment monitoring, proper record documentation, labelling of shipments and system integrity. Eventually, visual inspection for the target pests may be replaced by 100% reliance on a certification system for confirmation of treatment application and efficacy (IPPC 2009, Hallman 2008).

Compliance by the approved radiation facility with accurate records as specified by the relevant radiation licensing authorities and relevant plant quarantine authorities, regulated at the national, state and local government authority, in establishing traceability will be fully documented. The treatment facility must keep all dosimetry and treatment records.

A copy of the procedural documentation for Facility Records and Traceability used at the Steritech Narangba facility is attached in the following page. Mango and litchi are routinely irradiated at the facility prior to shipment to New Zealand.

Food irradiation may be incorporated as part of a Hazard Analysis and Critical Control Point (HACCP)-plan where applicable but a HACCP-plan is not required for the use of radiation processing of food processed for purposes other than for food safety. The provisions of this Code will provide guidance to the radiation processor to apply the HACCP (1997) system, as recommended in the Recommended International Code of Practice General Principles of Food Hygiene (2003d - CAC/RCP 1-1969, Rev 4-2003, Amd. 1-1999), where applicable for food safety purposes to foods processed by ionizing radiation.

Accurate records will allow tracking and tracing in addition to meeting regulatory compliance. Retail distribution channels are able to respond to needs from their suppliers about the status of production, manufacturing and shipping.



VICTORIA
160 South Gippsland
Highway
Dandenong 3175

PO Box 4040,
Dandenong South
Victoria 3164 Australia

Telephone: (03) 8726
5566
Fax No: (03) 9701 3158

NSW
5 Wildemere Rd
Wetherill Park 2164.

PO Box 6632,
Wetherill Park
N.S.W. 3164 Australia

Telephone: (02) 9609
5566
Fax No: (02) 9604 4396
FM

QLD
180 Potassium St
Narangba 4504

PO Box 376,
Burpengary
Qld 4505 Australia

Telephone: (07) 3293
1566
Fax No: (07) 3293 1544
FM



Facility Records and Traceability

On receipt of each delivery; pallets and trays are counted and verified by 2 staff. Accompanying mandatory documentation is checked for accuracy and completeness; tray count is verified in writing in the space allocated on the form.

All pallets must be packaged/wrapped/protected according to the guidelines set by AQIS/MAF/Biosecurity Australia to meet export requirements PRIOR to arrival at Steritech.

Each pallet is checked for damage and labeling as it is unloaded from the transport provider. Each tray must be labeled as outlined by FSANZ/AQIS/MAF/Biosecurity Australia and in accordance with the requirements of the destination country. If during the checking process damage to the product or incorrect or absence of labeling is found, the company/persons presenting the product for treatment are notified immediately by the Operations Supervisor. Treatment will be delayed and extra charges will be incurred by the company or persons responsible for payment of Steritech's invoice.

Pallets are to be held in the designated area to prevent cross contamination. A process indicator is placed on the outside of the pallet. A Process Indicator is also known as 'Gamma Dot'; 'Irradiation Indicator Label'; 'Go No Go Sticker'.

Product is then booked-in; to our system and given an identification/lot number, with the following information:

- Identification of Grower.
- Identification of Exporter.
- Identification of Facility.
- Number of trays per pallet.
- Number of pallets.
- Destination Country, and Country specific Irradiation Certificate requirements.
- Dose range; (e.g. 250Gy – 1000Gy).
- Fruit variety.
- Date of Treatment.

Treatment Load Station Log Requires:

- The date of processing and the signature of the operator.
- The sequential pallet number (log-in number).
- The customer's name (usually abbreviated) and the product lot number. This information identifies back to the Lot Number and Booking-in System.

Routine Dosimeter Placement and Records:

- Dosimeters are placed in the routine position, on every pallet of each consignment. Results to be recorded on the Certificate of Irradiation - Customer Copy, Warehouse Copy and Office Copy.
- Results are also recorded in the Processing Log Book and on an Electronic Perspex file.

****Steritech maintains records for a minimum of seven years.****

The following attachments are for grower/exporter to fill in prior to processing (mandatory).

Attachments:

- 1.1** Gamma Irradiation Agreement. **(completed at the start of every season)**
- 1.2** Request for Irradiation of Tropical Fruit – Purchase Order. **(required for every delivery)**
- 1.3** Acknowledgement of Treatment and Loading Services. **(completed at the start of every season)**

APPENDIX 5 – PACKAGING

Irradiation and packaging

Irradiation disinfestation takes place after final packaging. Fruits treated by irradiation are shipped in the same cartons in which they are treated. Packaging is important in maintaining hygiene. The structural integrity and purpose of the package must be maintained and no mobile chemical products that could migrate into the food should be produced following irradiation.

The IPPC, under Article IV(4) 2(g), imposes a responsibility on national plant protection organizations to ensure that the phytosanitary security of consignments after certification regarding composition, substitution and re-infestation is maintained prior to export. In Australia, ICA-55 (ICA 2011) imposes conditions on post-treatment security of packages in section 7.10 as follows. Treated fruit shall be held for the minimum practical period after treatment before it must be secured against infestation. Completed pallets shall be held for the minimum practical period before placing in secure conditions that prevent infestation. Certified fruit must be transported from the facility in secure conditions which prevent infestation by fruit fly.

Secure conditions include:

- (a) unvented packages;
- (b) vented packages with the vents secured with gauze/mesh with a maximum aperture of 1.6 mm;
- (c) fully enclosed under tarpaulins, hessian, shade cloth, mesh or other covering which provides a maximum aperture of 1.6 mm;
- (d) shrinkwrapped and sealed as a palletised unit;
- (e) fully enclosed or screened buildings, coldrooms, vehicles or other facilities free from gaps or other entry points greater than 1.6 mm.

The insect-proof cartons have no openings that will allow the entry of fruit flies and the cartons will be sealed with seals or polywrapped that will visually indicate if the cartons have been opened. Alternatively, each pallet of cartons must be completely enclosed in polyethylene, shrink-wrap, or another solid or netting covering that completely precludes access to the cartons by fruit flies before leaving the room.

Extra conditions apply to fruit transported to Tasmania.

The identity of treated lots is preserved by wrapping each pallet with polyethylene shrink wrap, net wrapping, or strapping so that each carton on the outside row is constrained, before leaving the irradiation facility.

Australia New Zealand Food Standards Code 1.4.3 provides permission for articles and materials to be in contact with food in accordance with conditions set out in the Standard. However, the Code does not specify the details of materials and places the responsibility on to manufacturers. There is an Australia/New Zealand standard for plastic materials in contact with food (SA 1999).

Australia New Zealand Food Code Standard 1.5.3 provides permission for the irradiation of a range of tropical fruits, including carambola, tomato and capsicum which, like apples, apricot, cherry, nectarine, peach, plum, strawberry and table grape, has edible peel. The

packages and packing materials should be of suitable quality and in an acceptable hygienic condition appropriate to this form of processing.

Currently, mango, papaya and litchi that are treated with ionizing radiation are packed and irradiated in standard fibreboard fruit and produce packages, and plastic inserts. These fibreboard packages are standard fruit boxes that are sized according to the dimensions of the particular fruit in question.

The corrugated or fibre board fruit boxes used for packing fresh produce are made from components consisting of kraft and recycled papers, inks, adhesives and various other coatings. The components used by Amcor, Carter Holt Harvey and Visy are listed in the Tables A5.2 and A5.3 and Plate A5.1, respectively. Material details are present individually or in combination.

The materials used in manufacturing the fibre board packages and the plastic inserts are radiation-resistant at the disinfestation dose applied (150 Gy–1 kGy) and are approved for use in irradiating fruits and vegetables, under US FDA 21 *CFR* § 179.45 *Packaging materials for use during the irradiation of prepackaged foods, Subpart C*.

The packaging will provide an effective barrier to re-contamination and re-infestation. Packaging must also meet the requirements of the importing region or country. Packaging will take into consideration the *Codex General Standard for Irradiated Foods (CODEX-STAN 106-1983, Rev. 1-2003)* and the *Recommended International Code of Practice for Radiation Processing of Food (CAC/RCP 19-1979, Rev. 2-2003)*.

Most food packaging materials have been shown to be resistant to irradiation damage at doses below 10 kGy and maintain integrity (Kilcast 1990, Morehouse and Komolprasert 2004, Komolprasert 2007). Komolprasert (2007) provides a useful review of packaging materials that have come into common use since the list of packaging materials for food irradiation was first approved by the FDA (2007), and how their safety may be assessed.

Both the EU and the USA have regulations to guard against the migration of chemicals from food packaging into the food or onto its skin. The selection and control of maximum migration levels of monomers in plastics and other materials used in the manufacture of food packaging in Australia and New Zealand has been based on what is permitted in some overseas legislation.

Irradiation breaks polymers down into smaller molecular compounds and it is important that irradiation does not produce chemicals that are capable of migrating into the food with which it may be in contact. A list of packaging materials that are safe for use with irradiation approved by the US FDA is shown in Table A5.1.

Safe packaging materials are also addressed in 21 *CFR* 179.21 which specifically allows the use of wax-coated paperboard, which are a common carton type for packaging fruit and vegetables. Most of the packaging materials will withstand doses up to 10 kGy which is considerably higher than proposed 1 kGy maximum dose apple, apricot, cherry, honeydew, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini.

Plastic inserts used do not discolour, lose strength or embrittle when irradiated at the recommended doses. Some of the plastics described above may be modified with various adjuvants and other preservatives. The Federal Code also addresses adjuvant substances and coatings.

Various commercial adhesives and inks used for labelling are safe and generally resistant to irradiation. The inks contain pigments and dyes that are stable under visible and ultra-

violet light. Adhesives are made from polymers and plastics that are resistant to irradiation.

ASTM Standard *Guide F1640-09 Standard Guide for Packaging Materials for Foods to be Irradiated*, written by ASTM International (ASTM 2009) Subcommittee *E10.06 on Food Irradiation Processing and Packaging*, also addresses issues in the selection and use of packaging materials for food and agricultural products to be irradiated.

The Canadian Food Inspection Agency (CFIA) *Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical* (updated 2007), has approved additional materials including a multilayered polyethylene film as safe for packaging food to be irradiated, to their Food and Drugs Regulations Div 23 Food packaging materials (Canada Food and Drugs Act., 2009).

Table A5.1: Food packaging materials for use with ionising radiation under Federal Register 21 CFR 179.45 (FDA 2007).

21 CFR Reference	Packaging materials	Max dose (kGy)
Section 179.45 (b)	nitrocellulose-coated cellophane	10
	glassine paper	10
	wax-coated paperboard	10
	polyolefin film ⁵	10
	Kraft paper	0.5
	polyethylene terephthalate film (basic polymer)	10
	polystyrene film ⁵	10
	rubber hydrochloride ⁵	10
	vinylidene chloride-vinyl chloride copolymer film	10
	nylon 11 (polyamide-11)	10
Section 179.45 (c)	ethylene-vinyl acetate copolymer	30
Section 179.45 (d)	vegetable parchment ⁵	60
	polyethylene film (basic polymer) ⁶	60
	polyethylene terephthalate film ⁶	60
	nylon 66 (polyamide-6)	60
	vinyl chloride – vinyl acetate copolymer film ⁶	60

Source website: <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=a734321f9234a292d78dbabf4671ba0b&rgn=div5&view=text&node=21:3.0.1.1.10&idno=21#21:3.0.1.1.10.3.1.1>.

⁵ containing various adjuvant substances and coatings

⁶ with or without added substances

Corrugated fibreboard packaging

Amcor, Carter Holt Harvey and Visy are the main manufacturers and suppliers of fruit and produce packaging in Australia. Apple, apricot, cherry, honeydew, peach, plum, nectarine, rockmelon, strawberry, table grape and zucchini, for irradiation treatment and onward shipment will generally be packaged in a number of traditional ways that include:

Standard design fibre board fruit and produce cartons;

- Corrugated cardboard;
- PET plastic punnets;
- PVC or food grade polymer returnable plastic crates (RPCs);
- 'flow-wrapped' onto a thin PET plastic plate, sealed and then packed into cartons.

Table A5.2. Amcor Fibre packaging components used in the manufacture of fruit and produce packaging.

Component	Description
Kraft Liners	manufactured from a blend of pine and eucalypt fibre incorporating a neutral sulphite semi-chemical pulp and Rosin sizing. Liners may include functional coatings, i.e. polyethylene terephthalate (PET) and medium density polyethylene (MDPE).
Recycled Liners and Medium	manufactured from various sources of paper stock including that provided by kerbside collection systems. In addition alkenylsuccinic anhydride (ASA) sizing and starch based filling agents are used in manufacture.
Inks	water based pigments incorporating amine binding agents.
Hot Melt Adhesive	ethylene-vinyl acetate (EVA) or metallocene based
Cold Adhesive	EVA based
Corrugator Starch	Manufactured from wheat starch and incorporating the following additives – Borax, Sodium Hydroxide, and natural polymer water proofing agents.
Wax	blend of microcrystalline and paraffin waxes with hydrogenated palm oil also being present in the formulation.


The standard materials used by Amcor, Carter Holt Harvey and Visy are listed in the Tables A5.2, A5.3 and Plate A5.1 respectively. Materials may be used individually or in combination. The materials used in manufacturing the fibreboard packages and the

plastic inserts are radiation-resistant at the disinfestation dose applied (150 Gy to 1 kGy) and are currently approved for use in irradiating fruits and vegetables by the US FDA (FDA 2007).

Table A5.3. Materials used by Carter Holt Harvey Corrugated Australia in the manufacture of fruit and produce packages.

Component	Description
Papers	
Kraft paperboard	
NSSC paperboard (semi-chem)	
Recycled paperboard	
Adhesives	<p>Non-hazardous emulsion polymer to laminate and glue papers together.</p> <p>Wheat starch-based adhesive to glue the papers into corrugated board.</p> <p>Hotmelt adhesive – comprising rosin and alum, for assembling boxes</p>
Inks	Non-hazardous Acrylic Emulsion w/non-hazardous water-based pigment dispersions

Plate A5.1. The components used in the manufacture of the fruit boxes by Visy from corrugated board grades produced from recycled and kraft papers.

 VISY BOARD INNOVATIVE PACKAGING SOLUTIONS.	Technical Data Sheet – Cardboard Products Issue Date: 2 nd May, 2008. Issued By: [REDACTED] Technical Supervisor
To Whom it May Concern: Visy Board Queensland manufactures cardboard products comprising of:	
Paper: <ul style="list-style-type: none">• Recycled Papers manufactured in conformance with FDA,176.260<ul style="list-style-type: none">◦ No hazardous substances are used within the manufacturing process• Kraft Papers.<ul style="list-style-type: none">◦ Raw materials sourced from sustainable Australian sources	
Starch: <ul style="list-style-type: none">• Tapioca Starch	
Inks: <ul style="list-style-type: none">• Water based Inks	
Adhesive: <ul style="list-style-type: none">• PVA adhesive	
Suitability for Food Use: Visy Cardboard Products are suitable for food use. Microbial & analytical testing, including heavy metals testing meeting the requirement of EC Packaging & Packaging Waste legislation is carried out routinely.	Certification: CODEX HACCP, GMP, ISO9001:2000. SAI Global. License Number: HAC20003. Certified: 25/8/1993.
Contact Information [REDACTED]	

Only a relatively small portion of the fruit surface is in contact with the packaging. Any plastic inserts and punnets that are used are made from polymers commonly used in food packaging materials that can be irradiated up to 10 kGy. Details of the plastic inserts that are commonly used by supplied by Q Pak Plastic Thermoformers are included.

The two PVC films used in the manufacture of the plastic inserts for food contact use were tested by Consulchem Australia and they comply with Australian Standard AS2070/2, 1992 Plastics Materials for Food Contact Use Part 2, Polyvinyl chloride (PVC) compound. A copy of the laboratory report is shown in Plate A5.2.

The test report of the PVC plastic film used in manufacturing the plastic insert is provided in Plates A5.3a and A5.3b. The laboratory certifying the test is SGS–CSTC Standards Technical Services Co., Ltd.

The material complies with the overall migration requirements stated in the latest European Commission Directive relating to plastic materials that come into contact with foodstuffs (EU 2009a). The packaging used will provide an effective barrier to re-contamination and re-infestation. Packaging must also meet the requirements of the importing region or country. Packaging will take into consideration the Codex General Standard for Irradiated Foods and the Recommended International Code of Practice for Radiation Processing of Food (CAC 2003a, b).

Plate A5.2. Test report for two PVC films used in the manufacture of plastic liners for fruit.

06 Feb 09 09:32a

From: NEIL MURK MARKETING

33344000

04/04/2000 11:10 #000 P.001/003

P.

Approved Analysts (Food Act)
A.C.N. 61 005 377 613

CONSULCHEM

Analytical & Consultant
Chemists & Microbiologists
A.C.N. 605 877 613

Reference: C8995/1-2 NT:yh
20th October, 2004

CGPC Group,
Suite 4, Level 3,
694 Burke Road,
CAMBERWELL VIC. 3124

A4

Attention:

LABORATORY REPORT

Sample:

Two PVC samples, identified below, as received on the 27th July, 2004 for food grade testing.

Method of Analysis:

The sample was tested as per the Australian Standard AS2070.2, 1992 - Plastics, Materials for Food Contact Use, Part 2. Polyvinyl chloride (PVC) compound.

Results:

Expressed in mg/Kg.

Test parameter	Hi Impact - Black	Hi Impact - Clear	AS specification
Vinyl chloride:	<2	<2	5
Cadmium:	<50	<50	100
Mercury:	<0.1	<0.1	50
Barium:	<50	<50	100
Selenium:	<50	<50	100
Chromium:	<50	<50	1,000
Lead:	<10	<10	100
Antimony:	<10	<10	500
Arsenic:	<2	<2	100

CONSULCHEM PTY LTD

Analyst

ISO
17025

NRA
01/01/2001

TGA
01/01/2001

Unit 1, 7-11 Racco Drive, Searesby, Vic. 3179, Australia. Tel: (03) 8764 8881 Fax: (03) 8764 8892
E-mail: consulchem@consulchem.com.au Web Page: www.consulchem.com.au

104

APPENDIX 6 – METHODS OF VERIFICATION OF IRRADIATED FOODS

There is no one simple method available for detecting whether food has been irradiated. This emphasises the minimal chemical changes that occur at doses below 10 kGy.

Post irradiation analytical method, such as include electron spin resonance (ESR), thermoluminescence, lipid-derived volatiles, viscometry, electrical impedance and DNAComet assay are available. None are generally not practical or reliable for easy and rapid verification at the low phytosanitary doses (<1kGy) requested in this application, again emphasizing the importance of proper documentation systems.

A number of post-irradiation analytical methods are available that can be applied to different kinds of food (Marchioni 2006). The methods are purpose-detection methods and applicable to foods containing fats, bone, cellulose or dry crystalline material such as dust particles present during irradiation. The methods have been verified in international trials. Verified detection methods (EU 2009b, CAC 2003d) are listed in Table A6.1. These methods are effective at doses in excess of 1 kGy. Detection of irradiated food containing cellulose by ESR spectroscopy (EN 1787:2000) may be applicable for fruit and vegetables at doses above 1 kGy within about three weeks after treatment.

The detection tests may estimate the dose delivered to the food approximately but cannot accurately measure it. They are not a form of post-treatment dosimetry. Detection tests however, can assist in the enforcement of labelling requirements by confirming whether or not a food has been irradiated.

Currently, countries permitting the use of irradiation for phytosanitary disinfestation and other uses, e.g. USA, Australia, New Zealand and India, have selected phytosanitary certification, systems audits and treatment monitoring procedures supported by record keeping for management of the irradiation process. Credible certification and accurate record keeping will continue to provide the most reliable and practical methods of tracking fruits that have been irradiated and for ensuring compliance with regulatory requirements. Adherence to the guidelines by all stakeholders will serve to uphold the current position within the principles on good manufacturing practice, good irradiation practice and food safety.

Table A6.1. The European Standards (EU 2009b) for the detection of irradiated foods.

Code	Purpose
EN 1784:2003	Detection of irradiated food containing fat – Gas chromatographic analysis of hydrocarbons
EN 1785:2003	Detection of irradiated food containing fat – Gas chromatographic/mass spectrometric analysis of 2-alkylcyclobutanones
EN 1786:1996	Detection of irradiated food containing bone □ Method by (electron spin resonance) ESR spectroscopy
EN 1787:2000	Detection of irradiated food containing cellulose by ESR spectroscopy
	EN 1788:2001 Thermoluminescence detection of irradiated food from which silicate minerals can be isolated
EN 13708:2001	Detection of irradiated food containing crystalline sugar by ESR spectroscopy
EN 13751:2002	Detection of irradiated food using photostimulated luminescence
EN 13783:2001	Detection of irradiated food using Direct Epifluorescent Filter Technique/Aerobic Plate Count (DEFT/APC) – Screening method
EN 13784:2001	DNA comet assay for the detection of irradiated foodstuffs – Screening method
EN 14569:2004	Microbiological screening for irradiated food using LAL/GNB procedures

EN 14569:2004 is the only method not listed by the Codex Alimentarius Commission (CAC 2003d).

APPENDIX 7 – LETTERS OF SUPPORT



Steritech Pty Ltd
A.C.N 007 308 027 A.B.N 30 451 935 502
www.steritech.com.au

29th July, 2013

VICTORIA
160 South Gippsland Hwy
Dandenong 3175

PO Box 4040
Dandenong South
Victoria 3164 Australia

Tel (03) 8726 5566
Fax (03) 9701 3158

NSW
5 Widemere Road
Wetherill Park 2164

PO Box 6632
Wetherill Park
N.S.W. 2164 Australia

Tel (02) 8785 4400
Fax (02) 9604 4396

QLD
180-186 Potassium Street
Narangba 4504

PO Box 376
Burrpengary
QLD 4505 Australia

Tel (07) 3293 1566
Fax (07) 3293 1544

**General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry**

Dear [REDACTED]

RE: Application to Food Standards Australia New Zealand (FSANZ) to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

For more than 30 years, Steritech has been a world leader in decontamination and sterilisation processing. Today, Steritech has plants operating in Melbourne, Sydney and Brisbane providing services to the medical, pharmaceutical, packaging and food industries. Steritech is proud to be an Australian family-owned company, operating the only commercially available irradiation plants in the country.

We believe changing the Code to allow the irradiation of: apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini is entirely consistent with FSANZ's legislated objective of protecting public health and safety. The widely held scientific consensus after more than 50-years of research is that when food irradiation is carried out in accordance with specified standards, it produces food that is safe and nutritious.

More than 50 countries currently allow the use of irradiation of food and international food regulatory bodies support use of the irradiation process at approved levels. Many countries, including the United States and the United Kingdom, have approved irradiation of fruit and vegetables as a food class for quarantine purposes and/or to extend shelf life.

With respect to consumer reaction to food irradiation, we wish to draw your attention to the New Zealand and US marketplaces. The availability of irradiation as a phytosanitary measure has opened up trade between Australia and New Zealand in mangoes, litchis, tomatoes, capsicums and papaya. Growing volumes of irradiated produce are now successfully being sold in New Zealand, a market that was previously shut to the horticulture industry in northern Australia due to quarantine restrictions on fruit fly host material.

The consumer and retailer acceptance of irradiated mangoes in New Zealand is high. Irradiated mangoes are now considered a mainstream product sold successfully in supermarkets and other fresh produce retail channels.

Food irradiation has given New Zealand consumers choice in tropical fruits where previously they had relied on often lower quality produce originating from Central and South America. As per FSANZ requirements the irradiated mangoes are sold in New Zealand with labels identifying they have been treated with ionising radiation. They are sold alongside non-irradiated products from other countries.

The success of the export of Australian irradiated tropical fruits to New Zealand confirms consumers are willing to purchase irradiated foods, particularly when it offers an advantage to them such as product quality and chemical residue free status.

In conclusion we would like to restate that not only is irradiation safe, it is technologically justified as it is effective against a broad spectrum of pests that create quarantine barriers for the horticultural industry. Moreover, irradiation is a commercially attractive phytosanitary measure for the industry as it is a non-invasive process that does not negatively impact food quality, leaves no chemical residues and is cost competitive.

Based on the above, we support Qld DAFF's proposal to amend the FSANZ Standard 1.5.3 Code to permit the irradiation of apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

Thank you for the opportunity to provide this 'Letter of Support' on the proposed changes to the Code. If you require any further information, please contact me on 03 8726 5566 or at mlynch@steritech.com.au

Yours faithfully,
Steritech Pty Ltd

A black rectangular box redacting the signature of the Chief Executive Officer.

Chief Executive Officer



Queensland Strawberry Growers Assoc. Inc.

ABN: 32 632 123 440

PO Box 917
COOROY Qld 4563

[REDACTED]
Fax: (07) 5474 0374

Email:

office@qldstrawberries.com.au

Web: www.qldstrawberries.com.au

30th July 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3

Please be advised that the Queensland Strawberry Industry supports the application submitted by DAFF Qld for the amendment of the Food Standards Code 1.5.3 to include strawberries on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose.

Yours Sincerely

[REDACTED]
Industry Development Officer



ABN: 77 797 945 686
Reg. No. IA10436

262 Argyle Street
Hobart Tas 7000
Tel: 03 62311 229
Fax: 03 62 311 929
Email: office@cherrygrowers.org

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

30 August 2013

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose.

Yours Sincerely

[REDACTED]
Chief Executive Officer



23rd July 2013

Australian Melon Association Inc

PO Box 913

Kenmore QLD 4069



General Manager

Strategic Policy and Planning

Agriculture and Forestry

Department of Agriculture, Fisheries and Forestry

Dear

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

I am writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose.

Yours Sincerely



Chairman



4 September 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

39 O'Connell Street
North Melbourne
Victoria 3051

P +61 (0) 3 9329 3511
F +61 (0) 3 9329 3522

info@apal.org.au
www.apal.org.au

ABN 55 490 626 489

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples.

We are writing to you to advise that we support the application submitted by Queensland DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples on the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

Yours sincerely

[REDACTED]

Industry Services Manager



27 August 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to you to advise that the Low Chill Executive, on behalf of low chill stone fruit growers in Australia, support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose.

We believe that low chill growers need as many options as possible at their disposal to control fruit fly. We must maintain access to our domestic and export markets and see irradiation as a useful tool. Irradiation will also allow us to access the ICA55 protocol

Yours sincerely

[REDACTED]

President

PO Box 25
Bangalow NSW 2479



5th August, 2013

General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes and zucchini.

In recent years the APVMA has been reviewing chemicals (notably dimethoate and fenthion) used for market access domestically and internationally. Due to this many industry bodies both locally and state wide have been investing in research into alternatives to current practices. One such research project was to confirm the possibility of using irradiation as an option for market access.

The Bowen Gumlu area is Australia's largest winter growing region and is worth an estimated \$400 million dollars annually. Over the years Bowen Gumlu Growers Association (BGGA) has established itself as a respected peak industry body that is known for its collaborative approach to managing key issues and priorities for the industry not just at a local level but state-wide and nationally. BGGA has contributed to many research projects including the irradiation research which has shown to be a safe, non-chemical, non-residual alternative.

BGGA are writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose.

Yours Sincerely, [REDACTED]

President

Bundaberg
Fruit & Vegetable
Growers



13/2 Tentitha Street
(PO Box 45)
Bundaberg QLD 4670

P: (07) 4153 3007

F: (07) 4153 1322

E: bfvg.info@bfvg.com.au

General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry

9th August, 2013

Dear [REDACTED]

RE: APPLICATION TO FSANZ TO AMEND THE FOOD STANDARDS CODE 1.5.3 TO INCLUDE APPLES; APRICOTS; CHERRIES; HONEYDEW MELONS; NECTARINES; PEACHES; PLUMS; ROCKMELONS; STRAWBERRIES; TABLE GRAPES AND ZUCCHINI

I am writing to you to advise that Bundaberg Fruit and Vegetable Growers Cooperative Ltd (BFVG) supports the application submitted by Queensland Department of Agriculture, Fisheries and Forestry (Q-DAFF), for the amendment of the Food Standards Code 1.5.3. I understand the application was for the inclusion of apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes and zucchini onto the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

BFVG was established in 1948 as a not-for-profit membership based organisation, becoming a non-trading Cooperative in 1997. Representing and advocating our members' interests at all levels of Industry and Government, BFVG has grown to become the central contact point for Horticulture in the Wide Bay Burnett. The organisation strives to provide up-to-date information to members through our office, regular newsletters, website and social media, funded projects and fee-for-service training. BFVG is passionate about promoting the industry and the healthy eating qualities of nutritious fruits, vegetable, nuts and herbs to the consumer.

BFVG now represents the whole supply chain for the Production Horticulture Industry of the Wide Bay Burnett region, particularly for our grower and Industry support members in the Bundaberg, Gayndah and Gympie Regional Council areas. The Wide Bay Burnett produces more than 30 different major horticultural commodities, several minor commodity lines and supports award-winning, innovative and progressive value-add businesses.

The horticulture industry of the Bundaberg Region alone employs over 5,000 people and now has an estimated farm gate value in excess of \$500 million, injecting over a billion dollars into Queensland's economy. Businesses in the Wide Bay Burnett now supply quality fresh and value-add products to the domestic and export markets, with the Wide Bay Burnett now recognised as one of the largest, most diverse food producing regions in Australia.

Therefore I welcome the opportunity to have Food Standards Code 1.5.3 amended as outlined, as this will allow producers and exporters of these commodities access to the Australian domestic markets in WA, SA and TAS under ICA-55, and to the New Zealand export market. This access will play a critical role for these businesses to maintain market integrity, competitiveness and profitability for their quality, safe products.

I trust the Q-DAFF application will be viewed favourably and assessed on the strong evidence provided which demonstrates irradiation as a safe, effective method for phytosanitary purposes.

Yours sincerely,

[REDACTED]
Executive Officer

CC: [REDACTED]

CLEAN • FRESH • QUALITY

This document (including attachments) is confidential and intended solely for the addressee(s). Unless you are the intended recipient's use, reading, printing, copying, storing or re-distribution of any part of this document is prohibited. If you are not the intended recipient of this document, please contact BFVG immediately.

Bundaberg Fruit & Vegetable
Growers Cooperative Ltd



2 August 2013

[Redacted]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
GPO Box 858
Canberra ACT 2601

ABN: 25 107 507 559
ACN: 107 507 559
PO Box 138
Camberwell VIC 3124
Level 2, 273 Camberwell Road
Camberwell VIC 3124
T (03) 9882 0277
F (03) 9882 6722
E info@ausveg.com.au
www.ausveg.com.au

[Redacted]

RE: Letter of Support - Application to FSANZ to amend the Food Standards Code 1.5.3

I am writing to you to advise that AUSVEG supports the application submitted by the Department of Agriculture, Fisheries and Forestry Queensland (DAFFQ), for the amendment of the Food Standards Code 1.5.3 to include zucchini on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose. Additionally, AUSVEG also supports the application for apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries and table grapes to be included on the approvals list.

Irradiation has proven to be an extremely effective method of pest disinfestation that has yielded several benefits for the Australian horticulture industry, including the opening of new export markets for a number of commodities, including mangoes to New Zealand.

If you have any questions or would like to discuss this matter further, please do not hesitate to contact me.

Yours sincerely

[Redacted Signature]
Chief Executive Officer



22 August 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

As a stone fruit and custard apple grower on the North Coast of New South Wales we are faced with producing fruit in a fruit fly endemic area. This task has become more difficult following the decision by APVMA to reduce the usage of Fenthion. Therefore to have irradiation as an approved disinfection treatment provides me with a much needed addition to my fruit fly control armory.

Yours sincerely

[REDACTED]



Director: [REDACTED] PO Box 25 Bangalow NSW 2479 |
email: fruitsofbyron@gmail.com | website: fruitsofbyron.com.au

CSI Group Pty Ltd

Exporters, Importers, Distributors of Fresh & Processed Produce
38 Walker st., Tennyson, Brisbane, QLD 4105, Australia
Ph. 61-7-38481299 e-mail: sales@csibris.com.au Fax. 61-7-38481233



[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

19th July 2013

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to advise you of our support of the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

This would considerably assist our domestic and export business, which has been severely hindered after FSANZ reviewed the use of dimethoate and fenthion

Yours Sincerely

[REDACTED]
Director

2nd August, 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

Yours Sincerely

[REDACTED]
[REDACTED]
Export Manager – The La Manna Group
[REDACTED]

The logo for La Manna Group, featuring the text "LA MANNA" in a bold, yellow, sans-serif font, with "GROUP" in a smaller, white, sans-serif font below it. The logo is set against a red rectangular background.



10th September, 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

Dear [REDACTED]

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini.

We are writing to you to advise that we support the application submitted by Qld DAFF, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes & zucchini, on the approvals list for the use of irradiation as a pest disinfestation treatment for a phytosanitary purpose.

Yours Sincerely

[REDACTED]

Divisional General Manager – Grapes & Citrus
Costa

26 August 2013

[REDACTED]
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry
[REDACTED]

Dear [REDACTED]

Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes and zucchini.

The New Zealand Fresh Produce Importers Association Inc. (NZ FPIA) represents importers, wholesalers, distributors and retailers of imported fresh produce. The current membership accounts for approximately 98% (by volume and value) of all fresh produce imported into New Zealand. This includes all currently approved products from Australia.

The NZ FPIA strongly supports the application submitted by Queensland Department of Agriculture and Forestry, for the amendment of the Food Standards Code 1.5.3 to include apples; apricots; cherries; honeydew melons; nectarines; peaches; plums; rockmelons; strawberries; table grapes and zucchini, on the approvals list for the use of irradiation as a pest disinfection treatment for phytosanitary purposes. The successful inclusion of the new commodities into the existing standard will be important for:

- Improving market access for those products already approved for export to New Zealand (e.g. grapes and zucchini) with the addition of irradiation as a viable and cost-effective treatment tool for a range of phytosanitary disinfection purposes.
- Developing market access opportunities using irradiation as a new treatment option for those commodities that do not have existing approval for export to New Zealand (e.g. cherries, nectarines, peaches and apricots).

The NZ FPIA looks forward to a favorable outcome from the FSANZ assessment process. Furthermore, the NZ FPIA also looks forward to working closely with interested parties on the “generic” (or grouped) application and assessment of horticultural commodities using irradiation as a post-harvest phytosanitary treatment in the very near future.

Yours Sincerely

[REDACTED]
Chief Executive Officer
New Zealand Fresh Produce Importers Association Inc.



Fresh Partners (Pacific) Ltd

5 August 2013

██████████
General Manager
Strategic Policy and Planning
Agriculture and Forestry
Department of Agriculture, Fisheries and Forestry

Dear ██████████

Re: Application to FSANZ to amend the Food Standards Code 1.5.3 to include apples, apricots, cherries, honeydew melons, nectarines, peaches, plums, rockmelons, strawberries, table grapes and zucchini.

We wish to advise that we support the application submitted by Queensland DAFF for the amendment of the Food Standard's Code 1.5.3 to include apples, apricots, cherries, honeydew melons, nectarines, peaches, plums, rockmelons, strawberries, table grapes, and zucchini on the approvals list for the use of irradiation as a pest disinfection treatment for a phytosanitary purpose.

Yours sincerely

██████████

Fresh Partners Pacific Ltd

705 Rosebank Road, Avondale, Auckland, NZ
PO Box 37601, Parnell, Auckland, 1151 NZ
Phone: 64-9-820-5294 Fax: 64-9-820-5295

REFERENCES

- ABS (1998). Australian Bureau of Statistics. National Nutrition Survey: Nutrient Intakes and Physical Measurements, Australia, 1995. Cat. No. 4805.0. Accessed July 2013 at <http://www.abs.gov.au/ausstats/abs@.nsf/0/95E87FE64B144FA3CA2568A9001393C0?OpenDocument> .
- ABS (1999). Australian Bureau of Statistics. National Nutrition Survey: Foods Eaten, Australia, 1995. Cat. No. 4804.0. Accessed July 2013 at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/0/9A125034802F94CECA2568A9001393CE?OpenDocument> .
- ABS (2008). Australian Bureau of Statistics. Agricultural Commodities: Small Area Data, Australia, 2006–07. Cat. No. 7125.0. Accessed July 2013 at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/productsbyCatalogue/950D33073DC81695CA25745F00205C9A> .
- ABS (2011a). Australian Bureau of Statistics. Agricultural Commodities, Australia, 2009–10. Horticulture. Cat. No. 7121.0. Accessed July 2013 at <http://www.abs.gov.au/ausstats/abs@.nsf/Products/7121.0~2009-10~Main+Features~Horticulture?OpenDocument> .
- ABS (2011b). Australian Bureau of Statistics. Value of Agricultural Commodities Produced., Australia, 2009–10. Crops. Cat. No. 7503.0. July 2013 at <http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7503.02009-10?OpenDocument> .
- ABS (2013). Value of Agricultural Commodities Produced, Australia, 2011–12. Accessed July 2013 at ABS 7503 <http://search.live.com/results.aspx?q=abs+7503&src=IE-SearchBox&Form=IE8SRC>).
- ABW (2009). Agriculture Business Week. External Hot Water Treatment: A Cheaper Alternative to Costly Vapour Heat Treatment in Mango. January. Accessed July 2013 at <http://www.agribusinessweek.com/external-hot-water-treatment-a-cheaper-alternative-to-costly-vapor-heat-treatment-in-mango/> .
- ADA (2000). American Dietetic Association. Position of the American Dietetic Association: Food Irradiation, by Wood, O.B. and Bruhn, C.M. American Dietetic Association. *Journal of the American Dietetic Association* **100** (2), 246–253.
- Adam, S. (1983). Recent Development in Irradiation Chemistry of Carbohydrate. In: *Recent Advances in Food Irradiation*. (Editors P.S. Elias and A.J. Cohen). Elsevier Biomedical Press, Amsterdam, the Netherlands, p 149–170.
- AFRA (undated). Agriculture, Food and Rural Affairs, Ontario, Canada. The Effect of Extreme Temperatures on the Tomato and Pepper Crop. Accessed July 2013 at http://www.omafra.gov.on.ca/english/crops/facts/info_tomtemp.htm .
- Akamine, E.K. and Moy, J.H. (1983). Delay in Postharvest Ripening and Senescence of Fruits. In: *Preservation of Food by Ionizing Radiation*, Vol III. (editors E.S. Josephson and M.S. Peterson) CRC Press, Inc., Boca Raton, Florida, pp. 129–158.
- Akbudak, B., Tezcan, H. and Eris, A. (2008). Effect of low dose irradiation on the quality of sweet cherry during storage. *Italian Journal of Food Science* **20**, 381–390.

Al-Bachir, M. (1998). Use of gamma-irradiation and sulfur dioxide to improve storability of two Syrian grape cultivars (*Vitis vinifera*). *International Journal of Food Science & Technology* **33**, 521–526.

Al-Bachir, M. 1999. Effect of gamma irradiation on storability of apples (*Malus domestica* L.). *Plant Foods for Human Nutrition* **54**, 1–11.

Allaume, K. (2010). The Australian Cherry Report. Commissioned by the Australian Cherry industry. Accessed July 2013 at <http://australiancherries.com.au/cherry-report>

Ampomah-Dwamena, C., McGhie, T., Wibisono, R., Montefiori, M., Hellens, R.P. and Allan, A.C. (2009). The kiwifruit lycopene beta-cyclase plays a significant role in carotenoid accumulation in fruit. *Journal of Experimental Botany Advance Access published July 2, 2009* 15pages.

APAL (2010). Apple and Pear Industry RD&E Investment Plan 2010–2015 - “Innovation making a difference”. Prepared by DR Research & Consulting. Accessed July 2013 at http://webcache.googleusercontent.com/search?hl=en-AU&q=cache:O8Jt3l7lbC8J:http://cms2live.horticulture.com.au/admin/assets/library/strategic_plans/pdfs/PDF_File_47.pdf%2BFresh+apple+imports+have+the+pote ntial+to+reduce+Australian+domestic+market+share+by+up+to+a+third+and+the+ returns+to+the+industry+by+up+to+40%25&gbv=2&gs_l=heirloom-hp.3...3421.3421.0.3905.1.1.0.0.0.0..0.0...0.0...1c.1.wXuoik9uZ7q&safe=active&ct=clnk

APAL (2012). Apple & Pear Australia Ltd. Industry Annual Report 2011/12. Accessed July 2013 at http://www.horticulture.com.au/industries/Apple_and_Pear/default.asp

Arvanitoyannis, I.S., Stratakis, A.Ch. and Tsarhouas, P. (2009). Irradiation Applications in Vegetables and Fruits: A Review. *Crit. Rev. Food Sci. Nutrition* **49**, 427–462.

Arvanitoyannis, I.S. and Stratakis, A.Ch. (2010a). Irradiation of Insects: Disinfestation. In: *Irradiation of Food Commodities* (editor I.S. Arvanitoyannis), Elsevier, London, U.K. pp.537–560.

Arvanitoyannis, I.S. and Stratakis, A.Ch. (2010b). Irradiation of Fruits and Vegetables. In: *Irradiation of Food Commodities* (editor I.S. Arvanitoyannis), Elsevier, London, U.K. pp 467–535.

ASEAN Cooperation in Food, Agriculture and Forestry (no date). Model Protocaol for the Use of Irradiation as a Quarantine Treatment for the Export and Import of Fresh Fruits and Vegetables for ASEAN. Food Handling Publication Series No. 2. Accessed July 2013 at http://www.asean.org/archive/agr_pub/food2.doc

ASEAN Cooperation in Food, Agriculture and Forestry (no date). A Harmonised Regulation on Food Irradiation for ASEAN. Food Handling Publication Series No. 3. http://www.aseansec.org/agr_pub/food3.doc

ASTM (2003). ASTM International Standard E2303 – 03. Standard Guide for Absorbed□Dose Mapping in Radiation Processing Facilities, ASTM International, West Conshohocken, PA, USA. DOI: 10.1520/E2303□03. Accessed July 2013 and E2303 – 11 available from <http://www.astm.org/Standards/E2303.htm>.

ASTM (2006). ASTM International ASTM F1355 – 06 (2006). Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment. ASTM

International, West Conshohocken, PA, USA. DOI: 10.1520/F1355–06. Accessed July 2013 and available from <http://www.astm.org/Standards/F1355.htm> .

ASTM (2009). ASTM International ASTM F1640 – 09. Standard Guide for Selection and Use of Packaging Materials for Foods to Be Irradiated, ASTM International, West Conshohocken, PA, DOI: 10.1520/F1640–09. Accessed July 2013 and available from <http://www.astm.org/Standards/F1640.htm> .

ATGA (2013). Australian Table Grape Association. Accessed July 2013 at <http://www.australiangrapes.com.au/consumers/facts>

Australian Standard AS2070 –1999. Australian Standard for Plastics Materials for Food Contact Use, 7 page summary. Standards Association of Australia, NSW 2140. ISBN 0 7337 2496 5.
<http://www.saiglobal.com/PDFTemp/Previews/OSH/As/as2000/2000/2070.pdf>

Australian Stonefruit Grower Magazine Nov 2012 Issue 4/12.
<http://www.summerfruit.com.au/Growers/Australian-FruitGrower.aspx>

AusVeg Vegetables grown in field. Accessed July 2013 at <http://ausveg.businesscatalyst.com/resources/statistics/domestic-industry/detailed-data.htm>

BA (2008a). Biosecurity Australia (2008). Quarantine Policy Determination for Fresh Mango Fruit from India.

BA (2008b). Biosecurity Australia. Final Import Risk Analysis Report for Fresh Mango Fruit from India. Accessed July 2013 at http://www.daff.gov.au/__data/assets/pdf_file/0003/771906/Mangoes_from_India_Final_Report.pdf .

Baker, G.A. and Crosbie, P.J. (1993). Measuring Food Safety Preferences: Identifying Consumer Segments. *J. Agricultural and Resource Economics*. **18 (2)**, 277–287.

Baker, G.A. (1999). Consumer Preferences for Food Safety Attributes in Fresh Apples: Market Segments, Consumer Characteristics, and Marketing Opportunities. *J. Agricultural and Resource Economics*. **24 (1)**, 80–97.

Becker, R.L. (1983). Absence of Induced Radioactivity in Irradiated Foods. In: *Recent Advances in Food Irradiation* (editors, P.S. Elias and A.J. Cohen) Elsevier Biomedical. pp. 285–313.

Beyers, M., Thomas, A.C. and van Tronder, A.J. (1979). Gamma–Irradiation of Sub–Tropical Fruits. I. Compositional Tables of Mango, Papaya, Strawberry and Litchi Fruits at the Edible Ripe Stage. *J. Agricultural and Food Chemistry* **27 (1)**, 37–42.

Belrose, Inc. World Apple Review– 2008 Edition: Accessed April 2013 at <http://www.e-belrose.com/2008WorldAppleReview.html> .

Beyers, M. and Thomas, A.C. (1979). Gamma–Irradiation of Subtropical Fruits. 4. Changes in Certain Nutrients Present in Mangoes, Papayas, and Litchis During Canning, Freezing and Gamma Irradiation. *Journal of Agricultural and Food Chemistry* **27 (1)**, 48–51.

Blakesley, C.N., Loots, J.G., du Plessis, L.M. and de Bruyn, G. (1979). γ Irradiation of subtropical fruits and vegetables. 2. Volatile components, lipids, and amino acids

- of mango, papaya and strawberry pulp. *Journal of Agricultural and Food Chemistry* **27**, 42–48.
- Bord, R.J. and O'Connor, R.E. (1989). Who wants irradiated food? Untangling complex public opinion. *Food Technology* **43** (10), 87–90.
- Boyd, D.R., Crone, A.V.J., Hamilton, J.T.G., Hand, M.V., Stevenson, M.H. and Stevenson, P.J. (1991). Synthesis, characterization, and potential use of 2-dodecylcyclobutanone as a marker for irradiated chicken. *Journal of Agricultural and Food Chemistry* **39** (4), 789–92.
- Boylston, T.D., Reitmeier, C.A., Moy, J.H., Mosher, G.A. and Taladriz, L. (2002). Sensory Quality and Nutrient Composition of Three Hawaiian Fruits Treated By X-Irradiation. *Journal of Food Quality* **25**, 419–433.
- Braddock, R.J., Dennison, R.A., Ahmed, E.M. (1966) The influence of gamma irradiation on textural changes in peaches. *Florida Agricultural Experiment Stations Journal Series* **2554**, 281–284.
- Bramlage, W.J. and Lipton, W.J. (1965). Gamma Radiation of Vegetables to Extend Market Life. *Marketing Research Report* Number 703, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C.
- Brewer, M.S. and Rojas, M. (2008). Consumer Attitudes toward Issues in Food Safety. *Journal of Food Safety* **28**, 1–22.
- Bruhn, C.M., Sommer, R. and Schutz, H.G. (1986). Effect of an Educational Pamphlet and Posters on Attitude toward Food Irradiation. *Journal of Industrial Irradiation Technology* **4** (1), 1–20.
- Bruhn, C.M. (1995). Consumer attitudes and market response to irradiated food. *Journal of Food Protection* **58** (2), 175–181.
- Bruhn, C.M. (1999). Consumer Attitudes and Market Response to Irradiated Food. International Consultative Group on Food Irradiation (ICGFI). Available from the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Vienna, Austria.
- Burditt, Jr. A.K. (1996). Irradiation as a Quarantine Treatment against Fruit Flies. In: *Fruit Fly Pests: A World Assessment of their Biology and Management*. (editors G. McPherson and G. Steck) St Lucie Press, Delaray Beach Florida. pp. 479–484.
- Bhushan, B. and Thomas, P. (1998). Quality of apples following gamma irradiation and cold storage. *International Journal of Food Sciences and Nutrition* **49** (6), 485–492.
- CAC (1983). Codex Standard Recommended International Code of Practice for the Operation of Irradiation Facilities Used for the Treatment of Foods (CAC/RCP 19–1979 (Rev. 1–1983). Codex Alimentarius, FAO/WHO, Rome. Accessed July 2013 at http://siweb.dss.go.th/standard/Fulltext/codex/CXP_019E.pdf.
- CAC (2003a). Codex Alimentarius Commission. General Standard for Irradiated Foods (CODEX STAN 106_1983, Rev.1–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed July 2013 at http://www.codexalimentarius.net/download/standards/16/CXS_106e.pdf.

- CAC (2003b). Codex Alimentarius Commission. Code of Practice for Radiation Processing of Food (CAC/RCP 19–1979 (Rev. 2–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed July 2013 at http://www.codexalimentarius.net/download/standards/18/CXP_019e.pdf
- CAC (2003c). Codex Alimentarius Commission. Code of Hygienic Practice for Fresh Fruits and Vegetables (CAC/RCP 53–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed July 2013 at http://www.codexalimentarius.net/download/standards/10200/CXP_053e.pdf.
- CAC (2003d) Codex Standard Recommended International Code of Practice General Principles of Food Hygiene CAC/RCP 1–1969, Rev. 4–2003. Codex Alimentarius, FAO/WHO, Rome. Accessed July 2013 at General Principles of Food Hygiene – CODEX Alimentarius
- CAC (2003e). Codex Alimentarius Commission. General Methods for the Detection of Irradiated Foods (CODEX STAN 231, Rev.1–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed July 2013 at http://www.codexalimentarius.net/download/standards/377/CXS_231e.pdf.
- Canada Food and Drugs Act (2009a). Food and Drug Regulations Div 26 Food Irradiation. Accessed July 2013 at http://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._870/FullText.html
- Canada Food and Drugs Act (2009b). Food and Drug Regulations Div 23 Food packaging materials. Accessed July 2013 at http://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._870/index.html
- CFIA (2009). Canadian Food Inspection Agency. Food and Drugs Regulations Div 23 Food packaging materials, Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical Products. Accessed July 2013 at <http://www.inspection.gc.ca/english/fssa/reference/refere.shtml>
- Carbone, K., Giannini, B., Picchi, V., Scalzo, R. L. and Cecchini, F. (2011). Phenolic composition and free radical scavenging activity of different apple varieties in relation to the cultivar, tissue type and storage. *Food Chemistry* **127** (2), 493–500.
- Cassidy, J.P, Caulfield, C, Jones, B.R, Worrall, L, Conlon, L, Palmer, A.C, and Kelly, J. (2007) Leukoencephalomyelopathy in Specific Pathogen–Free Cats. *Vet. Pathology*, **44**, 912–916.
- Castell-Perez E, Moreno M, Rodriguez O and Moreira, RG (2004). Electron beam irradiation treatment of cantaloupes: effect on product quality. *Food Science and Technology International* **10** (6): 383–390.
- Caulfield, C.D, Kelly, J.P, Jones, B.R, Worrall, S, Conlan, L, Palmer, A.C and Cassidy, J.P. (2009) The Experimental Induction of Leukoencephalomyelopathy in Cats. *Vet. Pathology*, **46**, 1258–1269.
- CDC (2011). Centers for Disease Control and Prevention. Fruit and Vegetable Benefits. Accessed July 2013 at <http://www.fruitsandveggiesmatter.gov/benefits/index.html>
- Cherry Growers Australia website. Accessed July 2013 at <http://www.cherrygrowers.org.au/>
- Cherry Growers Australia. Australian Cherry Strategic Marketing Plan 2012–2017. Accessed July 2013 at <http://cherrygrowers.org.au/marketing/>

Child, G, Foster, D.J, Fougere, B.J, Milan, J.M, and Rozmanec, M. (2009) Ataxia and Paralysis in Cats in Australia Associated with Exposure to in Imported Gamma-Irradiated Commercial Dry Pet Food. *Aus. Vet J.* **87** (9), 349–351.

CIE (2010). Centre for International Economics, 'Part 2: economic impact statement', Adjusting to apple imports, prepared for Apples and Pears Australia Limited, Canberra & Sydney, December 2010, viewed 27 June 2012, <http://www.apal.org.au/assets/content/3917/Final%20CIE%20Economic%20Impact%20Statement%20-%202016%20December%202010.pdf>

CONSLEG: 1999L0002 — 20/11/2003. Directive 1999/3/EC of the European Parliament and of the Council of 22 February 1999 on the establishment of a Community list of foods and food ingredients treated with ionising radiation. CONSLEG system of the Office for Official Publications of the European Communities. Accessed July 2013 at http://europa.eu/legislation_summaries/consumers/product_labelling_and_packaging/l21117_en.htm

Crawford, L.M. and Ruff, E.H. (1996). A Review of the Safety of Cold Pasteurization through Irradiation. *Food Control* **7**, 87–97.

Crone, A.V.J., Hamilton, J.T.G. and Stevenson, M.H. (1992). Detection of 2-Dodecylcyclobutanone in Radiation Sterilized Chicken Meat Stored for Several Years. *Int. J. Food Sci. Technol.* **27**, 691–696.

Cunningham, J.H., Milligan, G. and Trevisan. (2002) L. Minerals in Australian fruits and vegetables - a comparison of levels between the 1980s and 2000. FSANZ. Accessed July 2013 at <http://www.foodstandards.gov.au/publications/pages/minerallevelsinaustr2428.aspx>

DAFF Australian Horticulture Factsheet January 2012. Accessed July 2013 at <http://www.daff.gov.au/agriculture-food/food/publications/hort-fact-sheet>

DAFF (no date). Processed Fruit and Vegetables. Analysis of the determinants of prices and costs in product value chains.

DAFF Australia website. MICOR, Manual of Importing Country Requirements. (originally AQIS 2009) Mango Imports to Malaysia. Accessed July 2013 at http://www.daff.gov.au/micor/plants/malaysia_my2/mango

D'Amour J., Gosselin C., Arul J., Castaigne F., Willemot C. (1993) Gamma-radiation affects wall composition of strawberries. *Journal of Food Science*, 58: 182–185.

Delincee, H. and Pool-Zobel, B.L. (1998). Genotoxic Properties of 2-Dodecylcyclobutanone, A Compound Formed on Irradiation of Food Containing Fat. *Radiation Physics and Chemistry* **52**, 39–42.

DeRuiter, F.E. and Dwyer, J. (2002). Consumer Acceptance of Irradiated Foods: Dawn of a new era? *Food Service Technology* **2** (1), 47–58.

Diehl J.F. (1990). Safety of irradiated foods. 1st ed. New York: Marcel Dekker Inc. 196 p. unadulterated system.

Diehl, J.F., Hasselmann, C. and Kilcast, D. (1991). Regulation of Food Irradiation in the European Community: Is Nutrition an Issue? *Food Control*: October edition, 212–219.

Diehl, J.F. (1995). Chemical Effects of Ionizing Radiation. In: *Safety of Irradiated Foods*, 2nd Ed., CRC Press, New York. pp. 41–94.

Ding, C–K., Wang, C.Y., Gross, K.C. and Smith, D.L. (2002). Jasmonate and Salicylate Induce the Expression of Pathogenesis–Related–Protein Genes and Increase Resistance to Chilling Injury In Tomato Fruit. *Planta* **214**, 814–901.

Donini, L.M.B. and Pansolli, P. (1970). Gamma irradiation of table grapes of the "Hoanes" variety. *Food Irradiation* **10 (4)**, 15–21.

DQMAWG (2010). Domestic Quarantine & Market Access Working Group. National Response Plan. Responding Effectively to Changes in Approved Uses of Dimethoate and Fenthion. 17 December 2010. Accessed July 2013 at <http://www.domesticquarantine.org.au/go/dqmawg/issues-and-decisions/apvma-reviews-of-dimethoate-and-fenthion> .

DQMAWG (2013a). Domestic Quarantine & Market Access Working Group. Interstate Certification Assurance (ICA). Accessed July 2013 at <http://domesticquarantine.org.au/ica-database>

DQMAWG (2013b). Domestic Quarantine & Market Access Working Group. Accessed July 2013 at <http://domesticquarantine.org.au/>

Dragovic-Uzelac, V., Levaj, B., Mrkic, V., Bursac, D. and Boras, M. (2007). The content of polyphenols and carotenoids in three apricot cultivars depending on stage of maturity and geographical region. *Food Chem* **102**, 966–975.

Drake, S.R. and Neven, L.G. (1997). Quality Response of 'Bing' and 'Rainier' Sweet Cherry to Low Dose Electron Beam Irradiation. *Journal of Food Processing and Preservation* **21**, 345–351.

Drake, S.R. and Neven L.G. (1998). Irradiation as an alternative to methyl bromide for quarantine treatment of stone fruits. *Journal of Food Quality* **22**, 529–538.

Drake, S.R., Moffitt, H.R., Eakin, D.E. (1994). Low dose irradiation of 'Rainier' sweet cherries as a quarantine treatment. *Journal of Food Processing and Preservation* **18**, 473–481.

Drake, S. R., Sanderson, P.G. and Neven, L.G. (1998). Quality of apples and pears after exposure to irradiation as a quarantine treatment. USDA, ARS-TFRL 1104 N. Western Ave., Wenatchee, WA 98801. <http://www.mbao.org/1998airc/079drake.pdf>

Drake, S.R., Neven, L.G. and Sanderson, P.G. (2003). Carbohydrate concentrations of apples and pears as influenced by irradiation as a quarantine treatment. *Journal of Food Processing and Preservation*, 165–172.

Duncan, I.D, Brower, A, Kondo, Y, Curlee, J.F. and Schultz, R.D. (2009) Extensive Remyelination of the CNS Leads to Functional Recovery. *Proc. Nat. Acad. Sciences (US)*, April 21, **106 (16)**, 6832–6836.

Egea, M.I., Murcia, M.A., Sánchez-Bel, P., Romojaro, F. and Martínez-Madrid, M.C. (2005). Effect of electron beam ionization on shelf life of apricot. *ISHS Acta Horticulturae* **682**: V International Postharvest Symposium.

Egea, M.I., Martínez-Madrid, M.C., Sánchez-Bel, P., Murcia, M.A., Romojaro, F. (2007) The influence of electron-beam ionization on ethylene metabolism and quality parameters in apricot (*Prunus armeniaca* L., cv Búlida). *Food Science and Technology* **40**, 1027–1035.

EFSA (2011). European Food Safety Authority. Scientific Opinion on the Chemical Safety of Irradiation of Food. *EFSA Journal* **9** (4): 1930, pp57. Accessed July 2013 at <http://www.efsa.europa.eu/en/efsajournal/pub/1930.htm>

EPA (1996). U.S Environmental Protection Agency. Methyl Bromide Alternatives Case Study. Heat treatments (Hot–Water Immersion, High Temperature Forced Air, Vapor heat) as Alternative Quarantine Control Technologies for Perishable Commodities. December. Accessed July 2013 at <http://www.mbao.org/heatcom2.html>

EU (1999a). European Union. Directive 1999/2/EC of the European Parliament and of the Council. Concerning Food and Food Ingredients Treated with Ionizing Radiation. February 22nd 1999. Official Journal of the European Communities.

EU (1999b). European Union. Directive 1999/3/EC of the European Parliament and of the Council. On The Establishment of a Community List of Food and Food Ingredients Treated with Ionizing Radiation. February 22nd 1999. Official Journal of the European Communities.

EU (2009a). European Commission Directive 2009/975/EC Amending Directive 2002/72/EC Relating to Plastic Materials and Articles Intended to Come into Contact with Food. 19 October 2009. Official Journal of the European Communities Accessed July 2013 at <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:274:0003:0008:EN:PDF> .

EU (2009b). European Standards for Detection of Irradiated Foodstuffs. Accessed July 2013 at http://ec.europa.eu/food/food/biosafety/irradiation/anal_methods_en.htm .

European Commission (2002). Statement of the Scientific Committee on Food on a report on 2-alkylcyclobutanones. European Commission, Health and Consumer Protection Directorate–General, Directorate Scientific Opinions, C2-Management of Scientific Committee II: Scientific Cooperation, Brussels, Belgium. Accessed July 2013 at http://ec.europa.eu/food/fs/sc/scf/out135_en.pdf

Eustice, R.F. and Bruhn, C.M. (2006). Consumer Acceptance and Marketing of Irradiated Foods. In: *Food Irradiation Research and Technology* (editors C.H. Sommers and X. Fan) Blackwell Publications, Ames, Iowa, pp. 63–83.

Growcom (2011). Food security issues for the Australian horticulture industry. AH09009. A report prepared for HAL project AH09009.

Fan, X. and Sokorai, K.J. (2008). Effect of Ionising Radiation on Furan Formation in Fresh–Cut Fruits and Vegetables. *J. Food Science* **73**, C79–C83.

Farkas, J. and Mohacsi-Farkas, C. (2011). History and future of food irradiation. *Trends in Food Science & Technology* **22**, Issues 2–3, 121–126. Accessed July 2013 at <http://www.sciencedirect.com/science/article/pii/S0924224410001044>

- FAO (2002). Food and Agriculture Organisation of the United Nations. Food Energy – Methods of Analysis and Conversion Factors. Report of a Technical Workshop, 3–6 December, Rome. Chapter 3 – Calculation of the Energy Content of Foods – Energy Conservation Accessed July 2013 at <http://www.fao.org/DOCREP/006/Y5022E/y5022e04.htm> .
- FAO/IAEA (2011a). Food and Agriculture Organisation/International Atomic Energy Agency. International Database on Insect Disinfestation and Sterilisation. Accessed February 2012 at <http://ididas.iaea.org/default.aspx>.
- FAO Stat Agricultural Database website. Accessed July 2013 at <http://faostat.fao.org/site/339/default.aspx> for production, consumption and database stats.
- Farkas, J. (2006). Irradiation for better foods. *Trends in Food Science & Technology* **17**, 148–152. Elsevier.
- Farkas, J., Saray, T., Mohacsi–Farkas, C., Horti, K. and Andrassy, E. (1997). Effects of Low–Dose Gamma Radiation on the Shelf–Life and Microbiological Safety of Pre–Cut/Prepared Vegetables. *Adv. Food Science* **19**, 111–119.
- FDA (1986). Food and Drug Administration. Irradiation in the Production, Processing, and Handling of Food; Final Rule. 51 (75) FR 13376–13399. 18 April. Docket No. 81N–0004. e–CFR Data is current as of July 8 2013. Accessed July 2013 at <http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div5&view=text&node=21:3.0.1.1.10&idno=21> .
- FDA (2005). Food and Drug Administration. Irradiation in the Production, Processing and Handling of Food: Final Rule. Fresh or Frozen Molluscan Shellfish. Federal Register **21** CFR Part 179. 70 FR 48057, Docket Number 1999F–4372. 16 August 2006.
- FDA (2007). Food and Drug Administration. Packaging Materials Listed in **21** CFR 179.45 for Use During Irradiation of Pre–packaged Foods.
- FDA (2008). Food and Drug Administration. Irradiation in the Production, Processing and Handling of Food, Food and Drug Administration. Final rule: Iceberg lettuce and spinach. *Federal Register*. Vol **73**, No. 164, 21 CFR Part 179. [Docket No. FDA–1999–F–2405]. 73 FR 49593.
- FDA (2011). Food and Drug Administration. Ionizing Radiation for the Treatment of Food. e–CFR, Electronic Code of Federal Regulations. **21** CFR Part 179.26. Sub–part B. Accessed July 2013 at <http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=179> .
- Fennema, O. (1977). Loss of vitamins in fresh and frozen foods. *Food Technol.* **31** (12), 32–38.
- Fernandez, M., Rojo, M.I., Tomicic, I. and Toha, J. (1984). Genetic risk of irradiated food consumption evaluated theoretically and experimentally. *Environ. Exper. Botany* **24** (4), 311–319.
- Follett, P. A., and Armstrong, J. W. 2004. Revised irradiation doses to control melon fly, Mediterranean fruit fly, and oriental fruit fly (Diptera: Tephritidae) and a generic dose for Tephritid fruit flies. *J. Econ. Entomol.* **97** (4), 1254–1262.

- Follet, P. A., and Griffin, R. L. (2006). Irradiation as a Phytosanitary Treatment for Fresh Horticultural Commodities: Research and Regulations. In: *Food Irradiation Research and Technology* (editors C.H. Sommers and X. Fan) Blackwell Publications, Ames, Iowa, pp143–168.
- Follett, P. A. and Neven, L.G. (2006). Current Trends in Quarantine Entomology. *Ann. Rev. Entomol.* **51**, 359–385.
- Follett, P.A. and Sanxter, S.S. (2000). Comparison of Rambutan Quality after Hot Forced-Air and Irradiation Quarantine Treatments. *HortScience* **35** (7), 1315–1318.
- Follett, P.A. and Sanxter, S.S. (2002). Longan Quality after Hot Water Immersion and X-ray Irradiation Quarantine Treatments. *HortScience* **37** (3), 571–574.
- Follett, P.A. and Sanxter, S.S. (2003). Lychee Quality after Hot Water Immersion and X-ray Irradiation Quarantine Treatments. *HortScience* **38** (6), 1159–1162.
- Foster, M., Fell, J., To, H., Rees, G. and Bowen, B. (2010). Overview of the Australian food industry, 2009-10. ABARE. Accessed July 2013 at Australian Food Statistics 2009-10 - Department of Agriculture ...
- Fresh Intelligence Consulting (2013a). Analysis of Expected Volumes of Queensland Fruit and Vegetables Distributed to South Australia, Western Australia and Tasmania. May 2013.
- Fresh Intelligence Consulting (2013b). Fresh Fruit and Vegetable Export Analysis 2012. June 2013.
- Freshlogic (2012). Tasmania Department of Primary Industries, Parks, Water and Environment Strawberry Market Profile. Accessed July 2013 at <http://www.dpiw.tas.gov.au/inter.nsf/WebPages/JBAS-8M66QQ?open>
- L.J. Frewer *et al.* (2011). Trends in Food Science & Technology 22 (2011) 442-456. Accessed July 2013 at <http://www.sciencedirect.com/science/article/pii/S092422441100094X#>
- FSA (2004). Food Standards Agency (UK). Consumer Attitudes to Food Standards: Wave 4. Prepared for the Food Standards Agency and COI Communications. Accessed July 2013 at <http://www.food.gov.uk/multimedia/pdfs/cas2003.pdf>.
- FSA (2007). Food Standards Agency (UK). Minimising Pesticide Residues. Accessed July 2013 at <http://www.food.gov.uk/safereating/chemsafe/pesticides/pesticidesminimisehome/>
- FSANZ Standard 1.4.3. Food Standards Australia New Zealand. Articles and materials in contact with food. http://www.foodstandards.gov.au/srcfiles/Standard_1_4_3_Arts_&_Mats_v95.pdf
- FSANZ Standard 1.5.3. Food Standards Australia New Zealand. Irradiation of Food http://www.foodstandards.gov.au/srcfiles/Standard_1_5_3_Irrad_v104.pdf
- FSANZ (2001). Food Safety Australia New Zealand. Application A413. Irradiation of Herbs and Spices. Final Assessment Report and Regulatory Statement. Accessed July 2013 at <http://archive.foodstandards.gov.au/foodstandards/applications/applicationa413irradiationofherbsandspices/>

- FSANZ (2003). Food Safety Australia New Zealand. Application A 443. Irradiation of Tropical Fruit. Final Assessment Report. Accessed July 2013 at <http://www.foodstandards.gov.au/code/applications/Pages/applicationa443irradiationoftropicalfruit/Default.aspx>
- FSANZ (2008). Food Safety Australia New Zealand. TNS Social Research. *Consumer Attitudes Survey 2007*. Quoted in FSANZ summary of available literature on consumers and food irradiation.
- FSANZ (2010). Food Standards Australia New Zealand. NUTTAB 2010. Nutrient data for 2668 foods available in Australia. On-line search at <http://www.foodstandards.gov.au/science/monitoringnutrients/nutrientables/Pages/default.aspx>
- FSANZ (2011a). Food Standards Australia New Zealand. Application A1038 Irradiation of Persimmons. Assessment Report. Accessed July 2013 at <http://www.foodstandards.gov.au/code/applications/pages/applicationa1038irradiationofpersimmons/5.aspx>
- FSANZ (2012). Food Standards Australia New Zealand. Application A1069 Irradiation of Tomatoes & Capsicums. Approval Report. Accessed July 2013 at <http://www.foodstandards.gov.au/code/applications/Pages/applicationa1069irradiationoftomatoesandcapsicums/1.aspx>
- FSANZ. (2011b). Food Standards Australia New Zealand. Food Irradiation. Consumer Information Document. Accessed July 2013 at <http://archive.foodstandards.gov.au/consumerinformation/>
- Gadgil, P., Hachmeister, K. A., Smith, J. S. and Kropf, D.H. (2002). 2-Alkylcyclobutanones as Irradiation Dose Indicators in Irradiated Ground Beef Patties. *J. Agric. Food Chem.* **50** (20), 5746–5750.
- Gadgil, P. and Smith, J.S. (2004). Mutagenicity and Acute Toxicity Evaluation of 2-Dodecylcyclobutanone. *Journal of Food Science* **69** (9), 713–716.
- Gadgil, P., Smith, J. S., Hachmeister, K.A., and Kropf, D.H. (2005). Evaluation of 2-Dodecylcyclobutanone as an Irradiation Dose Indicator in Fresh Irradiated Ground Beef. *J. Agric. Food Chem.* **53** (6), 1890–1893.
- Gadgil, P. and Smith, J.S. (2006). Metabolism by Rats of 2-Dodecylcyclobutanone, a Radiolytic Compound Present in Irradiated Beef. *J. Agric. Food Chem.* **54** (13), 4896–4900.
- Gamble, J., Harker, R. and Gunson, A. (2002). New Zealand and Australian Perceptions of Irradiated Food. *Report to The Horticulture and Food Research Institute of NZ Ltd.* Horticulture Australia Ltd., Sydney. ISBN 0 7341 0501 0.
- Gholap, A.S., Bandyopadhyay, C. and Nair, P.M. (1990). Lipid composition and flavour changes in irradiated mango (var. Alphonso). *Journal of Food Science* **55** (6), 1579–1584.
- Gunes, G. and Tekin, M.D. (2006). Consumer awareness and acceptance of irradiated foods: Results of a survey conducted on Turkish consumers. *LWT Food Science and Technology* **39**, 443–447. Swiss Society of Food Science and Technology.

- Gomes, C., Moreira, R.G., Castell-Perez, M.E., Kim, J., Da Silva, P. and Castillo, A. (2008a). E-beam Irradiation of Bagged, Ready-To-Eat Spinach Leaves (*Spinacea oleracea*): An Engineering Approach. *Journal of Food Science* **73**, Nr. 2, 95–102.
- Gomes, C., Da Silva, P., Chimbombi, E., Kim, J., Castell-Perez, E. and Moreira, R.G. (2008b). Electron-Beam Irradiation of Fresh Broccoli Heads (*Brassica oleracea* L. *italica*). *LWT Food Science and Technology* **41**, 1828–1833. Swiss Society of Food Science and Technology.
- Graham, W.D and Stevenson, M.H. (1997). Effect of irradiation on vitamin C content of strawberries and potatoes in combination with storage and with further cooking in potatoes. *J Sci Food Agric* **75** (3), 371–377.
- HACCP - Hazard Analysis and Critical Control Point Principles and Application Guidelines (1997). National Advisory Committee on Microbiological Criteria for Foods, U. S. Food and Drug Administration, US Department of Agriculture.
- HAL (2008). Horticulture Australia Limited Submission to the Review of Export Policies and Programs. Accessed July 2013 at http://www.dfat.gov.au/trade/export_review/submissions_received/HorticultureAustraliaLimited.doc
- HAL (2012). The Australian Horticulture Statistics Handbook 2012. Compiled and published by Oliver & Doam.
- Hallman, G.J. (2000). Expanding Radiation Quarantine Treatments Beyond Fruit Flies. *Agricultural and Forest Entomology* **2**, 85–95.
- Hallman, G.J. (2008). Potential Increase in Fruit Fly (Diptera: Tephritidae) Interceptions Using Ionizing Irradiation Phytosanitary Treatments. *J. Econ. Entomol.* **101** (3), 716–719.
- Hallman, G. (2011). Phytosanitary Applications of Irradiation. *Comp. Reviews in Food Science and Food Safety* **10**, 143–151.
- Hartwig, A., Pelzer, A., Burnouf, D., Titeca, H., Delincee, H., Briviba, K., Soika, C., Hodapp, C., Raul, F., Miesch, M., Werner, D., Horvatovich, P. and Marchioni, E. (2007). Toxicological potential of 2-alkylcyclobutanones – specific radiolytic products in irradiated fat-containing food – in bacteria and human cell lines. *Food and Chemical Toxicology* **45**, 2581–2591.
- Health Canada (2002a). Regulations amending the Food and Drug Regulations (1094 – Food irradiation). Accessed July 2013 at <http://www.hc-sc.gc.ca/fn-an/securit/irridation/109401-eng.php>
- Health Canada (2002b). Recommended Canadian Code of Practice for Food Irradiation, Version Nov 19, 2002. Accessed July 2013 at http://www.hc-sc.gc.ca/fn-an/securit/irridation/code_of_practice-code_de_pratique01-eng.php
- Health Canada (2003). Evaluation of the significance of 2-dodecylcyclobutanone and other alkylcyclobutanones. Accessed July 2013 at <http://www.hc-sc.gc.ca/fn-an/securit/irridation/cyclobutanone-eng.php>
- Heather, N.W. and Hallman, G.J. (2008a). Phytosanitation with Ionizing Radiation. In: *Pest Management and Phytosanitary Trade Barriers*. CABI International, Wallingford, U.K. 132–152.

- Heather, N.W. and Hallman, G.J. (2008b). Pest Management and Phytosanitary Trade Barriers. CABI International, Wallingford, U.K: 257p. Standard book publication. To be provided if required.
- Herregods, M. and DeProost, M. (1963). The effect of gamma irradiation on the preservation of strawberries. *Food Irradiat.* **4(1)**, 35.
- Hicks, P. (2012). Crunch time – apple imports. Dept of Parliamentary Services. Parliamentary Library. 19 September 2012. 19 pp.
- Horvatovich, P., Raul, F., Miesch, M., Burnouf, D., Delincee, H., Hartwig, A., Werner, D. and Marchioni, E. (2002). Detection of 2-alkylcyclobutanones, markers for irradiated foods, in adipose tissues of animals fed with these substances. *J Food Prot.* **65 (10)**, 1610–1613.
- Hussain, P.R., Meena, R.S., Dar, M.A. and Wani, A.M. (2011). Gamma irradiation of sun-dried apricots (*Prunus armeniaca* L.) for quality maintenance and quarantine purposes. *Radiation Physics and Chemistry* **80 (7)**, 817–827.
- IAEA (2001). Consumer acceptance and market development of irradiated food in Asia and the Pacific, IAEA-TECDOC-1219. Proceedings of a Final Research Coordination Meeting organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Bangkok, Thailand, 21–25 September 1998. Food and Environmental Protection Section International Atomic Energy Agency, Vienna, Austria.
- IAEA (2002a). International Atomic Energy Agency. Natural and Induced Radioactivity in Food. *TECDOC-1287*. Vienna, 136p.
- IAEA (2002b). International Atomic Energy Agency. Dosimetry for Food Irradiation. *Technical Report Series 409*. IAEA, Vienna. 161p.
- IAEA (2008) International Atomic Energy Agency. Trends in Radiation Sterilization of Health Care Products. STI/PUB 1313. IAEA, Vienna. 261p.
- IAEA (2011). International Atomic Energy Agency. Food Irradiation Clearances Database, Irradiated Food Authorisation database (IFA). Accessed July 2013 at <http://nucleus.iaea.org/ifa/FoodAuthorisationDisplay.aspx?start=0&page=1&sort=1>
- ICA (2011). Interstate Certification Assurance National Protocol Number 55. Irradiation treatment. ICA 55 in Qld, accessed July 2013 at <http://domesticquarantine.org.au/ica-database/queensland/queensland-ica-55>
- ICGFI (1991). International Consultative Group on Food Irradiation. Code of Good Irradiation Practice for Insect Disinfestation of Fresh Fruits (as a Quarantine Treatment). *ICGFI Document 7*. Joint FAO/IAEA Division, IAEA. Vienna. Accessed July 2013 and available through <http://www-naweb.iaea.org/nafa/fep/public/manuals-fep.html> .
- ICGFI (1995a). International Consultative Group on Food Irradiation. Control of Irradiated Food in Trade – A Compilation of Principles and International Recommendations for Regulatory Control Measures. *ICGFI Document 21*, Available through Joint FAO/IAEA Division, IAEA, Vienna.

ICGFI (1999). International Consultative Group on Food Irradiation. Facts about Food Irradiation. IAEA, Vienna. Accessed July 2013 at www.iaea.org/Publications/Booklets/foodirradiation.pdf.

ICGFI website. Accessed July 21 03 at <http://www-naweb.iaea.org/nafa/fep/topic-food-irradiation.html>

ICGFI Documents. Accessed July 2013 at <https://apps.who.int/fsf/whopb3.htm>

IndexMundi <http://www.indexmundi.com/agriculture/> Accessed July 2013 for consumption, export figures and graphs.

Iordanescu, O., Alexa, E., Micu, R. and Poiana, M-At (2012). Bioactive compounds and antioxidant properties at different maturity stages of apple cultivars from Romania. *J Food, Agriculture & Environment* **10 (1)**, 147–151. 2012.

IPPC, International Plant Protection Convention. International Standards for Phytosanitary Measures can be accessed at <https://www.ippc.int/core-activities/standards-setting/ispms>

IPPC (2003). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 18 Guidelines for the Use of Irradiation as a Phytosanitary Measure. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy, 2006. Accessed July 2013 at <http://www.fao.org/docrep/009/a0450e/a0450e00.htm>

IPPC (2005). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 24 Guidelines for the Determination and Recognition of Equivalence of Phytosanitary Measures. Accessed July 2013 at international standards for phytosanitary measures - FAO.org

IPPC (2007). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28 Phytosanitary Treatments for Regulated Pests (2007), Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the United Nations, Rome, Italy. Accessed July 2013 at ISPM No. 28 PHYTOSANITARY TREATMENTS FOR REGULATED ...

IPPC (2008). International Plant Protection Convention, IPPC (2008). Replacement or Reduction of the Use of Methyl Bromide as a Phytosanitary Measure. Recommendation for the Implementation of the IPPC. Accessed February 2012 at http://ozone.unep.org/Meeting_Documents/oewg/28oewg/OEWG-28-INF4.pdf.

IPPC (2009). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28, Annex 7. Phytosanitary Treatments for Regulated Pests. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy. Accessed July 2013 at <https://www.ippc.int/publications/pt-7-2009-irradiation-treatment-fruit-flies-family-tephritidae-generic>.

ISO (2004). International Standards Organisation. ISO / ASTM51204– 04. Standard Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing, ASTM International, West Conshohocken, PA. Accessed July 2013 and available from <http://www.astm.org/Standards/ISOASTM51204.htm>.

ISO (2005). International Standards Organisation. ISO / ASTM51431 □ 05. Standard Practice for Dosimetry in Electron Beam and X□Ray (Bremsstrahlung) Irradiation

Facilities for Food Processing, ASTM International, West Conshohocken, PA.
Accessed July 2013 and available from
<http://www.astm.org/Standards/ISOASTM51431.htm> .

Jan, I., Rab, A. and Sajid, M. (2012). Storage performance of apple cultivars harvested at different stages of maturity. *The Journal of Animal & Plant Sciences* **22** (2), 438–447.

JECFI (1981). Joint FAO/IAEA/WHO Expert Committee on Food Irradiation. Wholesomeness of Irradiated Food. *Technical Report Series, No. 659*, World Health Organization, Geneva, Switzerland.

JECFI (1999). Joint FAO/IAEA/WHO Expert Committee on Food Irradiation. High-Dose Irradiation: Wholesomeness of Food Irradiated With Doses Above 10kGy. *Technical Report Series, No. 890*, World Health Organization, Geneva, Switzerland.

Jessup, A.J. (1990). Gamma Irradiation as a Quarantine Treatment for sweet cherries against Queensland Fruit Fly. *HortScience* **25** (4), 456–458.

Johnson, A.M. Reynolds, A.E. Chen, J. and Resurreccion, A. V. A. (2004). Consumer Attitudes Towards Food Irradiation 2003 vs. 1993. *Food Protection Trends*. **24**, 408–418.

Jordan, R.A. (2007). Effect of Irradiation Treatment on the Quality of Sweet Persimmons, PR 06008. *Final Report to Horticulture Australia Ltd*. Queensland Department of Primary Industries and Fisheries.

Josephson, E.S., Thomas, M.H. and Calhoun, W.K. (1978). Nutritional aspects of food irradiation: an overview. *Journal of Food Processing and Preservation* **2** (4), 299–313.

Kader, A.A. (1986). Potential Applications of Ionizing Radiation in Post-Harvest Handling of Fresh Fruits and Vegetables. *Food Technology* **40**, 117–121.

Kader, A.A. (1988). Influence of preharvest and postharvest environment on nutritional composition of fruits and vegetables. In: Quebedeaux, B., Bliss, F.A. (Eds.), *Horticulture and Human Health: Contributions of Fruits and Vegetables*. Proceedings of the 1st International Symposium on Horticulture and Human Health. Prentice-Hall, Englewood Cliffs, NJ, pp. 18–32.

Kang, F., Hallman, G. J., Wei, Y., Zhang, F and Li, Z. (2012). Effect of X-ray irradiation on the physical and chemical quality of America red globe grape. *African Journal of Biotechnology* **11** (31), 7966–7972.

Katayama, T., Nakayama, T., Lee, T.H. and Chichester, C.O. (1971). Carotenoid transformations in ripening apricots and peaches. *J Food Sci* **36**, 804-806.

Kilcast, D. (1990). Irradiation of Packaged Food. In: *Food Irradiation and the Chemist*. (editors D.E. Johnston and M.H. Stevenson). Royal Society of Chemistry, London, pp. 140–152.

Kilcast, D. (1994). Effect of Irradiation on Vitamins. *Food Chemistry* **49**, 157–164.

- Kim, K.S., Seo, H.Y., Lee, J.M., Park, E.R., Kim, J.H., Hong, C.H. and Byun, M.W. (2004). Analysis of radiation-induced hydrocarbons and -alkylcyclobutanones from dried shrimps (*Penaeus aztecus*). *Journal of Food Protection* **67** (1), 42–14.
- Koidsumi, K. (1930). Quantitative Studies on the Lethal Action of X–Rays upon Certain Insects. *J. Soc. Tropical Agriculture (Japan)* **2**, 243–263.
- Komolprasert, V. (2007). Packaging for Foods Treated with Ionizing Radiation. In: *Packaging for Non–thermal Treatment of Food* (edited by J.H. Han) DOI: 10.1002/9780470277720. Blackwell Press, Chapter 6.
- Kovacs, E., Balla, G and Nessinger, A. (1995). The effect of irradiation on sweet cherries. *Acta Alimentaria* **24** (4), 331–343.
- Kraybill, H.F. (1982). Effect of Processing on Nutritive Value of Food: Irradiation. In: *CRC Handbook of Nutritive Value of Processed Food* (editor M. Rechcigl) Vol 1, CRC Pres, Boca Raton, U.S.A. pp. 181–208.
- Lacson, L.R. (2007). Irradiation as a Phytosanitary Treatment of Agricultural Crops. 35th Atomic Energy Week Programme of Activities. Philippine Nuclear Research Institute, Department of Science and Technology. 20th December. Accessed July 2013 at Irradiation as Phytosanitary Treatment of Agricultural Crops - PNRI .
- Lee, C.Y. (1974). Effect of cultural practices on chemical composition of processing vegetables. A review. *J. Food Sci.* **39**, 1075–1079.
- Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology* **20**, 207–220.
- Lee, J.O., Lee, S.A., Kim, M.S. Hwang, H.R., Kim, K.H. Chun, J.P. and Yook, H.S. (2008a). The effects of low-dose electron beam irradiation on quality characteristics of stored apricots. *Journal of the Korean Society of Food Science and Nutrition* **37** (7), 934–941. Abstract.
- Lee, S.A., Lee, J.O., Kim, K.H., Kwon, J.S., Kim, H.G., Byun. M.W., Lee, J.W. and Yook, H.S. (2008b). Influence gamma irradiated on microbial and physicochemical changes of apricot. *Journal of the Korean Society of Food Science and Nutrition* **37** (6), 767–774. Abstract.
- Lim, C.S., Kang, S.M. Cho, J.L., Gross, K.C. and Woolf, A.B. (2007). Bell Pepper (*Capsicum annuum* L.) Fruits are Susceptible to Chilling Injury at the Breaker Stage of Ripeness. *Hort. Science.* **42**, 1659–1664.
- Loaharanu, P. (2003). Irradiated Foods, Fifth Edition. American Council on Science and Health. New York.
- Loaharanu, P. (2007). Irradiated Foods, Fifth Edition. American Council on Science and Health. New York. Viewed July 2013 at irradiated foods - American Council on Science and Health
- Lyons, J.M. (1973). Chilling Injury in Plants. *Ann. Rev. Plant Physiology.* **24**, 445–466.
- MAF (2008). Ministry of Agriculture and Forestry, New Zealand. Import Health Standard Commodity Sub-class: Fresh Fruit/Vegetables: Litchi, (*Litchi chinensis*) from Australia. Issued pursuant to Section 22 of the Biosecurity Act 1993, MAF

- Biosecurity Authority, Wellington, NZ. Accessed 8 July 2013
<http://www.biosecurity.govt.nz/files/regs/imports/risk/aus-litchi-ra.pdf>
- MAF (2009a). Ministry of Agriculture and Forestry, New Zealand. Import Health Standard Commodity Sub-class: Fresh Fruit/Vegetables: Mango, *Mangifera indica* from Australia. Issued pursuant to Section 22 of the Biosecurity Act 1993, MAF Biosecurity Authority, Wellington, NZ. Accessed July 2013 at <http://www.biosecurity.govt.nz/files/ihf/mango-au.pdf>
- MAF (2009b). Ministry of Agriculture and Forestry, New Zealand. Import Health Standard Commodity Sub-class: Fresh Fruit/Vegetables: Papaya, (*Carica papaya*) from Australia Issued pursuant to Section 22 of the Biosecurity Act 1993, MAF Biosecurity Authority, Wellington, NZ. Accessed July 2013 at <http://www.biosecurity.govt.nz/files/ihf/papaya-au.pdf>
- MAF (2009c). Ministry of Agriculture and Forestry, New Zealand. Import Health Standard Commodity Sub-class: Fresh Fruit/Vegetables: Papaya, (*Carica papaya*) from the United States – State of Hawaii. Issued 18 January pursuant to Section 22 of the Biosecurity Act 1993, MAF Biosecurity Authority, Wellington, NZ. Accessed July 2013 at www.biosecurity.govt.nz/files/ihf/papaya-us-hi.pdf
- MAF (2013a). Ministry of Agriculture and Forestry, New Zealand. Standard 152.02. Importation and Clearance of Fresh Fruits and Vegetables into New Zealand. Accessed August 2013 at www.biosecurity.govt.nz/files/ihf/152-02.pdf
- MAF (2013b). Ministry of Agriculture and Forestry, New Zealand. Import Health Standard Commodity Sub-class: Fresh Fruit/Vegetables: Capsicum (*Capsicum annum*) from Australia Issued pursuant to Section 24A of the Biosecurity Act 1993, MAF Biosecurity Authority, Wellington, NZ. Accessed August 2013 at <http://www.biosecurity.govt.nz/files/ihf/capsicum-au.pdf>
- MAF (2013c). Ministry of Agriculture and Forestry, New Zealand. Import Health Standard Commodity Sub-class: Fresh Fruit/Vegetables: Tomato (*Lycopersicon esculentum*) from Australia Issued pursuant to Section 24A of the Biosecurity Act 1993, MAF Biosecurity Authority, Wellington, NZ. Accessed August 2013 at <http://www.biosecurity.govt.nz/files/ihf/tomato-au.pdf>
- Marchioni, E., Raul, F., Burnouf, D., Miesch, M., Delincee, H., Hartwig, A. and Werner, D. (2004). Toxicological study on 2-alkylcyclobutanones—results of a collaborative study. *Radiation Physics and Chemistry* **71**, 147–150.
- Marchioni, E. (2006). Detection of Irradiated Food. In: *Food Irradiation Research and Technology* (editors, C.H. Sommers and X. Fan). Blackwell, Ames, Iowa, pp. 85–103.
- Massey, L.M. and Bourke, J.B. (1967). Some radiation-induced changes in fresh fruits and vegetables. In: Gould RF, editor. *Radiation preservation of foods*. Washington, DC: *American Chemical Society*. p 1–11.
- Maxie, E.C. and Abdel-Kader, A.S. (1966). Food Irradiation – Physiology of fruits as related to feasibility of technology. *Adv. Food Res.* **25**, 105–145.
- Maxie, E. C., Sommer, N. F. and Rae, H. L. (1964). Effect of gamma irradiation on Shasta strawberries under marketing conditions, *Isot., Radiat. Technol.*, **2** (1), 50–54.

- McDonald, H., McCulloch, M., Caporaso, F., Winborne, I., Oubichon, M., Rakovski, C., Prakash, A. (2012) Commercial scale irradiation for insect disinfestation preserves peach quality. *Radiation Physics and Chemistry* **81** (6), 697–704.
- Miller, W.R. and McDonald, R.E. (1999). Irradiation, Stage of Maturity at Harvest, and Storage Temperature during Ripening Affect Papaya Fruit Quality. *HortScience* **34** (6), 1112–1115.
- Mitchell, G.E., McLauchlan, R.L., Isaacs, A.R., Williams, D.J. and Nottingham, S.M. (1992). Effect of Low Dose Irradiation on Composition of Tropical Fruits and Vegetables. *Journal of Food Composition and Analysis* **5**, 291–311.
- MOH (1999). Ministry of Health, New Zealand. NZ Food: NZ People. Key Results of the 1997 National Nutrition Survey. Accessed July 2013 at [http://www.moh.govt.nz/notebook/nbbooks.nsf/0/62C5D9D4C418C4E74C2567D9007186C2/\\$file/nns.pdf](http://www.moh.govt.nz/notebook/nbbooks.nsf/0/62C5D9D4C418C4E74C2567D9007186C2/$file/nns.pdf).
- MOH (2009). Ministry of Health, New Zealand and Plant & Food Research: The Concise New Zealand Food Composition Tables (8th Edition). Accessed July 2013 at <http://www.foodcomposition.co.nz/concise-tables>.
- Molins, R.A. (Editor). 2001 Food Irradiation: Principles and Applications. Wiley and Sons. 488 pages.
- Morehouse KM. 2002. Food irradiation—US regulatory considerations. *Radiat Phys Chem* **64**, 281–4.
- Morehouse, K.M. and Komolprasert, V. (2004). Irradiation of Food and Packaging: An Overview. In: *Irradiation of Food and Packaging* ACS Symposium Series 875. Chapter 1, pp. 1–11.
- Moreno, M.A., Castell-Perez, M.E., Gomes, C., Da Silva, P.F. and Moreira, R.G. (2007). Quality of electron beam irradiation of blueberries (*Vaccinium corymbosum* L.) at medium dose levels (1.0–3.3 kGy). *LWT-Swiss Society for Food Science and Technology* **40**, 1123–1132.
- Morris, S. C. (1987). The practical and economic benefits of ionising radiation for the postharvest treatment of fruit and vegetables: an evaluation. *Food Technol Australia* **39**, 336–341.
- Morris, S.C. and Jessup, A.J. (1994). Irradiation. In: *Insect Pests and Fresh Horticultural Products: Treatments and Responses*. (Editors, R.E. Paull and J.W. Armstrong). CABI International, Wallingford, U.K., pp. 163–190.
- Moy, J.H., Kaneshiro, K.Y., Mila, A.T. and Nagai, N. (1983). Radiation Disinfestation of California Stone Fruits Infested by Medfly – Effectiveness and Fruit Quality. *J Food Science* **48**, 928–931.
- Moy, J.H. (1985). Prospects and problems of irradiating papaya: A case study in Hawaii. In: *Food Irradiation Processing*. Proceedings of an IAEA/FAO Symposium, Washington, DC, March 1985, International Atomic Energy Agency, Vienna, 61–68.
- Moy, J. (1993). Efficacy of Irradiation vs Thermal Methods as Quarantine Treatments for Tropical Fruits. *Radiation Physics and Chemistry* **42** (1–3), 269–272.

- Moy, J.H. and Wong, L. (2002). The Efficacy and Progress in Using Radiation as a Quarantine Treatment of Tropical Fruits – A Case Study in Hawaii. *Radiation Physics and Chemistry* **63**, 397–401.
- Moy, J.H. (2005). Tropical fruit irradiation – from research to commercial application. Proc International Symposium “New Frontier of Irradiated food and Non-Food Products, 22–23 September, KMUTT, Bangkok, Thailand.
- Mozafar, A. (1994). Enrichment of some B-Vitamins in Plants with Application of Organic Fertilisers. *Plant And Soil* **167 (2)**, 305–311.
- Murray, T.K. (1983). Nutritional Aspects of Food Irradiation. In: *Recent Advances in Food Irradiation* (editors P. Elias and A.J. Cohen). Elsevier Biomedical. The Netherlands, pp. 203–216.
- Nation, J.L., Smittle, B.J. and Milne, K.R (1999). Physiological Markers in Insects Indicating Treatment with Ionizing Radiation. In: *IAEA-TECDOC-1082*. International Atomic Energy Agency, Vienna, pp. 129–139.
- Nawar, W.W. (1986). Volatiles from Food Irradiation. *Food Reviews International* **2(1)**, 45–78.
- Nayga Jr., R. M., Aiew, W. and Nichols, J. P. (2005). Information Effects on Consumers' Willingness to Purchase Irradiated Food Products. *Review of Agricultural Economics* **27 (1)**, 37–48.
- NHMRC (2006) Nutrient Reference Values for Australia and New Zealand. Canberra: National Health and Medical Research Council.
- Niemira, B.A. and Fan, X. (2006). Low-dose Irradiation of Fresh and Fresh-cut Produce: Safety, Sensory and Shelf Life. In: Sommers, C., Fan, X., editors. *Food Irradiation Research and Technology*. Blackwell Publishing. p. 169–184.
- NMA (2010). National Measurement Act. Trade Measurement Act 1960 (last reviewed May 2007). Australian Department of Innovation, Science and Research. Accessed July 2013 at <http://www.comlaw.gov.au/Details/C2011C00871/Download> .
- Nunes, K. (2010) Irradiation's Future Potential, The Technology is Slowly Making Inroads. Accessed July 2013 at <http://www.meatpoultry.com/News/News%20Home/Food%20Safety/2010/11/Irradiations%20future%20potential.aspx?Newsletter=true> .
- NZIER (2007). Benefits of Imported Fresh fruit and Vegetables. Report to the New Zealand Fresh produce Importers' Association Inc.
- O'Bryan, C.A., Crandall, P.G., Ricke, S.C. and Olson, D.G. (2008). Impact of irradiation on the safety and quality of poultry and meat products: a review. *Critical Reviews in Food Science and Nutrition* **48**, 442–457.
- Olsen, K.L., Hungate, F.P., Drake, S.R. and Eakin, D.E. (1989). Red Delicious' Apple Response to Low Dose Irradiation. *Journal of Food Quality* **12 (2)**, 107–113.
- Otago Daily Times (2013) Bananas favourite fruit for Kiwis. 11th July 2013.

- Paek, G.C. (2011). Effects of low dose irradiation on the quality of fresh table grapes. Presentation. Chapman University. Marshall Cleland Award.
- Parveen and Mir (2011). Effect of Gamma Irradiation and Packaging on Storage Quality of Sweet Cherry. *Postharvest Technology*. Abstract.
- Perez, A. G., R. Olias, J. M. Olias and C. Sanz (1998). Strawberry quality as a function of the “high pressure fast cooling” design. *Food Chemistry* **62(2)**, 161–168.
- PFR (2012) Plant and Food Research. Fresh Facts: New Zealand Horticulture 2012. Accessed July 2013 at <http://www.freshfacts.co.nz/>
- Power Your Diet website. Zucchini Nutrition Facts. <http://www.nutrition-and-you.com/zucchini.html>
- Prakash, A. and Foley, D. (2004). Improving Safety and Extending Shelf-Life of Fresh-Cut Fruits and Vegetables Using Irradiation. In: *Irradiation of Food and Packaging*. American Chemical Society Symposium Series 875, 90–106.
- QH (2010). Queensland Health. The Facts About Food Irradiation. Consumer Factsheet 5. Accessed July 2013 at <http://www.health.qld.gov.au/ph/Documents/ehu/14775.pdf>
- QLD AgTrends, DAFF (2013). AgTrends 2012–13. Forecasts and trends in Queensland Agricultural, Fisheries and Forestry Production. Accessed July 2013 at Queensland AgTrends 2012–13 - Department of Primary Industries ...
- QPIF (2009). Queensland Primary Industries and Fisheries. Economic value impact report on selected Queensland horticulture industries of changes to approved use of dimethoate and fenthion as pre-harvest and/or post-harvest phytosanitary treatments. Joint Working Party Internal Report. (Compiled by Lloyd Russell). July.
- Raffi, J.J., Agnel, J.P.L., Thiery, C.J., Frejaville, C.M. and Saint-Lebe, L.R. (1981). Study of γ -irradiated starches derived from different foodstuffs: a way for extrapolating wholesomeness data. *J. Agric. Food Chem.* **29(6)**, 1227–1232.
- Rettke, M., Goodwin, I., Brown, P., Nissen R., Bright, J. and Portman, T. National Horticultural Research Network – Apricots. Accessed July 2013 at Apricots.pdf - Horticulture Industry Network.
- RIRDC (2010a) Rural Industries Research and Development Corporation. Apple. Pollination Aware Case Study 2. Code: 10–109. Accessed July 2013 at <https://rirdc.infoservices.com.au/items/10-109>.
- RIRDC (2010b) Rural Industries Research and Development Corporation. Apricot. Pollination Aware Case Study 3. Code: 10–110. Accessed July 2013 at <https://rirdc.infoservices.com.au/items/10-110>.
- RIRDC (2010c) Rural Industries Research and Development Corporation. Cherry. Pollination Aware Case Study 8. Code: 10–115. Accessed July 2013 at <https://rirdc.infoservices.com.au/items/10-115>.
- RIRDC (2010d) Rural Industries Research and Development Corporation. Melons. Pollination Aware Case Study 21. Code: 10–128. Accessed July 2013 at <https://rirdc.infoservices.com.au/items/10-128>.

RIRDC (2010e) Rural Industries Research and Development Corporation. Strawberries. Pollination Aware Case Study 32. Code: 10–139. Accessed July 2013 at <https://rirdc.infoservices.com.au/items/10-139>.

Roberts, P. (2012). Irradiation: An effective, sustainable post-harvest phytosanitary treatment option. AUSVEG Conference, Hobart 1012 May 2012.

SA (1999). Standards Association of Australia. Australian Standard AS2070 –1999. Australian Standard for Plastics Materials for Food Contact Use. Standards Association of Australia, NSW 2140. Accessed July 2013 at <http://www.saiglobal.com/PDFTemp/Previews/OSH/As/as2000/2000/2070.pdf>

Saluhnke, D.K., Gerber, R.K. and Pollard, L.H. (1959). Physiological and Chemical Effects of Gamma Radiation on Certain Fruits, Vegetables and Their Products. *Proc. Am. Soc. Hort. Sci.* **74**, 423–429.

Sanz, C., Perez, A.G., Olias, R. and Olias, J.M. (1999). Quality of strawberries packed with perforated polypropylene. *Journal of Food Science* 64(4): 748–752.

Saluhnke, D.K. (1961). Gamma Radiation Effect on Fruits and Vegetables. *Econ. Bot.* **15**, 26–56.

Saluhnke, D.K., Gerber, R.K. and Pollard, L.H. (1959). Physiological and Chemical Effects of Gamma Radiation on Certain Fruits, Vegetables and Their Products. *Proc. Am. Soc. Hort. Sci.*, **74**, 423–429.

SCF (2002). Scientific Committee on Food. Statement of the Scientific Committee on Food on a Report on 2–alkylcyclobutanones. Accessed July 2013 at http://ec.europa.eu/food/fs/sc/scf/out135_en.pdf.

SCF (2003). Scientific Committee on Food. Revision of the Opinion of the Scientific Committee on Food on the Irradiation of Food. Accessed July 2013 at http://ec.europa.eu/food/fs/sc/scf/out193_en.pdf.

Schubert, J., (1977). Toxicological studies on irradiated food and food constituents. In: *Food Preservation by Irradiation*, Vol. II, pg 3–29. International Atomic Energy Agency IAEA-SM-221/74, Vienna, Austria.

Schubert, J., Sanders, E. B., Pan, S. F., and Wald, N. (1973). Irradiated strawberries - chemical, cytogenetic and antibacterial properties. *Agric. Food Chem.* **21**, 684–692.

Somers, G.F. and Beeson, K.C. (1948). The influence of climate and fertilizer practices upon the vitamin and mineral content of vegetables. *Adv. Food Res.* **1**, 291–324.

Sommers, C.H., Delincee, H., Smith, J.S. and Marchioni, E. (2006). Toxicological Safety of Irradiated Foods. In: *Food Irradiation Research and Technology* (editors C.H. Sommers and X. Fan). Blackwell Publishing, Ames, Iowa, pp 43–61.

Sommers, C.H. (2003). 2–dodecylcyclobutanone does not induce mutations in the *Escherichia coli* Tryptophan Reverse Mutation Assay. *J. Agric. Food Chem.* **51** (21), 6367–6370.

Sommers, C.H. (2006). Recent advances in food irradiation: Mutagenicity testing of 2–dodecylcyclobutanone. *American Chemical Society Symposium Series* **931**, 109–120.

Sommers, C.H. and Schiestl, R.H. (2004). 2-dodecylcyclobutanone does not induce mutations in the *Salmonella* Mutagenicity Test or Intrachromosomal Recombination in *Saccharomyces cerevisiae*. *Journal of food Protection* **67** (6), 1293–1298.

Strawberries Australia Inc. Strawberry Industry Annual Report 2011/12. Accessed July 2013 at <http://www.strawberriesaustralia.com.au/17618350/strawberries-australia-annual-reports.htm>

Summerfruit Australia Ltd website. Accessed July 2013 at <http://www.summerfruit.com.au/Domestic/About-Australian-Summerfruit.aspx>. Hardcopy not printed.

Thayer, D.W., Christopher, J.P. and 5 others (1987). Toxicology Studies of Irradiation–Sterilized Chicken. *J. Food Prot.* **50** (4), 278–288.

Thayer, D.W., Fox, Jr, J.B. and Lakritz, L. (1991). Effects of Ionising Radiation on Vitamins. In: *Food Irradiation*, (editor S. Thorne). Elsevier Applied Science, London, UK. pp. 285–325.

Thomas, P. (1986a) Radiation Preservation of Foods of Plant Origin III. Tropical Fruits: Bananas, Mangoes and Papayas. *CRC Critical Reviews Food Sci.Nutr.* **23** (2), 147–205.

Thomas, P. (1986b) Radiation Preservation of Foods of Plant Origin. Part IV. Subtropical Fruits: Citrus, Grapes and Avocados. *CRC Critical Reviews Food Sci.Nutr.* **24** (1), 53–89.

Thomas, P. (1986c) Radiation Preservation of Foods of Plant Origin. Part V. Temperate Fruits: Pome Fruits, Stone Fruits and Berries. *CRC Critical Reviews Food Sci.Nutr.* **24** (4), 357–400.

Thomas, P. (1988) Radiation Preservation of Foods of Plant Origin VI. Mushrooms, Tomatoes, Minor Fruits and Vegetables, Dried Fruits, and Nuts. *CRC Critical Reviews Food Sci. Nutr.* **26** (4), 313–358.

UNEP (2009). United Nation Environmental Program. Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer. Eighth Edition. Ozone Secretariat of UNEP. Accessed July 2013 at http://ozone.unep.org/Publications/MP_Handbook/MP-Handbook-2009.pdf.

Urbain, W. M. (1986a). Fruits, Vegetables and Nuts. In: *Food irradiation*. Academic Press, Orlando, Florida, USA, pp. 170–216.

Urbain, W. M. (1986b). Radiation Chemistry of Food Components and Of Food. In: *Food irradiation*. Academic Press, Orlando, Florida, USA, pp. 37–82.

UC Davis - Postharvest Technology Center, University of California. Apple, Fuji: Recommendations for Maintaining Postharvest Quality. Accessed July 2013 at <http://postharvest.ucdavis.edu/PFfruits/applefuji/>

University of Technology Sydney (2010). Horticulture Australia Project. Con's Comeback for Australian Summer Stonefruit. Accessed August 2013 at <http://www.lib.uts.edu.au/gta/14476/cons-comeback-australian-summer-stonefruit>

- US General Accounting Office, Resources, Community, and Economic Development Division (2000). Food Irradiation. Available Research indicates that benefits outweigh risks. GAO/RCED-00-217 Benefits and Risks of Food Irradiation. Washington, DC.
- USDA (1997). US Department of Agriculture. Animal and Plant Health Inspection Service Irradiation for Phytosanitary Regulatory Treatment. Environmental Assessment October 1997. Accessed July 2013 at http://www.aphis.usda.gov/plant_health/ea/downloads/irradea.pdf .
- USDA (2002). US Department of Agriculture. Animal and Plant Health Inspection Service. 7 CFR Parts 305 and 319 [Docket No. 98-30-4] RIN 0579-AA97. Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables. Accessed July 2013 at <http://www.gpo.gov/fdsys/pkg/FR-2002-10-23/pdf/02-27027.pdf> .
- USDA (2006). US Department of Agriculture. Animal and Plant Health Inspection Service. Treatments for Fruits and Vegetables. Federal Register. US Department of Agriculture. Animal and Plant Health Inspection Service. **71(18)** 4451–4464. Viewed July 2013 at <http://www.gpo.gov/fdsys/pkg/FR-2006-01-27/pdf/06-746.pdf> .
- USDA (2007a). US Department of Agriculture, Animal and Plant Health Inspection Service. Importation of Mangoes from India. Federal Register. **72 (47)** 7 CFR Parts 305 and 319 (Docket number APHIS–2006–0121). RIN 0579–AC19. Final Rule.
- USDA (2007b). US Department of Agriculture, Animal and Plant Health Inspection Service. Importation of Fruit from Thailand. Federal Register. **72 (119)** 7 CFR Parts 305 and 319 (Docket number APHIS–2006–0040). RIN 0579–AC10. Final Rule.
- USDA (2008). US Department of Agriculture. Animal and Plant Health Inspection Service. Fresh Fruits and Vegetables Import Manual. Accessed July 2013 at http://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/fv.pdf .
- USDA (2008a). US Department of Agriculture. Animal and Plant Health Inspection Service. Importation of Fresh Guava (*Psidium guajava*) Fruit from Mexico into the United States Treated with 400 Gy Irradiation. Risk Management Document Sept 12 2008 Revision 004. (Docket ID: APHIS–2008–0066–004).
- USDA (2008b). US Department of Agriculture, Animal and Plant Health Inspection Service. Interstate Movement of Fruit from Hawaii. *Federal Register*. **73 (88)** 7 CFR Parts 305 and 318, Docket APHIS–2007–0050.
- USDA (2008c). US Department of Agriculture, Animal and Plant Health Inspection Service. Notice of Decision to Issue Permits for the Importation of Dragon Fruit from Vietnam into the Continental United States. *Federal Register*. **73 (147)** 7 CFR Parts 319.56, Docket APHIS–2008–0065.
- USDA (2009). US Department of Agriculture, Animal and Plant Health Inspection Service. Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables. Accessed July 2013 at <http://www.gpo.gov/fdsys/pkg/FR-2009-08-07/html/E9-18987.htm>
- USDA (2010). US Department of Agriculture, Animal and Plant Health Inspection Service. Notice of Decision to Issue Permits for the Importation of Fresh Mango Fruit from Pakistan into the Continental United States. *Federal Register*. **75 (166)**, Friday August 27 (75 FR 52712 – Docket APHIS–2010–0065).

- USDA (2011a). US Department of Agriculture, Animal and Plant Health Inspection Service. Notice of Decision to Authorize the Importation of Rambutan Fruit from Malaysia and Vietnam. *Fed Register* **76 (75)** April 19th.
- USDA (2011b). US Department of Agriculture: Agriculture Research Service: Nutrient Data Laboratory. The USDA National Nutrient Database. On-line search at <http://www.nal.usda.gov/fnic/foodcomp/search/>
- Variyar, P.S., Chatterjee, S., Sajilata, M.G., Singhal, R.S. and Sharma, A. (2008). Natural Existence of 2-Alkylcyclobutanones. *J. Agricultural and Food Chemistry*. **56 (24)**, 11817–11823.
- Vranova, J. and Ciesarova, Z.(2009). Furan in Food – A Review. *Czech J. Food Science* **27**, 1–10.
- Viljoen, H.W. (2011). Effect of gamma irradiation as a mitigation treatment on storage quality of plums. The South African Stone Fruit Producers Association, 7 pages.
- Wall, M.M. (2007). Postharvest quality and ripening of Dwarf Brazilian bananas (*Musa sp.*) after x-ray irradiation quarantine treatment. *Hort Sci.* **42**, 130–134.
- Wall, M. (2008). Quality of postharvest horticultural crops after irradiation treatment. *Stewart Postharvest Review* **2**, 1–7.
- Wang, C.Y., Jiang, M.Y., Gao, M.X., Ma, X.Y., Zhang, S.F. and Liu, S.C. (1993). A study of the physiological-changes and the nutritional qualities of irradiated apples and the effect of irradiation on apples stored at room temperature. *Radiation Physics and Chemistry* **42 (1–3)**, 347–350.
- Webley, P., Jiang, S., Balmer, B. and Ridley, L. (2011). China Cherry Snapshot. Dept Environment and Primary Industries, Vic.
- WHO (1994). World Health Organisation. Safety and Nutritional Adequacy of Irradiated Food, WHO, Geneva, 176 p.
- WHO (2002). World Health Organisation. WHO Global Strategy for Food Safety: Safer Food for Better Health. ISBN 92 4 154574 7. Food Safety Department, WHO, Geneva, Switzerland.
- WHO (2003). World Health Organisation. WHO Statement on 2–Dodecylcyclobutanone and Related Compounds. Accessed July 2013 at SUBJECT: 2-DCB in Irradiated Foods
- Wilkinson, V.M. (1985). Effect of Irradiation on the Nutrient Composition of Food, Leatherhead Food Research Association. The British Food Manufacturing Industries Research Association, Scientific and Technical Survey No. 151, October 1985.
- WTO (2011). World Trade Organisation. The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). Available from SPS Information Management System: Accessed July 2013 at Text of agreement available at http://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm .
- Wu, J., Gao, H., Zhao, L., Liao, X., Chen, F., Wang, Z. and Hu, X. (2007). Chemical compositional characterization of some apple cultivars. *Food Chemistry* **103 (1)**, 88–93.

Yu, L., Reitmeier, C.A., Gleason, M.L., Nonnecke, G.R., Olson, D.G. and Gladon, R.J. (1995). Quality of electron beam irradiated strawberries. *Journal of Food Science* **60**, 1084–1087.

Yu, L., Reitmeier, C.A., Love, M.H. (1996). Strawberry texture and pectin content as affected by electron beam irradiation. *Journal of Food Science* **61**, 844–846.

Call: 13 25 23 or +61 7 3404 6999

Visit: www.daff.qld.gov.au

