Queensland Government

Application to FSANZ

Application to amend Standard 1.5.3 Irradiation of Food of the Food Standards Code to include Tomatoes (*Lycopersicon esculentum*) and Capsicums (*Capsicum annuum)* using Irradiation as a Phytosanitary Measure

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EXECUTIVE SUMMARY

This application seeks a variation to the Food Standards Code, Standard 1.5.3 Irradiation of Food, by adding Tomatoes and Capsicums to the Table of Clause 4. No other variation is sought in this application. The conditions of irradiation will be the same as for the tropical fruits already approved for irradiation. The purpose of irradiation will be pest disinfestation for a phytosanitary objective and the minimum and maximum doses allowed will be 150 Gy and 1 kGy respectively.

Applicant

This application is submitted by the Queensland Department of Employment, Economic Development and Innovation (DEEDI) in association with the New Zealand Fresh Produce Importers Association (NZFPIA). DEEDI 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. NZFPIA represents wholesalers, traders and retailers who import fresh produce, including fruit 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.

Purpose

Tomatoes and capsicums 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. As Food Standards Australia and New Zealand (FSANZ) has 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." Therefore, irradiation is potentially a valuable tool to help the tomato and capsicum trade ensure biosecurity and phytosanitary requirements are met by controlling insects.

The need for irradiation

Several approved options exist for phytosanitary treatments of tomatoes and capsicums. Among the most commonly used are pre and postharvest treatments with insecticides. The Australian Pesticides and Veterinary Medicines Authority (APVMA) is presently reviewing current uses of two insecticides, dimethoate and fenthion. Approval for their use is expected to be curtailed or withdrawn and dimethoate use on some commodities has already been temporarily suspended. A national response to any change in use patterns of these insecticides is being co-ordinated by the Office of the Chief Plant Protection Office (OCPPO) and details of these activities can be found on the Domestic Quarantine and Market Access Working Group (DQMAWG) website.

The Queensland Department of Employment, Economic Development and Innovation (DEEDI) consider trade in tomato and capsicum to at risk of market disruption should phytosanitary uses of insecticide treatments use be withdrawn or restricted. The combined value of tomato and capsicum production in 2006/07 was approximately A$420 million of which Queensland produced approximately A$282 million. Approximately 70% of Queensland production was sent to markets in Australia with restrictions against the introduction of fruit fly. In addition, tomatoes and capsicums (value approximately A$11 million) were exported in 2006/07. Approximately 90% of these exports went to New Zealand where demand for Australian produce is strong in the winter and spring months.

The majority of the export figures listed above involved the use of postharvest chemical treatments with dimethoate or fenthion. In August 2011 the Australian Pesticides and Medicines Authority (APVMA) released the Dimethoate Residues and Dietary Risk Assessment Report. Based on the findings of the report the APVMA suspended the use of dimethoate on a number of crops on the 6th of October, 2011 due to potential dietary risks. The suspension period will last for twelve months and prohibits the use of both pre-harvest and postharvest uses of dimethoate on fresh tomatoes. As a result trade of Australian tomatoes to New Zealand has been halted until alternative treatments can be negotiated. For domestic trade, the tomato industry currently has several treatment options. The use of fenthion for both pre and postharvest use is still permitted. However, growers have been advised not to rely on fenthion as a long-term replacement as it is also under review and its use is likely to be severely curtailed or withdrawn.

For capsicum the APVMA review resulted in the pre-harvest use of dimethoate being retained but postharvest use was suspended. The loss of the postharvest use of dimethoate has resulted in a similar outcome to tomato where trade to New Zealand has halted until alternative treatments can be negotiated and postharvest treatment with fenthion is currently still permitted for trade on the domestic market.

In addition to the potential for 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.

Irradiation is one of several options being considered as a pest disinfestation treatment to replace dimethoate and fenthion use. Other options include methyl bromide fumigation and the use of systems approaches. While methyl bromide is approved for use in all states and territories within Australia it has the disadvantage that it can result in inferior product quality and doesn't address consumer concerns regarding chemical treatments. Systems approaches (pre-harvest cover sprays and postharvest inspection) are another option but the lack of harmonisation of on the use of systems approaches within Australia means that the only option for entry into several Australian markets if fenthion use is lost will be methyl bromide fumigation.

Irradiation would be a valuable new tool for tomato and capsicum growers, wholesalers and retailers as it is the only treatment that has an internationally endorsed generic treatment of fruit flies (ISPM 18 and 28). It is also a broad spectrum treatment; free of chemical treatment residues; well tolerated by most fresh produce; a cold process; penetrating; simple, rapid and cost competitive.

Irradiation as a quarantine measure

The international authority for standards and measures to prevent the introduction and spread of plant pests, the International Plant Protection Convention (IPPC), has 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 fruit and vegetables. While ISPM 28 "Phytosanitary Treatments for Regulated Pests" sets out minimum doses for a range of pests. 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.

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 over 1,200 tonnes were irradiated for export to New Zealand in the 2009/2010 season. In addition, the USA now imports several irradiated fruits from many developing countries, with over 13,000 tons imported in 2010.

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. Only one facility in Australia is currently accredited to treat fruit for phytosanitary purposes (domestic and international exports) and operational procedures employed are in compliance with FSANZ, Australian Quarantine Inspection Service, Biosecurity New Zealand, Codex and IPPC standards and approvals.

Safety

There are over 100 facilities for food irradiation worldwide and over 50 countries have approved irradiation of at least one type of food. Thirty five countries approve irradiation up to a dose of 1 kGy for fresh fruits and vegetables. Of those approvals, 28 are for pest disinfestation (quarantine) purposes. Twenty three of the 35 countries approve irradiation of fresh fruit and vegetables as a food class (i.e. for any fruit or vegetable).

The international authority for the development of food standards related to human health is the Codex Alimentarius Commission. Codex has adopted a General Standard for Irradiated Foods which, in summary, recommends that irradiation should be regarded as any other food process, and safe and nutritionally adequate for any food. Codex recommends that the maximum absorbed dose delivered to a food should not exceed 10 kGy, except when necessary to achieve a legitimate technological purpose.

The Codex Standard was adopted after a series of Joint Expert Committees on Food Irradiation (JECFI) which evaluated the safety and wholesomeness of irradiated foods. The JECFI concluded that “Irradiation of food up to an overall average dose of 10 kGy presents no toxicological hazard; hence, toxicological testing of foods so treated is no longer required”. The JECFI also concluded that such irradiation “introduces no special nutritional or microbiological problems”.

The evidence considered by the JECFI, plus later data, has been reviewed by several international committees. These reviews have endorsed the toxicological and microbiological safety and the nutritional adequacy of irradiated foods.

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.

There is abundant evidence from the literature that the macronutrients and mineral content in food are unaffected by doses up to 10 kGy and that the micronutrient content is minimally affected at doses below 1 kGy. A search of the literature and recent Australian research data confirm that this is the situation for tomato and capsicum irradiated for phytosanitary purposes. Australian and New Zealand data on the consumption and nutrient content of tomato and capsicum suggest that the small losses feasible after irradiation below 1 kGy should be of no concern to consumers.

Other implications

Literature data and recent data produced by the Queensland Department of Employment, Economic Development and Innovation (DEEDI) show that doses below 1 kGy do not affect adversely the quality or marketability of tomatoes and capsicums.

The labelling requirements of FSANZ Standard 1.5.3 will provide choice for consumers in relation to irradiated tomatoes and capsicums. Consumer surveys indicate that many consumers initially have reservations about food irradiation. Acceptance of the irradiation process increases when the process is explained to them, and irradiation is generally preferred to treatments that include the risk of the food containing chemical residues. Globally, relatively small volumes of labelled irradiated food have been made available in retail stores, but it has been purchased and accepted. Irradiated tropical fruits are now marketed successfully in New Zealand and the USA. Demand for irradiated mangoes and litchis has increased steadily in New Zealand and the New Zealand Fruit Importers Association (NZFPIA) now consider them mainstream imported products that are sold successfully in New Zealand supermarkets and other fresh produce market channels.

The various standard packaging materials used for tomatoes and capsicums conform to materials approved for use in food irradiation by the US Food and Drug Administration. They do not lose their integrity or break down to mobile, diffusible smaller molecules during irradiation at permitted doses.

Conclusion

The approval of irradiation of tomatoes and capsicums for pest disinfestation will provide a safe and effective option to maintain market access throughout Australia and New Zealand for crops grown in areas that endemic fruit fly populations and other regulated pests. Consumers will benefit from the continued availability and price stability of two nutritious popular fresh foods.

PART 1 – GENERAL INFORMATION

1.1 Applicant

(a) Name of organisation:

Queensland Primary Industries and Fisheries
Department of Employment, Economic Development and Innovation
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(c) Contact: Peter Leach
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(d) Nature of Applicant's Business:

Queensland Primary Industries and Fisheries (QPIF - part of the Department of Employment, Economic Development and Innovation) has a vision of 'profitable primary industries for Queensland', and supports strategic industry development at all stages of the industry life cycle and throughout the entire value chain - from production to consumption. The mission of QPIF is to maximise the economic potential for Queensland's primary industries on a sustainable basis.

(e) Other companies associated with application:

1. New Zealand Fresh Produce Importers Association, Inc

   NZFPIA represents wholesalers, traders and retailers who import fresh produce, including fruit and vegetables, into New Zealand. NZFPIA's objectives include: improvement of access for fresh produce into New Zealand; active involvement in the development of biosecurity decisions, policies and practices; and to act as an independent forum for importers of fresh produce to discuss and advance issues of mutual interest.

2. Steritech Pty Ltd, which is a sterilisation and decontamination processor

3. Horticulture Australia Limited (HAL)
4. Vegetable R & D Levy
5. Summerfruit R & D Levy
6. Bowen Gumlu Growers Association Inc.

Portions of this Application have been reproduced from the application A1038, "Application to amend Standard 1.5.3 Irradiation of Food of the Food Standards Code to include persimmon (*Diospyros kaki*) using irradiation as a phytosanitary measure" previously submitted.

1.2 Nature of application

This application seeks to amend an existing standard 1.5.3 – *Irradiation of Foods* (FSANZ, 2003), to provide for the safe use of ionising radiation as a phytosanitary measure[1] in Tomatoes & Capsicum only.

1.3 Support for the application

Letters of support are appended (Appendix E) from:

New Zealand:	Turners and Growers
	Countdown
	Fresh Direct Ltd
	Freshmax NZ Ltd
Australia:	Bowen Gumlu Growers Association Inc.
	Bundaberg Fruit & Vegetable Growers Cooperative Ltd
	CSI Brisbane Pty Ltd
	La Manna Group
	Mountainview Exports
	Pac-Sure Pty Limited
	SP Exports

[1] ***1****Phytosanitary measure* - Any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests [FAO 2010]

PART 2 – SPECIFIC INFORMATION

2.1 Details of the application

This application seeks to amend the Food Standards Code, Standard 1.5.3 by adding tomatoes (*Lycopersicon esculentum* or *Solanum lycopersicon*) and capsicums (*Capsicum annuum*) to the Table of Clause 4 under the same dose and usage conditions presently prescribed for tropical fruits currently approved in the Australia New Zealand Food Standards Code (Table 1). No other variation to Standard 1.5.3 is sought.

Several varieties of tomatoes are grown in Australia and New Zealand but all significant commercial varieties fall into the genus *Lycopersicon esculentum*. Capsicums (also known as bell or sweet peppers or *Capsicum annuum*) are commonly produced as green, yellow, orange and red varieties. Jalapeno peppers, hot peppers and *Capsicum frutescens* are not being considered in this application.

The edible portions of tomatoes and capsicums are botanically fruits, but are usually classed as vegetables in nutritional tables. This application will refer to them as fruits or fruiting vegetables.

Table 1: Requested amendment to Standard 1.5.3, Clause 4, Table.

Column 1	**Column2**	**Column3**
Food	**Minimum and Maximum Dose (kGy)**	**Conditions**
Tomato; Capsicum	**Minimum dose:** 0.15 kGy as a phytosanitary measure. **Maximum dose:** 1.0 kGy as a phytosanitary measure.	Pest disinfestation for a phytosanitary objective

Tomatoes and capsicums are both potential fruit fly hosts and are subject by regulation to plant quarantine (phytosanitary) treatments against fruit fly and other regulated pests[2] as a condition of entry and/or movement into certain plant quarantine jurisdictions. This applies to both domestic and international markets.

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[2] 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.

Under the proposed amendment to Standard 1.5.3 it would be permitted to irradiate tomatoes and capsicums as a postharvest phytosanitary treatment between a minimum dose of 150 Gray (Gy) and a maximum dose of 1000 Gy. The precise minimum dose chosen will depend upon the specific pests to be treated and directives from quarantine agencies.

The applicant submits that the amendment would provide tomato and capsicum growers with a phytosanitary option that is –

- Justified (Part 2.2) due to a technical need for new options for phytosanitary treatments -
    - To provide an alternative method to using insecticide treatments.
    - To maintain the existing access of tomato and capsicum 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 an important segment of the horticulture sector.
    - To provide consumers with a full range of choice to two popular and nutritious food items, with sufficient labelling to clearly inform consumers of the treatment method (Part 4.1).
- Toxicologically and microbiologically safe and which results in nutritionally adequate food (Part 3).
- Highly effective as a broad spectrum method of pest disinfestation that is more practical than most other non-chemical treatment options, is well tolerated by tomato and capsicum, and is cost-competitive (Part 2.2).
- 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 tomato and capsicum industries with the option to use irradiation as a phytosanitary measure. Quarantine pests can disrupt the access and marketing of fresh tomatoes and capsicums between areas within Australia and to overseas markets unless bilaterally accepted phytosanitary measures are available.

The insecticides dimethoate and fenthion were two commonly-used treatments for tomatoes and capsicums for control of regulated pests, such as the Queensland fruit fly. In August 2011 the Australian Pesticides and Medicines Authority (APVMA) released the Dimethoate Residues and Dietary Risk Assessment Report. Based on the findings of the report the APVMA suspended the use of dimethoate on a number of crops on the 6th of October, 2011 due to potential dietary risks. As a result the use of dimethoate was suspended on a number of crops due to potential dietary risks. The suspension period will last for twelve months and prohibits the use of both pre-harvest and postharvest uses of dimethoate on tomatoes. The only exception to this is the use of dimethoate on processing tomatoes but an increased withholding period of 21 days has been imposed on this use. The suspension of dimethoate use on fresh tomatoes has resulted in the loss of market access protocols which incorporate postharvest dimethoate use as a dip or spray. For the New Zealand export market trade has ceased until alternative treatments can be negotiated. For domestic trade, the tomato industry currently has several options. The use of fenthion for both pre and postharvest use is still permitted. However, growers have been advised not to rely on fenthion as a long-term replacement as it is also under review and it's use is likely to be severely curtailed or withdrawn. Other options available to growers include the use of systems approaches or methyl bromide fumigation.

For capsicum the APVMA review resulted in the pre-harvest use of dimethoate being retained but postharvest use was suspended. The loss of the postharvest use of dimethoate has resulted in a similar outcome as tomato where trade to New Zealand has halted and industry have the option of postharvest treatment with fenthion in the short-term on the domestic market. Other options available to growers for the domestic market include the use of systems approaches or methyl bromide fumigation.

A National Response Plan to respond effectively to the APVMA reviews on dimethoate and fenthion is being coordinated by the Office of the Chief Plant Protection Officer (OCPPO) and details of these activities can be found on the Domestic Quarantine and Market Access Working Group website (DQMAWG 2010).

As discussed in more detail in the next sections, non-chemical postharvest treatments are under consideration (heat treatment and irradiation) as well as chemical fumigation with methyl bromide. Irradiation is a cost-competitive disinfestation process which can be described as a simple, safe, versatile, and efficacious method that is already used for some Australian exports. However, some other postharvest options are unsuited for use with tomatoes and capsicums due to phytotoxity issues, length of treatment time, costs or the time frame needed to gain approval from quarantine authorities.

Efficacy –phytosanitary effectiveness

Industrial radiation processing has been a global commercial business for over 50 years with applications that include sterilization of medical, pharmaceutical and other products and the cross-linking of polymers (IAEA 2008). The principles are well-understood and operational controls are based on internationally agreed protocols. Irradiation processing of food has been slower to expand commercially but is now thought to involve between 0.5 to 1 million tonnes of food per annum (Kume *et al*. 2009, P. Roberts, *personal communication*). 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.

The ability of low dose irradiation to sterilize, prevent emergence or kill insect pests of concern has been known for many years (Koidsumi 1930). However, except in the USA, it was not seriously considered as a quarantine treatment for foods moving across country or state borders until recently, since this requires bilateral agreement between countries (or states) and there was no international guidance on how this could be safely and fairly conducted until 2003.

In 2003 the international authority for standards and measures to prevent the introduction and spread of plant pests, the International Plant Protection Convention (IPPC), published its Guidelines for the Use of Irradiation as Phytosanitary Measure ISPM 18 (IPPC 2003). 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). ISPM 18 lays out basic protocols that countries should adopt when trading in irradiated fresh fruit and vegetables.

ASTM International has produced a Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment (ASTM 2006). It details procedures for the radiation disinfestation of fresh produce as 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.

ISPM 18 stimulated expert evaluations of the minimum dose required to kill, sterilize or arrest the development into an adult of different insect species. Since fresh produce does not usually maintain adequate quality at the doses required to ensure rapid kill, it is accepted in ISPM 18 that irradiation can be used as a phytosanitary treatment with the end points either inability to reproduce (sterility) or failure to develop into an adult capable of reproduction.

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). Minimum phytosanitary doses for almost all insects lie in a relatively narrow dose range, from approximately 100 to 600 Gy (ASTM 2006, Hallman 2011, Arvanitoyannis and Stratakos 2010a). Thus 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). In 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). A 400 Gy generic dose for most insect pests and some other arthropod pests (e.g. mites) is still under consideration by the IPPC.

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). Similarly, the New Zealand Ministry of Agriculture and Forestry accepts "generic" irradiation treatments for a range of regulated pests on Australian mango, papaya and litchi currently exported to New Zealand (MAF 2004, 2006a, 2008).

In 2011, the use of irradiation for phytosanitary purposes for domestic trade was approved by all states and territories in Australia. This treatment is available to businesses under the national Interstate Certification Assurance (ICA) Scheme as Operational Procedure Number 55 (i.e. 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.

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;
- a broad spectrum treatment (few insects and other arthropod pests have or 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;
- rapid and able to provide treated products 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).

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 that are valued by consumers. Such qualities include, in very broad terms, appearance, taste, texture, firmness and smell. Economics dictate that growers and retailers will also be interested in any change in shelf-life. Numerous studies have considered the quality of many fruits and vegetables after irradiation. Useful reviews have been conducted by Akamine and Moy (1983), Kader (1986), Urbain (1986a), Thomas (1986a, b, c and 1988), Morris and Jessup (1994) and Arvanitoyannis and Stratakos (2010b).

A majority 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. Delay of ripening may occur at doses within the phytosanitary dose range. A significant decrease in storage decay, however, requires doses in excess of 1 kGy. Most research on fresh produce generally involved these higher doses.

Recently, DEEDI conducted tests on the quality of Australian tomatoes and capsicums after irradiation doses in the disinfestation range up to 1 kGy (see ANNEX). The varieties were firm ripe Gourmet Swanson tomatoes and fresh green Plato capsicums. Fruit quality was assessed immediately after irradiation and during and after removal from storage (14 days at 10^oC for tomatoes and 21 days at 8^oC for capsicums). 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.

DEEDI concluded that the application of up to 1 kGy irradiation did not result in any detrimental damage to the quality of tomato and capsicum fruit. In general, the quality parameters assessed were impacted to a greater extent by storage time than by irradiation.

The absorbed dose, commodity maturity and physiological state at harvest, time of irradiation after 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 a literature that can appear confused and conflicting, as noted by Thomas (1988), Morris and Jessup (1994) and DEEDI (see ANNEX).

Morris and Jessup (1994) succinctly discuss the multiple effects that irradiation at doses of approximately 1 kGy may have on fresh fruits and vegetables which have led to the conflicting data. Possible effects and findings which can confound generalization 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 (CO_2 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.

Thomas (1988) provided an extensive review of the literature on the effects of irradiation on tomatoes. These involved mainly doses above 1 kGy. A few studies examined delay of ripening at doses less than 1 kGy (Mathur 1962, 1963; Hugue and Khaleque 1970, Kovacs and Vas 1974 and Van der Linde 1982). The results are conflicting in terms of effects on ripening but when a delay was observed, it was found with tomatoes at the green mature stage, and the fruit often failed to develop a uniform red colour. Fruit irradiated at the breaker, pink or early red ripe stage developed normally.

Most of the data examined by Thomas involved doses above 1 kGy and examined the potential for increased shelf-life through controlling spoilage organisms. Yasia *et al* (1987) studied the loss of firmness of tomatoes between 500 Gy and 2.5 kGy and linked this to degradation of pectic fractions into lower molecular weight components. They concluded that loss of firmness occurred at doses above 1 kGy. Salunkhe (1961) concluded that tomato quality decreased above 1.5 kGy. More recent studies on fruit firmness and shelf-life and the associated chemical changes include that of El Assi *et al* (1997) who used mature green and pink tomatoes and doses between 0.7 and 2.22 kGy, and Aneesh *et al* (2007) who used doses from 1 to 4 kGy with modified atmosphere packaging of breaker stage tomatoes. Larrigaudiere *et al* (1990) studied ethylene production in breaker cherry tomatoes. Results are again variable but there seems little doubt that at doses up to at least 2 kGy the fruit maintained acceptable overall quality.

Thomas (1988) and other reviewers (Akamine and Moy 1983, Abdel-Kader *et al*. 1968 and Arvanitoyannis and Stratakos 2010b) concluded that tomatoes maintain good quality after doses in the range used for pest disinfestation and can probably withstand doses up to at least 2 kGy satisfactorily.

The literature on irradiated capsicums is more limited than on tomatoes. Softening and yellowing which is storage temperature dependent was found in an early study by Bramlage and Lipton (1965) in which the minimum dose applied was 1.25 kGy. In his review, Thomas (1988) cited the study by Ravetto *et al* (1970; reference unable to access), who found doses in the range 2 to 6 kGy caused injury to capsicums. They also noted that a 500 Gy dose caused an increase in CO_2 production mimicking a climacteric-type response. At very low doses (20 to 100 Gy), Farkas *et al* (1966) found small, complex effects on ripening and pigment formation.

On the basis of this fairly limited information, reviewers such as Thomas (1988), Akamine and Moy (1983) and Kader (1986) declared capsicum irradiation to be non-beneficial (that is, quality was compromised) if shelf-life extension was the purpose of irradiation as this requires doses above 1.5 kGy. Thomas and Kader noted that irradiation was still a practical possibility for lower dose, pest disinfestation. These authors noted that injury to some fruit could occur as the dose approached 1 kGy but also that product quality was influenced by many factors.

More recent research on capsicum irradiation, when the many factors influencing final quality have become better understood and managed, has also been limited and has still involved doses greater than required for pest disinfestation. Ramamurthy *et al* (2004) claim that 2 kGy improved both the hygienic quality and shelf-life of minimally processed capsicum without affecting the nutritional quality. Prakash and Foley (2004) studied the effect on diced capsicum of 0.5, 1.8 and 3.7 kGy gamma irradiation. They found that after an initial softening at 24 hours post-irradiation (14% at 0.5 kGy), sensory and other quality attributes were acceptable even at 1.8 kGy.

Although the literature data are not as convincing as for tomatoes, it is highly likely that a phytosanitary irradiation regime can be devised that results in capsicums of marketable quality. Irradiated tomatoes and capsicums may also experience an extension of shelf-life under certain conditions.

Overall, a consensus has emerged that nearly all fruits and vegetables will be of acceptable quality at doses within the phytosanitary range up to 600 Gy (Arvanitoyannis and Stratakos 2010b, Heather and Hallman 2008a, b). Hallman (2011) asserts that more types of fresh fruit and vegetables tolerate irradiation than any other commercially available phytosanitary treatment. Exceptions may be products that naturally auto-oxidize rapidly, such as avocado. As the dose delivered increases towards 1 kGy, a slight loss of quality can be observed in some fruits and vegetables. Above 1.5 kGy, loss of firmness and other attributes result in relatively few irradiated fruits and vegetables being of saleable quality, strawberries being the clear exception.

Efficacy – International trade

Proof of efficacy exists in the recent acceptance of irradiation as a measure accepted by the plant protection authorities of the USA and New Zealand and the consequent commercial importation of irradiated fresh fruits into those countries.

A trial shipment of mangoes irradiated for fruit fly disinfestation took place between Puerto Rico and Florida in 1986, and in 1992 an irradiation plant in Mulberry, Florida, began an operation to treat fresh crops for shipment to California and other Western states of the US (Heather and Hallman 2008b).

Commencing in 1995, non-irradiated papaya was air freighted from Hawaii to the cool climate area of Chicago and irradiated on arrival. In 2000 an x-ray facility in Hilo, Hawaii began operation to treat fruits prior to shipment to the continental USA. Initially papaya was treated but now sweet potato is the major crop treated. Based on this experience, the USDA approved irradiation as a phytosanitary treatment for imported fruits and vegetables (USDA 2002). After generic doses were agreed for fruit flies and all other pests (USDA 2006), Final Rules were issued permitting the import of irradiated fresh fruits from a number of developing countries, notably Mexico, India, Thailand, Pakistan, Malaysia and Vietnam (USDA 2007a, b, 2008a, b, c, 2010, 2011a).

The first truly international commercial export of irradiated fruit resulted after Biosecurity New Zealand accepted irradiation as a phytosanitary treatment of mangoes from Australia in 2004. Biosecurity New Zealand, part of the New Zealand Ministry of Agriculture and Forestry, has issued Import Health Standards for imports of irradiated mangoes, papaya and litchi from Australia and irradiated papaya from the USA (MAF 2004, 2006a,b and 2008).

Table 2 shows the amount of fresh produce irradiated in Australia for importation into New Zealand. The amount available for treatment in the 2010/2011 season was adversely affected by widespread floods in the main growing areas of Queensland. Table 3 shows irradiated fruit imports into the USA. The amounts irradiated for both New Zealand and the USA are relatively small, but increasing rapidly since being initiated.

Table 2: Australian fruit (tonnes) irradiated in Australia for import into New Zealand *

	2004/05 Season	2005/06 Season	20006/07 Season	2007/08 Season	2008/09 Season	2009/2010 Season	2010/11 Season
Mango	19	129	201	346	585	1,095	377
Papaya	0	0	12	1	0	0	0
Litchi	0	5	10	20	57	110	15
TOTAL	**19**	**134**	**223**	**367**	**642**	**1205**	**392**

*Data obtained from Steritech and Biosecurity NZ.

Table 3: Amounts of irradiated fruit (tons) imported into the USA*

	2008	2009	2010
India (mango)	275	130	195
Thailand (mainly longan)	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**

*Data for Mexico obtained from Hallman (2011). Data for Asian countries was reported at the Final Project Review Meeting of the RCA/IAEA Project on Novel Applications of Food Irradiation, Beijing, March 2011 (P Roberts, *Pers. Comm.)*

2.3 Justification for the application

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 tomato and capsicum growers, exporters and importers with a chemical free postharvest treatment. Without access to an effective treatment, the economic viability of growers will be compromised and consumers may be disadvantaged through decreasing availability and increasing prices.

As a result of the APVMA review on dimethoate (6 Oct 2011) the use of dimethoate on a number of crops has been suspended due to potential dietary risks. As a result, the trade in capsicums and tomatoes to New Zealand has ceased until alternative treatments can be negotiated. The Queensland Government has undertaken research on system approaches for tomatoes and capsicums in North Queensland but the necessary approvals may not be in place by the start of the export season. The systems approach proposes to use a series of pre-harvest sprays combined with postharvest inspection. Another DEEDI research project is investigating the use of reduced levels of methyl bromide in an attempt to maintain product quality while providing the necessary level of control against a range of fruit fly species. Once again, results of this project will not be available prior to the commencement of the export season. In the interim an emergency protocol is being negotiated which may incorporate all of the following risk mitigation measures; pre-harvest covers sprays with alternative chemicals, postharvest inspection and methyl bromide fumigation.

In addition to the potential for increased regulatory restrictions on insecticides, there is a growing recognition within the horticultural sector of the need for alternative treatments. Surveys of consumers in the UK and USA in which respondents are prompted to rank various concerns about food have consistently shown a high level of concern about pesticide and chemical residues, a concern that is higher than concern about irradiation (FSA 2004, Johnson *et al* 2004, Eustice and Bruhn 2006). Limited surveys in Australasia indicate a similar situation (Gamble *et al* 2002, FSANZ 2008). 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.

Regulated pests, including Queensland fruit fly, require the application of agreed phytosanitary measures before host fruits such as tomatoes and capsicums can be shipped to areas of Australia, New Zealand and other overseas markets in which the pests are absent. Quarantine restrictions apply and, under a system of phytosanitary certification based on quality management principles, an accredited business must be able to demonstrate it has effective procedures that ensure that produce meets specified quarantine requirements.

A requirement for phytosanitary disinfestation is usually regulated by a relevant quarantine agreement and/or phytosanitary protocol agreed between biosecurity/quarantine agencies such as National Plant Protection Organisations (NPPOs). The harmonisation of phytosanitary irradiation treatments for regulated pests through ISPM No. 18, ISPM No. 28 and ICA 55 will support efficient and effective phytosanitary measures. This, in turn, will encourage the mutual recognition of treatment efficacy and treatment delivery, which would facilitate domestic and international trade.

Irradiation is not the sole option as a replacement for dimethoate and fenthion (DQMAWG 2010, and see section below on phytosanitary options). This application to FSANZ demonstrates that irradiation is an effective phytosanitary treatment that is safe, available for immediate implementation and which has several significant practical advantages over other options. However, which option or mix of options is actually adopted by the fresh produce suppliers, the supporting wholesalers and the retail industry will be decided on a commercial evaluation of the relative merits of each option.

Phytosanitary treatment options

The national Interstate Certificate Assurance (ICA) Scheme provides a harmonised approach to the audit and accreditation of businesses in Australia. The ICA scheme is based on documented operational procedures developed 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. A summary of existing ICA Operating Procedures can be found at http://www.dpi.qld.gov.au/4790_20196.htm.

The existing options for a disinfestation treatment of tomatoes and capsicums within Australia are postharvest treatment fenthion (ICA-02), systems approaches (ICA 26 and 27) and methyl bromide fumigation (ICA-04). The APVMA review of the dimethoate and fenthion has encouraged industry to seek alternative treatment options.

An IPPC (2008) report on the replacement or reduction of the use of methyl bromide considered 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).

Irradiation is more efficient and less phytotoxic than thermal, cold or fumigation treatments in tropical fruits (Moy 1993, Moy and Wong 2002, Hallman 2008a, Hallman 2011, Follett and Sanxter 2000, 2002, 2003). Research on heat treatment of capsicum and tomato has been undertaken in Australia but no protocols have been developed for the domestic or international markets for either crop (Leach unpublished). In the case of capsicum extensive research was undertaken using vapour heat treatment (VHT), controlled atmosphere and VHT, and VHT and cold storage. While the treatment combinations could control Australian fruit flies it resulted in a severe reduction in fruit quality. For tomatoes research on heat treatment has been successfully completed but industry has not requested the negotiation of new market access protocols due to concerns about the economic viability of the treatment. Cold treatment is another suggested alternative but tomatoes and capsicums are susceptible to cold injury, treatment time is approximately 2 weeks and like heat treatments the cost is considerably higher than insecticide treatments (Lyons 1973, AFRA undated, Ding *et al* 2002*,* Lim *et al* 2007, DQMAWG 2010, Lacson 2007).

Other chemical disinfestation treatments such as phosphine are relatively slow and phytotoxic to fresh fruits and vegetables. Produce treated with any chemical treatment will contain chemical residues that, although in small concentrations are of significant, increasing consumer concern (Johnson *et al* 2004, FSA 2004, 2007). In contrast, irradiation produces no chemical residues. There are non-chemical phytosanitary treatments at an experimental stage, such as radiofrequency heating, microwaves, ultrasound and pressure, but it will take many years before they are considered practical, proven and accepted by the IPPC and national plant protection organisations. A useful reference is Heather and Hallman (2008b) which contains chapters on all the presently used pest management techniques, plus a chapter on miscellaneous methods under development. In contrast, irradiation treatment has the advantage that it is known in advance that most fruits and vegetables are radiation-tolerant below 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.

The cost for irradiation treatment by an Australian facility is currently in the range A$50-70 per tonne of fruit. This may be expected to decrease if greater disinfestation use is made of the irradiation facility (Steritech, *private communication*). The irradiation treatment cost is greater than the cost of the insecticide treatments, although the cost difference 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.

Irradiation costs should be compared with the costs of other alternatives to insecticides. Unfortunately comparisons are not straightforward as costs quoted in the literature are highly variable as factors such as the facility capacity, annual throughput and amortization method. For example, vapour heat treatment has been quoted as approximately US$30/tonne (1996 figures) based on a prediction for a high throughput plant operating at near full capacity for 20 years (EPA 1996) to US$400/tonne for the Philippine experience for treating mangoes for export to China in 2009 (ABW 2009).

Lacson (2007) has presented Australian data that indicates that treatment costs are 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. Hallman (2011), in a more general categorization, places heated air and irradiation as moderate cost alternatives and cold, hot water immersion and methyl bromide as low cost alternatives. The food industry will make commercial decisions based only partly on costs of treatment. Product quality, treatment speed and convenience will also enter into decisions. Irradiation generally has significant advantages over other alternatives due to the superior quality of irradiated fresh commodities (Hallman 2011, Heather and Hallman 2008b, EPA 1996) and it has the most rapid turnaround time. On the basis of the above considerations, the applicant considers irradiation to be a cost-competitive option for industry to consider.

2.4 Costs and benefits

To industry

Tomatoes are the second most valuable vegetable crop after potatoes in both Australia and New Zealand. Capsicums are a far smaller but still valuable crop that appears to be increasing in popularity. Tomatoes in particular are such a major crop that its socio-economic benefit within the distribution and supply chain and the jobs involved in it are a significant addition to the jobs created on-farm.

Production volumes, farm gate and retail values and import/export figures can differ quite dramatically year-on-year, but 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 (QPIF 2009), Tomatoes New Zealand (TNZ 2011) and Plant and Food Research (PFR 2009). The data from these publications is used in the following sections.

Australia - Tomatoes

Tomato production for fresh sale and for processing is carried out in all the states of Australia and the Northern Territories and totalled 474,000 tonnes in 2009-10. The most extensive data available is for 2006/07. Only fresh tomatoes may require disinfestation.

Nationwide, fresh tomato production in 2006/07 was approximately 179,000 tonnes of which approximately 67% (121,000) tonnes was produced in Queensland according to data produced for Queensland industry (QPIF 2009). Another publication (RIRDC 2010a) quotes total production of 234,000 tonnes with Queensland contributing about 55%. The differences may be due to the timing and methods used for data collection. The value of production nationally was approximately A$282 million and the value of production for Queensland was approximately A$169 million. The major growing areas in Queensland are around the Bundaberg and Bowen regions. While fruit flies and other regulated pests are endemic to Queensland they are also present in other production areas such as coastal areas of New South Wales, Victoria, Western Australia and the Northern Territory. However, fresh tomato production in the three other tomato producing states is much less than production in Queensland (less than 20% of total production).

Tomatoes for processing are also produced but the bulk of such production is in Victoria. In 2006/07 the production for processing was approximately 148,000 tonnes of which 86% was in Victoria. In contrast, Queensland only produced approximately 1.6% of the nation's tomatoes for processing (approximately 2,300 tonnes).

In order to service consumer requirements throughout the year, tomatoes are traded across state boundaries. In 2006/07, approximately 70% of Queensland production went to markets in other states with a value of approximately A$118 million. Melbourne and Adelaide were the major markets, receiving a combined total of about 35% of Queensland production (A$59 million). Postharvest treatment using ICA-01 and ICA-02 (dimethoate and fenthion dips and sprays) were the major operational procedures used by Queensland growers to access these restricted markets. As stated previously the APVMA review of dimethoate has resulted in the loss of postharvest use of dimethoate and fenthion use is expected to be suspended in the near future. The loss of postharvest chemical treatments means that growers in Queensland, in particular, face great difficulties unless effective alternatives are put in place (DQMAWG 2010, QPIF 2009).

Australia also exported almost 3,900 tonnes of fresh tomatoes worth approximately A$8 million (FOB). The major market was New Zealand which received approximately 3,000 tonnes with an estimated retail value of approximately NZ$6 million (NZ Fresh Produce Importers Association database, *personal communication)*. Tomatoes were imported into New Zealand under an Import Health Standard (MAF 1995, 2011) that required the use pre-harvest field sprays and postharvest treatment with dimethoate.

Australia - Capsicums

Total capsicum production in Australia in 2006/07 was approximately 56,000 tonnes with 47,000 tonnes (84%) being produced in Queensland. Total value of production was approximately A$138 million of which A$113 million was produced in Queensland. Approximately 70% of Queensland production (value A$79 million) was shipped to other states, with 40% of production (A$45 million) going to Melbourne and Adelaide.

Export volumes were 977 tonnes worth A$3 million. New Zealand received almost 800 tonnes with an estimated retail value of over NZ$8 million (NZ Fresh Produce Importers Association database, *personal communication)*.

Overall industry cost-benefit

Approval for the use of irradiation as a disinfestation treatment for tomatoes and capsicums will provide an alternative phytosanitary measure for use on produce shipped to pest-free areas in the south and west of Australia at a time when existing measures are under threat of further restrictions on use or being suspended.

Tomatoes and capsicums are among the highest priorities in the horticulture industries for maintaining domestic market access in Australia if dimethoate and fenthion use is suspended or their conditions of use severely restricted (DQMAWG 2010, QPIF 2009). For New Zealand, the ability to import Australian tomatoes and capsicums is of the highest priority for fresh produce importers (New Zealand Fresh Produce Importers Association (NZFPIA), *personal communication*). The NZFPIA has implemented a special levy to assist with funding for finding alternative treatment options to maintain future market access if the insecticides are withdrawn or restricted.

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

The availability of an alternative option can help reduce the risk of product shortages, higher prices and uninterrupted access.

To consumers

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

Part 3 considers the nutritional adequacy of irradiated tomatoes and capsicums. In brief, no significant change in dietary intake of nutrients will occur as a result of irradiation. Part 2.2 discussed the evidence that the quality of tomatoes and capsicums would be unaffected by irradiation disinfestation.

Consumer attitudes and responses to irradiated foods are discussed in detail in Part 5.3. However, the export of irradiated mangoes 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 mangoes. The NZFPIA is supporting activities that will ensure a continuing supply of tomatoes and capsicums from Australia in the event of a withdrawal of approval for dimethoate and fenthion, and generally wish to see an increase in supply (NZFPIA, *personal communication)*.

Consumers increasingly perceive a human health risk from chemical pesticide/insecticide residues in food, although their tolerance for more regulation or to pay more for residue-free food 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 fuller information is provided, and is greater than for chemically treated food when surveys are framed in terms of either consuming irradiated foods or foods containing with pesticide residues (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 A) will ensure that consumers are informed that the food has been irradiated and that they can make informed choices.

To government

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 Alimentatrius 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).

Under the SPS Agreement, the International Plant Protection Convention (IPPC) is the international treaty relating to plant health and biosecurity, to which 177 governments (as of June 2011) adhere. Australia and New Zealand are contracting parties. The purpose of the treaty is to secure action to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control. The IPPC has issued an international standard and guidelines (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, Appendix 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. 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. The amendment of Standard 1.5.3 to add tomatoes and capsicums to the Table of Clause 4 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.

Approval of irradiation would also provide industry with the opportunity to reject or lessen the use of methyl bromide as a treatment option and contribute to a reduction in Australia's use of this fumigant in accord with Australia's commitments under the Montreal Protocol.

There would also be reductions in pesticides use with consequent environmental benefits (Part 5.1).

The benefits to industry discussed in Part 2.4 would lead to stability in the fresh produce market and in tomato and capsicum prices as well as potential for increased export returns. The continued prosperity and growth of the sector and its associated supply chain partners would have a positive benefit to government revenue and society generally.

PART 3 – SAFETY ASSESSMENT

3.1 Nutritional data

Nutritional value of raw tomatoes and capsicums

Tomatoes are one of the most consumed type of fresh produce in both Australia and New Zealand. Fresh and processed tomatoes are the second most consumed vegetable (after potatoes) by adult Australians and New Zealanders (ABS 1999, VEG 2011, PFR 2009). A 2007 Household Economic Survey (STATS 2007) scored tomatoes as the number one favourite vegetable in New Zealand.

In 1997, 83% of New Zealanders across all age groups (European and other heritage) consumed tomatoes at least once a week; for Pacific and Maori populations the percentages were 77% and 68% respectively (MOH 1999). The average consumption/adult /day was 21.3g for whole tomatoes and 46.4g for all tomatoes including in mixed foods. For Australians in 1995, (ABS 1999) the average consumption per day of tomatoes and tomato products was 35.3g for adult males and 31.6g for adult females.

Capsicum consumption is significantly less, with 36% of New Zealanders across all age groups (European and other heritage) consuming it at least weekly and average consumption/person/day at 0.4g for raw capsicums and 2.3g for capsicums in all foods. It appears to be increasing in popularity and is used as a component of salads, stir-fried and other dishes. Australian data for capsicums is unavailable as the data is captured within “other fruiting vegetables” (ABS 1998, 1999).

Tables 4 and 5 provide key nutritional data for fresh raw tomatoes and for green and red capsicums. 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.

Both tomatoes and capsicums have high water contents (approximately 92-94%). Macronutrient levels and energy content are, therefore, low relative to many other foods. Tables 4 and 5 can be used to derive the average nutrient content per single serve (75g for fresh vegetables). The percentage contributions to daily intake of nutrients based on FSANZ Reference Values can also be derived (Table 6).

The percentage of the daily intake from a single serve of tomatoes is approximately 0.6% energy, 1.5% protein, 0.6% available carbohydrate, 3% total dietary fibre, 2% total sugar and 0.2% sodium. A serve of capsicums (average of green and red) accounts for approximately 0.9% energy, 2.1% protein, 0.9% available carbohydrate, 4.5% total dietary fibre, 3% total sugar and 0.05% sodium. Using standard energy factors for carbohydrate, protein, fats and fibre (FAO 2002), the energy value from available carbohydrate is approximately 42kJ/100g for tomatoes and 62kJ/100g for capsicums (average of green and red fruit). Just over 50% of the energy value comes from carbohydrate with the rest from protein, fats and dietary fibre.

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 of produce such as tomatoes and capsicums. 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 tomatoes and capsicums.

Fresh produce are a major source of essential vitamins, minerals and fibre (ABS 1998, FDA 2008, CDC 2011). Tomatoes, for example, are a valuable source of vitamin C, vitamin A precursors (mainly ß-carotene), as well as some vitamin E, folic acid, potassium and other trace elements (Hedges and Lister 2005). In tomatoes, ß-carotene concentrations are similar to concentrations in other vegetables such as broccoli and courgettes. Vitamin C concentrations are similar to those found in broccoli and cauliflower. In addition, a carotene anti-oxidant, lycopene, is found in relatively large quantities. Lycopene, the cause of the red colour, is found in relatively few other foods and tomatoes are the pre-dominant food source (Table 4; Hedges and Lister 2005).

The vitamin C content of both green and red capsicums is higher than most other vegetables (approximately twice as high as broccoli and cauliflower for example) and similar to that in kiwifruit. The ß-carotene content of green capsicum (200µg per 100g) is in the range found for many other vegetables, but rises significantly in red capsicum to approximately 1400µg per 100g. Carrots contain approximately 6000µg per 100g of ß-carotene. Table 7 compares vitamin values for the nine tropical fruits already approved for irradiation by FSANZ and for tomatoes and capsicums. Generally the pattern of vitamin content is similar across these foods but tomatoes contain more thiamine while capsicums contain more vitamin C.

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 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.

Tomatoes are a significant part of the average consumer's diet. As discussed more in Part 3.1.2 their contribution to overall micronutrient intake will be significant but not pre-dominant. Capsicums are also a useful source of micronutrients, but they 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 (see 3.1.2).

Table 4: Nutritional data for raw tomatoes per 100g edible portion

Nutrient	USDA 2011b	FSANZ 2010	MOH 2009
Water	94.5g	94.2g	94g
Energy	74kJ	74kJ	68kJ
Protein	0.88g	1.0g	0.9g
Nitrogen		0.16g	
Total lipid (fat)	0.2g	0.1g	0.2g
Malic Acid		0.1g	
Carbohydrate	3.89g	2.4g	2.7g
Total dietary fibre	1.2g	1.2g	1.2g
Ash	0.5g	0.6g	
Total sugars	2.63g	2.3g	2.7g
Fructose	1.37g	1.2g	
Glucose	1.25g	1.1g	
Sucrose	0	0	
Ascorbic acid, Vit C	13.7mg	18mg	24mg
Thiamin, Vit B1	0.037mg	0.02mg	0.02mg
Riboflavin Vit B2	0.019mg	0.02mg	0.01mg
Niacin	0.594mg		
Niacin Equivalents		0.17mg	0.6mg
Vitamin B6	0.08mg	0.03mg	0.01mg
Folate Vit B9, total	15µg	16µg	14µg
Vit A (retinol equiv.)	42µg	26µg	92µg
Alpha carotene	101µg	0µg	
Beta carotene	449µg	153 µg	549µg
Beta cryptoxanthin	0	n.a.	
Cryptoxanthin		7 µg	
Lycopene	2573µg	537.5µg	
Vit E	0.54mg	0.26mg	
Vit K	7.9µg	n.a.	
Calcium	10mg	9mg	11mg
Iron	0.27mg	0.27mg	0.1mg
Magnesium	11mg	7mg	
Phosphorus	24mg	26mg	23mg
Potassium	237mg	214mg	265mg
Sodium	5mg	8mg	4mg
Zinc	0.17mg	0.31mg	0.1mg
Copper	0.059mg	0.042mg	
Manganese	0.114mg	0.092mg	
Selenium	0µg	0.4µg	0.1µg

Table 5: Nutritional data for raw green and red capsicum per 100g edible portion

	Green Capsicum			Red Capsicum		
Nutrient	**USDA 2011b**	**FSANZ 2010**	**MOH 2009**	**USDA 2011b**	**FSANZ 2010**	**MOH 2009**
Water	93.9g	93.2g	94g	92.2g	92.2g	91g
Energy	84kJ	92kJ	66kJ	129kJ	106kJ	146kJ
Protein	0.86g	1.6g	0.9g	0.99g	1.5g	1.7g
Nitrogen		0.26g			0.24g	
Total lipid (fat)	0.17g	0.1g	0.4g	0.30g	0.2g	0.2g
Malic Acid		0.1mg			0.1g	
Carbohydrate	4.64g	2.5g	2.2g	6.03g	3.5g	6.7g
Total dietary fibre	1.7g	2.4g	1.6g	2.1g	1.8g	1.6g
Ash	0.43g	0.2g		0.47g	0.4g	
Total sugars	2.4g	2.5g	2.2g	4.20g	3.5g	6.1g
Fructose	1.12g	1.0g		2.26g	1.9g	
Glucose	1.16g	1.3g		1.94g	1.7g	
Sucrose	0.11g	0.2g		0	0	
Ascorbic acid, Vit C	80.4mg	98mg	100mg	127.7mg	152mg	170mg
Thiamin, Vit B1	0.057mg	0.033mg	0.07mg	0.054mg	0.035mg	0.04mg
Riboflavin Vit B2	0.028mg	0.033mg	0.03mg	0.085mg	0.044mg	0.05mg
Niacin	0.48mg	0.54mg		0.979mg	0.88mg	
Niacin Equiv.		0.81mg	0.9mg		1.13mg	1.2mg
Vitamin B6	0.224mg	0	0.17mg	0.291mg	0.30mg	0.36mg
Folate Vit B9, total	10µg	10µg	11µg	46µg	60µg	21µg
Vit A, retinol equiv.	18µg	29µg	33µg	157µg	215µg	245µg
Alpha carotene	21µg	16µg		20µg	9µg	
Beta carotene	208µg	161µg		1624µg	282µg	
Beta carotene equiv.		175µg	200µg		1292µg	1470µg
Beta cryptoxanthin	7µg			490µg		
Cryptoxanthin		11µg			2011µg	
Vit E	0.37mg	0.05mg		1.582mg	4.03mg	
Vit K	7.4µg			4.92µg		
Calcium	10mg	9mg	9mg	7mg	4mg	2mg
Iron	0.34mg	0.58mg	0.4mg	0.43mg	0.3mg	0.3mg
Magnesium	10mg	10mg		12mg	6mg	
Phosphorus	20mg	20mg	25mg	26mg	28mg	34mg
Potassium	175mg	165mg	210mg	211mg	174mg	180mg
Sodium	3mg	2mg	2mg	4mg	2mg	1mg
Zinc	0.13mg	0.19mg	0.2mg	0.25mg	0.19mg	0.4mg
Copper	0.066mg	0.072mg		0.017mg	0.091mg	
Manganese	0.122mg	0.133mg		0.012mg	0.139mg	
Selenium	0	0.4µg	0.1µg	0.1µg	0.5µg	

Table 6. Nutrient values are per 100 g edible portion

NUTRITIONAL INFORMATION							
One serve of fresh vegetables is 75 grams (Department of Health and Ageing Go for 2&5® campaign)							
	Average quantity per 100g		Average quantity per serving (75g)		% Daily Intake per serving[a]		Reference value
Nutrient	**FSANZ 2010**	**MOH 2009**	**FSANZ 2010**	**MOH 2009**	**FSANZ 2010**	**MOH 2009**	
Tomatoes (common, raw)							
Water	94.2g	94.0g					
Energy	74kJ	68kJ	55.5kJ	51.0kJ	0.64	0.59	8700kJ
Protein	1.0g	0.9g	0.75g	0.68g	1.5	1.4	50g
Total lipid (fat)	0.1g	0.2g	0.075g	0.15g	0.1	0.2	70g
Fatty acids, total saturated	0g	0.04g	0g	0.03g	0	0.1	24g
Available Carbohydrate	2.4g	2.7g	1.8g	2.03g	0.58	0.65	310g
Sugar	2.3g	2.7g	1.73g	2.03g	1.92	2.26	90g
Total dietary fibre	1.2g	1.2g	0.9g	0.9g	3.0	3.0	30g
Sodium	8mg	4mg	6mg	4mg	0.26	0.17	2300mg
Capsicums (raw, average of green and red)							
Water	92.7g	92.5g					
Energy	99kJ	106kJ	74.25g	79.5g	0.85	0.91	8700kJ
Protein	1.55g	1.3g	1.16g	0.98g	2.3	2.0	50g
Total lipid (fat)	0.15g	0.3g	0.11g	0.23g	0.16	0.33	70g
Fatty acids, total saturated	0g	0.05g	0g	0.038g	0	0.16	24g
Available Carbohydrate	3.0g	4.4g	2.25g	3.3g	0.73	1.06	310g
Sugar	3.0	4.2g	2.25g	3.15g	2.5	3.5	90g
Total dietary fibre	2.1g	1.6g	1.58g	1.2g	5.3	4.0	30g
Sodium	2mg	1.5mg	1.5mg	1.13mg	0.06	0.05	2300mg
a. Percentage Daily Intakes are based on an average adult diet of 8700 kJ. Actual daily intakes may be higher or lower depending on individual energy needs.							

Table 7: Vitamin values for fresh produce approved within Standard 1.5.3 and for persimmons, tomatoes and capsicums per 100 g (FSANZ 2010, USDA 2011b)

	Breadfruit	Carambola	Custard apple	Longan	Lychee	Mango	Papaya	Rambutan	Persimmon	Tomato	Capsicum (average)
Thiamin (mg)	0.110	0.14	0.05	0.031	0.05	0.018	0.03	0.015	0.01	0.02	0.034
Riboflavin (mg)	0.030	0.16	0.08	0.14	0.07	0.037	0.03	0.065	0.10	0.02	0.038
Niacin (mg)	0.900	0.367	0.8	0.30	0.5	0.56	0.3	0.79	0.5	0.2	0.7
Niacin from tryptophan or protein (mg)			0.2		0.2	0.3	0.1	0.2	0.1		0.3
Niacin equivalents (mg)			1.03		0.68	0.84	0.37	0.96	0.6	0.17	0.97
Vitamin C (mg)	29	34.4	43	84	49	26	60	70	14	18	125
Alpha carotene (µg)	0	24	10		0	9	0	0	20	0	12.5
Beta carotene (µg)	0	25	0		0	1433	240	0	200	153	220
Cryptoxanthin (µg)	0	0	0		0	1516	1350	0	1230	7	1.11
Beta Carotene equivalents(µg)			5		0	2195	915	0	825		
Retinol equivalents (µg)			1		0	366	152	0	138	26	122
Vitamin E (mg)	0.10	0.15				1.3			0.73	0.26	2.04

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 reviewed by several organizations 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 (and probably higher) 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 but some are destroyed with the extent increasing with increasing dose. At doses below 1 kGy vitamin losses are minimal. The losses are probably within variations found between varieties of a specific food or the losses caused by storage (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 processing foods in other ways such as heating, freezing or canning (Kraybill 1982, Murray 1983, WHO 1994, JECFI 1999, SCF 2003, EFSA 2011**)**.

The Food and Agriculture Organisation and the World Health Organisation of the United Nations convened a series of Joint Expert Committees on Food Irradiation (JECFI) which evaluated the safety and wholesomeness of irradiated foods. Prior to the approval of the Codex General Standard for Irradiated Foods, JECFI (1981) concluded that "irradiation of food up to an overall average dose of 10 kGy introduces no special nutritional or microbiological problems" JECFI did not rule out nutritional changes, but 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. Attention should be paid to any significant changes in relation to each particular food and its role in the diet, including for sub-populations. The American Dietetics Association (ADA 2000) 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 United Kingdom have approved the use of irradiation for pest disinfestation or maturation control of fresh produce. FSANZ has also concluded that irradiation up to 1 kGy has no impact on the nutritional adequacy of 10 tropical fruits (FSANZ 2003, 2011a).

Vitamins differ in their sensitivity to radiation as shown in Tables 8 and 9.

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
C (ascorbic plus dehydroascorbic acids)	ß-carotene	D
Thiamine (B1)	K (in meat)	K (in vegetables)
α-tocopherol (E)		Riboflavin (B2)
Retinol (A)		Pyridoxine (B6)
		Cobalamin (B12)
		Niacin (B3)
		Folic acid
		Pantothenic acid
		Biotin (B10)

Tomatoes and Capsicums

A report of irradiation studies of Australian tomatoes and capsicums conducted in 2011 is provided in full in the **Annex** to this application. The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety Gourmet Swanson and fresh green capsicum (*Capsicum annuum*), variety Plato. The research investigated the effect of low dose gamma (ɣ)–irradiation on the nutritional profile and postharvest quality of tomato and capsicum irradiated at pest disinfestation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The proximate and chemical measurements for each commodity were analysed using analysis of variance at Time 1 (one day after irradiation) and at Time 2 (after a recommended period in cold storage) after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy. Time 2 was 14 days at 10^{o}C for tomato and 21 days at 8^{o}C for capsicum. 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).

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 for the two commodities were also completed.

For tomato, no significant dose effects for all the nutritional components tested were detected immediately after irradiation treatment or after 14 days storage. Specifically, there were no significant differences in mean Vitamin C (ascorbic acid) and beta-carotene for the irradiated samples and corresponding controls one day after irradiation. No significant dose effects for Vitamin C (ascorbic acid) or beta-carotene were detected after 14 days storage.

For capsicum, no significant dose effects were found within one day after irradiation. Specifically, there were no significant differences in mean Vitamin C (ascorbic acid) and beta-carotene between the irradiated samples and corresponding controls. No significant dose effects in Vitamin C (ascorbic acid) or beta-carotene were detected after 21 days.

However, significant ($p<0.05$) small changes were detected in some variables for capsicum after 21 days storage. A significant dose effect after 21 days was found for moisture, fructose and poly-unsaturated fat. For moisture, the mean after exposure to 1000 Gy was significantly lower than the control mean (0 Gy). The mean poly-unsaturated fat content was significantly lower after exposure to 150 Gy compared to 600 Gy and 1000 Gy, but was not significantly different to the control mean.

Some significant dose by time interactions and time effects were found in tomato and capsicum. However, the impact of time in storage generally affected the chemical components more than irradiation itself.

Overall, the results showed that tomato and green capsicum can tolerate 1000 Gy radiation without significant deterioration in the chemical and proximate components before storage. The nutritional components of fresh whole tomato and capsicum were not negatively affected by low dose irradiation. Time in storage had a larger impact on these components than irradiation itself.

Fruit quality evaluations were conducted on tomato and capsicum after being treated with gamma irradiation and following a recommended cold storage period of up to 21 days. For each commodity, 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 physio-chemical measurements were conducted on fruit immediately after treatment (within 24 hours), during and after removal from their recommended storage period.

Generally, fruit quality in tomato and capsicum were primarily impacted more by storage time than by irradiation. In this case, changes in skin and flesh colour, along with fruit softening and moisture loss rates were primarily associated with the biological ripening processes that normally occur during storage. The use of higher doses of irradiation (600 to 1000 Gy) on capsicum did result in minor changes in quality, such as slight increase in moisture loss and Brix levels. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit.

The overall findings of study suggest that an application of up to 1 kGy will not result in any detrimental damage to the quality of tomato and capsicum fruit.

Data in the scientific literature on vitamin changes in tomatoes and capsicums following irradiation at doses below 1 kGy is limited. Part 2.2 *Efficacy – Product Quality* discussed in some detail how the absorbed dose, fruit maturity and physiological state at harvest, time of irradiation after harvest, pre- and post-irradiation handling, storage environment and storage time all interact to affect product quality and shelf-life. The interactions can result in some difficulties in interpreting the literature, especially some older papers in which the emphasis was often on doses above 1 kGy. Similar difficulties can be found in the literature on the nutritional effects of irradiation.

A study by Abdel-Kader (1968) on an Early Pak variety found that, at the mature green and early breaker stage, vitamin C loss was nil after 500 Gy but 6% loss was observed in the mature ripe stage. At higher doses (2 to 3.5 kGy) and with other varieties, Abdel-Kader and some other authors found no loss of vitamin C while other authors report 10 to 15% loss (see review article by Thomas 1988). Vitamin C loss is sometimes overestimated unless dehydroascorbic acid (DHAA) is also measured. DHAA is the main oxidation product from the irradiation of vitamin C and it also has vitamin C activity.

Several authors (reviewed by Thomas 1988) reported on carotene and lycopene response to irradiation at doses above 1 kGy. Saluhnke *et al* (1959) suggest 1.86 kGy is a threshold for loss, but generally the results are variable with a strong dependence on fruit maturity and ripening. No significant loss was observed in the total carotenoid or vitamin C concentrations of sliced tomatoes after 1 kGy irradiation (Mohacsi-Farkas *et al* 2006). A 40% decrease in vitamin E (α -tocopherol) concentration was found, however.

Mitchell *et al* (1992) analysed the composition of green and red capsicums after 0, 75 or 300 Gy in detail. For both red and green capsicums, irradiation had no significant effects on soluble solids, pH, acidity, internal colour, vitamin C, dehydroascorbic acid or sugars, either before or after 26-29 days storage at 5^{o}C. In green capsicums, a significantly higher citric acid level was detected in 75 Gy irradiated fruit before storage but the effect was not evident after storage. Malic acid levels were unaffected. Irradiation of red capsicums at both 75 and 300 Gy increased citric acid by 20 -25% over control values immediately after irradiation. This effect was lost during storage.

Farkas *et al* (1997) measured a 12% decrease in ascorbic acid concentrations in sliced yellow capsicums at 1 kGy. Further loss occurred in both irradiated and unirradiated capsicum upon storage. The loss attributed to irradiation was relatively small compared to the variations observed between varieties and storage times.

In the dose range 1 to 3 kGy, Ramamurthy *et al* (2004) found marginal 5-10% reductions in vitamin C and carotenoids in capsicums. However, the irradiated samples retained the remaining vitamin C and carotenoids better than non-irradiated samples.

Other fresh produce

The principle of 'chemiclearance' has been accepted by international and national agencies responsible for food safety. This principle is based on radiation chemistry data and states that the chemical changes in individual food components induced by radiation will be similar in foods of similar composition (JECFI 1981, 1999, FDA 2008).

Many fresh fruits and vegetables have been examined at doses up to 2 – 3 kGy and found to have no or only slight loss of a range of vitamins, carotenoids and folate. Not all nutrient parameters were analysed in all studies. The commodities studied have included mangoes, papayas, strawberries, pineapples, lemons, mandarins, peaches, nectarines, bananas, litchis, rambutans, custard apples, persimmons, carrots, onions, endives, broccoli, spinach, brussels sprouts, zucchini, cucumber, cabbage and potatoes (Boylston *et al* 2002, Beyer *et al* 1979, Beyer and Thomas 1979, Murray 1983, Kraybill 1982, Muller and Diehl 1996, Mitchell *et* al 1992, Gomes *et al* 2008a,b, Arvanitoyannis *et al* 2009).

In 2008 the USFDA (FDA 2008) approved the use of irradiation up to 4 kGy for the bacterial decontamination of iceberg lettuce and spinach. Table 10 compares some major nutrients in tomatoes, capsicums, iceberg lettuce and spinach. Tomatoes and capsicums have higher vitamin C and carbohydrate concentrations than lettuce and spinach, but otherwise the nutrient contents are similar. In determining the safety of this relatively high dose procedure, the FDA paid special attention to the potential loss from the diet of vitamin C, vitamin A precursors, and vitamins K, E and folate. The FDA concluded that the treatment would not have an adverse impact on the nutritional adequacy and, particularly, the vitamin content of the overall diet.

Potential impact of irradiated produce on dietary intake

Overview

Irradiation does not affect the macronutrient or mineral content of food at doses up to 10 kGy (JECFI 1999, WHO 2002, SCF 2003, EFSA 2011, FSANZ 2011a). At doses below 1 kGy vitamin losses are minimal and probably within variations found between varieties of a specific food or the losses caused by storage (see Part 3.1.2). However, it is prudent to consider possible irradiation effects, even at doses below 1 kGy, on radiation-sensitive vitamins (see Tables 8 and 9) in foods that contribute significantly to the dietary intake of such vitamins. The credible cumulative loss to the average daily intake of radiation-sensitive vitamins from all foods that could be potentially irradiated may also be considered.

At present, the foods permitted for irradiation in FSANZ Standard 1.5.3 are herbs, spices, herbal infusions and 9 tropical fruits. FSANZ approved these foods, and also persimmons, for irradiation after a safety assessment including dietary implications (FSANZ 2001, 2003, 2011a). Herbs and spices are minor food ingredients and are not considered important sources of nutrients (FSANZ 2001). Herbal infusions may be a significant source of some anti-oxidants but are not generally considered a major source of micronutrients. The tropical fruits that have been approved are seasonal and do not constitute a major part of the diet of Australians and New Zealanders, and FSANZ (2003, 2011a) has already ruled that “there are no public health and safety issues associated with their consumption when irradiated up to a maximum dose of 1 kGy” and “no significant nutritional losses of vitamins and minerals”.

Table 10: Selected Nutrient Content per 100g edible portion for tomatoes, capsicums, iceberg lettuce and spinach (FSANZ 2010, USDA 2011b)

	Tomatoes	Capsicums (average green/red)	Iceberg lettuce	Spinach
Water (g)	94.2	92.7	95.5	92.9
Energy kJ	74	99	40	68
Protein (g)	1.0	1.55	1.0	2.6
Total Lipid (g)	0.1	0.15	0.1	0.3
Carbohydrate (g)	2.4	3.0	0.4	0.7
Total fibre (g)	1.2	2.1	1.5	2.2
Sodium (mg)	8	2	25	23
Vitamin C (mg)	18	125	4	29
Vitamin A or Retinol equiv.(µg)	26	122	23	336
B-carotene (µg)	153	221	120	1969
Thiamine (mg)	0.02	0.03	0.03	0.07
R'flavin (mg)	0.02	0.04	0.03	0.18
Niacin Equiv. (mg)	0.17	0.97	0.5	1.1

Contribution to dietary intake of non-irradiated tomatoes and capsicums

If this application is successful, tomatoes and capsicums will be added to the fresh produce that that may be irradiated and consumed in Australia and New Zealand. There have been some limited surveys of food consumption patterns in the population. The Australian National Nutrition Survey of 1995 (ABS 1998, 1999), a FSANZ database (DIAMOND) based on that survey (FSANZ, *personal communication*) and a 1997 New Zealand report (MOH 1999) provide data on the daily consumption of various foods and the major food sources that contribute to the intake of specific nutrients. Potato, tomato, carrot, onion and pumpkin are the most commonly consumed vegetables and fruiting vegetables.

The average consumption/adult/day of tomatoes and tomato products in 1997 was 46.4g for New Zealanders with 46% (21.3g) contributed by whole, fresh tomatoes (MOH 1999). For adult Australians in 1995 (ABS 1998, 1999), the figures for tomatoes plus tomato products were 35.3g/day (males) and 31.6g (females). Capsicum consumption was much less with New Zealand data (MOH 1999) indicating an average daily consumption per adult of 0.4g for raw capsicums and 2.3g for capsicums in all foods.

Tomatoes, tomato products and other fruiting vegetables make only a small contribution to vitamin intake compared to other vegetables such as potatoes and pumpkin. Tomatoes and capsicums are not listed as making a significant contribution to the daily intake of pre-formed vitamin A, thiamin, riboflavin or niacin. Table 11 provides data for tomatoes and tomato products and for 'other fruiting vegetables' for several important vitamins that are radiation sensitive. Capsicums are included as a minor contributor to "other fruiting vegetables". The data are an average for male and female adults (+19 years). Younger people receive a smaller percentage than adults of these vitamins from tomatoes and other fruiting vegetables.

Only fresh, whole tomatoes are candidates for irradiation (see Part 3.5) and fresh whole tomatoes comprise about half of total consumption of tomatoes and tomato products (MOH 1999). Processing of tomatoes tends to degrade vitamins, but the products often contain reduced amounts of water, which compensates by increasing vitamin concentrations. As an approximation, the daily intake for tomato and tomato products may be halved to obtain the contribution from fresh, whole tomatoes to nutrient intake. The greatest contribution of fresh tomatoes is to vitamin C and carotenes at approximately 2.5% and 1.75% respectively.

Other fruiting vegetables as a group contribute more to the intake of the listed vitamins. However, the category includes many vegetables. Pumpkin makes the predominant contribution to carotene intake and the net contribution of capsicums to the vitamins listed is small. Irradiation has the greater potential for affecting dietary intake from tomato than capsicum, and is further considered in the next section.

Table 11: Contribution to daily intake of selected vitamins (from ABS 1998)

	Percent Contribution to Daily Intake (average for males and females 19 years and over)	
Vitamin	**Tomato and Tomato Products**	**Other Fruiting Vegetables***
Vitamin C	4.95	5.5
Retinal Equivalents	1.8	6.0
Provitamin A (carotene)	3.45	11.8
Vitamin E	3	3
Total Folate	1.75	2.45
* pumpkin, zucchini, avocado, cucumber, eggplant, okra and more minor contributors, including capsicum		

Potential impact of irradiated tomatoes

Section 3.1.2 referenced the nutritional (vitamin) losses likely from the irradiation of fresh produce generally and tomatoes and capsicums in particular. Some references concluded that there is no effect of irradiation below 1 kGy; others that the effect is not significant or small. Even in the dose range 1-3 kGy, the effects appear small, though a few references mention losses of up to 15%. A recent Australian study (see Annex) concluded that no significant dose effects on all nutritional components tested were detected in tomatoes irradiated at doses up to 1 kGy either within 1 day after irradiation or after 14 days cool storage.

For any given fruit or vegetable, there can be significant variations in vitamin content between individual items (due to growing conditions) and between varieties. In addition, changes in content occur on storage. It is possible that any changes due to irradiation are less than such normal variations found in non-irradiated fruit, as pointed out by Mitchell *et al* (1992), Farkas *et al* (1997), Boylston *et al* (2002) and Fan and Sokorai (2008) for persimmons, capsicums and other fruits and vegetables.

Given the probable small loss incurred after disinfestation doses and an overall contribution of fresh tomatoes to vitamin C and carotene intakes of only 2.5% and 1.75% approximately, it would appear that even a diet in which 100% of tomatoes were irradiated should not be a public health concern.

Table 12: Production of tomatoes for the fresh market (2006/07)

	NSW	SA	QLD	WA	VIC	TAS	NT
'000 tonnes	28,912	14,715	130,147	12,043	47,433	997	30
% of Australian production	12.34	6.28	55.55	5.14	20.24	0.42	0.01

3.2 Toxicological data

The Food and Agriculture Organisation and the World Health Organisation of the United Nations convened a series of Joint Expert Committees on Food Irradiation (JECFI) which evaluated the safety and wholesomeness of irradiated foods. The JECFI evaluated the numerous studies related to 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, including 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. In addition, no adverse effects had been seen (and still have not been seen) over many years in which laboratory rodents, astronauts and immune-suppressed patients had received sterile diets irradiated at high doses and whose health was well-monitored.

Although it was not possible to test all foods that could conceivably be irradiated, the JECFI accepted the principle of chemi-clearance which states that the chemical changes in individual food components induced by radiation will be similar in foods of similar composition, that is, the yield and type of radiation products formed will be similar. Radiation chemistry data also supports the concept that the yield of products will be approximately proportional to the dose, at least for macronutrients. The JECFI concluded that, from the range of foods tested, it was possible to extrapolate to all foods.

The 1981 report stated ""irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard; 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).

Since the 1981 JECFI report, the toxicological safety of irradiated foods has been kept under periodic review. In 1999, another JECFI concluded that foods irradiated with doses above 10 kGy were also safe and wholesome (the 1981 report had not intended the 10 kGy limit to imply that higher doses were unsafe). This report stated "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 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.

These recent evaluations have concentrated mainly on the potential toxicity of specific products of irradiation (radiolytic products) that have emerged since the 1981 JECFI. At the time of 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 (Nawar 1986, Adam 1983). Since that time, 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).

Initially, these ACBs and DCBs were thought to be unique radiolytic compounds and not found in non-irradiated food or foods processed in other ways. 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). The overall conclusions of these reviews can be summarized as follows.

There is evidence in a few, but not all, of the *in vitro* tests performed that some ACBs may be genotoxic. 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). There is also a recent report that ACBs are found in non-irradiated nuts and nutmeg and may not be unique radiolytic products (Variya *et al* 2008)

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).

In relation to this application it is relevant that individual radiolytic products such as ACBs are measured in trace concentrations only, even after relatively high doses. The doses applied to tomatoes and capsicums will be under 1 kGy. Further, the concentrations of fats from which ACBS are formed are very low in tomatoes and capsicums, of the order of 0.1 to 0.2% (FSANZ 2010; USDA 2011b).

Radiolytic furans have also been put forward recently 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) in tomatoes and capsicums (2 to 4% approximately) are significantly lower than those in grapes (approximately 14 to 15%) and pineapples (approximately 8%), fruits which showed the greatest, but still low levels of furan.

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.

FSANZ, in its recent assessment of Application 1038 (Persimmons), evaluated post-2002 data on the toxicological safety of irradiated foods. The assessment included a detailed assessment of the various recent studies involving ACBs and furans. FSANZ concluded there was no public health or safety issue associated with the consumption of irradiated persimmons (FSANZ 2011a). A comparison of ACB and furan precursor concentrations in persimmons, tomatoes and capsicums (USDA 2011b) indicates that the risk from irradiated tomatoes and capsicums will be no greater than for irradiated persimmons.

Another issue emerged between 2007 and 2009 when four scientific studies reported that high dose (between approximately 25 and 53 kGy) gamma irradiation of dry cat diet can lead to an increase in the incidence of neurological defects and clinical disease in cats fed the diet [Cassidy *et al* 2007, Caulfield *et al* 2009, Duncan *et al* 2009, Child *et al* 2009). Three of the studies involved laboratory-bred cats fed the diet exclusively. The other was based on Australian experience of domestic cats fed on an imported irradiated cat food, in some cases exclusively, in some cases not. The syndrome includes an inability to coordinate and regulate hind limb movement. The syndrome is similar to a spontaneous syndrome reported in the literature in several species of the cat family. The relevant studies have been summarized by EFSA (2011).

The evidence for a link between the irradiated feed and disease is strong. However, the mechanism remains uncertain despite analyses of the chemical changes in the cat diet composition such as a reduction in vitamin A content, and elevated peroxide and free radical concentrations. These severe, unmistakable clinical effects have not been seen in species other than cats. It is possible that the effects of high-dose, irradiated diet are specific to cats and other felids which, for example, require pre-formed vitamin A in the diet.

Duncan *et al* (2009) expressed the view that the phenomenon could be specific to cats and the Australian Veterinary Association, in a joint statement with FSANZ and Biosecurity Australia, also suggested a cat-specific effect.

Perhaps even more importantly, no effect has been seen in any other species fed irradiated foods either in feeding trials or as a major part of the long-term diet of specific-pathogen-free and gnobiotic animal colonies. The feeding trials included an extensive study using several animal species and chicken treated with over 50 kGy (Thayer *et al* 1987). 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.

EFSA (2011) declined to speculate on the relevance of the cat diet results to irradiation of food for human consumption while noting the differences in the irradiation dose and diet in the two situations. 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.

A literature search of papers published since the EFSA (2011) and FSANZ (2011a) reports has revealed no further radiolytic products that might be considered unique to irradiation or especially toxic from irradiation of fresh produce. In assessing the toxicological hazard from any of the radiolytic products identified relatively recently, account should be taken that they were inevitably present in many of the irradiated foods tested in feeding trials and evaluated in the JECFI reports of 1981 and 1999.

The health or food safety authorities in approximately 60 countries have now approved the use of irradiation in order to benefit at least one food. Since Standard 1.5.3 was gazetted, FSANZ has approved the irradiation of herbs and spices to a maximum dose of 30 kGy and herbal infusions to a maximum dose of 10 kGy for the purpose of decontamination (1999) and nine tropical fruits to a maximum dose of 1 kGy for the purpose of pest disinfestation (2003). FSANZ has also approved irradiation of persimmons (2011) but persimmons have not yet been added to the Standard.

Thirty five countries approve irradiation up to a dose of 1 kGy for fresh fruits and vegetables. Of those approvals, 28 are for pest disinfestation (quarantine) purposes; the others are for delay of ripening or maturation control (IAEA 2011a). Twenty three of these 35 countries approve irradiation of fresh fruit and vegetables as a food class (i.e. for any fruit or vegetable).

The US FDA conducts some of the most rigorous assessments of any application for permission to irradiate food. The FDA has now issued 13 approvals for irradiation of various foods and food classes (FDA 2011). In 1986, the FDA approved irradiation up to a maximum dose of 1 kGy for fresh fruits and vegetables for the purpose of pest disinfestation or maturation control. One of its more recent approvals (FDA 2008) was for the decontamination of iceberg lettuce and spinach at a maximum dose of 4 kGy. In its assessment the FDA considered the toxicological implications of irradiating these leafy vegetables at 4 kGy. Included in the assessment was data on alkyl-cyclobutanones and furans plus issues raised by persons and organizations responding to the draft rule. The FDA concluded there was no toxicological hazard from irradiating iceberg lettuce or spinach at doses up to 4 kGy.

In summary, the conclusion of the 1981 JECFI that ""irradiation of food up to an overall average dose of 10 kGy presents no toxicological hazard" is still valid.

3.3 Microbiological data

Not relevant to the request for approval to irradiate for a phytosanitary purpose.

3.4 Induction of radioactivity

Irradiation of food with the sources approved in the Codex General Standard for Irradiated Food and FSANZ Standard 1.5.3 does not make food radioactive. The energy of the radiation is simply insufficient to bring about any changes in the nuclei of atoms and induce radioactivity that could be detectable above normal levels in food (Becker 1983). The increase in radiation background dose from consumption of food irradiated to an average dose below 60 kGy, is insignificant and best characterized as zero (IAEA 2002a).

3.5 Tomato and capsicum products and ingredients

Australians and New Zealanders consume significant amounts of fresh tomatoes. The amount of tomato products that is consumed as sauce, paste, canned and dried is approximately similar to the amount of fresh tomatoes consumed (MOH 2009, ABS 1999). Data discussed in Part 2.4 (ABS 2008, 2011a,b; RIRDC 2010 a,b; QPIF 2009) showed that 148,000 tonnes were produced in Australia for processing versus 179,000 tonnes of fresh tomatoes in 2006/07. However, only 1.6% of processing tomatoes were produced in Queensland. Most capsicum production (83%) is in Queensland. Based on consumption figures (MOH 1999) far more capsicums are sold in mixed foods than as whole raw capsicum.

It is a general principle of irradiating food that only high quality food is treated (ICGFI 1991). Irradiation of fruits for pest disinfestation (which is only available in Queensland at present) will be carried out only on high 'export' quality produce sent from Queensland to pest-free regions of Australia or to New Zealand.

There are no further issues related to safety should, in an unlikely future event, irradiated tomatoes or capsicums be diverted for processing. The extra storage, transport and processing will deplete nutrients far more than the negligible losses caused by irradiation.

Irradiated foods being transported are subject to the labelling requirements of Standard 1.5.3. (see Appendix A). The Standard also mandates the labelling of any irradiated ingredients.

PART 4 – INTERNATIONAL AND NATIONAL STANDARDS AND REGULATIONS: GLOBAL USE OF FOOD IRRADIATION

4.1 International standards

The safety and benefits of food irradiation are supported and endorsed by the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO). The internationally recognized standard-setting bodies for human and plant health are the Codex Alimentarius Commission (Codex) and the International Plant Protection Convention (IPPC). Codex and IPPC standards have been referred to earlier in this application.

Codex Standards

The safety and nutritional aspects of irradiated foods are ensured through compliance with the Codex General Standard for Irradiated Foods (CAC 2003a), which applies to foods processed by ionizing radiation. The standard is to be used in conjunction with its associated Code of Practice and other applicable Codex food standards, hygienic codes, and transportation codes.

The Codex standard permits the use of four sources of radiation, gamma rays from cobalt-60, gamma rays from caesium-137, electrons with a maximum energy of 10 MeV and X-rays with a maximum energy of 5 MeV. Irradiation of food should only be used for a technological requirement by the food industry or to promote food safety and should not be used as a substitute for good manufacturing practices.

A key clause in the Codex standard states "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 maximum absorbed dose delivered to a food should not exceed 10 kGy, except when necessary to achieve a legitimate technological purpose".

The Standard provides general guidelines on facilities, process control, packaging and labelling. Process control is taken up in more detail in the Codex Recommended International Code of Practice for Radiation Processing of Food (CAC 2003b). The operation of facilities, dosimetry, record keeping, food packaging and pre- and post-irradiation handling and storage in the Steritech Narangba facility, which treats tropical fruits, conform to the Code of Practice (Appendices B and C).

The Code of Hygienic Practice for Fresh Fruits and Vegetables (CAC 2003c) addresses Good Agricultural Practices (GAPs) and Good Manufacturing Practices (GMPs) in the production of fresh fruits and vegetables from primary production to packing. Irradiation is not a substitute procedure for GAP or GMP.

Various methods developed for the detection of irradiated foods (see Appendix D) are encoded in General Methods for the Detection of Irradiated Foods (CAC 2003d).

The Codex standard and code of practice refer to the Codes of Practice of the International Consultative Group on Food Irradiation (ICGFI) and Standards of ASTM International (formerly the American Society for Testing and Materials). These provide more detail on proper process control and dosimetry. ICGFI has produced a series of Codes of Good Irradiation Practice for different food classes, including one for insect disinfestation of fresh fruits as a quarantine method (ICGFI 1991), and training manuals for facility operators. A compilation of principles and international recommendations for regulatory control measures on food irradiation is published in ICGFI Document 21 (ICGFI 1995). ICGFI has been disbanded but a list of its published documents is available at https://apps.who.int/fsf/whopb3.htm.

ASTM has produced Standard Guides for the Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment (ASTM 2006), for Packaging Materials for Foods to be Irradiated (ASTM 2009), and for Absorbed Dose Mapping in Radiation Processing Facilities (ASTM 2003).

There are also Codes of Standard Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing and for Dosimetry in Electron Beam and X-Ray Facilities for Food Processing that are jointly published by ASTM and the International Standards Organisation (ISO 2004, 2005). The standards outline the qualification program for the installation of a facility and describe routine processing in the facilities that irradiate food using gamma sources or high-energy electrons and X-rays.

International Plant Protection Convention

The main purpose of the International Plant Protection Convention (IPPC) and the responsibility 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 International Standards for Phytosanitary Measures (ISPMs).

The ISPMs provide guidelines to achieve international harmonisation of phytosanitary measures and can help facilitate trade. The harmonisation of phytosanitary measures can help to avoid the use of unjustifiable measures as barriers to trade.

ISPM No. 18 Guidelines for the Use of Irradiation as a Phytosanitary Measure (IPPC 2003) 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 (IPPC 2009) considers harmonizing phytosanitary treatments, particularly in international trade, which may also facilitate trade. It includes the recommendation of generic minimum doses for several insect pests, notably a minimum of 150 Gy for Tephritid fruit flies (IPPC 2009, Appendix 7 and other Appendices).

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 (IPPC 2005). This standard considers equivalent phytosanitary measures that achieve appropriate levels of protection for the regulated pest(s) and accounts for the changing phytosanitary situations in exporting countries. The IPPC has also provided a recommendation to National Plant Protection Organisations for the replacement of, or reduction in use of, methyl bromide as a phytosanitary measure. Appendix 1 of the IPPC recommendation (IPPC 2008) lists possible replacement options for various food classes. These include irradiation and other options that have been considered in Part 2.3.

Irradiation treatment of tomatoes & capsicums in Australia (following approval) would comply with the relevant IPPC, Codex, FSANZ 1.5.3, ASTM and ICGFI standards and codes of practice.

4.2 National standards and 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 fulfills a technological need and conforms to good radiation processing practice. The absorbed dose applied should be the minimum required for the technological purpose to be achieved. The standard also specifies labelling and record keeping requirements in relation to the irradiation of food. Irradiation is not to be a substitute procedure for good manufacturing practice.

Currently, Standard 1.5.3 permits the irradiation of specified tropical fruits (breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya and rambutan) as a phytosanitary measure. FSANZ has recommended that persimmons be added to the list of tropical fruits that may be irradiated, but the standard is yet to be amended.

MAF Biosecurity New Zealand Standard 152.02: Importation and Clearance of Fresh Fruit and Vegetables into New Zealand (MAF 2011), and Import Health Standard Sub-class: Fresh Fruit/Vegetables specifically provide for the import of mango (MAF 2004), papaya (MAF 2006a) and litchi (MAF 2008) from Australia, and papaya from Hawaii (MAF 2006b) when irradiation has been used as a phytosanitary measure.

FSANZ Standard 1.4.3 on 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 responsibility on to manufacturers.

Australian Standard for Plastics Materials for Food Contact Use, AS2070 –1999 (SA 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 intended for food contact applications.

The Trade Measurement Act 1989 (NMA 2010) specifies carton marking and labelling, and is particularly important as a means of identifying fruit treated by irradiation.

Australia has a national system of plant health certification based on quality management principles and agreed to by the quarantine agencies of all States and Territories. Interstate Certification Assurance Scheme Operational Procedure Number 55 (ICA 55) was adopted in 2011 (ICA 2011). ICA 55 is an operational procedure for irradiation treatment as a quarantine entry requirement and 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. The irradiation procedure conforms to the principles of ISPM 18 and is accepted by Biosecurity Australia. 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.

Irradiation facilities in Australia are regulated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) or by the respective state and territory authorities. The National Radiation Laboratory (NRL) under delegated authority from the Ministry of Health regulates all radiation facilities and radioactive substances and apparatus in New Zealand.

United States of America

The safety and benefits of food irradiation in the US are approved or endorsed by authorities including; the US Surgeon General, the Food & Drug Administration (FDA), the Center 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 wide range of foods. For current information, the Code of Federal Regulations pertaining to irradiation is revised annually, and can be accessed at http://www.gpoaccess.gov/cfr/index.html. The Electronic Code of Federal Regulations (e-CFR) is the currently updated version of the Code of Federal Regulations (CFR) although it is not an official legal edition of the CFR.

Relevant FDA regulations are Title 21 Part 179 Irradiation in the production, processing and handling of food (FDA 2011). Subparts are listed in Table 13 and the approved uses of ionising radiation on various foodstuffs under defined conditions from sub-part 179.26 are listed in Table 14. They include fresh fruits and vegetables as a food class approved in 1986 for the purpose of disinfestation or maturation control. In 2008 iceberg lettuce and spinach were approved for irradiation at up to 4 kGy for the purpose of decontamination.

The Animal and Plant Health Inspection Service (APHIS) of the USDA 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. A Manual (USDA 2007c) provides 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.

Table 13. List of regulations Federal Register 21 Part 179 relevant to irradiation in the production, processing and handling of food (FDA 2011)

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.

Mangosteen, dragon fruit, papaya, sweet potato, melon, pods of cowpea and its relatives, breadfruit, jackfruit, and fresh moringa pods may to be moved interstate from Hawaii after irradiation under certain conditions into continental US (USDA 2008b).

In October 2002, the 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, thus opening up the possibility of international trade (USDA 2002). This Final Rule permits the importation of fresh produce that has undergone a phytosanitary irradiation treatment. 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. Following the Final Rule, specific permissions have been given to import irradiated mangoes from India, litchi, longan, mangosteen, pineapple and rambutan from Thailand, dragon fruit from Vietnam, mangoes from Pakistan, rambutan from Vietnam and Malaysia, and guava and other fruits from Mexico (USDA 2007a, b, 2008a, b, c, 2010, 2011a).

In addition to USDA requirements, the Food and Drug Administration (FDA) and the Department of Homeland Security's Customs and Border Group have specific requirements for importing fresh fruits.

Table 14: Food Irradiation Approvals in the USA (FDA 2011, 21 CFR 179.26)

Approval Year	Food	Dose range or dose maximum	Purpose
1963	Wheat Flour	0.2 – 0.5 kGy	Control of mold
	White Potatoes	0.05 – 0.15 kGy	Inhibit sprouting
1986	Pork	0.3 – 1.0 kGy	Control of Trichinella parasites
1986	Fruit and Vegetables	1 kGy	Insect control, extend shelf-life
1986	Herbs and Spices	30 kGy	Sterilization
1990 – FDA	Poultry	3 kGy	Bacterial pathogen reduction
1992 – USDA	Poultry	1.5 – 3.0 kGy	Bacterial pathogen reduction
1997 –FDA 2000 – USDA	Fresh Meat	4.5 kGy	Bacterial pathogen reduction
1997 – FDA 2000 - USDA	Frozen Meat	7.0 kGy	Bacterial pathogen reduction
2000	Shell Eggs	3 kGy	Bacterial pathogen reduction
2000	Seeds for sprouting	8 kGy	Bacterial pathogen reduction
2005	Molluscan Shellfish	5.5 kGy	Bacterial pathogen reduction
2008	Iceberg Lettuce and Spinach	4.0 kGy	Bacterial pathogen reduction and shelf-life extension

European Union

Regulations on food irradiation in the European Union are not yet fully harmonised.

Framework Directive 1999/2/EC (EU 1999a) establishes an EU-wide framework for controlling irradiated foods, labelling and importation. The Directive also covers general and technical aspects of radiation processing and conditions for authorising food irradiation. Foodstuffs must only be irradiated in approved facilities in member states or in facilities in third countries approved by the EU in accordance with Article 4(4) of Directive 1999/2/EC.

Framework Directive 1999/3/EC (EU 1999b) permits the irradiation of dried aromatic herbs, spices and vegetable seasonings. These are the only food group permitted to be irradiated in all EU member states and to cross EU boundaries. It is the intention of the EU to harmonise food irradiation regulations under a single "positive list" of foods or food classes that may be irradiated. However, agreement on the list does not appear to be close.

Pending agreement on the list, 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, fresh fruits and vegetables, seafood and other meat products.

Analytical methods for the detection of irradiated foods standardized by the European Committee for Standardisation (CEN) are described in Appendix D.

Other nations and global use of food irradiation

Today over 50 countries approve at least one type of application of food irradiation, usually through their Ministry of Health or equivalent. Approximately 35 types of food have been approved across those countries and there are well over 100 facilities for food irradiation worldwide. Details can be obtained from IAEA databases (IAEA 2011a,b). However, in many of the facilities food irradiation is a minor component of their output and mainly restricted to research or small scale market-trials.

China is currently the biggest user of irradiation, with significant usage in the USA, Belgium, Vietnam and South Africa. Other countries with approval for food irradiation include Canada and Mexico in North America; UK, France and the Netherlands in the EU; Bangladesh, India, Indonesia, Iran, Israel, Japan, Korea, Pakistan, Philippines, Russia, Syria and Thailand and Vietnam in Asia; the South American countries of Argentina, Brazil, Chile, Peru, and Uruguay; and Algeria in Africa.

It is difficult to obtain an exact estimate of the amount of food being irradiated globally, partly due to commercial sensitivity. A minimum estimate of the amount of food irradiated world-wide in 2005 was 405,000 tonnes (Kume 2009). Herbs, spices and dried vegetables comprised the greatest amount treated (46%), followed by garlic and potatoes (22%), grain and fruit (22%), meat and seafood (8%). With significant growth in the number of food irradiation plants operating in developing countries such as China, India and Vietnam, the amount presently being treated may be closer to 1 million tonnes p.a. (P. Roberts, *personal communication)*.

In the USA about 1/3 of all herbs and spices are decontaminated by irradiation (approximately 70,000 tonnes annually). This is likely to continue to increase further. The major interest in the USA, however, is in ground beef (hamburger) and chicken, although the recent importation of irradiated tropical fruits is starting to make an impact. Potatoes and garlic are irradiated in Japan and China respectively. Dried fish, a staple in countries such as Bangladesh, are irradiated to prevent depredation by insects.

PART 5 – OTHER IMPLICATIONS

5.1 Environmental implications

Fresh Australian mango and litchi fruit destined for New Zealand are currently irradiated at the Steritech Narangba facility. The facility is the only irradiation facility that is AQIS accredited. Other irradiation facilities are located at Wetherill Park, NSW and Melbourne, VIC. The facilities are regulated and licensed by the relevant federal, state and local authorities. All three facilities use radioactive cobalt-60 as the gamma radiation source. The cobalt-60 is an insoluble, high melting-point metal that is produced as nickel-plated slugs. These are sealed into an alloy cylinder and doubly encapsulated in corrosion resistant steel pencils. The facilities are designed with multiple fail-safe measures, and have established extensive and well-documented safety procedures, occupational health and extensive worker training.

There are approximately 200 commercial cobalt-60 irradiation facilities world-wide, mostly for non-food sterilization uses (IAEA 2008). Their safety and environmental record is excellent. Electron accelerators are the radiation source for a few thousand facilities that provide sterilization, polymer cross-linking and surface and material modification services. A few accelerator facilities convert the electrons into X-rays. Accelerators are electrically-driven machines and do not use or create radioactive material. To date, accelerators have had very limited use for food irradiation but greater use is expected in future.

The approval of irradiation as an alternative phytosanitary measure to the postharvest insecticides dimethoate and fenthion will result in the easier implementation of any suspension on these chemicals. A suspension would reduce pesticide exposures to the public and pesticide use and storage in packing sheds. Methyl bromide, another alternative option, is on the list of banned ozone-depleting substances under the Montreal Protocol. However, it was granted a critical use exemption for quarantine purposes. Availability of an irradiation option may result in lower usage would further discourage the use of methyl bromide.

Irradiation treatments have the advantage over pesticides and fumigants that there are no chemical residues left on the fruit from irradiation treatment and no emissions or waste stream.

The USDA prepared an environmental assessment on “Irradiation for Phytosanitary Regulatory Treatment” (USDA 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 as a phytosanitary treatment of fruits and vegetables.

5.2 Implications for consumers

Consumers in pest-free areas of Australia would be adversely affected in terms of availability and price if access to tomatoes and capsicums grown in Queensland was restricted. In Queensland there could be an oversupply and cheaper prices until the local growers responded by lowering production. Given the popularity and consumption rates of these fruits, particularly tomatoes, consumers would be best served if supplies were not subject to major disruptions due to a lack of alternatives to insecticide applications. The availability of a postharvest phytosanitary treatment option other than dimethoate and fenthion, such as irradiation, would ensure continuing year-round supplies of tomatoes and capsicums and be a net benefit to consumers.

In addition, there is increasing consumer concern about chemical residues on fresh produce. This could be lessened by the availability of irradiated tomatoes and capsicums since irradiation appears to be of lesser concern than chemical residues (Gamble *et al* 2002, FSA 2004, Johnson *et al* 2004, Eustice and Bruhn 2006).

Consumer responses to irradiated foods

Consumer decisions to purchase a new type of food product are based on a complex decision-making process with perceived risks and benefits considered and compared to existing options. For irradiated foods, part of the perceived risk involves whether the food is safe, but there are also concerns linked to general public fears that the terms 'radiation' or 'irradiation' generate (Underhill and Figueroa 1996, Lyndhurst 2009, Gamble *et al* 2002, Osterholm and Norgen 2004).

Many consumers initially fear or distrust several new food technologies as pointed out by FSANZ (2011a, Supplementary Document 3). Consumers are generally wary of new food technologies particularly when there is a strong prior perception of a risk from the food or the process before balanced information is available and/or the new product is available to see and try. Consumers hope, even expect, new innovations to be risk free (DeGregori 2002).

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 declared to be safe by the US FDA are indeed safe to eat, more than 20% would reduce their consumption and pay more for untreated products.

Available information specifically on food irradiation is of two types. The more useful is from consumer reaction when irradiated foods are sold in retail stores. This tells us how consumers actually *behave* when presented with the opportunity to purchase. However, most of the published information comes from surveys of attitude in which questions are posed prior to the consumer actually having the opportunity to experience irradiated products. These surveys measure *intention* to buy/reject.

In New Zealand, there has been a steady increase in the volume of irradiated mangoes imported and sold since their initial introduction in the 2004/05 season. In 2009/10, more than 1200 tonnes of mangoes and litchis were irradiated in Queensland for subsequent export and retail in New Zealand (see Part 2.2). A fall in imports in the 2010/2011 season can be attributed to the lack of available product due to disastrous floods in the growing areas. The Australian mangoes have provided New Zealand consumers with a choice over cheaper but inferior fruit from other countries. According to the Australian Mango Industry Association (Sexton-McGrath 2010), New Zealand is the fastest growing market for Australian mangoes.

When irradiated mangoes were first put on retail shelves there was a brief period when some concern and negative comment was expressed by some consumers via the media and in cyberspace. The increasing amounts of irradiated fruit in New Zealand are now sold without significant negative comment. According to the New Zealand Fresh Produce Importers Association, irradiated, labelled mangoes are now considered a mainstream imported product sold successfully in supermarkets and other fresh produce market channels, and they wish to see greater availability (NZ Fresh Produce Importers Association, *personal communication*). A major supermarket chain in New Zealand is also supportive of this application (see Appendix E)

There is now considerable experience with labelled, irradiated foods, including ground beef, chicken and tropical fruits, being sold in retail outlets in the USA. Initial rapid growth in sales of irradiated ground beef (2001-2004) stalled when a new irradiation processing company responsible for establishing the trade failed. Since 2005, there has been a shortage of food irradiation capacity. However, irradiated ground beef is still sold in several medium sized retail outlets and has held steady at about 7000 tonnes per year (Nunes 2010). Consumers make repeat purchases even when the irradiated food is somewhat more expensive (NCBA 2002) and little, if any, consumer opposition to the sales has been reported.

This response at a retail level may seem at odds to many surveys of consumer attitudes. There have been few surveys of consumer attitudes to food irradiation in Australasia. In a representative study of Australian consumers commissioned by FSANZ, 13% of Australian respondents expressed concern about the irradiation of food and food ingredients (FSANZ 2008). The survey found that Australians and New Zealanders were less concerned about irradiation of food and food ingredients than they were with food poisoning and food safety.

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. Australians (60%) and New Zealanders (68%) were aware of the term 'food irradiation', somewhat higher than found in surveys in other countries (Eustice and Bruhn 2006). However, few understood what the process involved or the reasons why it might be used.

In the Gamble survey, 48% and 22% of those Australians and New Zealanders who were 'aware' of the technology had negative perceptions to food irradiation. Positive responses were reported from 19% of Australians and 30% of New Zealanders. However, when consumers were presented with a scenario and background information where irradiation was one method for removing insect pests, more respondents clearly preferred irradiation (45% of Australians and 56% of New Zealanders) over heat and fumigation options. The findings that acceptance of food irradiation increases as information is provided, and that irradiation is preferred as a treatment option to a chemical equivalent, also mirror overseas findings (FSA 2004, Johnson *et al* 2004, Eustice and Bruhn 2006).

A report commissioned by Horticulture Australia (Richards *et al*. 2003) stated that "Where appropriate information has been disseminated, consumers are quite accepting that irradiation can provide them with worthwhile benefits and their purchasing patterns are surprisingly positive". In a report to Queensland Primary Industries and Fisheries and Horticulture Australia, Campbell (2009) indicated consumer resistance to irradiation was unlikely.

Consumer surveys outside Australasia are mostly US-based and explore attitudes to irradiated beef or chicken. As summarized by Eustice and Bruhn (2006), all surveys suggest that a majority of consumers have varying degrees of concern about food irradiation. However, studies also show clearly that accurate information about food irradiation could determine consumer choice in purchasing irradiated food products, hence expanding the market for these products (Bruhn *et al.* 1986; Fox *et al* 2001; Fox 2002; DeRuiter and Dwyer 2002; Aiew *et al*. 2003; Nayga *et al.* 2005; Gunes and Tekin 2006). When irradiated foods become available in the marketplace, having been approved as safe by health authorities, this is itself an endorsement of product quality and safety (Bruhn 1999). When presented with factual information and, especially, samples of the product, and when presented with different options for providing food that is safe and containing reduced amounts of chemical residues, then a majority of consumers indicate that they will either accept, be willing to try or have a neutral attitude to irradiated foods (Eustice and Bruhn 2006 and articles quote therein).

It is probable that a major barrier to wider use of food irradiation is the perception that growers and retailers have of a possible consumer backlash rather than actual consumer resistance *per se* (Eustice and Bruhn 2006). The National Cattlemen's Beef Association in America published a report that examines the complex attitudes of retail and food service outlets towards the technology. The 2004 survey contacted knowledgeable and non-knowledgeable current purchasers, past purchasers and non-purchasers of irradiated meat (NCBA 2007). The letter of support for this application from a major food retailer in New Zealand may represent a shift in attitude towards irradiation when a clear benefit is apparent.

Tomatoes and capsicums are fresh produce with a far higher 'profile' than exotic fruits such as mangoes and litchis. Successful placement in the market of irradiated tomatoes and capsicums will probably require balanced information to be provided to consumers and industry. FSANZ already has communication fact sheets available (FSANZ 2011b) as has Queensland Health (QH 2008) and the Centers for Disease Control in the USA (CDC undated). The International Consultative Group on Food Irradiation has produced a series of fact sheets (ICGFI 1999).

The overall situation appears to be that irradiated foods in relatively small quantities are being purchased wherever they are available. However, some consumers wish strongly to avoid eating irradiated foods. The mandatory labelling provisions of FSANZ Food Standards Code 1.5.3 is designed to ensure this choice can be exercised.

PART 6 – FOOD IRRADIATION DATABASES

A database on food irradiation approvals is maintained by the Food and Environmental Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and is available on the International Atomic Energy Agency (IAEA) website (IAEA 2011a). Fifty five countries have approvals listed as at June 2011. Not all countries have registered their approvals list with the database, for example, the United Kingdom. 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.

There is also a database of approved food irradiation facilities maintained by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture (IAEA 2011b). This database shows 81 facilities in 39 countries. Registration on this database, however, is voluntary and not all operating food irradiation plants may be registered. Many that are registered treat only small volumes of food for research purposes or pilot scale trade trials.

The European Union also keeps a list of facilities approved for the treatment of foods and food ingredients by ionizing radiation in the Member States. The database shows 20 facilities in 12 member States (http://ec.europa.eu/food/food/biosafety/irradiation/approved_facilities_en.pdf).

The Joint Division of the Food and Agriculture Organisation and the International Atomic Energy Agency maintains a database on the effects of irradiation on insects relevant to disinfestation and sterilization (FAO/IAEA 2011a).

PART 7 – STATUTORY DECLARATION – NEW ZEALAND

STATUTORY DECLARATION

Oaths and Declarations Act 1957

I, PETER BROOKES ROBERTS, Science Consultant, of 31 Wyndrum Avenue, Lower Hutt 5011, New Zealand, solemnly and sincerely declare that

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

And I make this declaration conscientiously believing the same to be true and by virtue of the *Oaths and Declarations Act of 1957*.

[redacted]

Declared at 47 Laings Road, Lower Hutt on 10 November 2011

Declared before me

[redacted]

P.K. Mishra, JP
#6109
LOWER HUTT
Justice of the Peace for New Zealand

ANNEX

Department of Employment, Economic Development and Innovation

Effect of irradiation on the nutritional profile and postharvest quality of tomato and capsicum.

HAL
Know-how for Horticulture™

Queensland Government

Project Title

Effect of irradiation on the nutritional profile and postharvest quality of tomato and capsicum.

This report is separated into two parts. Part A provides the results of irradiation on the nutritional profile of tomato and capsicum after irradiation treatment and after a recommended period in cold storage. Part B provides the fruit quality evaluations of tomato and capsicum after being treated with low dose gamma irradiation and following a recommended period in cold storage.

Part A –
Effect of low dose gamma (ɣ)-irradiation on the nutritional profile of tomato and capsicum.
Part B –
Effect of phytosanitary irradiation on postharvest quality of tomato and capsicum.

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Date of Report

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Contents

Part A. Effect of low dose gamma (γ)–irradiation on the nutritional profile of tomato and capsicum

Summary

This report examines the radio-tolerance of tomato and capsicum at doses at and below 1000 Gy for the purposes of quarantine disinfestation. The study provides an analysis of data on the nutritional profile of tomato and capsicum that have been irradiated with 0 Gy, 150 Gy, 600 Gy and 1000 Gy.

The proximate and chemical measurements for each commodity at time 1 (one day after irradiation) and at time 2 (period in cold storage) after receiving irradiation doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy were analysed using analysis of variance. Time 2 is the number of days in cold storage; 14 days for tomato and 21 days for capsicum. 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 by dose interactions, at the four doses and measured on the two occasions for the two commodities were also investigated.

The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety 'Gourmet Swanson' and fresh green capsicum (*Capsicum annuum*), variety 'Plato'.

Tomato and capsicum contain about 94% moisture and are low in protein and fat. However, compositions of vegetables and fruit will 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 profile analysed includes 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 and capsicum can tolerate 1000 Gy radiation without significant deterioration in nutrient content after irradiation treatment and before storage. The nutritional components of fresh whole tomato and capsicum were not negatively affected by low dose irradiation. Time in storage had a larger impact on these components than irradiation itself.

Where there are effects, the extent of nutrient changes is variable and may be insignificant compared with losses during handling, storage and microbial degradation, as they do during the accepted freezing, canning, heat treatment and pickling processes.

No significant dose effects on any of the nutritional components tested were detected following irradiation treatment in tomato after 14 days. Significant ($p<0.05$) small changes were detected in some variables for capsicum after the 21 days storage.

Some significant dose by time interactions and time effects were found in tomato and capsicum and are presented. In this study, the impact of time in storage generally affected the chemical components that were measured, more than irradiation itself.

One day after irradiation, there were no significant differences in mean Vitamin C (ascorbic acid) and beta-carotene between the irradiated samples and corresponding controls for both

commodities. No significant dose effects in both Vitamin C (ascorbic acid) and beta-carotene were detected after 14 days for tomato and 21 days for capsicum.

Tomato: No significant dose effects were found after irradiation and after 14 days cold storage.

Capsicum: No significant dose effects were found immediately after irradiation. A significant dose effect after 21 days was found for moisture, fructose and poly-unsaturated fat. For moisture, the mean after exposure to 1000 Gy was significantly lower than the control mean (0 Gy). The mean poly-unsaturated fat content was significantly lower after exposure to 150 Gy compared to 600 Gy and 1000 Gy, but was not significantly different to the control mean.

Introduction

The objective of this study is to investigate the effects of low dose gamma (ɣ)-irradiation for disinfestation purposes on the nutritional components and fruit quality attributes of harvest ready, export quality tomato and capsicum.

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 150 Gy and the maximum of 1 kGy.

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.

Export quality fresh whole tomato and capsicum fruit were sourced for this study. Treatment doses were 0 Gy, 150 Gy, 600 Gy and 1000 Gy. The effect of low dose ɣ-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.

Materials and methods

Whole, fresh tomato and capsicum were purchased from the Sydney Wholesale Market on 28th February 2011. 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 dates were 28th February – 2nd March 2011.

A second set of tomato and capsicum, of the same variety, were purchased and treated 18th July 2011 and sent for beta-carotene analysis as the previous analysis was done in error. These were treated in the same way using the same experimental design.

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 (0 Gy, 150 Gy, 600 Gy and 1000 Gy) and the effects of irradiation were measured at two stages: before storage (Time 1; one day after mean irradiation treatment) and after a period of storage (Time 2; 14 days for tomato and 21 days for capsicum).

For tomato, each replicate consisted of 10 pieces of fruit per treatment dose per assessment time. For capsicum, each replicate consisted of 5 pieces of produce 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).

Table 1. Storage conditions for tomato and capsicum.

Commodity	Set storage temp	Duration
Tomato (red)	10°C	14 days
Capsicum (green)	8°C	21 days

Cultivars

Export quality fresh fruits were selected. The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety 'Gourmet Swanson' and green capsicum (*Capsicum annuum*), variety 'Plato'. To minimise variation, each commodity was sourced from only one producer.

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. There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 22.7–24.5°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.

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).

Figure 1. Boxes of produce positioned for irradiation. Dosimeters attached on the outside of boxes of packed produce.

The irradiation doses were confirmed by dosimeters. Dosimeters (Frickes) 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 sited 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).

Figure 2. Capsicum and tomato arranged in a cardboard box ready for irradiation. Dosimeter attached to a piece of produce for monitoring doses received within the box.

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 the two occasions, after treatment and after a period in cold storage.

Tomato and capsicum were deseeded and blended at each time point. For tomato, each replicate consisted of 10 pieces of fruit per treatment dose per assessment time. For capsicum, each replicate consisted of 5 pieces of produce per treatment dose per assessment time. There were three replicates. Each replicate sample was homogenised for chemical 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. 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).

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.

Protein. Reference method AOAC 928.08

Protein was determined with acid digestion, followed by distillation and titration (Keldahl Method).

Digest sample with sulphuric acid and catalyst.

Add caustic to neutralise.
Distil and collect the ammonia.
Titrate ammonia and calculate as protein.

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. 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 10 ml acid and digest to dissolve sample.
Cool.
Add 10 ml alcohol.
Extract with diethyl ether and petroleum spirits.
Decant solvents and evaporate to recover fat.
Back-wash if necessary.
Calculate fat result.

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.

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.

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 cid, dry, re-ash.
Dissolve ash in 1:1 hydrochloric acid.
Make to volume.
Run standards on AAS.
Run samples on AAS.
Calculate result.

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.

Carbohydrates. Reference Method Food Standard Code 1.2.8

Carbohydrates are determined by difference.

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.

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 & 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°Cc 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 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.

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 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.

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 censored values were: for fat, saturated fat, mono-unsaturated fat, poly-unsaturated fat and trans fat <0.1g/100g; for dietary fibre <0.1g/100g; for sucrose <0.2 mg/100g and; maltose and lactose were <0.5g/100g.

All statistical analyses were conducted using GenStat for Windows 14th Edition (VSN International, 2011).

Results

Irradiation treatment– Dosimetry

The results of dosimetry indicate that the average absorbed dose complies with the required specifications (Appendix 2). 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%.

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 10ºC.

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 (150 Gy, 600 Gy and 1000 Gy) 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 Table 2 and Table 3.

Table 2. Mean chemical measurements in 'Gourmet Swanson' tomato after irradiation treatment (Time1).

Time 1	Dose (Gy)					
Parameter	0	150	600	1000	p-value	SED
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
Fat (g/100g)	0.12 (0.058)	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

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.

Standard deviations of the raw data are presented in brackets under the means.

Table 3. Mean chemical measurements in untreated and irradiated 'Gourmet Swanson' tomato after 14 days cold storage at 10°C (Time 2).

Time 2	Dose (Gy)					
Parameter	0	150	600	1000	p-value	SED
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 (80.58)	0.882	52.27

'C' means that all, or the majority of data was censored (below the level of detection) and therefore have not been analysed.

Standard deviations are presented in brackets beneath the means.

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 18.3 mg/100g while the irradiated samples ranged between 17.0–18.0 mg/100g (Table 2). After 14 days storage, mean Vitamin C (ascorbic acid) ranged between 16.7–25.0 mg/100g (Table 3).

Fresh untreated tomato, variety 'Gourmet Swanson' contained a mean of 180.0 µg/100g of beta-carotene, the 150 Gy and 1000 Gy irradiated samples contained means of 196.7 µg/100g and 600 Gy tomato contained a mean of 210 µg/100g.

Potentially there could be a time by dose interaction and a full factorial analysis is shown in Table 3. Exploration of the variation of treatment effect over time to partly understand the changes is presented.

Energy was the only component that showed a significant time by dose interaction in tomato. At 600 Gy and 1000 Gy, Time 1 showed a slight increase in energy while Time 2 showed a slight decrease. However, no dose was significantly different to the control within each time.

Tables 4a and 4b also present 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 195.8 µg/100g to 312.0 µg/100g during the 14 days cold storage at 10°C.

Control and irradiated tomato showed a mean of 3.24 g/100g carbohydrate before storage which reduced to 2.99 g/100g within 14 days of storage at 10ºC.

Tomato fruit contain slightly higher amounts of free fructose to glucose and sucrose was below the detection level. These levels remained unchanged or declined with storage and were not affected by low dose irradiation (Table 4b). Mean total sugars decreased from 2.92 g/100 g to 2.79 g/100g and mean glucose also reduced from 1.37 g/100g to 1.27 g/100g after 14 days.

On the other hand, there was a significant increase in the moisture content from 94.30 g/100g to 94.76 g/100g and mean fat increased from 0.17 g/100g to 0.28 g/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.

Table 4a. Mean chemical measurements in untreated and irradiated (150 Gy, 600 Gy and 1000 Gy) 'Gourmet Swanson' tomato before storage (Time 1) and after 14 days cold storage (Time 2).

		Irradiation dose (Gy)					ANOVA's		
Variable	Day	0	150	600	1000	Mean	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. dose	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

Means in a treatment followed by the same letter are not significantly different.
ns= not significant

Contd. **Table 4b.** Mean chemical measurements in untreated and irradiated (150 Gy, 600 Gy and 1000 Gy) 'Gourmet Swanson' tomato before storage (Time 1) and after 14 days cold storage (Time 2).

		Irradiation dose (Gy)					ANOVA's		
Variable	Day	0	150	600	1000	Mean	Factor	P-value	SED
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. dose	0.566	0.084
	Mean	2.90	2.80	2.83	2.90		Day x Irrad.	0.405	0.119
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.

ns= not significant

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.

Capsicum

Medium dark green, firm, blocky capsicum fruit, variety 'Plato' were treated in 1st March 2011. The samples were analysed at 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 of capsicum one day after irradiation at Time 1 (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 1000 Gy (93.97 g/100g) was significantly lower than the control mean (94.30 mg/100g). The mean poly-unsaturated fat content was significantly lower after exposure to 150 Gy compared to 600 Gy and 1000 Gy, but was not significantly different to the control mean. The mean fructose content increased with increasing dose, with 150 Gy and 1000 Gy being significantly higher than the control.

Mean Vitamin C (ascorbic acid) in the control sample was 82.7 mg/100g one day after irradiation while mean Vitamin C (ascorbic acid) in the irradiated samples ranged between 61.0–76.3 mg/100g (Table 5).

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 70.7 mg/100g to 116.5 g/100g after storage at 8°C for 3 weeks. The mean Vitamin C (ascorbic acid) in the control increased from 82.7 mg/100g to 127.7 mg/100g.

Mean beta-carotene ranged between 47.7–62.0 µg/100g before storage and increased levels were observed across all irradiated samples (130–137 µg/100g) and the control sample (143 µg/100g) after 3 weeks storage (Table 5 and Table 6). Mean beta-carotene in capsicum increased in storage from 52 µg/100g to 135 µg/100g, with the relative increase in irradiated samples being greater than in the control sample (Table 7).

Table 7a and Table 7b show 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 1000 Gy 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.

Tables 7a and 7b also show instances where the interaction of time and dose was not significant, there was a significant main effect of time.

After 21 days mean dietary fibre, ash and protein were found to be lower while fat, polyunsaturated fat and Vitamin C (ascorbic acid) increased.

Overall, our results show that green capsicum can tolerate up to 1000Gy irradiation without significant deterioration in nutritional content.

Table 5. Mean chemical measurements in 'Plato' capsicum after irradiation treatment (Time 1).

Time 1	Dose (Gy)					
Parameter	0	150	600	1000	p-value	SED
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 (0.000)	0.200 (0.000)	0.220 (0.035)	0.203 (0.006)	0.517	0.0147
Mono-Unsaturated Fat (g/100g)	C	C	C	C		
Poly-Unsaturated Fat (g/100g)	0.10 (0.000)	0.13 (0.058)	0.12 (0.058)	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

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.
Standard deviations are presented in brackets beneath the means.

Table 6. Mean chemical measurements in untreated and irradiated 'Plato' capsicum after 21 days cold storage at 8°C (Time 2).

Time 2 Parameter	Dose (Gy) 0	150	600	1000	p-value	SED
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 (0.058)	0.10b (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)	0.83c (0.208)	1.27ab (0.058)	1.13bc (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 (36.94)	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

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.
Standard deviations are presented in brackets beneath the means.
Analysed on the $\log_{10}$ scale. Reported means are back-transformed. SED is on the $\log_{10}$ scale.

Table 7a. Mean chemical measurements in untreated and irradiated (150 Gy, 600 Gy and 1000 Gy) capsicum, variety 'Plato' before storage and after 14 days cold storage (Time 2).

		Irradiation dose (Gy)					ANOVA's		
Variable	Day	0	150	600	1000	Mean	Factor	P-value	SED
Ash (g/100g)	1	0.37	0.50	0.47	0.50	0.46a	Day	0.003	0.025
	21	0.40	0.40	0.30	0.37	0.37 b	Irrad. dose	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
	21	2.90 d	3.07bcd	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
	21	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	88.0bcde	91.9a	Day	<0.001	1.35
	21	82.7 e	84.3 de	86.3cde	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
	21	94.30ab	94.20ab	94.40a	93.97 bc	94.22a	Irrad.	0.813	0.125
	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
	21	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
	21	20.0a	7.3 d	11.7bcd	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
	21	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.	0.923	20.63
Beta-carotene (µg/100g)	1	62.0	47.7	48.7	52.0	52.6 b	Day	<0.001	7.12
	21	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

Means in a treatment followed by the same letter are not significantly different.
ns= not significant.
Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Contd. **Table 7b.** Mean chemical measurements in untreated and irradiated (150 Gy, 600 Gy and 1000 Gy) capsicum, variety 'Plato' before storage and after 14 days cold storage (Time 2).

		Irradiation dose (Gy)					ANOVA's		
Variable	**Day**	**0**	**150**	**600**	**1000**	**Mean**	**Factor**	**P-value**	**SED**
Total Sugars	1	2.93a	2.83ab	2.73ab	2.60ab	2.77	Day	<0.001	0.111
(g/100g)	21	1.73 d	2.37 bc	2.10 cd	2.70ab	2.22	Irrad. dose	0.189	0.157
	Mean	2.33	2.60	2.42	2.65		Day x Irrad.	0.008	0.222
Fructose	1	1.43a	1.40ab	1.40ab	1.30ab	1.38a	Day	0.012	0.066
(g/100g)	21	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	1	1.47a	1.40ab	1.37ab	1.30ab	1.38a	Day	<0.001	0.043
(g/100g)	21	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	1	C	C	C	C		Day		
(kJ/100g)	21	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose	1	C	C	C	C		Day		
(g/100g)	21	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat	1	0.20	0.20	0.22	0.20	0.21 b	Day	<0.001	0.011
(g/100g)	21	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-		C	C	C	C				
Unsaturated Fat	1						Day		
(g/100g)	21	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-Unsaturated		0.10	0.13	0.12	0.10				
Fat	1					0.11 b	Day	0.010	0.017
(g/100g)	21	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	1	C	C	C	C		Day		
(g/100g)	21	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans Fat	1	C	C	C	C		Day		
(g/100g)	21	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

Means in a treatment followed by the same letter are not significantly different. ns= not significant.
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 level of detection) and therefore have not been analysed.

Discussion

In this study, low dose irradiation (≤ 1000 Gy) had little or no effect on the range of nutritional and proximate components measured in tomato (*L. esculentum*), variety 'Gourmet Swanson' and green capsicum (*C. annuum*), variety 'Plato'. These measurements were analysed after being treated with gamma irradiation and following a recommended period of cold storage; 14 days at 10°C for tomato and 21 days at 8°C for capsicum. Gamma irradiation treatments consisted of doses of 0 Gy, 150 Gy, 600 Gy and 1000 Gy applied at three separate times, each representing a replicate block

Fresh ripe tomato and green capsicum tolerated low irradiation dose (≤ 1000 Gy) without significant losses in nutritional composition. The effect of storage time was greater than by irradiation itself and the changes were 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).

For tomato, mean Vitamin C (ascorbic acid) in the control sample after irradiation was 18.3 mg/100g while the irradiated samples ranged between 17.0-18.0 mg/100g. These figures are comparable with the reference data in the Food Standard Australia New Zealand (FSANZ) nutrient database of 18 mg/100g (FSANZ, 2011 website) and 13.7 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 dehyroascorbic acid while the USDA database refers to total ascorbic acid for red ripe tomato.

Fresh untreated tomato, variety 'Gourmet Swanson' contained a mean of 180.0 µg/100g of beta-carotene, the 150 Gy and 1000 Gy irradiated samples contained means of 196.7 µg/100g and the 600 Gy tomato contained a mean of 210.0 µg/100g. The value recorded in the FSANZ nutrient database is 150 µg/100g while the recorded beta-carotene value is 449 µg/100g in the USDA database for year round average of red ripe tomatoes.

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.

In capsicum, irradiation had no significant effects on Vitamin C (ascorbic acid). For capsicum, the mean Vitamin C (ascorbic acid) in the control sample was 82.7 mg/100g one day after irradiation compared to the reference data of 98 mg/100g of total Vitamin C activity (ascorbic acid and dehyroascorbic acid) in the FSANZ nutrient database (FSANZ, 2011 website) and 80.4 mg/100g total ascorbic acid in the USDA nutrient database (US Dept Agric, 2011 website). Topuz and Ozdemir (2007) reported values for Vitamin C of 63.1-64.9 mg/ 100 g 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 70.7 mg/100g to 116.5 g/100g after storage at 10°C for 3 weeks. The mean Vitamin C (ascorbic acid) in the control increased from 82.7 mg/100g to 127.7 mg/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 56.5 mg/100g to 83.8 mg/100 g and for dehydroascorbic acid, this increased from 7.7 mg/100g to 10.0 g/100g after storage at 5°C for 3.5 weeks.

The FSANZ nutrient database (FSANZ, 2011 website) records a mean of 161 µg/100g for beta-carotene whereas it is 208 µg/100g in the USDA database (US Dept Agric, 2011 website). Our results for beta-carotene were much lower immediately after irradiation (47.7–62.0 µg/100g) and increased with storage (130.0-143.3 µg/100g).

In a study with red capsicum, the beta-carotene levels were roughly four times higher (Mitchell *et al.*, 1990) and increased slightly during 3 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 1000 Gy 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 to 3.5 weeks. They also showed that time in storage had a greater effect on physio-chemical components in tomato and capsicum than irradiation.

In conclusion, the results reported show that while tomato and capsicum responded differently when exposed to ionising low dose γ -irradiation the overall findings of this study show that an application of up to 1000 Gy did not result in any significant detrimental damage to the nutritional quality of tomato and capsicum.

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 a range of factors; by variety, storage conditions, handling and presence of microorganism.

Recommendations

In this study, the overall results show that applications of gamma irradiation treatments of ≤1000 Gy may be used as a phytosanitary measure without inducing significant deleterious effects on the chemical and proximate components in tomato and green capsicum.

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Part B. Effect of phytosanitary irradiation on postharvest quality of selected fruit commodities.

Summary

Fruit quality evaluations were conducted on tomato and capsicum after being treated with gamma irradiation and following a recommended cold storage period of up to 21 days. For each commodity, 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), during and after removal from their recommended storage period.

Generally, fruit quality in tomato and capsicum were primarily impacted more by storage time than by irradiation. In this case, changes in skin and flesh colour, along with fruit softening and moisture loss rates were primarily associated with the biological ripening processes that normally occur during storage. The use of higher doses of irradiation (600 to 1000 Gy) on capsicum did result in minor changes in quality, such as slight increase in moisture loss and Brix levels. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit.

In conclusion, the overall findings of study suggest that an application of up to 1 kGy will not result in any detrimental damage to the quality of tomato and capsicum fruit.

Introduction

The present report serves to compliment the existing nutritional component of this study, where the focus is primarily directed towards examining the effects of irradiation on the quality of tomato and capsicum. The work was undertaken using a corresponding set of fruit that had undergone the same postharvest irradiation treatments and subsequent storage duration conditions as those in the nutritional component.

Specifically, fruit quality assessments in this report entailed measurements of physico-chemical attributes of each commodity, with evaluations conducted immediately after each irradiation event, during and after a recommended cold storage period. The findings of this study are anticipated to contribute to our overall understanding of the impact of low doses of gamma irradiation (≤1 kGy) on fruit storage life and on overall quality maintenance. For each commodity, recommendations on the irradiation dose limits for ensuring product integrity are also presented.

Materials and methods

Experimental layout

Tomato and capsicum (Table 1) were sourced from the Sydney Markets, NSW between February and March 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 150, 600 and 1000 Gy. A corresponding set of untreated fruit (0 Gy) served as a control group. For tomato and capsicum, replication consisted of 10 replicate fruit per block per irradiation treatment per assessment time (two times).

Following the irradiation treatment, each commodity was immediately transported by air to the DEEDI 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. Tomato and capsicum were stored for 14 and 21 days, respectively, and then destructively assessed. Over the storage period, fruit were also assessed for any visual defects and weighed at 7 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 1).

Table 1. 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	90-95%	14
Capsicum, green	'Plato'	7.5	>95%	21

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 7 days during the storage period. 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 on every evaluation day and percent moisture loss was calculated by determining the proportion of weight lost from their initial weight on the first assessment date (Day

1) with a subsequent evaluation date. 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 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 0.1 N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

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

Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (Payne *et al.*, 2008). For each crop, 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 for a given commodity. A significant result occurred when $P \leq 0.05$, and not significant findings were reported as "n.s.". Differences between treatment levels were determined using a least square difference (LSD) test at 5%.

Results

Tomato

The effects of irradiation and storage duration on tomato fruit quality attributes are summarised in Table 2. Over the storage period, tomato fruit firmness decreased significantly by 19% from 3.2 to 2.6 N although 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 1).

TSS in tomato flesh remained relatively constant over the storage period, showing only a 0.1° difference from the mean Brix levels (~4.9°) 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 2. Effect of irradiation dose and storage duration on tomato quality attributes. Fruit were gamma irradiated (Irrad.) up to 1 kGy and then assessed within 24 hours (Day 1) and after cold storage (10°C) for 14 days (Day 14).

		Irradiation dose (Gy)					ANOVA's	
Variable	**Day**	**0**	**150**	**600**	**1000**	**Mean**	**Factor**	**P-value**
Firmness N	1	3.3	3.2	3.1	3	3.2a	Day	<0.001
	14	2.8	2.5	2.6	2.5	2.6b	Irrad.	0.093
	Mean	3.1	2.9	2.9	2.8		Day x Irrad.	0.836
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	37.2b	Irrad.	0.207
	Mean	38.1	38.0	38.4	38.2		Day x Irrad.	0.37
Skin chroma	1	34	32.7	34	33.8	33.6a	Day	<0.01
	14	36.1	34.9	35.7	33.6	35.1b	Irrad.	0.072
	Mean	35.1	33.8	34.8	33.7		Day x Irrad.	0.178
Skin hue angle	1	44.2	45.7	44.69	45.7	45a	Day	<0.001
	14	43	43.4	43.2	43.2	43.2b	Irrad.	<0.05
	Mean	43.6a	44.6b	43.9ab	44.4b		Day x Irrad.	0.247
TSS (°Brix)	1	4.9	4.8	5.0	4.9	4.9	Day	0.599
	14	4.9	4.7	4.9	4.9	4.9	Irrad.	<0.05
	Mean	4.9a	4.8b	4.9a	4.9a		Day x Irrad.	0.763
TA (% citric acid)	1	0.39	0.38	0.40	0.38	0.39b	Day	<0.001
	14	0.44	0.44	0.43	0.42	0.43a	Irrad.	0.732
	Mean	0.42	0.41	0.42	0.4		Day x Irrad.	0.763

Means in a treatment followed by the same letter are not significantly different.
ns= not significant

Capsicum

The effects of irradiation and storage duration on green capsicum quality attributes are summarised in Table 3. Both storage time and irradiation dose independently affected fruit firmness levels, resulting in fruit becoming softer (up to 1.6 N) after 21 days of storage and with increasing doses of irradiation. Fruit softening during storage was also associated with significantly higher rates of moisture loss rates in 1 kGy-treated fruit compared with all other treatments ($P<0.05$) (Figure 1).

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 shade of green by 21 days (Table 3). Fruit treated to 600 Gy and above were also slightly darker than 0 and 150 Gy-treated fruit, although this was not visually detectable (Appendix 1).

Internal quality, such as TSS and TA levels, were both affected independently by storage time and irradiation dose (Table 3). TSS levels increased from 4.1 to 4.5°Brix over the 21 day storage period and with increasing irradiation dose. 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%).

Table 3. Effect of irradiation dose and storage duration on green capsicum quality attributes. Fruit were gamma irradiated (Irrad.) up to 1 kGy and then assessed within 24 hours (Day 1) and after cold storage (7.5°C) for 21 days (Day 21).

		Irradiation dose (Gy)					ANOVA's	
Variable	**Day**	**0**	**150**	**600**	**1000**	**Mean**	**Factor**	**P-value**
Firmness N	1	7.9	7.1	6.6	5.8	6.9a	Day	<0.001
	21	5.8	5.6	5.2	4.8	5.3b	Irrad.	<0.01
	Mean	6.9a	6.3ab	5.9bc	5.3c		Day x Irrad.	0.386
Degreen (%)	1	1.0	0.3	0	0.3	0.4b	Day	<0.001
	21	3.0	2.3	7.5	3.3	4.0a	Irrad.	0.239
	Mean	2.0	1.3	3.8	1.8		Day x Irrad.	0.106
Skin lightness	1	35.9	36.2	36	36.4	36.1a	Day	<0.001
	21	33.7	33.4	33.4	34.1	33.7b	Irrad.	0.459
	Mean	34.8	34.8	34.7	35.3		Day x Irrad.	0.822
Skin chroma	1	16.2	16.8	17	17.1	16.8a	Day	<0.01
	21	14.9	14.3	14.6	15.2	14.7b	Irrad.	0.81
	Mean	15.5	15.5	15.8	16.2		Day x Irrad.	0.868
Skin hue angle	1	129.5	128.2	127.7	128	128.4b	Day	<0.01
	21	131	130.8	129.5	128.7	130.0a	Irrad.	<0.01
	Mean	130.2a	129.5ab	128.6b	128.4b		Day x Irrad.	0.452
TSS (°Brix)	1	3.9	3.9	4.2	4.5	4.1b	Day	<0.001
	21	4.3	4.5	4.6	4.5	4.5a	Irrad.	<0.05
	Mean	4.1c	4.2bc	4.4ab	4.5a		Day x Irrad.	0.097
TA (% citric acid)	1	0.14	0.15	0.16	0.15	0.15a	Day	<0.001
	21	0.11	0.13	0.14	0.13	0.13b	Irrad.	<0.001
	Mean	0.13b	0.14a	0.15a	0.14a		Day x Irrad.	0.157

Means in a treatment followed by the same letter are not significantly different.
ns= not significant

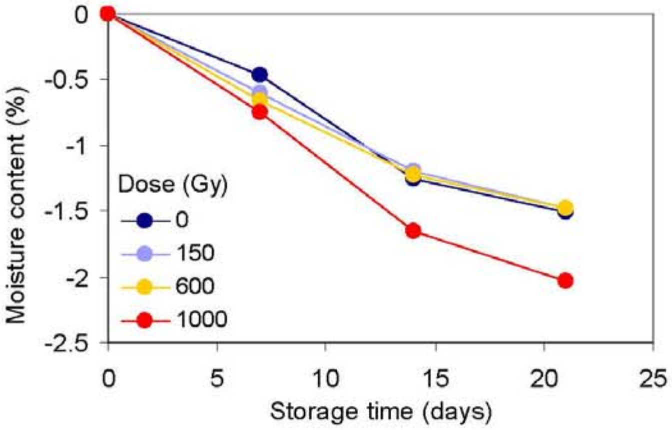

Figure 1. Effect of irradiation dose on fruit moisture content during cold (7.5°C) storage of green capsicum.

Discussion

The following study contributes towards further enhancing our baseline knowledge of the effects of irradiation on fruit quality. In this study, irradiation applied up to 1 kGy overall had little to no effect on a range of fruit quality attributes measured in tomato and capsicum. 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. No defects were observed in tomato and capsicum.

As a result of irradiation, capsicum fruit in particular did exhibit some small although statistically significant changes in fruit quality. At high doses of irradiation (600 to 1000 Gy), a slight increase in moisture loss and Brix levels was observed. These effects overall were minor as they did not detract from the integrity or overall visual appearance of the fruit. Mitchell *et al.* (1992) also reported similar findings in a trial which included irradiated green capsicum fruit stored at 5°C for 3.5 weeks. Although they only applied doses up to 300 Gy, they found that storage time had a greater effect on physico-chemical properties than did the effect of irradiation itself. These effects included decreases in soluble solids, acidity and fruit colour properties. Overall, these results were consistent with findings by Kader (1986) which showed that tomato had a relatively higher tolerance to irradiation compared with capsicum.

Recommendations

Applications of gamma irradiation treatments of ≤1 kGy can be used as a phytosanitary measure without inducing any deleterious effects on fruit quality in tomato and green capsicum.

References

Kader, A. A. (1986). Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. Food Technol. 40(6):117-121.

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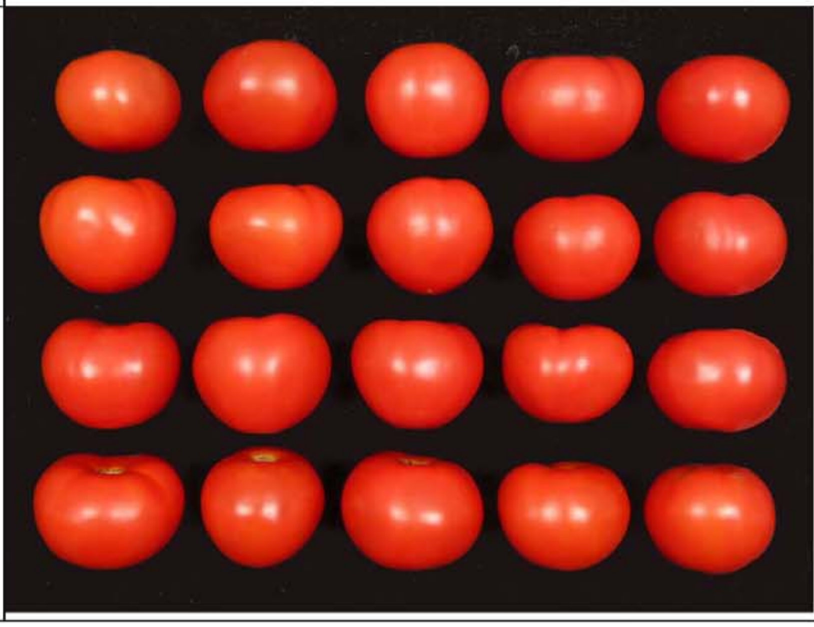
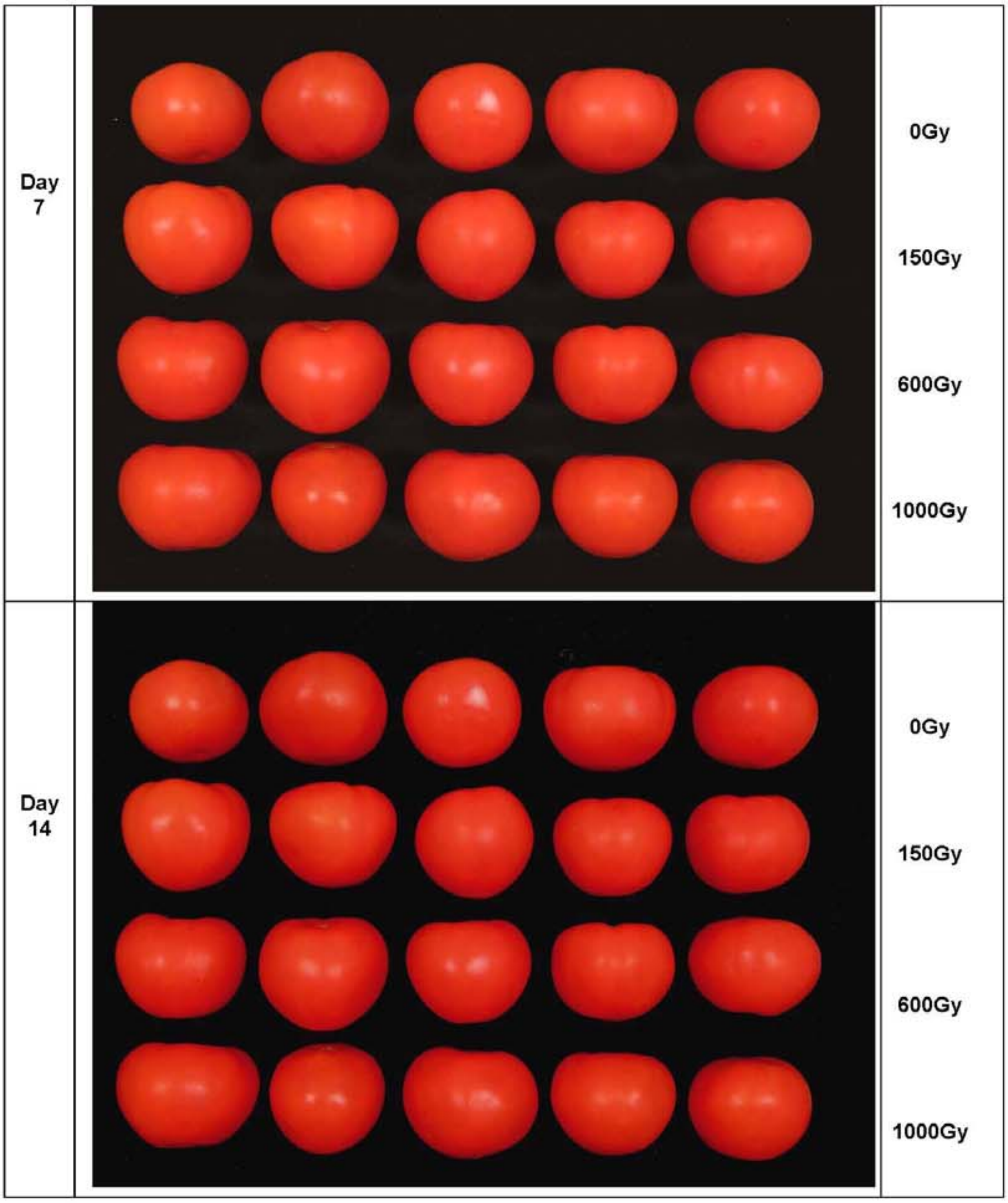
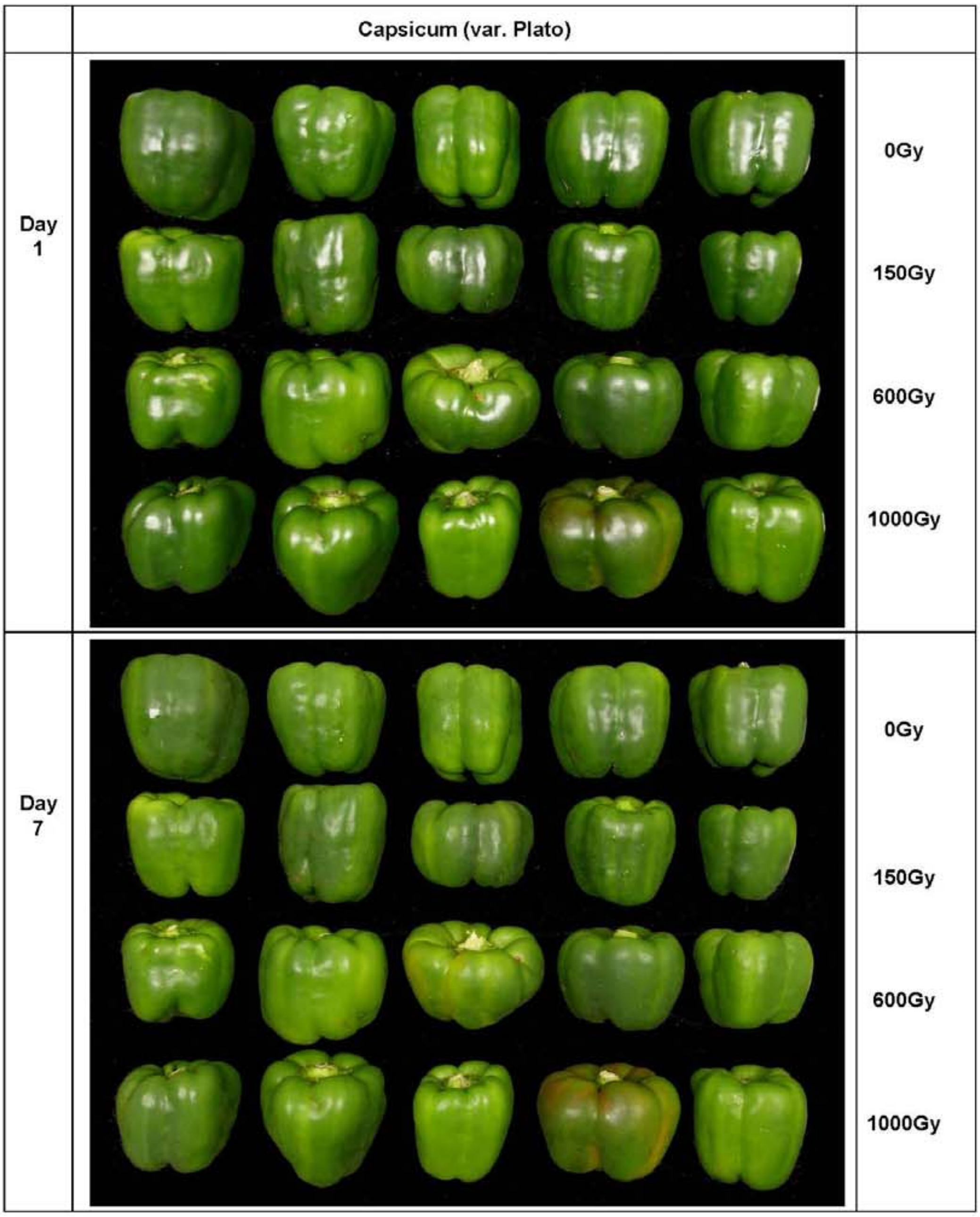
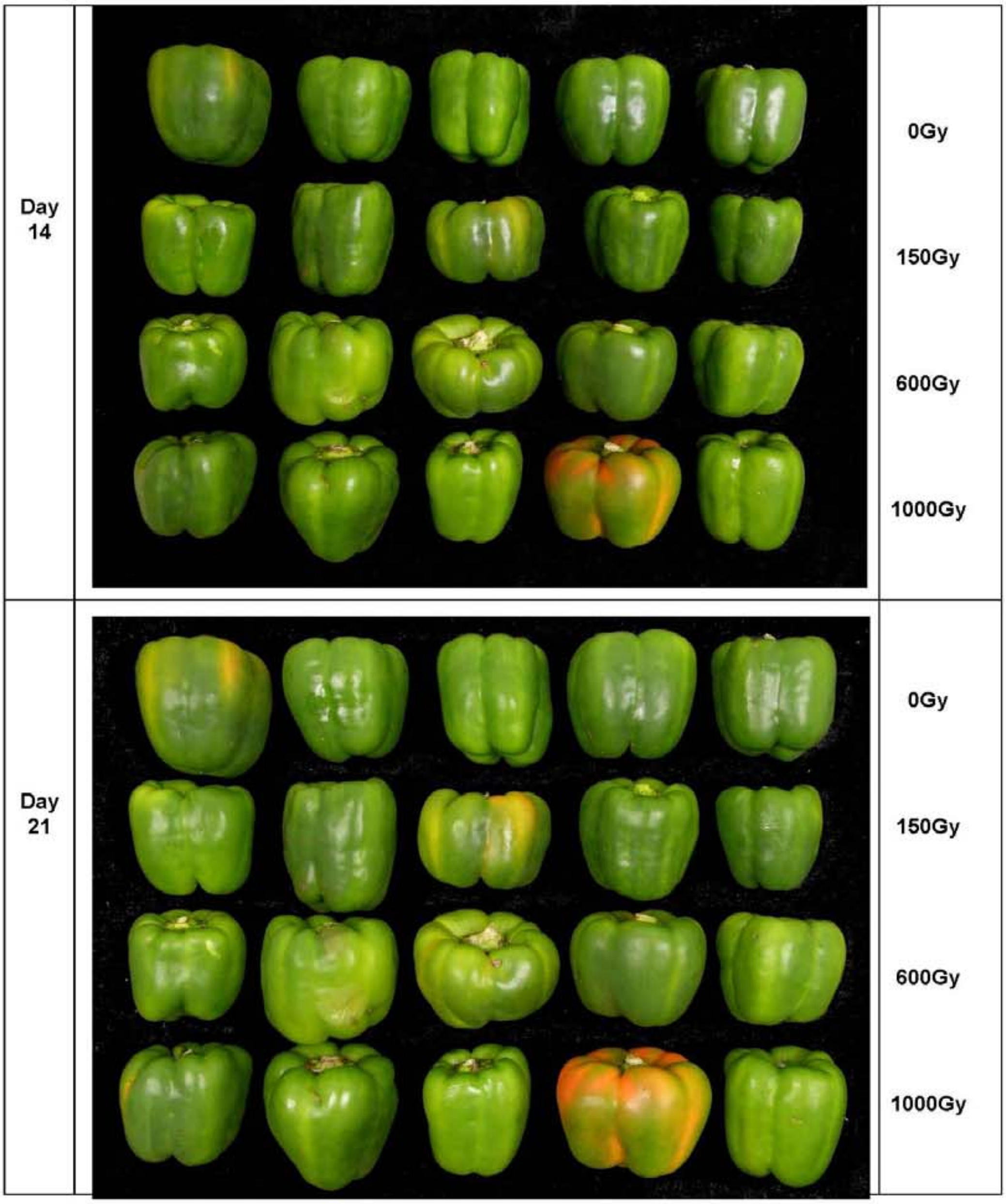
Appendix 1:

Photographs of tomato and capsicum fruit irradiated between 0 to 1000 Gy and held in cold storage for 14 and 21 days, respectively.

	Tomato (var. Gourmet Swanson)	
Day 1		0Gy 150Gy 600Gy 1000Gy


Day
7
0Gy
150Gy
600Gy
1000Gy
Day
14
0Gy
150Gy
600Gy
1000Gy


Capsicum (var. Plato)
Day 1
0Gy
150Gy
600Gy
1000Gy
Day 7
0Gy
150Gy
600Gy
1000Gy


Day 14
0Gy
150Gy
600Gy
1000Gy
Day 21
0Gy
150Gy
600Gy
1000Gy

Appendix 2:

Dosimetry Report

Tomato and Capsicum Irradiation Report

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30 MAR 2011
DEEDI Cairns

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

15 March 2011

Irradiation Report

ANSTO Reference	G11142
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	PO 4550047094

ANSTO Ref: G11142 SRT F 004

Prepared CLB Authorised JD Date 18-3-11 Page 1 of 5

Connie Banos Justin Davies

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

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

Prepared [signature] Authorised [signature] Date 18-3-11

Connie Banos Justin Davies

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 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.

ANSTO Ref: G11142 SRT F 004

Prepared [signature] Authorised [signature] Date 18.3.11 Page 4 of 5

Connie Banos Justin Davies

Appendix A – Labelling

Packages containing treated tomatoes and capsicums 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 ELECTRONS’

‘TREATED WITH IONISING RADIATION’

‘IRRADIATED TOMATOES & CAPSICUM’

The **Radura** logo, used to show a food has been treated with ionizing radiation (international version)

(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 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.

(4) Notwithstanding clause 3 of Standard 1.2.1, the label on a package of irradiated food which is sold other than for retail sale must include –

(a) a statement that the food has been irradiated; and

(b) the minimum and maximum dose of the irradiation; and

(c) the identity of the facility where the food was irradiated; and

(d) the date or dates of irradiation.

Usual carton marking and labelling is a requirement under the Trade Measurement Act 1989 (NMA 2010). Labelling is an important means of identifying fruit treated by irradiation. Labelling will ensure that consumers are not misinformed. Correct labelling can enhance consumer confidence so that they are able to make informed choices.

Appendix B – Facilities, dosimetry and record keeping

B.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 safety of operations of irradiation facilities is regulated separately. 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 National Radiation Laboratory (NRL) under delegated authority from the Ministry of Health regulates all radiation facilities and radioactive substances and apparatus in New Zealand. Extensive worker training, supervision and regulatory oversight are required.

Any facility used to irradiate food will be a licensed and prescribed radiation facility. The radiation facilities are licensed in accordance with any relevant State, and Territory, and New Zealand law governing radiation control and operation. 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 Department of Environment and Climate Change
- NT Department of Health and Community Services (DHCS)
- QLD Department of Health
- SA Environment Protection Authority
- TAS Dept of Health and Human Services
- VIC Department of Human Services
- WA Radiological Council, Department of Health.

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.

The Codex General Standard for Irradiated Foods (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 tomatoes and capsicums 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	**Address**	**Contact details**
Steritech Pty Ltd	5 Widemere Road Wetherill Park NSW 2164	Tel: 02 9609 5566 Fax: 02 9604 4396
Steritech Pty Ltd	180-186 Potassium Street Narangba QLD 4504	Tel: 07 3293 1566 Fax: 07 3293 1544
Steritech Pty Ltd	160 South Gippsland Highway Dandenong VIC 3175	Tel 03 9793 5566 Fax 03 9701 3158

The Certificates of Registration and AQIS certification for the Steritech facility are attached.

There is a commercial irradiation facility in New Zealand – Schering Plough Animal Health Ltd., 33, Whakatiki Street, Upper Hutt, New Zealand. It conducts occasional sterilization treatments of imported goods at the request of importers and Biosecurity NZ. It is unsuitable for the general irradiation of fruits and vegetables.

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

[redacted]

Alex Ezrakhovich
General Manager – Certification Services

Duncan Lilley
Global Head – Assurance Services

Certified System
ISO 9001

JAS-ANZ
WWW.JAS-ANZ.ORG/REGISTER

SAI GLOBAL

Plate 2. Approval of Place for Quarantine, AQIS

COPY

Australian Government
Australian Quarantine and Inspection Service

Australian Quarantine and Inspection Service
Quarantine Act 1908

Approval of Place for Quarantine

The following place has been approved under Section 46A of the *Quarantine Act 1908* as a place where goods of the classes specified below that are subject to Quarantine may be treated or otherwise dealt with.

Steritech Pty Ltd
180-186 Potassium Street
NARANGBA QLD 4504

Approval Number
Q1279

This approval is granted subject to any condition imposed by the approval, including those conditions attached to specified classes of goods. Grounds for the suspension or revocation of the approval include non-compliance with any one or more of the procedures carried out in relation to the goods at the approved place/or contravention of a condition of the approved place. In addition, reckless contravention of a condition imposed by the approval is a criminal offence. Maximum penalty: Imprisonment for 2 years: section 46A(8).

The approval of this place does not constitute approval or delegation or authority to exercise any statutory power or function or otherwise act on behalf of the Director of Quarantine, AQIS or any other part of the Commonwealth of Australia. The owner or occupier of the approved place (specified above) is responsible for ensuring compliance with the procedures carried out in relation to goods at the approved place. The involvement of the Commonwealth or its representatives in monitoring compliance with those procedures does not relieve or diminish this responsibility.

This approval is valid from 1 July 2010 to 30 June 2011

CLASS (ES) OF GOODS
4.2 Gamma irradiation facilities

[redacted]

RICK HAWE
REGIONAL MANAGER STH QLD
Delegate of the Director of Animal and
Plant Quarantine pursuant to Section 10b
of the *Quarantine Act 1908 (Cth)*.

DEPARTMENT OF AGRICULTURE, FISHERIES & FORESTRY
QUARANTINE
AUSTRALIA

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	Location of Premises or Name of Ship and Home Port
STERITECH PTY LTD ACN 007 308 027 ABN 30 451 935 502	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
PIGOTT, J.M HAY, S.M CRAWFORD, G.L ROBERTSON, G.J SCOTT, M

Registered subject to the following conditions (if any)

This certificate is issued in accordance the *Export Control Act 1982* and its subordinate Orders and Regulations

Date of Effect 19 Jul 2010

Jose Stokman — Secretary or Delegate

19 Jul 2010 — Date

Department Seal
DEPARTMENT OF AGRICULTURE, FISHERIES & FORESTRY
AUSTRALIA
3660

✻ denotes a suspended Registered Operation or Country Eligibility

EX23A - 11/03

B.2 Dosimetry

Dosimetry is one component of a total quality assurance programme for adherence to good irradiation (manufacturing) practice. Record–keeping (Appendix B.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 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 irradiated first from one side and then, after turning the package or pallet, from 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;

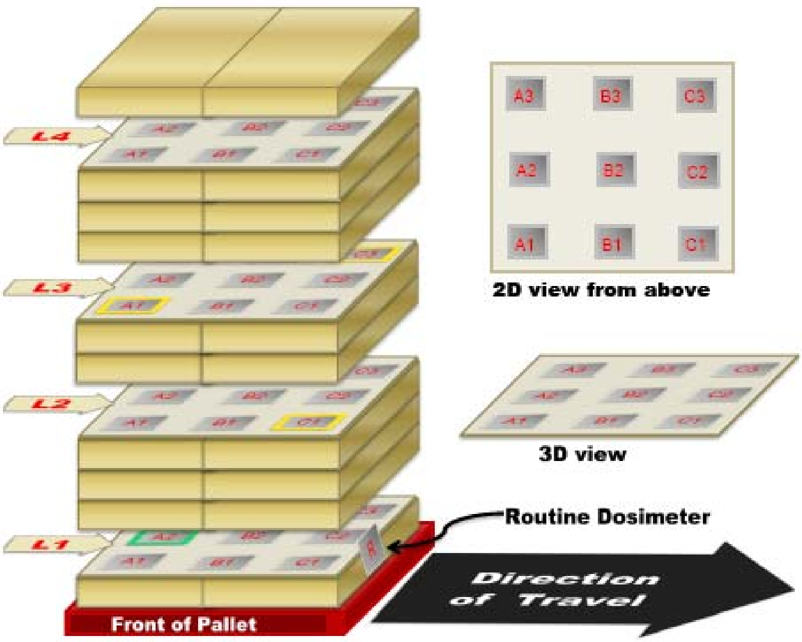
(g) the type of dosimeter;

(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 a 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). 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.

B.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:

(a). the nature and quantity of the food treated;
(b). lot identification;
(c). the minimum durable life of the food treated;
(d). the process used;
(e). compliance with the process used;
(f). the minimum and maximum dose absorbed by the food;
(g). an indication whether or not the product has been irradiated previously and if so, details of such treatment;
(h). 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 1 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 labeling 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).

The following is the procedural documentation for Facility Records and Traceability used at the Steritech Narangba facility. Mango and litchi are routinely irradiated at the facility prior to shipment to New Zealand.

Steritech

VICTORIA
160 South Gippsland Highway
Dandenong 3175

PO Box 4040,
Dandenong South
Victoria 3164 Australia

Telephone: (03) 8726 5566
Fax No: (03) 9701 3158
EM: sterivic@steritech.com.au

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
EM: sterinsw@steritech.com.au

QLD
180 Potassium St
Narangba 4504

PO Box 376,
Burpengary
Qld 4505 Australia

Telephone: (07) 3293 1566
Fax No: (07) 3293 1544
EM: steriqld@steritech.com.au

Quality System
Quality Endorsed Company
ISO9001:2000
QEC11523
Standards Australia

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; (eg. 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:

- Dosimeter 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.

<u>Steritech maintains records for a minimum of seven years.**</u>**

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 C – 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.

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 which, like tomatoes and capsicums, 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. These fibreboard packages are standard fruit boxes that are sized according to the dimensions of the particular fruit in question.

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 2008). Komolprasert (2008) 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. The US FDA has listed packaging materials that are safe for use with irradiation. (Table C.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 for tomatoes and capsicums.

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.

Table C.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 films[5]	10
	Kraft paper	0.5
	polyethylene terephthalate film (basic polymer)	10
	polystyrene films[5]	10
	rubber hydrochlorides[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 parchments[5]	60
	polyethylene film (basic polymer) [6]	60
	polyethylene terephthalate film[6]	60
	nylon 6[6] (polyamide-6)	60
	vinyl chloride - vinyl acetate copolymer film[6]	60

Packaging for tomatoes and capsicums

Amcor, Carter Holt Harvey and Visy are the main manufacturers and suppliers of fruit and produce packaging in Australia. Tomatoes and capsicums 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.

The standard materials used by Amcor, Carter Holt Harvey and Visy are listed in the Tables C.2, C.3 and Plate C.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 C.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.

Only a relatively small portion of the fruit surface is in contact with the packaging. Any plastic inserts that are used are made from polymers commonly used in food packaging materials that can be irradiated up to 10 kGy. Inserts that are commonly used by growers in the packaging of tomatoes and capsicum are supplied by Q Pak Plastic Thermoformers, and the details 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 C.2.

The test report of the PVC plastic film used in manufacturing the plastic insert is provided in Plate C.3. 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).

Table C.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	Non-hazardous emulsion polymer to laminate and glue papers together. Wheat starch-based adhesive to glue the papers into corrugated board. Hotmelt adhesive - comprising rosin and alum, for assembling boxes
Inks	Non-hazardous Acrylic Emulsion w/non-hazardous water-based pigment dispersions

Plate C.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: 2nd May, 2008.
Issued By: Mark Young, Technical Supervisor

To Whom it May Concern:

Visy Board Queensland manufactures cardboard products comprising of:

Paper:

- Recycled Papers manufactured in conformance with FDA.176.260
  - No hazardous substances are used within the manufacturing process
- Kraft Papers.
  - Raw materials sourced from sustainable Australian sources

Starch:

- Tapioca Starch

Inks:

- Water based Inks

Adhesive:

- 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.

Contact Information
Mark Young 07 3248 1460
Email: mark.young@visy.com.au

Certification:
CODEX HACCP, GMP, ISO9001:2000.
SAI Global.
License Number: HAC20003. Certified: 25/8/1993.

Plate C.2. Test report for two PVC films used in the manufacture of plastic liners for fruit.

06 Feb 09 09:32a John Stevenson 07 5456 2388 p.
From:NETWORK MARKETING 95544090 04/04/2006 11:10 #065 P.001/003

Approved Analysts (Food Act)
A.B.N. 61 005 377 613

CONSULCHEM PTY. LTD.

Analytical & Consultant Chemists & Microbiologists
A.C.N. 005 377 613

Reference: C3995/1-2 NT:yh
20th October, 2004

CGPC Group,
Suite 4, Level 3,
694 Burke Road,
CAMBERWELL VIC. 3124

Att: John

Attention: Mr. R. Yeh

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	Silicone – Clear	AS specifications
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

[redacted]

NATASHA TRAN
Chemist

17025 NRA

Unit 1, 7-11 Rocco Drive, Scoresby, Vic. 3179, Australia. Tel: (03) 9764 8881 Fax: (03) 9764 8892
E-mail: conchem@consulchem.com.au Web Page: www.consulchem.com.au

Plate C.3. SGS Test report of PVC plastic film intended for use in plastic materials and articles intended to come into contact with foodstuffs.

06 Feb 09 09:32a John Stevenson 07 5456 2388 p.8
From:network marketing syd. To:0754561444 02/10/2008 17:00 #769 P.002/003

19/09 2008 11:44 FAX 001

SGS

Test Report No.: GLHGR080606068CM Date: JULY 10, 2008 Page 1 of 2

HAN RIGID PLASTICS CORP. (GUANGZHOU)
1, YUN PU 1ST ROAD, YUN PU INDUSTRIAL ZONE, GUANGZHOU CHINA

The following sample(s) was/were submitted and identified on behalf of the applicant as :

Product Description	: PVC PLASTICS FILM
SGS Ref No.	: GZ0806110265/CHEM
Style/ Item No.	: RIGID PVC PLASTICS FILM
Test Performed	: Selected test(s) as requested by applicant
Sample Receiving Date	: JUNE 20, 2008
Testing Period	: JUNE 20, 2008 TO JULY 09, 2008
Test Results	: Please refer to the next page

Test Requested : To determine the Overall Migration in accordance with European Commission Directive 2007/19/EC (2002/72/EC amendment) relating to plastic materials and articles intended to come into contact with foodstuffs.

Test Method : With reference to EN 1186-1:2002 for selection of conditions and test methods;
EN 1186-3:2002 aqueous food simulants by total immersion method;
EN 1186-2:2002 olive oil by total immersion method.

Conclusion : When tested as specified, the submitted sample(s) comply with the overall migration requirements stated in European Commission Directive 2007/19/EC (2002/72/EC amendment) relating to plastic materials and articles intended to come into contact with foodstuffs.

Signed for and on behalf of
SGS-CSTC Ltd.

[redacted]

Tony Peng
Engineer

Appendix D – 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.

A number of post-irradiation analytical methods are available that can be applied to different kinds of food (Marchioni 2006). The methods are 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 D.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. None are generally practical or reliable for easy verification at the low phytosanitary doses (<1 kGy) requested in this application, again emphasizing the importance of proper documentation systems.

Table D.1. The European Standards (EU 2009b) for the detection of irradiated foods. EN 14569:2004 is the only method not listed by the Codex Alimentarius Commission (CAC 2003d).

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

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 for the foreseeable future.

Appendix E – Letters of support

Turners & Growers

Elton Miller
General Manager Food & Agribusiness - Agriculture & Food
Department of Employment, Economic Development and Innovation
GPO Box 46
BRISBANE QLD 4000

2nd November 2011

Dear Mr Miller

AMENDEMENT OF FOOD STANDARDS CODE 1.5.3

Turners and Growers are importers of fresh fruit and vegetables into New Zealand.

Recent amendments to Food Standards Code 1.5.3 relating to the use of Dimethoate as a phytosanitary measure to control fruit fly on tomatoes and capsicums has the potential to have serious impact on trade between New Zealand and Australia as well as NZ destabilising the market during winter period.

Turners and Growers supports any application to have the Food Standards Code 1.5.3 amended to to have irradiation included as a phytosantiary measure for use on tomatoes and capsicums.

We have been importing mangoes for the past 5 years that have been irradiated and have seen no negative issues that would have us worry about the treatment being extended to other commodities.

We request this matter be given high priority.

Yours faithfully,

[redacted]

Patrick T C Corson
Imports Manager

countdown

14th November 2011
FSANZ
Regarding support of changes to the food standard code

Dear Sir/Madam,

Countdown is a retail chain based in New Zealand and has 159 stores nationwide. We are committed to meeting our customer's needs in providing good quality fruit and vegetables.

We have strong growing programs with local growers however there is a seasonal gap over winter where there is not enough NZ product to meet our customer demand. As a result we need to import tomatoes and capsicums from Australia. Failure to import would mean the NZ consumers would have limited options to buy these products during the winter period. Prices would also rise as the cost of production increases significantly in the winter months thus pushing the cost of living up. From a healthy eating aspect, Progressive is a strong supporter of the United Fresh 5+Aday healthy eating initiative and these basic lines play an important part in our programme.

Countdown has been importing Australian tomatoes and capsicums through market wholesalers for decades and more recently direct through Australian growers. In the last financial year Countdown imported approx $5.5m (retail sales) of Australian tomatoes and capsicums.

The Australia produce was well received by our customers and enabled New Zealanders to purchase these products at competitive prices. For these reasons maintaining the ability to import Australian tomatoes and capsicum is important not only to Countdown but for the NZ Consumer as well. Our view is the need for alternative treatments (including Irradiation or Low dose methyl bromide) needs to be urgently implemented.

Countdown has supported the nutrient research work underpinning the application through funding via the NZ Fresh Produce Importers Association and will be willing to provide further information on request to support the application.

Regards

[redacted]

Ian Pavey
Divisional Manager Fresh Produce
Countdown

FRESH DIRECT LIMITED

29 Clemow Drive
Mt Wellington
P O Box 17 470
Auckland 1546
New Zealand

Telephone: 0064 9 573 4100
Facsimile: 0064 9 573 1101

fresh direct

The General Manager Food and Agribusiness
Agriculture and Food
Dept of Employment, Economic Development and Innovation
GPO Box 46
Brisbane
Queensland 4000
AUSTRALIA

Dear Mr Miller,

Re Amendment of Food Standards Code 1.5.3

Fresh Direct Ltd are importers of fresh fruit and vegetables into New Zealand.

As you are aware, the use of Dimethoate as a control for Fruit Fly has been suspended for certain uses including as a phytosanitary measure for tomato and capsicum.

We are writing to you to advise that we support the application for the amendment of the Food Standards Code 1.5.3 to include tomatoes and capsicums on the approvals list for the use of irradiation as a phytosanitary measure.

Fresh Direct has supported the nutrient research work surrounding the application through the provision of funding via the NZ Fresh Produce Importers Association of which we are members.

The Australian tomato and capsicum imports are important to our business and indeed for the whole New Zealand market in which these products have held an important seasonal supply position for at least the past 20 years. In this regard, Fresh Direct strongly requests that the need for alternative treatments (including irradiation) be urgently approved.

We respectfully ask that this application be given high priority, as the continuation of these key products is most important, not only for the Australian growers and NZ consumers, but also given the significant commercial impact they have over a wide range of industries from primary production through to end point transportation.

Please advise if we can provide any further information.

Yours faithfully,

[redacted]

Doug Hamilton
Import Manager

Manager- Food and Agribusiness
Agriculture and Food
Department of Employment, Economic Development and Innovation
P.O. Box 46
Brisbane, QLD 4000
AUSTRALIA

freshmax
www.freshmax.co.nz

31st October 2011

To Whom It May Concern

Re- Amendment of Food Standards Code 1.5.3.

Freshmax NZ Ltd, Is an active importer of fresh fruit and vegetables into New Zealand from Australia.

As you are aware, the use of Diamethoate as a control for Fruit Fly infestation and establishment in free areas has been suspended for certain uses, including as a phytosanitary measure to allow the importation of tomato and capsicum to New Zealand during winter months.

I write to you to advise that Freshmax supports the nutrient research work behind the application to consider alternative treatments methods, through the provision of funding by the New Zealand Fresh Produce Importers Association.

The trans-tasman import trade of fresh tomatoes and capsicums during the New Zealand winter months is a significant part of Freshmax's business and considered a high-priority matter to investigate and implement an alternative treatment for phytosanitary approval (such as irradiation) as soon as possible.

In relation to the above, Freshmax has been a fresh produce importer to New Zealand for the past 15 years, and in the past three years has imported a total volume of 46,000 units (10kg per each) at a total turnover value of $1.5million NZD.

In order to assist/support the processing of the application, Freshmax is willing to provide further information upon request.

Yours sincerely,

[redacted]

Ryan Wilson
Division Manager- import
Freshmax NZ Ltd

Bowen District Growers Association Inc.

PO Box 489
BOWEN QLD 4805
ABN 35 729 953 455

Ph: 07 4785 2860
Fax: 07 4785 2211
Email: bdgainc@bigpond.com

24 October 2011

Elton Miller
General Manager Food & Agribusiness
Agriculture & Food
Department of Employment, Economic Development and Innovation
GPO Box 46
Brisbane Queensland 4000

RE: Letter of Support for the application to FSANZ to amend the Food Standards Code 1.5.3 to include Tomatoes & Capsicums

Elton

Over the past several years the APVMA has been reviewing chemicals (Dimethoate & Fenthion) used for market access domestically and internationally which has meant many industry bodies both locally and state have been investing in research into alternative options for market access. One such research project was to confirm the possibility of irradiation as an option for market access. Irradiation is already accepted for market access for mangoes, which should complement acceptance for other commodities such as tomatoes and capsicums.

In recent times we have seen Dimethoate suspended for postharvest use by the APVMA. We could also see Fenthion suspended in the new year, which will significantly impact on the industry in Queensland and its ability to supply fresh vegetables domestically and internationally.

Bowen District Growers Association (BDGA) has been a contributor to many research projects including the irradiation research which has shown to be a safe, non-chemical, non-residual alternative.

BDGA believes irradiation would support market access domestically and internationally and would like to provide a letter of support for the application to FSANZ to amend the Food Standards Code 1.5.3 to include Tomatoes & Capsicums on the approvals list for using Irradiation as a Phytosanitary Measure.

Yours sincerely

[redacted]

Carl Walker
President

A strong and cohesive organisation providing a voice for our members

Bundaberg
Fruit & Vegetable
Growers

13/2 Tantitha Street
(PO Box 45)
Bundaberg QLD 4670

P: (07) 4153 3007
F: (07) 4153 1322
E: bfvg.info@bfvg.com.au

Elton Miller
General Manager Food & Agribusiness - Agriculture & Food
Department of Employment, Economic Development and Innovation
GPO Box 46
BRISBANE QLD 4000

1st November 2011

Dear Elton,

RE: FSANZ APPLICATION TO AMEND FOOD STANDARDS CODE 1.5.3 TO INCLUDE TOMATOES AND CAPSICUM ON THE APPROVALS LIST FOR USE OF IRRIDATION.

Bundaberg Fruit and Vegetable Growers Cooperative Ltd (BFVG) is pleased to support this application to FSANZ as outlined above. BFVG is of the opinion that Irradiation, as a Phytosanitary measure, will form a critical post-harvest treatment in the future for many horticultural commodities. It is important that horticultural growers are provided with a range of options for their business operations and market. In relation to post-harvest treatment enabling market access, Irradiation could well be the choice of many growers.

In reference to this specific application for the inclusion of Tomatoes and Capsicum, I would like to highlight the total farm-gate production value of Tomatoes in the Bundaberg region was estimated in 2009 to be $156 million, while Capsicum production was estimated to be $17.5 million. With a regional production value of all horticultural crops estimated in 2009 to be nearly $454 million, these two crops represent 38% of the crops produced in the Bundaberg region.

A large proportion of the Tomato and Capsicum production in the Bundaberg region is destined for the southern state and export market places. Given the current situation regarding the interim findings of the Dimethoate review by the APVMA, and the subsequent impact on market access for growers of these two commodities, it stands to reason that alternative solutions be immediately granted to the Horticulture industry - Irradiation is one such alternative.

BFVG has undertaken a project in area wide Integrated Pest Management which contained an element of pest activity monitoring including monitoring of Fruitfly, Macadamia and Heliothis. This research helped identify hotshots of pest activity on a weekly basis over the past 12 months.

Through this project, BFVG is well placed to understand the significant threats to horticultural crops from Fruitfly, the challenges and costs growers face in reducing this risk, and implications to growers' profitability and productivity now they have reduced access to cost-effective on-farm Fruitfly control and post-harvest treatments that do not impact fruit quality and shelf life.

I trust this Letter of Support and the application to amend the Food Standards Code 1.5.3 is viewed favourably by FSANZ - particularly so for the application's merit and benefits to the production horticulture industry today worth nearly $500 million farm-gate value in the Bundaberg region alone.

Yours sincerely,

[redacted]

Peter Hockings
Executive Officer

CC: Bill Hatton, representative of Steritech Pty Ltd

Bundaberg Fruit & Vegetable Growers Cooperative Ltd

CSI Brisbane 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

CSI brisbane

Mr Elton Miller
General Manager Food & Agribusiness
Agriculture & Food
Department of Employment , Economic Development and Innovation

GPO Box 46 Brisbane Queensland 4000

25th October 2011

Dear Sir

It is imperative that we have an alternative treatment process available to maintain the export trade to New Zealand for tomatoes and capsicums as a priority
With the use of dimethoate now banned, it is essential FSANZ approval of irradiation is processed promptly, to allow any chance of exports to recommence as early as possible 2012

We support the application to FSANZ to amend the Food Standards Code 1.5.3 to include Tomatoes & Capsicums on the approvals list for using Irradiation as a Phytosanitary Measure

Yours Faithfully,

[redacted]

D.J.Hammonds
Director

LA MANNA

24th October 2011
Department of Employment,
Economic Development and Innovation
GPO Box 46 Brisbane, Queensland 4000

Attn: **Elton Miller**
General Manager Food & Agribusiness Agriculture & Food

Dear Sir,

The application by Steritech Pty Ltd for the application to FSANZ to amend the Food Standards Code 1.5.3 to include Tomatoes & Capsicums on the approvals list for using Irradiation as a Phytosanitary Measure, has the full support of the La Manna Group.

We have been successfully exporting both produce items to New Zealand for 20 years as it provides the Bowen and Bundaberg Growers an invaluable outlet for their produce. This market is particularly handy through times of over supply to the domestic market and because of the preference by the New Zealand consumer for smaller fruit, these exports allow a wider range of sizes to be marketed and therefore greater financial yields per hectare.

The ramifications of cessation of trade across the Tasman would have serious effects on the viability of crops which is why this chemical free treatment provides such a good option long term. The fact that we have re-opened the market for Australian Mangoes bears out this fact.

We also welcome the introduction of ICA-55 as it provides a long term solution to the control of Queensland Fruit Fly on Fruit Fly host produce into the southern states. The fact that Queensland supplies 80% of Tomatoes and Capsicums through the winter period means we must have an effective solution to the management of this insidious pest.

We would appreciate your support to complete the process of approval in the shortest time possible given the importance of this strategic winter supply of these fundamental food items to consumers in New Zealand and the Southern States.

Yours Faithfully,

[redacted]

A.G. Walsh – Export Manager

Mountview Exports

Address

PO Box 809
THURINGOWA BC QLD 4817

Telephone (07) 4755 4700
Facsimile (07) 4755 4799

email mtview2@bigpond.com.au

Our reference: Jason Pertile
Your reference:

25 October, 2011

The General Manager Food and Agribusiness
Agriculture and Food
Department of Employment, Economic Development and Innovation
GPO Box 46
Brisbane Qld 4000

Attention: Mr. Elton Miller

Dear Mr. Miller,

Amendment of Food Standards Code 1.5.3

We are exporters of fresh fruit and vegetables to New Zealand.

As you are aware the use of Dimethoate as a control for Fruit Fly has been suspended for certain uses including as a phytosanitary measure for Tomato and Capsicum.

We are writing to you to advise that we support the application of Steritech Pty. Ltd. for the amendment of the Food Standards Code 1.5.3 to include tomatoes and capsicums on the approvals list for the use of irradiation as a Phytosanitary Measure.

We request that this application be given a high priority as it has significant commercial value over a wide range of industries from primary production through to end point transportation.

If you have any queries or require any further information from us please advise.

Yours faithfully,

[redacted]

PO Box 5740, Bundaberg,West, QLD 4670
ABN 82 144 004 768

10th November 2011

Mr Elton Miller
General Manager
Food & Agribusiness, Agriculture & Food
DEEDI
GPO Box 46
BRISBANE QLD 4000

Dear Mr Miller

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include tomatoes

The withdrawal of Dimethoate for all uses on tomatoes, has already presented significant problems to our business and it is more than assured that further removal of chemical phytosanitary methods will pose similar problems for us in the future. From our perspective we have been looking for a non-chemical solution which will be stable protocol into the future. One we can set our business plans to for the medium to long term.

We have reviewed all of the options available to us and considered their practical application in our business and their food safety aspects. It is our view that the irradiation protocol ICA-55 is the preferred solution for the long term sustainability of Queensland tomato growers for access to the southern states. We strongly urge the authorities to support the approval of this protocol to allow stability to return to our industry and to allow the consumers a safe non-chemical alternative for tomatoes consumed from Queensland.

Yours Sincerely

Phillip Alexander
Managing Director
Pac-Sure Pty Ltd

SP EXPORTS
Export Quality Produce
Bundaberg, Queensland, Australia
ABN: 19 010 745 294

25th October 2011

Mr Elton Miller

General Manager

Food & Agribusiness, Agriculture & Food

DEEDI

GPO Box 46

BRISBANE QLD 4000

Dear Mr Miller

RE: Application to FSANZ to amend the Food Standards Code 1.5.3 to include tomatoes

The withdrawal of Dimethoate for all uses on edible skin commodities, particularly tomatoes, presents enormous problems to the tomato industry if access to critical markets is in any way impeded. Continuing reviews by APVMA will undoubtedly result in further removal of current chemical use patterns.

For SP Exports and all tomatoes growers to have Southern and New Zealand market access and to remain sustainable in our industry it is critical that tomatoes are included on the approvals list for using Irradiation as a Phytosanitary Measure. The signing off by respective State regulatory authorities on ICA-55 is an extremely positive step in the process and will allow continual growth and business sustainability for our industry. Without this there will be key stakeholders in the industry not being able to continue business which have a major effect on regional Queenslanders.

Approval is very important for the tomato industry, as Irradiation will provide consumers with a safe non-chemical, non-residual alternative.

Yours Sincerely

Andrew Philip

Managing Director

SP Exports Pty Ltd

9 Kevin Livingston Drive, Childers
Queensland 4660
Email: pexports@spexports.com.au

Phone: +61 7 4126 4600
Fax: +61 7 4126 6995
Website: www.spexports.com.au

Appendix F – References

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