APPLICATION TO FSANZ

Application to amend Standard 1.5.3 to include irradiation as a phytosanitary measure for all fresh fruit and vegetables.

November 2019

Queensland Government

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EXECUTIVE SUMMARY

This application seeks a variation to the Food Standards Code, Standard 1.5.3 Irradiation of Food (FSANZ 2017). The variation requested is to replace the list of 26 fruits and vegetables in the table in Division 2, section 1.5.3-3, sub-section 2, with “fresh fruits and vegetables”. Included in the scope of the application are all those fresh fruits and vegetables presently described within Schedule 22 of the Food Standards Code plus any other fresh commodity generally understood to be a fruit or vegetable, including crops grown overseas. Excluded from the application are dried pulses, legumes, nuts and seeds.

Under the proposed amendment the purpose of the irradiation of fruits and vegetables and the minimum and maximum absorbed doses will remain the same (Division 2, section 1.5.3-3, sub-section 1). That is, the purpose is pest disinfestation for a phytosanitary objective and the minimum and maximum absorbed doses are 150 Gy and 1 kGy, respectively.

Applicant

This application is submitted by the Queensland Department of Agriculture and Fisheries (QLD DAF). QLD DAF's focus is on areas of policy development, leading-edge science, biosecurity, fisheries and forestry management, trade and export. The Agriculture Business Group focuses on lifting the productivity of Queensland’s food and fibre businesses.

Purpose

The purpose of the amendment is to extend the option of phytosanitary irradiation to all types of fresh fruits and vegetables. The existing Standard 1.5.3 approves irradiation for a phytosanitary purpose for 26 fruits or vegetables.

A phytosanitary measure is required whenever commodities are subject to a mandatory treatment to ensure freedom from regulated pests. This requirement can apply whenever fresh produce is exported to another Australian state, territory or region or to another country that is free of the pest. The requirement also applies to imports into Australia and New Zealand. Irradiation at doses between 150 Gy and 1 kGy is a highly effective phytosanitary measure. It is well suited to assist in expanding market access, both export and import, and for the evolving regulatory and international trade environment for fresh produce.

Justification

Phytosanitary measures for imports are used to protect the horticultural sectors of both Australia and New Zealand that have a value of several billion dollars. Similarly, horticultural exports from Australia and New Zealand may be subject to pre-shipment phytosanitary treatments. The majority of the fresh produce consumed in both countries is not subject to a treatment as it is produced and eaten in the same quarantine jurisdiction.

There is a range of treatments that may be used as phytosanitary measures. The options can be based on treatments that are physical (cold, heat) or chemical (fumigation, insecticide) or, in limited cases, a systems approach including in-field insecticides, non-host status or area freedom. Irradiation is the most recently established option. Each has different advantages and disadvantages. The key advantages of irradiation are that –

- It is subject to internationally recognized protocols (FAO IPPC 2003) and is unique among phytosanitary treatments as a broad-spectrum treatment for almost all important regulated arthropod pests (Follett and Neven 2006). A minimum dose of 150 Gy is internationally recognized as a generic treatment for all Tephritid fruit flies in all host fruits and vegetables *(*FAO IPPC 2009c). Australian states and territories and the USA recognise 400 Gy as a generic treatment of all insects in all host fruits and vegetables except adult *Lepidoptera* that pupate internally (USDA 2006; ICA 2011).
- Unlike competing treatments, long and costly research on host produce that have not been previously investigated is no longer required to prove effectiveness against fruit flies and most insects.
- It is a chemical-free treatment resulting in no harmful treatment residues on the produce and no release of any chemicals that may be harmful to the environment, including the ozone layer, or human health.
- It has the practical advantages of simplicity, application at the optimum storage temperature of the produce and independence from ambient conditions such as temperature, humidity and pressure. It is a rapid, well-tolerated treatment that is penetrating and applied to the commodity in its final packaging.

The first FSANZ approval of phytosanitary irradiation was for nine tropical fruits in 2004. Further approvals followed for 17 more fruits and fruiting vegetables (2011 to 2016), Australian exports of irradiated fresh produce have grown from 19 tonnes of mangoes exported to New Zealand in 2004 to over 5,300 tonnes of 10 different fruits and vegetables to 5 countries.

Five countries have negotiated access to Australia for irradiated fruits. Vietnam (mango, litchi) and India (mango) have begun exporting irradiated fruit to Australia.

Modification of Standard 1.5.3 as requested would further increase both market access opportunities for Australian exports and the availability of imported fresh produce to the benefit of the health and choice of Australian and New Zealand consumers.

International trade of irradiated fresh produce has evolved during the last decade. The initial trans-Tasman trade in irradiated mango in 2004 was the first truly international trade in irradiated fresh produce. Since then phytosanitary irradiation has become firmly established as a phytosanitary measure of choice between many trading partners (Roberts and Follett 2018). There are now at least 15 countries trading in irradiated produce (USDA 2018 and Table 1). Over 40,000 tonnes of irradiated fresh produce is now being traded internationally.

Approval of phytosanitary irradiation for all fresh produce would make Standard 1.5.3 fit-for-purpose in today's trading environment for several reasons.

Choice of most appropriate treatment

In Australia and New Zealand, irradiation is the only phytosanitary treatment that requires a variation to a food standard before it can be considered by biosecurity authorities. This is a barrier to uptake by the horticulture industry as a result of the time and cost involved and the perception that irradiation must be uniquely hazardous and difficult. Approval of this application would ensure that industries choose a phytosanitary treatment governed solely by which option is optimal, based on effectiveness, quality retention and cost.

Reducing environmental and health hazards

Fumigation using methyl bromide (MeBr) is a frequently used phytosanitary measure but it is a known ozone depleting gas (UNEP 2019) and replacement by irradiation is regarded as a good option for encouraging the reduction and replacement of MeBr fumigation (UNEP 2016). MeBr is also a known human health and workplace hazard (USEPA 2019, MPI 2019). The use of insecticides is being increasingly restricted and irradiation provides a replacement option.

Harmonisation of regulations and reciprocal trade arrangements

With the exception of Australia and New Zealand, all the countries that are presently trading in irradiated fruits and vegetables approve phytosanitary irradiation for all fruits and vegetables. Many other countries, some of which are likely target markets for irradiated Australian exports, also approve irradiation treatment of all fresh fruits and vegetables (GHI 2018; PNS 2015; FDA 2019; DOH 2018; EU 2009a).

While Australia is expanding exports of irradiated fruit to several Asian countries and the USA, some economically important fruits grown in such countries cannot be irradiated and imported into Australia as they are not already FSANZ approved. As they are not grown significantly in Australia, local industry is unlikely to lodge an amendment application. Overseas markets can question why Australian industry seeks to export produce to their country when that product is not approved (i.e., considered safe) within Australia. Access to a market can be expedited if the importing country knows that a reciprocal approval for its commodities is possible.

A generic approval for phytosanitary irradiation would bring Standard 1.5.3 fully into line with international standards and recommendations. The Codex General Standard (CAC 2003a) treats irradiation as any other food process that is safe and nutritionally adequate for any food. The WHO Sanitary and Phytosanitary Agreement requires all measures to be the least restrictive to trade (WTO 2011).

The International Plant Protection Convention is the recognised agency for establishing global practice in phytosanitary measures (IPPC 2019a) through its International Standards for Phytosanitary Measures (IPPC 2019b) or ISPMs. Harmonisation of phytosanitary irradiation treatments for regulated pests through ISPM 18 and ISPM 28 (FAO IPPC 2003, 2007) support efficient and effective phytosanitary measures and encourage the mutual recognition of treatment efficacy and treatment delivery. This can facilitate domestic and international trade. ISPM 28 Appendix 7 recognises 150 Gy as the dose to guarantee sterility, preventing adult emergence, of all fruit flies in all hosts (FAO IPPC 2009c). These measures apply to all fresh fruits and vegetables and Australian states have agreed to take the same approach via ICA 55 (ICA 2011). In future, a dose of 400 Gy is expected to become the recognised world standard for phytosanitary treatment of all insects in all host fruits and vegetables except pupae and adult *Lepidoptera*. It is already recognised as such by the USA and by Australian states and territories (USDA 2006, ICA 2011).

Other considerations

A generic approval for phytosanitary irradiation will allow a rapid response to new opportunities, threats and emergency requirements. As experience is gained with optimising irradiation and supply chain logistics for fresh produce it is becoming clear that more fruits and vegetables can tolerate phytosanitary doses than was thought likely a few years ago. For example, some citrus types are now traded overseas. As a treatment that requires no research on most pest-host combinations, irradiation is ideally placed to ensure that markets are not lost when existing treatments are no longer viable or approved, as was the case with tomatoes to New Zealand a few years ago. Irradiation can also be put in place rapidly for niche opportunities in the marketplace and can be used as an emergency measure when a pest incursion is suspected.

Given the complexities of international trade in fresh produce and predicting future changes, and given the probability that more crops will be found suitable for irradiation as experience is gained with phytosanitary irradiation, this application does not attempt to 'cherry-pick' which crops not presently permitted under Standard 1.5.3. might be treated in future. Rather the variation sought is to expand the crops that can be treated for a phytosanitary purpose to all fresh fruits and vegetables.

Costs and benefits

The socio-economic value of Australian and New Zealand horticulture industries (production, export, supply chain and retail) to both central and state governments is substantial. Phytosanitary measures such as irradiation help protect and expand these industries. There is significant benefit in having a range of phytosanitary measures available especially as chemical treatments and fumigation come under greater scrutiny and restrictions.

There are costs to providing irradiation treatments including not only the processing costs but transport to a specialised facility, packaging and labelling. Irradiation processing costs are comparable to alternative post-harvest physical and fumigation treatments; insecticide treatments will be cheaper and vapour heat treatments more expensive (Loaharanu 2003). Other treatments are of comparable cost (Hallman 2011). MeBr treatment costs will rise as MeBr reduction or recapture technologies are required. The present average costs of treatment at the Steritech facility of $170 per tonne or $0.17c per kg (private communication) will not add significantly to the cost of high value fruits and vegetables.

The acceptance of irradiation as a phytosanitary treatment option may speed up and reduce the costs of negotiations for market access of some Australian exports. Research into effectiveness against fruit flies is no longer required for irradiation, unlike other treatments. The loss of export markets is costly to industry and it is often challenging and complex to re-enter markets, as export markets are very competitive. Addition of irradiation to the treatment options available will mitigate against the changes that can occur, sometimes very rapidly, in the importing requirements of Australia's trading partners.

Industry benefits when the best possible choice from various treatment options can be made. If irradiation is approved as a generic treatment, then choice will be based solely on effectiveness, quality retention and cost. This will allow the optimum choice to be made, for example, when comparing cold storage *versus* irradiation treatments, sea-freight *versus* air freight.

A simplified (i.e., generic) approval of phytosanitary irradiation will also be beneficial to both government and industry through a reduction in regulatory and management costs.

Cost considerations regarding capital investment, an inability to feasibly locate a treatment facility within packing facilities, and remaining concerns about the process by key decision makers, packers, shippers, and retailers remain challenges.

The estimates for the percentage of fresh fruits and vegetables that may be irradiated if phytosanitary irradiation is permitted for all fresh produce (see below) suggest that the effect on the overall volumes and types of fresh produce consumed will not be large. This is because the majority of fresh produce is consumed within the production region and not subject to a phytosanitary treatment, and alternative treatment methods will still be available. There will be a benefit from new fruits from overseas that are not presently available entering the local markets.

A generic approval will not mean the unjustified use of irradiation. Standard 1.5.3 requires irradiation of fruits and vegetables to be for a phytosanitary purpose. For commodities being sold in markets with no phytosanitary restrictions, the use of irradiation would not be required or permitted. All phytosanitary treatments are authorised under established protocols between national or state plant protection agencies. The full range of traditional phytosanitary measures will still be available and will often remain the best option.

Safety and dietary impact

There has been no revision of international scientific opinion or significant literature on the toxicological or microbiological effects of irradiation on food since the most recent Applications to amend Standard 1.5.3.

Australians and New Zealanders generally have a nutritionally adequate diet (FSANZ 2014b). Even in people with the lowest intake levels, vitamin C intake is adequate. It is also pertinent that the vitamin C content of even the same fruit or vegetable variety is subject to natural, storage and processing variations significantly greater than any radiation -induced change.

Macronutrients are not significantly affected at low doses and minerals and trace elements are not sensitive to irradiation. Vitamins, however, range from relatively high to low sensitivity to radiation with vitamin C, thiamine, vitamin E and Vitamin A being most sensitive.

The first steps taken to estimate the potential impact on dietary nutrient intake for Australia and New Zealand were to:

- Review the contribution of fresh produce to the intake of vitamins A, C, E and thiamine; and then to estimate -
- Total consumption (tonnes) of fresh fruits and vegetables sub-divided into major categories (Prowse 2019).
- The tonnes and percentage of total consumption that involved produce imported across a border and, therefore, potentially subject to a phytosanitary measure; the border could be national (for overseas imports) or, for Australia, an inter-state boundary (Prowse 2019).
- The percentage of the imports that is likely to switch from an existing treatment to irradiation (G. Robertson, Steritech, *private communication)*; this percentage was estimated conservatively (i.e., was likely to be an over-estimate) and used to

calculate the percentage of total consumption that might be irradiated. It was assumed that irradiation is fully available as one of several potential phytosanitary measures along with existing treatments such as cold, heat, fumigation and area-free freedom and systems approaches.

In summary, it was estimated that approximately 2% of the total vitamin C intake of New Zealanders might be subjected to phytosanitary irradiation and approximately 0.4%, 0.6% and 0.4 of the other three key micronutrients. On a national basis, approximately 1% of the total vitamin C intake of Australians might be irradiated and approximately 0.6%, 0.3% and 0.2 of the other three micronutrients. Tasmanians constitute a most-at-risk group because higher volumes of fruit are imported from other states than the national average. For Tasmanians, approximately 5% of total vitamin C intake might be irradiated. These percentages have been conservatively estimated and could possibly be significantly lower.

For an assessment of the extent to which the key micronutrients could be changed (decreased or increased) by phytosanitary doses, it was noted that a 2014 review by FSANZ (2014b) concluded that phytosanitary doses of irradiation:

- Have no effect on carotene levels in fruits and vegetables;
- Have little effect on non-vitamin bioactives;
- Do not decrease vitamin C levels in the majority of fruits and vegetables;
- For fruits and vegetables where a decrease in vitamin C is reported, the decrease is no greater than for other processing methods. Most importantly, vitamin C levels remain well within the range of concentrations that can result from natural variations, storage and processing.

On the basis of the available data and dietary modelling, FSANZ also concluded that

- Doses no greater than 1 kGy would not adversely affect dietary vitamin C and carotene intakes from all fruit.
- As a result of the more limited data available for fresh vegetables, particularly roots and tubers, leafy vegetables, brassicas and legumes, there remained some uncertainty about the effects of phytosanitary doses on fresh vegetables.
- Data would be required on vitamin E, thiamine and non-bioactives if present at high levels and making an important contribution to dietary intake.

This application presents further data from more recent literature, particularly for potential radiation-induced changes to vitamins A (carotenes), C, E and thiamine for leafy greens, brassicas and roots and tubers. Recent data for fruits, fruiting vegetables and cucurbits are briefly summarised. The recent data are consistent with the data reviewed by FSANZ and the related conclusions (FSANZ 2014b).

Overall the recent data reviewed in this application confirm the conclusions of the FSANZ review and suggest that the conclusions can be extended to all vegetables including leafy greens, brassicas and roots and tubers. Phytosanitary doses cause changes to the concentrations of radiation-sensitive micronutrients that are insignificant when compared with the changes due to natural variations, storage and other food processes. Specifically, any loss of total vitamin C activity will be much less than natural variations and will be negligible in practice.

In summary –

- Australians and New Zealanders generally have a nutritionally adequate diet;
- In the general population, the proportion of the intake of radiation-sensitive micronutrients derived from fresh fruits and vegetables that will be irradiated is less than 2% for vitamin C and less than 1% for vitamins A, E and thiamine;
- any radiation-induced effects on the micronutrients can be considered negligible.

We conclude that the risk of an adverse nutritional impact from approving phytosanitary irradiation for all fresh produce is of no practical concern.

Regulatory and legislative impacts

The internationally recognized standard-setting agencies for human and plant health are Codex Alimentarius and the International Plant Protection Commission (IPPC). The international regulatory and legislative standards and criteria related to irradiated food and phytosanitary measures have not changed recently (CAC 2003a,b; FAO IPPC 2003, 2007, 2009a,b,c).

National regulations on food irradiation have also remained largely unchanged with almost 60 countries approving irradiation of at least one food and application. However, far fewer are actually using food irradiation commercially (Roberts 2016). Of more interest to this Application is the significant number of countries that approve phytosanitary irradiation for all fruits and vegetables. This includes all the countries other than Australia and New Zealand that are trading in irradiated fresh produce, several other countries that could be future markets for irradiated Australian produce and several countries in South America and the EU.

Other implications

Environment

Greater use of irradiation as a phytosanitary measure will provide an alternative to MeBr fumigation which has detrimental effects on the ozone layer (UNEP 2019) and potentially on human health (USEPA 2019, MPI 2019). Irradiation is already reducing MeBr use for produce entering the USA. It has the potential to reduce MeBr use more widely (FAO IPPC 2008; UNEP 2016) and also to reduce use of post-harvest insecticides. In-depth environmental assessments of phytosanitary irradiation in the USA found irradiation would not have a significant impact on the quality of the human environment (USDA 1997, 2002).

There are strict guidelines and standards on the establishment and routine operation of irradiation facilities and on the transport and disposal of radioactive material. A second food irradiation facility being constructed in Melbourne is an X-ray facility that neither uses nor produces radioactive material. This is an example of a trend towards use of non-radioactive radiation sources.

The purpose of phytosanitary measures is to prevent the spread of plant pests which could have devastating impacts and severe consequences for industries, communities and the environment.

Consumers

Numerous surveys of consumer acceptance of irradiation have generally indicated consumer opposition or reluctance to purchase irradiated foods, including a 2002 study of New Zealand and Australia consumers (Gamble, Harker and Gunson 2002). Some of the studies, including the local study, suggest that consumers may be more concerned about chemical residues than irradiation. However, most surveys were conducted in situations when irradiated produce was not available for sale and there was no option to fully evaluate or purchase irradiated product. However, there is now significant experience of consumers having the option to purchase irradiated food. A review of actual purchase behaviour suggests that while a fraction of the public will not buy irradiated food, a much larger fraction will (Roberts and Henon 2015).

There has been no negative reaction to 15 years of irradiated mango sales in New Zealand. Retail sales of irradiated tomatoes have been far smaller but, apart from some negative comments from the domestic tomato industry and some members of the public prior to the commencement of such trade, there has been no adverse reaction since. The amount of irradiated produce available within Australia has been under 100 tonnes per year. There have been no protests or negative publicity regarding irradiated fruit on the Australian domestic market.

There is educational material to help consumers make better-informed choices regarding irradiated fruit and vegetables. The mandatory labelling of irradiated fruit and vegetables provides consumers with choice when it comes to purchasing or not purchasing irradiated fruit and vegetables.

PART 1 - GENERAL INFORMATION

1.1. Applicant

(a) Name of Queensland Department of Agriculture and Fisheries

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(c) Contact: [redacted]

(d) Nature of Applicant's Business:

Queensland Department of Agriculture and Fisheries (QLD DAF).

DAF's focus is on areas of policy development, leading-edge science, biosecurity, fisheries and forestry management, trade and export.

The Agriculture Business Group focuses on lifting the productivity of Queensland's food and fibre businesses. We work with producers, other members of agribusiness supply chains, peak industry bodies, Research Development Corporations, natural resource management groups, the private sector and all levels of government to:

- Secure the future of the agricultural industry through planning and supporting regional opportunities to create long term jobs
- Undertake research development and extension and deliver services that enable producers and other agribusinesses to build capacity, improve productivity growth, adopt new technologies and practices, manage risks and increase sustainability and resilience.

(e) Other companies associated with application:

Hort Innovation

Steritech (Pty)

1.2. Nature of application

This application seeks a variation to the Food Standards Code, Standard 1.5.3 Irradiation of Food (FSANZ 2017). The variation requested is to replace the list of 26 fruits and vegetables in the table in Division 2, section 1.5.3-3, sub-section 2, with "fresh fruits and vegetables". Included in the scope of the application are all those fresh fruits and vegetables presently described within Schedule 22 of the Food Standards Code plus any other fresh commodity generally understood to be a fruit or vegetable, including crops grown overseas. Excluded from the application are dried pulses, legumes, nuts and seeds.

The purpose of irradiation will be for a phytosanitary objective.

The minimum dose requested for phytosanitary purposes is 150 gray (Gy) and the maximum is 1000 Gy (1 kGy). These doses are those approved for quarantine purposes of other fruits and vegetables in the Code. No other variation to Standard 1.5.3 is sought.

1.3. Support for the application

Letters of support (Annex) from Australia and New Zealand:

- Australian Department of Agriculture
- Steritech Pty Ltd
- AUSVEG
- Citrus Australia
- Australian Horticulture Exporters' and Importers' Association Ltd
- New Zealand Fresh Produce Importers Association, Inc.
- 2PH Farms

1.4. Other information

Mandatory requirements and information on labelling, irradiation facilities, dosimetry and record keeping, packaging and methods of verification in Australia and New Zealand have not significantly changed since the previous applications and are not included. Data on nutritional studies by the Queensland DAF – A1038 Irradiation of Persimmon, A1069 Irradiation of Tomatoes & Capsicums, and A1092 Irradiation of Specific Fruits and Vegetables and the New South Wales application A1115 Irradiation of Blueberries and Raspberries, are referred to in this Application. Risk assessments for these applications (FSANZ 2002, 2011, 2013a, 2014a, 2016) and a nutrition review conducted by FSANZ (2014b) are also referenced.

PART 2 - SPECIFIC INFORMATION

2.1. **Details of application**

This application seeks a variation to the Food Standards Code, Standard 1.5.3 Irradiation of Food (FSANZ 2017). The variation requested is to replace the list of 26 fruits and vegetables in the table in Division 2, section 1.5.3-3, sub-section 2, with “fresh fruits and vegetables”. Included in the scope of the application are all those fresh fruits and vegetables presently described within Schedule 22 of the Food Standards Code plus any other fresh commodity generally understood to be a fruit or vegetable, including crops grown overseas. Excluded from the application are dried pulses, legumes, nuts and seeds.

Under the proposed amendment the purpose of the irradiation of fruits and vegetables and the minimum and maximum absorbed doses will remain the same (Division 2, section 1.5.3-3, sub-section 1). That is, the purpose is pest disinfestation for a phytosanitary objective and the minimum and maximum absorbed doses are 150 Gy and 1 kGy, respectively.

The purpose of the amendment (Part 2.2) is to extend the option of phytosanitary irradiation to all types of fresh fruits and vegetables as defined above. A phytosanitary measure is required whenever commodities are subject to a mandatory treatment to ensure freedom from regulated pests. This requirement can apply whenever fresh produce are exported to another Australian state, territory or region or to another country that is free of the pest. It also applies to imports into Australia and New Zealand.

The requested amendment would provide the horticulture industry with a phytosanitary option that is justified due to a technical need to provide a superior quarantine treatment better suited to the present trading environment (Part 2.3) which results in nutritionally adequate food that is toxicologically safe (Part 3).

2.2. **Purpose of the application**

Throughout the document, terms such as all fresh produce/commodities or all fruits and vegetables shall be understood to have the meaning as defined in section 2.1 The existing Standard 1.5.3 approves irradiation for a phytosanitary purpose for 26 fruits or vegetables. Approval of the requested amendment to extend the option of phytosanitary irradiation to all fresh fruits and vegetables will not mean that all fresh produce consumed will or even might be irradiated (Part 3.1). Only a small fraction is likely to be irradiated. Fresh produce consumed within a region that has no concerns about possible pests in the production area does not require a phytosanitary treatment. Existing pre- and post-harvest options for phytosanitary treatments will remain and irradiation will be just one of several phytosanitary options.

If approved, the amendment will recognize irradiation as a safe phytosanitary treatment for all fresh produce. This will remove a barrier to irradiation being considered equally alongside competing treatments by industry and government biosecurity agencies, with the choice being dictated by efficacy, quality retention and cost. Approval will encourage the optimum treatment for a specific commodity or situation to be used.

Previous applications for specified fresh produce (A1038, A1069, A 1092 and A1115) have stressed the advantages of improved market access for Australian exporters. This application seeks to further increase these market opportunities. It will also provide new opportunities for Australian and New Zealand consumers to purchase fruits from other countries that are not available, or rarely available, locally.

However, since those applications, the international trading environment in irradiated fresh fruits and vegetables has evolved significantly. The wider advantages of extending the phytosanitary irradiation option to all produce include:

- Ensuring the most appropriate treatment is used for a given host-pest problem;
- Encouraging the replacement of treatments that are now regarded as damaging to the environment, health and/or product quality;
- Harmonising regulations with trading partners and potential trading partners;
- Facilitating trade negotiations through an ability to enter reciprocal trading arrangements;
- Ensuring timely responses to new opportunities, threats and emergency situations.

These advantages of the proposed amendment are explored in the next section.

2.3. Justification for the application

The need for phytosanitary treatments

Phytosanitary measures against regulated pests are an essential part of trade in fresh fruits and vegetables. Countries, states and regions mandate such treatments to ensure that pests that are absent from their territory are not brought in on imported commodities. Establishment of a new pest can threaten the agricultural economy of the importing country or state. Phytosanitary measures are therefore used to protect the horticultural sectors of both Australia and New Zealand. Horticulture is the third largest agricultural sector in Australia. In 2017-18, total fruit and nuts (excluding grapes) were worth A$4,568 mil, grapes were worth A$1,397 mil and vegetables were valued at A$4,096 mil (ABS 2019). For New Zealand, in 2016-17 the total value of horticulture products was NZ$8.8 bil (Hort NZ 2017).

Similarly, horticultural exports from Australia and New Zealand may be subject to pre-shipment phytosanitary treatments. New Zealand export receipts from fresh fruits and vegetables in 2017-18 totalled NZ$5.5 bil (Hort NZ 2018). Australia exports more than 90 fresh fruit and vegetable products to more than 60 countries. In 2017-18 Australian growers exported fresh fruits and vegetables valued at A$1.1 bil (Hort Innov 2019a,b,c). Queensland, Victoria and NSW, which lie within the Queensland fruit fly zone for Australia, are the major production areas for fruit and vegetables in Australia. Queensland alone accounts for > 30% of the nation’s total fruits, nuts and vegetables (excl. grapes).

The majority of fresh fruit and vegetables that are consumed in Australia and New Zealand are not subject to any phytosanitary measures as they are produced and consumed regionally. That is, they are consumed in a region that has no concerns about pests in the production area.

Phytosanitary options

There is a range of treatments that may be used as phytosanitary measures. The options can be based on methods that are physical or chemical treatments or, in limited cases, a production-based systems approach including in-field insecticides, non-host status or area freedom. Irradiation is the most recently established option. Each has different advantages and disadvantages as discussed fully in Appendix 1. The effectiveness of irradiation as a phytosanitary measure and the tolerance of fruits and vegetables to low dose irradiation have been fully discussed in previous successful applications to modify Standard 1.5.3 (A1038, A1069, A1092 and A1115**)**. Briefly, the key advantages of irradiation are that –

- It is subject to internationally recognized protocols (FAO IPPC 2003) and trade in irradiated products is conducted under agreements between national plant protection authorities such as the Australian Department of Agriculture - and the New Zealand Ministry of Primary Industries.
- Irradiation is unique among phytosanitary treatments as a broad-spectrum treatment for almost all important regulated arthropod pests (Follett and Neven 2006). A minimum dose of 150 Gy is internationally recognized as a generic treatment for all Tephritid fruit flies in all host fruits and vegetables *(*FAO IPPC 2009c). Australian states and territories and the USA recognise 400 Gy as a generic treatment of all insects except the adult *Lepidoptera* that pupate internally in all host fruits and vegetables (USDA 2006; ICA 2011).
- It is also unique in that research on host produce that have not been previously investigated is no longer required to prove effectiveness against fruit flies and most insects. Conventional alternatives can still require lengthy and costly research to establish accepted conditions for treatment.
- Irradiation is a chemical-free treatment. This results in no harmful treatment residues on the produce and no release of any chemicals that may be harmful to the environment, including the ozone layer, or human health.
- Practical advantages of the treatment process are that it is simple to apply and is -
    - applied at the optimum storage temperature of the produce and the temperature of the produce is not raised or lowered.
    - essentially independent of the ambient conditions of temperature, pressure and relative humidity
    - a penetrating treatment making it relatively independent of commodity shape and size that can be applied when the commodity is in its final packaging, such as in boxes or on pallets, with no 'dead' spots.
    - a rapid treatment with the product available for onward shipment immediately afterwards.
    - well tolerated by the majority of fruits and vegetables provided proper harvesting and post-harvest handling procedures are followed.

Expanding exports of Australian irradiated fresh produce

The first commercial consignments of irradiated fruit treatments were sent in 1995 with exports from Hawaii to mainland United States (Follett and Griffin 2013). However, Australia and New Zealand initiated the first truly international consignments of irradiated produce in December 2004 when 19 tonnes of mango were exported from Australia to New Zealand. Since then export volumes (Table 1 for recent years) have expanded significantly as have overseas approvals (Table 2) for Australian irradiated products.

Table 1: Export of irradiated produce from Australia (tonnes).

Season	2015-16	2016-17	2017-18	2018-19
Fruit (Country)				
Mangoes (NZ)	1024	982	1297	1357
Mangoes (US)	179	141	107	114
Mangoes (Malaysia)	79	21	14	15
Tomatoes (NZ)	349	134	269	517
Capsicums (NZ)	9	0	9	0
Lychees (NZ)	64	72	216	459
Lychees (USA)		6	12	16
Papaya (NZ)	104	0	22	57
Plums (Indonesia)	4	0	0	0
Table Grapes (Vietnam)	843	1121	1747	2105
Table Grapes (Indonesia)				
Cherries (Indonesia)	2	6	0	16
Mandarins (Vietnam)	67	40	55	103
Oranges (Vietnam)	2	14	54	14
Cherries (Vietnam)			402	609
TOTALS	**2726**	**2537**	**4204**	**5306**

Source: G. Robertson, Steritech Pty, QLD, private communication

Table 2: Countries granting permission to import irradiated Australian commodities.

Importing country	*Fruits*
Cook Island	*Capsicum*
Indonesia	*Mango, lychee, tomato, plum, table grape, cherry, mandarin, Oranges, persimmon, grapefruit, lemon, lime, tangerine, zucchini, scallopini, pumpkins, pear, peach, nectarine, custard apple, melon, apricot, pomegranate, garlic, onion, avocado, cucumber and apple*
Malaysia	*Mango*
New Zealand	*Mango, lychee, papaya, tomato, capsicum*
Thailand	*Persimmon*
United States	*Mango and lychee*
Vietnam	*Table grape, cherry, mandarin, oranges*

Source: DA (2019a) MICOR Accessed October 2019 at
https://micor.agriculture.gov.au/Plants/Pages/SearchResults.aspx?k=irradiation

Steritech (Pty) operates the only plant that can conduct food irradiation in Australia. Based near Brisbane, it has irradiated mainly tropical fruits grown in Queensland for export. A second Steritech facility capable of irradiating food will become operational in the Melbourne area at the end of 2019. This will be available to treat fresh produce grown in Victoria, South Australia and southern New South Wales. New Zealand does not have a food irradiation facility and is unlikely to establish one in the medium term.

The volume of irradiated crops exported is anticipated to increase to the countries to which they are presently exported and access to new markets for more commodities will become available. Commodities that do not tolerate heat, fumigation or prolonged cold storage treatments well are obvious possibilities. The second irradiation facility near Melbourne will contribute to this expansion. Irradiated exports do not require FSANZ approval, but such an approval will assist expand this trade, as discussed below.

Expanding global trade in irradiated fresh produce

Since 2007, other countries have exported/imported irradiated fresh produce and at least 15 countries now participate in such trade. In 2017, the USA imported almost 30,000 tonnes of irradiated produce from 10 countries (USDA 2018). In addition, over 5,000 tonnes of Hawaiian produce was irradiated and shipped to the continental USA (USDA 2018). Significant but undocumented growth has occurred since with China establishing a dedicated facility for phytosanitary irradiation near the China-Vietnam border for commodities moving across the border**.** The annual amount of irradiated fresh produce moving across regulated borders is over 40,000 tonnes.

The USA is the main importer of irradiated fresh fruits and vegetables while China, New Zealand, Malaysia and Indonesia also import but do not currently export. Mexico, Vietnam and Australia are the main exporters. Other exporters are Domenica, Grenada, India, Thailand, Pakistan, Peru and South Africa. Irradiated commodities that are traded now include those listed in Table 1, plus large volumes of guava, dragon fruit (pitaya), longan, sweet potato and smaller amounts of at least 14 other items (UDSA 2018).

Five countries have negotiated access to Australia for irradiated fruits. Vietnam (mango, litchi) and India (mango) have begun exporting irradiated fruit to Australia (DA 2019b)**.** If Standard 1.5.3 is amended to include all fresh produce, the ability of Australian and New Zealand consumers to try, consume and benefit from overseas fruits will be increased.

Evolving trade environment for irradiated fresh produce

Significance of a generic approval of fresh produce

Irradiation is now established as a viable and valuable phytosanitary treatment. As a result, there has been an evolution in phytosanitary practice and the place of irradiation in international trade. In addition to increased opportunities for market access both from and to Australia, generic approval of phytosanitary irradiation will have other advantages,

Choice of most appropriate treatment

Irradiation is the only phytosanitary treatment that requires a variation to a food standard before it can be considered by biosecurity authorities. This is a barrier to uptake by the horticulture industry as a result of the time and cost involved and the perception that irradiation must, therefore, be uniquely hazardous and difficult. Approval of this application would ensure that the choice of a phytosanitary treatment would be governed solely by which option is optimal, based on effectiveness, quality retention and cost.

The barrier has resulted in irradiation being under-utilised as a treatment and, consequently, a reduction in trade opportunities despite irradiation's advantages. Other postharvest options for example, heat treatments, cold disinfestation and fumigants, are available for some crops but are not suited for use on a broad range of crops due to possible phytotoxicity and quality issues, length of treatment time, costs or the time frame needed to gain approval from quarantine authorities. Systems approaches and non-host status are available for some crops on the domestic market but many of Australia's trading partners do not approve these treatment options. Hallman (2011) and Hallman and Blackburn (2016) have noted that irradiation is usually less phytotoxic than treatments using methyl bromide, heat or long-term cold storage.

Reducing environmental and health hazards

Methyl bromide (MeBr) is an accepted phytosanitary treatment of fresh produce in Australia (ICA 2019, see ICA 04) and many other countries. It is used as an emergency option for treating imports that may otherwise be non-compliant with Biosecurity Australia requirements. MeBr is known to deplete the ozone layer (UNEP 2019). Quarantine and pre-shipment (QPS) use has a critical use exemption under the Montreal Protocol but strategies are in place to minimise and eventually phase out such uses through adopting alternative treatments (FAO-IPPC 2008, UNEP 2016). A major reason for the expansion of trade in irradiated produce has been the encouragement by the USA of irradiation as a MeBr replacement option and its acceptance of irradiated produce from several developing countries (Roberts and Follett 2018, USDA 2018).

MeBr is also a human health hazard (USEPA 2019, MPI 2019a) and worker poisonings have been reported (NZ Herald 2018). MeBr emissions recapture or destruction will be compulsory in New Zealand from October 2020 (MPI 2018) and there are stringent limits for Tolerable Exposure Limits in the vicinity of MeBr treatments which will add significant costs and may be difficult to achieve (Armstrong 2019). Similar legislation is also being reviewed by the Environment Protection Authority in Victoria and a decision is expected in mid-2020 (EPA 2019).

There is also continuing consumer concern about foods that contain chemical contaminants and pesticide residues (Baker and Crosbie 1993, Baker 1999, Gamble, Harker and Gunson 2002, Koch *et al* 2017).

Harmonisation of regulations and reciprocal trade arrangements

The International Plant Protection Convention is the recognised agency for establishing global practice in phytosanitary measures (IPPC 2019a) through its International Standards for Phytosanitary Measures (IPPC 2019b) or ISPMs. Harmonisation of phytosanitary irradiation treatments for regulated pests through ISPM 18 and ISPM 28 (FAO IPPC 2003, 2007) support efficient and effective phytosanitary measures and encourage the mutual recognition of treatment efficacy and treatment delivery, which would facilitate domestic and international trade. ISPM 28 Appendix 7 recognises 150 Gy as the dose to guarantee sterility of all fruit flies in all hosts (FAO IPPC 2009c). These measures apply to all fresh fruits and vegetables and Australian states have agreed to take the same approach via ICA 55 (ICA 2011).

In future, a dose of 400 Gy is expected to become the recognised world standard for phytosanitary treatment of all insects in all host fruits and vegetables except pupae and adult *Lepidoptera*. It is already recognised as such by the USA and by Australian states and territories (USDA 2006, ICA 2011).

There is a regional Asia Pacific Plant Protection Commission (APPPC) that develops regional standards for phytosanitary measures (RSPMs) including RSPM No 9 for the approval of irradiation facilities (APPPC 2014). There is an internationally-agreed Manual on Good Practice in Food Irradiation, including phytosanitary applications, based on the Codex Code of Practice (IAEA 2015).

Approval for all fruits and vegetables to have the option of phytosanitary irradiation will also harmonise Australian legislation with the Codex Recommended General Standard for Irradiated Food (CAC 2003a) which deals with irradiation as any other food process that is safe and nutritionally adequate for any food. Vas (1978), a member of JECFI and of an Advisory Group assisting Codex has stated “The advisory group thought that legal control should not be based upon prohibition of the process of food irradiation with permitted exceptions, but rather upon acceptance of the principle of the process of food irradiation provided that regulations define the limitations or conditions for each food type”.

Alignment with Codex recommendations would also be consistent with the principles of the World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) to which Australia and New Zealand are signatories (WTO 2011). The SPS Agreement allows countries to set their own standards but all phytosanitary measures should be the least restrictive to trade possible and be based on sound scientific principles.

With the exception of Australia and New Zealand, all the countries that are presently trading in irradiated fruits and vegetables, plus several countries that are likely target markets for irradiated Australian exports approve phytosanitary irradiation for all fruits and vegetables (see Table 3).

Several other countries also approve of phytosanitary irradiation for all fresh produce. Four countries, Brazil, Singapore, Cuba and Mexico (the latter is listed in Table 3) implement the Codex Standard, permitting any food including any fruit or vegetable to be irradiated up to a maximum of 10 kGy (GHI 2018). Practical limits are then advised when a particular use is commenced. Three EU countries, Belgium, Czech Republic and the U.K. maintain approvals for phytosanitary treatment of all fruits and vegetables as specified national exemptions to the general EU regulation on food irradiation (EU 2009a). Several other countries approved phytosanitary irradiation for fruits and vegetables as a class more than 20 years ago but they are not thought to be seriously considering phytosanitary treatments at present. These countries include Algeria, Croatia, Ghana, Israel, Paraguay, Saudi Arabia, Syria, Turkey, and Zambia (C. Blackburn, FAO/IAEA Joint Division, personal communication).

Further background to the approvals of fruits and vegetables in other countries is provided in Part 4.

Table 3: Countries that approve irradiation phytosanitary treatments for fresh fruits and vegetables as a class and which trade in irradiated produce and/or are likely target markets for Australian produce.

Countries	References
China	GHI (2018); ANT (2018)
India	GHI (2018); GAZ (2012)
Indonesia	GHI (2018)
Malaysia	GHI (2018)
Mexico	GHI (2018)
Pakistan	GHI (2018)
Philippines	GHI (2018); PNS (2015)
South Africa	DOH (2013)
Thailand	GHI (2018)
U.S.A.	FDA (2019)
Vietnam	GHI (2018)

The USA only initiates negotiations to permit access to irradiated commodities if the exporting country indicates willingness to agree to a reciprocal agreement to accept irradiated commodities from the USA. This requirement is not usually enforced but is a specific example of how access to a market may be expedited if the importing country knows that a reciprocal approval for its commodities is possible.

At present, Australia is expanding exports of irradiated fruit to several Asian countries, such as Vietnam, Indonesia and Malaysia, plus the USA. However, some economically important fruits grown in such countries cannot be irradiated and imported into Australia as they are not already FSANZ approved. Dragon fruit, star apple, and pomegranate are examples of fruits exported by Asian countries to the USA (USDA 2018) but which cannot presently be exported to Australia or New Zealand. Salaka (Indonesia), dragon fruit (Vietnam) and several other fruits are commodities of potential export importance to Asian neighbours. As they are not grown significantly in Australia, local industry is unlikely to lodge an amendment application.

In addition, overseas markets may question why Australian industry seeks to export produce to their country when that product is not approved (i.e., considered safe) within Australia.

Timely reaction to opportunities, threats and emergency requirements

Between 2005 and 2009, Australia exported approximately 3,000 tonnes per year of tomatoes worth A$6 million to New Zealand during winter (TNZ 2018). Export volumes then dropped dramatically as restrictions on the use of the insecticides dimethoate and fenthion were considered, then subject to temporary suspensions and finally implemented (APVMA 2014, 2015, 2017). Effectively, from 2011 Australian growers could not ship insecticide treated tomatoes to New Zealand until irradiation was approved as a treatment, first by FSANZ and subsequently by the NZ Ministry of Primary Industries. In the interim New Zealand growers made a concerted effort to replace Australian tomatoes with local production. In the 5 seasons since irradiated tomatoes became available, exports to New

Zealand have fluctuated between 134 and 517 tonnes (Table 1). In the absence of a readily available irradiation option, tomato exports to New Zealand were completely lost and have only recovered to about 10% of previous peak levels.

Irradiation of Australian table grapes was identified as a useful phytosanitary option to replace long term cold storage in 2012. Irradiated table grapes can be on market shelves within days of harvest and are of higher quality than cold treated product which only reach the market after about 3 weeks and close to the end of their shelf-life. Approval to irradiate table grapes became effective in 2015 and irradiated product was exported to Indonesia and Vietnam within a year (Table 1). However, for the New Zealand market, which is ideally suited to benefit from irradiated grapes being on the shelves shortly after harvest, the process of gaining MPI approval could only begin in 2015, and was only completed in 2019.

A recent example of improved market access using irradiation is the export of Australian mango and lychee (litchi) to the United States which was approved in 2015 (USDA 2019). During a decade of negotiations to access this market, alternative treatments such as vapour heat treatment (Gaffney *et al.* 1990) were not permitted due to the presence of pests other than fruit fly (mango seed weevil and various other species.

As experience is gained with optimising irradiation and supply chain logistics for fresh produce it is becoming clear that more fruits and vegetables can tolerate phytosanitary doses than was thought likely a few years ago (Kader 1986, Morris and Jessup 1994). When a recent application for approval of phytosanitary irradiation was lodged for 11 specified fruits (A1092), citrus was not on the list. When work on the application began, citrus fruits were thought to be too intolerant of irradiation for consideration. More recently, many citrus varieties have been shown to withstand phytosanitary doses. Mandarins are good candidates for irradiation since they do not withstand cold storage treatment well. Small volumes of mandarins and oranges (Table 1) have been exported to Vietnam since the 2015-16 season but sale of irradiated citrus is not still permitted in Australia under Standard 1.5.3. Export volumes are likely to remain low while Asian markets await FSANZ approval of citrus and a reciprocal opportunity to export some of their important produce to Australia and New Zealand.

These examples are indications of how the requirement to apply for a variation to Standard 1.5.3 can lose market opportunities and export receipts. An ability to implement irradiation as a phytosanitary measure promptly is likely to become more pressing as the impact of climate change on horticulture is felt. Changing conditions in growing areas will mean the host-pest-environment dynamic will change with consequent greater challenges to global biosecurity.

Irradiation may also be an improved option for on-arrival treatments, for example for produce from the Pacific Islands that is treated with MeBr with no alternative treatment available in the Islands.

Irradiation can be a better candidate than presently used methods for temporary emergency use when a pest incursion is suspected. Temporary phytosanitary measures are imposed on in-bound shipments if the presence of a regulated pest is detected or believed likely. Such emergency treatments are imposed regardless of the prior treatments that the shipment may have received.

Protocols and pathways have been established to eliminate any risk of pest escape while the shipment is moved to or within the emergency treatment zone or facility. MeBr is the most likely option to be imposed at present as it simple and relatively quick, but other measures such as extending a cold storage period can be used. Given its recognised broad-spectrum effectiveness against insect pests, irradiation could be an ideal emergency measure.

By their very nature emergency measures must be implemented immediately. The lack of approval for many potential imports means the adoption of irradiation as an emergency measure or on-arrival treatment is not possible.

Other

A generic approval for phytosanitary irradiation of all fruits and vegetables will not mean the unjustified use of irradiation for any commodity. Standard 1.5.3 requires irradiation of fruits and vegetables to be for a phytosanitary purpose. All phytosanitary treatments are authorised under established protocols between agencies responsible for the protection of plant heath in the exporting and importing states or countries. The full range of existing measures for phytosanitary treatment will still be available and in many cases will remain the best option (see Part 3.1). However, it is expected that the availability of irradiation will reduce the use of post-harvest treatments such as MeBr and insecticides.

For commodities being sold in markets with no phytosanitary restrictions, the use of irradiation would not be required or permitted. Irradiation adds a small processing cost for growers, requires labelling of product and adds extra time and handling within the supply chain. Irradiation also requires the involvement of a contract irradiator outside the horticulture industry. There is no incentive for the industry to use irradiation unnecessarily.

Given the complexities of international trade in fresh produce and predicting future changes, and given the probability that more crops will be found suitable for irradiation as experience is gained with phytosanitary irradiation, this application does not attempt to 'cherry-pick' which crops not presently permitted under Standard 1.5.3. might be treated in future. Rather the variation sought is to expand the crops that can be treated for a phytosanitary purpose to all fresh fruits and vegetables.

2.4. Costs and benefits

To industry and government

The costs and benefits of phytosanitary irradiation remain essentially as described in earlier submissions (A1038, A1069, A 1092 and A1115) plus the added benefits that having a generic rather than limited approval will have.

Recent overall values of the fresh fruit and vegetable sectors (production value and export receipts) for Australia and New Zealand in 2017 were provided in Part 2.3. Appendix 2 provides further detail for Australia based on 2015-16 data by commodity and state.

Endpoint treatments are required for most imports to prevent regulated pests arriving in Australia and New Zealand and damaging the local production base that supplies the majority of domestic consumption. Table 4 shows the volume of production, exports and imports and the common endpoint treatments used for particular fruit and vegetables. In Australia 95% of the kiwifruit consumed, and > 20% of table grapes, cherries and avocados were imported, and these were cold disinfested, fumigated or produced in areas that are fruit fly free. Fifty percent of imported asparagus was methyl bromide fumigated. Overall, Australia imports only 5% of fruits and 1% of vegetables consumed (Prowse 2019).

New Zealand imports few vegetables and 46% of the fruit consumed domestically (Prowse 2019). Importation occurs when there is limited or no local availability and cold disinfestation is the main endpoint treatment utilised. Fumigation, conditional non-host status or insecticide treatment are other treatment options depending on the fruit or vegetable. For many tropical products or industries that want to use air freight, fumigation or irradiation are the preferred end point treatments. Irradiated mangoes have been imported into New Zealand for many years and, more recently, a small percentage of tomatoes imported in the winter season are irradiated (Table 1).

Horticultural exporters remain highly dependent upon pre-shipment treatments or they face the highly uncertain prospect of having the importing country delay or further treat their products both of which can adversely affect fruit quality.

Table 4: Production, imports and exports of fruit and vegetables in Australia, 2017.

Product	Production (t)	Exports (t)	Imports (t)	% of Consumption Imported	Treatment
Apple*	313,730	4,834	1,227	0.40	
Table grapes*	164,271	111,496	15,265	22.43	Cold disinfestation / Fumigation
Pear	96,741	9,583	1,980	2.22	
Peach*	47,817	3,902	0	0	
Strawberry*	45,251	4,502	0	0	
Nectarine*	34,842	5,314	2,190	6.90	
Plums*	17,992	4,824	434	3.19	
Cherry*	11,532	3,428	2,506	23.62	Fumigated
Blueberry*	6,810	238	1,241	15.88	Fumigated
Apricot*	5,351	500	803	14.20	Fumigated
Banana	412,972	142	166	0.04	
Orange	332,321	197,448	20,435	13.16	Cold Disinfestation
Melon*	263,528	21,669	0	0	
Mandarin	127,267	71,214	4,337	7.18	
Pineapple	85,922	30	147	0.17	
Avocado	56,501	1,750	16,407	23.06	Cold Disinfestation
Mango*	43,748	8,554	1,035	2.86	
Lemon	37,490	3,061	5,597	13.98	Cold Disinfestation / Fumigation
Lime	9,297	58	0	0	
Grapefruit	8,192	1,369	1,231	15.28	Cold Disinfestation /
Kiwifruit	2,082	1,020	20,234	95.01	Pest free condition / Cold Disinfestation / Fumigation
Total	**2,123,658**	**454,935**	**95,235**	**5.4**	
Asparagus	8,034	3,838	4,184	49.93	Fumigated
Tomato*	371,578	694	1,234	0.33	
Lettuce	146,262	1,685	4	0	
Cabbage	99,102	2,345	2	0	

Cauliflower	72,505	0	0	0
Broccoli	68,152	6,380	0	0
Bean (fresh)	41,373	2,347	734	1.85
Capsicum*	38,579	337	1,334	3.37
Pea	20,574	346	824	3.91
Brussels sprouts	6,193	260	0	0
Potato	1,105,194	44,431	1	0
Carrot	283,816	105,601	5	0
Onion	263,236	27,777	17,906	7.07
Sweet Corn	102,665	0	0	0
Pumpkin	101,504	2,045	0	0
Total	**2,720,733**	**194,248**	**22,044**	**0.86**

Source: ABS 71210 Agricultural Commodities 2016/17; Fresh Intelligence Analysis
End Point Treatment Source: DA (2019a,b)
* FSANZ approved for irradiation

Quarantine (biosecurity) requirements can change rapidly and unexpectedly. Even within Australia there has been a recent change. In July 2013 the Victorian Government revoked the Queensland fruit fly area freedom status for Victoria except in the Greater Sunraysia Pest Free Area (currently suspended but still supported legislatively). This spread of Queensland fruit fly into Victoria has had major implications of growers in the state and the Victorian Government has funded various programs to educate industry and communities on how to control fruit flies. However, the fact that Victoria is no longer free from Queensland fly means that that producers in the Northern Territory, Queensland and New South Wales can access the Melbourne market without the need to treat for fruit fly. The serious downside to the spread of Queensland fruit fly is that growers in Victoria (including the Greater Sunraysia Pest free Area) now need to treat produce to access domestic (Tasmania, South Australia and Western Australia) and international markets.

There are costs to providing irradiation treatments including not only the processing costs but transport to a specialised facility, packaging and labelling. The present average cost of treatment at the Steritech facility of $170 per tonne or $0.17c per kg (private communication) will not add significantly to the cost of high value fruits and vegetables. The cost of irradiation treatment is comparable to alternative post-harvest physical and fumigation treatments and cheaper than vapour heat treatments (Loaharanu 2003, Hallman 2011). Additionally, it is expected that MeBr treatment costs will rise as MeBr reduction or recapture technologies are required.

Cost considerations regarding capital investment, an inability to feasibly locate a treatment facility within packing facilities, and remaining concerns about the process by key decision makers, packers, shippers, and retailers remain challenges. However, overall cost considerations are far less significant to industry than the costs associated with potential loss or gain of market access. The generic dose of 150 Gy for all fruit flies in all host produce is a considerable advantage in reacting quickly to changing quarantine restrictions.

A report by NZIER (2007) on the benefits of fresh fruit and vegetables imported into New Zealand showed gains between 5% and 15% in allocative and dynamic efficiency gains, with 0.5–1.5% productive efficiency gains. NZIER concluded that welfare gains were between NZ$19.4–$58.2 mil. The costs from imported fresh fruit and vegetables included perceived biosecurity threats associated with potential entry and establishment of pests and the competitive threat the imports pose to locally grown produce.

The estimates for the percentage of fresh fruits and vegetables that may be irradiated if phytosanitary irradiation is permitted for all fresh produce (see Part 3.1) suggest that the effect on the overall volumes and types of fresh produce consumed will not be large. This is because the majority of fresh produce is consumed within the production region and not subject to a phytosanitary treatment, and alternative treatment methods will still be available. There will be a benefit from new fruits from overseas that are not presently available entering the local markets.

Several government agencies in Australia and New Zealand are responsible for the protection of the valuable domestic horticulture industry and the expansion of trade in exports. Table 5 provides a summary of the benefits of a generic approval for fresh fruits and vegetables to the governments of Australia, its states and territories, and New Zealand as well as to the horticulture industry.

Table 5: Summary of benefits to government and industry

Australia & New Zealand governments	Australian state and territory governments	Horticultural growers and associated industries
Harmonised trade regulations in compliance with international recommendations	Improved and streamlined state quarantine and trade regulations	Maintained and increased market access
Reduced management costs	Reduced risk of non-endemic pests	Increased international trade
Growth in export receipts	Maintained healthy regional communities	Increased inter-state trade
Better protected local horticulture industry		Improved on-farm profitability
Better food security		Simplified regulatory environment, quicker and cheaper
Reduced environmental impacts		
Improved regional economies and communities		

To consumers

Phytosanitary measures ensure that consumers are able to access their favourite nutritious foods and guard against seasonal shortages and price rises. Irradiation is an effective, safe and cost-effective measure (see Parts 2 and 3). If industry is able to use irradiation as a phytosanitary option, industry will choose the one that best suits the quality of the treated commodity at the optimum cost, benefits that will flow through to the consumer. If phytosanitary irradiation is permitted for all fruits and vegetables it will provide a further option to enable other countries to import their fresh produce to Australia and New Zealand. Local consumers will therefore be able to purchase fruits not presently available or to continue to purchase fruits out of season.

Consumers are concerned about any process that may reduce the vitamin content of their food. Part 3 demonstrates that irradiation up to a maximum of 1 kGy will have minimal or no impact in the dietary intake of micronutrients. Consumers are also becoming more concerned about exposure to chemical residues from food processes (Koch *et* al 2017) and there are reports that they may be more concerned about such residues than irradiation though their willingness to pay for more residue-free food varies (Baker and Crosbie 1993, Baker 1999, Gamble, Harker and Gunson 2002**)**.

Globally the amount of irradiated food offered to consumers remains limited at perhaps 1 million tonnes per year (Roberts and Follett 2018). Trade in irradiated fresh produce is growing rapidly since 2010 and now totals over 40,000 tonnes per year (Table 1 and USDA 2018). Consumer acceptance of irradiated food generally will be discussed in Part 5.4 but it is clear that irradiated fruits and vegetables are being purchased and consumed.

Consumers have the right to reject irradiated foods and to avoid consuming them. The mandatory labelling requirements for irradiated produce allows consumers to make informed choices.

PART 3 - PART 3 – SAFETY CONSIDERATIONS

3.1. **Nutritional data**

An assessment on the likely dietary impact on Australian and New Zealand consumers of approving phytosanitary irradiation of all fruits and vegetables requires the following steps; an assessment of –

- The sensitivity of nutrients to phytosanitary irradiation and especially identification of the micronutrients most susceptible to low dose irradiation.
- The contribution of fresh fruits and vegetables to the intake of radiation-sensitive nutrients including which specific commodity types are responsible for the majority of that intake.
- The percentage of fruits and vegetables consumed that could potentially be irradiated if irradiation was a phytosanitary treatment option alongside existing treatments for all fresh produce.
- Consideration of any most-at-risk groups.
- Possible changes to the concentration of key micronutrients in fresh produce treated with doses below 1 kGy.
- Combination of the data into an assessment of dietary impact.

Part 3.1 demonstrates that irradiated fresh produce will remain a minor part of the overall diet, that the percentage of key micronutrients derived from fresh produce that will be irradiated will be very low and that phytosanitary doses do not have significant adverse effects on these key micronutrients. The risk of an adverse nutritional impact on Australian and New Zealand consumers from approving phytosanitary irradiation for all fresh produce is negligible.

A safety assessment of irradiated produce that may be exported is not required. However, for completeness, fruits and vegetables produced in Australia for export have been categorised into those that are probable, possible and unlikely candidates for irradiation as shown in Appendix 3, as well as an indication of irradiated fruits that could be imported.

Sensitivity of nutrients to phytosanitary irradiation

In agreement with earlier publications, FSANZ (2014b) concluded that macronutrients are not significantly affected at low doses and that minerals and trace elements are not sensitive to irradiation. Vitamins, however, range from relatively high to low sensitivity to irradiation (see Table 6).

Table 6: General sensitivities of key vitamins in foods.

High sensitivity	Medium sensitivity	Low sensitivity
Vitamin C*	β-carotene	Vitamin D
Vitamin B_1 (thiamine)*	Vitamin K (in meat)	Vitamin K (in vegetables)
Vitamin E (α-tocopherol)		Vitamin B_2 (riboflavin)*
Vitamin A (retinol)		Vitamin B_6 (pyridoxine)*
		Vitamin B_{12} (cobalamin)*
		Vitamin B_3 (niacin)*
		Vitamin B_9 (folate)*
		Pantothenic acid*
		Vitamin B_{10} (biotin)
		Choline

* Water-soluble vitamins, Fat-soluble vitamin. Updated from Kilcast 1994 and Woodside 2015.

On the basis of these relative sensitivities and the contribution of fruits and vegetables to the overall dietary intake of vitamins, FSANZ concluded that nutritional safety assessments of phytosanitary irradiation should focus on changes to vitamin C, carotenes and non-vitamin bioactive compounds, such as polyphenols and the carotenoids without vitamin A activity.

On the basis of the available data and dietary modelling, FSANZ concluded that

- Doses no greater than 1 kGy would not adversely affect dietary vitamin C and carotene intakes from all fruit.
- As a result of the more limited data available for fresh vegetables, particularly roots and tuber, leafy vegetables, brassicas and legumes, there remained some uncertainty about the effects of phytosanitary doses on fresh vegetables.
- Data would be required on vitamin E, thiamine and non-vitamin bioactives if present at high levels and making an important contribution to dietary intake.

Based on the FSANZ (2014b) report and feedback from FSANZ staff during the application process, this application focuses on vitamins A (carotenes), C, E and thiamine as the key micronutrients for assessing the potential impact of phytosanitary irradiation of all fresh fruits and vegetables.

Micronutrient intake from fresh fruits and vegetables

The percent contribution of fresh fruits and vegetables to the intake of the key radiation sensitive micronutrients are shown in Table 7 together with the other food classes that make a major contribution. A more detailed breakdown by fruit and vegetable type for Australia is given in Table 8. The data used in the Tables are from the most recent studies on diet and nutrition, the 2011-12 Australian Health Survey, (ABS 2014), the 2008/09 NZ Adult Nutrition Survey (MOH 2011) and the 2002 National Children's Nutrition Survey (MOH 2003).

The data show that fresh fruits and vegetables contribute significantly to vitamin C intake but much less to vitamin E and thiamine intake. Vegetables, but not fruit, make a major contribution to vitamin A intake.

Table 7: Percent contribution to micronutrient intake from all fruits and vegetables.

Percent contribution				
	Vitamin C	**Vitamin A equiv.**	**Vitamin E**	**Thiamine**
Australia (age 2+)				
Fresh Fruits[a]	23.1	5.3	5.1	2.9
Fresh Vegetables	25.1	34.9	10.0	6.2
Other major contributors (%)	Fruit & vegetable juices & drinks (32.5)	Dairy & its products & fats, oils (25.0) Meats (11.6)	Cereals & cereal-based products (31.1) Meats (15.3)	Cereal & its products (43.2)
New Zealand (age 15+)				
Fruit	22.4	4.3	7.2	3.9
Vegetables[b]	28.1	27.2	11.3	7.3
Potato, kumara, taro[b]	12.8	--	5.8	5.5
Other major contributors (%)	Non-alcoholic beverages (14.6)	Dairy & dairy products[c]; (25.8)	Butter & margarine; bread-based dishes (18.2)	Bread, bread-based dishes, b'fast cereals (36.3)

[a] Total includes an approximate 10% contribution from dried and preserved fruits.

[b] In the NZ data, potato, kumara and taro are given separately to other vegetables where appropriate.

[c] includes butter, margarine, eggs & egg products, cheese and dairy products.

Table 8: Percent contribution of various fruit and vegetable classes to micronutrient intake of Australians aged 2 and over.

	Vitamin C	Vitamin A equiv.	Vitamin E	Thiamin
Pome	2.2	0.1	1.4	0.7
Berry	2.1	0	0.2	0.1
Citrus	11.6	0.3	0.4	1.1
Stone	1.6	0.5	1.0	0.1
Trop/Sub-trop	3.9	2.9	1.0	0.4
Other	3.1	0.9	0.4	0.2
Mixtures	1.2	0.3	0.2	0.1
Dried/preserved	0	0.2	0.4	0.2
Mixed dishes, predominant fruit	0	0	0.1	0
Total Fruit	**25.8**	**5.3**	**5.1**	**2.9**
Potato	4.1	0.4	2.1	2.2
Brassica	3.7	0.3	0.5	0.4
Root	1.8	19.8	1.0	0.4
Leaf/stalk	0.9	1.3	0.3	0.2
Peas & beans	0.9	0.4	0.1	0.4
Tomato & products	2.4	0.6	0.6	0.2
Other fruiting	3.8	1.2	1.6	0.7
Other and combined	3.3	5.3	0.7	0.6
Dish with major veg component	5.8	5.6	3.2	1.1
Total veg	**26.8**	**34.9**	**10.0**	**6.2**

Present consumption of irradiated fresh produce

In 2018/19, New Zealanders were able to purchase 1357, 459 and 517 tonnes of irradiated mangoes, litchis and tomatoes respectively (Table 1), a total of 2,333 tonnes. Approximately 11,000 tonnes of mangoes, 115,000 tonnes of tropical fruits and 38,000 tonnes of fresh (unprocessed) tomatoes were consumed in total in 2018 (Prowse 2019, Hort NZ 2018), a total of 164,000 tonnes. Thus, the irradiated produce consumed is presently about 1.4% of the total consumed for these types of fruit.

Table 9 shows that the domestic use of irradiated produce in Australia has been negligible to date. Among the reasons are that irradiation is only used when there are no alternatives or when there has been a suspension of a traditional treatment, and with the only irradiation facility based in Queensland it is difficult to fit in to the supply chain for out-of-state produce.

Table 9: Irradiated produce treated and consumed in Australia

History of Domestic Irradiated Produce in Australia						
Season	**(2013-14)**	**(2014-15)**	**(2015-16)**	**(2016-17)**	**(2017-18)**	**(2018-19)**
Tomatoes	4	8	1	15	-	3
Capsicums	121	14	19	-	-	-
Mangoes	28	-	-	-	-	8
Lychees	-	-	-	3	-	-
Plums	-	-	23	26	-	10
Persimmons	-	-	-	3	-	-
Raspberries	-	-	-	1	-	-
TOTALS:	153	22	43	48	0	21

Source: G. Robertson, Steritech Pty, QLD, private communication.

Potential consumption of irradiated fresh produce

The majority of produce produced in Australia and New Zealand does not require a phytosanitary treatment because they are produced and consumed within the same quarantine jurisdiction (i.e. state/territory or, for New Zealand, country). For many Australian-grown vegetables an end point phytosanitary treatment is unnecessary because of the harvesting and processing requirements result in soil and pest free commodities.

Appendix 6 is an independent report on fresh produce consumption patterns in Australia and New Zealand (Prowse 2019). It includes estimates of -

- Total consumption by major fruit and vegetable groups.
- The share of imports from overseas.
- For Australia, an indication of inter-state trade that could be subject to a phytosanitary treatment, notably produce from Queensland and Victoria into South Australia, Western Australia and Tasmania.

The key results detailed in Appendix 6 (Prowse 2019) are used in the following analysis for New Zealand and Australia.

New Zealand

New Zealand has no need to irradiate produce consumed locally and there are no current plans for a commercial food irradiation facility.

Table 10: Total consumption and imports of fresh fruits and vegetables in New Zealand (2018).

	Tonnes		
	Total consumption	**Imports**	**%Imports**
Fruit			
Pomme	103,687	3,814	4
Citrus	44,315	18,184	41
Soft	50.903	15,744	31
Tropical	114,754	104,499	91
Melons	10,643	5,488	52
Total fruits	**324,302**	**147,729**	**46**
Vegetables			
Potato	116,590	427	0
Onion	133,269	5,169	4
Root	78,289	45	0
Green	108,116	3,263	3
Fruiting	85,669	1,796	2
Total vegetables	**846,235**	**10,700**	**2**

Source: Prowse 2019.

Table 10 shows that New Zealand is virtually self-sufficient in fresh vegetables and little opportunity is seen for irradiated imports. Those opportunities would come from green and fruiting vegetables. As a very conservative assumption we estimate that 25% of present green and fruiting vegetable imports may be switched to an irradiation treatment and that an extra 25% may be imported as a result of new opportunities if Standard 1.5.3 is modified as requested. Therefore, perhaps irradiated green and fruiting vegetables could total 2,500 tonnes out of a total of 846,000 tonnes of total vegetables (0.3%).

In contrast, New Zealand imports a high percentage (46%) of its fruit; only pomme fruits are not extensively supplied from overseas.

Table 11: Estimation of percent of present imported fruit that might switch to irradiation treatment (New Zealand)

	Imports (t)	Commentary	Estimate Irradiated (%)	Irradiated imports (t)
Pomme	3,814	Cold storage unlikely to be replaced	0	0
Citrus	18,184	Oranges suit cold storage, mandarins, lemons and limes may change to irradiation	20	3,637
Soft	15,744	A variety of methods used. Most grapes may be irradiated and a small proportion of other fruits	30	4,723
Tropical	104,499	Bananas are the greatest volume and do not suit phytosanitary irradiation at present. Irradiation likely for mangoes, litchi, and several other fruits	15	16,498
Melons	5,488			
Total	**147,729**		**17**	**24,858**

Source: Prowse 2019, and G Robertson, Steritech Pty

From Table 10 and 11 we can estimate very conservatively that approximately 17% of fruit imports and 8% of total fruit consumed might be irradiated in the future.

Australia

Table 12 shows Australian consumption and imports of fresh produce. It also shows an estimate of fresh produce that may be given a phytosanitary treatment as part of domestic trade. This is mainly trade between the exporting states Queensland and Victoria and the fruit-fly free importing states of South Australia, Western Australia and Tasmania.

Table 12: Total consumption of fresh fruits and vegetables in Australia and the volumes imported from overseas or inter-state and liable to be given a phytosanitary treatment (2018). Some figures rounded.

	TONNES			TONNES	
	Total consumption	**Overseas Imports**	**%Imports**	**Inter-state**	**% Inter-state**
Fruit					
Pomme	357,366	2,380	1	4,648	1
Citrus	333,765	26,710	8	19,411	6
Soft	288,707	46,046	16	16,087	6
Tropical	602.623	16,794	3	88,018	15
Melons	204.572	97	0	17,352	8
Total fruits	**1,787,032**	**92,027**	**5**	**145,517**	**8**
Vegetables					
Potato	478,096	680	0	0	0
Onion	262,134	17,280	7	0	0
Root	171.583	-	0	0	0
Green	528,002	5,962	1	44,655	8
Fruiting	356,487	1,344	0	13,513	4
Total vegetables	**1,796,302**	**25,266**	**1**	**58,168**	**3**

Source: Prowse 2019.

Table 13 combines the volumes of imported and inter-state trade and provides an estimate of the maximum likely change from an existing treatment to irradiation. The assumptions for the estimated changes are given. The total potentially irradiated is then compared with total consumption (from Table 12).

Table 13: Estimate of the volume of fresh produce potentially irradiated (Australia).
Some figures are rounded.

	TONNES	%	TONNES	%	
	Total Imports + Inter-state	**Potential for change to irradiation**	**Total Irradiated**	**Irradiated as a share of total consumption**	**Assumptions**
Fruit					
Pomme	7,028	50	3,514	1	50% remain as alternate treatments (cold, MeBr, etc)
Citrus	46,121	20	9,224	3	Most oranges and mandarins treated by cold. Airfreight shipments irradiated.
Soft	62,133	50	31,067	11	Grapes are the large volume commodity and 50% may be irradiated
Tropical	104,812	10	10,481	2	Largest volumes inter-state are bananas, avocado, pineapple and do not require treatment. Some mangoes, litchis may be irradiated.
Melons	17,449	<<1	49	0	Inter-state do not require treatment. 50% of imports may be irradiated.
Total fruits	**237,544**	**25**	**54,335**	**3**	
Vegetables					
Potato	680	50	340	<<1	No treatments needed for inter-state. 50% of imports continue alternate treatment
Onion	17,280	50	8,640	3	No treatments needed for inter-state. 50% of imports continue alternate treatment
Root	0	0	0	0	-
Green	50,617	10	5,062	1	Most imports and inter-state continue existing treatments. Assume 10% of imports and inter-states irradiated.

Fruiting	14,857	50	7,429	2	Assume 50% of imports and inter-states irradiated and 50% continue existing treatments.
Total vegetables	**83,434**	**32**	**21,471**	**1.2**	

Table 13 indicates that even with conservative (i.e., higher than probable) assumptions, only 3% of total fruit and 1.2% of total vegetables consumed in Australia will be irradiated if Standard 1.5.3 is amended to allow phytosanitary irradiation of all fresh fruits and vegetables.

However, Appendix 6 (Tables 6 and 7) shows that 3 states, South Australia, Western Australia and Tasmania, consume significantly more fresh produce that has crossed a quarantine boundary than the Australian national average, with Tasmania being the worst-case scenario. Tasmania imports 76% of fruit inter-state and 12% of fruiting vegetables.

The data of Appendix 6 and the assumptions used to estimate the maximum likely change from an existing treatment to irradiation (Table 13) can be used to estimate the volume of fruit and fruiting vegetables that could be irradiated prior to import into Tasmania. The estimates, which are very approximate, are shown in Table 14. Table 14 also includes an allowance for the relatively small amount of the total Australian overseas imports of fruits and fruiting vegetables that could go to Tasmania on a per capita basis.

Table 14: Estimate for potentially irradiated fresh produce imported into Tasmania

	Potential for change to irradiation	**Total irradiated (tonnes)**	**Irradiated as share of total consumption**
Fruit			
Imports via QLD	10% tropical	1,267	
Imports via VIC	50% pomme, 20% citrus, 50% soft	3,908	
Imports via overseas	50% pomme, 20% citrus, 50% soft, 10% tropical	625	
Total		**5,800**	**15%**
Fruiting Vegetables			
Imports via QLD	50%	2,280	
Imports via VIC	50%	0	
Imports via overseas	50%	14	
Total		**2,294**	**6%**

The conservative estimates for the percentage of irradiated produce that Tasmanians might potentially consume are 15% for all fruits and 6% for all vegetables.

Future imports of irradiated fruits and emergency on-arrival treatment

Developing countries are now sending such fruits as guava, dragon fruit, chile manzano, pomegranate, star apple, pitaya, ambarella and fig to the US (USDA 2018). There is a probability that such countries will seek to increase further the range of fruits that they send to Australia and New Zealand using irradiation as the phytosanitary treatment. This trade has already commenced and is being actively pursued by Vietnam and India (see Part 2.3).

However, the entry of such fruits would be a very minor part of the overall market and would add to opportunities for consumers to purchase fruit that may not be not grown commercially in Australia or New Zealand. It could be argued that that the overall impact on nutrition, and certainly on consumer choice, would be beneficial.

Irradiation might be used for future emergency treatments of suspect shipments on arrival. However, by their very nature, such treatments are infrequent and not routine. They are not significant from a dietary perspective.

Potential for irradiation of key micronutrients

Australian consumers (aged 2+) obtain 23.1% and 25.1% of their vitamin C from fresh fruits and fresh vegetables respectively (Table 7). Nationally, it is conservatively estimated (Table 13) that 3% of fresh fruits and 1.2% of fresh vegetables might be irradiated in future. Therefore, approximately 0.7% plus 0.3% (1.0%) of total vitamin C intake could be irradiated.

New Zealand consumers (aged 15+) obtain 22.4% and 40.9% of their vitamin C from fresh fruits and fresh vegetables (including potatoes, kumara and taro) respectively (Table 7). It is conservatively estimated (Tables 10 and 11) that 8% of fresh fruits and 0.3% of fresh vegetables might be irradiated in future. Therefore, approximately 1.8% plus 0.1% (1.9%) of total vitamin C intake respectively could be irradiated.

A similar analysis for all four most radiation-sensitive vitamins is shown in Table 15.

Table 15: Percentage of total vitamin intake that could be irradiated for Australians (age 2+) and New Zealanders (aged 15+).

	Percent of intake potentially irradiated			
	Vitamin C	**Vitamin A equiv.**	**Vitamin E**	**Thiamine**
Australians				
Fresh fruits	0.69	0.16	0.15	0.09
Fresh vegetables	0.30	0.42	0.12	0.07
Total	**0.99**	**0.58**	**0.27**	**0.16**
New Zealanders				
Fresh fruits	1.79	0.34	0.58	0.31
Fresh vegetables	0.12	0.08	0.05	0.04
Total	**1.91**	**0.42**	**0.63**	**0.35**

Tasmania may be taken as a worst-case scenario for Australia since 15% and 6% of fruits and vegetables might be irradiated (Table 14) and 3.5% plus 1.5% (5.0%) of total vitamin C intake could be irradiated.

In summary, approximately 2% of the total vitamin C intake of New Zealanders might be subjected to phytosanitary irradiation and approximately 0.4%, 0.6% and 0.4 of the other three key micronutrients. On a national basis, approximately 1 % of the total vitamin C intake of Australians might be irradiated and approximately 0.6%, 0.3% and 0.2 of the other three micronutrients. For Tasmanians approximately 5% of total vitamin C intake might be irradiated. These percentages have been conservatively estimated and could possibly be significantly lower.

Changes in key micronutrients due to low dose irradiation

The following contains references to doses higher than the phytosanitary dose of ≤1 kGy. This is to provide a comprehensive review and does not imply that doses higher than 1 kGy will be used.

A FSANZ review (FSANZ 2014b, Tables 6.1 to 6.10) examined the losses reported after irradiation of fruits for vitamin C (29 studies) and carotene (10 studies). Fewer studies were available for vegetables. FSANZ (2014b) also reviewed available evidence on the natural variation in the nutritional content of individual fruit and vegetable types due to cultivar, season, growing location and degree of ripeness. The effect on nutrient composition of post-harvest storage and processing was also considered. FSANZ concluded that phytosanitary doses of irradiation:

- Have no effect on carotene levels in fruits and vegetables;
- Have little effect on non-vitamin bioactives;
- Do not decrease vitamin C levels in the majority of fruits and vegetables;
- For fruits and vegetables where a decrease in vitamin C is reported, the decrease is no greater than for other processing methods. Most importantly, vitamin C levels remain well within the range of concentrations that can result from natural variations, storage and other processing.

A literature search was been carried out in September 2019 for data on micronutrient changes following irradiation that have been published after the FSANZ (2014b) review. The databases searched were EBSCOhost, Science Direct, Wiley Online Library and Researchgate using the terms –

- fruit and vegetable + irradiation + ascorbic acid + vitamin C
- fruit and vegetable + irradiation + carotene + vitamin A
- fruit and vegetable + irradiation + carotene + carotenoid + vitamin A
- fruit and vegetable + irradiation + tocopherol + vitamin E
- fruit and vegetable + irradiation + nutrient + vitamin

The period searched was 2011 to 2019.

As recommended by FSANZ (2014b) new data for the key radiation-sensitive micronutrients in vegetables, especially leafy greens, brassicas and roots and tubas, is considered in detail below. These data are also summarised in Appendix 4 which also provides brief details of the analytical and statistical methods used.

Recent data on micronutrient changes in fruits, fruiting vegetables and cucurbits are summarised in Appendix 5. These data are of variable quality but are presented as they are generally consistent with the FSANZ conclusion that micronutrient changes from doses up to 1 kGy are not significant for these types of commodity.

Leafy greens

Spinach and fenugreek

Fan and Sokorai (2011) studied spinach irradiated at 0, 1, 2, 3 and 4 kGy and stored for 1,7 and 14 days at 4^{o}C. Ascorbic acid (AA) levels (µg/g fresh weight) of control samples were 645 ± 94, 557 ± 111 and 432 ± 42 after 1,7 and 14 days. Samples treated with 1 kGy had AA levels of 666 ± 91, 341 ± 120 and 175 ± 78 over the same storage period. The loss of AA in 1 kGy irradiated spinach was not significantly different from controls after 1 day but over 14 days the loss was more than doubled (73.7% *vs* 33.0%). The loss compared to controls was greater at the higher doses.

However, overall anti-oxidant was largely unaffected at any dose over the 14 days. Anti-oxidant capacities (µmol TE/g) were 102 ± 24 and 84 ± 22 for the control at 1 and 14 days and 83 ± 7 and 74 ± 11 for 1 kGy irradiated samples. At 4 kGy, activity was 97 ± 24 and 87 ± 12 at 1 and 14 days respectively. Phenolic content was even less affected over all doses and storage times.

Hussain *et al* (2016) evaluated spinach treated with doses from 0.25 to 1.5 kGy in 0.25 kGy increments with storage for 4 days at 3^{o}C. They found a small dose-dependent increase in total phenols, flavonoids and carotenoids. For example, the comparative concentrations (mg/100 g) for samples given 0 and 1.5 kGy were 209.4 ± 9.6 *vs* 216.2 ± 10.2 (phenols), 80.2 ± 4.1 *vs* 92.3 ± 3.6 (flavonoids) and 35.4 ± 2.0 *vs* 43.1 ± 4.1 (carotenoids). Total ascorbic acid levels (ascorbic plus dehydroascorbic acids) were not significantly affected at any dose (controls 75.6 ± 2.1 *vs* 74.1 ± 2.2 at 1.5 kGy).

In the same set of experiments, Hussein *et al* (2016) also examined fenugreek with essentially similar results. That is, a small dose- dependent increase in total phenols, flavonoids and carotenoids and no significant difference in total ascorbic acid concentrations.

Akhter *et al* (2013) irradiated spinach at 0.5 and 1 kGy and followed ascorbic acid over 12 days at 12^{o}C. They reported (mean of 2 replicates) an immediate increase in ascorbic acid with irradiation treatment but a greater decrease in irradiated samples over 12 days. Control values (mg/100g) dropped steadily from 13.37 to 7.56 over 12 days whereas samples treated with 0.5 kGy, after an initial (day 0) increase, decreased from 17.39 to 5.23 and 1 kGy samples decreased from 17.39 to 3.49.

Al-Suhaibani and Al-Kuraieef (2016) treated spinach at 0.5 kGy increments to 2 kGy but temperature and storage conditions are unclear. They appear to have taken measurements shortly after treatment at room temperature. Based on mean ± s.d from 5 samples, they claim a significant increase in activity (mg/100g) for total anti-oxidants, phenols and flavonoids over the complete dose range. For example, activity for controls vs 1 kGy dose was 23.32 ± 1.06 *vs* 51.20 ± 1.92 for anti-oxidant activity, 58.17 ± 1.47 *vs* 142.19 ± 0.83 for phenolics and 4.32 ± 0.92 *vs* 5.25 ± 1.50 for flavonoids.

Lettuce

Fan *et al* (2012) measured ascorbic acid 1 and 14 days after doses of 0 to 4 kGy in 1 kGy steps. Storage was at 4^{o}C. There was no significant difference between irradiated samples and controls after 1 day. Values (mg/g fresh weight) were 2.42 ± 1.2, 2.15 ± 0.19, 2.46 ± 0.84, 1.50 ± .83 and 1.58 ± 0.37 for 0, 1, 2. 3 and 4 kGy respectively. At 14 days, ascorbic acid was reduced by 22-40% relative to controls with values of 3.05 ± 0.93, 1.82 ± 0.58, 2.00 ± 0.32, 1.90 ± 0.43 and 2.15 ± 0.60.

Sarker (2014) studied the ascorbic acid and total carotenoid content of green leaf lettuce. Measurements appear to have been taken shortly after treatment of the three replicates for each of 5 samples. AA concentrations (mg/g fresh weight) were 3.786 ± 0.765, 3.279 ± 0.0, 2.292 ± 0.0, 2.322 ± 0.0 and 2.175 ± 0.0 for at 0, 1, 2, 2.5 and 3 kGy respectively. The corresponding total carotenoid measurements (µg/g fresh weight) were 24.5 ± 0.707, 24.7 ± 0.707, 18 ± 4.243, 17 ± 2.828 and 18 ± 0.0.

Other

Nunes *et al* (2013) examined changes in total ascorbic acid and carotenoids for arugula treated with 0, 1 and 2 kGy with storage at 5^{o}C for up to 16 and 13 days respectively. The data for total ascorbic acid are provided as a figure (Figure 3). The authors state that there was a significant decrease of total ascorbic acid during the storage period for both controls and irradiated samples. The decrease was significantly affected by the dose ($P \leq 0.05$) up to the 5th day of storage but the levels were not significantly affected by dose at days 9 and 13. From the figure, it appears the decrease in the samples given 1 kGy may be about 20% lower than controls at day 5.

In contrast, provitamin A carotenoids showed no significant changes as a result of irradiation throughout storage. For example, the concentrations of controls (µg/g fell from 61.10 ± 3.24 to 56.45 ± 3.46 over 13 days while 1 kGy samples fell from 64.24 ± 3.42 to 51.37 ± 0.24.

In studies of watercress (Pinela *et al* 2018) samples were irradiated at 1, 2 and 5 kGy and stored in air at 4°C for 7 days. The results (mean ± s.d) for 0, 1, 2 and 5 kGy samples at 7 days were 6.3 ± 0.5, 6.7 ± 0.5, 5.2 ± 0.5 and 7.6 ± 0.5 for total phenolic acids, 26 ± 2, 26 ± 2, 23 ± 1 and 28 ± 2 for total phenolic compounds and 20 ± 1, 20 ± 2, 17 ± 1 and 21 ± 2 for total flavonoids. For all three types of measure, the 0 kGy samples at 7 days were not significantly different to 0 kGy samples at day 0. In a second study with different methodology (Pinela *et al* 2016), the results for total phenolics were 97.2 ± 2, 93.1 ± 1, 92 ± 3 and 98 ± 1 over the 0 to 5 kGy dose range and, for total flavonoids, 25 ± 1, 26 ± 2, 21 ± 2 and 34 ± 2.

Pinela *et al* (2016) also measured reducing power and $DPPH^-$ scavenging ability (measures of overall anti-oxidant capacity) as EC_{50} values where a lower number denotes greater anti-oxidant activity. Anti-oxidant activity was greatest in unirradiated fresh samples measured immediately after harvest with a reducing power of 0.38 ± 0.01 and $DPPH^-$ scavenging ability of 0.49 ± 0.01. Storage alone for 7 days at 4°C reduced anti-oxidant activity but irradiation had little further influence. Reducing power for control, 1, 2 and 5 kGy samples were 0.48 ± 0.01, 0.45 ± 0.01, 0.46 ± 0.01 and 0.42 ± 0.01. $DPPH^-$ scavenging ability was 0.81 ± 0.01, 0.85 ± 0.01, 1.01 ± 0.02 and 0.58 ± 0.01.

For total tocopherols, the results (mg/100 g fresh weight) were variable. Storage alone increased tocopherol concentrations over 7 days. For 2 and 5 kGy, tocopherol concentrations were similar to controls but with 2 kGy, a significant, possibly anomalous drop was observed. The concentrations after 7 days were 1.34 ± 0.05, 1.04 ± 0.05, 0.31 ± 0.01 and 1.44 ± 0.05 for samples given 0, 1, 2 and 5 kGy respectively. These results should also be compared to the non-stored control of 0.55 ± 0.04 mg/100g.

Brassicas

Cauliflower

Cut samples of minimally-processed cauliflower were irradiated (0.5 kGy) and stored at 4°C and tested at 0, 7, 14 and 21 days (Vaishnav *et al* 2015). Total phenolic content (TPC) was 42.86 ± 1.6 and 50.49 ± 3.69 mg/100g for controls and irradiated samples respectively on day 0. Over a 21 day storage period, TPC reduced significantly in the controls but did not change significantly in the irradiated samples (shown in Fig 4A of the paper). Total flavonoid content was reduced over the storage period but there was no significant difference between control and irradiated samples except at 21 days (Fig 4B). Total anti-oxidant activity was significantly increased for irradiated *vs* control samples at all storage times (Fig 4C) but there was no significant difference in total ascorbic acid concentrations on day 0 (41.13 ± 1.37 *vs* 41.75 ± 2 mg/100g) and no change throughput the storage period (Fig 5).

Cabbage

Banerjee *et al* (2016) examined ready-to consume shredded cabbage stored at 4ºC and 10ºC for up to 15 days. Nutrient data was obtained for control and 2 kGy irradiated samples. Figure 4 of the paper shows relatively small changes interpreted by the authors as showing anti-oxidant activity to be increased significantly as a result of irradiation throughout storage at both temperatures. No significant changes as a result of irradiation were noted as a result of irradiation for total phenolic, total flavonoid or ascorbic acid content.

Another study of cut cabbage (Frimpong *et al* 2015) examined samples irradiated from 0 to 3 kGy in 1 kGy increments and stored at 8ºC for 5, 10 and 15 days. Total ascorbic acid, total anti-oxidant activity, total phenolic and total flavonoid concentrations were measured, with all measurements made in triplicate. The results are shown in a series of figures (1 to 4) in the paper. Statistically significant changes due to storage were observed. Small increases or decreases in irradiated samples compared to controls were observed at different doses and storage times, but none of these changes were statistically significant.

Roots and tubers

Carrots

Mohacsi-Farkas *et al* (2014) irradiated pre-cut carrots and samples were stored for 8 days at 5ºC. Ascorbic acid measurements were made on control and 1 kGy treated carrots while tocopherol and carotenoids were measured on control and 2 kGy samples. Ascorbic acid concentrations were reduced from a control value of 27.85 ± 0.24 µg/g to 18.88 ± 0.32 by 1 kGy. A dose of 2 kGy reduced α- tocopherol from 4.24 ± 0.16 µg/g to 2.37 ± 0.02, β-tocopherol from 0.31 ± 0.02 to 0.23 ± 0.01 and γ-tocopherol from 0.34 ± 0.02 ± 0.20 ± 0.00. Carotenoids were less affected with the greatest decrease as a result of 2 kGy irradiation being for β-carotene with a decrease from 100 ± 0.75 to 82.08 ± 0.57 µg/g. Other carotenoids measured were reduced less and in one case carotene even increased slightly, from 4.28 ± 0.11 to 4.53 ± 0.10 µg/g.

Harashima *et al* (2013) treated baby carrots kept a 4ºC with 0.5 and 1 kGy doses and extracted 5g shredded samples for measurement of total phenolic content (6 replicates) almost immediately. The mean ± s.d levels (expressed as µg eq. gallic acid/g) for controls, 0.5 and 1.0 kGy were 330 ± 8, 308 ± 8.3 and 266 ± 10.6 respectively, showing an approximate 10 and 20% decrease for 0.5 kGy and 1.0 kGy samples respectively.

Sarker *et al* (2014) treated sliced carrots with doses from 0 to 3 kGy in 1 kGy increments. Unfortunately, the precise storage and temperature conditions used are not provided. It may be presumed that measurements were taken shortly after room temperature treatments. Ascorbic acid content (mg/100g) was little altered except at the highest dose. Values were 4.643 ± 0.219, 5.376 ± 0.272, 4.144 ± 0.374, 4.184 ± 0.296 and 3.250 ± 0.270 for 0, 1, 2 and 3 kGy respectively. The same doses showed little effect for total carotenoid content: 6.869 ± 2.49, 6.665 ± 0.615, 5.043 ± 0.603, 6.056 ± 2.65 and 6.321 ± 0.538, all measured as µg/g.

In experiments of possibly limited relevance to fresh carrots, Chaturvedi *et al* (2013) applied a dose of 0.5 kGy as an adjunct to drying shredded carrot to an intermediate moisture level of 30-40% using either infra-red or tray drying. Samples were stored at ambient 30ºC temperature and micronutrients measured at 30 day intervals for up to 180 days or until discarded for loss of quality. All experiments were repeated three times and statistically analysed using Analysis of Variance.

Irradiation increased the useful shelf life, especially for infra-red dried carrots while slightly decreasing the levels of ascorbic acid, β-carotene and total carotenoids. For example, using the infra-red drying method, vitamin C levels (mg/100g) for unirradiated and irradiated samples were 11.5 and 11.0 at 1 month, 9.9 and 9.9 at 2 months and 7.7 and 6.2 at 3 months. B-carotene levels (µg/100g) for the same times were 931 and 921, 902 and 892, and 768 and 835. Total carotene levels (µg/100g) were 9579 and 9529, 9381 and 9233, and 8690 and 8789. The process of drying and irradiation caused a 68.1% decrease in vitamin C but β-carotene and total carotene levels were substantially increased (4.6 times and 4.7 times respectively).

Sweet potato

Sweet potato roots were irradiated with doses up to 1 kGy and examined every 2 weeks for 8 weeks with storage at 25°C (Lim *et al* 2013). Lower storage temperatures were also studied but the results were not provided as the higher temperature produced the greatest change relative to unirradiated samples. Vitamin C and β-carotene levels were not significantly affected. Over the 8 weeks, control values for vitamin C were in the range 24.8 ± 2.8 to 31.9 ± 2.8 and for irradiated (1kGy) samples the range was 29.8 ± 4.2 to 25.6 ± 4.2. For β-carotene the respective values were 113.4 ± 10.2 to 135.4 ± 14.2 (controls) and 96.2 ± 12/4 to 137.2 ± 10.4 (irradiated).

Oner and Wall (2013) examined the anthocyanin content of sweet potato after doses up to 1 kGy and storage for 14 days at 4°C. Anthocycanin content (mg cyanidin-3-glucoside/100g dry weight) were not significantly affected during 14 day storage. For example, control values decreased from 57.4 ± 1.5 to 53.6 ± 4.7 while 1 kGy treated samples increased from 58.7 ± 1.7 to 60.3 ± 1.4.

Potato

Rezaee *et al* (2013) examined ascorbic acid in potatoes irradiated at very low doses (50 and 100Gy) and stored for up to 5 months at 10°C. The results were highly variable depending when the potatoes were treated relative to harvest and the dose with ascorbic acid losses between 8.5% and 24,8%.

Summary of changes in key micronutrients due to phytosanitary irradiation

The data above and Appendix 4 show that the effects of doses up to 1 kGy on key micronutrients in leafy greens, brassicas and roots and tubers are broadly the same as the effects in fruits discussed by FSANZ (2014b). That is, changes in ascorbic acid are variable but generally show a decrease compared to unirradiated controls particularly as the dose increases above 1 kGy. Any decrease is partly or completely compensated for by an increase in dehydroascorbic acid which also has vitamin C activity, as shown by available measurements on total ascorbic acid.

B-carotene and total carotene concentrations are generally little affected by irradiation and total phenolic and flavonoid compounds tend to increase following irradiation as does total anti-oxidant activity. There are limited new data on changes to vitamin E and tocopherols.

The recent data for fruit, fruiting vegetables and cucurbits (Appendix 5) are consistent with the data reviewed by FSANZ (2014b).

Overall the data discussed here and in the previous review by FSANZ indicate that any loss of micronutrients in fresh fruits and vegetables caused by phytosanitary irradiation will not be significant and concentrations will remain within the range found naturally due to natural variations, storage and other processes.

Fruit and vegetable juices

Table 7 indicated that the greatest contribution to vitamin C intake for Australians comes from fruit and vegetable juices and drinks (32.5%). Non-alcoholic beverages are also a significant source of vitamin C for New Zealanders. Juicing or processing of fruit and vegetables is recognised as reducing the risk of transporting live insects and processed products as are normally exempt from phytosanitary treatment requirements. Additionally, fruits and vegetables for juicing or other processing are generally lower value produce (i.e. not export quality) that are unlikely to be exported internationally. The intake of vitamin C from fruit and vegetable juices will not affected by the phytosanitary irradiation treatment of fresh fruits and vegetables.

Implications for dietary intake of micronutrients

As noted in the FSANZ (2014b) review, data from health surveys show that Australians and New Zealanders generally have a nutritionally adequate diet. Specifically, vitamin C intake is adequate in the Australian and New Zealand populations, even in people with the lowest intake levels. Mean vitamin C intakes exceed both the Estimated Average Requirement (EAR) and Recommended Daily Intakes (RDI) for all population groups. Furthermore, vitamin C intake at the 5th percentile also exceeds the EAR and RDI in all groups.

The assessment of the maximum foreseeable use of phytosanitary irradiation carried out in this application (see above) indicated that approximately 2% of the total vitamin C intake of New Zealanders might be subjected to phytosanitary irradiation and approximately 0.4%, 0.6% and 0.4 of the other three key micronutrients. On a national basis, approximately 1 % of the total vitamin C intake of Australians might be irradiated and approximately 0.6%, 0.3% and 0.2 of the other three micronutrients. For Tasmanians approximately 5% of total vitamin C intake might be irradiated.

The conclusions of the FSANZ review (2014b) have been confirmed by more recent data and can be extended to all vegetables including leafy greens, brassicas and roots and tubers. Phytosanitary doses cause changes to the concentrations of radiation-sensitive micronutrients that are insignificant when compared with the changes due to natural variations, storage and other food processes. Specifically, any loss of total vitamin C activity will be negligible and much less than natural variations.

In summary –

- Australians and New Zealanders generally have a nutritionally adequate diet;

- the proportion of the intake of radiation-sensitive micronutrients derived from fresh fruits and vegetables that will be irradiated is generally less than 2%;
- any radiation-induced effects on the micronutrients can be considered negligible.

We conclude that the risk of an adverse nutritional impact from approving phytosanitary irradiation for all fresh produce is of no practical concern.

3.2. **Toxicological data**

The safety of irradiated food has been extensively assessed by various national regulators and international scientific agencies (e.g. the US FDA, Canada and European Union, Joint Expert Committee on Food Irradiation) and they have approved the use of irradiation of specific foods following a safety assessment.

FSANZ have accepted the toxicological safety of irradiated food within assessments of previous applications (FSANZ 2001, 2002, 2011, 2013a, 2014a, 2016). We are unaware of any more scientific reports bringing the toxicological safety of irradiated food into question. The situation is therefore only briefly reviewed here.

Toxicological safety was assessed by an FAO/WHO Joint Expert Committee on Food Irradiation (JECFI 1981). JECFI found no adverse toxicological effects and no specific nutritional or microbiological effects. No adverse effects have ever been reported over many years in which laboratory rodents, astronauts and immune-suppressed patients had received sterile diets irradiated at high doses (25 kGy) and whose health was well-monitored.

The conclusion of JECFI (1981) "Irradiation of food up to an overall average dose of 10 kGy presents no toxicological hazard and introduces no special nutritional or microbiological changes" (JECFI 1981) was the basis for the original and revised Codex Alimentarius General Standard for Irradiated Foods (CAC 1983, 2003a). In 1999, the JECFI further concluded that foods irradiated with doses above 10 kGy were also safe and wholesome, and "food irradiated to any dose appropriate to achieve the intended technological objective is both safe to consume and nutritionally adequate" (WHO 1999). The dose applied to any food would be limited by considerations of marketable quality before any toxicological hazard would arise.

Since the original JECFI finding, several major evaluations of the chemical and toxicological safety of irradiated food have concluded that food irradiation was a safe process (WHO 1994, 1999, 2003, SCF 2002, 2003, EFSA 2011a, b). Authorities responsible for food safety and/or human health in many countries, for example the US Food and Drug Administration (FDA 2019), have approved uses of food irradiation in the last 20 years. FSANZ has approved 5 separate applications for phytosanitary irradiation of various commodities since 2003.

In the approval process authorities such as FSANZ have continued to accept the general JECFI finding but examined specific new issues that have arisen. The main issues have been the radiolytic products alkylcyclobutanones and furans and the high dose irradiation of pet food.

Radiological products

Alkylcyclobutanones (ACBs) and, especially, 2-dodecyl-cyclobutanones (2-DCBs) are compounds formed when triglycerides-containing (or fat-containing) food products are irradiated (Diehl 1995, WHO 1999, Kim *et al*. 2004). Production is proportional to fat content. Except in rare instances they have not been detected in non-irradiated foods.

There is a low potential to generate 2-ACBs in fruit and vegetables because of the low lipid content and their production of does not appear to be a toxicological risk for phytosanitary irradiation.

Furan, a genotoxic carcinogen, can be induced by irradiation of solutions of simple sugars and ascorbic acids and in fruit juices (Fan 2005, Vranova and Ciesarova 2009). Many fruits and some vegetables are rich in sugars and ascorbic acid and the potential for production must be considered.

Furan has been detected in some fruits irradiated at 5 kGy but not in any vegetable tested (Fan and Sokorai 2008). The USFDA reported that tests that showed that furan was undetected in spinach and lettuce irradiated to doses up to 4 kGy (FDA 2008). The majority of fruit and vegetables irradiated with 5 kGy produced non-detectable levels, or less than 1 ng/g of furan from fruits that had a high level of simple sugars and low pH, such as, grape and pineapple (Fan and Sokorai 2008). The maximum dose for phytosanitary irradiation (1 kGy) is five times lower and furan levels, if produced, are likely to be at undetectable levels generally considered not high enough to have a toxicological effect.

Furan is a highly volatile compound with a boiling point of 31°C (Vranova and Ciesarova 2009) and can be expected to evaporate from fresh produce left at ambient temperature or for cut-produce that are not packaged in sealed containers.

In a preliminary 2004 report, the FDA found furan in many heat-treated foods and many of these were bottled or canned baby foods (FDA 2004). Subsequent work, much of it initiated by the European Food Safety Authority, provided further evidence that furans can be found in a wide variety of foods and drinks. Coffee is a prime example of a beverage containing heat-induced furan. Crews and Castle (2007) and Vranova and Ciesarova (2009) have reviewed the evidence that furans, as well as some hydrocarbons, cholesterol oxides and aldehydes are found in foods subjected to non-irradiation processing especially heating.

Possible furan production does not appear to be a realistic risk following phytosanitary irradiation (EFSA 2011a).

Pet food

An exclusive diet of dry pet food irradiated at 26-54 kGy caused serious neurological defects in laboratory cats bred to be pathogen-free (Cassidy *et al* 2007, Caulfield *et* al 2008, 2009). Lesser but still concerning defects were found in some domestic cats on a mixed diet (Child *et al* 2009). The mechanism for the pathology is uncertain but may be due to the serious depletion of vitamin A which cannot be produced metabolically by cats and must be obtained through diet. High peroxide production from the high doses and dry condition of the food are another possible cause. Cats are prone to neurological problems if vitamin A deprived for any reason and there have been no reports of symptoms in other animals on a similar diet, for example dogs. Given the very high doses involved and the specific cat -vitamin A link, there appears to be no cause for concern about phytosanitary irradiation.

The FDA also investigated reports from the period around 2007 that illnesses and some deaths had been occurred in dogs eating jerky treats, all apparently sourced from China (FDA 2018). It proved difficult to determine what processing the jerky treats had been subjected to. Markers for many possible processing methods were investigated, including irradiation among others, but no evidence was found indicating why the treats might contain toxic products. Treats were allowed on sale again several years later and there is no reason to question the safety of phytosanitary irradiation.

3.3. **Products and ingredients**

Not relevant to the request for a phytosanitary purpose.

3.4. **Microbiological data**

Not relevant to the request for a phytosanitary purpose.

PART 4 - REGULATORY AND LEGISLATIVE IMPLICATIONS

4.1. International standards

The internationally recognized standard-setting agencies for human and plant health are Codex Alimentarius and the International Plant Protection Commission (IPPC). These agencies have regard to the scientific findings of the WHO and FAO which have endorsed food irradiation as safe and wholesome. Amendment of Standard 1.5.3 to approve all fruits and vegetables for phytosanitary irradiation would bring the standard into line with the principles of the Codex standard (CAC 2003a) and with the IPPC recommended guidelines under International Standards for Phytosanitary Measures (ISPM) 18 and 28 (FAO IPPC 2003, 2007). Irradiation processing of fruit and vegetables in Australia comply with the relevant international codes of practice Codex (CAC 2003b), ASTM 2013, 2014, 2015).

The international regulatory and legislative standards and criteria have not changed recently and there has been some progress towards development of regional standards for phytosanitary measures, particularly in the Asia Pacific. The regulatory and legislative implications have been considered and reported thoroughly in A1038, A1069, A1092 and A1115. A summary is provided here.

Codex

The safety and nutritional aspects of irradiated foods are ensured through compliance with the Codex General Standard for Irradiated Foods (CAC 2003a). Codex recommends process control principles in its International Code of Practice for Radiation Processing of Food (CAC 2003b). Various methods developed for the detection of irradiated foods are encoded in General Methods for the Detection of Irradiated Foods (CAC 2003e, IAEA 2009).

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 fruit and vegetables from primary production to packing. Irradiation is not a substitute procedure for GAP or GMP (CAC 2003d).

The Codex Code of Practice refers to the Codes of Good Irradiation Practice of the International Consultative Group on Food Irradiation (ICGFI) such as a Code for Insect Disinfestation of Fresh Fruits. ICGFI has been disbanded although publications are available through the FAO/IAEA Joint Division in Vienna (ICGFI 1991). Codex also refers to Standards of ASTM International (formerly ASTM). ASTM codes include Standard Guides for the Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment (ASTM 2014), Packaging Materials for Foods to be Irradiated (ASTM 2016), dosimetry (ASTM 2013) and Absorbed Dose Mapping in Radiation Processing Facilities (ASTM 2015).

IPPC

ISPMs are recognised by the WTO Sanitary and Phytosanitary Standards (SPS) Agreement (WTO 2011) that are designed to facilitate safe trade in food and agricultural products.

ISPM No. 18 Guidelines for the Use of Irradiation as a Phytosanitary Measure (FAO 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 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 (FAO IPPC 2007, 2009a,b,c).

An IPPC recommendation (FAO IPPC 2008) lists possible options for replacement or reduction in use of methyl bromide as a phytosanitary measure.

As a member of the Asia Pacific Plant Protection Commission (APPPC), Australia has led the development of new regional standards for phytosanitary measures (RSPMs) including RSPM No 9, the approval of irradiation facilities (APPPC 2014).

Viable phytosanitary treatments are those that are economically and technically feasible (HAL 2002) and meet ISPM No. 24 Guidelines for the Determination and Recognition of Equivalence of Phytosanitary Measures (FAO IPPC 2005).

4.2. National standards or regulations

Australia and New Zealand

Australia and New Zealand have a joint Food Standards Code administered by FSANZ. The current Standard 1.5.3 (FSANZ 2017) permits the use of irradiation on 26 specified fruits and vegetables, and on herbs, spices, and herbal infusions (FSANZ 2001, 2002, 2011, 2013a, 2014a, 2016).

The use of irradiation for phytosanitary purposes for domestic trade was approved by all states and territories in Australia in 2011 as ICA-55 (ICA 2011). Only fruit and vegetables that are approved by FSANZ are permitted to use ICA-55.

In New Zealand the Ministry of Primary Industries is responsible for establishing import health standards that detail the requirements that must be met before risk goods can be imported. Import health standards are documents issued under Section 24A of the Biosecurity Act 1993 (MPI 2019b). The current Import Health Standards for irradiated fruit from Australia approved by NZMPI (MPI 2019c) include litchi (*Litchi chinensis*), mango (*Mangifera indica*), papaya (*Carica papaya*), tomato (*Lycopersicon esculentum*), capsicum (*Capsicum annuum*) and table grapes (*Vitus vinifera*).

Likewise, import permits are required for importation of irradiated fresh produce into Australia. The Department of Agriculture regulates products imported into Australia under the Biosecurity Import Conditions System (BICON) and exports under MICoR (DA 2019a,b). The Department has also issued a Phytosanitary Treatment Application Standard for Irradiation Treatment (DA 2018).

FSANZ Standard 1.4.3. *Articles and materials in contact with food*, provides permission for materials and articles to be in contact with food (FSANZ Standard 1.4.3).

Australian Standard for *Plastics Materials for Food Contact Use, AS2070 –1999* (AS) 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 (SA1999).

United States

In the US, the FDA regulates food irradiation as a food additive and not a food process because the Food Additives Amendment to the Federal Food, Drug, and Cosmetic Act (FD&C Act) of 1958 places food irradiation under the food additive regulations.

The FDA food irradiation regulations are *Title 21 Part 179 Irradiation in the production, processing and handling of food*, *21 CFR 179* and all sub-parts are available electronically (FDA 2019).

Fresh fruits and vegetables as a class were approved for irradiation up to 1 kGy to disinfest of arthropod pests in 1986 (FDA 1986). The current regulation simply stipulates disinfestation of arthropod pests in any food (FDA 2019). Irradiation of iceberg lettuce and spinach at up to 4 kGy has been approved for microbial control (FDA 2008). Approved packaging materials for irradiated foods as stipulated in sub-part *§179.45 for prepackaged foods* (FDA 2007).

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

Rule 7 CFR Parts 305 and 319 Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables (USDA 2002, 2010) provides for the use of irradiation as a phytosanitary treatment for fruits and vegetables imported into the USA. The *USDA Fresh Fruits and Vegetables Import Manual* is available on-line (USDA 2019) and 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, and treatments (USDA 2002, 2010, 2016).

Table 15 shows the extensive range of irradiated produce and countries of origin that have been granted approval to be imported into the USA. Only some of these approvals have been converted into commercial trade to date and some other fruits from countries not listed have recently been imported into the USA (USDA 2018).

Table 16: Irradiated produce eligible for import into the USA

Exporting country	Fruits
Australia	*Litchi, Mango*
Ghana	*Eggplant, Okra, Pepper*
Hawaii	*Abiu, Atemoya, Banana, Breadfruit, Capsicum spp. (Peppers), Carambola, Cucurbita spp. (squash, pumpkins), Cowpea, Pitaya (dragon fruit), Eggplant, Jackfruit, Litchi, Longan, Mango, Mangosteen, Melon, Moringa pods, Papaya, Pineapple, Rambutan, Sapodilla, Sweet potato, Tomato, Starfruit, Curry leaf*
India	*Mango*
Malaysia	*Rambutan*
Mexico	*Carambola, Clementine, Grapefruit, Guava, Mango, Manzano, Sweet lime, Sweet orange, Tangelo*
Pakistan	*Mango*
South Africa	*Grapes, Stone fruit, Pear, Persimmon*
Thailand	*Litchi, Longan, Mango, Mangosteen, Pineapple, Pomello, Rambutan, Dragon fruit*
Vietnam	*Dragon fruit, Rambutan*

Source: USDA (2016, 2019)

European Union

Regulations on food irradiation in the European Union are currently not fully harmonised. *Framework Directive 1999/2/EC* (EU 1999a) establishes a general framework for controlling irradiated foods, labelling and importation. There is a community list of food and food ingredients that can be irradiated but dried aromatic herbs, spices and vegetable seasonings is the only food group currently on the list under *Framework Directive 1999/3/EC* (EU 1999b). The maximum authorised dose is 10 kGy.

In the absence of a final community-wide list, member states may operate under national regulations in place prior to the establishment of the community list (EU 2009a). Belgium, the Czech Republic and the UK permit phytosanitary irradiation of all fruits and vegetables but no such treatments are believed to take place. Commercial food irradiation is minimal at 7000 tonnes of food in the EU in 2013, half being frog legs (Roberts and Henon 2015).

Article 2(6) of Directive 1999/2/EC states that member States may not prohibit, restrict or hinder the marketing of irradiated foodstuffs. European Commission Directive 2009/975/EC Amending Directive 2002/72/EC also addresses plastic materials and articles intended to come into contact with food (EU 2009b).

Analytical methods (EU 2009c) for the detection of irradiated foods standardized by the European Committee for Standardisation (CEN) are described in IAEA literature (IAEA 2009). These standards have been adopted by the Codex except for EN14569:2004 (*CODEX STAN 231e, Rev.1-2003)*.

Other nations

Canada has a regulatory approach similar to Australia and New Zealand. Health Canada is responsible for approval of food irradiation uses. These are coded in the Canadian *Food and Drugs Regulations Division 26 Food Irradiation* (CFIA 2009). Several foods may be irradiated but at present fruits and vegetables are not included.

Over 60 countries approve at least one use of food irradiation but many of these regulations are old and have not been utilised on any significant scale. Perhaps 25 to 30 countries use irradiation as a food process (Roberts 2016). Differences exist between the regulatory requirements concerning food irradiation in the Asia Pacific but countries have begun to harmonise food irradiation regulations based on conformance with Codex requirements (APPPC 2014).

Approvals for phytosanitary treatment of all fruits and vegetables

Many countries permit phytosanitary irradiation for all fresh fruits and vegetables as tabulated and discussed in Part 2.3 and Table 3. The majority of the related regulations were issued in the years following the publication of the JECFI report (1981) and the Codex General Standard on Irradiated Foods (CAC 1983).

The JECFI report concluded that "irradiation of any food commodity up to an overall average dose of 10 kGy introduces no toxicological hazard "and "introduces no special microbiological or nutritional problems". Codex accepted the JECFI conclusions and its recommendation stated that "any food irradiated up to an overall dose of 10 kGy is safe and wholesome ".

Many countries re-assessed their food and/or food irradiation regulations in the light of the Codex recommendation. The process of re-assessment in Australia and New Zealand between 1986-1989 involved a considerable consultation with consumers who perceived food irradiation negatively. As a result, Australia placed a moratorium on food irradiation and the New Zealand government issued a policy statement that "irradiation processing of food for human consumption will not be permitted in New Zealand at the present time".

However, by about 2000 over 50 countries had enacted regulations permitting at least some uses of food irradiation. Although the Codex Standard refers to any food irradiated up to an overall dose of 10 kGy being safe and wholesome, the regulations generally were more restrictive, specifying both the purpose of irradiation and the foods that could be treated. Many countries opted to approve classes of food, including fruits and vegetables as documented in Part 2.3.

The safety assessments carried out by national regulatory or food safety agencies prior to publishing their food irradiation regulations are not easily available. An exception is the USFDA which publishes its Rule Making process via the Federal Register. It is likely that many of the older national safety assessments were reviews of the adequacy of the JECFI (1981) and Codex recommendations, recommendations that had received further, later endorsements from international authorities (WHO 1994, 1999, 2003, SCF 2002, 2003, EFSA 2011a,b). An example is the UK approval process described by Kilcast (1994). An Advisory Committee on Irradiated and Novel Foods was established and reported in 1986, broadly endorsing the JECFI recommendations with new regulations enacted in 1991.

PART 5 - THE IMPLICATIONS

5.1. Environmental

Phytosanitary irradiation (≤ 1.0 kGy) of fresh fruit and vegetables results in a reduced environmental impact relative to some traditional processes, e.g. use of postharvest insecticides or methyl bromide fumigation. There is no chemical residue from irradiation treatment and approval of phytosanitary irradiation will result in reductions in pesticide use and disposal, storage of postharvest insecticides on-farm and reduced workplace health safety issues. Methyl bromide is an ozone-depleting substance and is on the list of banned ozone-depleting substances under the Montreal protocol; however, it was granted a critical use exemption for use as a phytosanitary treatment for agricultural commodities (UNEP 2019). Nevertheless, there is an intention to reduce its use and replace it with alternative measures (FAO IPPC 2008; UNEP 2016). Acceptance of phytosanitary irradiation for imports into the USA is based, in part, on a strategy towards decreasing the dependence of the USA on MeBr use.

An environmental assessment on “Irradiation for Phytosanitary Regulatory Treatment” found that there was no need for an environmental impact statement (USDA 1997). Potential environmental consequences were analysed, and no significant impact on the quality of the human environment was found for irradiation as a phytosanitary regulatory treatment of fruit and vegetables. No adverse impacts to threatened or endangered species or their habitats were anticipated, and no disproportionate effects on any minority and low-income populations were found. “The overall effect from the use of irradiation treatments, therefore, is regarded as positive.”

In 2002, APHIS undertook an environmental assessment regarding the Rule on “Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables” (USDA 2002) and concluded that the irradiation methods in this rule would not present a risk of introducing or disseminating plant pests and would not have a significant impact on the quality of the human environment. Therefore, an environmental impact statement need not be prepared. The use of phytosanitary irradiation would have an insignificant environmental impact and, by decreasing the use of methyl bromide, would have a net positive effect.

There are strict guidelines and standards on the establishment and routine operation of irradiation facilities and, transport and disposal of radioactive material. The second food irradiation facility being constructed in Melbourne is an X-ray facility. It uses an electrically-driven accelerator to produce X-rays and no radioactive material is involved. This is an example of a trend to non-radioactive radiation sources that is expected to increase.

The use of irradiation (and any other phytosanitary measure) is to prevent the spread of plant pests which could have devastating impacts and severe consequences for industries, communities and the environment.

5.2. Consumer acceptance

There have been numerous surveys of consumer acceptance of irradiation (see Applications A1038, A1069, A1092, A1115 and the related FSANZ risk assessments) with most indicating consumer opposition or reluctance to purchase. The FSANZ risk assessments consider irradiation as one of a number of recently introduced food technologies (such as genetic modification) that cause concern among many consumers (FSANZ 2008).

However, in many cases the assessments of irradiation were conducted in situations when irradiated produce was not available for sale and there was no option to fully evaluate or purchase irradiated product. A need to examine actual consumer behaviour was emphasized in a recent review on consumer attitudes by Roberts and Henon (2015). The major finding of the review was:

> "A significant number of consumers around the world have now purchased and re-purchased irradiated fresh produce, meat products and a few other products. The evidence is substantial that while a fraction of the public will not buy irradiated food, a much larger fraction will".

Bruhn (1999) suggested that an alternative to conducting consumer surveys is to acknowledge the fact that the availability of irradiated foods in the marketplace is itself an endorsement of product quality and safety. The world-wide use of irradiation for both sanitary and phytosanitary purposes has recently begun to increase. It may be approximately 1 million tonnes per year (Roberts and Follett 2018). The increasing use of phytosanitary irradiation by Mexico, Vietnam and some other Asian countries in order to gain overseas market access is even greater than in Australia. At least 15 countries are now involved in the import and/or export of irradiation fruits and vegetables which totalled over 40,000 tonnes in 2017 (Table 1 and USDA 2018).

A good example of retailers' assumptions on consumer perceptions of irradiated food is the case study of Australian mangoes to New Zealand. In the first few years of exports the major chains did not stock irradiated mangoes but several small independent stores did. After several years of successful sales irradiated mangoes can now be purchased from both major and independent stores (Roberts and Henon 2015). There has been no negative reaction to 15 years of irradiated mango sales in New Zealand. Retail sales of irradiated tomatoes have been far smaller but, apart from some negative comments from the domestic tomato industry and some members of the public prior to the commencement of such trade, there has been no adverse reaction since.

The amount of irradiated produce available within Australia has been under 100 tonnes per year (Table 9). However, there has been no protests or negative publicity regarding irradiated fruit on the domestic market and the low volume of treated produce simply reflects the fact that produce grown and sold on the east coast of Australia can now be sold without the need for treatment for fruit fly. It also suggests that for access to restricted markets such as Tasmania that methyl bromide fumigation or postharvest treatment with insecticides are still the predominant treatments

There is no obvious example worldwide where a product has been withdrawn from a market because it is irradiated (Roberts and Henon 2015). In some case sales may not have grown as rapidly as expected but this does not mean consumers are rejecting products because they are irradiated. In some instances, the cost of imported crops cannot compete with locally grown produce or the supply chain logistics are too onerous for perishable commodities (e.g. it can take up to six weeks to sea freight products from Australia to the United States).

Alternative treatments such as heat and cold treatment are routinely suggested as viable alternatives to irradiation. While this may be true for some lucrative export markets the fact that not a single business in Queensland is currently registered for either treatment suggests industry does not view them as viable alternatives for the domestic market.

All three technologies, heat and cold treatments and irradiation, are physical treatments. While irradiation has been perceived negatively, cold and heat treatments are actively promoted as alternatives to irradiation. This may stem from the fact that consumers and retailers are familiar with heat and cold treatments while the technical aspects of irradiation are largely unknown or completely misinterpreted by the general public (Roberts and Henon 2015).

There is certainly a lack of knowledge and understanding of food irradiation as recorded consistently in numerous surveys on consumer attitudes, particularly in the US (Bord and O'Connor 1989, Bruhn 1995, 1999, ICGFI 1999, DeRuiter and Dwyer 2002, Nayga *et al*. 2005, Gunes and Tekin 2006, Mehmetoglu 2007). The studies also revealed that providing accurate information about food irradiation could influence consumer choice in purchasing irradiated food products, hence expanding the market for these products as public perception of irradiation matures and confidence develops.

Similar results were recorded for both Australian and New Zealand consumers (Gamble *et al*. 2002). The people who were surveyed lacked knowledge about irradiation and use of the technology as a disinfestation treatment and that influenced their perception and choice to purchase irradiated products. Respondents appeared to be more positive in supporting food irradiation over other chemical alternatives when they were made aware of the purpose or need for the disinfestation treatment in fruit and vegetables. Concerns about pesticide residues, preservatives and microbiological contamination rated higher than irradiation.

There is educational material to help consumers make better-informed choices regarding irradiated fruit and vegetables. Various government bodies have produced communication factsheets to assist consumers and industry and government, e.g. Queensland Health and FSANZ (QH 2010, FSANZ 2013b). The ICGFI and the IAEA have also produced numerous publications and information sheets about food irradiation to help address various aspects of concern and these can be accessed from their website www.iaea.org.

The mandatory labelling of irradiated fruit and vegetables provides consumers with choice when it comes to purchasing or not purchasing irradiated fruit and vegetables.

PART 6 - STATUTORY DECLARATION

Statutory Declaration – Australia

STATUTORY DECLARATION

Statutory Declarations Act 1959 [1]

I, Peter Leach, Senior Principal Entomologist, in the Queensland Department of Agriculture and Fisheries, 21 Redden Street, Portsmith, Qld 4870 make the following declaration under the *Statutory Declarations Act 1959*:

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

I understand that a person who intentionally makes a false statement in a statutory declaration is guilty of an offence under section 11 of the *Statutory Declara*[redacted] are true in every particu[redacted]

Declared at [redacted]

Selwyn Noel Leslie Johnston
Justice of the Peace (Qualified)
State of Queensland

Justice of the Peace Branch
Department of Justice and Attorney-General
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[*Signature of person before whom the declaration is made*][2]
[*Full name, qualification and address of person before whom the declaration is made (in printed letters)*]

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[1] http://www.comlaw.gov.au/Series/C1959A00052.
[2] A statutory declaration must be made before a prescribed person under the *Statutory Declarations Act 1959*. The list of prescribed persons is available in the Statutory Declarations Regulations 1993 at http://www.comlaw.gov.au/Series/F1996B00198.

REFERENCES

This reference section contains all the application references from the main text and Appendices. Highlighted references are new references that have not been included in previous QDAF submissions to FSANZ.

ABS, Australian Bureau of Statistics. (2014). Australian Bureau of Statistics 4364.0.55.007 – Australian Health Survey: Nutrition First Results – Foods and Nutrients, 2011–12. Table 10. Accessed October 2019 at http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4364.0.55.0072011-12?OpenDocument

ABS, Australian Bureau of Statistics. (2019). Value of Agricultural Commodities Produced, Australia, 2017-2018. 7503.0. See data cubes. Accessed October 2019 at https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7503.02017-18?OpenDocument

Akamine, E.K, and Goo, T. (1971). Respiration of gamma-irradiated fresh fruits. *Journal of Food Science 36* (7), 1074–1076.

Akamine, E.K., and Moy, J.H. (1983). Delay in Postharvest Ripening and Senescence of Fruits. In E.S. Josephson and M.S. Peterson (Eds.), *Preservation of Food by Ionizing Radiation*, Vol III. (pp. 129–158). CRC Press, Inc., Boca Raton, Florida.

Akhter, F., Islam, M., Khatun, A. and 4 others (2013). Biochemical composition and effects of radiation on sensory, biochemical and physiological qualities of fresh spinach. *Int. J. Biosciences 3 (5)* 25-34.

Al-Kuraieef, A.N., Alshawi, A.H., and Alasuhaibani, A.M.A. (2019). Effect of combined action of potassium sorbate and irradiation on the quality maintenance of strawberries. *J. Food Sci. Technol. 56 (7)* 3374-3379.

Al-Suhaibani, A.M. and Al-Kuraieef. A.N. (2016). The effects of gamma irradiation on the microbiological quality and anti-oxidant activity of spinach. *Int. J. ChemTech Res. 9 (6)* 39-47.

ANT, AntionGlobal. (2018). 8 May. Regulations Requirements on Food Irradiation in China. Accessed October 2019 at http://www.antionchina.com/en/News/2018/050X0502018.html

APPPC, Asia Pacific Plant Protection Commission. (2014). Approval of Irradiation Facilities. Regional Standards for Phytosanitary Measures, APPPC RSPM No 9.

APVMA, Australian Pesticides and Veterinary Medicines Authority. (2014). Final Fenthion Review Decision. Accessed October 2019 at https://apvma.gov.au/node/12271

APVMA, Australian Pesticides and Veterinary Medicines Authority. (2015). Fenthion Chemical Review. Last update September 2017. Accessed October 2019 at https://apvma.gov.au/node/12541

APVMA, Australian Pesticides and Veterinary Medicines Authority. (2017). Dimethoate: Regulatory decisions. The reconsideration of the active constituent dimethoate, registration of products containing dimethoate and approvals of their associated labels. Accessed October 2019 at http://apvma.gov.au/sites/default/files/publication/26571-dimethoate-regulatory-decision-report-final_0.pdf

Armstrong, J. (2019). Response to an additional information request from the EPA. Updated report on methyl bromide destruction and recapture technologies. A report to the STIMBR Board. 28 June.

Arvanitoyannis, I.S., and Stratakos, A.Ch. (2010a). Irradiation of Insects: Disinfestation. In: I.S. Arvanitoyannis (Ed.), *Irradiation of Food Commodities* (pp.537–560). Elsevier, London, U.K.

Arvanitoyannis, I.S., and Stratakos, A.Ch. (2010b). Irradiation of Fruits and Vegetables. In: I.S. Arvanitoyannis (Ed.), *Irradiation of Food* Commodities (pp. 467–535). Elsevier, London, U.K.

ASTM, (2013). ISO/ ASTM International Standard ISO / ASTM51702–13. Standard Practice for Dosimetry in a Gamma Facility for Radiation Processing, ASTM International, West Conshohocken, PA, USA. DOI: 10.1520/ISOASTM51702–13 PA. Accessed October 2019 at https://www.astm.org/Standards/ISOASTM51702.htm

ASTM, (2014). Active standard ASTM International ASTM F1355–06. Standard Guide for Irradiation of Fresh Agricultural Produce as a Phytosanitary Treatment, ASTM International, West Conshohocken, PA, USA. DOI: 10.1520/F1355-06R14. Accessed October 2019 at https://www.astm.org/Standards/F1355.htm

ASTM, (2015). ISO / ASTM International Standard 52303–15. Standard Guide for Absorbed-Dose Mapping in Radiation Processing Facilities, ASTM International, West Conshohocken, PA, USA. DOI: 10.1520/ISOASTM52303-15. (2003 doc). Accessed October 2019 at https://www.astm.org/Standards/ISOASTM52303.htm

ASTM (2016). ASTM International ASTM F1640–16. Standard Guide for Selection and Use of Packaging Materials for Foods to Be Irradiated, ASTM International, West Conshohocken, PA, USA. DOI: 10.1520/F1640-16. (2009 doc). Accessed October 2019 at https://www.astm.org/Standards/F1640.htm

Aylangan, A and Erhan, I.C. (2014). Quality of mandarins (*Citrus reticulata* Blanco) influenced by gamma irradiation. *Report of the Turkish Atomic Energy Authority.* Ankara University.

Baker, G.A., and Crosbie, P.J. (1993). Measuring Food Safety Preferences: Identifying Consumer Segments. *Journal of Agricultural and Resource Economics 18*(2), 277–287.

Baker, G.A. (1999). Consumer Preferences for Food Safety Attributes in Fresh Apples: Market Segments, Consumer Characteristics, and Marketing Opportunities. *Journal of Agricultural and Resource Economics 24(1)*, 80–97.

Banerjee, A, Chatterjee, S, Variyar, P.S. and Sharma, A (2016). Shelf life extension of minimally process, ready-to-cook (RTC) cabbage by gamma irradiation. *J. Food Sci. Technol. 53 (1)* 233-244.

Bord, R.J., and O'Connor, R.E. (1989). Who wants irradiated food? Untangling complex public opinion. *Food Technology 43(10)*, 87–90.

Bruhn, C.M. (1995). Consumer attitudes and market response to irradiated food. *Journal of Food Protection 58(2)*, 175–181.

Bruhn, C.M. (1999). Consumer Attitudes and Market Response to Irradiated Food. International Consultative Group on Food Irradiation (ICGFI). Available from the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Vienna, Austria.

Burditt, Jr. A.K. (1996). Irradiation as a Quarantine Treatment against Fruit Flies. In G. McPheron, G. and Steck, G. (Eds.), *Fruit Fly Pests: A World Assessment of their Biology and Management* (pp. 479–484). St Lucie Press, Delaray Beach Florida.

CAC, Codex Alimentarius Commission. (1983). Codex Standard Recommended International Code of Practice for the Operation of Irradiation Facilities Used for the Treatment of Foods (CAC/RCP 19–1979 (Rev. 1– 1983). Codex Alimentarius, FAO/WHO, Rome. Accessed October 2019 at http://siweb.dss.go.th/standard/Fulltext/codex/CXP_019E.pdf

CAC, Codex Alimentarius Commission. (2003a). General Standard for Irradiated Foods (CODEX STAN 106_1983, Rev.1–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed October 2019 at http://www.codexalimentarius.net/download/standards/16/CXS_106e.pdf

CAC, Codex Alimentarius Commission. (2003b). Code of Practice for Radiation Processing of Food (CAC/RCP 19–1979 (Rev. 2–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed October 2019 at http://www.codexalimentarius.net/download/standards/18/CXP_019e.pdf

CAC, Codex Alimentarius Commission. (2003c). Code of Hygienic Practice for Fresh Fruits and Vegetables (CAC/RCP 53–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed October 2019 at http://www.fao.org/input/download/standards/10200/CXP_053e_2013.pdf

CAC, Codex Alimentarius Commission. (2003d). Codex Standard Recommended International Code of Practice General Principles of Food Hygiene CAC/RCP 1–1969, Rev. 4–2003. Codex Alimentarius, FAO/WHO, Rome. Accessed October 2019 at http://www.fao.org/input/download/standards/23/CXP_001e.pdf

CAC, Codex Alimentarius Commission. (2003e). General Methods for the Detection of Irradiated Foods (CODEX STAN 231, Rev.1–2003). Codex Alimentarius, FAO/WHO, Rome. Accessed October 2019 at http://www.codexalimentarius.net/download/standards/377/CXS_231e.pdf

Cassidy, J.P, Caulfield, C, Jones, B.R, Worrall, L, Conlon, L, Palmer, A.C, and Kelly, J. (2007). Leukoencephalomyelopathy in Specific Pathogen–Free Cats. *Veterinary. Pathology 44,* 912–916.

Caulfield, C.D., Cassidy, J.P. and Kelly, J.P. (2008). Effects of Gamma Irradiation and Pasteurization on the Nutritive Composition of Commercially Available Animal Diets. *Journal of the American Association for Laboratory Animal Science 47(6)*: 61–66.

Caulfield, C.D, Kelly, J.P, Jones, B.R, Worrall, S., Conlan, L., Palmer, A.C., and Cassidy, J.P. (2009). The Experimental Induction of Leukoencephalomyelopathy in Cats. *Veterinary Pathology 46*, 1258–1269.

CFIA, Canadian Food Inspection Agency. Canada Food and Drugs Act. (2009). Food and Drug Regulations Div 26 Food Irradiation. Accessed October 2019 at https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._870/FullText.html#h-574534

Cho, Y. J., Kim, K. H., and Yook, H. S. (2016). Effect of low-dosage electron beam irradiation on antioxidant activities of navel oranges during storage at a low temperature of 3°C. *Food Science and Biotechnology 25(2),* 601–606.

Child, G, Foster, D.J, Fougere, B.J, Milan, J.M, and Rozmanec, M. (2009). Ataxia and Paralysis in Cats in Australia Associated with Exposure to Imported Gamma–Irradiated Commercial Dry Pet Food. *Australian Veterinary Journal 87(9),* 349–351.

Chaturvedi, A, Sujatha, V, Ramesh, C. and Dilip Babu, J. (2013). Development of shelf stable intermediate moisture carrot shreds using radiation as a hurdle technology. *Int. Food Research Journal. 20(2)* 775-781.

Contreras-Oliva, A., Perez-Gago, M.B., Palou, L., and Rojas-Argudo, C. (2011). Effect of insecticidal atmosphere and low dose x-ray irradiation in combination with cold quarantine storage on bioactive compounds of clementine mandarins cv. "Clemenules'**.** *International Journal of Food Science* **&** *Technology 46,* 612–619.

Crews, C, and Castle, L. (2007). A review of the occurrence, formation and analysis of furan in heat-processed foods. *Trends in Food Science and Technology 18 (7)*, 365–372.

Da Silva, S.R., Bezerra, D.N.F., Bassan, M.M. and 2 others (2016). Postharvest of irradiated Tahiti Lime Fruits. *Rev.Bras. Frutic. Jaboticabal-SP, 38(4)* e-272. http://dx.doi.org/10.1590/0100-29452016272

De Figueiredo, S. G., Silva-Sena, G.G., de Santana, E.N. and 3 others (2014). *J. Food Process. Technol. 5(6)* doi:10.4172/2157-7110.1000337

De Lima, C.P.F., Mansfield, E.R., and Poogoda, S.R. (2017). International market access for Australian tablegrapes through cold treatment of fruit flies with a review of methods, model and data for fresh fruit disinfestation. *Australian Journal of Grape and Wine Research 23,* 306-317.

DeRuiter, F.E., and Dwyer, J. (2002). Consumer Acceptance of Irradiated Foods: Dawn of a new era? *Food Service Technology 2(1)*, 47–58.

Devi, M.P., Sahoo, M.R., Kuna, A. and 2 others (2018). Effect of gamma irradiation on nutritional properties and anti-nutritional content of *Citrus jambhiri* Lush, K. *Pharmacognosy Phytochemistry 7 (4)* 2833-2836.

Diehl, J.F. (1995). Chemical Effects of Ionizing Radiation. In: *Safety of Irradiated Foods, 2nd Ed*., CRC Press, New York, pp. 41–94.

DA, Department of Agriculture, Australia, formerly Department of Agriculture and Water Resources. (2018). Australian phytosanitary treatment application standard for irradiation treatment. Accessed October 2019 at http://www.agriculture.gov.au/SiteCollectionDocuments/biosecurity/export/plants-plant-products/plant-exports-manual/resources/phytosanitary-treatment-irradiation.pdf

DA, Department of Agriculture, Australia. (2019a). MICoR. Manual of Importing Countries Requirements. Accessed October 2019 at https://micor.agriculture.gov.au/Plants/Pages/SearchResults.aspx?k=irradiation

DA, Department of Agriculture, Australia. (2019b). BICON, Biosecurity Import Conditions System. Accessed October 2019 at http://www.agriculture.gov.au/import/online-services/bicon

DOH, Department of Health, Republic of South Africa. (2013). Guidelines for Monitoring Irradiated Foodstuffs in South Africa. Food Control Directorate, Department of Health Pretoria, South Africa.

EFSA, European Food Safety Authority. (2011a). Scientific Opinion on the Chemical Safety of Irradiation of Food. *EFSA Journal 9(4),* 1930, pp57. Accessed October 2019 at http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2011.1930/epdf

EFSA, European Food Safety Authority. (2011b). Statement summarising the Conclusions and Recommendations from the Opinions on the Safety of Irradiation of Food adopted by the BIOHAZ and CEF Panels. *EFSA Journal 9(4),* pp2107. Accessed October 2019 at http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2011.2107/epdf

EPA, Environment Protection Authority Victoria (2019). Environment Protection Regulations Exposure Draft. Division 3- Protection of the ozone layer. Accessed October 2019 at https://engage.vic.gov.au/new-environmental-laws/subordinate-legislation

EU, European Union. (1999a). Directive 1999/2/EC of the European Parliament and of the Council. Foodstuffs treated with Ionizing Radiation. February 22nd 1999. Official Journal of the European Communities. Accessed October 2019 at http://eur-lex.europa.eu/legal-content/EN/LSU/?uri=CELEX:31999L0002

EU, European Union. (1999b). Directive 1999/3/EC of the European Parliament and of the Council. On the Establishment of a Community List of Food and Food Ingredients Treated with Ionizing Radiation. February 22nd 1999. Official Journal of the European Communities. Accessed October 2019 at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:31999L0003

EU, European Union. (2009a), Official Journal of the EU, OJC 283/5, EC 2009. List of Member States' Authorisations of Food and Food Ingredients which may be Treated with Ionising Radiation. Accessed October 2019 at http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52009XC1124(02)

EU, European Union. (2009b). European Commission Directive 2009/975/EC Amending Directive 2002/72/EC Relating to Plastic Materials and Articles Intended to Come into Contact with Food. 19 October 2009. Official Journal of the European Communities Accessed October 2019 at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:274:0003:0008:EN:PDF

EU, European Union. (2009c). European Commission Legislation. Analytical Methods Official Journal of the European Communities Accessed October 2019 at https://ec.europa.eu/food/safety/biosafety/irradiation/legislation_en

Fan, X. (2005). Formation of Furan from Carbohydrates and Ascorbic Acid Following Exposure to Ionizing Radiation and Thermal Processing. *Journal of Agricultural and Food Chemistry 53 (20),* 7826-7831.

Fan, X., and Sokorai, K.J. (2008). Effect of Ionising Radiation on Furan Formation in Fresh–Cut Fruits and Vegetables. *Journal of Food Science 73*, C79–C83.

Fan, X. and Sokorai, K.J.B. (2011). Changes in Quality, Liking and Purchase intent of irradiated fresh-cut spinach during storage. *J. Food Science 76(6)* S364-S368.

Fan, X., Guan, W., and Sokorai, K.J.B. (2012). Quality of fresh-cut Iceberg lettuce and spinach irradiated at doses up to 4kGy. *Radiation Physics and Chemistry 81(8),* 1071–1075.

FAO/IAEA, Food and Agriculture Organisation/International Atomic Energy Agency. (2013). International Database on Insect Disinfestation and Sterilisation. Accessed October 2019 at https://nucleus.iaea.org/Pages/ididas.aspx

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2003). 2016 Version Published. International Standards for Phytosanitary Measures, ISPM No. 18 Guidelines for the Use of Irradiation as a Phytosanitary Measure. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy, 2006. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2016/01/ISPM_18_2003_En_2015-12-22_PostCPM10_InkAmReformatted.pdf

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2005). 2017 Version Published. International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 24 Guidelines for the Determination and Recognition of Equivalence of Phytosanitary Measures. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2017/05/ISPM_24_2005_En_2017-05-25_PostCPM12_InkAm.pdf

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2007). 2016 Version Published. International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28 Phytosanitary Treatments for Regulated Pests (2007), Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the United Nations, Rome, Italy. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2016/01/ISPM_28_2007_WithoutApp1_En_2015-12-22_PostCPM10_InkAmReformatted.pdf

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2008). 2017 Version Published. International Plant Protection Convention, IPPC (2008). Replacement or Reduction of the Use of Methyl Bromide as a Phytosanitary Measure. Recommendation for the Implementation of the IPPC. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2017/04/R_03_En_2017-04-26_Combined.pdf

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2009a). 2016 Version Published. International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28, Annex 04. Phytosanitary Treatments for Regulated Pests. Irradiation Treatment for *Bactrocera jarvisi*. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2016/06/PT_04_2009_En_2016-04-22_PostCPM11_InkAm.pdf

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2009b). 2016 Version Published. International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28, Annex 05. Phytosanitary Treatments for Regulated Pests. Irradiation Treatment for *Bactrocera tryoni*. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2016/06/PT_05_2009_En_2016-04-22_PostCPM11_InkAm.pdf

FAO IPPC, Food and Agriculture Organisation International Plant Protection Convention. (2009c).2016 Version Published. International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28, Annex 07. Phytosanitary Treatments for Regulated Pests. Irradiation Treatment for fruit flies of the family Tephritidae (generic). Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy. Accessed October 2019 at https://www.ippc.int/static/media/files/publication/en/2016/06/PT_07_2009_En_2016-04-22_PostCPM11_InkAm.pdf

FDA, US Food and Drug Administration. (1986). Irradiation in the Production, Processing, and Handling of Food; Final Rule. 51 (75) FR 13376–13399. 18 April. Docket No. 81N–0004.

FDA, US Food and Drug Administration. (2004). Furan in Food, Thermal Treatment; Request for Data and Information Federal Register [Docket No. 2004N–0205]. *Federal Register*. Vol 69, No. 90. Accessed October 2019 at https://www.gpo.gov/fdsys/search/pagedetails.action?st=04-10588&granuleId=04-10588&packageId=FR-2004-05-10

FDA, US Food and Drug Administration. (2007). Food and Drug Administration. Subpart C. Packaging Materials for Irradiated Foods **21** CFR 179.45 Packaging Materials for Use During Irradiation of Pre–packaged Foods. Accessed October 2019 at https://www.ecfr.gov/cgi-bin/text-idx?SID=3ef25686a345f03836a83c84e97c294e&mc=true&node=pt21.3.179&rgn=div5#se21.3.179_145

FDA, US Food and Drug Administration. (2008). Food and Drug Administration. Irradiation in the Production, Processing and Handling of Food, Food and Drug Administration. Final rule: Iceberg lettuce and spinach. *Federal Register*. Vol **73**, No. 164, 21 CFR Part 179. [Docket No. FDA–1999–F–2405]. 73 FR 49593.

FDA, US Food and Drug Administration. (2018). Food and Drug Administration. FDA Investigates Animal Illnesses Linked to Jerky Pet Treats. Accessed October 2019 at https://www.fda.gov/AnimalVeterinary/NewsEvents/ucm360951.htm

FDA, US Food and Drug Administration. (2019). Food and Drug Administration. Ionizing Radiation for the Treatment of Food. e–CFR, Electronic Code of Federal Regulations. **21** CFR Part 179.26. Sub–part B. Accessed October 2019 at https://www.ecfr.gov/cgi-bin/text-idx?SID=3ef25686a345f03836a83c84e97c294e&mc=true&node=pt21.3.179&rgn=div5

Follet, P. A., and Griffin, R. L. (2013). Irradiation as a Phytosanitary Treatment for Fresh Horticultural Commodities: Research and Regulations. In C.H. Sommers and X. Fan (Eds.), *Food Irradiation Research and Technology, Chapter 13* (pp227–249). Wiley-Blackwell Publications, Ames, Iowa.

Follett, P. A., and Neven, L.G. (2006). Current Trends in Quarantine Entomology. *Annual Review of Entomology 51*, 359–385.

Follett, P.A., and Sanxter, S.S. (2000). Comparison of Rambutan Quality after Hot Forced-Air and Irradiation Quarantine Treatments. *HortScience 35(7),* 1315–1318.

Follett, P.A., and Sanxter, S.S. (2002). Longan Quality after Hot-Water Immersion and X-ray Irradiation Quarantine Treatments. *HortScience 37(3)*, 571–574.

Follett, P.A., and Sanxter, S.S. (2003). Lychee Quality after Hot-Water Immersion and X-ray Irradiation Quarantine Treatments. *HortScience 38(6)*, 1159–1162.

Frimpong, G.K., Kottoh, I.D. and Ofosu, D.O. (2015). Gamma irradiation effect on the phytochemical and sensory quality of minimally processed cabbage in selected supermarkets in Accra – Ghana. *J. Yoga. Phys. Therapy 5(4)* doi:10.4172/2157-7595.1000206

FSANZ, Food Standards Australia New Zealand (2001). Previously Food Safety Australia New Zealand. Application A413. Irradiation of Herbs and Spices. Final Assessment Report and Regulatory Statement. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/documents/A413_FAR.pdf

FSANZ, Food Standards Australia New Zealand. (2002). Application A443. Irradiation of Tropical Fruit. Final Assessment Report. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/applicationa443irradiationoftropicalfruit/Default.aspx

FSANZ, Food Safety Australia New Zealand. (2008). TNS Social Research. *Consumer Attitudes Survey 2007*. Accessed October 2019 at http://www.foodstandards.gov.au/publications/documents/Consumer%20Attitudes%20Survey.pdf

FSANZ, Food Standards Australia New Zealand. (2011). Application A1038. Irradiation of Persimmons. Final Assessment Report. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/applicationa1038irra4655.aspx

FSANZ, Food Standards Australia New Zealand. (2013a). Application A1069. Irradiation of Tomatoes and Capsicums. Approval Report. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/applicationa1069irra5511.aspx

FSANZ, Food Standards Australia New Zealand. (2013b). Food Irradiation. Consumer Information Document. Accessed October 2019 at http://archive.foodstandards.gov.au/consumerinformation/

FSANZ, Food Standards Australia New Zealand (2014a). Application A1092. Irradiation of Specific Fruits and Vegetables. Approval Report. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/A1092-Irradiation.aspx

FSANZ, Food Standards Australia New Zealand. (2014b). Nutritional impact of phytosanitary irradiation of fruits and vegetables. Accessed October 2019 at http://www.foodstandards.gov.au/publications/Pages/Nutritional-impact-of-phytosanitary-irradiation-of-fruits-and-vegetables.aspx

FSANZ, Food Standards Australia New Zealand. (2016). Application A1115. Irradiation of Blueberries and Raspberries. Approval Report. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/A1115IrradiationBlueberriesandRaspberries.aspx

FSANZ, Food Standards Australia New Zealand. (2017). Standard 1.5.3. Irradiation of Food. Accessed October 2019 at https://www.legislation.gov.au/Series/F2015L00406

Gaffney, J., Hallman, and G., Sharp, J. (1990). Vapor heat research unit for insect quarantine treatments. *Journal of Economic Entomology 83*, 1965–1971.

Gamble, J., Harker, R., and Gunson, A. (2002). New Zealand and Australian Perceptions of Irradiated Food. *Report to the Horticulture and Food Research Institute of NZ Ltd.* Horticulture Australia Ltd., Sydney. ISBN 0 7341 0501 0.

GAZ, The Gazette of India, (2012). G.S.R. 158. Atomic Energy (Radiation Processing of Food and Allied Products) Rules. 30 June.

GHI, Global Harmonization Initiative. (2018). Consensus Document on Food Irradiation. Food irradiation legislations in Asia. Table 5, China, India, Indonesia, Malaysia, Pakistan, Thailand, Vietnam.

Guimaraes, I.C., Menezes, E.G.T., de Abreu, P.S. and 5 others (2013). Physicochemical and microbiological quality of raspberries treated with different doses of gamma radiation. *Food Sci. Technology, Campinas, 33(2)* 316-322. http://dx.doi.org/10.1590/S0101-20612013005000040

Gunes, G., and Tekin, M.D. (2006). Consumer awareness and acceptance of irradiated foods: Results of a survey conducted on Turkish consumers. *LWT Food Science and Technology 39*, 443–447. Swiss Society of Food Science and Technology.

HAL, Horticulture Australia Limited. (2002). Methyl bromide use and alternatives for disinfestation treatments. AH01034. Accessed October 2019 at https://ausveg.com.au/app/data/technical-insights/docs/AH01034.pdf

Hall EA, Leach PL and Kopittke RA. (2007) Non-Chemical Postharvest Disinfestation Treatments for Cucurbits against *Bactrocera cucumis* (French) (Diptera: Tephritidae). Proceedings of the Third International Symposium on Cucurbits. Acta Horticulturae. 731: 59-65.

Hallman, G.J. (1999). Ionizing radiation quarantine treatments against tephritid fruit flies. *Postharvest Biology and Technology 16*, 93–106.

Hallman, G.J. (2000). Expanding Radiation Quarantine Treatments Beyond Fruit Flies. *Agricultural and Forest Entomology 2*, 85–95.

Hallman, G.J. (2008). Potential Increase in Fruit Fly (Diptera: Tephritidae) Interceptions Using Ionizing Irradiation Phytosanitary Treatments. *Journal of Economic Entomol*ogy *101(3)*, 716–719.

Hallman, G. (2011). Phytosanitary Applications of Irradiation. *Comp. Reviews in Food Science and Food Safety 10*, 143–151.

Hallman, G. (2012). Generic phytosanitary irradiation treatments. *Radiation Physics and Chemistry 81(7),* 861–866.

Hallman, G., and Blackburn, C.M. (2016). Review. Phytosanitary irradiation. *Foods 5(1)*, 10p.

Heather, N.W., and Hallman, G.J. (2008a). Phytosanitation with Ionizing Radiation. In: *Pest Management and Phytosanitary Trade Barriers* (pp 132–152). CABI International, Wallingford, U.K.

Heather, N.W. and Hallman, G.J. (2008b). Pest Management and Phytosanitary Trade Barriers. CABI International, Wallingford, U.K: 257p. Standard book publication.

Hirashima, F.K., Fabbri, A.D.T., Sagretti, J.M.A. and 4 others (2013) Influence of gamma irradiation on phenolic compounds of minimally processed carrots. *Int. Nuclear Atlantic Conf. INAC-2013. Recife, PE, Brazil,* November 24-29*. ISBN:* 978-85-99141-05-2.

Hort Innovation Australia Limited. (2019a). Australian Horticulture Statistics Handbook. Vegetables 2017/18. Accessed October 2019 http://horticulture.com.au/resource/australian-horticulture-statistics-handbook/

Hort Innovation Australia Limited. (2019b). Australian Horticulture Statistics Handbook. Fruit 2017/18. Accessed October 2019 http://horticulture.com.au/resource/australian-horticulture-statistics-handbook/

Hort Innovation Australia Limited. (2019c). Australian Horticulture Statistics Handbook. Other Horticulture 2017/18. Accessed October 2019 http://horticulture.com.au/resource/australian-horticulture-statistics-handbook/

Hort NZ, Horticulture New Zealand, Plant & Food Research. (2017). Fresh facts New Zealand Horticulture. Accessed October 2019 at http://www.freshfacts.co.nz/files/freshfacts-2017.pdf

Hort NZ, Horticulture New Zealand, Plant & Food Research. (2018). Fresh facts. New Zealand Horticulture. Accessed October 2019 at https://www.freshfacts.co.nz/files/freshfacts-2018.pdf

Hussain, P.R., Dar, M.A. and Wani, A.M. (2012). Effect of edible coating and gamma irradiation on inhibition of mould growth and quality retention of strawberry during refrigerated storage. *Int. J. Food Sci. Technology 47* 2318-2324.

Hussain, P. R., Chatterjee, S., Variyar, P.S. and 3 others (2013). Bioactive compounds and antioxidant activity of gamma irradiated sun-dried apricots. *J. Food Comp Analysis 30* 59-66.

Hussain, P.R., Suradkar, P., Jacaid, S. and 2 others (2016). Influence of post-harvest irradiation on the content of bioactive compounds and antioxidant activity of fenugreek and spinach leaves. *Innovative Science and Emerging Technologies 33* 268-281.

IAEA, International Atomic Energy Agency. (2001). Consumer acceptance and market development of irradiated food in Asia and the Pacific, IAEA-TECDOC-1219. Proceedings of a Final Research Coordination Meeting organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Bangkok, Thailand, 21–25 September 1998. Food and Environmental Protection Section International Atomic Energy Agency, Vienna, Austria.

IAEA, International Atomic Energy Agency. EU (2009). Analytical detection methods for irradiated foods. A review of the current literature. IAEA-TECDOC-587. European Standards for Detection of Irradiated Foodstuffs. Accessed October 2019 at http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/22/033/22033514.pdf

IAEA, International Atomic Energy Agency. (2015). Manual of good practice in food irradiation. Sanitary, phytosanitary and other applications. Technical Reports Series 481. Accessed October 2019 at http://www-pub.iaea.org/MTCD/Publications/PDF/trs481web-98290059.pdf

IAEA IDCT, International Atomic Energy Agency International Database on Commodity Tolerance. (2017). Accessed October 2019 at https://nucleus.iaea.org/sites/naipc/IDCT/Pages/default.aspx

ICA, Interstate Certification Assurance (2011). National Protocol Number 55. Irradiation treatment. ICA 55 in Qld, Accessed October 2019 at http://www.interstatequarantine.org.au/wp-content/uploads/2016/05/QLD-ICA-55.pdf

ICA, Interstate Certification Assurance – Australian Interstate Quarantine. (2019). Moving plant goods inter-state. Front page accessed October 2019 at https://www.interstatequarantine.org.au/producers/interstate-certification-assurance/

ICGFI, International Consultative Group on Food Irradiation. (1991). Code of Good Irradiation Practice for Insect Disinfestation of Fresh Fruits (as a Quarantine Treatment). *ICGFI Document 7*. Joint FAO/IAEA Division, IAEA. Vienna. Accessed October 2019 at http://www-naweb.iaea.org/nafa/fep/public/manuals-fep.html .

ICGFI, International Consultative Group on Food Irradiation. (1999). Consumer attitudes and market response to irradiated food. International Consultative Group on Food Irradiation, Vienna. Accessed October 2019 at http://www-naweb.iaea.org/nafa/fep/public/consume.pdf

IPPC, International Plant Protection Convention. (2019a). Home page accessed October 2019 at https://www.ippc.int/en/

IPPC, International Plant Protection Convention. (2019b). International Standards for Phytosanitary Measures (ISPMs). Accessed October 2019 at https://www.ippc.int/core-activities/standards-setting/ispms.

Jamieson. L.E., Brown, S.D.J., Bellve, A., Follet, P.A., Armstrong, J.W., Wyatt, P.M., Maindonald, J.H., Golding, J.B., De Lima, C.P.F., Waddell, B.C. and Woolf, A.B. (2018). Improved postharvest market access treatments for horticultural commodities. PBCRC3097 Final Report: Executive Summary. Accessed October 2019 at http://www.pbcrc.com.au/research/project/3097/

JECFI, Joint FAO/IAEA/WHO Expert Committee on Food Irradiation. (1981). Wholesomeness of Irradiated Food. *Technical Report Series, No. 659*, World Health Organization, Geneva, Switzerland.

Jo, Y., Nam, H-A., Ramakrishnan, S.R. and 3 others. Jo, Y., Nam, H-A., Ramakrishnan, S.R. and 3 others. (2018). Post-harvest irradiation as a quarantine treatment and its effect on physicochemical and sensory qualities of Korean citrus fruit. *Scientia Horticulturae 236* 265-271.

Kader, A.A. (1986). Potential Applications of Ionizing Radiation in Post–Harvest Handling of Fresh Fruits and Vegetables. *Food Technology 40*, 117–121.

Kavitha, C., Kuna, A., Supraja, T. and 3 others (2015). Effect of gamma irradiation on anti-oxidant properties of ber fruit. *J. Food Sci. Technology 52(5)* 3123-3128.

Khan, Q.U., Mohammadzai, I., Shah, Z. and 4 others (2018). Effect of gamma irradiation on nutrients and shelf-life of peach stored at ambient temperature. *Open Conference Proceedings J. 9* 8-15. DOI: 10.2174/2210289201809010008

Khanh, N.T., Ly, N.T. The, D.T. and 2 others (2013), Study on irradiated VietnamJava rambutan fruit which was post-harvest treatment to prolong the shelf-life for export purposes. *Annual Report for VINATOM 2013* 180-190.

Khatun, A., Hossain, A., Islam, F. and 3 others (2012). Effect of gamma irradiation on antioxidant marker and microbial safety of fresh bitter gourd. *Int. J. Biosciences 11(2)* 43-49. http://www.innspub.net.

Kilcast, D. (1994). Effect of Irradiation on Vitamins. *Food Chemistry 49*, 157–164.

Kim, K.S., Seo, H.Y., Lee, J.M., Park, E.R., Kim, J.H., Hong, C.H., and Byun, M.W. (2004). Analysis of radiation-induced hydrocarbons and 2-alkylcyclobutanones from dried shrimps (*Penaeus aztecus*). *Journal of Food Protection 67(1),* 42–14.

Koch, S., Epp, A. Lohmann, M. and Boll, G.F. (2017). Pesticide residues in food: attitudes, beliefs and misconceptions among conventional and organic consumers. *J. Food Protection 80* (12) 2083-2089.

Koidsumi, K. (1930). Quantitative Studies on the Lethal Action of X–Rays upon Certain Insects. *J. Soc. Tropical Agriculture (Japan) 2*, 243–263.

Leach, P. (2019) Phytosanitary measures. In: Clarke, A.R. Biology and Management of Bactrocera and Related Fruit Flies. CAB International, Wallingford, U.K., 195-225.

Lim, S.J., Chung, B.Y., Park, M.G., and Cho, J.Y. (2013). Effect of γ-ray irradiation on food qualities and sprouting inhibition of sweet potato roots (*Lomea batataslam*). *Journal of Food Quality 36(5),* 309–315.

Loaharanu, P. (2003). Irradiated Foods, Fifth Edition. American Council on Science and Health. New York.

McDonald, H., Arpaia, M.L., Caporaso, F., Obenland, D., Were, L., Rakovski, C., and Prakash, A. (2013). Effect of gamma irradiation treatment at phytosanitary dose levels on the quality of 'Lane Late' navel oranges. *Postharvest Biology and Technology 86*, 91–99.

Mehmetoglu A.C., and Demirkol O. (2007). Preferences of Turkish people for irradiated, GM or organic foods. *Journal of Food, Agriculture and Environment 5*, 74–80.

Mohacsi-Farkas, Cs., Nyiro-Feketi, B., Daood, H., and 2 others (2014) Improving microbiological safety and maintaining sensory and nutritional quality of pre-cut tomato and carrot by gamma irradiation. *Rad. Phys. Chem. 99* 79-85.

MOH, Ministry of Health, New Zealand. (2003) NZ Food, NZ Children. 2002 National Children's Nutrition Survey, 2 November. Accessed October 2019 at https://www.health.govt.nz/publication/nz-food-nz-children

MOH, Ministry of Health, New Zealand. (2011). 2008/09 New Zealand Adult Nutrition Survey data tables. Chapter 4. Accessed October 2019 at http://www.health.govt.nz/publication/2008-09-new-zealand-adult-nutrition-survey-data-tables

Morris, S.C., and Jessup, A.J. (1994). Irradiation. In R.E. Paull and J.W. Armstrong (Eds.), *Insect Pests and Fresh Horticultural Products: Treatments and Responses* (pp. 163–190). CABI International, Wallingford, U.K.

Moy, J. (1993). Efficacy of Irradiation *vs* Thermal Methods as Quarantine Treatments for Tropical Fruits. *Radiation Physics and Chemistry 42,* 269–272.

Moy, J. and Wong, L. (1996). Efficacy of gamma-radiation as a quarantine treatment of fruits, herbs, and ornamentals for Hawaii. *Radiation Physics and Chemistry 48*, 373–374.

Moy, J.H., and Wong, L. (2002). The Efficacy and Progress in Using Radiation as a Quarantine Treatment of Tropical Fruits – A Case Study in Hawaii. *Radiation Physics and Chemistry 63*, 397–401.

MPI, Ministry for Primary Industries, New Zealand. (2018). Methyl Bromide 2020 Deadline. Accessed October 2019 at https://www.mpi.govt.nz/exporting/forest-products/wood-and-wood-products/methyl-bromide-2020-deadline/

MPI, Ministry for Primary Industries, New Zealand. (2019a). Methyl Bromide Information. Accessed October 2019 at https://www.mpi.govt.nz/dmsdocument/14869-methyl-bromide-information

MPI, Ministry for Primary Industries, New Zealand. (2019b). Standard 152.02. Importation and Clearance of Fresh Fruits and Vegetables into New Zealand. Accessed October 2019 at http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiFg8XmqcvVAhUBybwKHSe7CwIQFggmMAA&url=http%3A%2F%2Fwww.mpi.govt.nz%2Fdocument-vault%2F1147&usg=AFQjCNG62Q4PKW5q9_IYb5m9sknv0ZiWZQ

MPI, Ministry for Primary Industries, New Zealand. (2019c). Ministry of Agriculture and Forestry, New Zealand. Import Health Standards Issued pursuant to Section 24A of the Biosecurity Act 1993, MPI Biosecurity Authority, Wellington, NZ. Accessed October 2019 at http://www.mpi.govt.nz/law-and-policy/requirements/import-health-standards/

Mridha, F., Huque, R., Khatun, A. and 4 others (2017). Effects of gamma irradiation on Antioxidant markers, microbial population and sensory attributes of strawberry. *Plant Cell Biotech. Mol. Biol. 18* 208-218.

Najafabadi, N.S., Sahari, M.A., Barzegar, M. and Esfahani, Z.H. (2017). Effect of gamma irradiation on some physicochemical properties and bioactive compounds in jujube fruit. *Rad. Phys. Chem. 130 62-68.*

Nayga Jr., R.M., Aiew, W., and Nichols, J. P. (2005). Information Effects on Consumers' Willingness to Purchase Irradiated Food Products. *Review of Agricultural Economics 27(1),* 37–48.

Nunes, T.P., Martins, C.G., Faria, A.F. and 5 others (2013). Changes in total ascorbic acid and carotenoids in minimally processed irradiated arugula stored under refrigeration. *Rad. Phys. Chem. 90* 125-130.

NSW DPI, New South Wales Department of Primary Industries. (2015). Application to amend Standard 1.5.3 Irradiation of Food of the Food Standards Code to include Raspberry (*Rubus idaeus)* and Blueberry (*Vaccinium corymbosum, Vaccinium strigosus, Vaccinium angustifolium, Vaccinium virgatum* v *ashei)*. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/A1115IrradiationBlueberriesandRaspberries.aspx

NZ Herald, New Zealand Herald. (2018). Methyl bromide suspected as Tauranga port worker quarantined and decontaminated. 9 March. Accessed October 2019 at https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12009447

NZIER, New Zealand Institute of Economic Research. (2007). Benefits of Imported Fresh fruit and Vegetables. Report to the New Zealand Fresh produce Importers' Association Inc.

Oner, M.E., and Wall, M.M. (2013). Quality of fresh-cut purple-fleshed sweet potatoes after X-ray irradiation treatment and refrigerated storage. *International Journal of Food Science and Technology 48(10),* 2064–2070.

Ornelas-Paz, J. de J., Meza, M. B., Obenland, D. and 4 others (2017). Effect of phytosanitary irradiation on the postharvest quality of seedless Kishu mandarins. *Food Chemistry 230* 712-720.

PHA (2018). Plant Health Australia National Plant Biosecurity Status Report. Accessed October 2019 at https://www.planthealthaustralia.com.au/national-programs/national-plant-biosecurity-status-report/

Pinela, J., Barreira, J.C.M., Barros, L. and 6 others (2016). Suitability of gamma irradiation for preserving fresh-cut watercress quality during cold storage. *Food Chemistry 206* 50-58.

Pinela, J., Barros, L, Barreira, J.C.M. and 5 others (2018). Postharvest changes in the phenolic profile of watercress induced by post-packaging irradiation and modified atmosphere packaging. *Food Chemistry 254* 70-77.

PNS (2015). Philippine National Standard. Code of Practice for the Radiation Processing of Food. PNS/BAFS 151.

Prowse, W. (2019). Appendix 6 of this Application. Fruit and vegetable consumption in Australia and New Zealand. A report by Fresh Intelligence Consulting.

QLD DAF, Queensland Department of Agriculture and Fisheries. (2012). Formerly Department of Employment, Economic Development and Innovation. 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. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/applicationa1069irra5511.aspx

QLD DAF, Queensland Department of Agriculture and Fisheries. (2013). Formerly Queensland Department of Primary Industries, Fisheries and Forestry. Application to amend Standard 1.5.3 Irradiation of Food of the Food Standards Code to apple, apricot, cherry, honeydew melon, nectarine, peach, plum, rockmelon, strawberry, table grape and zucchini using Irradiation as a Phytosanitary Measure. Accessed October 2019 at http://www.foodstandards.gov.au/code/applications/Pages/A1092-Irradiation.aspx

QH, Queensland Health. (2010). Food Irradiation. Accessed October 2019 at https://publications.qld.gov.au/dataset/potentially-hazardous-foods/resource/30a4630e-72e9-49ef-bf8e-6de4da54f05c

Rezaee, M., Almassi, M., Minaei, S., and Paknejad, F. (2013). Impact of post-harvest radiation treatment timing on shelf life and quality characteristics of potatoes. *Journal of Food Science and Technology 50(2),* 339–345.

Rojas-Argudo, C., Paloua, L., Bermejob, A., Canob, A., del Ríoa, M.A., and González-Masb. M.C. (2012). Effect of X-ray irradiation on nutritional and antifungal bioactive compounds of ‘Clemenules’ clementine mandarins. *Postharvest Biology and Technology 68,* 47–53.

Roberts, P.B. (2016). Food Irradiation: standards, regulations and world-wide trade. Rad. Phys. Chem. 129. 30-34.

Roberts, P.B. and Follett, P.A (2018). Food irradiation for phytosanitary and quarantine requirements. In. Food Irradiation Technologies; Concepts, Applications and Outcomes. (Editors, Ferreira, I.C.F.R. Amilcar, L.A. and Cabo Verde, S.). Royal Society of Chemistry. London. Chapter 9 (pp169-182). DOI 10.1039/9781788010252

Roberts, P.B., and Hénon, Y.M. (2015). Consumer response to irradiated food: Purchase versus perception. *Stewart Postharvest Review 11(3),* 1–6.

SA, Standards Association of Australia. (1999). Australian Standard AS2070 –1999. Australian Standard for Plastics Materials for Food Contact Use. Standards Association of Australia, NSW 2140. Accessed October 2019 at http://www.saiglobal.com/PDFTemp/Previews/OSH/As/as2000/2000/2070.pdf

Sarker, S., Hussain, M.S., Khatun, A. and 3 others (2014). Development of gamma-irradiated low microbial vegetable salads for immunocompromised patients. *Annals Food Science Technology 15(1)* 203-219.

SCF, Scientific Committee on Food. (2002). Statement of the Scientific Committee on Food on a Report on 2–alkylcyclobutanones. Accessed October 2019 at https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scf_out135_en.pdf

SCF, Scientific Committee on Food. (2003). Revision of the Opinion of the Scientific Committee on Food on the Irradiation of Food. Accessed October 2019 at https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scf_out193_en.pdf

Thomas, P. (1986a). Radiation Preservation of Foods of Plant Origin III. Tropical Fruits: Bananas, Mangoes and Papayas. *CRC Critical Reviews in Food Science and Nutrition 23(2),* 147–205.

Thomas, P. (1986b) Radiation Preservation of Foods of Plant Origin. Part IV. Subtropical Fruits: Citrus, Grapes and Avocados. *CRC Critical Reviews Food Science and Nutrition 24(1),* 53–89.

Thomas, P. (1986c) Radiation Preservation of Foods of Plant Origin. Part V. Temperate Fruits: Pome Fruits, Stone Fruits and Berries. *CRC Critical Reviews Food Science and Nutrition 24(4),* 357–400.

Thomas, P. (1988) Radiation Preservation of Foods of Plant Origin VI. Mushrooms, Tomatoes, Minor Fruits and Vegetables, Dried Fruits, and Nuts. *CRC Critical Reviews Food Science and Nutrition 26(4),* 313–358.

TNZ. TomatoesNZ. (2018) Tomato-Imports-2018. Link available at the TomatoesNZ Industry Statistics website. Accessed October 2019 at https://www.tomatoesnz.co.nz/industry/statistics/

Tripathi, J., Chatterjee, S., Vaishnav, J. and 2 others (2013). Gamma irradiation increases storability and shelf-life of minimally-processed ready-to-cook (RTC) ash gourd cubes. *Postharvest Biol. Technology 76* 17-25.

Tripathi, J. Gupta, S., Mishra, P.K. and 2 others (2014). Optimization of radiation dose and quality parameters for development of ready-to-cook pumpkin cubes using a statistical approach. *Innovative Food Science and Emerging Technologies 26* 248-256.

UNEP, United Nation Environmental Program. (2016). Minimising Quarantine and Pre-shipment (QPS) use of Methyl; Bromide. Document produce by the OzoneAction Programme of UNEP. Accessed October 2019 at https://wedocs.unep.org/bitstream/handle/20.500.11822/14879/7792-e-Minimisingquarantineandpre-shipment%28QPS%29usesofmethylbromide.pdf?sequence=1&isAllowed=y

UNEP, United Nation Environmental Program. (2019). Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer. Thirteenth Edition. Ozone Secretariat of UNEP. Accessed October 2019 at https://ozone.unep.org/sites/default/files/2019-08/MP_Handbook_2019_1.pdf

Urbain, W.M. (1986). Fruits, Vegetables and Nuts. In: *Food irradiation*. Academic Press, Orlando, Florida, USA, pp. 170–216.

USDA, US Department of Agriculture. (1997). Animal and Plant Health Inspection Service Irradiation for Phytosanitary Regulatory Treatment. Environmental Assessment October 1997. Accessed October 2019 at http://www.aphis.usda.gov/plant_health/ea/downloads/irradea.pdf .

USDA, US Department of Agriculture. (2002). Animal and Plant Health Inspection Service. 7 CFR Parts 305 and 319 [Docket No. 98–30–4] RIN 0579–AA97. Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables. Accessed October 2019 at http://www.gpo.gov/fdsys/pkg/FR-2002-10-23/pdf/02-27027.pdf

USDA, US Department of Agriculture. (2006). Animal and Plant Health Inspection Service. Treatments for Fruits and Vegetables. *Federal Register 71(18)* 4451–4464. Accessed October 2019 at http://www.gpo.gov/fdsys/pkg/FR-2006-01-27/pdf/06-746.pdf

USDA, US Department of Agriculture. (2010). APHIS, Animal and Plant Health Inspection Service. *Federal Register*. Irradiation Phytosanitary Treatment of Imported Fruits and Vegetables. Rule on 23/10/2002. Accessed October 2019 at https://www.federalregister.gov/documents/2002/10/23/02-27027/irradiation-phytosanitary-treatment-of-imported-fruits-and-vegetables

USDA, US Department of Agriculture. (2016). APHIS, Animal and Plant Health Inspection Service. Treatment manual. Accessed October 2019 at https://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/treatment.pdf

USDA, US Department of Agriculture. (2018). Animal and Plant Health Inspection Service. Phytosanitary Irradiation. A Presentation to the 8th Chapman Phytosanitary Irradiation Forum, Bangkok, June 2018. Accessed October 2019 at https://www.chapman.edu/scst/_files/conferences-and-events/18B-maggie-smither---country-update.pdf

USDA, US Department of Agriculture. (2019). Animal and Plant Health Inspection Service. Fresh Fruits and Vegetables Import Manual. Accessed October 2019 at https://www.aphis.usda.gov/aphis/ourfocus/planthealth/sa_import/sa_permits/sa_plant_plant_products/sa_fruits_vegetables/ct_favir/

USEPA, US Environmental Protection Agency. (2019). Methyl Bromide. Accessed October 2019 at https://www.epa.gov/ods-phaseout/methyl-bromide

Vaishnav, J., Adiani, V. and Varyar, P.S. (2015). Radiation processing for enhancing the shelf-life and quality characteristics of minimally-processed ready-to-cook (RTC) cauliflower. *Food Packaging and Shelf-Life 5* 50-55.

Vas, K (1978). The development of international standards for irradiated foods. IAEA Bulletin *20 (5)* 1-6.

Vranova, J., and Ciesarova, Z. (2009). Furan in Food – A Review. *Czech Journal of Food Sciences 27*, 1–10.

Wall, M. (2008). Quality of postharvest horticultural crops after irradiation treatment. *Stewart Postharvest Review 2*, 1–7.

Wang, C and Meng, X. (2016). Effect of ^{60}Co gamma irradiation on storage quality and cell-wall ultra-structure of blueberry fruit during cold storage. *Innovative Food Science and Emerging Technologies 38* 91-97.

WHO, World Health Organisation. (1994). Safety and Nutritional Adequacy of Irradiated Food, WHO, Geneva, 176p.

WHO, World Health Organisation. (1999). High-dose irradiation: wholesomeness of food irradiated with doses above 10 kGy. Report of a Joint FAO/IEAE/WHO study group. WHO Technical Report Series 890.

WHO, World Health Organisation. (2003). WHO Statement on 2–Dodecylcyclobutanone and Related Compounds. Accessed October 2019 at http://www.jrafi.jp/cyclo%20WHO%20Statement(200303).pdf

Woodside, J.V. (2015). Nutritional Aspects of Irradiated Food. *Stewart Postharvest Review 11(3)*. Article No. 2.

WTO, World Trade Organisation. (2011). The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). Available from SPS Information Management System: Accessed October 2019 at Text of agreement available at http://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm

Zaman, A., Insanullah, I., Shah, A.A. and 3 others (2013). Combined effect of gamma irradiation and hot water dipping on the selected nutrients and shelf-life of peach. *J. Radioanal. Nucl. Chem. 298* 1665-1672.

Zhang, K., Deng, Y., Fu, H. and Weng, Q. (2014). Effects of Cobalt-60 gamma-irradiation and refrigerated storage on the quality of Shatang mandarin. *Food Science and Human Wellness 3* 9–15. http://dx.doi.org/10.1016/j.fshw.2014.01.002

APPENDIX 1 – PHYTOSANITARY TREATMENTS: EFFECTIVENESS, TOLERANCE AND OPTIONS

Phytosanitary effectiveness

Irradiation is widely regarded as the most studied new food technology and the ability of low dose irradiation to sterilize, prevent emergence or kill insect pests of concern has been known for many years (Koidsumi 1930). The International Database on Insect Disinfestation and Sterilization (IDIDAS) contains over 3300 references on more than 300 species of arthropods (FAO/IAEA 2013). Data show that minimum phytosanitary doses for almost all insects lie in a relatively narrow dose range, from approximately 100 to 600 Gy (ASTM 2014, Hallman 2011, Arvanitoyannis and Stratakos 2010a, Hallman and Blackburn 2016). Thus, irradiation is unique among phytosanitary treatments in its ability to be a broad-spectrum treatment for almost all arthropod pests of importance regardless of the commodity being treated (Follet and Neven 2006).

Of the phytosanitary treatments available, irradiation has the most comprehensive international plant health legislation. In 2003, the IPPC published its Guidelines for the Use of Irradiation as Phytosanitary Measure ISPM 18 (FAO IPPC 2003). This standard is recognized under the WTO SPS Agreement (WTO 2011). ISPM 18 provided technical guidance on the procedures that National Plant Protection Organisations (NPPO's) should follow so trading partners could be assured the treatment objective has been met. A Manual of Good Practice in Food Irradiation for Sanitary, Phytosanitary and other Applications was published in 2015 (IAEA 2015).

In 2006, the US Department of Agriculture ruled 150 Gy to be a generic minimum dose for all Tephritid fruit flies and 400 Gy to be 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 fruit and vegetables (FAO IPPC 2009c). The USDA 400 Gy generic dose is still under consideration by the IPPC but has been approved for exports on a range of fruits exported from Australia, Domenica, Grenada, Hawaii, India, Indonesia, Malaysia, Mexico, Pakistan, Peru, South Africa, Thailand and Vietnam to the US mainland (USDA 2006, 2010, 2016, 2018, 2019)

In 2011, Australia approved the use of irradiation for phytosanitary purposes for domestic trade within all states and territories in Australia. This treatment is available to businesses under the national ICA Scheme as Operational Procedure Number 55 (i.e. ICA-55). ICA-55 (ICA 2011) adopts the 150 Gy generic treatment for fruit fly and the 400 Gy generic treatment for all insects (excluding only Lepidoptera that pupate internally) and can be used on all fruit and vegetables for which FSANZ has approved the use of irradiation. The adoption of a generic treatments for fruit flies and other pests is a huge advantage for small industries in Australia who cannot afford the time and cost to undertake large scale efficacy trials to meet international standards (De Lima *et al* 2017).

Another major difference between irradiation and other phytosanitary treatments is the fact that irradiation does not result in rapid mortality. Treated insects will die without successfully reproducing (i.e. present no risk of spreading to new regions) but may be still be alive during a regularity inspection. Doses that guarantee acute mortality of all insect life stages have not been adopted as these doses are relatively high (a few to several kGy) and would result in reduced fruit quality. ISPM 18 and its explanatory notes developed in 2006 (FAO IPPC 2003) provide guidance on defining the treatment objective, application of the treatment, measurement of the required treatment parameters (foremost among them being dose), the treatment facility, phytosanitary security, documentation and inspection.

Discussions and reviews of the history, development and research on irradiation as a phytosanitary treatment can be found in Burditt (1996), Follet and Griffin (2013), Hallman (1999, 2000, 2011, 2012), Heather and Hallman (2008a) and Hallman and Blackburn (2016).

Commodity tolerance

A phytosanitary treatment of a fresh fruit or vegetable may be effective but it will only be used commercially if it does not degrade the qualities valued by consumers. Irradiation has an advantage over other phytosanitary treatments in that more types of fresh fruit and vegetables tolerate irradiation than any other commercially available phytosanitary treatment (Hallman 2011). An exception may be products that naturally auto-oxidize rapidly, such as avocado. For example, avocado has a very low tolerance to irradiation (Akamine and Goo 1971, Thomas 1986b) and irradiation is not likely to be used commercially. Avocado is recognised as a non-host to a range of fruit fly species if harvested in a hard mature condition and negotiations are currently underway with international trading partners to have this treatment option approved for Australian avocado growers and exporters.

There are numerous reviews on radio-tolerance of various fresh commodities (Akamine and Moy 1983, Arvanitoyannis and Stratakos 2010b, Follett and Sanxter 2000, 2002, 2003, Hallman 2008, Hallman 2011, Heather and Hallman 2008a,b, IAEA 2001, Kader 1986, Urbain 1986, Thomas 1986a,b,c, 1988, Morris and Jessup 1994, Moy 1993, Moy and Wong 1996, 2002, NSW DPI 2015, QLD DAF 2012, 2013, Wall 2008, Hallman and Blackburn 2016).

In some of the early studies of commodity tolerance there was insufficient attention paid to the importance of commodity maturity and physiological state at harvest, time of irradiation after harvest, pre- and post-irradiation handling, storage environment and storage time. This may have led to an underestimate of how well most commodities withstand phytosanitary doses, as pointed out by Morris and Jessup (1994). It is now thought that most commodities if provided with optimum harvesting, storage and handling conditions tolerate irradiation quite well, and better than competing technologies (Hallman 2011, Hallman and Blackburn 2016).

Irradiation is the only treatment technology that has databases for both fruit quality and insect tolerance. The International Database on Commodity Tolerance (IDCT) contains information regarding commodity quality after irradiation treatment, doses of irradiation tolerated by different commodities, optimum methods of applying irradiation and pre- and post-treatment handling and links to the literature (IAEA IDCT 2017).

Treatment options

Irradiation is one of a number of options used for post-harvest phytosanitary treatments, as detailed by Heather and Hallman (2008b). Other options include cold storage, dry or moist heat, modified atmosphere storage, fumigation (MeBr being by far the most used fumigant), pesticide applications or some combination of the above.

Irradiation has a key advantage over all the other options. Whereas development and approval of heat, cold and fumigation treatments involve generating data for each fruit-pest combination, irradiation treatments are developed for a pest species irrespective of commodity. Irradiation is the only treatment that has a generic fruit fly treatment **(**150 Gy) approved by the IPPC and is also the only treatment that has a generic approval for all insect pests (except Lepidoptera that pupate internally) in Australia, Indonesia, Malaysia, Mexico, New Zealand, Thailand, USA, and Vietnam.

Generic irradiation treatment approvals mean that new negotiations for market access can be expedited. While full pest risk analysis will still need to be completed there will no longer be a need for treatment efficacy data packages, which is a benefit for small industries that simply cannot afford to fund efficacy packages that meet international standards. An example is Australian cold treatment research on grapes to access Japan. Research was conducted at three temperatures in nine grape varieties and took over a decade to complete (De Lima *et al* 2017). By the time verification trials were conducted the research had cost industry more than $3 million dollars. At peak periods over 140 staff were employed. While the research was originally for Japan, it resulted in market access to several international markets. However, it is beyond the funding capability of small industries to undertake such research. Approval of irradiation for all fruit and vegetables will dramatically reduce the research requirement for both small and large Australian industries looking to export.

Methyl bromide has a reputation for effectiveness against a wide range of quarantine and other pests and has a low material cost. It is a relatively quick treatment and it is approved domestically within Australia for all fruit and vegetables. However, the treatment rates for international exports vary dramatically. Treatment rates also vary depending on the treatment temperature. The efficacy of irradiation is not influenced by temperature and fruit can be treated at low storage temperatures while methyl bromide treatment typically require fruit to be heated up to temperatures ≥ 16°C. Methyl bromide is a broad-spectrum treatment when compared to cold and heat treatments although it cannot control such a wide range of insects as irradiation.

Methyl bromide fumigation and insecticide treatments are traditional treatments that are coming under increasing restriction and scrutiny. Physical treatments including irradiation, heat and cold are increasingly preferred or required. Under the Montreal Protocol countries are obliged to reduce and ultimately phase out use of MeBr and there is an international effort in place to seek alternatives for quarantine pre-shipment (FAO IPPC 2008; UNEP 2016, 2019). As a health and safety precaution MeBr re-capture or destruction is being required with stringent targets for Tolerable Exposure Limits, a difficult and costly process (MPI 2018; Armstrong 2019).

Similar legislation is also being reviewed by the Environment Protection Authority in Victoria and draft regulations were provided for public comment (EPA 2019). Included in the draft proposal were new regulations for handling methyl bromide such as “so far as reasonably possible replace methyl bromide with an alternative substance or technology” or eliminate or reduce emissions (EPA 2019). The public consultation period has closed and new environmental protection laws are intended to come into effect on 1 July 2020.

In Australia the Plant Biosecurity Cooperative Research Centre (PBCRC) recently funded a collaborative project between Australia, New Zealand and the United states to undertake a review on postharvest disinfestation techniques. Over 30 fumigants, including 15 major fumigants and 18 minor fumigants, were reviewed. Despite numerous publications stating alternatives to methyl bromide fumigation were being developed the reality is that there have been no major recent advances in the field of fumigant development for control of fruit fly (Jamieson et al 2018). Less harmful but still effective insecticide treatments have also been sought but without much success. Present day scrutiny of the health and environmental issues with such treatments make success unlikely.

Treatment with prolonged cold is attractive as it uses such as familiar technology. Many, but certainly not all, fresh produce can withstand the prolonged time (up to approximately 20 days in some cases) required to achieve the necessary phytosanitary goal. Power or data logging problems during storage can mean that an extra treatment may be imposed. A key drawback for many fruits and vegetables is that quality is not at its peak even for produce that basically withstand the treatment and the storage period greatly reduces the shelf-life at retail. Table grapes to New Zealand and Vietnam and litchis to Indonesia are good examples of this. Modified atmosphere storage is a somewhat more complex technology with similar issues in to cold storage.

Treatments involving the application of heat are fundamentally at odds with maintaining product quality and can be very expensive.

Only a small tonnage of fruit has been irradiated for sale on the domestic market in Australia (Part 3.1, Table 9). However, there were no exports out of Queensland using heat or cold treatments during the same time period. These treatments are routinely listed as environmentally safe alternatives to irradiation but there is no business entity registered in Queensland to conduct heat or cold treatments for the domestic market. The major limitations to cold treatments are the infrastructure costs, the long exposure time and quality issues. Both treatments are not economically viable alternatives for sales on the domestic market.

While heat treatment is a relatively quick treatment, the only crop that uses heat treatment for phytosanitary disinfestation in Australia is mango for export to Japan, Korea and China. Research on tomato, melons, zucchini and squash has been completed (Hall *et al* 2007) but the treatment has not been adopted by industry as it is not viewed as cost competitive with alternative treatments such as methyl bromide, insecticide treatments, irradiation or systems approaches (Leach 2019).

One of the major disadvantages of heat treatment is the volume of produce that can be treated at a time. The majority of VHT (vapour heat treatment) units in operation worldwide are 5 tonne units. With the treatment taking 6 to 8 hours (including warm up and cool down) it is very difficult to conduct more than 2 treatments per days. As such, throughput of the VHT facility is only 10 tonnes per day. A new facility has recently been constructed in Brisbane, Queensland with a 10 tonne unit. This will improve throughput but the volume of fruit that can be treated per day is still very low compared to treatments like irradiation and methyl bromide which can potentially treat hundreds of tonnes per day at a lower cost (Leach 2019).

There are positive publications available on treatments still under development such as controlled energy treatments (electrical, microwave, radio frequency), controlled atmosphere treatments and physical treatments (e.g. pressure, vacuum or physical removal) but the major commercial treatments for fruit fly are still cold, heat and more recently irradiation. One of the major issues with developing new technologies is that it very time consuming and expensive to demonstrate to international and national plant protection authorities that a technology is proven, practical and will be adopted by industry. As mentioned earlier irradiation has a major advantage over other technologies in terms of the volume of research that has been undertaken, the number of international approvals already in place and commercial adoption is expanding rapidly.

The cost for irradiation treatment by an Australian facility is currently in the range A$170 per tonne of fruit (Steritech *pers comm.*) and is expected to decrease with greater disinfestation use made of the irradiation facility. The irradiation treatment cost is greater than the cost of the insecticide treatments (estimated to be A$1per tonne), but 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, this relative advantage becomes irrelevant if chemical use is withdrawn.

Comparisons of the costs of different treatments are not straightforward as costs quoted in the literature are highly variable depending on the facility capacity, annual throughput and amortization method. Additionally, many operators of treatment facilities are large agri-businesses who conduct an in-house treatment only (i.e. they are not treatment providers), and the cost of treatment is not publicly available. Hallman (2011) considered heated air and irradiation as moderate cost and cold, hot water immersion and methyl bromide as low-cost alternatives. Product quality, treatment speed, convenience and access to treatment facilities will also enter into industry decisions as to which treatment option best suits their needs.

Inter-state Certification Assurance Scheme

Australia has quarantine controls in place for both international imports and movement of goods within Australia. Fruit flies are considered the major pest for domestic movement of goods but there are approximately 80 plant pest and diseases in Australia that are considered regionalised (i.e. they are not present in all parts of Australia) (https://www.interstatequarantine.org.au/major-pests/). To restrict the introduction of these plant pest and diseases to new areas there are various restrictions placed on the movement of fruit, vegetables, plants flowers, plant products and soil. Details of interstate quarantine or biosecurity measure for producers and travellers moving between states can be found at https://www.interstatequarantine.org.au/travellers/interstate-quarantine/.

Commercial producers sending consignments into markets with quarantine restrictions need to certify that their product is free of pests, diseases or weeds. This can be done two ways. The consignment can be certified by a government inspector but this can be time consuming and expensive though in the case of a new pest incursion the use of government inspectors may be the only option until new protocols and procedures can be negotiated. The second option is for businesses to be accredited under the Interstate Certification Assurance (ICA) scheme. For producers who frequently move goods interstate or between quarantine zones, applying for their business to be accredited could be a better option in terms of time, flexibility and cost (https://www.interstatequarantine.org.au/producers/interstate-certification-assurance/).

The ICA scheme is a cost-efficient way for producers to meet the certification requirements of importing jurisdictions within Australia. The use of irradiation is approved under ICA 55 (ICA 2011) but volumes of treated irradiated Australian produce remain under 100 tonne per annum and there is currently only one certified treatment provider. For producers where fruit fly is the only restriction, the use of the ICA procedure where produce is treated/inspected/certified on farm is by far the cheapest option. However, in the case of a new incursion (an exotic species introduction or a change in distribution of an existing pest species within Australia) irradiation has the significant advantage that it can be implemented immediately for commodities that have FSANZ approval to use irradiation because the generic dose of 150 Gy is recognised throughput Australia. No other treatment has this advantage.

Overall procedures for treatments such as methyl bromide fumigation and cold treatment have been approved nationally. Specific approved treatments can be accessed via the ICA website (ICA 2019). In practice, the actual treatment schedules can vary between jurisdictions. There are several examples of a lack of harmonisation in acceptance criteria between states. For example, under ICA -15 “Mature Green Condition of Passionfruit, Tahitian limes, Black Sapotes and Tomatoes”, fruit from areas with Queensland fruit fly and Mediterranean fruit fly can be exported to markets such as South Australia and Tasmania but Western Australia has not approved this procedure for passionfruit. Queensland and the Northern Territory do not approve the procedure for Western Australian grown tomatoes.

Growing threats to Plant Health

The importance of plant biosecurity and managing the growing threat to plant health in Australia is summarised in the 2018 “National Plant Biosecurity Status Report” (PHA 2018). The system is based on the three strategies. Pre-border, at the border and post-border activities. Post border activities include preventing the spread of regionalised pests, managing established pests and managing fruit flies on a national basis (PHA 2018). All three activities are crucial as more than 350,000 items of biosecurity concern were detected across Australia in 2018. The state and territory governments are also running 110 surveillance programs across Australia to provide evidence of area freedom and detect any new pest incursions.

Additionally, Plant Health Australia and peak industry bodies have listed 370 high priority plant pests that pose a threat to Australian industries and together they have developed industry specific biosecurity plans to help reduce the impact of potential incursions. Irradiation has a distinct advantage of other phytosanitary treatments in the fact that it has generic treatments already approved and can adopted immediately without the need for additional research. This has the potential to save industries millions of dollars on research projects and more importantly industries can regain market access relatively quickly.

APPENDIX 2 – VALUE OF AUSTRALIAN FRESH PRODUCE

Table 1: Value of fresh fruits, nuts and vegetables, gross value, Australia, 2015-16.

Category	2015-16 ($)	Category	2015-16 ($)
Fruit and nuts (excluding grapes) - Total	4,224,576,623	Vegetables for human consumption - Total	3,585,393,897
Almonds	700,580,343	Potatoes	520,333,928
Apples*	540,521,432	Mushrooms	323,412,213
Bananas	408,990,573	Tomatoes*	304,841,280
Oranges	377,409,751	Onions	210,623,831
Avocados	330,306,987	Melons*	204,865,242
Strawberries*	310,162,770	Carrots	198,667,034
Macadamias	202,028,040	Capsicum* - (excluding chillies)	109,610,207
Mandarins	199,128,546	All other vegetables for human consumption n.e.c.	1,713,040,162
Cherries*	172,606,827		
Mangoes*	123,626,474		
Pears (including Nashi)*	90,935,649		
Nectarines*	85,551,914		
Peaches*	66,377,147		
All other fruit and nuts n.e.c.	616,350,169		
Fruit and nuts – Grapes* - Total	1,333,928,388		

Source Australian Bureau of Statistics http://www.abs.gov.au/ausstats/abs@.nsf/mf/7503.0, download cubes, n.e.c. not elsewhere classified,

*Irradiation treatment 0.15–1.0 kGy is an approved treatment in Australia and New Zealand, melon is considered a fruit in other literature.

Table 2: Value by state of fresh fruits, nuts and vegetables, Australia, 2015-16, ($)

Region	Total agriculture	Total Fruit and nuts (excl. grapes)	Vegetables	% of Australian fruit and nuts and vegetables
Australia	55,993,952	4,224,577	3,585,394	
New South Wales	13,085,846	613,972	419,919	13.24
Victoria	13,079,965	1,218,876	972,548	28.06
Queensland	13,216,926	1,303,424	1,087,261	30.61
South Australia	6,228,768	549,785	467,325	13.02
Western Australia	8,192,486	335,553	379,735	9.16
Tasmania	1,484,905	169,689	217,119	4.95
Northern Territory	696,723	33,278	41,293	0.95
ACT	8,334	na	194,333	2.49

Source: Source Australian Bureau of Statistics http://www.abs.gov.au/ausstats/abs@.nsf/mf/7503.0, download cubes by state.

APPENDIX 3 – POTENTIAL FOR PHYTOSANITARY IRRADIATION TREATMENT OF FRESH PRODUCE PRIOR TO EXPORT OR IMPORT

Table 1 provides a simple classification (high, medium, low) for the expected commercial significance of irradiation to meet pest quarantine requirements and sustain commercially viable trade of common fresh produce crops.

Table 2 similarly provides a simple classification (year round, seasonally, rarely) indicating the significance of the treatment to balance seasonal supply and demand of these crops.

The Tables are indicative only and take a medium term (10 year) view of potential assuming that the Standard is modified as requested.

The classification is based on experience (existing irradiated exports), expected commodity tolerance relative to other phytosanitary treatments and informal market assessments.

A 'high/medium' or 'year-round/seasonal' classification does not mean that large volumes of that crop will be irradiated. For example, it is possible that the bulk of supply may be sourced from a pest free region, or via a high-volume cold disinfestation treatment, while irradiation is used for niche opportunities such as air freighting a premium quality product or to fulfil an urgent market shortage.

Table 1: Commercial significance of irradiation to meet quarantine requirements and or industry needs (quality, seasonal availability)

High	Medium	Low
asparagus, berry, cherry, garlic, ginger, lemon, lime, lychee, longan, mango, papaya, peach, persimmon, plum, pomegranate, nectarine, table grape, tomato,	dragon fruit, melon, pear, capsicum	apple, avocado, broccoli, carrot, corn, cucumber, cauliflower, mandarin, onion, orange, potato, pumpkin, salad leaf, zucchini

Table 2: Supply and demand influences on the use of irradiation

Year Round / Regularly	Seasonally / Spot Markets	Rarely / Emergency Trade Needs
garlic	berry, cherry, dragon fruit, ginger lemon, lime, mango, nectarine, papaya, peach, pear, plum, pomegranate, lychee, longan, table grape, tomato	apple, asparagus, avocado, broccoli, capsicum, carrot, corn, cucumber, cauliflower, mandarin, melon, onion, orange, potato, onion, pumpkin, salad leaf, zucchini

As discussed in Part 2.3, *Harmonisation of regulations and reciprocal trade arrangements,* the two way trade relationship with other countries, especially South East Asian countries, is important for Australian and New Zealand horticultural exports and for the security and sustainability of the local food chain. South East Asia is a source of tropical and exotic fruits to Australia and New Zealand and, in future, other regions may also become important.

Products like salaka from Indonesia, dragon fruit from Vietnam and other niche exotics are typically very sensitive to existing treatments often resulting in unviable trade. It is unhelpful to trade negotiations if, for example, Indonesia, accepts phytosanitary irradiation of all fresh produce but finds that Australia does not accept irradiation of crops such as salaka that are economically important to Indonesia. Star apple and pomegranate are examples of fruits that are exported from South East Asian countries to the USA, but which cannot be imported into Australia or New Zealand.

The lack of efficiency data on many crops for alternate treatments or the lack of local facilities for such treatments is a hindrance to trade from many South East Asian countries and from Pacific Islands that could be overcome if phytosanitary irradiation was permitted.

APPENDIX 4 – LITERATURE ON EFFECTS OF IRRADIATION ON MICRONUTRIENTS, POST 2011: LEAFY GREENS, BRASSICAS, ROOTS AND TUBERS

FSANZ (2014b) reviewed the existing literature on the effect of phytosanitary irradiation on the nutrient composition of food, with a focus on radiation sensitive micronutrients.

FSANZ noted that limited data was available for leafy greens, brassicas and roots and tubers. Part 3.1 contains data on these crops that has become available more recently. The following table summarises the findings and provides brief details on analytical methods and statistical analysis.

The literature was searched in September 2019 for data on micronutrient changes following irradiation that have been published after the FSANZ (2014b) review. The databases searched were EBSCOhost, Science Direct, Wiley Online Library and Researchgate using the terms –

- fruit and vegetable + irradiation + ascorbic acid + vitamin C
- fruit and vegetable + irradiation + carotene + vitamin A
- fruit and vegetable + irradiation + carotene + carotenoid + vitamin A
- fruit and vegetable + irradiation + tocopherol + vitamin E
- fruit and vegetable + irradiation + nutrient + vitamin

The period searched was 2011 to 2019.

Table: Recent data on effects of radiation on leafy greens, brassicas and roots and tubers

Abbr: AA = ascorbic acid; TAA = total ascorbic acid (AA + DHAA); AOA + Anti-oxidant activity; TP = total phenolic compounds; TF = total flavonoids;

Vegetable	Dose and storage	Summary of micronutrient changes versus controls	Methods & Reference
Leafy greens			
Spinach	0, 1, 2 ,3 4 kGy: 4ºC for 1, 7 14 days	AA loss over 14d was doubled after 1 kGy (73%) *vs* control (33%). AOA and TP relatively unchanged at all doses and storage times	Fan & Sokorai (2011) AA by HPLC & spectrophotometry AOA by oxygen radical absorbance capacity TP by colorimetry 6 replicates; least significant difference analysis
	0 to 1.5 kGy in 0.25 kGy steps 3ºC for 4 days	TAA not significantly affected at any dose Small dose-dependent increase in carotenes, TP and TF	Hussain *et al* (2016) TP and TF by spectrophotometry AA, TAA & carotenoids by HPLC & spectrophotometry 3 replicates, Analysis of Variance
	0, 0.5 and 1.0 kGy 12ºC for 12 days	AA increased immediately after irradiation (approx. 30%) but showed a decrease with storage (approx. 30% for 0.5 kGy and 50% for 1 kGy	Akhter *et al* (2013). AA by titration 2 measurements on each of 2 replicates. Microsoft SPSS statistical package
	0 to 2 kGy in 0.2 kGy steps. Ambient, no storage	Significant increase over dose range for AOA, TP and TF, over 50% for 1 kGy	Al-Suhaibani & Al-Kuraieef (2016) AOA by DPPH⁻ scavenging TP, TF by spectrophotometry 5 replicates, Cary SAS stats package
Fenugreek	0 to 1.5 kGy in 0.25 kGy steps 3ºC for 4 days	TAA not significantly affected at any dose Small dose-dependent increase in carotenes, TP and TF	Hussain *et al* (2016) TP and TF by spectrophotometry AA, TAA & carotenoids by HPLC & spectrophotometry 3 replicates, Analysis of Variance
Lettuce	0, 1, 2, 3 and 4 kGy	AA not significantly different at 1 day but reduced by 22-40% at 14 days	Fan *et al* (2012) HPLC

	4^{0}C, 1 and 14 days		4 replicates, SAS version 9.2 and Least Significant Difference.
	0, 1, 2, 2.5 and 3 kGy Ambient, no storage	AA decreased (40% at 1 kGy) Total carotenoids increased little changed at 1 kGy but a 30% decrease at 3 kGy	Sarker *et al* (2014) AA by titration Carotenoids by spectrophotometry 5 replicates, Analysis of Variance and StatView 5.
Argula	0, 1 2 kGy 5^{o}C for 13 or 16 days	TAA shows loss *cf* control after 5 days (20% at 1 kGy) but no loss *cf* control at days 9 or 13 as a result of irradiation. Provitamin A carotenoids showed no radiation-induced loss	Nunes *et al* (2013) TAA by HPLC & spectrophotometry Carotenoids by HPLC. 3 replicates, ANOVA and StatView 5.5
Watercress	0, 1, 2, 5 kGy 4^{o}C for 7 days	For TP and TF, no significant difference between controls and irradiated at any dose For AOA, no significant difference in the decrease of AOA activity with time. For tocopherols, results were variable.	Pinela *et al* (2016) TP and TF by spectrophotometry. AOA by DPPH^{-} scavenging and ferric ion reduction by spectrophotometry Tocopherols by HPLC/florescence ANOVAR and Microsoft SPSS stats package
Watercress	0, 1, 2, 5 kGy 4^{o}C for 7 days	For TP and TF, no significant difference between controls and irradiated at any dose	Pinela *et al* (2018) TP by HPLC/MS ANOVA and Microsoft SPSS stats package
Brassicas			
Cauliflower	0, 0.5 kGy 4^{o}C for 0, 7, 14, 21 days	TAA unchanged throughout storage period AOA significantly increased throughout storage period TP slightly increased by irradiation and concentrations did not decrease over 21 days whereas control concentrations decreased with storage TF displayed no significant differences between irradiated and controls up to 14 days but a slight decrease was seen at 21 days.	Vaishnav *et al* (2015) TAA by titration AOA by DPPH^{-} scavenging TP by spectrophotometry 3 replicates, ANOVA and Tukey's test
Cabbage	0, 2 kGy 4^{o}C and 10^{o}C for 10 days	AOA increased slightly throughout storage time TAA, TP and TF not significantly affected by irradiation.	Banerjee *et al* (2016) TAA by titration TP and TF by spectrophotometry AOA by DPPH^{-} scavenging and ferric ion reduction.

			3 replicates, ANOVA and Onofri's DSAASTAT
	0 to 3 kGy in 1 kGy steps 8ºC for 5, 10, 15 days	TAA, AOA, TP and TF all decreased with time in controls but irradiated samples showed small increases or decreases *cf* controls depending on time/dose but none were statistically significant	Frimpong *et al* (2015) TAA by titration AOA by $DPPH^-$ scavenging TP and TF by spectrophotometry 3 replicates, simple mean ± S.D.
Roots and tubers			
Carrot	0 and 1 or 2 kGy 5ºC for 8 days	AA decreased by 33% after 1 kGy β-carotene decreased by 33% after 2 kGy Various tocopherols decreased by between 25 and 45% by 2 kGy	Mohacsi-Farkas *et al* (2014) AA by HPLC/spectrophotometry Carotenes and tocopherols by HPLC 3 replicates, ANOVA and SPSS software
	0, 0.2, 1.0 kGy 4ºC, no storage	TP content decreased by approx.10 and 20% for 0.5 and 1 kGy respectively	Harashima *et al* (2013) TP by spectrophotometry 6 replicates, ANOVA and Tukey's test
	0, 1, 2, 2.5, 3 kGy Storage conditions unclear, probably none.	AA not significantly changed except at 3 kGy (30%) Carotenoids not significantly affected	Sarker *et al* (2014) AA by titration Carotenoids by spectrophotometry 5 replicates, Analysis of Variance and StatView 5
	0 and 0.5 kGy Ambient and monthly to 6 months at 30 to 40% moisture	AA decrease by 20% over 3 months B-carotene and total carotenes not significantly changed over 3 months but the drying and irradiation process had caused a > 4 fold increase in carotenes	Chaturvedi *et al* (2013) AA by titration Carotenes by spectrophotometry 3 replicates, ANOVA and AGRES software
Sweet potato	0, 0.1, 0.2, 0.4 and 1 kGy 4, 12 and 25ºC, 8 weeks	No significant change in vitamin C or β-carotene	Lim *et al* (2013) AA by spectrophotometry Carotene by HPLC 3 replicates, SPSS statistical package and Dunnet's test
	0 to 1 kGy. 4ºC and 14 days	No significant change in anthocyanins	Oner and Wall (2013) pH differential method with spectrophotometry. 3 replicates, ANOVA using JMP software and Tukey's inter-comparison

Potato	0, 50 Gy and 100 Gy 10ºC for up to 5 months	Highly variable results depending upon time of irradiation with ascorbic acid losses between 8.5 % and 24.8%	Rezaee *et al* (2013). Enzymatic analysis and spectrophotometry. 4 replicates. Analysis of variance and statistical analysis using SAS.

APPENDIX 5 – LITERATURE ON EFFECTS OF IRRADIATION ON MICRONUTRIENTS, POST 2011: FRUITS, FRUITING VEGETABLES AND CUCURBITS

The literature was searched (as described in Part 3.1 and Appendix 4) for new data on micronutrient changes resulting from low dose irradiation in fruits, fruiting vegetables and cucurbits. The data are summarised briefly in the following table for comparison with the findings of the FSANZ (2014b) review.

Table: Recent data on effects of radiation on fruits, fruiting vegetables and cucurbits

Abbr: AA = ascorbic acid; TAA = total ascorbic acid (AA + DHAA); AOA + Anti-oxidant activity; TP = total phenolic compounds; TF = total flavonoids;

Commodity	Dose and storage	Summary of micronutrient changes versus controls	Methods & Reference
Fruits			
Citrus			
Mandarins	0 and up to 164Gy 1.5ºC for 0, 6, 12 days then 20ºC for 7 days	No significant changes in TAA, AOA or TP. Minor changes in TF	Contreras-Oliva *et al* (2011) HPLC and spectrophotometry, 3 replicates, ANOVA and Statgraphics 4.1
	0, 510, 875 Gy 5ºC for 60 days then 20ºC for 7 days	No significant change in TAA, Flavanone glycosides slightly increased	Rojas-Argudo *et al* (2012) Analysis by HPLC-MS 3 replicates, ANOVA and Statgraphics 4.1
	0, 0.5, 1, 1.5 kGy Temp unstated, 0, 1, 15, 30, 45 days	Small but variable effect on carotenoids. Small decrease in AA above 1 kGy	Aylangan and Erhan (2014) AA by HPLC, carotenoids by spectrophotometry
	O, 0.2, 0.3, 0.4, 0.5, 0.6 kGy; 4ºC to 45d	No significant difference in AA at 7, 15 days, variable decrease at 30 days and approx. 30% loss at 45 days	Zhang *et al* (2014) AA by titration, ANOVA and SPSS package
	0.15, 0.4, 1 kGy; 6ºC for 21d, ambient further 7d	Increased AA at 2 days then dose dependent decrease at longer times AA loss approx. 50% at 21 days; TP slightly increased, dose dependent loss of carotenoids and α-tocopherol that increased with storage (approx. 50% at 1 kGy)	Ornelas-Paz *et al (*2017) HPLC and spectrophotometry; ANOVA and Tukey's test with JMP statistics pack
Limes	0, 200 to 750Gy. 20ºC for 20 days	No significant effect on AA at 200Gy and a small drop at 750 Gy	Da Silva *et al* (2016) Reduction of DCFI by spectrophotometry; 4 replicates and Tukey's test
Oranges	0, 0.2, 0.4, 0.6 kGy	No significant change in AA, or TP or oxygen radical scavenging.	McDonald *et al* (2013)

	5ºC for 1 and 21 days, then 20ºC for 7 days		AA by titration, TP by HPLC, oxygen radical absorbance by fluorimetry 3 replicates, ANOVA by SPSS software and Tukey's test
	0 to 1 kGy in 0.2 kGy steps 3ºC, intervals up to 45 days	No significant changes in TP, TF or AOA.	Cho *et al* (2016) TP, TF by spectrophotometry, AOA by several reducing power methods 3 replicates, ANOVA with Duncan's multiple range test
Korean citrus	0, 0.4, 1 kGy; 4ºC to 21d	No significant change in AA or with no change in some flavonoids and slight drop in others.	Jo *et al* (2018) HPLV analysis; 3 replicated and ANOVA with SAS 8.1
Lemon	0 to 1 kGy in 0.25 kGy steps; Ambient storage, 30 days	Slight AA increase at 0.25 kGy, decrease at higher doses (approx. 50% at 1 kGy).	Devi *et al* (2018) DNH reduction and spectrophotometry. 3 replicates and ANOVA
Berry			
Strawberry	0, 2 kGy, 2ºC, 21d	AA decrease with but compensated by increase in DHA after irradiation Any TAA loss is due more to storage than irradiation. Initial increase in anthocyanins followed by decrease on prolonged storage; phenolic content increased.	Hussain *et al* (2012) ZHPLC analysis 3 replicates, ANOVA by Minitab.
	0, 0.5, 1, 1.5kGy; ambient to 6d	Total phenolics and flavonoids increased. AA decreased slightly at 1 and 1.5 kGy though at 0.5 kGy there appeared to be an approx. 50% decrease (anomalous?)	Mridha *et al* (2017) AA by titration, TP and TF by spectrophotometry 3 replicates, Student's t-test
	0, 3 kGy. 4ºC, 0, 7, 14 and 21 days storage	No significant change in AA up to 21 days	Al-Kuraieef *et al* (2019) Titration; replicates nit given. SAS statistical package
Raspberry	0, 0.5, 1 and 2 kGy; 1ºC, 3 day intervals to 12d	0.5 kGy showed no differences of AA through 9 days storage then held constant while control dropped at 12 days. 1 and 2 kGy showed initial drop of AA approaching 50% but then increased to well above controls at 12 days.	Guimaraes *et al* (2013) AA and TP by colorimetry, AOA by DPPH reduction and spectrophotometry,

		Phenolic concentrations, no effect, and total anti-oxidant increased at 2 kGy and 12 days with little change at lower doses and shorter storage.	3 replicates, ANOVA and Tukey's test
Blueberries	0.5kGy steps to 3 kGy; storage at 0°C up to 35d	TAA content reduced immediately up to about 10% at 3 kGy immediately after irradiation but irradiated samples have lower loss than controls at some storage times and doses especially at 1 to 2.5 kGy. Variable results overall Anthocycanin content changed little but irradiation was slightly protective during storage.	Wang and Meng (2016) TAA by titration, anthocyanin by spectrophotometry 3 replicates and ANOVA and SPSS software
Stonefruit			
Peach	0.5, 1 kGy; ambient and 7, 14d storage	Slight increase in ascorbic acid concentration after 7d,; data at 14 days poorly controlled	Zaman *et al* (2013) AA by titration Statistical analysis unclear
	0, 2.5, 5 kGy ambient	AA decrease 10-20% over 2 weeks	Khan *et al* (2018) Analytical and statistical methods unclear
Apricot (dried)	0, 3kGy; ambient 1d	TP and TF increased by irradiation (11-16% approx.). No significant change in AA and TAA. AOA increased significantly	Hussain *et al* (2013) TP by HPLC, AOA by three different methods 3 replicates, ANOVA by Minitab
Tropicals			
Rambutan	0, 0.2 to 0.5 kGy 13°C, 13 days	No significant effect on AA or a small effect dependent on packaging.	Khanh *et al* (2013) Titration; 2 replicates
Papaya	0, 0.8 kGy 24°C, 5, 7 and 9 days	Total carotenoids unaffected on days 5 and 9 but 35% decrease on day 7. Decrease in vitamin A at 5 and 7 days and increase at 9 days. AA decreased (27-52%) throughout storage period. No difference in lycopene.	De Figueiredo *et al* (2014) HPLC and spectrophotometry 3 replicates, ANOVA and Tukey's test
Ber fruit	0, 0.25 to 1 kGy in 0.25 kGy steps, no storage	3-fold increase in TF; approx. 15% decrease in TP; total anti-oxidant activity decreased.	Kavitha *et al* (2015) TP and TF by spectrophotometry AOA by several methods for reducing power. Replicates unclear. ANOVA and Person's bivariate test
Jujube (dried)	0, 0.5, 1, 2.5, 5 kGy; 4°C, 1 month	Anthocyanin and TP slightly increased up to 2.5 kGy, decrease at 5 kgy; AA	Nafabajadi *et al* (2017)

		concentrations decreased at all doses, about 15% at 1 kGy.	Colorimery and spectrophotometry 3 replicates and ANOVA and Duncan's test using SPSS software
Fruiting vegetables			
Tomatoes (cut)	0, 1, 1.5 and 2 kGy 5ºC, 0 and 8 days	α-tocopherol, carotenoids lose about 1/3 of concentration at 2 kGy, AA loses about 10% concentration at 1 kGy	Mohacsi-Farkas *et al* **(**2014) HPLC, replicates unstated, ANOVA with SPSS V20 software
	0, 1, 1.5, 2, 2.5 3 kGy Measurements appear to have been immediately after irradiation	No significant change in AA or carotenoids.	Sarker *et al* (2014) AA by titration, carotenoids by spectrophotometry 5 replicates, ANOVA and Statview 5.0
Capsicum (green)	0, 1, 1.5, 2, 2.5 3 kGy Measurements appear to have been immediately after irradiation	Small change in AA up to 1.5 kGy, then a decrease of about 40%. Slight decrease in carotenoid at all doses	Sarker *et al* (2014) AA by titration, carotenoids by spectrophotometry 5 replicates, ANOVA and Statview 5.0
Cucurbits			
Bitter gourd	0, 0.25, 0.5 kGy No storage	AA decreased by approx. 20%. Slight increase (approx. 20%) in TP at 0.25 kGy but no significant change at 0.5 kGy. TF greatly increased especially at 0.5 kGy.	Khatun *et al* (2012) AA by titration; TP and TF by spectrophotometry 3 replicates, SPSS statistical package
Ash gourd	0 and 2 kGy 10ºC 12 days	TAA was not significantly affected AOA significantly higher (100% at day 0 and 230% at day 12) TP was significantly increased (23% at day 0 and 51% at day 12)	Tripathi *et al* (2013) TAA by microfluorimetry AOA by DPPH$^-$ scavenging TP by spectrophotometry 3 replicates, ANOVA and Tukey's test
Pumpkin	0 and 1 kGy 10ºC and 0, 7, 14, 21 days	TAA decreased immediately (27%) but then stayed constant and was greater than control at 21 days by 66% AOA was decreased slightly but not significantly on day 0 but AOA was	Tripathi *et al* (2014) TAA by microfluorimetry AOA by DPPH$^-$ scavenging

		maintained better and was more than 10% greater by day 21 TP was not significantly affected B-carotene and lutein concentration were not significantly affected at day 0 but were 30% and 40% lower at day 21 for β-carotene and lutein respectively	TP and carotenoids by HPLC 3 replicates, ANOVA and Tukey's test
Cucumber	0, 1, 2, 2.5, 3 kGy Storage conditions unclear, probably none	AA showed variable changes but were only significant at 2.5 kGy (14% increase) and 3 kGy (30% decrease) Carotenoids were decreased significantly only at 2.5 kGy (57%) and 3 kGy (45%)	Sarker *et al* (2014) AA by titration Carotenoids by spectrophotometry 5 replicates, Analysis of Variance and StatView 5

APPENDIX 6 – FRUIT AND VEGETABLE CONSUMPTION IN AUSTRALIA AND NEW ZEALAND

The following is a report by W. Prowse of Fresh Intelligence Consulting prepared for Steritech Pty.

Fruit and Vegetable Consumption in Australia and New Zealand

Prepared for

STERITECH
Protecting what matters

By

Fresh Intelligence Consulting

29th July 2019

Introduction

This paper seeks to assess the volume of fresh fruit and vegetables consumed in Australia, and New Zealand from local production and imported produce. Products have been aggregated into strategic groups as follows:

Fruit

Pome Fruits	Apples and pears
Citrus Fruits	Oranges, mandarins, lemons, limes, tangerines, satsumas, grapefruit (including pomelos), fruit (citrus nes)
Soft Fruits	Grapes, kiwifruit, peaches, nectarines, strawberries, fruit (fresh nes), plums and sloes, cherries, blueberries, currants, berries nes, apricots, fruit (stone nes), raspberries, gooseberries
Tropical Fruits	Bananas, mangoes, mangosteen, guava, avocados, pineapples, papayas, persimmons, figs, fruit (fresh tropical nes)
Melons	Rock melons and watermelons

Vegetables

Potatoes	Fresh potatoes excluding for processing, sweet potato
Onions	Onions, shallots, leaks and garlic
Root Vegetables	Carrots, turnips, beetroot, radishes
Green Vegetables	Lettuce, chicory, cauliflowers, broccoli, cabbages and other brassicas, maize, peas, beans, kale, spinach, asparagus, vegetables (fresh nes), vegetables (leguminous nes)
Fruiting Vegetables	Tomatoes, cucumbers, gherkins, capsicum, chillies, other peppers, pumpkins, squash, gourds

nes = not elsewhere specified

Specific analysis for Australia and New Zealand includes

New Zealand

For each major class of fruit/vegetable show:

- Consumption (tonnes) (production + imports - exports)

- Imports (tonnes)

- % imports as a share of total consumption

Australia - as above, plus for interstate trade:

For each major class of fruit/vegetable show:

- Consumption in SA, Tasmania and WA (tonnes)

- QLD produce sent to SA, Tasmania and WA (tonnes)

- VIC produce sent to SA, Tasmania and WA (tonnes)

New Zealand

According to the latest production and trade data New Zealanders consumed 324,302 tonnes of fruit and 521,933 tonnes of vegetables in 2018. The total volumes exclude as far as possible all produce grown for processing, which is up to 60 per cent of potato and green vegetable production. By converting to per capita, New Zealand consumers consume around 67 kg of fruit and 108 kg of fresh vegetables per year, again excluding any consumption of processed foods (Table 1). Of this some 46 per cent of fruit and just 2 per cent of vegetables are imported (Table 2)

Table 1 – New Zealand Fruit and Vegetable Consumption

- Consumption (tonnes) (production + imports - exports)		
	Consumption	***per capita***
	tonnes	***kg pp per yr***
Pome Fruits	***103,687***	*21.60*
Citrus Fruits	***44,315***	*9.23*
Soft Fruits	***50,903***	*10.60*
Tropical Fruits	***114,754***	*23.91*
Melons	***10,643***	*2.22*
Sub Total - Fruit	***324,302***	*67.56*
Potatoes	***116,590***	*24.29*
Onions	***133,269***	*27.76*
Root Vegetables	***78,289***	*16.31*
Green Vegetables	***108,116***	*22.52*
Fruiting Vegetables	***85,669***	*17.85*
Sub Total - Vegetables	***521,933***	*108.74*
Total Fruit & Vegetables	***846,235***	*176.30*

Source: FAOSTAT 2017, ITC Trademap; Fresh Intelligence analysis

Table 2 – New Zealand Fruit and Vegetable Import share of consumption

- Imports (tonnes)		Imports as a
	2018 Imports	share of consumption
	tonnes	
Pome Fruits	3,814	**4%**
Citrus Fruits	18,184	**41%**
Soft Fruits	15,744	**31%**
Tropical Fruits	104,499	**91%**
Melons	5,488	**52%**
Sub Total - Fruit	147,729	**46%**
Potatoes	427	**0%**
Onions	5,169	**4%**
Root Vegetables	45	**0%**
Green Vegetables	3,263	**3%**
Fruiting Vegetables	1,796	**2%**
Sub Total - Vegetables	10,700	**2%**
Total Fruit & Vegetables	158,429	**19%**

Source: FAOSTAT 2017, ITC Trademap; Fresh Intelligence analysis

Australia

According to the latest production and trade data Australians consumed 1.8 million tonnes of fruit and 1.8 million tonnes of vegetables. The total volumes exclude as far as possible all produce grown for processing, including wine grapes, tomatoes and potatoes. By converting to per capita, Australian consumers consume around 71 kg of fruit and 71 kg of fresh vegetables per year, again excluding any consumption of processed foods (Table 3). Of this 5 per cent of fruit and just 1 per cent of vegetables are imported (Table 4)

Table 3 – Australian Fruit and Vegetable Consumption

- Consumption (tonnes) (production + imports - exports)

	Consumption tonnes	*per capita*
Pome Fruits	*357,366*	*14.20*
Citrus Fruits	*333,765*	*13.26*
Soft Fruits	*288,707*	*11.47*
Tropical Fruits	*602,623*	*23.94*
Melons	*204,572*	*8.13*
Sub Total - Fruit	*1,787,032*	71.00
serves per day		
Potatoes	*478,096*	*18.99*
Onions	*262,134*	*10.41*
Root Vegetables	*171,583*	*6.82*
Green Vegetables	*528,002*	*20.98*
Fruiting Vegetables	*356,487*	*14.16*
Sub Total - Vegetables	*1,796,302*	*71.37*
serves per day		
Total Fruit & Vegetables	*3,583,334*	142.37

Source: ABS 2019; ITC Trademap; Fresh Intelligence analysis

Table 4 – Australian Fruit and Vegetable Import share of consumption

- Imports (tonnes)	2018 Imports *tonnes*	Imports as a share of consumption	
Pome Fruits	2,380	**1%**	
Citrus Fruits	26,710	**8%**	
Soft Fruits	46,046	**16%**	
Tropical Fruits	16,794	**3%**	
Melons	97	**0%**	
Sub Total - Fruit	**92,027**	**5%**	
Potatoes	680	**0%**	
Onions	17,280	**7%**	mostly garlic
Root Vegetables	-	**0%**	
Green Vegetables	5,962	**1%**	
Fruiting Vegetables	1,344	**0%**	
Sub Total - Vegetables	25,266	**1%**	
Total Fruit & Vegetables	**117,293**	**3%**	

Source: ABS 2019; ITC Trademap; Fresh Intelligence analysis

Production by state utilized the latest ABS data (Cat 7210) and then estimated the average consumption by state based on simple split according to population (Table 5). These all assume that the production plus imports minus exports is consistent across all states even though in reality some states will import or exports less proportions.

Table 5 – Consumption by South Australia, Western Australia and Tasmania

Population (Million)	National	SA	WA	TAS
	tonnes	tonnes	tonnes	tonnes
Pome Fruits	357,366	24,730	36,996	7,538
Citrus Fruits	333,765	23,097	34,553	7,040
Soft Fruits	288,707	19,979	29,888	6,090
Tropical Fruits	602,623	41,702	62,386	12,712
Melons	204,572	14,157	21,178	4,315
Sub Total - Fruit	1,787,032	123,665	185,000	37,696
Potatoes	478,096	33,085	49,494	10,085
Onions	262,134	18,140	27,137	5,529
Root Vegetables	171,583	11,874	17,763	3,619
Green Vegetables	528,002	36,538	54,661	11,138
Fruiting Vegetables	356,487	24,669	36,905	7,520
Sub Total - Vegetables	1,796,302	124,306	185,960	37,891
Total Fruit & Vegetables	3,583,334	247,971	370,960	75,587

Source: ABS 2019; Fresh Intelligence analysis

Assessing the volume of fruit and vegetables moved from Queensland and Victoria to Western Australia, South Australia and Tasmania relies on several broad assumptions involving whether or not the state could be self-sufficient and whether Queensland or Victoria was the key supplier of a product nationally. In this calculation Queensland is more likely to send tropical fruit and melons since there is no advantage to send pome fruit, citrus or soft fruits. South Australia is self-sufficient in vegetables and would not need to draw from Queensland, and similarly Tasmania is almost self-sufficient with vegetables.

The total volumes estimated from Queensland represent around 20 – 30 per cent of the total consumption of fresh fruit and vegetables in these states, which is a likely maximum level since these states may also draw on some products from states other than Queensland (Table 6).

Similarly fruit drawn from Victoria would represent fruit and vegetables that are surplus to Victorian needs and tend to be more temperate fruits that fill a need gap in South Australia, Western Australia and Tasmania. We acknowledge that Western Australia's deficit for citrus and pome fruits are more likely to be covered from South Australia before Victoria although some will be drawn from Victoria. Tasmanian needs will most likely be covered from Victoria for citrus and some soft fruit (grapes and stone fruits) although should be self-sufficient for apples. Pears would need to be supplied from Victoria. (Table 7)

Most states appear self-sufficient for heavy vegetables (potatoes and onions) though green vegetables are more likely to be supplied form Queensland or Victoria depending on the season to Western Australia and Tasmania. However more analysis is needed to truly understand the Tasmanian needs which, though appears more than self-sufficient, utilizes a vast amount of green vegetable production for the processing sector (e.g. Birdseye Frozen Peas etc) which are all harvested in summer months.

Table 6 – Possible movements from Queensland to South Australia, Western Australia and Tasmania

	QLD Surplus	SA	WA	TAS
Pome Fruits				
Citrus Fruits				
Soft Fruits				
Tropical Fruits	411,200	40,242	35,099	12,677
Melons	48,383	13,037	0	4,315
Sub Total - Fruit	459,583	53,279	35,099	16,992
Potatoes				
Onions				
Root Vegetables	14,803	-	-	-
Green Vegetables	96,644	-	14,885	-
Fruiting Vegetables	90,993	-	8,952	4,561
Sub Total - Vegetables	202,440	-	23,837	4,561
Total Fruit & Vegetables	662,023	53,279	58,936	21,553
share of total consumption		***21%***	***16%***	***29%***

Source: ABS 2019; Fresh Intelligence analysis

Table 7 – Possible movements from Victoria to South Australia, Western Australia and Tasmania

	VIC Surplus	SA	WA	TAS
Pome Fruits	125,386		3,648	1,000
Citrus Fruits	14,155	3,000	9,371	7,040
Soft Fruits	166,569	5,167	6,920	4,000
Tropical Fruits				
Melons				
Sub Total - Fruit	306,110	8,167	19,939	12,040
Potatoes				
Onions				
Root Vegetables				
Green Vegetables	56,266		14,885	
Fruiting Vegetables				
Sub Total - Vegetables	56,266	-	14,885	-
Total Fruit & Vegetables	31,608	8,167	34,825	12,040
share of total consumption		***3%***	***9%***	***16%***

Source: ABS 2019; Fresh Intelligence analysis

At this stage we are not making any allowance for fruit and vegetables to be moved from New South Wales to South Australia, Western Australia or Tasmania since the state has a deficit for almost all fruit and vegetables and must draw from Queensland and Victoria to make up the deficit in consumption. While there maybe times that fruit or vegetables may be moved from New South Wales to SA, WA or Tas, this would be an exception rather than a regular occurrence.

References

International Trade Centre, *Trade Map* Retrieved July 22 2019

ABS Cat 7210.0 Released 30 April 2019

FAOSTAT Food & Agriculture Organisation 2019.

Disclaimer

Fresh Intelligence Consulting provides analysis of trade information available from various sources to assist Steritech with a better understanding of trade flows for better decision making. Fresh Intelligence Consulting however will not be held responsible for errors and omissions in the data.

For more Information contact:

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[redacted]

ANNEX – LETTERS OF SUPPORT

[redacted]

[redacted]

[redacted]

National

[redacted]

[redacted]

NEW ZEALAND
FRESH PRODUCE
IMPORTERS
ASSOCIATION INC.

14 November 2017

FSANZ Review Committee
Canberra
AUSTRALIA

Dear FSANZ review committee,

The New Zealand Fresh Produce Importers Association Inc (NZ FPIA) represents the major importers and retailers of fresh produce imported into New Zealand. Collectively, the NZ FPIA members account for 95%+ of fresh produce imports by value and volume.

The current FSANZ application system is cumbersome, costly and no longer scientifically justified. Consequently, the NZ FPIA fully supports the application to FSANZ for irradiation to be a phytosanitary treatment for all horticultural crops distributed and sold in New Zealand and Australia.

New Zealand has a valuable agricultural and horticultural production industry which must be protected so that it can continue to produce food for all New Zealand consumers as well as the millions of consumers in export markets around the world, including Australia. New Zealand growers cannot supply all fresh fruits and vegetables that consumers expect, particularly during the colder winter months and/or those products that cannot be grown in New Zealand (e.g. tropical fruits). To fill the many supply gaps, ongoing access to imported fresh produce is vital. Phytosanitary irradiation further helps ensure New Zealand consumers have access to produce which has been efficiently and sustainably produced with fewer chemical inputs and reduced food waste.

Irradiation is an extremely effective tool for treating fresh produce. Its flexibly meets the needs and best handling practices of many different crops. It is fast, chemical and fumigant free and cold chain friendly. These attributes help to deliver fresher, high quality horticultural products to New Zealand consumers. The "generic" application of irradiation is an important advantage when compared to many other post-harvest treatments. Phytosanitary irradiation also stands to benefit two-way trade by enabling New Zealand producers to supply fresh produce to Australian consumers among others using this treatment technology.

Irradiation is operationally effective and efficient as proven by the high volume of Australian mangoes currently exported to New Zealand through this treatment. Mangoes were approved over ten years ago under FSANZ Standard 1.5.3. which has since seen numerous other fruits and vegetables approved and added to the Standard.

By approving this treatment for all horticultural crops, industry in both countries will be able to responsibly maximise the benefit of the technology for the benefit of consumers.

[redacted]

Chief Executive Officer
New Zealand Fresh Produce Importers Inc.

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2.P.H.

To whom it may concern,

2PH is a family owned Queensland farming company growing and packing citrus and grapes for domestic and export markets.

2PH citrus production is predominantly export focused, supplying premium quality citrus to consumers around the world.

Effective, efficient market access for Australian Citrus exports is important for the ongoing success of 2PH and industry in general.

If phytosanitary irradiation is approved by FSANZ to treat citrus, it will strengthen future market access negotiations for Australian citrus where it may be one of a number of preferred treatments of the industry.

Current domestic treatment options for the Australian citrus industry are highly effective and efficient for 2PH. We hope to see phytosanitary irradiation approved however to strengthen future export market access request by demonstrating to Australia's trading partners that the treatment is considered safe and effective in Australia.

Yours sincerely,

[redacted]

Director/Marketing Manager
2PH Farms
Selma Road, Emerald, Queensland. 4720

15th November 2017