AM19002 Building Capacity in Irradiation

A review of the regulatory environment for phytosanitary irradiation as a trade pathway for Australian exports

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EXECUTIVE SUMMARY

This literature review was conducted as part of project AM19002 - Building Capacity in Irradiation. The objectives of this project are to:

- Build a body of knowledge concerning phytosanitary irradiation for the Australian horticulture sector, government and our international trading partners.
- Fill gaps in our knowledge regarding the effective use of phytosanitary irradiation.
- Identify future research and development activities that will increase the use and acceptance of phytosanitary irradiation domestically and internationally.

This report reviews the Australian and global regulatory environment for trade in fresh produce treated by phytosanitary irradiation. A summary of the pests of concern and the relevant minimum required doses for domestic markets and major export markets is presented. The present status of, and potential for, international trade in irradiated fresh produce is also reviewed. Potential pathways to facilitate the expansion of irradiated Australian exports are provided. Initial conclusions and recommendations are made on the regulatory challenges.

Irradiation is established as an option for phytosanitary treatment of fresh produce alongside the traditional methods of heat, cold, fumigation and modified atmospheres. Most fresh produce tolerates the relatively low doses (less than 1 kGy) required for phytosanitary irradiation. Irradiation has the advantages of being a quick, broad-spectrum, non-heat and residue-free treatment, applied within the final packaging of up to a pallet in size. Australia now exports approximately 5000 pallets of irradiated fresh produce annually, with 11 different commodities exported and 6 countries accepting irradiated Australian exports. Australian exports comprise approximately 10% of total world trade in irradiated produce.

Food irradiated at far higher doses than used for phytosanitary treatments was determined to be safe to consume by the Codex Alimentarius and many other international and national authorities in the 1980s. There is a Codex Recommended General Standard for Irradiated Food (the Codex). The Codex makes recommendations on the maximum dose for any food, radiation sources, general food hygiene, packaging, re-irradiation and verification. All irradiated food must be clearly labelled.

Over 60 countries have health or food safety regulations that permit the use of irradiation for one or more foods and purposes, based on the Codex. More than 25 countries specifically permit the sale and consumption of food irradiated for a phytosanitary purpose. The maximum permitted phytosanitary dose is usually 1 kGy although lower doses are applied in practice.

Food Standards Australia New Zealand (FSANZ) defines the general conditions and requirements under which food may be irradiated consistent with the Codex, in Standard 1.5.3 of the Food Standards Code (the Standard). In July 2021, a variation to the Standard was approved that extended the permission for phytosanitary irradiation to all fresh produce (dried pulses, legumes, nuts and seeds are not considered fruits or vegetables). A minimum dose of 150 Gy must be applied to the fresh produce with a maximum of 1 kGy. The irradiated product must be labelled with a statement that the food has been treated with ionizing radiation.

For fresh produce moving between countries (or states within Australia), protocols must be agreed between governments on how regulated pests will be treated in addition to health and/or food safety regulations that permit the food to be consumed. A framework of rules for the conduct of trade in irradiated fresh produce was not available until 2003 with the adoption of ISPM 18 by the International Plant Protection Commission (IPPC). In following years, ISPM 28 and its Annexes specified recommended minimum doses for many regulated pests. Of particular note was Annex 7 of ISPM 28 that asserted that 150 Gy (0.15 kGy) was sufficient to ensure the non-emergence of adults of all Tephritidae fruit flies on all host commodities, the so-called generic dose.

The USA recognises 400 Gy as a generic dose for all insects with the exception of the pupa and adults of Lepidoptera. In Australia, under the Interstate Certification Assurance Protocol 55, a minimum dose of 150 Gy is recognized as a sufficient treatment for all Tephritidae fruit flies, 300 Gy for mango seed weevil and 400 Gy for all arthropods except Lepidoptera that pupate internally. These minimum doses are applicable to all fresh produce.

It should be noted that the IPPC has not yet recommended the 400 Gy minimum dose as a generic treatment for all insects. Irradiation is the only phytosanitary treatment to have generic treatments for pests on all fresh produce acknowledged by the IPPC and national biosecurity agencies. The IPPC recognizes that provided the minimum dose is given to ensure non-emergence of adults or sterilization of the pest, no other treatment is required. This is important since phytosanitary doses can result in the occasional live pest being found in consignments.

Steritech (Pty) operates the only facilities that can conduct food irradiation in Australia. In 2004, the gamma irradiation processing facility near Brisbane was accredited to irradiate and certify fresh produce for exports, mainly tropical fruits from Queensland. Under an almost identical accreditation scheme, certification for domestic trade of irradiated fresh produce commenced in 2010. In January 2020, a second Steritech facility capable of X-Ray irradiation food became operational near Melbourne. The Melbourne facility treats fresh produce grown in Victoria, South Australia and southern New South Wales.

Phytosanitary irradiation was first used commercially in 2000 when irradiated papaya was shipped between Hawaii and mainland USA. Australia was the first country to export irradiated fresh produce internationally when 94 tonnes of irradiated mango were sent to New Zealand in December 2004.

Australian exports of irradiated fresh produce to New Zealand have steadily expanded since the 2004-05 season, both in terms of volume and type of product. Small markets in the USA were opened up in 2014 for mango followed by lychee. Trade with several Asian countries is now established with Vietnam a particularly successful market.

In the last three growing seasons, Australia irradiated and exported an average of over 5000 tonnes of fresh produce. Over 7000 tonnes are expected to be exported in 2021/22 despite issues due to Covid 19 and air freight issues. Exports have included mango, table grape, lychee, tomato, capsicum, papaya, mandarin, orange, cherry, plum, melon and persimmon to six countries (New Zealand, Vietnam, USA, Indonesia, Malaysia and Thailand).

Until recently, less than 100 tonnes of irradiated fresh produce per annum was moved between Australian states, mostly Queensland fresh produce treated for fruit fly and consigned to Tasmania, South Australia and Western Australia. However, 100 tonnes was exceeded in 2019/20 and 2020/21, and over 1000 tonnes is expected to be shipped in 2021/22. The main products that have contributed to recent growth are mangoes, tomatoes, capsicum and lemons to Tasmania, mangoes and summer fruit to South Australia, and mangoes and baby broccoli to Western Australia. The domestic growth in trade of irradiated fresh produce has been due to FSANZ approval of phytosanitary irradiation for all fresh produce, access to the new Melbourne irradiation facility and permission in Western Australia for use of 400Gy as a treatment for Serpentine Leaf Miner after an outbreak in New South Wales and Victoria in 2020.

Several Asian countries have a strong interest in exporting irradiated fruit into Australia. Thailand, Vietnam, Pakistan, and India have import protocols established for irradiated fruit such as mango, lychee and longan. Mexico (mango) and Israel (Etrog) also have agreed protocols to import irradiated fruit to Australia.

Overseas, the USA is the main importer of irradiated fresh produce as part of a policy to reduce the use of methyl bromide. The USA has accepted imports of many types of irradiated fresh produce from at least 10 countries. In total, international trade in irradiated fresh produce has grown from a few thousand tons in 2007 to nearly 50,000 tons in 2019. At least 13 countries are involved in the trade either as importers, exporters or both.

Conclusion and Recommendations

World trade in irradiated fresh produce is growing, and Australia is considered to be a world leader. Harmonising domestic quarantine entry conditions, and simplifying certification will be key steps in driving both domestic and export market expansion.

An increase in the volume of commodities that Australia already exports to six countries, and diversification into other commodities should be achievable in the near-term using established mechanisms (Pathway 1). Developing new markets in countries that export irradiated fruit (e.g., India and Pakistan) should be possible in the next few years (Pathway 2). More difficult markets to penetrate will be those that have approved consumption of irradiated fresh produce but do not currently engage in trade (Pathway 3, e.g., China), countries that currently permit irradiation of some foods but not fresh produce (Pathway 4, e.g., Japan and South Korea) and countries that do not permit any food to be irradiated (Pathway 5).

The recommendations are:

1. Obtain data on the dose response of pest species in support of widening the generic dose concept to other pests and vectors. [Researchers via Output 1]
2. Harmonize domestic entry regulations, allowing for generic doses of irradiation as a phytosanitary treatment domestically, for all fresh produce [Australian state governments within Output 3.2]
3. Simplify domestic certification requirement for irradiation as a phytosanitary treatment to remove audit and accreditation costs [Australian state governments within Output 3.2].
4. Prepare a prioritized list of specific irradiated commodity-target markets, noting the likely pathway as identified in this report and gauging the interest of importers in the target market. [Industry and Output 3.1].
5. Support domestic and export regulators through providing information on phytosanitary irradiation via in-house workshops (for detailed background) and brochures (for quick reference and hand-outs during negotiations). [Output 3.2, 3.3 and 3.4]

6. Commence negotiations to increase market access with target export markets falling within pathways 1 and 2 [government officials familiar with the process, supported by research and industry as required]. For those countries that are considered highly important economically but are likely to be harder to access (Pathways 3, 4 and 5, and especially China, Japan and South Korea), the work on changes to the national regulations and import protocols that will be necessary to gain access to the target market should begin as soon as possible (government officials). The identification by Australian industry of champions within the target markets who could assist with initiating the necessary regulatory changes would be useful.
7. Support efforts to encourage the IPPC to update ISPM 28, including wider use of the generic dose concept. This will require provision of data on the dose-response of pests, sharing of research data among countries and official negotiations with IPPC members, particularly those countries conducting, or interested in conducting, trade in irradiated fresh produce such as New Zealand, USA, Vietnam and others.

INTRODUCTION

It is over 90 years since low dose irradiation was first proposed as a means to sterilize, prevent emergence or kill insect pests of concern (Koidsumi 1930) but international trade in irradiated fresh fruits and vegetables (fresh produce) did not begin until 2004. The early applications of commercial irradiation focussed on decontamination of food pathogens and extension of shelf-life starting in 1957 with decontamination of spices (Roberts 2016; GIPA 2017; Craven, Schlecht and Stein 2018; Miller 2018).

In the 1980s, international authorities declared that food irradiated up to a dose of 10 kGy was safe to consume (JECFI 1981, CAC 1983). A later revision allowed for a higher dose if it was needed to achieve a legitimate technical purpose (CAC 2003). Phytosanitary treatment of fresh produce, however, requires far lower doses than 10kGy, usually in the range 150 to 500 Gy[1] with a maximum of 1 kGy (FDA 1986, FSANZ 2021).

In the 1980s, many countries enacted health or food safety legislation that permitted foods to be irradiated for a variety of purposes, including insect disinfestation of fresh produce. However, it was only in 2003 that the International Plant Protection Convention (IPPC) adopted an International Standard Phytosanitary Measure (ISMP 18) with guidelines for the use of irradiation as a phytosanitary measure when conducting trade in fresh produce (IPPC 2003). In 2004, the gamma irradiation processing facility near Brisbane was accredited to irradiate and certify fresh produce for exports, mainly tropical fruits from Queensland. In 2009, the IPPC adopted ISPM 28 which recommends phytosanitary treatments (specified minimum doses) for regulated pests (IPPC 2009a). By the close of 2010, Australian States and Territories harmonized their entry conditions to be consistent with ISPM 28, and Queensland implemented ICA55 allowing Steritech to commence certifying irradiated fresh produce for domestic trade.

Adoption of ISPMs 18 and 28 triggered the start of international trade in irradiated fresh produce which reached almost 50,000 tons in 2019 (PSIP 2021).

The regulatory challenge for irradiated fresh produce moving across borders that separate different regions with different pests is greater than for other applications of food irradiation. Foods treated and consumed in the same country (or state in Australia) need only the appropriate health or food safety regulation. However, exported fresh produce subject to phytosanitary irradiation needs both a health or food safety regulation in the importing country and a negotiated agreement between the National Plant Protection Organizations in both the exporting and importing country on the pests of concern, and on the protocols for the mitigation of the pest risks. These protocols include the specified irradiation treatment and also pre- and post- treatment conditions and documentation.

This review on the status of phytosanitary irradiation comprises 4 parts:

Part 1: A review of global regulations based on Health or Food Safety.

Part 2: The development of commercial phytosanitary irradiation.

Part 3: A review of pests of concern and irradiation doses for the top 15 markets by volume (2021).

Part 4: Trade in irradiated fresh produce.

[1] Gy = Gray, the unit of absorbed radiation dose. 1 Gy = 1 Joule/kg. 1 kGy = 1000Gy

PART 1: A REVIEW OF GLOBAL REGULATIONS BASED ON HEALTH OR FOOD SAFETY

The Codex Alimentarius is a collection of internationally recognized standards, codes of practice and guidelines related to food, food production and food safety for the protection of consumer health. The standards and codes of practice inform policy and legislation, allowing governments to establish science-based, internationally acceptable food standards for trade in food to be conducted safely.

The Codex Alimentarius General Standard for Irradiated Foods (the Codex) does not impose any restriction on the type of fresh produce that may be irradiated (CAC 2003). It states "For the irradiation of any food, the minimum absorbed dose should be sufficient to achieve the technological purpose and the maximum absorbed dose should be less than that which would compromise consumer safety, wholesomeness or would adversely affect structural integrity, functional properties, or sensory attributes. The maximum absorbed dose delivered to a food should not exceed 10 kGy, except when necessary to achieve a legitimate technological purpose."

The Codex also makes recommendations on radiation sources, general food hygiene, packaging, re-irradiation, verification and labelling.

Approximately 60 countries have health or food safety regulations that permit the use of irradiation for one or more foods and purposes. Brazil, Singapore, Mexico and Cuba (ANVISA 2001, AFVAS 2014, GHI 2018) have legislation that requires only that the irradiation treatment complies with the Codex. No other restriction is placed on the food, dose or purposes[2]. While regulations in other countries are generally based on the Codex, national oversight of the use of irradiation is maintained by stipulating the foods or food classes that may be irradiated, the purpose of the treatment, the maximum dose and, sometimes, the minimum dose.

There are regulations in some countries permitting irradiation of fresh produce for purposes such as sprout inhibition, manipulation of maturation or ripening, extension of shelf-life and prevention of decay or mold growth. However, permission to irradiate for these reasons does not provide permission to irradiate for a phytosanitary purpose.

All national legislations impose maximum dose limits and requirements for labelling as discussed below.

Global irradiation legislation

Countries can be placed into three groups (with the caveat noted in Footnote 2):

Group 1: permit the irradiation and sale of fresh produce treated for a phytosanitary or insect disinfestation purpose. Almost all these approvals specify all fresh produce as a class.

Group 2: permit irradiation of some foods but not fresh produce for a phytosanitary purpose

The remaining countries are in a group that do not have regulations permitting food irradiation (or the situation is unknown).

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[2] It is difficult to be definitive about regulations in every country, partly because of difficulties accessing all national legislations and translation. From 1983 to 2003, The International Consultative Group on Food Irradiation took responsibility for collating national food irradiation authorizations. After that, the Joint FAO/IAEA Division in Vienna took responsibility for the database of authorizations but funding for this work soon dried up. There is now no entity responsible for maintaining a database, though member states are encouraged to inform the WTO of any relevant legislation. The information provided in this report has been obtained from the FAO/IAEA database, personal communications from C. Blackburn of the Joint FAO/IAEA Division and through recent meetings, publications and personal contacts.

Table 1: Countries in Groups 1 and 2 by region.

	Group 1	Group 2
Asia & Pacific	Australia; Bangladesh; China; India; Indonesia; Malaysia; New Zealand; Pakistan; Philippines; Singapore; Sri Lanka; Thailand; Vietnam	Japan; Republic of Korea;
N America	USA	Canada
Central, S America & Caribbean	Argentina; Bolivia; Brazil; Chile; Cuba; Ecuador; Peru;	
Africa	Algeria; South Africa	Ghana; Egypt
Europe	Russia; U.K;	EU; Ukraine

Maximum dose limit for phytosanitary irradiation

The 1986 approval of phytosanitary irradiation by the US Food and Drug Administration (FDA 1986) was highly influential. In the USA, food irradiation is in the unique position of being classed as a food additive. This proved problematic when considering safety testing. The 1 kGy limit was adopted by the FDA on the theoretical grounds that at 1 kGy irradiated and unirradiated food would be "chemically indistinguishable" with the analytical methods available at that time. It was also generally accepted at the time that some fresh produce would lose quality above 1 kGy.

Despite this unique way of assessing the safety of irradiated food, a maximum dose of 1 kGy has become the default setting for most national legislation. China and Thailand use maximum dose limits of 1.5 and 2 kGy respectively.

Standard 1.5.3 of the Australia New Zealand Food Standards Code

Standard 1.5.3 defines the general conditions and requirements under which food may be irradiated in Australia and New Zealand (FSANZ 2021). It also specifies the foods that may be irradiated, the purpose of irradiation and any dose limits that must be applied. In a precautionary approach, the relevant authority (Food Standards Australia New Zealand, FSANZ) initially considered applications to permit the phytosanitary irradiation of fresh produce on a case-by-case basis. A series of applications between 2003 and 2016 led to approvals to irradiate 26 types of fresh produce for a phytosanitary purpose with a minimum dose of 150 Gy and a maximum dose of 1 kGy.

In July 2021, a variation to the Standard was approved that extended the permission for phytosanitary irradiation to all fresh produce (dried pulses, legumes, nuts and seeds are not considered fruits or vegetables).

Labelling

The Codex recommends that all irradiated foods be labelled and national regulations have followed this recommendation, except in some countries when the irradiated food becomes an ingredient.

The requirement to label fresh produce as "irradiated", "treated by ionizing radiation" or similar wording may be a disadvantage, since produce treated by other phytosanitary treatments (methyl bromide, heat, cold) do not require labelling. Fresh produce may be labelled on an individual item (eg., a sticker on a mango) or by placing a notice close to the place where the produce is displayed in bulk (see Figure 1). Use of the green "Radura" logo is optional.

Figure 1: Examples of labelling required for irradiated fresh produce

PART 2: THE DEVELOPMENT OF COMMERCIAL PHYTOSANITARY IRRADIATION.

Most phytosanitary treatments are designed to kill the target pests outright. However, irradiation doses that guarantee near-immediate mortality of all insects and life stages may affect the sensory qualities of most fresh produce. Phytosanitary irradiation is designed to prevent reproduction through the prevention of adult emergence or through sterility of the adult or the first generation of offspring. Intuitively, this goal appears less certain than mortality, but irradiation is in fact a highly effective and efficient method of insect disinfestation. It is the only method that has an internationally agreed generic dose to sterilise all fruit flies on any host (IPPC 2009b).

ISPM 18 "Guidelines for the Use of Irradiation as a Phytosanitary Measure" sets out the rules for the conduct of bilateral trade in irradiated food and ISPM 28 details minimum doses that ensure the non-viability of a range of regulated pests (IPPC 2003, IPPC 2009a). ISPM 28 broke new ground when it asserted that 150 Gy was sufficient to ensure the non-emergence of adults of all Tephritidae fruit flies on all host commodities, the so-called generic dose (IPPC 2009b).

In 2006, the US Department of Agriculture (USDA 2006) recognized 400 Gy as the generic dose for all insects with the exception of the pupa and adults of Lepidoptera. The 150 Gy generic dose for fruit flies and the 400 Gy generic dose for insects was later adopted by Australia in various entry conditions (see Table 2) but the IPPC has not yet adopted a similar position.

The first trial consignments of irradiated fresh produce were between states in the USA in the 1990s. Trial exports of irradiated papaya from Hawaii to mainland United States led to the establishment of a commercial X-ray facility for phytosanitary treatments in Hawaii in 2000. Australia and New Zealand initiated the first truly international consignments of irradiated fresh produce in December 2004 when 19 tonnes of mango were exported from Australia to New Zealand (see Part 4).

In recent years, international trade in irradiated food has grown rapidly (see Figs 2 and 3). This increase has been driven by an increasing realization that most fresh produce tolerate phytosanitary doses well. Other advantages of the irradiation process include irradiation is a quick, broad-spectrum, non-heat and residue-free treatment applied within the final packaging of up to a pallet in size.

Facilities and accreditation in Australia

Steritech (Pty) operates the only facilities that can conduct food irradiation in Australia. An irradiation processing facility near Brisbane has irradiated fresh produce for exports, mainly tropical fruits from Queensland, since 2004. In January 2020, a second Steritech facility capable of irradiating food became operational near Melbourne. The Melbourne facility treats fresh produce grown in Victoria, South Australia and southern New South Wales.

A commercial irradiation facility in Australia must be accredited under the DAWE Performance Standard for exports to issue a treatment certificate before a Phytosanitary Certificate is issued (DAWE 2021b), as well as ICA55 for domestic trade to issue a Plant Health Assurance Certificate (DEEDI 2010).

Both accreditation arrangements are based on ISPM18, and include auditable requirements for the irradiation facility, the irradiator, dosimeters for dose mapping, load configuration, treatment times, equipment calibration and maintenance, segregation, traceability and post treatment phytosanitary security. There are also requirements for process interruptions and treatment failure. There is some scope to remove the regulatory burden on irradiation providers in Australia by amending domestic entry conditions to accept a treatment certificate from any treatment facility which meets the irradiation treatment performance standard and is approved by the Australian Radiation Protection and Nuclear Safety agency.

PART 3: PESTS OF CONCERN AND IRRADIATION DOSES FOR THE 15 HIGHEST VOLUME MARKETS (2021)

This analysis of pests of concern and their minimum required doses was compiled by determining the overall volume of commodities treated, and a review of the export and domestic quarantine entry conditions.

Steritech Brisbane is the only commercial provider of phytosanitary irradiation of fresh produce for export and domestic trade established in Australia. Steritech have provided 15 of the most commonly certified fresh produce for the period 2014-2021 (see Tables 2 & 3).

The Australian Government's Department of Agriculture, Water and the Environment maintains the Manual of Importing Country Requirements (Micor) as a reference tool detailing the negotiated export requirements for exporters of Australian agricultural products. Micor Plants was reviewed to determine the regulated pest(s) for exports, and their required minimum and maximum absorbed dose (see Table 2) (DAWE 2021a).

Plant health regulators from all Australian States and Territories agreed to ensure the inclusion of irradiation as a treatment alternative (mostly for fruit flies) by the end of 2007 (DQMAWG 2007). A review of each jurisdictions plant quarantine entry conditions confirms that this agreement was implemented mostly for the treatment of Mediterranean fruit fly and Queensland fruit fly with irradiation at 150 Gy generic dose for fruit flies, and that the treatment is mostly applied on mixed consignments of Queensland fruit fly host produce destined for South Australia, Tasmania and Western Australia (AF 2021, AV 2021, PI 2021, PIRD 2021, PIR 2021, PIR 2018, PIPWE 2021)(see Table 3).

Table 2: Summary of pests of concern and minimum irradiation dose for the top 14 export markets (2020-21 season)

Market and commodity ranked by 2020-21 volume of produce.	Pest, and additional requirements	Min. absorbed dose
NZ – Mangoes, 1282t	Yellow peach moth and fruit flies. (As for NZ table grapes)	289 Gy
NZ - Table grapes, 1003t	Latrodectus hasselti (Australian redback spider), Conogethes punctiferalis (Yellow peach moth) and fruit flies. Other regulated pests (Mites?) treat consignment at a minimum dose of 400 Gy or 500 Gy. Tolerances are for a 600-unit sample are 25g of soil, 12 leaves, 8 regulated weed seeds	289 Gy
Vietnam - Table grapes, 904t	Hemiptera (Aspidiotus nerii; Diaspidiotus ancylus; Diaspidiotus perniciosus; Hemiberlesia Latoniae; Planococcus minor; Pseudococcus calceolariae; Peseudococcus viburni and fruit flies Ceratitis capitate (MFF) and Bactrocera tryoni (QFF).	400 Gy
NZ – Lychee, 554t	Bactrocera jarvisi (JFF), Bactrocera neohumeralis (lesser Queensland fruit fly) and Bactrocera tryoni (QFF) Other regulated pests treat consignment at a minimum dose of 400 Gy or 500 Gy.	150 Gy
Vietnam – Cherry, 552t	Oriental fruit moth, QFF, MFF. Include treatment rate on certificate	200 Gy
USA – Mangoes, 215t	Listed in the Operational Work Plan. Maintain phytosanitary security and undergo appropriate pest control activities for target fungi quarantine pests.	300Gy
USA – Lychee, 174t	Listed in the Operational Work Plan. 30/150 bunches, or 300pcs / block inspected and all infested fruit cut and inspected. Free from pests, soil, weed seeds and extraneous material	400 Gy

NZ – Tomato, 92t	QFF, MFF. As for NZ table grapes	150 Gy
Vietnam - Mandarin, 25t	Aspidiotus nerii; Hemiberlesia lataniae; Isotenes miserana; Lepidosaphes gloverii; and Pseudococcus viburni and fruit flies of the family Tephritidae.	400 Gy
Indonesia – Cherry, 18t	QFF, JFF, MFF	150 Gy
NZ – Capsicum, 15t	*Bactrocera bryoniae, Bactrocera musae,* Yellow peach moth. As for NZ table grapes	150 Gy 289 Gy
Thailand – Persimmon, 9t	QFF, JFF and MFF, other insect pests except pupae and adults of the order Lepidoptera	150 Gy 400 Gy
Malaysia – Mangoes, 3t	Mango Seed Weevil (Sternochetus mangiferae). Free from pests, soil, weed seeds and extraneous material.	300 Gy
NZ – Papaya, 3t	Yellow peach moth and fruit flies. As for NZ table grapes	289 Gy

By volume, the domestic trade of 112t of irradiated fresh produce in 2020/21 (see Table 3) was the eighth largest destination for irradiated fresh produce from Steritech (pers. Comm., Ben Reilly, Steritech, 2021).

Table 3. Summary of approved fresh produce, domestic market regulated pests, and minimum absorbed dose in Australian domestic regulations.

Jurisdiction	Approved fresh produce	Pest, and additional requirements	Min. absorbed dose
NSW	FSANZ approved	MFF	150 kGy
SA	FSANZ approved	Fruit fly Insecta except pupae and adults of Lepidoptera	150 Gy 400 Gy
Tas	FSANZ approved	QFF, MFF	150 Gy
WA	On a commodity basis	QFF Arthropods including Serpentine Life Miner and Melon Thrips, but excluding Lepidopteron that pupate internally,	150 Gy 400 Gy
Vic	FSANZ approved	MFF. The quarantine manual only lists 19 FSANZ approved fruit and veg.	150 Gy
Qld	FSANZ approved	MFF. The quarantine manual only lists 26 FSANZ approved fruit and veg.	150 Gy
NT	All host produce	*Bactrocera musae,* MFF	150 Gy

PART 4: PRESENT AND FUTURE TRADE IN IRRADIATED FRESH PRODUCE

Australia

Inter-state, domestic trade

Until recently there has been limited use of irradiation in inter-state trade following the adoption of the Interstate Certification Assurance Protocol 55 (ICA55) in 2011 (DEEDI 2010). Until recently, less than 100 tonnes of irradiated fresh produce per annum was moved between states; mostly Queensland fresh produce treated for fruit fly and consigned to Tasmania, South Australia and Western Australia.

However, 100 tonnes was exceeded in 2019/20 and 2020/21, and over 1000 tonnes is expected to be shipped in 2021/22. (pers. communication, Ben Reilly, Steritech).The main products that have contributed to recent growth are mangoes, tomatoes, capsicum and lemons to Tasmania, mangoes and summer fruit to South Australia and mangoes and baby broccoli to Western Australia. Baby broccoli is an example of the use of irradiation for ice-packed vegetables and other items that cannot be fumigated effectively. The growth in use domestically has been due to FSANZ approval for all fresh produce, access to the new Melbourne irradiation facility and permission in Western Australia for use of 400Gy as a treatment for Serpentine Leaf Miner after an outbreak in NSW and Vic in 2020. Other factors have included the commercial and technical benefits proven in export trade and, indirectly, the failure of some alternate pathways over the last few years and the quality challenges associated with stricter fumigation schedules.

Exports

Australian exports of irradiated fresh produce to New Zealand have steadily expanded since the 2004-05 season both in terms of volume and type of product. In recent years export markets in the USA, Vietnam, Indonesia, Malaysia and Thailand have been developed with Vietnam a particularly successful newer market (see Figure 2). Volumes are low in several markets but the demonstrated market acceptance and potential growth at this stage in the development of international trade is of more importance.

In the last three growing seasons, Australia irradiated and exported an average of approximately 5000 tonnes of fresh produce. Over 7000 tonnes are expected to be exported in 2021/22 despite issues due to Covid 19 and air freight issues. Exports have included mango, table grape, lychee, tomato, capsicum, papaya, mandarin, orange, cherry, plum, melon and persimmon to six countries (New Zealand, Vietnam, USA, Indonesia, Malaysia and Thailand).

Imports

Many Asian countries have a strong interest in exporting fruit into Australia. Several have import protocols established for irradiated fruit as shown in Table 4.

In the period 2015-2021, irradiated consignments totaling 1100t have been imported; 1067t from Vietnam and 35t from Thailand, with over 500t being mangoes, over 300t being Lychees, and 200t being Longan. There has also been low volumes of mango from India, Pakistan and Mexico and etrog from Israel.

Figure 2: Tonnes of Australian irradiated fresh produce exports (Data provided by Steritech Pty.).

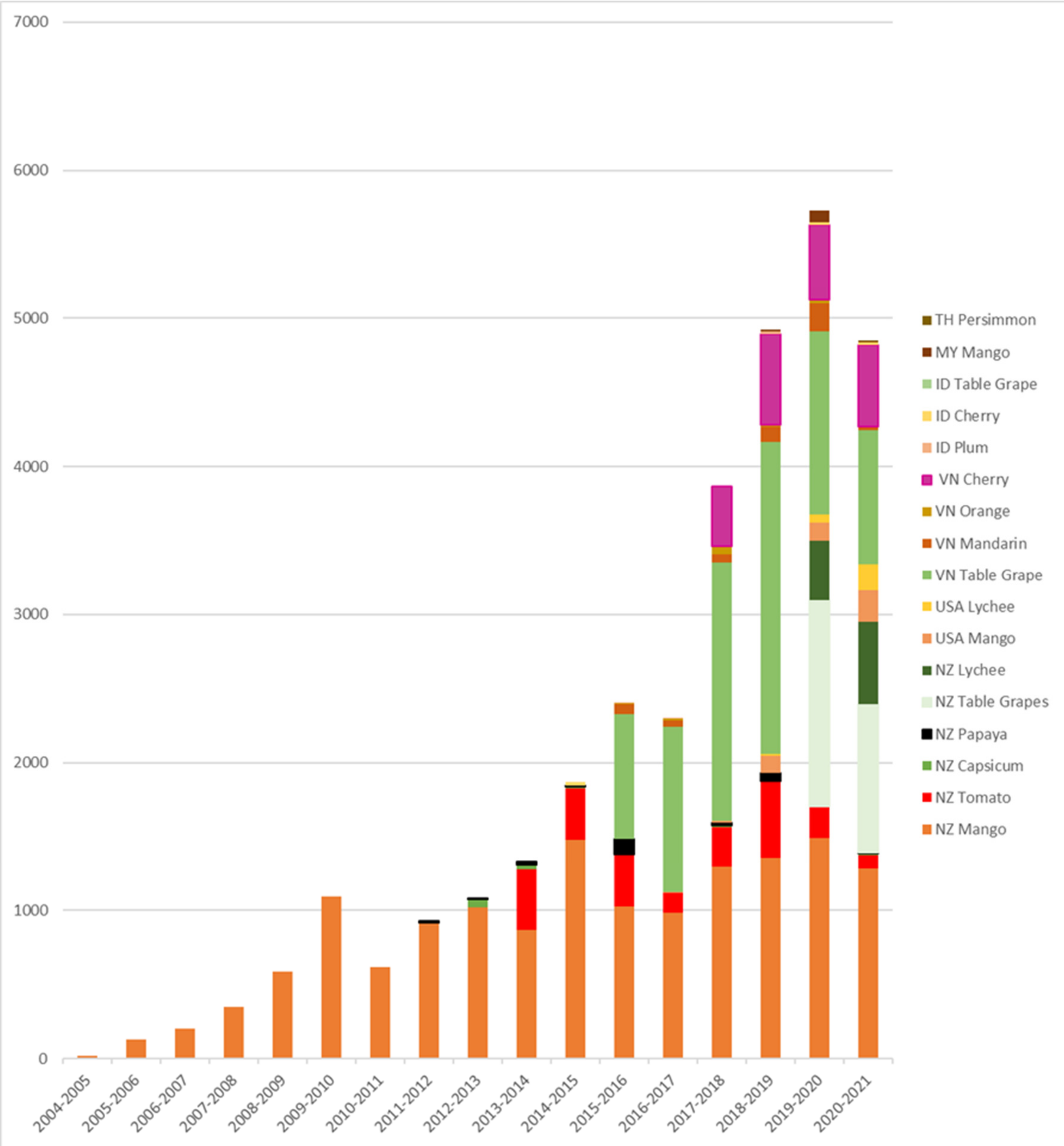


Table 4: Established protocols for irradiated fruit imports into Australia (data from DAWE).

Country	Commodity	Minimum dose (Gy)
Thailand	Mango	400
Vietnam	Lychee	400
	Longan	400
	Mango	400
Pakistan	Mango	400
India	Mango	400
Mexico	Mango	150
Israel	Etrog	150

United States

Encouraged by United States of America (USA) authorities to consider irradiation as a replacement for methyl bromide fumigation, developing countries in Central and South America and in Asia began to export fruits treated by phytosanitary irradiation to the USA. In most instances, the fruit were treated prior to shipment. In a few instances, due to lack of confidence by USA quarantine officials in the operation of facilities in the exporting country, the fruit has been treated on arrival into the USA at an irradiation facility in Gulfport, Mississippi.

Table 5 provides information on the countries that have exported irradiated commodities to the USA in recent years. A few other countries have agreements in place to allow irradiated products to be imported into the USA but it is not known whether trade has commenced. These include Chile (blueberry, grape), Ecuador (gooseberry), Jamaica (mango), St Vincent (ambarella).

Irradiated produce from Hawaii is still imported into the continental USA although the volumes have been decreasing in recent years from a peak of 20,000 tonnes to approximately 5,000 tonnes per year, mainly of sweet potato. Small amounts of papaya, lychee, longan, mango and rambutan are also irradiated.

The USA has not been very active in exporting irradiated products, with peaches to Mexico being one of the few examples (USDA 2018).

Table 5: Countries that have exported irradiated fruits and vegetables into the USA in recent years and the main produce involved (Roberts and Follett 2018; USDA 2018; Hénon 2021)

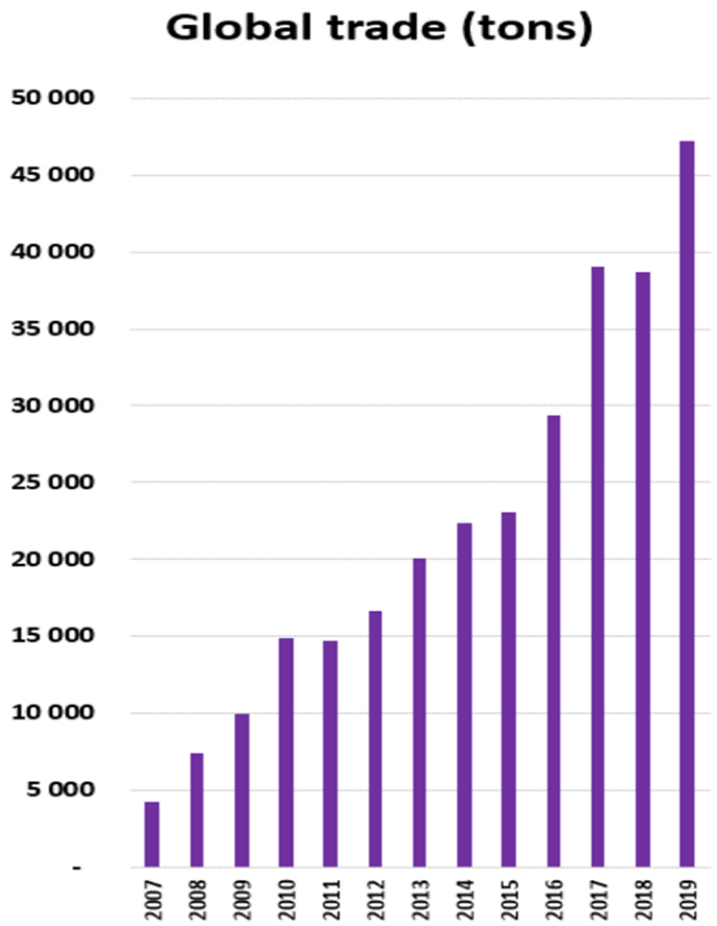
Exporting country	Irradiated produce
Mexico	Guava, fig, carambola, manzano pepper, dragon fruit, pomegranate
Vietnam	Longan, dragon fruit, rambutan, lychee, star apple, mango
Australia	Mango, lychee
India	Mango, pomegranate
Thailand	Mangosteen, mango
Pakistan	Mango
S Africa	Lychee, persimmon
Peru	Pomegranate, fig
Dominican Republic	Mango
Grenada	Ambarella

Overview of present trade in irradiated produce

Mexico and Vietnam are the leading exporters of irradiated fresh produce, while the USA, Vietnam and New Zealand are the major importers. Australia both exports and imports irradiated fresh produce. It is thought that at least 13 countries are involved with trade in irradiated fresh produce with a wide range of products treated. For some of these countries, the trade has been exploratory or irregular.

The overall growth in international trade from a few thousand tons in 2007 to nearly 50,000 tons in 2019 is shown in Figure 3. The growth in Australian irradiated fresh produce exports has grown from a few hundred tonnes to New Zealand in 2007 to over 5000t to six countries in 2021, which is approximately 10% of global trade in irradiated fresh produce.

Figure 3: Global trade in irradiated fruits and vegetables (PSIP 2021)



Potential for future growth of trade in irradiated Australian exports

Table 6 ranks a number of countries as potential export markets by the likelihood that access might be granted for irradiated Australian produce. The ranking is given on the basis of conditions such as whether the country has already accepted irradiated Australian produce, is engaged in trade in irradiated produce with other countries, its food regulations and, to some extent, on consumer attitudes. It is highly subjective and there will be trade, political and supply/demand issues that could influence market access. New Zealand in 2020/21 accepted irradiation of eight commodities totaling almost 3000t of irradiated fresh produce, so it is assumed to be fully open to trade in irradiated Australian exports.

Negotiations to open new markets will be assisted if the regulators in that market can be presented with evidence for the minimum dose needed to sterilize Australian pests of concern or in support of use of a generic dose. Reciprocity is an important concept in trade and it would support export negotiations if potential markets could see that the rules for entry for their irradiated produce into Australia are the same as for Australian domestic trade.

Table 6: Ranking of selected countries by the likelihood of gaining market access (1 = high; 10 = low)

COUNTRY	RANKING	BASIS FOR RANKING
USA	1	Already imports irradiated produce from Australia and several other countries; is trying to minimize MeBr use and encourages its replacement by irradiation; general trade with Australia well established and high level of trust between biosecurity agencies.
Vietnam; Indonesia; Malaysia; Thailand	2	Have accepted Australian irradiated commodities; have generic approval in food regulations; wish to increase irradiated exports to Australia

India; Pakistan	4	Have exported irradiated foods to US; have generic approval in food regulations; may wish to increase exports to Australia; within the ASEAN region of strategic importance to Australia.
China	6	Has generic approval for irradiated fresh produce and have established a facility on Vietnam border; the major user of food irradiation generally but has not shown interest in importing irradiated food; traditionally difficult to negotiate bilateral agreements.
Mexico; Peru	7	Have exported irradiated foods to US; have generic approval in food regulations; outside our normal sphere of interest.
Bangladesh; Sri Lanka; Philippines	8	Strong interest in irradiating food including for export; economics have limited them to small research-scale facilities at present. Generally small markets for Australian produce.
Chile; Brazil	8	Strong interest in irradiating fruit including for export; generic approval for irradiated fresh produce
Japan; South Korea	9	Regulations do not permit phytosanitary irradiation and are generally very limited. Commercial use only for potatoes (sprout inhibition) in Japan and 300 t/a of spices in Korea. Strong consumer and agriculture lobbies active against any relaxing of regulations.
United Kingdom (UK)	10	Doubtful but possible that Brexit will provide an opportunity as UK does have a generic phytosanitary use regulation. No food irradiation conducted at present.
European Union (EU)	10	EU Parliament only permits historical pre-2000 uses of irradiation which have now shrunk to be very minor. Only herbs and spices have EU-wide approval. General political stance against irradiation, GE etc.

CONCLUSIONS

General

Irradiation is established as a phytosanitary treatment and at least 13 countries are trading in irradiated fresh produce with approximately 50,000 tons traded worldwide in 2019.

Australia has developed markets for irradiate fresh products in New Zealand, USA, Vietnam, Indonesia, Malaysia and Thailand. Eleven irradiated commodities have been exported (mango, table grape, lychee, tomato, capsicum, papaya, mandarin, orange, cherry, plum and persimmons). Australia is regarded as world leader in establishing trade in irradiated commodities.

Harmonising domestic arrangements for the phytosanitary use of irradiation will allow for further expansion in use domestically. Providing data to set a harmonized entry condition for a generic dose of 400Gy for all insects (apart from pupae and adults of Lepidoptera) and 150Gy for all Tephritidae as a treatment for all fresh produce will be an important first step. Convincing domestic regulators to accept a treatment certificate from a treatment facility which meets the irradiation treatment performance standard, and is approved by the Australian Radiation Protection and Nuclear Safety agency will reduce the administration costs of irradiation as a treatment as well.

Harmonized domestic entry conditions will also support export negotiations. To successfully develop a new export market, two regulatory criteria have to be fulfilled. First, the importing country must have a food regulation that allows the consumption of the imported fresh produce after it has been irradiated for a phytosanitary purpose. Then, the importing and exporting countries must agree a protocol for the irradiation process that satisfies the importing country that any pest risk will be managed.

Pathways to expanding exports

Expansion of Australian exports of irradiated fresh products can follow one of several pathways that depend upon the status of the food regulations in the potential market country and its experience with phytosanitary protocols for irradiation treatment. Assessment of the general commercial feasibility of a particular market for a specific commodity would be a further requirement of all pathways. The pathways, in order of increasing difficulty are –

Pathway 1: Australia has already been established trade with six countries. An increase in volumes of commodities already exported and diversification into other commodities should be achievable in the near-term using established mechanisms.

Pathway 2: Developing new markets in countries that export irradiated fruit should be the next target with success possible in the next few years. These countries have experience with the establishment of phytosanitary protocols and the necessary food regulations. Included in this group are several countries that have expressed interest in exporting fruit to Australia and, therefore, should be amenable to reciprocal arrangements. Key targets in this group would include India and Pakistan in Asia, with Mexico and Peru also candidates.

Pathway 3: There are several countries with food regulations that permit the sale of all fresh fruit that have been treated by phytosanitary irradiation, but which have not engaged in trade and have no experience with negotiating irradiation protocols to allow trade. The most important target in this group would be China, with several other potential markets in Bangladesh, Philippines, Singapore, Sri Lanka and a few South American countries such as Chile and Brazil.

The UK is also in this group but, until Brexit, the UK was essentially bound by an EU regulation that permits only the irradiation of herbs and spices for decontamination. Interest and support for food irradiation in the EU has been extremely limited for over 20 years. Strong public resistance to any changes to the present, restrictive regulation is expected and there appears to be no political will to examine the issues involved. The UK has been heavily influenced by the EU environment and does not irradiate any food at present.

Pathway 4: Over 30 countries permit one or more uses of food irradiation but do not yet permit the phytosanitary irradiation of fresh produce. Before any trade can be contemplated, the target country would need to modify its food regulations to permit phytosanitary irradiation of food for human consumption. Only then could meaningful discussions on trade opportunities and import protocols be held.

The key potential markets within this group would be Japan, South Korea and the EU. The situation in the EU was noted above. The EU is the only region in the world where the volume of food treated with irradiation has been decreasing, with only a few small, niche uses left. Japan and South Korea enacted regulations for a single use of irradiation many years ago (inhibition of potato sprouting in Japan and decontamination of spices in South Korea). There has been strong public, agricultural sector and political resistance to widening the scope of the regulation in both countries. In practice, these countries are only a little more promising in the near term than the countries in Pathway 5.

Pathway 5: This pathway includes all the many countries that do not have any regulation permitting the irradiation of food, effectively banning the use of the process at this time.

Pathways 3 and 4 include markets of high potential economic value (China, Japan and South Korea). Given the relative difficulty associated with accessing those markets, it will be vital to begin the long process of trade negotiations as soon as possible.

Phytosanitary protocols

Negotiations establishing phytosanitary protocols should be based on ISPM 18 and ISPM 28. Agreement on generic doses that guarantee that any host commodity will achieve pest-free status for a stipulated pest or group of pests can be very helpful in shortening negotiation times and reducing the research required on pest-dose response.

The generic dose of 150 Gy for all Tephritidae fruit flies recommended in ISPM 28, and the 400 Gy generic dose agreed by the USA and Australia for all insects except Lepidoptera that pupate internally are examples of such generic doses. It would reduce barriers to trade if the IPPC could be convinced to adopt the 400 Gy generic dose for all insects except Lepidoptera that pupate internally or, preferably, all arthropod species. Barriers would be further reduced if research information could be provided to the IPPC and Australian domestic regulatory authorities to establish generic doses or the minimum dose required for satisfactory treatment of non-insect pests such as mites and vectoring species.

A practical barrier to trade can be the occasional, unnecessary requirement for remedial treatment by the importing country due to a lack of understanding of generic doses and that a live species that has undergone the stipulated treatment is not a threat. Training support for border staff in some importing countries could be helpful.

Treatment times, cost and any possible detrimental effects on quality are reduced as the minimum required dose is lowered. Therefore, if research information is available that shows that the risk from pests for a specific commodity and country can be eliminated with a lower dose than the generic dose, then the lower dose is preferable.

RECOMMENDATIONS

All the recommendations form an essential part of the long-term roadmap for developing trade and can be initiated through the existing project and completed with some extension to parts of the project.

1. Obtain data on the dose response of pest species in support of widening the generic dose concept to other pests and vectors. [Researchers via Output 1]
2. Harmonize domestic entry regulations, allowing for generic doses of irradiation as a phytosanitary treatment domestically, for all fresh produce. [Australian state governments Output 3.2]
3. Simplify domestic certification requirement for irradiation as a phytosanitary treatment to remove audit and accreditation costs. [Australian state governments Output 3.2].
4. Prepare a prioritized list of specific irradiated commodity-target markets, noting the likely pathway as identified in this report and gauging the interest of importers in the target market. [Industry and Output 3.1].
5. Support domestic and export regulators through providing information on phytosanitary irradiation via in-house workshops (for detailed background) and brochures (for quick reference and hand-outs during negotiations). [Output 3.2, 3.3 and 3.4]
6. Commence negotiations to increase market access with target export markets falling within pathways 1 and 2 [government officials familiar with the process, supported by research and industry as required]. For those countries that are considered highly important economically but are likely to be harder to access (Pathways 3, 4 and 5, and especially China, Japan and South Korea), work on changes to the national regulations and import protocols that will be necessary to gain access to the target market should begin as soon as possible [government officials]. The identification by Australian industry of champions within the target markets who could assist with initiating the necessary regulatory changes would be useful.
7. Support efforts to encourage the IPPC to update ISPM 28, including wider use of the generic dose concept. This will require provision of data on the dose-response of pests, sharing of research data among countries and official negotiations with IPPC members, particularly those countries conducting, or interested in conducting, trade in irradiated fresh produce such as New Zealand, USA, Vietnam etc.

REFERENCES

AFVAS (2014). Agri-Food and Veterinary Authority of Singapore. Food Regulations, Part 3, Irradiated Food. ⟨http://www.ava.gov.sg/docs/default-source/legislation/ sale-of-food-act/2-web_sof_food-regulations-15-dec-2014⟩ (accessed 03.16).

AF (2021). Agriculture and Fisheries. Queensland Biosecurity Manual version 15.0. Accessed November 2021 at https://www.daf.qld.gov.au/business-priorities/biosecurity/policy-legislation-regulation/qld-biosecurity-manual-certificates

AV (2021). Agriculture Victoria. Plant Quarantine Manual. Accessed November 2021 at https://agriculture.vic.gov.au/biosecurity/moving-plants-and-plant-products/plant-quarantine-manual

ANVISA (2001). Agência Nacional de Vigilância Sanitária. Resolução RDCNo.21.São Paulo, Brazil, Diário Oficial da União (inPortugese).

CAC (1983). Codex Alimentarius Commission. General Standard for Irradiated Foods (CODEX STAN 106-1983). Codex Alimentarius, FAO/WHO, Rome.

CAC (2003). Codex Alimentarius Commission. General Standard for Irradiated Foods (CODEX STAN 106-1983, Rev.1-2003). Codex Alimentarius, FAO/WHO, Rome. Accessed June 2011 at http://www.codexalimentarius.net/download/standards/16/CXS_106e.pdf.

Craven, E., Schlecht, J. and Stein, R (2018). Gamma irradiation plants. 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 3. P.28.

DAWE (2021a). Department of Agriculture, Water and the Environment. Micor Plants https://micor.agriculture.gov.au/Plants/Pages/default.aspx , accessed 13 October 2021

DAWE (2021b). Department of Agriculture, Water and the Environment. Performance standards – irradiation treatment – horticulture exports version 3. Accessed November 2021 at https://www.awe.gov.au/biosecurity-trade/export/controlled-goods/plants-plant-products/plantexportsmanual#treatments

DEEDI (2010). Department of Employment, Economic Development and Innovation. Irradiation Treatment (ICA55) Interstate Certification Assurance National protocol.

DQMAWG (2007). Domestic Quarantine and Market Access Working Group 27. Minutes of Meeting 5/6 September, Brisbane.

FDA (1986). Food and Drug Administration. Irradiation in the production, processing and handling of food: Final Rule. Irradiation of Fresh Fruits and Vegetables. 51 FR 13375-13399. 18 April.

FSANZ (2021). Food Standards Australia New Zealand. Food Standards Code. Standard 1.5.3. Irradiation of Food. https://www.foodstandards.govt.nz/code/Pages/default.aspx

GHI (2018). Global Harmonization Initiative. Consensus Document on Food Irradiation. A Working Group on Food Preservation Technologies. October. https://www.globalharmonization.net/node/279

GIPA (2017) Gamma Industry Processing Alliance. A comparison of gamma, electron beam, x-ray and ethylene oxide technologies for the industrial sterilization of medical devices and health-care products. A White Paper. 31 August. Available from GIPA and the International Irradiation Association via www.gpialliance.net and www.iiaglobal.com

Hallman, G. (2011). Phytosanitary applications of irradiation. *Comp.Reviews in Food Sciences and Food Safety*. **10**, 143-151.

Henon, Y (2021). Recent Developments in Food Irradiation. A presentation to the International Food Irradiation Symposium, March 9-11th.

IPPC (2003). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 18 Guidelines for the Use of Irradiation as a Phytosanitary Measure. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy, 2006. ***Accessed June 2011 at https://www.ippc.int/index.php?id=ispms&no_cache=1&L=0***

IPPC (2009a). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28. Phytosanitary treatments for regulated pests. Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy. Accessed August 2021 at https://www.ippc.int/en/publications/591/

IPPC (2009b). International Plant Protection Convention. International Standards for Phytosanitary Measures, ISPM No. 28. Annex 07. Irradiation treatment for fruit flies of the family Tephriditae (generic). Secretariat of the International Plant Protection Convention. Food and Agriculture Organisation of the UN, Rome, Italy. Accessed August 2021 at https://www.ippc.int/en/publications/633/

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

Koidsumi, K. (1930). Quantitative studies on the lethal action of X-rays upon certain insects. *J. Soc. Tropical Agriculture (Japan)* **2**, 243-263.

Miller, R.B. (2018). 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 4, p51.

PI (2021). Primary Industries. NSW Biosecurity Order (Permitted Activities). Accessed November 2021 at https://www.dpi.nsw.gov.au/about-us/legislation/list/biosecurity-act-2015

PIPWE (2021). Primary Industries, Parks, Water and Environment. Plant Biosecurity Manual Tasmania, 2021 Edition. Accessed November 2021 at https://dpipwe.tas.gov.au/biosecurity-tasmania/plant-biosecurity/plant-biosecurity-manual

PIR (2018). Primary Industries and Resources. Northern Territory Plant Quarantine Manual. Accessed November 2021 at https://industry.nt.gov.au/__data/assets/pdf_file/0011/396587/Plant-Quarantine-Manual.pdf

PIR (2021). Primary Industries and Regions. Plant Quarantine Standard South Australia Version 17.2. Accessed November 2021 at https://pir.sa.gov.au/__data/assets/pdf_file/0008/362285/plant-quarantine-standard-south-australia-v-17.2.pdf

PIRD (2021). Primary Industries and Regional Development. Quarantine WA Import Requirements Search. Accessed November 2021 at https://www.agric.wa.gov.au/iaquarantine/

PSIP (2021). Phytosanitary Irradiation Platform. Global trade overview. Accessed August 2021 at https://psipglobal.org/members/global-trade-overview/

Roberts, P.B. (2016). Irradiation of Food. Development, status and prospects. Reference Module in Food Sciences. Accessed August 2021 at https://doi.org/10.1016/B978-0-08-100596-5.21104-9

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

USDA (2006). United States Department of Agriculture- Animal and Plant Health Inspection Service, Treatments for fruits and vegetables, *Fed. Register*, **71(18)**, 4451.

USDA (2018). US Department of Agriculture. Phytosanitary Irradiation. A presentation by Maggie Smither of the Animal and Plant Health Protection Service to the 8th Chapman Phytosanitary Irradiation Forum, June 14-15th 2018.