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Supporting document 1

Risk and technical assessment report – Application A1193

Irradiation as a phytosanitary measure for all fresh fruit and vegetables

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Executive summary

The Queensland Government Department of Agriculture and Fisheries (QLD DAF) has applied to Food Standards Australia New Zealand (FSANZ) for permission to irradiate all types of fresh fruit and vegetables for the purpose of pest disinfestation for a phytosanitary objective. A phytosanitary treatment is used on a food that is entering another quarantine region, when there is a requirement that the food is free from regulated pests such as fruit fly. Excluded from the scope of the application are dried pulses and legumes, and nuts and seeds. The permission would apply to both domestically produced and imported fruit and vegetables requiring a phytosanitary treatment.

The current assessment extends FSANZ's previous approval of 26 fruits and vegetables for irradiation with doses of up to 1 kiloGray (kGy). It addresses whether irradiation of all fresh fruit and vegetables for the purpose of pest disinfestation for a phytosanitary objective is technologically justified, and whether all fresh fruit and vegetables irradiated with a dose of up to 1 kGy are as safe as, and nutritionally equivalent to, non-irradiated fruit and vegetables.

The evidence supporting the proposed use of irradiation as a phytosanitary measure for all fresh fruit and vegetables, within the specified dose range, provides adequate assurance that this method is technologically justified and effective in achieving its stated purpose. The assessment recognises that the minimum absorbed dose should be sufficient to achieve the technological purpose, and the maximum absorbed dose should not compromise the properties of the food. Irradiation as a phytosanitary measure is not a substitute for good hygienic, manufacturing or agricultural practices.

A toxicological assessment concluded that on the basis of the available evidence there are no safety concerns associated with the consumption of fresh fruit and vegetables that have been irradiated with doses of up to 1 kGy. Radiolytic compounds are not produced at levels that are likely to result in harm. The levels of these compounds are generally comparable to those naturally present in cooked food. There is no evidence to indicate that phytosanitary irradiation at the proposed doses would increase the allergenicity of food, or increase the toxicity associated with any mycotoxin contamination or result in additional dietary exposure to furan.

These conclusions are consistent with those reached by the European Commission's (EC)

Scientific Committee on Food, the World Health Organization (WHO), Health Canada and the European Food Safety Authority (EFSA).

FSANZ previously reviewed the nutritional impact of phytosanitary irradiation on 22 fruits and four vegetables (Applications A0443, A1038, A1069, A1092 and A1115) as well as on herbs and spices (Application A0413) and, based on the evidence available at the time of those assessments, concluded that the minor nutrient losses caused by irradiation were not a concern for public health. The fruit approved for irradiation include tropical fruit (e.g. breadfruit, mango, and papaya) and commonly consumed fruit (e.g. apples, apricots, peaches, plums, nectarines, cherries, strawberries, raspberries, and blueberries) as well as four vegetables – tomatoes, capsicums, scallopini (squash) and zucchini (courgette). Nutritional assessment of the impact of irradiation has centred on the losses of five micronutrients known to be sensitive to irradiation. Vitamin A (retinol), vitamin C, vitamin E, and thiamin are considered highly sensitive, while β-carotene is of medium sensitivity.

Given that FSANZ has previously reviewed and approved irradiation for phytosanitary purposes for a wide range of fruit and had undertaken a review of the effect of irradiation on additional categories of fruit and vegetables in 2004, the present assessment focused primarily on the effect of irradiation on vitamin C and β-carotene (pro-vitamin A) in three categories of vegetables – namely Brassicas, leafy vegetables, and roots and tubers – that together make an important contribution to population intakes of vitamin C and β-carotene and that were not assessed by FSANZ in previous applications to irradiate fruit and vegetables. Vitamin A (retinol), which is highly sensitive to irradiation, was excluded from the nutritional assessment because retinol is not present in plant foods. Thiamin and vitamin E, also highly sensitive to irradiation, were considered but a firm judgement about the extent of irradiation-induced losses is not made because too few relevant studies were identified. Concern about the absence of evidence for thiamin and vitamin E is obviated by the fact that vegetables make only a relatively small contribution to population intakes of thiamin (less than 10%) and vitamin E (10 – 17%).

Irradiation of leafy vegetables, Brassicas, and roots and tubers at doses of up to 1 kGy caused only small losses of vitamin C. Across all vegetables, the overall mean decrease in vitamin C content was 2 mg/100 g (95% CI; -3 to -1), representing approximately a 5% loss. The only exceptions across the eleven types of vegetables assessed were spinach and rocket where the mean loss in spinach was 10 mg/100 g (95% CI; -15 to -6), representing an 18% loss and in rocket 6 mg/100 g (95% CI; -7 to -5) representing a 34% loss. Losses in β-carotene or carotenoid content of leafy vegetables and roots and tubers after irradiation were very small with an overall mean decrease of 3 mg/kg (95% CI; -8 to +3); representing approximately a 3% loss.

FSANZ considers that based on the available evidence, irradiation will have minimal effect on population micronutrient intake from fruit and vegetables. The range of fruit that has been assessed is comprehensive, accounting for most types of fruit consumed in Australia and New Zealand; however, the range of vegetables examined is not as comprehensive. An evaluation by FSANZ showed that for the commodities where nutrient impact data were available, they contributed to a large proportion of the dietary intakes from fruit and vegetables, and included the most commonly consumed commodities. While the body of evidence for fruit and vegetables suggests that irradiation-induced losses of micronutrients that are more sensitive to irradiation is small, there is variability as well as examples of a few foods in which losses are higher.

However, the few instances of higher losses in nutrient content are not of concern because there will only be a small proportion of domestically produced and imported fruit and vegetables in Australia and New Zealand likely to be treated by irradiation, with some commodities not requiring irradiation due to localised consumption and technological reasons. The Queensland Department of Agriculture and Fisheries provided conservative estimates that between 0.3 – 8% of total fruit and vegetables consumed in Australia and New Zealand might be irradiated.

Therefore the dietary intake of nutrients is likely to come from a mix of non-irradiated and a small amount of irradiated produce over the course of a lifetime. This minimises any impact on population nutrient intakes from consuming irradiated produce.

On the basis of the available evidence and the above considerations FSANZ concludes that in relation to the current application there are no public health and safety concerns associated with the use of irradiation (up to 1 kGy) as a phytosanitary measure for fresh fruit and vegetables.

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1 Introduction

The Queensland Government Department of Agriculture and Fisheries (QLD DAF) has applied to Food Standards Australia New Zealand (FSANZ) for permission to irradiate all types of fresh fruit and vegetables for the purpose of pest disinfestation for a phytosanitary objective[1]. Excluded from scope are dried pulses and legumes, and nuts and seeds. The permission would apply to both domestically produced and imported fruit and vegetables requiring a phytosanitary treatment to ensure freedom from regulated pests[2].

Paragraphs 1.1.1—10(5)(d) and (6)(h) of the Australia New Zealand Food Standards Code (the Code) provide that a food for sale must not consist of, or have as an ingredient or a component, a food that has been irradiated, unless expressly permitted by the Code. Division 2 of Standard 1.5.3 of the Code contains the relevant permissions for the irradiation (and re-irradiation) of food[3]. Currently, 26 fruits and vegetables are permitted to be irradiated for the purpose of pest disinfestation for a phytosanitary objective. The permitted minimum and maximum absorbed doses are 150 Gray (Gy) and 1 kiloGray (kGy), respectively. A pre-market assessment is required before any irradiated fruit and vegetable can be sold in Australia or New Zealand.

FSANZ has previously undertaken risk assessments for the following: a range of tropical fruit (Applications A0443 and A1038, FSANZ 2002 and 2011); tomatoes and capsicums (Application A1069, FSANZ 2013); 12 additional fruit and vegetables (Application A1092, FSANZ 2014a); and, most recently, blueberries and raspberries (Application A1115, FSANZ 2016). FSANZ's first risk assessment, undertaken in 2001, related to the irradiation of herbs, spices and plant material for herbal infusions (Application A0413, ANZFA 2001).

Previous risk assessments for fruit and vegetables identified that irradiation as a phytosanitary measure fulfilled its technological purpose, and concluded that there were no food safety concerns associated with the consumption of the commodities under evaluation, when irradiated within the proposed dose range. In addition, there were no major concerns identified regarding potential nutrient losses due to irradiation and the impact of these losses on total dietary intake.

Should this application be approved, the existing permissions for 26 fruits and vegetables would be replaced with a generic permission for the irradiation of all fresh fruit and vegetables. The permitted minimum and maximum absorbed doses would remain unchanged. The minimum dose of 150 Gy corresponds to a generic treatment for fruit fly species.

Whilst the permission covers 'all' fresh fruit and vegetables, in practice, only a proportion of the fresh produce available for consumption in Australia and New Zealand might be irradiated. Permission covers the use of irradiation solely for the purpose of pest disinfestation for a phytosanitary objective. Produce grown and consumed in the same quarantine region does not require such a phytosanitary treatment and, as such, the use of irradiation would not apply to these commodities. For some produce that does cross quarantine borders, e.g. Australian-grown vegetables, an end point phytosanitary treatment is unnecessary because the harvesting and processing requirements result in soil and pest free commodities. In other cases, a proportion of the produce item may continue to be

[1] A phytosanitary measure includes any legislation, regulation or official requirement that prevents the introduction and/or spread of quarantine pests.
[2] A regulated pest is a quarantine pest or a regulated non-quarantine pest, for which phytosanitary actions would be undertaken if it were intercepted/detected.
[3] For the purposes of this application, 'food irradiation' is the process of applying ionising radiation to food to achieve a sanitary, phytosanitary or other specific purpose that helps to maintain the quality of the food.

treated with existing phytosanitary treatments, which are well established, rather than switch to irradiation. Some commodities, for example, bananas, may simply not suit phytosanitary irradiation. In all, the use of irradiation as a phytosanitary measure will be voluntary, used only where necessary and permitted, and irradiation will be only one of a number of other phytosanitary treatment options available.

1.1 Assessments by other agencies

The safety of irradiated foods has been evaluated by international scientific bodies and regulatory agencies in other countries. These include several Joint FAO/IAEA/WHO bodies: the Expert Committee on Food Irradiation (JECFI) (WHO 1981); the International Consultative Group on Food Irradiation (WHO 1994); and the Study Group on High-Dose Irradiation (WHO 1999). Regulatory agencies include Health Canada (CFIA 2009), the Hong Kong Centre for Food Safety (2009), and the European Food Safety Authority (2011a, b).

As part of these assessments, the safety, including any adverse nutritional impacts, of irradiation on a wide range of foods have been examined. The weight of scientific evidence is that irradiated food is safe to consume when irradiated at doses necessary to achieve the intended technological function and in accordance with the International Atomic Energy Agency's Manual of Good Practice in Food Irradiation (IAEA 2015). The Study Group on High-Dose Irradiation determined that irradiation does not compromise the nutritional value of food nor does it result in any toxicological hazards. Irradiated foods are deemed wholesome throughout the technologically useful dose ranges (WHO 1999).

2 Technological need and quarantine requirements

2.1 Objectives for the food technology assessment

To determine whether there is an established technological purpose for using irradiation for pest disinfestation for a phytosanitary objective on all fresh fruit and vegetables at the proposed dose range, and whether that dose range is consistent with quarantine requirements.

2.2 What is food irradiation?

Food irradiation is the process of applying ionising radiation to food to improve its safety or maintain its quality.

Food can be exposed to ionising radiation provided by radioactive isotopes (gamma rays from cobalt-60 (^{60}Co) or caesium-137 (^{137}Cs))[4], and machine sources of electron beams or X-rays. Each of these sources have different operational characteristics, including their level of penetration, direction of emission, and dose rate (IAEA 2015). In Australia, food irradiation is undertaken using the radionuclide ^{60}Co and, more recently, X-rays.

During irradiation, energy is transferred from the source of ionising radiation into the product being treated. The amount of energy absorbed per unit mass of the treated product is expressed as the 'absorbed dose' or simply 'dose'. Applying the specified minimum dose is critical in phytosanitary treatments, to ensure that the desired treatment outcome (e.g. pest mortality or sterility) is achieved, and the absorbed dose is measured using dosimeters (IAEA 2015). During irradiation, the food does not come into contact with the radioactive source. Rays pass through the food without heating it up to any great extent. No radioactive energy remains in the food after treatment.

Whilst irradiation facilities can differ in their construction and layout depending on the source of ionising radiation, the type of product being treated, and the purpose for irradiation, they are essentially a warehouse with the irradiator situated in a segregated irradiation chamber. In continuous irradiation, products may move continuously through the chamber via conveyer. In batch irradiators, products are taken in and out of the irradiation chamber upon completion of treatment. It is important for irradiation facilities to maintain well-separated areas for storing non-irradiated and irradiated products, particularly where phytosanitary irradiation is the objective. This is to avoid accidental intermingling of products whereby pest re-infestation might occur (IAEA 2015). The Asia Pacific Plant Protection Commission (APPPC) has developed Regional Standards for Phytosanitary Measures (RSPMs), including RSPM No. 9 *Approval of irradiation facilities.* This standard provides guidelines for approval (certification or accreditation) of facilities irradiating commodities for phytosanitary purposes consistent with those of the International Plant Protection Convention (IPPC). Accreditation is undertaken by the national plant protection organisations (NPPO). Facilities may also be audited by importing countries' NPPOs. The role of the NPPO is to ensure that the equipment, as installed and properly operated, consistently performs as expected and that treatment parameters can be met.

2.3 Uses of food irradiation

The treatment of foods with ionising radiation is an effective method for achieving phytosanitary and sanitary objectives, as well as several beneficial physiological effects on the plant.

[4] ^{137}Cs is not approved as a source of ionising radiation for food in Australia and New Zealand.

The current application is seeking permission to use irradiation for a phytosanitary objective only (specifically, pest disinfestation). Phytosanitary measures include those that protect the health of plants and, in particular, prevent the introduction or spread of pests that may be present in or on fresh produce, such as fruit flies and other insect pests (e.g. mealy bugs, mango weevils). Treatment may result in pest mortality, sterility, or failed development (i.e. no emergence of adults).

Sanitary measures include those that destroy microorganisms such as Salmonella and *Escherichia coli* (*E. coli*), which might otherwise cause foodborne illnesses or reduce the shelf-life of foods by causing spoilage or decomposition (e.g. moulds, parasites, bacteria). Applications for irradiation that cause a physiological effect on the plant include sprouting inhibition (e.g. potatoes, onions) and delay of ripening.

2.4 Current status of food irradiation for phytosanitary purposes in Australia and New Zealand

A phytosanitary treatment is used on food that is entering another quarantine region, when there is a requirement that the food is free from regulated pests. There are a range of phytosanitary treatment options available to the horticultural industry in addition to irradiation. These are based on physical (heat, cold), chemical (fumigation), and systems approaches, which integrate different risk management measures that together achieve the appropriate level of protection against regulated pests.

The vast majority of fresh fruit and vegetables that are consumed in Australia and New Zealand are not subject to any phytosanitary treatments as they are produced and consumed within the same quarantine region. New Zealand has no need for phytosanitary treatments for produce consumed locally. Therefore, the use of irradiation as a phytosanitary treatment only applies to overseas imports into Australia and New Zealand, and for Australia, to interstate trade across different quarantine jurisdictions, in particular, the movement of produce from Queensland and Victoria (which lie within the Queensland fruit fly zone for Australia), to South Australia, Western Australia and Tasmania. To illustrate the small quantities involved, the applicant provided data for 2018-19 indicating that only 21 tonnes of irradiated produce was involved in interstate trade that year. There is currently one food irradiation facility in Queensland and another in Victoria; the amount of produce that can be irradiated is limited by practical constraints. New Zealand does not have a food irradiation facility. In terms of imports from overseas, only 5% and 1% of fruit and vegetables respectively consumed in Australia originate from overseas and five countries have negotiated access to Australia for irradiated fruit.

From 2001, FSANZ has considered six applications for the irradiation of foods, namely, herbs, spices and plant material for herbal infusions, and 26 fruits and vegetables. Under Division 2 of Standard 1.5.3 of the Code, herbs, spices and plant material for a herbal infusion may be irradiated for pest disinfestation (among other objectives) if the absorbed dose is no higher than 6 kGy. Twenty-six fruits and vegetables may be irradiated for the purpose of pest disinfestation for a phytosanitary objective, if the absorbed dose is no lower than 150 Gy (the generic treatment for fruit fly species), and no higher than 1 kGy. Further details on the foods permitted for irradiation as a result of applications submitted to FSANZ are provided in Table 1.

As part of FSANZ's assessment of previous fruit and vegetable applications, advice on the technological need and appropriate dose ranges for phytosanitary purposes was obtained from the relevant quarantine agencies, and this helped inform FSANZ's decision to permit the irradiation of those fruit and vegetables. Currently, these agencies are the Australian

Government Department of Agriculture, Water and the Environment (DAWE), and Biosecurity New Zealand (in the New Zealand Ministry for Primary Industries (MPI)). Although FSANZ is responsible for assessing applications to vary the Code, it is not responsible for compliance activities. Enforcement functions rest the relevant quarantine agencies in each jurisdiction. Ultimately, it is the responsibility of the retailer to ensure they are providing safe and suitable food.

Table 1: Foods permitted to be irradiated in Australia and New Zealand, purpose of irradiation, and dose range

Application	Year	Food	Permitted purpose and dose range
A0413	2001	Irradiation of herbs and spices – Herbs, spices and plant material for a herbal infusion	Controlling sprouting and pest disinfestation, including the control of weeds. Absorbed dose is no higher than 6 kGy. Bacterial decontamination. Absorbed dose is: (a) no lower than 2 kGy and (b) no higher than 30 kGy (herbs and spices) no higher than 10 kGy (plant material for a herbal infusion).
A0443	2002	Irradiation of tropical fruit – Breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya and rambutan	Pest disinfestation for a phytosanitary objective. Absorbed dose is: (a) no lower than 150 Gy and (b) no higher than 1 kGy.
A1038	2011	Irradiation of persimmons	As above.
A1069	2013	Irradiation of tomatoes and capsicums	As above.
A1092	2014	Irradiation of specific fruits and vegetables – Apple, apricot, cherry, nectarine, peach, plum, honeydew, rockmelon, scallopini, strawberry, table grape and zucchini (courgette)	As above.
A1115	2016	Irradiation of blueberries and raspberries	As above.

2.4.1 Import of irradiated fruit and vegetables into New Zealand

Whilst Standard 1.5.3 of the Code lists the range of fresh fruit and vegetables that are allowed to be irradiated, these are not permitted into New Zealand until a corresponding import health standard is in place. MPI is responsible for establishing these import health standards, including a separate biosecurity risk assessment, ensuring that the food proposed for import meets all of the New Zealand standards and requirements. The biosecurity risk assessment is a separate process to the food standards approval process.

As of September 2020, import health standards were in place for a number of fresh commodities from Australia irradiated for quarantine purposes including capsicum, grapes, papaya, lychee (litchi), mango and tomato (MPI 2020a). Examples of approvals by MPI are outlined in Table 2.

Table 2: Examples of MPI approvals for the import of irradiated fruit and vegetables from Australia

Commodity	Date issued	Purpose	Dose
Litchi	23 April 2009	Control of fruit fly and hemiptera bugs.	Minimum dose of 250 Gy
Mango	23 April 2009	Control of fruit fly and other insect pests.	Minimum dose of 150 Gy (fruit fly) Minimum dose of 250 Gy (other)
Papaya	15 March 2019	Control of fruit fly and other insect pests.	Minimum dose of 150 Gy
Tomato	14 August 2013	Control of fruit fly and other insect pests.	Minimum dose of 150 Gy (fruit fly) Minimum dose of 400 Gy

2.4.2 Import of irradiated fruit and vegetables into Australia

Australia has quarantine controls in place for international imports, ensuring the safe importation of risk products so that the country remains protected from pests such as fruit fly. DAWE undertakes import risk analyses for fresh fruit and vegetables, which assess the level of biosecurity risk and establish appropriate risk management measures; irradiation being one of the possible treatment options. These analyses are done independently of the food standards process and are completed before the produce in question is imported into Australia.

If the import risk analysis indicates that an appropriate level of protection can be achieved through identified risk management measures, the Department issues import permits detailing the specific conditions and requirements for importation of each product, including the requisite phytosanitary treatments, which may include irradiation. Import conditions are published on the Department's Biosecurity Import Conditions Database (BICON). The applicant advises that of the five countries that have negotiated access to Australia for irradiated fruit, two countries, Vietnam and India, have begun exporting irradiated fruit to Australia. Examples of approvals by DAWE for the import of fresh fruit and vegetables irradiated for quarantine purposes are outlined in Table 3.

Table 3: Examples of DAWE approvals for the import of irradiated fruit and vegetables from other countries

Commodity	Exporting country	Report date	Purpose	Dose
Longan	Vietnam	May 2019	Control of fruit fly and litchi fruit borer.	Minimum dose of 400 Gy
Mango	India	April 2011	Control of fruit fly, mango weevil, mealybug, and red-banded mango caterpillar.	Minimum dose of 400 Gy
Mango	Thailand	November 2015	Control of mango weevil, fruit fly, mealybug, and red-banded mango caterpillar.	Minimum dose of 150 Gy (fruit fly) Minimum dose of 300 Gy (weevil) Minimum dose of 400 Gy (re-banded mango caterpillar)
Lychee	Vietnam	April 2013	Control of fruit fly, litchi fruit	Minimum dose of 400 Gy

Commodity	Exporting country	Report date	Purpose	Dose
			borer and mealybug.	

2.4.3 Trade of irradiated fruit and vegetables within Australia

The domestic movement of fruit and vegetables within Australia is also covered by quarantine controls. Fruit flies are considered the major pest in relation to the domestic movement of goods, but there are numerous other plant pests that also require appropriate quarantine controls. Trade in produce that has been irradiated for a phytosanitary objective is permitted via the Interstate Certification Assurance (ICA) Scheme under Operational Procedure Number 55 (ICA-55) (QLD ICA 2011; VIC ICA 2020), which is accepted by the other states and territories to control fruit fly in all commodities approved by FSANZ. ICA-55 conforms to the principles detailed in the associated international standards (see Section 2.5).

The procedures set out in ICA-55 do not abrogate or override the responsibility of irradiation facilities to comply with the legislative requirements as prescribed in the Radiation Safety Acts and Food Acts that apply in the respective jurisdictions. Further, fresh fruit and vegetables must first be approved by FSANZ to be irradiated under this Operational Procedure. The minimum doses set by ICA-55 are as follows:

- 150 Gy for fruit flies of the family Tephritidae
- 300 Gy for the mango seed weevil
- 400 Gy for all pests of the of the phylum Arthropoda (excluding *Lepidopteron* that pupate internally).

2.5 Worldwide permissions for food irradiation

The two internationally recognised standards-setting agencies for human and plant health, Codex Alimentarius (Codex) and the International Plant Protection Convention (IPPC), support the use of food irradiation, having regard to the scientific findings of the FAO and WHO.

The Codex General Standard for Irradiated Foods (CXS 106-1983, Rev.1–2003) (CAC 2003) states that the irradiation of food is justified only when it fulfils a technological requirement and/or is beneficial for the protection of consumer health. It should not be used as a substitute for good hygienic and good manufacturing practices or good agricultural practices. Further, for the irradiation of any food, the minimum absorbed dose should be sufficient to achieve the technological purpose, and the maximum absorbed dose should not compromise consumer safety, or the wholesomeness or quality of the food. The maximum absorbed dose should not exceed 10 kGy, except when necessary to achieve a legitimate technological purpose. Countries that have adopted the Codex standard include Brazil, Singapore, Cuba and Mexico.

Food irradiation is subject to the internationally recognised protocols and standards as set by the IPPC (FAO IPPC 2003). The International Standard for Phytosanitary Measures 18 (ISPM 18) – *Guidelines for the use of irradiation as a phytosanitary measure*, provides technical guidance on the application of ionising radiation as a phytosanitary treatment (FAO IPPC 2003). ISPM 28 – *Phytosanitary treatments for regulated pests* includes conditions for the use of irradiation as they relate to specific pests, with Part 7 being specific to fruit flies (FAO IPPC 2007).

In the European Union, Directive 1999/2/EC concerning foods and food ingredients treated

with ionising radiation provides a framework for controlling irradiated foods, record-keeping, labelling and importation. It also makes reference to a community list of foods and food ingredients that may be irradiated. There is one food group included on the community list of foods: dried aromatic herbs, spices and vegetable seasonings, with a maximum authorised dose of 10 kGy. Authorisations made by seven Member States prior to 1999 for the irradiation of various foods remain in force. However, since these foods are not on the community list, other Member States may still impose a ban or restrictions on these foodstuffs.

The US also supports the use of food irradiation – through the US Food and Drug Administration (FDA) Code of Federal Regulations Title 21 Part 179 – *Irradiation in the production, processing and handling of food* (FDA 2019). The regulation does not make reference to any specific foods, rather, gives a general approval for the use of irradiation for the disinfestation of arthropod (i.e. insect) pests in food.

There are a number of countries worldwide with specific, national regulations covering the irradiation of food, including fresh fruit and vegetables. Most of those trading in irradiated fresh produce grant a generic permission (without any foods specifically listed). Irradiation cannot be used to improve the odour, taste or appearance of spoiled food (EFSA 2011b).

Irradiation as a quarantine treatment of fresh produce for trade may be performed in the importing country or prior to export – in which case the regulatory requirements of the importing country will apply, irrespective of the regulations (including the minimum doses and dose ranges) of the exporting country.

2.5.1 Regulations supporting the proposed dose range

The applicant has proposed minimum and maximum absorbed doses of 150 Gy and 1 kGy, respectively. These doses remain the same as those already approved for quarantine purposes for other fruit and vegetables in the Code. Irradiation at doses between 150 Gy and 1 kGy is a highly effective phytosanitary measure, complying with the IPPC ISPM 18 and ISPM 28 requirements.

2.5.1.1 Background to setting and applying minimum absorbed doses

Ionising radiation does not deliver a uniform dose throughout the pallet. To account for this, the area of the pallet receiving the lowest absorbed dose is identified prior to treatment. By ensuring this area receives the minimum absorbed dose guarantees that the treatment will be effective, that is, that all of the other regions of the pallet will receive equal to or more than the minimum dose, whilst still remaining below the maximum permitted dose. For example, for fruit flies, where the minimum dose required is 150 Gy (see Section 2.5.1.2), then the maximum dose received by some areas of the pallet may be up to 300 Gy. For other regulated pests a higher minimum dose may be required and a small part of the pallet will receive a maximum dose closer to 1 kGy.

2.5.1.2 Generic treatment for fruit fly (150 Gy)

A minimum dose of 150 Gy, as proposed by the applicant, is recognised by the IPPC as a generic treatment for all tephritid fruit flies in all host fruit and vegetables (FAO IPPC 2009). The required treatment is applied in accordance with ISPM 18 and, more specifically, ISPM 28, Part 7 – *Irradiation treatment for fruit flies of the family Tephritidae* (FAO IPPC 2009), whereby a minimum dose of 150 Gy can prevent the emergence of adult fruit flies in fruit and vegetables. In 2006, the US Animal and Plant Health Inspection Service (APHIS), which regulates the use of irradiation for quarantine purposes, also approved a generic dose of 150 Gy for fruit fly infestation on imported fruit (USDA 2006). Similarly, the minimum dose set

by ICA-55 for Australian states and territories is 150 Gy *for fruit flies of the family Tephritidae* (ICA 2011) (See Section 2.4.3).

2.5.1.3 Generic treatment for insects (400 Gy)

The minimum dose of 400 Gy, which sits within the proposed treatment range, is recognised in US regulations as a generic treatment for all insects in all host fruit and vegetables (except adult *Lepidoptera* that pupate internally). The applicant advises that this is still under consideration by the IPPC, but is expected to become a world standard in the future – noting that it has already been approved for the export of a range of fruit from over 10 countries (including Australia, Hawaii, India, Indonesia, Thailand and Vietnam) to the US mainland. Additionally, it is already recognised by New Zealand for imported produce as an effective quarantine treatment for the life stages of most arthropod pests of relevance. Again, this is consistent with ICA-55 for Australian states and territories, whereby 400 Gy is prescribed for *all pests of the phylum Arthropoda (excluding* Lepidopteron *that pupate internally*) (ICA 2011) (See Section 2.4.3).

2.5.1.4 Maximum absorbed dose (1 kGy)

The first approval for phytosanitary irradiation of fresh produce was granted by the US FDA in 1986 (FDA 1986). The applicant advises that, at that time, the rationale for setting a maximum absorbed dose of 1 kGy centred around the sensitivity of the available methods of detection and what was then known about commodity tolerance. Following the FDA ruling, most countries harmonised with the 1 kGy maximum. A few countries (e.g. Thailand) permit a maximum absorbed dose of 2 kGy (See Appendix 1 in the Approval report).

Whilst this rationale may no longer be as valid now as at the time, the applicant indicates that there may be some overseas facilities that might encounter difficulties in ensuring that all parts of the pallet are treated with the minimum absorbed dose if the permission to apply a dose of up to 1 kGy is lowered. With this in mind, overall, there has been no appetite for changing the generally accepted maximum absorbed dose of 1 kGy.

The applicant states that, in practice, irradiation of fruit and vegetables will normally fall in the range of 420 to 840 Gy.

2.6 Justification for use of irradiation as a phytosanitary measure

Insect pests of quarantine significance are a major barrier in gaining access to some markets. The applicant claims that the use of irradiation as a phytosanitary measure is technologically justified as it provides an effective quarantine treatment that is well established in the international trade of horticultural products. The following section provides further information justifying the use of irradiation as a generic phytosanitary treatment for pest disinfestation for all fresh fruit and vegetables in Australia and New Zealand.

2.6.1 An appropriate treatment option

There are a range of phytosanitary treatment options available to the horticultural industry to treat regulated pests. In addition to ionising radiation, treatments include physical (e.g. heat treatment, cold disinfestation) and chemical (e.g. fumigation) treatments, and production-based systems approaches incorporating non-host status or area freedom.

The applicant has indicated irradiation is useful for treating commodities that do not tolerate other treatment options well (due to possible phytotoxicity, quality issues or the prolonged storage times involved), or where systems approaches that integrate different risk management measures are not available or suitable.

In addition, irradiation presents the following advantages over existing phytosanitary treatments:

- It is a broad-spectrum treatment for almost all important regulated arthropod pests
- It may be applied at the product's optimum storage temperature and its application is independent of ambient conditions such as temperature, humidity and pressure
- It is a rapid treatment and well-tolerated by the majority of fruit of vegetables
- As a penetrating treatment, it is relatively independent of commodity shape and size and can be applied to the commodity in its final packaging including boxes and pallets.

2.6.2 High commodity tolerance

Irradiation as a phytosanitary treatment can only be used if it achieves its technical objective at a dose that is lower than one where detrimental effects to the product begin to occur (e.g. structural integrity, functional properties or sensory attributes). The applicant has listed numerous studies reviewing the tolerance of various fresh commodities to irradiation at phytosanitary doses. More types of fresh fruit and vegetables tolerate irradiation than any other commercially available phytosanitary treatment (Hallman 2011). Possible exceptions include produce that auto-oxidises quickly, such as avocado, which has a low tolerance to irradiation, with detrimental effects like discolouration occurring (Akamine and Goo 1971; Thomas 1986). Irradiation is not likely to be used commercially for this product. Information provided by the applicant indicates that in 2017, approximately 20% of avocados consumed in Australia were imported; these were cold disinfested. Even though the permission being sought is a generic one for all fruit and vegetables, there will be no benefit to using irradiation on any products (such as avocado) that cannot tolerate phytosanitary doses.

2.6.3 An alternative to chemical treatments

Ionising radiation is a viable and effective substitute to chemical treatments, particularly in cases where such treatments have been restricted or are being phased-out. As an example, following reviews of dimethoate and fenthion use by the Australian Pesticides and Veterinary Medicines Authority (APVMA), phytosanitary uses of these insecticides became subject to restrictions and there are currently no registered uses for fenthion in Australia.

Another example relates to the use of methyl bromide (MeBr), a phytosanitary treatment of fresh produce accepted by states and territories in Australia to control fruit fly in all commodities (ICA 2018) and also approved for international exports. MeBr has had restrictions put around its use due to potential negative effects on the environment and human health. MeBr is a known human health and workplace hazard (US EPA 2019; MPI 2019) and is listed as an ozone-depleting substance subject to phase-out provisions in the Montreal Protocol (FAO IPPC 2008). Irradiation as a phytosanitary treatment option is an effective alternative in such circumstances.

2.6.4 Increased consumer choice

There may be an increased choice for consumers in the fresh produce available for purchase from other countries that are not available, or rarely available, locally. For example, the applicant states that irradiation as a phytosanitary measure could help open up the trade in certain niche exotics such as salaka from Indonesia and dragon fruit from Vietnam. The use of irradiation as a phytosanitary measure will also help maintain a consistent supply, and guard against seasonal shortages and price rises. Its use is voluntary and only one of a number of phytosanitary measures. Ultimately, it is up to the consumer as to whether or not they wish to purchase irradiated fruit and vegetables. Existing labelling provisions will assist with making this choice.

The safety and nutritional aspects associated with permitting the phytosanitary irradiation of fresh fruit and vegetables are discussed in Sections 3 – 6 of this report.

2.6.5 Potential for unjustified use

Food irradiation, like other food processing practices, is strictly regulated. Therefore, should this application be approved, this does not mean that there will be greater potential for the unjustified use of irradiation, or for uses other than what has been permitted. There are additional costs associated with using irradiation as a phytosanitary treatment. Products require labelling and the process adds extra time and handling within the supply chain, including transport to and from the irradiation facility. Collateral benefits of treatment such as shelf life extension or microbial decontamination are unlikely to be realised because permitted doses are insufficient for microbial decontamination, nor will they markedly increase shelf life. Considering the above factors, there is no incentive for industry to use irradiation unnecessarily.

For imported produce, all phytosanitary treatments are authorised between the relevant agencies in the exporting and importing jurisdictions. There are a range of internationally accepted methods of detection for irradiated foods that could be used for enforcement purposes. The current detection methods for irradiated food are able to determine whether a food has been irradiated or not, but cannot accurately measure absorbed doses. As there is no easy way at international entry points to determine if an import has received the correct irradiation treatment, quarantine agencies refer to shipping documents and process control records at point of entry, which must be provided in accordance with international standards (IAEA 2002).

In terms of domestically produced fresh produce, the majority of fresh produce in both countries is not subject to any phytosanitary treatment as it is produced and eaten in the same quarantine jurisdiction. Overall, even if this application is approved, only a small proportion of the fruit and vegetables available for consumption by Australian and New Zealand consumers will be irradiated (see Section 5.2.3).

2.7 Australian and New Zealand quarantine agencies advice

The Biosecurity Plant Division of the Australian Government Department of Agriculture, Water and the Environment (DAWE – previously the Department of Agriculture) has provided a letter indicating its strong and urgent interest in this application progressing to allow irradiation of all fresh fruit and vegetable commodities as a phytosanitary measure. Their advice is that expansion of the scope of fruit and vegetables that are permitted to be irradiated would have the potential to improve agricultural trade relationships and provide further trade opportunities for Australia. Irradiation has the ability to ensure absolute sterility in pests, providing quarantine security by ensuring that any contaminating pests are unable to establish in the recipient country. The adoption of ISPM 28, Part 7, outlining the requirements for phytosanitary irradiation of tephritid fruit flies, has significantly enhanced the opportunities for negotiating international trade with irradiation as the chosen phytosanitary measure, and has provided benefits for Australian export trade. The application is also consistent with Australia's international obligations as a signatory to the Sanitary and Phytosanitary (SPS) Agreements as a member of the World Trade Organization (WTO).

The New Zealand Ministry for Primary Industries (MPI) gives general support for the use of irradiation as a phytosanitary treatment option for all fresh fruit and vegetables under ISPM 18 and ISPM 28. Absorbed minimum doses of 400 Gy and 500 Gy are effective treatments for many arthropods and many mite species, respectively. An absorbed minimum dose of 150 Gy is recognised as efficacious for all tephritid fruit flies (*Diptera: Tephritidae*) of

economic importance. Currently, MPI approves use of irradiation as a phytosanitary treatment and, as such, it is listed as an option for capsicum, grapes, lychee, mango, papaya and tomato imported into New Zealand from Australia.

In terms of interstate trade, Tasmania has the greatest amount of fresh produce crossing a quarantine boundary, compared with the Australian national average (see Section 5.2.3). Biosecurity Tasmania has advised FSANZ that it considers irradiation to be an effective phytosanitary measure as it provides a quality alternative to MeBr fumigation and use of certain insecticides that are becoming more restricted or being phased out.

2.8 Food technology assessment conclusions

Advice received by FSANZ from the relevant quarantine authorities (DAWE in Australia and Biosecurity New Zealand), is that irradiation is an efficacious and cost-effective phytosanitary treatment option for international trade of fresh fruit and vegetables and as such, they support its use. Both agencies will still independently perform import risk assessments (for quarantine purposes) specifically for food imported into Australia or New Zealand; this is separate from (and additional to) FSANZ's approval processes.

The proposed minimum and maximum doses of 150 Gy and 1 kGy, respectively comply with international requirements, whereby 150 Gy is the generic minimum dose for fruit fly and 400 Gy is the minimum dose for arthropod pests (excluding *Lepidopteron* that pupate internally). This provides a dose range for quarantine agencies to work within, when undertaking future import risk assessments that also consider irradiation as one of the possible treatment options.

For the movement of fresh produce domestically, irradiation is an important pest reduction protocol for acceptance of Australian produce interstate. There are numerous plant pests, foremost amongst them fruit fly, that require appropriate quarantine controls. ICA-55 recognises irradiation for the quarantine treatment of fresh fruit and vegetables provided they are first approved by FSANZ. ICA-55 incorporates irradiation at the generic minimum dose of 150 Gy for fruit fly, and 400 Gy for other pests (excluding adult *Lepidoptera* that pupate internally), reflecting international requirements.

Food irradiation is an effective and important addition to existing physical and chemical phytosanitary treatments for pest disinfestation. The use of irradiation is voluntary, and it will continue to be only one of a number of phytosanitary options available to producers and suppliers of fresh produce. Enforcement functions will continue to be the responsibility of the relevant quarantine agencies in each jurisdiction. Ultimately, the preferred option for producers and suppliers will be largely dictated by efficacy, quality retention and cost.

3 Hazard assessment

3.1 Introduction

FSANZ has previously conducted risk assessments of the irradiation of a number of fruit and vegetables as outlined in Table 1 (see Section 2.4). The conclusions of those assessments were that the specified fruit and vegetables irradiated at up to 1 kGy are as safe to consume as their non-irradiated counterparts.

The purpose of this hazard assessment was to evaluate any new information published since FSANZ's previous assessment. Literature searches of PubMed and EBSCO were conducted using the search terms "phytosanitary irradiation safety", "phytosanitary irradiation toxic", alkylcyclobutanone safety", alkylcyclobutanone toxic", "furan safety", "furan toxic", food irradiation safety", and "food irradiation toxic". As a result of the initial searches, further searches were conducted for "food irradiation mycotoxin" and "food irradiation allergy".

3.2 Evaluation

3.2.1 Compounds generated in irradiated foods

There are a number of compounds that may be generated during the irradiation of food. These compounds are termed radiolytic compounds and may include free radicals, various hydrocarbons, formaldehyde, amines, furan and 2-alkylcyclobutanones (2-ACBs) (FSANZ, A1092).

Of the radiolytic compounds, 2-ACBs and furan have been the subjects of particular attention; 2-ACBs because they are generally considered to be unique to irradiated food, and furan because IARC (1995) classified it as Group 2B: *possibly carcinogenic to humans*. With the exception of 2-ACBs, radiolytic compounds are not unique to irradiated food and are naturally present at low levels in food, or are generated via other food processing treatments such as thermal treatment.

3.2.1.1 2-ACBs

2-ACBs are generated by the radiation-induced breakdown of triglycerides (Song et al. 2018). The levels of 2-ACBs in irradiated food are therefore dependent on the lipid content in the food, and have been found to be very low in fruit and vegetables previously assessed by FSANZ.

In previous evaluations of irradiated fruit and vegetables (A1115, A1068, A1038), FSANZ concluded that 2-ACBs are unique radiolytic products formed at levels dependent on the lipid content of food. Numerous *in vitro* genotoxicity assays have been conducted, and the weight of evidence is that 2-ACBs are not genotoxic. FSANZ has previously reviewed a large number of laboratory animal studies demonstrating that long-term consumption of irradiated foodstuffs, which would contain low concentrations of 2-ACBs and other radiolytic compounds, is safe. These conclusions are consistent with those reached by the European Commission's (EC) Scientific Committee on Food (2003), WHO (2003), Health Canada (2008) and the European Food Safety Authority (EFSA) (2011a, 2011b).

1. 2-ACBs as markers of ionising radiation

In recent years, a small number of studies have examined whether 2-ACBs are exclusively products of ionising radiation of food.

Variyar et al. (2008) reported that they found 2-ACBs in cashews and nutmegs that had not been irradiated. However other research teams were unable to replicate their findings (Chen et al. 2012; Leung et al. 2013; Driffield et al. 2014).

Breidbach and Ulberth (2016) developed a method, using high performance-high resolution mass spectrometry, that is considerably more sensitive than the European Standard EN 1785:2003 for the detection of 2-ACBs, and analysed 26 cashew and 14 nutmeg samples that had not been irradiated. They did not find 2-ACBs in any of the samples, and concluded 2-ACBs are unique indicators of treatment with ionising radiation.

Meng and Chan (2017) reported that 2-ACBs were detected in fatty acids, triglycerides, corn oil and pork fat after irradiation with a non-ionising short-wave UV (UV-C) light source, and increased in quantity with increased UV-C irradiation. Direct heating, microwave heating and ultrasonication did not result in the formation of 2-ACBs in samples of the same commodities (Meng and Chan 2017). FSANZ notes that there is not a single agreed standard defining the UV – X-ray boundary; that is, distinguishing ionising from non-ionising irradiation.

2. Genotoxicity of 2-ACBs

In previous hazard assessments of phytosanitary irradiation, FSANZ has concluded that based on the weight of evidence 2-ACBs are not genotoxic.

A literature search identified two new publications. A review of the results of bacterial reverse mutation assays (Ames tests) of 2-ACBs was carried out by Barbezan et al. (2017). The review covered papers published between 1971 and 2016 that could be located using Sciencedirect, Scielo, PubMed, Web of Science, and/or USP Digital Library. No mutagenic activity was observed in any of the studies evaluated.

The second publication reported the results of a battery of genotoxicity assays of a specific 2-ACB, 2-dodecylcyclobutanone (2-dDCB).

Battery of genotoxicity assays of 2-dDCB (Song et al. 2018). Regulatory status: Non GLP

The test article for all assays in the battery was 2-dDCB purchased from Sigma-Aldrich Chemical Co., St Louis, MO, USA. Purity was not stated by the authors, but the Sigma-Aldrich website specifies a purity of > 95%.

A bacterial reverse mutation assay was conducted, with and without inclusion of S9 mix for metabolic activation. The test system comprised *Salmonella typhimurium* strains TA98, TA100, TA1535 and TA1537. The vehicle and negative control article was DMSO. The test article was administered at concentrations up to 1000 µg/plate, the highest concentration at which no inhibition of bacterial growth was observed in preliminary tests. Positive control substances were sodium azide in distilled water (TA100 and TA1535), 4-nitroquinoline N-oxide in DMSO (TA98), acridine mutagen ICR-191 in DMSO (TA1537), benzo(α)pyrene in DMSO (TA98), and 2-aminoanthracene in DMSO (TA100, TA1535, TA1537). The assay was conducted in triplicate by the plate incorporation method. The mean number of revertant colonies per plate was not increased, relative to that in negative controls, at concentrations of 2-dDCB ≤ 1000 µg/plate, but the mean number of revertant colonies per plate was significantly increased in the presence of all the positive control substances, confirming the validity of the assay.

A chromosomal aberration assay was conducted using a Chinese hamster lung fibroblast cell line. The assay was based on OECD guideline 473, and conducted in triplicate. The concentrations of 2-dDCB were 25, 50 and 100 µg/mL in DMSO. Positive controls were benzo(α)pyrene in DMSO in the presence of S9 mix, and ethyl methane sulphonate in

distilled water in the absence of S9 mix. Cells were incubated with the test article for 6 h, then washed and incubated for a further 16 h in fresh medium, with addition of colcemid to arrest mitosis 1 h before the end of incubation. Cells were harvested and processed to slides for counting of the number and types of chromosomal aberrations in 100 well-spread metaphase cells/culture. There were no significant differences in frequency for any type of chromosomal aberration associated with exposure to 2-dDCB, with or without S9 mix, when compared to negative controls. The positive control articles caused the expected significant increases in chromosomal aberrations.

The micronucleus test was conducted using 5-week-old male ICR mice, in accordance with OECD guideline 473. Mice were acclimatised to laboratory conditions for one week prior to study start. Mice in negative control and treatment groups (5 mice/group) were gavaged once daily for two days with 2-dDCB at dose levels up to 2000 mg/kg bw/day. A positive control group was administered cyclophosphamide although details of dose and route were not provided. Mice were killed 24 h after the last dose administration, and bone marrow smears were prepared. Two thousand polychromatic erythrocytes were examined from each mouse, and the number of micronucleated polychromatic erythrocytes (MNPCEs) recorded. There were no significant differences in group mean number of MNPCEs between 2-dDCB treated mice and negative controls. Mice in the positive control group exhibited the expected significant increase in MNPCE/2000 PCE.

It was concluded from this battery of genotoxicity assays that 2-dDCB is unlikely to be genotoxic.

3. Toxicity of 2-ACBs

One new publication, describing acute and repeat-dose studies of toxicity of 2-dodecylcyclobutanone (2-dDCB), was located by literature search.

Acute toxicity study of 2-dDCB in mice (Song et al. 2018). Regulatory status: Non GLP

Acute toxicity of 2-dDCB (Sigma-Aldrich; > 95% pure) was determined in female Balb/c mice. Mice were acclimatised to standard laboratory husbandry conditions for a week prior to study start. The study was conducted according to OECD Guideline 423. Mice, 2/group, were gavaged with 0, 300 or 2000 mg/kg bw 2-dDCB in corn oil and subject to clinical observations, measurement of body weights, and measurement of food consumption for 14 days. At the end of the observation period, blood was collected and mice were killed and necropsied. Brain, heart, lung, liver, kidney, spleen and intestines were weighed and preserved for histopathological examination. All mice survived to scheduled necropsy and there were no abnormal clinical observations. There were no treatment-related effects on bodyweights, haematology findings, necropsy findings or microscopic findings. It was concluded that the acute oral LD50 of 2-dDCB in the mouse is > 2000 mg/kg bw.

28-day repeat-dose study of 2-dDCB in Sprague Dawley rats (Song et al. 2018). Regulatory status: Non GLP

This study was conducted in accordance with OECD guideline 407. Rats, 10/sex/group, were gavaged daily with dDCB for 28 days at dose levels of 0, 0.5, 1.0 or 2.0 mg/kg bw/day. The vehicle/control article is not specified, but may be corn oil, which was the vehicle/control article for the acute study in mice that was reported in the same publication. Clinical observations were recorded daily during the in-life phase, while body weight, food intake and water intake were recorded weekly. At the end of the study, blood was collected for haematology, clinical chemistry and measurement of selected hormones (thyroid stimulating hormone (TSH), thyroxine, follicle-stimulating hormone (FSH), luteinizing hormone (LH), oestrogen, testosterone), and rats were killed. Gross findings were recorded, as well as fresh

organ weights for brain, pituitary, thyroid, thymus, heart, lung, liver, spleen, kidneys, adrenal glands, gonads and, as sex-appropriate, epididymides, seminal vesicles, or uterus. Organs and tissues were fixed and processed to slides and stained with haematoxylin and eosin (HE) for microscopic examination.

All rats survived to scheduled necropsy and there were no treatment-related effects on clinical signs, body weights, food consumption, gross necropsy findings, organ weights, or group mean values for haematology.

The group mean value for creatine phosphokinase was significantly decreased in male and female rats in the 2.0 mg/kg bw/day group, when compared to their respective controls, but the values remained within the historical control range for the laboratory, and were not considered to be biologically relevant. Group mean values for blood urea nitrogen (BUN) were also lower in 2.0 mg/kg bw/day females, and in males in all treatment groups, when compared to their respective controls, but the changes were very small and remained within the historical control range for the laboratory. Group mean thyroxine level of the 2.0 mg/kg bw/day males was significantly higher than that of male controls but the level remained within the historical control range and was not considered to be biologically relevant. A local monocytic infiltration of thyroid tissue in two 2 mg/kg bw/day males was not considered to be test article-related, but attributed to stress, although the reasoning behind this interpretation was not stated. The authors concluded that the No Observed Adverse Effect Level (NOAEL) for 2-dDCB was 2.0 mg/kg bw/day, the highest dose tested. FSANZ considered that the monocytic infiltration of the thyroid is adverse, and the NOAEL is 1.0 mg/kg bw/day.

3.2.2 Other relevant safety matters

3.2.2.1 Furan

1. Formation and dietary sources of furan

Furan is a colourless heterocyclic compound with a boiling point around 31° C. The main source of furan in the human diet is thermal processing, including cooking, roasting, baking, pasteurization and sterilization. There are multiple pathways of furan formation, including thermal degradation or rearrangement of carbohydrates, thermal degradation of amino acids, oxidation of ascorbic acid, and oxidation of polyunsaturated fatty acids and carotenoids. Furan is found in a wide range of foodstuffs (Seok et al. 2015).

Many studies on furan concentrations in different foods have been conducted internationally. Concentration data are available for furan in foods from New Zealand and Australia through the New Zealand Ministry for Primary Industries 2012-2017 Dietary Furan Program (MPI 2020b). Many studies report coffee as a major source of furan with mean concentrations reported in prepared plunger coffee of 71.6 µg/kg and 370 µg/kg for expresso (Vannoort and Chappell 2012); short black 110 µg/L (FSANZ 2010); and for instant coffee (prepared) of 3.9 µg/kg (EFSA 2011) and 2-2.5 µg/L (FSANZ 2008). For fruit and vegetables, processed heat-treated products are often sampled. In New Zealand, a mean furan concentration of 7.6 µg/kg was found for canned/bottled fruit and 17.9 µg/kg for canned/bottled vegetables. These results were slightly higher than those reported for the same products by EFSA of 2 µg/kg – 6.4 µg/kg for fruit and 6.9 – 9.6 µg/kg for vegetables (MPI 2020b). Fresh fruit and vegetables were not sampled as part of the New Zealand survey.

In relation to dietary exposure to furan, total mean dietary exposure was estimated for New Zealand to be 1.0 µg/kg bw/day for adults 15 years and above and 1.4 µg/kg bw/day for children 5 – 15 years (Chappell and Ashmore 2017). These estimates were greater than those for the European Union (0.22 µg/kg bw/ day for adults; 0.08 µg/kg bw/day for children) (EFSA 2011); and Canadian estimates (0.37 µg/kg bw/ day for adults; 1.12 µg/kg bw/day for

toddlers 1-4 years) (Health Canada 2016). Higher exposures in New Zealand were attributed to the more targeted sampling of foods, including packaged foods, that are known to have concentrations of furan.

The four main contributors to dietary furan exposure for the New Zealand adult population were coffee (21%), meat (21%), dairy products (19%) and bread and other flour based baking products (15%). For New Zealand children, meat contributed 26%, 19% from dairy products and 15% from bread and other flour based baked products. There was very little contribution resulting from coffee as daily consumption of this food by children is low (MPI 2020b). The contribution from canned/bottled fruit and vegetable products was not provided. In Europe, coffee is the main contributor to dietary exposure to furan in adults. Grains and grain-based products are the major source of dietary furan in toddlers, children and adolescents, while ready-to-eat meals, such as baby foods sold in jars or cans, are the major source of dietary furan in infants (EFSA 2017). Gruczyńska et al. (2018) concluded that in Poland, 50% of annual furan exposure for adults is from coffee consumption alone, and furan exposure from coffee is 35 to 180 higher than exposure from the next highest source, which is crisps and chips.

Fan and Sokorai (2008) analysed furan in a variety of fresh, cut fruit and vegetables that had been irradiated at 5 kGy, a fivefold higher dose of radiation than that in the current application. The produce included grapes, pineapple, apple, strawberry, banana, watermelon, cantaloupe, honeydew melon, tomato, green pepper, broccoli, carrot, celery, iceberg lettuce, Romaine lettuce, red cabbage, snap pea and spinach. For most of the fruit and vegetables, furan levels were undetectable. Detectable levels of furan were found only in grape, pineapple, apple, strawberry and watermelon, and levels exceeding 1 ng/g were found only in grapes (3.2 ng/g) and pineapple (3.0 ng/g). Levels of furan resulting from irradiation at ≤1 kGy are therefore likely to be undetectable and of no toxicological concern, particularly when considered relative to dietary furan exposure from other sources.

A worst case deterministic furan dietary exposure was calculated by FSANZ for fruit and vegetables to put any exposure from irradiated produce into the context of furan exposure from the whole diet. The calculation was done using consumption data from the Australian 2011-12 National Nutrition and Physical Activity Survey and the highest detectable concentration from irradiated produce (3.2 ng/g (or µg/kg) following irradiation at 5 kGy). Total consumption of all fruit and vegetables, and fruit- and vegetable-based products and dishes, was 302 g/person/day. The estimated worst case dietary exposure to furan for the population from all fruit and vegetables based on a 70 kg body weight would be 0.014 µg/kg bw/day. This equates to around 1.4% of the total dietary exposure from all foods for New Zealand adults and 1% for children. This is an overestimate of the dietary exposure as most irradiated fruit and vegetables in the Fan and Sokorai (2008) study had no detectable furan concentrations, and the residues were based on irradiation at 5 kGy. In addition, any exposure to furan from the small amount of fruit and vegetables that will be irradiated using a maximum dose of only 1 kGy would be negligible in the context of current estimated total dietary exposures.

FSANZ further notes that furan is highly volatile, with a boiling point of 31° C, and consequently evaporates over time from produce held at ambient temperature.

2. Toxicity of furan

Furan is carcinogenic to rats and mice, and is classified by IARC as possibly carcinogenic to human beings (Seok et al. 2013). The carcinogenicity of furan has been attributed to a combination of genotoxic and non-genotoxic mechanisms (de Conti et al. 2015; Dong et al. 2016).

Reproductive toxicity study of furan in male rats. (Rehman et al. 2019). Regulatory status: Non-GLP

Furan, 99% purity, was purchased from Sigma-Aldrich, USA and dose formulations were prepared using corn oil as the vehicle. The rats were male Sprague Dawley rats, aged 80 to 90 days at study start. Rats were maintained under standard environmental conditions and group-housed by study group, 7/group. Dose levels of 0, 5, 10, 20 and 40 mg/kg bw/day were administered by oral gavage for 28 consecutive days. On Day 29, rats were weighed and decapitated, blood was collected and processed to plasma, and reproductive organs were collected and weighed. Sperm collected from the cauda of an epididymis was examined for sperm count, sperm motility and sperm viability. The left testis and epididymis were stored in liquid nitrogen, and the right testis and epididymis were preserved for histopathology. Antioxidant assays (catalase (CAT), superoxide dismutase (SOD), peroxidase (POD), thiobarbituric acid-reactive substances (TBARS), and reactive oxygen species (ROS)) were conducted on plasma and testicular tissue. Plasma was also analysed for total cholesterol, triglycerides, low density lipoprotein (LDL) and testosterone. Total protein content of tissues, and intratesticular testosterone concentration, were assayed.

There were no treatment-related effects on group mean values for weight gain, or group mean values for weights of testis, epididymis, seminal vesicles or prostate. Group mean SOD concentration was significantly lower in groups dosed with 40 mg/kg bw/day furan when compared to controls, and group mean plasma POD concentration was significantly lower in groups dosed with ≥ 10 mg/kg bw/day than in controls. Group mean values for total ROS in testicular tissue were significantly increased in groups treated with ≥ 20 mg/kg bw/day furan, compared to controls, whereas group mean values for total testicular tissue protein were significantly decreased, relative to controls, in the same groups. Relative to controls, groups treated with ≥ 10 mg/kg bw/day furan had significantly higher group mean values for triglyceride, total cholesterol and LDL, but significantly lower group mean HDL. Furan was also associated with significant decreases in group mean values for sperm motility, sperm count and sperm viability in groups treated with ≥ 20 mg/kg bw/day furan. Group mean values for plasma and intra-testicular testosterone were significantly lower than those of controls in the 40 mg/kg bw/day group. In rats dosed with ≥ 20 mg/kg bw/day furan, seminiferous tubules in the testes showed significantly increased group mean values for lumen diameter and significantly decreased group mean values for total tubular diameter, when compared to controls, and epithelial height in the tubules was also significantly decreased. In the 40 mg/kg bw/day group, there was also a significant decrease, relative to that of controls, in group mean thickness of the tunica albuginea. In the caput epididymis, the group mean values of the ≥ 20 mg/kg bw/day groups for tubular diameter were significantly decreased relative to that of controls. In the cauda epididymis, group mean values for epithelial height in tubules were significantly decreased, relative to that of controls, in rats dosed with ≥ 20 mg/kg bw/day furan.

The authors concluded that furan is a reproductive toxicant in the male rat. They did not specify a NOAEL. They attributed the adverse effects on the reproductive organs to oxidative stress.

FSANZ notes that the lowest dose of furan used in this study, 5 mg/kg bw/day, is higher than previously identified NOAELs. Gill et al. (2010) conducted a 90-day subchronic oral toxicity study of furan in F344 rats, observed histopathological lesions in the liver at doses ≥ 0.12 mg/kg bw/day, and identified a NOAEL of 0.03 mg/kg bw/day. Therefore although the study by Rehman et al. (2019) provides information on another toxic effect, it does not result in a lower NOAEL or Lowest Observed Adverse Effect Level (LOAEL) than previously identified.

Two year oral gavage toxicity/carcinogenicity study of furan in male F344/N Nctr rats (von Tungeln et al. *2017). Regulatory status: GLP, conducted in accordance with NTP*

specifications.

This study was conducted only in male rats, because previous studies, such as an NTP study published in 1993, showed that male rats are slightly more susceptible to the induction of cholangiocarcinoma than females. The test article was furan, purity 99.5%, purchased from Sigma-Aldrich. The vehicle/control article was corn oil. Dose levels were 0, 0.02, 0.044, 0.092, 0.2, 0.44, 0.92 and 2 mg/kg bw/day. Dose formulations were prepared weekly and all dose formulations were subject to dose analysis. Male rats were pair-housed under standard laboratory environmental conditions, and dosing was initiated when the rats were 7 weeks of age. Dose formulations were administered 5 days/week for up to 2 years, with interim terminations at 36 weeks (9 months) and 60 weeks (15 months). In-life data recorded included twice-daily mortality/moribundity checks, detailed clinical observations not less than every four weeks, and body weights recorded weekly for the first 13 weeks and at least every 4 weeks thereafter. Complete necropsies were conducted on all rats, at both scheduled and unscheduled deaths. All proliferative lesions were processed for histopathology.

Clinical observations were not reported. Treatment with furan had no effect on survival to any of the three scheduled terminations, or on group mean values for body weight or body weight gain. There were no treatment-related effects on neoplastic findings in either the 36-week cohort or the 60-week cohort. In the rats treated for two years (104 weeks), there were dose-related increases in the prevalence of malignant mesothelioma, most commonly found on membranes surrounding the epididymides, and on testicular tunics. There was also a dose-related increase in the prevalence of mononuclear cell leukaemia in rats treated with ≥ 0.092 mg/kg bw furan. Treatment with furan was also associated with increases in prevalence of non-neoplastic lesions in livers, with significant, dose-related increases in cholangiofibrosis, chronic inflammation and pigmentation in 36-week groups treated with ≥ 0.44 mg/kg bw/day furan, and in ≥ 60-week groups treated with ≥ 0.2 mg/kg bw/day furan. In rats treated for two years, there were also dose-related increases in bone marrow hyperplasia, lens cataracts and epithelial lesions of the forestomach, in groups treated with ≥ 0.2 mg/kg bw/day furan. Forestomach lesions included oedema, epithelial hyperplasia, inflammation, and ulceration.

The authors concluded that the results of their study, when benchmark dose modelling is applied to cholangiofibrosis, lead to $BMDL_{10}$[5] values of 0.11 to 0.12 mg/kg bw/day furan, in contrast to a previously calculated $BMDL_{10}$ value of 1.23 mg/kg bw/day furan based on furan-induced hepatocellular neoplasia. Although this study supports a lower Health Based Guidance Value (HBGV) for dietary furan, it does not affect the current application because it does not change FSANZ's assessment that dietary exposure to furan from phytosanitary irradiation is negligible when compared to dietary exposure to furan from other sources.

3.2.2.2 Effects of irradiation on mycotoxins

A number of recent publications have explored the use of irradiation to reduce the concentration of mycotoxins in plant-based food for humans (Luo et al. 2017, 2020; Luo et al. 2018; Ismail et al. 2018; Kalagatur et al. 2018; Byun et al. 2019; Li et al. 2019) and in animal feed (Deepthi et al. 2017). A number of mycotoxins are potent toxicants, and some contamination of plant-based foods by mycotoxins may be unavoidable even when good agricultural and processing practices are followed. Produce that contains mycotoxins does not necessarily appear to be mouldy on visual inspection. Although mycotoxins are more commonly associated with cereals and nuts, some mycotoxins may be found in fruit (Fernández-Cruz et al. 2010) or vegetables (Ráduly et al. 2020).

Reduction of concentration of mycotoxins is not an intended purpose of the current application, and there is a lack of evidence that radiation doses ≤ 1 kGy, the maximum

[5] $BMDL_{10}$ is the lower 95% confidence limit of the benchmark dose (µmol furan/kg BW).

permitted dose for phytosanitary irradiation, significantly decrease mycotoxin concentrations, because no references were found in which doses as low as 1 kGy were tested. However, a question that remains relevant to this application is whether food irradiation has the potential to convert mycotoxins to even more potent toxicants. A small number of studies were located that investigate this possibility.

Kalagatur et al. (2018) added pure (> 99%) zearalenone (ZEA) to distilled water at a concentration of 3 µg/mL. Gamma irradiation was carried out at 35° C at doses of 5 and 10 kGy. The test system was the mouse macrophage cell line RAW 264.7. Cells were seeded in culture plates and allowed to adhere for 12 h before being incubated with irradiated and non-irradiated samples of ZEA for 12 h. A control group of cells that were treated only with distilled water was included. Evaluations of the cell cultures included viability (3-(4,5-dimethylthiazolyl-2)-2,5-diphenyltetrazoliumbromide (MTT) and live/dead staining with calcein AM and ethidium homodimer-1), intracellular ROS assay, mitochondrial membrane potential, nuclear damage and caspase-3 assay. Viability of cells, and mitochondrial membrane potential was significantly increased, in a dose-dependent manner, in cell cultures exposed to irradiated zearalenone when compared to cell cultures exposed to zearalenone that had not been irradiated. Presence of intracellular ROS, and caspase-3 activity, were significantly decreased in the cell cultures exposed to irradiated zearalenone when compared to cell cultures exposed to zearalenone that had not been irradiated. The authors concluded that this study confirmed that toxicity of zearalenone was decreased by gamma irradiation.

The cytotoxicity of gamma-irradiated aflatoxin B_1 and ochratoxin A was investigated in an *in vitro* study conducted by Domijan et al. (2019). The mycotoxins were prepared as 50 mM stock solutions in methanol, and irradiated at 5 and 10 kGy. The test systems were the porcine kidney epithelial cell line Pk15, the human hepatoma cell line HepG2 and the human neuroblastoma cell line SH-SY5Y. Cell viability was determined using the 3-(4,5-dimethylthiazolyl-2)-2,5-diphenyltetrazoliumbromide (MTT) assay. Negative and positive controls were included in the assays. The mycotoxin solutions that had not been irradiated were cytotoxic to all the cell lines. The cytotoxicity of irradiated mycotoxin solutions was decreased from 5 to 40%, when compared to the non-irradiated solutions. It was concluded that radiolytic products of irradiation of aflatoxin B_1 and ochratoxin A are less cytotoxic than the parent molecules.

The degradation of triplicate solutions of deoxynivalenol (DON) in acetonitrile-water, resulting from gamma irradiation, was analysed by LC-UV analysis. Doses of radiation were 0, 5, 10, 15 and 20 kGy. Degradation efficiency of DON following a 5 kGy dose was 47%, and the efficiency increased in a dose-related manner to a maximum of 83% degradation at 20 kGy. When the experiment was repeated with DON dissolved in ultra-pure water, degradation of DON was 100% at ≥ 5 kGy. The toxicity of the irradiated solutions was tested in male Kunming mice. Mice were one month old at arrival, and were acclimated for one week prior to study start. Mice were individually housed under standard laboratory environmental conditions, and provided with food and water *ad libitum*. Mice were assigned to four groups, 10/group, and dosed by gavage for 15 days. The negative control group was gavaged with sterile water. The positive control group was gavaged with 2.0 mg/kg bw/day DON in sterile water. The treatment groups were given solutions of DON in sterile water made up to the same concentration as that given to the positive control group, but irradiated with either 10 or 20 kGy. The dose volume was 1% of bodyweight for all groups. Bodyweights and food consumption were recorded daily during the study, and clinical observations were recorded daily prior to dosing. At the end of the 15 days of treatment, mice were fasted, anesthetised, bled and killed. Serum was harvested for clinical pathology. Fresh weights of heart, liver, kidney and spleen were recorded, and heart, liver and kidney were processed for standard histopathology examination. All mice survived to the end of the study. Mice in the positive control group exhibited diarrhoea, and decreases in food consumption and weight gain when

compared to the negative control group. Statistically significant differences in group mean values for clinical pathology parameters in the positive control group, compared to the negative control group, were slightly elevated alanine aminotransferase (ALT), moderately elevated aspartate aminotransferase (AST), and decreased total protein, albumin, creatinine, total cholesterol, LDH and triglycerides. Group mean values for clinical pathology parameters in the groups gavaged with irradiated solutions were comparable to those of the negative control group. Group mean ratios of heart-, liver- and kidney-to-bodyweight were increased in the positive control group, when compared to the negative control group, but no similar changes were observed in groups treated with irradiated DON solutions. Histopathological findings were confined to the positive control group and included swollen cardiac muscle fibres, myocardial necrosis, myocardial haemorrhages, hepatic congestion, and vacuolar degeneration and necrosis of renal tubular cells. It was concluded that gamma irradiation degraded DON in solution, and the radiolytic products of DON were not toxic in mice (Li et al. 2019).

The effect of electron beam irradiation on the toxicity of corn contaminated with zearalenone and ochratoxin A was studied by Luo et al. (2020), using male ICR mice. They were assigned to four groups, 8/group, and housed under standard laboratory conditions. It is not clear whether mice were housed individually or group-housed. The negative control (NC) group was fed a corn-based fodder made with corn that was not contaminated with either mycotoxin. The positive control (CC) group was fed a corn-based fodder made with corn that was naturally contaminated with both zearalenone and ochratoxin A. The fodder contained zearalenone at 1366.9 µg/kg and ochratoxin A at 30.9 µg/kg. The third (ENC) group was fed fodder made with uncontaminated corn that had been irradiated with 50 kGy. The fourth (ECC) group was fed fodder made with contaminated corn that had been irradiated with 50 kGy. The concentrations of zearalenone and ochratoxin A in the fodder provided to the fourth group were 346.6 and 8.2 µg/kg respectively. Mice were maintained on the fodders for 5 weeks. Bodyweights were recorded weekly. At the end of the in-life phase, mice were fasted, bled, and killed. Livers, kidneys, spleens and testes were weighed and then fixed for microscopic examination. Mice in the CC group had slightly lower values for group mean bodyweight than the other groups from the end of the first week through to the end of the study, but the difference was not statistically significant at any time point. There were no statistically significant effects on absolute or relative organ weights. Group mean values for serum AST, ALT, total bilirubin, BUN and creatinine were significantly higher in the CC group compared to the NC group, and those for serum total protein and albumin were significantly lower. The clinical pathology values for the ENC group were closely comparable to those of the NC group, indicating that irradiation of uncontaminated corn did not have an effect. Group mean values for ALT and AST in the ECC group were elevated relative to the NC group, but lower than those for the CC group. Group mean values of the ECC group for total bilirubin, total protein, albumin, BUN and creatinine were not significantly different to those of the NC group. Histopathological changes in livers of mice in the CC group included nuclear heteromorphism and nuclear swelling. The tissues of other groups were normal. It was concluded that gamma irradiation reduced the toxicity of the mycotoxins.

FSANZ concludes that the available evidence does not support that gamma irradiation of mycotoxins results in radiolytic products that are more toxic than the parent molecules.

3.2.2.3 Food irradiation and allergenicity

Naei et al. (2019) suggested that gamma irradiation could reduce the allergenicity of food allergens. This was based on a study in which they irradiated pistachio nuts with 1, 10 or 100 kGy by gamma irradiation, and measured the binding rate of mouse and human antibodies to the allergens in extracts from the pistachio nuts by Western blot analysis. They reported that there was a dose-related decrease in binding. On the other hand, sensory evaluation of the irradiated nuts, as assessed by 40 volunteers, revealed that the doses

≥ 10 kGy had adverse effects on palatability. The results presented by Naei et al. (2019) tend to indicate that a dose of 1 kGy, the highest dose permitted by FSANZ for phytosanitary irradiation purposes, did not detract from palatability but also had minimal, if any, effect on allergenicity as measured by antibody binding.

No evidence was located by literature searches that would suggest that phytosanitary irradiation could lead to increased allergenicity.

3.2.2.4 Jerky pet treats

The United States Food and Drug Administration (US FDA) has received thousands of complaints of illnesses, primarily in dogs, that are apparently associated with the feeding of jerky pet treats imported from China. The complaints concerned illness in more than 6200 dogs as well as 26 cats and three people, and deaths in more than 1140 dogs. Some of the pet treats had been irradiated, although it is not clear from the available evidence that all the pet treats had been irradiated. The FDA has been investigating these adverse events since 2007. Approximately 60% of reports described gastrointestinal illness and about 30% concerned kidney or urinary problems. A distinctive characteristic has been the high incidence of acquired Fanconi syndrome (Fanconi-like syndrome or FLS), a disease in which there are functional changes in the proximal renal tubules. Most of the dogs with FLS survived and the disease appeared to resolve once feeding of the treats was discontinued. The FDA has analysed jerky treats for a wide range of possible nephrotoxicants including bacteria, bacterial enterotoxins, elemental poisons, radiolytic compounds, pesticides, antibiotics, mycotoxins, pharmaceutical drugs and other poisonous compounds. A number of necropsies have been performed on dogs, and approximately half the dogs necropsied were found to have disorders that were not related to the pet treats (e.g. cancer and other chronic disorders, infections, etc.). Investigation to determine how strong the association between FLS in dogs on the one hand, and feeding of jerky pet treats on the other, is ongoing (FDA 2018).

3.3 Hazard assessment conclusions

With the exception of 2-ACBs, radiolytic compounds formed by irradiation of food are not unique to irradiated food but are naturally present in food, or are generated via other food processing treatments such as thermal treatment.

Generation of 2-ACBs is likely to be negligible or minimal due to the low lipid content of fruit and vegetables. Previous FSANZ assessments have reviewed large number of studies conducted to determine whether 2-ACBs are genotoxic, and the results have been consistently negative. The available new studies support this conclusion.

FSANZ has previously reviewed a large number of laboratory animal studies demonstrating that long-term consumption of irradiated foodstuffs, which would contain low concentrations of 2-ACBs and other radiolytic compounds, is safe. FSANZ notes that a number of irradiated diets for laboratory animals are commercially available. An updated literature review identified only two new studies related to 2-ACBs. The acute oral LD50 of a specific 2-ACB, 2-dodecylcyclobutanone (2-dDCB) in the mouse was > 2000 mg/kg bw. In a 28-day repeat-dose study of 2-dDCB in Sprague Dawley rats, the NOAEL for 2-dDCB was 1.0 mg/kg bw/day.

Furan is a genotoxic carcinogen formed by a number of food processes including cooking, roasting, baking, pasteurization and sterilization, and is found in a wide variety of human foodstuffs, particularly coffee, grain-based products, and infant foods sold in jars or cans. Levels of furan resulting from irradiation of fresh fruit and vegetables are not of toxicological concern, particularly when considered relative to dietary furan exposure from other sources.

Furthermore, furan is highly volatile, with a boiling point of 31° C, and consequently evaporates over time from produce held at ambient temperature.

There is no evidence that irradiation of fruit and vegetables would increase the toxicity of any mycotoxin contamination of the produce, or increase the allergenicity of the food.

FSANZ concludes that there are no safety concerns associated with the irradiation of fruit and vegetables.

4 Nutrition assessment

4.1 Introduction

4.1.1 Impact of irradiation on nutrients in food

The effects of irradiation on the safety and nutritional quality of foods has been reviewed several times over the past 40 years (WHO 1981, 1988, 1994; SCF 2003; Arvanitoyannis 2009; Arvanitoyannis 2010; EFSA 2011a and 2011b). A joint FAO/IAEA/WHO Expert Committee report concluded that irradiation of foods, up to a dose of 10 kGy, does not raise nutritional concerns (WHO 1981). However, irradiation can cause some changes in the nutrient content of food, depending on a variety of factors including the irradiation dose, composition of the food, packaging material, ambient temperature and atmospheric oxygen concentration (Diehl et al. 1991; Kilcast 1994; WHO 1994).

Low and medium doses of irradiation (< 1 kGy and 1 – 10 kGy respectively) do not affect the nutritional quality[6] of proteins, carbohydrates, fats, or most vitamins and has no effect on essential minerals in terms of concentration or bioavailability (Diehl 1990, 1991; Diehl et al. 1991; WHO 1994). However, several vitamins are sensitive to irradiation, with their concentrations in food decreasing with irradiation dose (Diehl et al. 1991; WHO 1999). Vitamins C and B_1 (thiamin) are the most sensitive water soluble vitamins, and vitamins E and A are the most sensitive fat-soluble vitamins (Diehl et al. 1991; Kilcast 1994) (Figure 1). Changes in vitamin content due to irradiation must be considered in the context of wide natural variation that is dependent on plant and animal variety, season and storage conditions (WHO 1994).

Vitamin C is an antioxidant that is required for normal regulatory functions, immune functioning, and collagen synthesis (Davey et al. 2000). It exists in two redox states, as L-ascorbic acid (AA) and its oxidised form L-dehydroascorbic acid (DHAA), which have similar bioavailability in humans (Wilson and Murphy 2002).

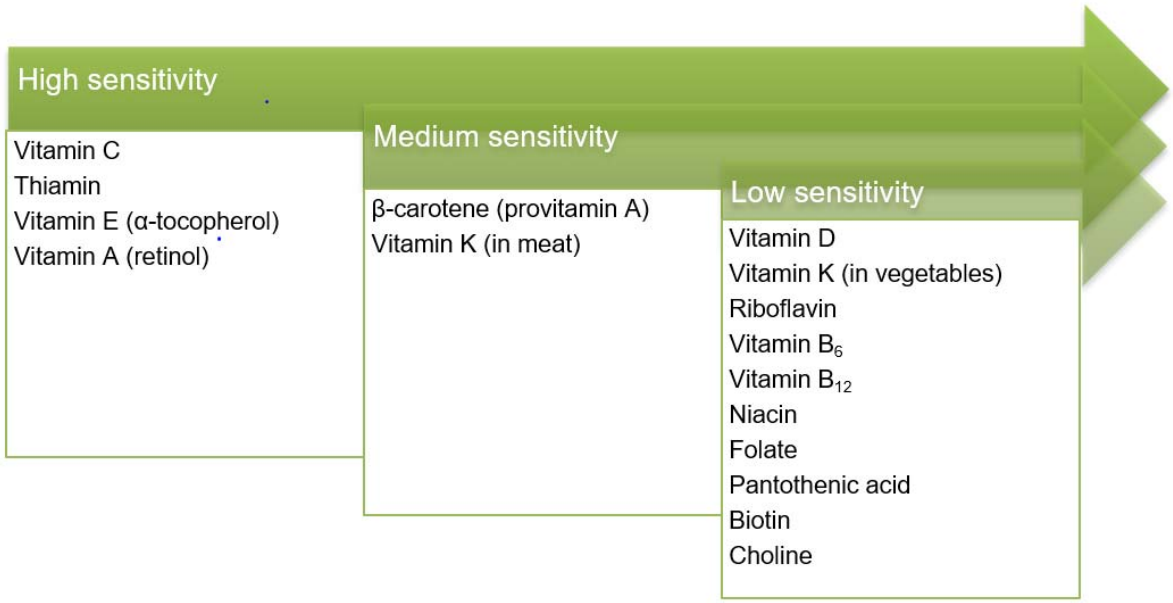

Figure 1: General sensitivity of vitamins in food to irradiation (modified from Kilcast 1994)

[6] Nutritional quality includes nutrient content and potential changes in bioavailability, protein efficiency ratio and potential formation of antinutrients.

Freshly harvested fruit and vegetables contain mostly AA, however the ratio of AA to DHAA can change significantly during storage and processing (Diehl et al. 1991). Irradiation may result in increased amounts of DHAA with a resulting decrease in AA (WHO 1994). Therefore, when assessing literature in relation to the effects of irradiation on vitamin C content it is important to consider whether total vitamin C or only AA is measured.

Vitamin A is required for vision, growth, reproduction, cell division and immunity. Retinol, a form of vitamin A, is sensitive to irradiation (Diehl et al. 1979). However, it is found only in foods of animal origin and is therefore not relevant for the purposes of this application. Many fruit and vegetables contain carotenoids, such as β-carotene, which can be converted in the body to retinol. β-Carotene has the highest vitamin A activity of the carotenoids and is the most abundant in food (Wahlqvist 2002). β-Carotene levels in some food commodities are sensitive to the effects of irradiation (Diehl et al. 1991).

Thiamin is a co-enzyme that is involved in the release of energy from carbohydrate, protein and fat. It is the most irradiation-sensitive water-soluble vitamin (Kilcast 1994). The major sources of thiamin in Australia and New Zealand are whole grains, meat and yeast extracts (ABS 2014a; Ministry of Health 2003; Ministry of Health 2012).

Vitamin E is an antioxidant that is naturally present in nuts and seeds and oils therefrom and is the most radiation-sensitive of the fat-soluble vitamins (Kilcast 1994). The most common sources of vitamin E in the Australian and New Zealand diet are cereals and cereal based products, meat, fats and oils, and only a small percentage is derived from fruit and vegetables (ABS 2014a; Ministry of Health 2003; Ministry of Health 2012).

Non-vitamin bioactive compounds from plant foods are not regarded as essential nutrients but have biological activity that can have desirable effects on health (Wahlqvist 2002). These compounds, often referred to generically as phytochemicals, vary in chemical structure and function and include non-provitamin A carotenoids and phenolic compounds, such as flavonoids, polyphenols and non-digestible oligosaccharides. There are no nutrient reference values in Australia and New Zealand for intake of phytochemicals though a few countries have formulated recommendations. Little research exists on the sensitivity of phytochemicals to irradiation.

4.1.2 Previous FSANZ assessments of the effect of irradiation on nutrients in food

FSANZ has previously evaluated the effect of low-dose irradiation on the nutrient profile of a number of fruit and vegetables in five applications to amend the Code, as outlined in Table 1 (see Section 2.4). In these applications, FSANZ concluded that the carbohydrate, fat, protein and mineral content of these foods was not affected by irradiation up to a dose of 1 kGy. Concentrations of certain water soluble vitamins (vitamin C, folate, thiamin or β-carotene) may potentially be reduced, however it was concluded that there was minimal potential for the consumption of irradiated fruit and vegetables to affect the nutritional adequacy of Australian and New Zealand populations. FSANZ anticipated receiving additional applications to irradiate a variety of other fresh fruit and vegetables for phytosanitary purposes therefore, in 2014, FSANZ undertook a review to determine the effect of low dose irradiation (≤ 1 kGy) on a wide range of fruit and vegetables.

4.1.3 Update of 2014 FSANZ review of the effect of irradiation on fruit and vegetables

The 2014 FSANZ review – *Nutritional impact of phytosanitary irradiation of fruits and vegetables* concluded that:

- Low dose irradiation (up to 1 kGy) does not affect the macronutrient, mineral or trace element content of fruit or vegetables.

- Vitamins A, C, E and thiamin are the most sensitive to irradiation and β-carotene has moderate sensitivity to irradiation.
- Fruit, cucurbit and fruiting vegetables that were considered as part of the 2014 review provide only limited contribution to vitamin E or thiamin intake and therefore were not considered further.
- Phytosanitary doses of irradiation did not affect carotene or non-vitamin bioactive levels and therefore their intake would not be compromised.
- A decrease in vitamin C was observed following phytosanitary doses of irradiation in some fruit but this was judged to be low.
- Data requirements for future applications to irradiate fruit and vegetables can focus on vitamin C, with requirements for other nutrients determined on a case-by-case basis.
- The effects of irradiation on Brassicas, leafy vegetables, and roots and tubers would need to be considered in future applications.

The FSANZ 2014 review is used in the body of evidence for the present application. Therefore a literature review was conducted to identify additional studies published since the 2014 review. The details of this assessment are in Appendix 1. Based on these findings, FSANZ maintains the conclusion from the 2014 review that carotene levels are unaffected and, in general, vitamin C levels are maintained following phytosanitary doses of irradiation of the fruit and vegetables that were assessed in the FSANZ 2014 review.

4.1.4 Updated information on the contribution of fruit and vegetables to nutrient intakes

In the 2014 assessment, FSANZ used information from the 1995 Australian National Nutrition Survey (McLennan & Podger 1997), the 2007 National Children's Nutrition Survey (CSIRO 2008), the 1997 New Zealand National Nutrition Survey (Russell et al. 1999) and the 2002 New Zealand National Children's Nutrition Survey (Ministry of Health 2003) to determine the contributions of fruit and vegetables to the intake of vitamin A, vitamin C, vitamin E, thiamin and folate.

Since the FSANZ 2014 review was conducted, more recent national nutrition survey data have become available. This includes the 2011-12 National Nutrition and Physical Activity Survey (NNPAS) for Australia (2 years and above) and, for New Zealand, the 2008-09 Adults Nutrition Survey (Ministry of Health 2011a; Ministry of Health 2011b). FSANZ reviewed the contribution from the more recent surveys to determine if it was consistent with the results and conclusions from previous surveys (Appendix 2). The 2014 review conclusion that fruit, fruiting vegetables and cucurbits are not major contributors to vitamin E and thiamin intake is supported by the more recent nutrition survey data (summarised in Table 4). The scope of the present assessment includes all fruit and vegetables, and recent nutrition survey data indicates that fruit and vegetable products and dishes are not major contributors to thiamin intake, and contribute 15% and 24% of vitamin E intake in Australian and New Zealand populations respectively. The source of vitamin E may be from oils present in the dishes. More detailed data on the foods contributing to intakes of thiamin, vitamin C, vitamin E, and vitamin A (retinol equivalents and β-carotene), can be found in Appendix 2.

Table 4: Contributions of fruit and vegetables to intakes of selected irradiation sensitive vitamins for Australia and New Zealand*

Food groups	Contribution to dietary intake (%)				
	Retinol Equivalents (RE)	β-carotene	Thiamin	Vitamin C	Vitamin E
Fruit and fruit based products and dishes	4–5	7–9	3	23–24	5–8
Vegetables and vegetable based products and dishes**	33–35	55–64	6–9	19–39	10–17***

* Sources: Australian 2011-12 National Nutrition and Physical Activity Survey, 2 years and above; 2002 New Zealand Children's Nutrition survey, 5-14 years; 2008-09 New Zealand Adults Nutrition Survey, 15 years and above; day 1 data only; see Appendix 2 for further details.

** Two categories for New Zealand data were combined, namely 'vegetables' and 'potatoes, kumara and taro'. Excludes legumes.

*** Some of the vitamin E in this food category may come from fats and oils added during cooking and vegetable based snack foods such as potato crisps as these were classified within the vegetable category for New Zealand nutrition surveys.

4.2 Evaluation

The evaluation of the potential effect of phytosanitary doses of irradiation (up to 1 kGy) on all fruit and vegetables is based on the following considerations:

- The 2014 review assessed the effects of irradiation on a wide range of fruit and vegetables including fruit, cucurbits and fruiting vegetables. Based on the conclusions from the 2014 FSANZ review and previous assessments undertaken by FSANZ, the present evaluation focused on the effect of irradiation on leafy vegetables, Brassicas and roots and tubers.

- A literature review of suitably designed studies provided by the applicant or identified by FSANZ was undertaken.

- Five micronutrients – vitamins A (as retinol), C, E, thiamin and to a lesser extent β-carotene are sensitive to irradiation. Vitamin A (as retinol) is not found in fruit and vegetables so was excluded from the review. Thiamin and vitamin E are not abundant in fruit and vegetables and these foods account for less than 10%, in the case of thiamin, and 20% in the case of vitamin E, of total population intakes (Table 4). Therefore, although a search for relevant studies on stability of thiamin and vitamin E was undertaken, the primary focus of the current assessment was on the effect of irradiation on vitamin C and β-carotene content of vegetables.

- Sufficient data were available to undertake meta-analyses of the effect of irradiation on vitamin C and β-carotene content on leafy vegetables, Brassicas, and roots and tubers.

4.2.1 Search strategy and inclusion criteria

In addition to the papers provided by the applicant, FSANZ searched PubMed and EBSCO databases on 14 January 2020. The search strategies are provided in Appendix 3.

Eligibility criteria for consideration in the evidence base included studies that undertook irradiation of leafy vegetables, Brassicas, or roots and tubers at doses of up to 1 kGy and measured the effects on vitamin C, carotenes, thiamin or vitamin E. All studies that were included in the body of evidence included a non-irradiated control sample that was otherwise treated in a similar manner to irradiated samples in terms of preparation, storage duration

and other conditions. The applicant has indicated that the use of irradiation as a phytosanitary measure is limited to whole vegetables, however in cases where no or limited data were available, studies that measured nutrient content in fresh-cut or minimally processed vegetables were considered.

4.2.2 Statistical analyses

Stata 16 software was used for analyses (StataCorp 2019). Meta-analyses were performed using a random effects model and restricted maximum likelihood method. The I^2 statistic was used to assess the inconsistency in results across the studies (heterogeneity). I^2 describes the "percentage of total variation in the estimated effect that is not due to chance" with 0%, 25%, 50% and 75% interpreted as indicating no, low, medium or high heterogeneity respectively (Higgins et al. 2003).

Following data extraction, differences in nutrient concentration were calculated if values were not stated by study authors. If the data were present only in graphs, the means and standard deviations or standard errors were extracted using the online program WebPlotDigitizer Version 3.12.

Mean differences in nutrient concentrations were calculated as:

$$\text{Mean difference} = \text{Nutrient concentration}_{(\text{irradiated group})} - \text{Nutrient concentration}_{(\text{control group})}$$

and its standard error as:

$$\text{SE of Mean difference} = \sqrt{[(\text{SEM}_{(\text{irradiated group})}^2 + \text{SEM}_{(\text{control group})}^2)]}$$

4.2.3 Baseline nutrient profiles of vegetables

Extensive natural variation occurs in the nutrient composition of vegetables. The main sources of variation are cultivar type, season, growing location and maturity at harvest. Climatic conditions including light and average temperature can have an influence on the chemical composition of horticultural crops (Klein and Perry 1992). Post-harvest handling and storage can also significantly impact nutrient composition of fresh produce. In addition, different parts of the same plant can have different vitamin content. For example the outer leaves of leafy vegetables contain more vitamin C than inner leaves (Lee and Kader 2000) and analysis of a sample of carrots showed that the outer part contained twice as much β-carotene as the inner part (Hart and Scott 1995).

FSANZ notes that the potential impact of irradiation on vitamin content in fruit and vegetables is in addition to variation that occurs due to natural variation but can provide context to the magnitude of potential vitamin losses due to irradiation. Tables 5 – 8 below summarise the range of naturally occurring concentrations for irradiation-sensitive nutrients in Brassica, leafy vegetables, and roots and tubers based on Australian, New Zealand and other countries' food composition tables. Further detail is provided in Appendix 4.

Table 5: Vitamin C[ǂ] concentration (mg/100 g) in raw vegetables

Vegetable category	Vegetable#	Vitamin C[ǂ] (mg/100 g)			
		AUS*	NZ^	Other countries[δ]	Consolidated range
Roots and tubers	Potato	12–25	3–12	7–14	3–25
	Sweet potato	31	2–32	0–23	0–32
	Taro, flesh	16	4	5–13	4–16
	Taro, leaves	n/a	90	52	52–90
	Carrot	3–7	0–2	1–9	0–9
Brassicas	Broccoli	106	99	57–105	57–106
	Cauliflower	12–55	36	46–118	12–118
	Brussels sprout	110	9	85–115	9–115
	Cabbage	20–100	13–60	21–55	13–100
	Bok choy/choy sum	17	8	45	8–45
Leafy greens	Lettuce	4–13	0–12	1–13	0–13
	Spinach, baby	25	n/a	29	25–29
	Spinach, mature English	27	3	26–28	3–28
	Silver beet/Swiss chard	21	5	30	5–30
	Rocket	16–150	2	15–20	2–150
	Parsley	95–132	150	133–190	95–190

Detailed data on natural variation are provided in Appendix 4
* Australian Food Composition Database (AFCD) Release 1
^ New Zealand FOODfiles™ 2018 Version 01
δ Other countries dataset include USDA Food Data Central & McCance and Widdowson's The Composition of Foods integrated dataset
n/a – not analysed
Where values are provided for different varieties a range is given.
ǂ In the food composition tables, vitamin C refers to the two related compounds that have vitamin C activity: ascorbic acid and dehydroascorbic acid.

Table 6: β-carotene concentration (µg/100 g) in raw vegetables

Vegetable category	Vegetable#	β-carotene (µg/100 g)			
		AUS*	NZ^	Other countries[δ]	Consolidated range
Roots and tubers	Potato	0	0	0–6	0–6
	Sweet potato	6600	118–3530	3960–16000	118–16000
	Taro, flesh	20	11	35–37	11–37
	Taro, leaves	n/a	3410	2895–6980	2895–6980
	Carrot	5700–9900	4300–8900	1990–21000	1990–21000
Brassicas	Broccoli	285	630	54–675	54–675
	Cauliflower	n/a	n/a	20–166	20–166
	Brussels sprout	160	19	215–530	19–530
	Cabbage	5–1550	6–670	0–1800	0–1800
	Bok choy/choy sum	545	1030–1160	2681	545–2681
Leafy greens	Lettuce	115–1210	267–506	57–8746	57–8746
	Spinach, baby	3600–5200	n/a	1559	1559–5200
	Spinach, mature English	1920	2410	3970–8900	1920–8900
	Silver beet/Swiss chard	1540	1900	2725–4569	1540–4569
	Rocket	1900–4100	2660	1132–1424	1132–4100
	Parsley	3810–4740	7000	4523–5600	3810–7000

Detailed data on natural variation are in Appendix 4
* Australian Food Composition Database (AFCD) Release 1
^ New Zealand FOODfiles™ 2018 Version 01
δ Other countries dataset include USDA Food Data Central & McCance and Widdowson's The Composition of Foods integrated dataset
n/a – not analysed
Where values are provided for different varieties a range is given.

Table 7: Thiamin concentration (mg/100 g) in raw vegetables

Vegetable category	Vegetable#	Thiamin (mg/100 g)			
		AUS*	NZ^	Other countries$^{\delta}$	Consolidated range
Roots and tubers	Potato	0.07–0.09	0.04–0.12	0.06–0.20	0.04–0.20
	Sweet potato	0.03	0.07–0.10	0.07–0.17	0.03–0.17
	Taro, flesh	0.06	0.10	0.08–0.10	0.06–0.10
	Taro, leaves	n/a	0.15	0.21	0.15–0.21
	Carrot	0.02–0.04	0.03–0.04	0.02–0.13	0.02–0.13
Brassicas	Broccoli	0.08	0.08	0.06–0.15	0.06–0.15
	Cauliflower	0.04	0.04	0.02–0.09	0.02–0.09
	Brussels sprout	0.09	0.15	0.14–0.15	0.09–0.15
	Cabbage	0.01–0.09	0.03–0.06	0.02–0.33	0.01–0.33
	Bok choy/choy sum	0.11	0.01–0.11	0.04	0.01–0.11
Leafy greens	Lettuce	0.01–0.09	0.02–0.09	0.01–0.14	0.01–0.14
	Spinach, baby	0.07	n/a	0.09	0.07–0.09
	Spinach, mature English	0.06	n/a	0.07–0.08	0.06–0.08
	Silver beet/Swiss chard	0.03	0.06	0.04	0.03–0.06
	Rocket	0.07	0.04	0.04–0.19	0.04–0.19
	Parsley	0.15–0.16	0.15	0.09–0.23	0.09–0.23

Detailed data on natural variation are in Appendix 4
* Australian Food Composition Database (AFCD) Release 1
^ New Zealand FOODfiles™ 2018 Version 01
$^{\delta}$ Other countries dataset include USDA Food Data Central & McCance and Widdowson's The Composition of Foods integrated dataset
n/a – not analysed
Where values are provided for different varieties a range is given.

Table 8: Vitamin E (mg/100 g) concentrations in raw vegetables

Vegetable category	Vegetable#	Vitamin E (mg/100g)			
		AUS*	NZ^	Other countries$^{\delta}$	Consolidated range
Roots and tubers	Potato	n/a	0–0.08	0–0.06	0–0.08
	Sweet potato	0.70	0.07–0.6	0.04–0.48	0.04–0.70
	Taro, flesh	2.38	1.61	2.38	1.61–2.38
	Taro, leaves	n/a	2.30	2.02	2.02–2.30
	Carrot	n/a	0.20–0.67	0.09–1.46	0.09–1.46
Brassicas	Broccoli	0.18	0.98	0.04–1.72	0.04–1.72
	Cauliflower	n/a	n/a	0.09	0.09
	Brussels sprout	0.88	0.11	0.88–1.00	0.11–1.00
	Cabbage	0–0.14	0.16–0.20	0.05–0.27	0–0.27
	Bok choy/choy sum	0.14	0.10	0.09	0.09–0.14
Leafy greens	Lettuce	0.04–0.21	0.08–0.77	0.03–0.64	0.03–0.77
	Spinach, baby	1.62	n/a	0.48	0.48–1.62
	Spinach, mature English	1.30	n/a	1.41–2.70	1.30–2.70
	Silver beet/Swiss chard	0.16	0.30	1.89	0.16–1.89
	Rocket	1.30	0.35	0.22–0.43	0.22–1.30
	Parsley	0.80–0.90	0.75	0.75–1.70	0.75–1.70

Detailed data on natural variation are in Appendix 4
* Australian Food Composition Database (AFCD) Release 1
^ New Zealand FOODfiles™ 2018 Version 01
$^{\delta}$ Other countries dataset include USDA Food Data Central & McCance and Widdowson's The Composition of Foods integrated dataset
n/a – not analysed
Where values are provided for different varieties a range is given.

4.2.4 Impact of storage conditions and cooking on the vitamin content of vegetables

In addition to irradiation, storage conditions and cooking can affect the vitamin content of vegetables. The effect of storage on vitamin C and carotene content in vegetables is variable. For example, minimal loss of AA in Brassica vegetables has been reported during

storage (Lee and Kader 2000), while total vitamin C and β-carotene concentration of capsicum, jalapeno and chillies were shown to increase through green and red stages of maturity (Howard et al. 1994). Table 9 summarises the effect that different storage conditions and cooking methods have on the concentrations of vitamin C and carotenoids in leafy vegetables, potatoes, carrots, broccoli and other vegetables.

Table 9: Changes in vitamin C (as ascorbic acid) and carotenoid content of leafy vegetables, potatoes, carrots, broccoli and other vegetables following storage and cooking

Vegetable	Processing step	% Change	Reference
Vitamin C (ascorbic acid)			
Leafy vegetables	Storage at 6º C for 6 days	-10	Zepplin & Elvehjem (1944)
	Storage at room temp for 2 days	-20	
Spinach	Storage at 20º C (ambient) for 3 days	-90	Favell (1998)
	Storage at 4º C for 7 days	-80	
Potatoes	Storage at 4º C for 2 months	-24	Kulen et al. (2013)
	Storage at 4º C for 4 months	-45	
	Storage at 4º C for 7 months	-52	
Carrots	Storage at 20º C (ambient) for 7 days	-19 to -34	Favell (1998)
	Storage at 4º C for 14 days	-15	
	Blanching before freezing	No change	
Broccoli	Storage at 4º C for 3 days & 2 days display case at 10-16º C	No change	Wu et al. (1992)
	Blanching before freezing	-40	
	Freezing at -20º C for 16 weeks	No change	
Vegetables (all types)	Frying	-5 to -50	Bell et al. (2006)
	Baking	-5 to -50	
	Boiling	-5 to -80	
Carotenoids			
Spinach*	Storage at 4º C for 8 days	-46	Pandrangi & LaBorde(2004)
	Storage at 10º C for 6 days	-39	
	Storage at 20º C for 4 days	-56	
Broccoli^	Storage at 4º C for 3 days & 2 days display case at 10-16º C	No change	Wu et al. (1992)
	Freezing at -20º C for 16 weeks	No change	
Vegetables (all types)^	Frying	-10 to -15	Bell et al. (2006)
	Baking	0 to -20	
	Boiling	-5 to -20	

* Total carotenoids analysed
^ β-carotene analysed

4.2.5 Literature review

4.2.5.1 Brassicas

The applicant provided four publications that considered the effect of irradiation on the nutritional value of fresh-cut Brassicas (Fan and Sokorai 2008; Frimpong et al. 2015; Vaishnav et al. 2015; Banerjee et al. 2016). FSANZ did not identify any additional relevant publications to include in the evaluation. The studies are summarised below and in Appendix 5.

Fan and Sokorai (2008) studied the effects of 1 kGy irradiation on the texture, aroma, appearance and vitamin C content of thirteen major fresh-cut vegetables. The relevant vegetables for the purposes of this assessment include fresh-cut broccoli, carrot, red cabbage, iceberg, Romaine, green and red lettuce and spinach packaged in either modified atmosphere packaging (MAP) or air.

Packaged fresh-cut broccoli, shredded carrots and red cabbage, iceberg and Romaine lettuce, and spinach with at least 7 days shelf life were purchased from supermarkets and no further processing was undertaken. Whole iceberg, red and green leaf lettuce were cut into 3 cm square pieces and prepared by dipping into chlorine solutions and rinsed. Samples were irradiated at 4 ± 2° C. After irradiation samples were stored at 4° C for either 1 or 14 days. Total vitamin C content (AA and DHAA) was then determined using ion exclusion chromatography.

No statistically significant differences ($p > 0.05$) in vitamin C content were observed at either time point between irradiated samples and controls for broccoli (air), red cabbage (air and MAP), Romaine lettuce (MAP) or carrot (air). The vitamin C content of the fresh-cut broccoli samples decreased by 2.6% (902 ± 101 vs 926 ± 71.7 µg/g) at Day 1 and was unchanged at Day 14. Vitamin C content of red cabbage in MAP decreased by 7.2% (632 ± 29.9 µg/g vs 681 ± 31.8 µg/g) compared to controls at Day 1 and increased by 4.6% at Day 14 (653 ± 21.9 vs 624 ± 44.2 µg/g). The results for leafy vegetables and roots and tubers are described in the relevant sections below.

Frimpong et al. (2015) assessed the effect of gamma irradiation on the sensory and phytochemical content of cut cabbage. AA concentration was measured in three irradiated cut cabbage samples that were stored for up to 15 days at 8 ± 2° C. Irradiation was performed at doses of 1, 2 and 3 kGy and AA was measured at 0, 5, 10 and 15 days post-treatment. Irradiated samples did not have significantly different AA concentrations to non-irradiated samples at any time point. Differences in AA concentration between samples irradiated with 1 kGy compared to controls were as follows: +7.6% at day 0 (11.77 ± 1.95 vs 10.94 ± 2.12); -9.0% at day 5 (11.66 ± 1.84 vs 14.40 ± 1.40); -9.4% at day 10 (18.86 ± 1.90 vs 20.82 ± 2.12) and +3.9% at day 15 (17.69 ± 1.84 vs 17.02 ± 2.07); $p > 0.05$.

Vaishnav et al. (2015) investigated the nutritional, physiochemical and sensory effects of irradiation and storage on ready-to-cook cauliflower. Fresh white cauliflowers were harvested and stored at 4° C. Cauliflower heads of high quality were washed, outer leaves were removed and samples were cut into 4 – 5 cm pieces, washed and dried on blotting paper. The pieces were then randomised and packaged in polystyrene trays, covered in cling film and sealed with adhesive tape to prevent air leakage. Gamma irradiation was performed at ambient temperature (27° C) at a dose of 0.5 kGy. Samples were stored at 4° C for 0, 7, 14, and 21 days prior to analysis. AA content was determined (AOAC 1990) and expressed as mg per 100 g fresh weight of cauliflower. The authors reported that no statistically significant difference was observed between irradiated and control samples on day 0 (41.75 ± 2 mg/100 g vs 41.13 ± 1.37 mg/100 g; p value not provided). AA content was similar during the entire storage period, with the greatest loss (5%) at day 7 (47.72 ± 3.1 mg/100 g vs 50.22 ± 6.88 mg/100 g) and a 10% increase compared to controls at day 14 (46.12 ± 3.79 mg/100 g vs 42.13 ± 3.69 mg/100 g) (Appendix 5).

Banerjee et al. (2016) studied the effect of irradiation (2.0 kGy) on AA content of packaged cabbage samples that were cut into 1 cm by 3.0 – 3.5 cm long strips, packed in polystyrene and covered in cling wrap. Irradiated samples were stored in the dark at 4 ± 1 and 10 ± 1° C for 16 and 21 days respectively following irradiation. Non-irradiated samples were used as controls. AA content of cabbage was estimated (AOAC 1990). At 4° C, AA content was -4.3% to +4.2% of control samples (Day 0: 17.85 ± 2.09 mg/100 g irradiated vs 18.73 ± 2.89 for controls; Day 5: 17.93 ± 2.89 mg/100 g for irradiated vs 17.20 ± 3.06 for controls), and at 10° C -0.47% to +7.6% of controls (Day 0: 17.85 ± 2.97 mg/100 g in irradiated samples vs 18.65 ± 2.97 in controls; Day 13: 18.17 ± 1.45 mg/100 g in irradiated samples vs 16.88 ± 1.53 in controls). No statistically significant difference was found in the mean AA content of samples stored for any time points ($p > 0.05$). As the irradiation dose was higher than maximum dose requested in the application (1 kGy) these data were not used in the meta-analysis.

Meta-analysis of the effect of irradiation on vitamin C or AA in Brassicas

Meta-analysis was undertaken for the effect of up to 1 kGy irradiation on total vitamin C or AA concentration in Brassicas in all studies in which the effect on either AA or vitamin C was reported. Irradiation at a dose of 0.5 – 1 kGy followed by storage of 0 – 21 days caused a change of 0 mg/100 g (95% CI [-2, +1]) compared to non-irradiated food with the confidence interval of most data points crossing the line of no effect. Heterogeneity between studies was low (I^2 = 29%) (Figure 2).

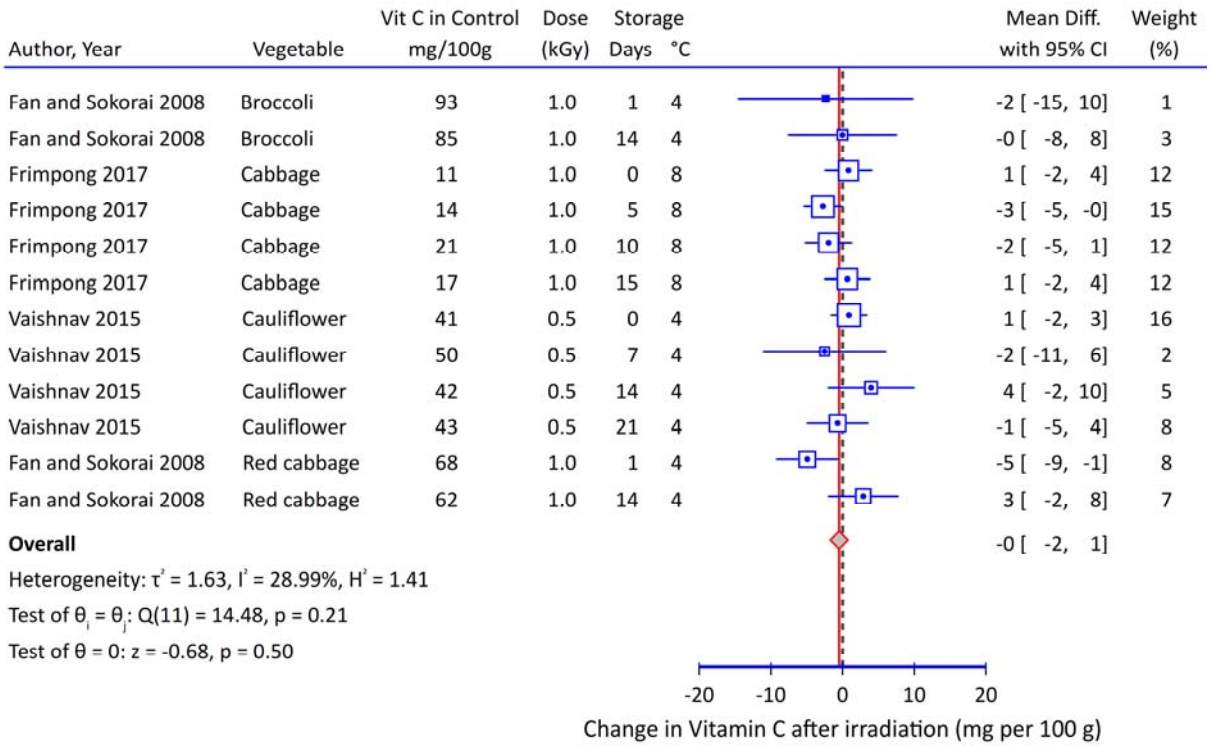

Figure 2: Forest plot of studies measuring the effect (mg/100 g) of up to 1 kGy irradiation on ascorbic acid or total vitamin C in Brassicas

None of the studies included in the body of evidence considered the effects of irradiation on the carotene, thiamin or vitamin E content of Brassicas.

4.2.5.2 Leafy vegetables

The assessment of the effect of irradiation on leafy vegetables includes fresh cut or minimally processed vegetables. Few studies were identified that investigated the effects of irradiation on whole leaf vegetables. Consumption of fresh-cut vegetables has increased over the past number of years and several studies have investigated the effect of irradiation on fresh-cut leafy vegetables used for the purpose of elimination of food-borne pathogens.

Twelve papers were considered in the body of evidence for the effect of irradiation on leafy vegetables of which five were provided by the applicant (Fan and Sokorai 2008; Akhter et al. 2013; Nunes et al. 2013; Sarker et al. 2014; Hussain et al. 2016) and seven were identified by FSANZ (Langerak et al. 1978; Fan and Sokorai 2002; Fan et al. 2003; Zhang et al. 2004; Lester et al. 2010; Fan and Sokorai 2011; Fan et al. 2012).

Langerak et al. (1978) studied the effects of irradiation at 1 kGy on the AA and total vitamin C content of endive. Whole endive were washed and cut into strips of 10 mm width and packaged in perforated or intact polythene bags, irradiated and stored at 10° C for up to 7

days. Total vitamin C content decreased over time in all samples, with a greater loss observed in the irradiated samples up to 2 days storage. Samples in perforated bags deteriorated faster than non-perforated samples. Up to 37% of vitamin C content was lost in irradiated samples in perforated bags after two days storage (3.86 ± 0.25 mg/100 g vs 6.09 ± 0.17 mg/100 g) although after 5 and 7 days storage vitamin content was slightly higher in irradiated samples. In the non-perforated bags vitamin content was up to 11% lower in the irradiated samples compared to non-irradiated (9.68 ± 0.55 vs 8.66 ± 0.62 mg/100 g) except after 7 days storage when irradiated samples had slightly higher levels (6.16 ± 0.36 vs 5.03 ± 0.8 mg/100 g) (Appendix 5). No statistical analysis was undertaken.

Fan and Sokorai (2002) investigated the effects of irradiation on the quality of packaged fresh-cut iceberg lettuce at doses of 0 – 4 kGy and stored at 3° C for 14 days. Heads of lettuce were cored and leaves were cut into 3 – 4 square centimetre pieces and packaged in film bags. Total vitamin C decreased during storage in both the non-irradiated and irradiated lettuce. Losses of between 4 and 19% were observed in the irradiated samples compared to controls (9.6 vs 10 µg/g at 14 days and 21.2 vs 26.1 µg/g at 3 days; $p > 0.05$).

Fan et al. (2003) observed the effects of irradiation on fresh-cut iceberg lettuce. Leaves were cut into 3 cm square pieces, dipped in either cold water (4° C) or warm (47° C) and then cold water, spin-dried and packaged in film bags with modified atmosphere and exposed to 0, 0.5, 1, or 2 kGy gamma irradiation. Bags were stored at 3° C for up to 21 days. Total vitamin C was measured.

Most of the vitamin C content was lost between 1 and 7 days storage in both irradiated and control samples (26.5 µg/g and 7.17 µg/g in control samples at day 1 and 7 respectively). Samples pre-treated at 47° C and irradiated with 1 kGy had higher vitamin C than control samples at most time points (-25% at day 14 to +62% at day 7). Samples pre-treated at 4° C and irradiated with 1 kGy had lower vitamin C content compared to controls at each time point (-13% at day 14 to -58% at day 7) (Appendix 5). Statistical analysis for individual differences were not provided.

Zhang et al. (2004) observed the effects of irradiation on fresh-cut lettuce. Green leaves and damaged stalks were removed and the remaining leaves were cut into 2 cm squares, washed, placed in polyethylene bags and irradiated at 0.5, 1.0 or 1.5 kGy at room temperature (15° C), transferred to 4° C and stored for up to 9 days. AA concentration was 20% lower in samples irradiated at 1 kGy compared to controls at 3 days (4.4 ± 0.0 mg/100 g vs 5.5 ± 0.31 mg/100 g; $p < 0.05$); 26% higher than controls at 6 days storage (4.16 ± 0.34 vs 3.3 ± 0.31, $p < 0.05$) and 67% higher (3.3 ± 0.2 vs 1.98 ± 0.4, $p < 0.05$) at 9 days storage.

Details of a study by Fan and Sokorai (2008) on the effect of irradiation on 13 vegetables were described above. Following 1 kGy irradiation, vitamin C concentration decreased by 48% (39.1 ± 5.9 vs 74.5 ± 9.1 µg/g) at Day 1 and by 53% (15.7 ± 1.2 vs 33.7 ± 6.3 µg/g) at Day 14 in red leaf lettuce ($p < 0.05$). In green leaf lettuce the concentration decreased by 24% (67.1 ± 15.9 vs 88.8 ± 14.2 µg/g) and 47% (28.2 ± 8.2 vs 52.8 ± 10.1 µg/g) at Day 1 and 14 respectively. In iceberg lettuce vitamin C concentrations were similar after irradiation compared to controls irrespective of storage conditions, but after 14 days storage slightly higher concentrations were observed in iceberg samples in MAP (12.9 ± 4.5 µg/g vs 10.9 ± 2.6 µg/g). Similar losses were observed in spinach in MAP and Romaine lettuce stored for 14 days however immediately following irradiation levels were higher in irradiated samples compared to controls (Appendix 5).

Lester et al. (2010) studied the effect of increasing doses of irradiation (0, 0.5, 1.0, 1.5 and 2 kGy) on the vitamins C, E, and carotenoid content of flat-leaf Lazio and crinkled-leaf Samish baby-leaf spinach packaged in N_2 or air. Baby leaves were removed from plants and placed in polyethylene bags at 4° C and irradiation was performed at 21° C. Nitrogen

atmosphere treatment was achieved in half the samples by flushing bags with ultra-high purity nitrogen. Samples were then stored at 4° C for 14 days. Total vitamin C decreased by 12 – 16% (Lazio N_2: 53.9 ± 5.2 mg/100 g vs 61.2 ± 2.5 mg/100 g; Samish N_2: 64.2 ± 1.5 vs 76.3 ± 2.5 mg/100 g) compared to controls after storage and irradiation at 1 kGy ($p < 0.05$ in each case). β-Carotene levels were similar to, or slightly lower than control in both storage conditions, with the greatest loss observed in Samish spinach stored in N_2 (-11%: 52.9 ± 2.7 µg/g vs 59.7 ± 3.7 µg/g; $p < 0.05$) compared to controls. α-Tocopherol levels were similar in all groups.

Fan and Sokorai (2011) studied the effects of gamma radiation at doses up to 4 kGy (0, 1, 2, 3, 4 kGy) on the texture, acceptance and nutritional quality including vitamin C, total antioxidant capacity and total phenolics of fresh-cut spinach after treatment and during post-irradiation storage. Organic ready-to-eat spinach from two 1.16 kg bags were randomised and placed in perforated polyethylene bags and irradiated using gamma irradiation. Samples were then stored at 4° C for up to 14 days. Immediately following irradiation at 1 kGy, vitamin C was slightly higher in irradiated compared to control samples, however after storage for 7 and 14 days irradiated samples had lower concentrations compared to controls: -39% at day 7 (341 ± 120 µg/g vs 557 ± 111 µg/g; $p < 0.05$) and -60% at day 14 (175 ± 78 vs 432 ± 42 µg/g; $p < 0.05$) respectively.

Fan et al. (2012) investigated the effect of up to 4 kGy irradiation on AA content of fresh-cut iceberg lettuce. Whole heads of lettuce were cut into 1 inch square pieces, randomised by hand mixing and sealed in film bags after being flushed with nitrogen. AA content decreased following 1 kGy irradiation with 11% decrease in samples stored for 1 day compared to controls (2.15 ± 0.19 mg/g vs 2.42 ± 1.21 mg/g fresh weight) with greater losses observed when samples were stored for 14 days following irradiation, that reached statistical significance (1.82 ± 0.58 vs 3.06 ± 0.93 mg/g; $p < 0.05$).

Akhter et al. (2013) studied the effects of irradiation (0.5 and 1.0 kGy) on sensory, biochemical and physiological attributes of spinach. Undamaged leaves were selected and placed in polythene bags and sealed. Irradiation using a ^{60}Co gamma source was performed and samples stored for 12 days at 12° C. AA concentration decreased in all treatment groups during the storage period ($p < 0.001$). Mean AA concentration was 30% higher in the samples irradiated with 1 kGy compared to controls immediately following treatment (17.39 vs 13.37 mg/100 g) however AA concentration decreased by 22% to 54% compared to controls between 3 and 12 days storage (p value not provided) (Appendix 5).

Nunes et al. (2013) investigated the effect of irradiation (1 and 2 kGy) on the content of vitamin C and carotenoids in minimally processed arugula (field rocket) following storage at 5 ± 1° C for up to 13 and 16 days. Damaged leaves were discarded, leaves and stalks were rinsed in cold water, immersed in ozone treated water, dried by centrifugation and packed in polyethylene bags. Most of the vitamin C content was lost in non-irradiated samples after 16 days storage: 46.07 ± 1.5 mg/100 g vs 0.08 mg/100 g. Losses were greater in samples irradiated with 1 kGy at each time point compared to controls (18.9 ± 2.01 vs 23.8 ± 1.0 mg/100 g at day 5; $p < 0.05$). Total carotenoid concentration decreased by 9 – 29% over the 13 day storage period (Appendix 5Appendix).

Sarker et al. (2014) studied the effects of irradiation on nutritional quality of five vegetables – including green leaf lettuce and carrot. Samples were washed and stems were removed. Carrots were peeled and sliced and lettuce was chopped. Samples were placed in low-density polythene and sealed. Irradiation was performed with ^{60}Co gamma irradiation source at 5 doses – 0, 1, 2, 2.5, 3 kGy. The authors did not discuss storage prior to nutrient testing. At 1 kGy, AA concentration decreased by 13% in green leaf lettuce and increased by 16% in carrots ($p > 0.05$). Total carotenoids did not change in green leaf lettuce.

In a study by Hussain et al. (2016) fresh samples of spinach and fenugreek leaves were tested for total vitamin C and β-carotene content following irradiation at doses between 0.25 and 1.5 kGy using ^{60}Co at 10 ± 2° C. Leaves were detached from the stem, washed, dried and placed in perforated polyethylene bags prior to irradiation. After irradiation, samples were stored at 3 ± 1° C for 4 days before analysis. Results for samples irradiated with doses up to 1 kGy are shown in Appendix 5. Total vitamin C content decreased by 1% (75.6 ± 2.1 vs 74.6 ± 2.2 mg/100 g; $p > 0.05$) and 2% (51.4 ± 1.2 vs 50.6 ± 1.2 mg/100 g; $p > 0.05$) compared to controls in the spinach and fenugreek samples irradiated at 1 kGy. β-Carotene increased by 74% and 21% respectively in spinach and fenugreek when irradiated at the same dose (spinach: 6.1 ± 0.45 vs 3.5 ± 0.21 mg/100 g; fenugreek 17.2 ± 2.3 vs 14.2 ± 1.5 mg/100 g; $p \leq 0.05$ for both) compared to controls.

Meta-analyses of the effect of irradiation on total vitamin C or AA in leafy vegetables

Meta-analyses were undertaken on the effects of irradiation on total vitamin C or AA concentration in leafy vegetables (Figure 3). Data from nine studies of which three measured AA (Zhang et al. 2004; Fan et al. 2012 and Sarker et al. 2014) were included in the analysis. Irradiation at a dose of 1 kGy followed by storage of 0 – 14 days caused a decrease of 3 mg/100 g (95% CI [-5, -2]; $p < 0.001$) compared to non-irradiated food. Heterogeneity between studies was high ($I^2 = 99\%$).

For raw iceberg lettuce, Fan et al. (2012) reported AA concentrations that were ~60 fold higher than concentrations in the FSANZ food composition database. Due to the high standard error, weighting for these studies was 0.

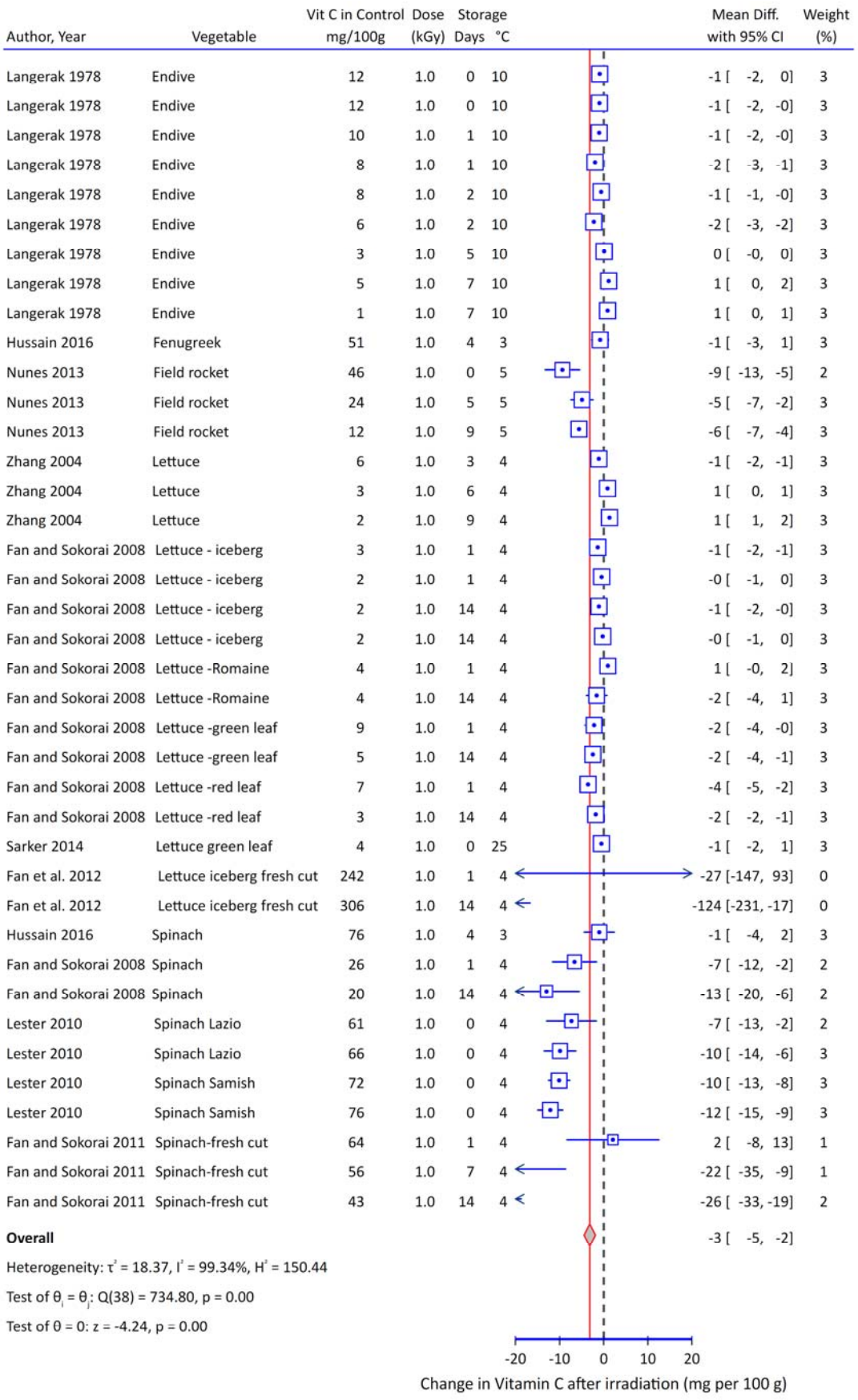

Figure 3: Forest plot of studies measuring effect of 1 kGy irradiation on ascorbic acid or total vitamin C concentration in leafy vegetables

Meta-analyses of the effect of irradiation on β-carotene or total carotenoids in leafy vegetables

Meta-analysis was undertaken on the effects of irradiation on β-carotene or total carotenoid concentration in leafy vegetables (Figure 4). Data from four studies of which two measured β-carotene (Lester et al. 2010; Hussain et al. 2016) and two measured total carotenoids (Sarker et al. 2014; Nunes et al. 2013) were included in the analysis. Irradiation at a dose of 0.8 – 1 kGy followed by storage of 0 – 10 days caused a decrease of 3 mg/kg (95% CI [-10, + 4]), with the 95% confidence interval crossing zero. Heterogeneity between studies was high (I^2 = 97%).

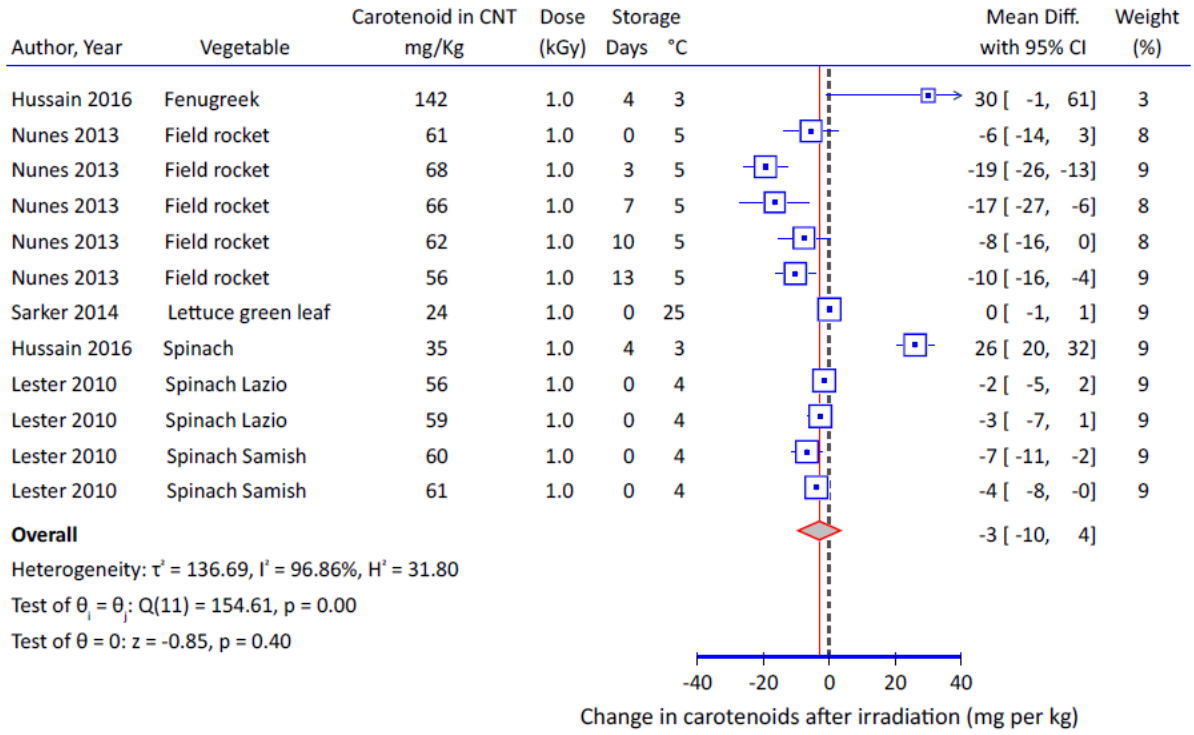

Figure 4: Forest plot of studies measuring the effect of irradiation on β-carotene or total carotenoid concentration in leafy vegetables

Effect of irradiation on vitamin E and thiamin in leafy vegetables

None of the studies included in the body of evidence considered the effects of irradiation on thiamin content of leafy vegetables. One study (Lester et al. 2010) found similar levels of α-tocopherol in irradiated and non-irradiated samples.

4.2.5.3 Roots and tubers

FSANZ reviewed 10 suitably designed studies that observed the effects of irradiation on vitamin content in roots and tubers (Lee and Kim 1972; Ismail and Afifi 1976; Lu et al. 1986; 1989; Graham and Stevenson 1997; Lima et al. 2001; Fan and Sokorai 2008; Rezaee et al. 2011; Lim et al. 2013 and Sarker et al. 2014). Ten studies measured the effects of irradiation on either AA or vitamin C content, seven studies observed the effects on β-carotene or total carotenoid levels and two studies measured thiamin levels. None of the studies considered the effects of irradiation on vitamin E content (Appendix 5).

Lee and Kim (1972) studied the effect of 0.16 kGy irradiation on the nutritive value of potato tubers using the Irish Cobbler variety. Potatoes were harvested and stored at 5° C and 90% relative humidity (RH) for 4.5 months, irradiated and stored in the dark at room temperature for 2 months prior to analysis. AA content was 22% higher in irradiated potatoes compared to controls: 12.1 vs 9.9 mg/100 g ($p < 0.05$). Thiamin concentrations were 11% lower (14.0 µg/100 g compared to 15.7 µg/100 g in controls).

Ismail and Afifi (1976) measured the effects of gamma irradiation on the composition of carrots including AA and β-carotene levels. Samples were harvested and stored at 2° C (95-100% RH) for 12 hr, irradiated at 0.75 kGy and stored either under the same conditions or at room temperature (25 – 30° C and 50 – 60% RH) for 1 – 32 days.

Under cool conditions differences in nutrient composition were observed in irradiated samples compared to controls. These differences varied according to storage time: β-carotene: -28% (2 day storage: 30.2 mg/kg vs 42.0 mg/kg), no difference at 8 or 32 days. An 8% loss of AA was observed at 4 days (15.1 vs 16.4 mg/100 g) and a 26% gain was observed at 32 days (17.9 mg/100 g vs 14.2 mg/100 g). When stored at 25° C nutrient losses were similar for β-carotene, with a 16% loss at 2 days (114 vs 136 mg/kg) and similar levels at 3 days (99.8 vs 98.0 mg/kg), and for AA a 10% loss was observed at 5 days (14.2 vs 15.7 mg/100 g) and a 6% gain at day 0 (14.5 vs 13.7 mg/kg). No statistical analysis was undertaken.

Lu et al. (1986) investigated the effects of low and medium dose gamma irradiation (0.1, 0.5, 0.8, 1.5 and 2 kGy) on the quality of sweet potato roots. Sweet potatoes were harvested and cured at 27 – 33° C and 80-90% RH for one week and then stored at 15° C and 85% RH for two weeks until irradiation when they were stored for a further two weeks at 15° C and 85% RH. Samples were analysed for several nutrients including AA and total carotenoids. At doses of 0.8 kGy AA concentration decreased by 2% and 7% in Georgia Set (10.3 vs 10.5 mg/100 g; $p > 0.05$) and Jewel cultivars (17.3 vs 18.6 mg/100 g; $p > 0.05$) respectively compared to controls and total carotenoid levels decreased by 4% in Jewel (10.7 vs 11.2 mg/100 g; $p > 0.05$) and increased by 24% in Georgia Set cultivars (9.3 vs 7.5 mg/100 g; $p > 0.05$).

Lu et al. (1989) studied the effects of 1 kGy irradiation with different dose rates (1, 4.94, 7.44, 10.4, and 15.3 kGy/hr) on AA, carotenoid, thiamin and riboflavin levels in Jewel sweet potatoes. AA concentration decreased by 2% – 15% compared to controls (14.65 – 16.93 mg/100 g vs 17.3 mg/100 g in controls) depending on dose rate, with the 15% loss reaching statistical significance ($p < 0.05$). Total carotenoid content ranged from a 3% increase to 40% decrease (7.55 – 12.93 mg/100 g vs 12.61 mg/100 g) compared to controls. Thiamin content varied from 15 – 17 µg/100 g in irradiated samples compared to 18 µg/100 g in controls, a decrease of 6 – 17% ($p > 0.05$).

Graham and Stevenson (1997) investigated the vitamin C content of potatoes after treatment with ionising radiation. The Pentland Dell variety of potatoes were harvested and stored at 12° C for 1 month prior to 150 Gy irradiation and then stored for 0, 1, 2 or 5 months. Total vitamin C was determined using ion exclusion HPLC. Vitamin C was lost through cooking in both irradiated and non-irradiated samples, with a greater loss observed in baked compared to boiled potatoes. Most irradiated samples had a lower vitamin C content compared to controls with ~35% vitamin C lost after 1 month of storage, however as storage time increased the difference between irradiated and control samples decreased. By 5 months storage the vitamin C content in irradiated samples was similar to or higher than controls (baked at 5 months: 4.12 mg/100 g vs 3.68 mg/100 g) (Appendix 5).

Lima et al. (2004) studied the effect of gamma irradiation at doses of 0.25, 0.5, 0.75 and 1.0 kGy on the total carotenoid and AA content of ready-to-eat carrots. AA levels were 1%

higher in the samples irradiated at 1 kGy compared to controls (8.29 vs 8.21 mg/100 g) and total carotene level was 11% lower than controls (9.27 vs 10.47 mg/100 g). The author reported that differences in nutrient levels between irradiated and control samples did not reach statistical significance ($p > 0.05$), however as only the abstract was published in English further details were not available.

A study by Fan and Sokorai (2008) investigated the effect of irradiation on several vegetables including shredded carrots. Details of the study are described above. The vitamin C content of shredded carrots was 4.3% lower compared to controls on Day 1 (88.6 ± 3.9 µg/g vs 92.6 ± 11.7 µg/g; $p > 0.05$) but 6.7% higher on Day 14 (59.1 ± 5.3 µg/g vs 55.4 ± 36.1 µg/g; $p > 0.05$).

Rezaee et al. (2011) studied the effects of low dose gamma irradiation (0, 50, 100 and 150 Gy) and time of irradiation (10, 30 or 50 days after harvest) on the composition of Agria potatoes during 5 months storage at different temperatures (8° C and 16° C). Percentage difference in AA content was described for each storage condition, however raw data or statistical analysis was not provided. Irradiation with a dose of 150 Gy followed by 5 months storage at 8° C resulted in a 21% reduction in AA concentration when stored for 10 days prior to irradiation, compared to 10% in the control, however this decreased to 13% when stored for 30 days prior to irradiation. Storage at 16° C caused a greater loss of AA in irradiated samples: 21% when stored for 10 days prior to irradiation compared to 17% in controls. Longer storage of 30 days and 50 days caused 31% and 39% loss of AA compared to levels in recently harvested potatoes.

Lim et al. (2013) examined the effect of irradiation at doses of 0 – 1 kGy on food quality including β-carotene and vitamin C content in sweet potato roots (*Ipomea batatas* Lam.) that were stored at 4, 12, or 25° C for 8 weeks. Units were not provided in the study for vitamin C or β-carotene content. Vitamin C content increased compared to controls immediately following (+20%) and two months after irradiation (+15%) however levels were slightly lower at 4, 6, and 8 weeks following irradiation (Appendix 5). β-carotene levels were lower than controls immediately following irradiation but were similar at all other time points.

Units for vitamin C concentration were not defined in the publication. The Australian Food Composition Database reports that vitamin C concentration in sweet potato is 31 mg/100 g and the data range reported by Lim et al. (2013) was 25 – 32, therefore it was concluded that the units for vitamin C content were likely to be mg/100 g and therefore mg/100 g were used as the units for meta-analysis. The reported range of β-carotene concentrations was not consistent with any units in the database and therefore were not used for further analysis.

Soares et al. (2016) evaluated the effects of irradiation at doses of 0.1, 0.15, and 2 kGy on the physico-chemical and sensory properties including AA content of the potato cultivar Agata. After irradiation potatoes were stored for 35 days at 24 ± 2° C and 39% RH. Data were not provided however the author reported that the mean value of AA between samples was not significantly different between doses ($p < 0.05$).

Meta-analysis of the effect of irradiation on vitamin C or AA in roots and tubers

Meta-analysis was undertaken on the effects of irradiation on vitamin C or AA concentration in roots and tubers (Figure 5). Most studies in the body of evidence could not be included in the analysis as suitable statistics were not reported. Data from three studies of sweet potato and carrot (Fan and Sokorai 2008; Lim et al. 2013; Sarker et al. 2014) were included in the analysis and results from the remaining studies are described below.

Irradiation at a dose of 1 kGy followed by storage of 0 – 56 days caused a change of 0 mg/100 g (95% CI [-1, +1]) compared to non-irradiated food with the confidence interval of

all data points crossing the line of no effect. Moderate heterogeneity between studies was observed (I^2 = 20%) (Figure 5).

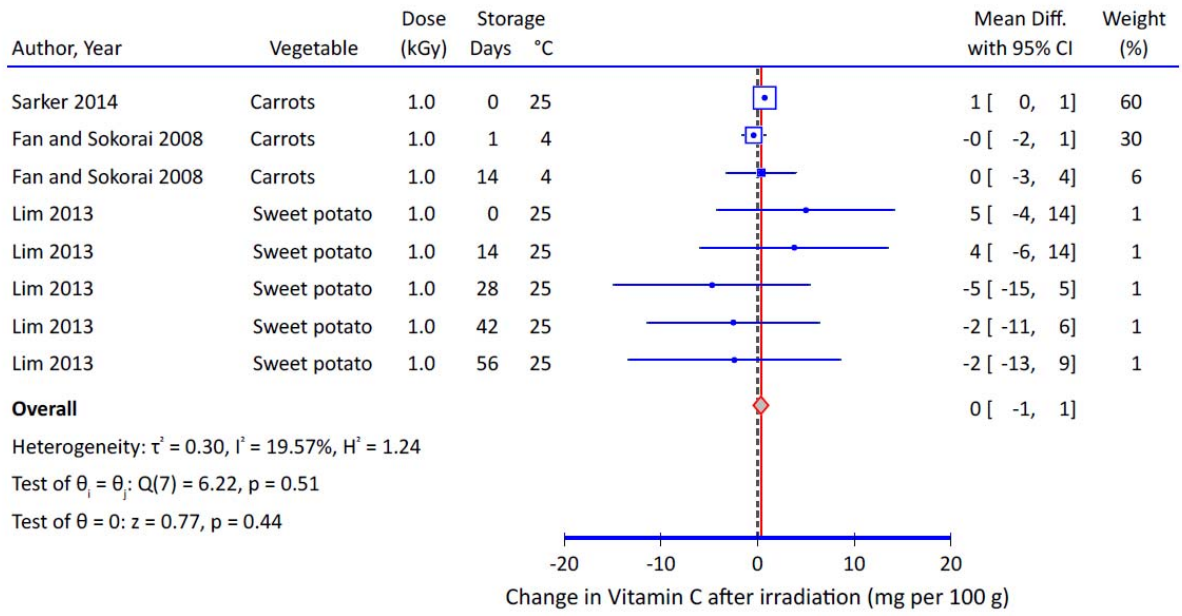

Figure 5: Forest plot of studies measuring the effect of irradiation on total vitamin C or ascorbic acid concentration in roots and tubers

Potatoes
Three publications reported the effects of irradiation on micronutrient content in whole potatoes (Lee and Kim 1972; Graham and Stevenson 1997; Rezaee et al. 2011). Lee and Kim (1972) reported that AA content was higher in irradiated potatoes stored for 4.5 months prior to irradiation compared to controls. Rezaee et al. (2011) reported a 4% and 11% greater loss of AA compared to controls in potatoes stored at 16° C and 8° C respectively for 10 days prior to irradiation. In a study by Graham and Stevenson (1997) total vitamin C content decreased due to cooking and storage, with greater losses in irradiated samples compared to controls in potatoes that were stored for up to 2 months after which time vitamin C concentration was similar to or higher than non-irradiated samples.

Carrots
Four papers studied the effects of irradiation on carrots (Ismail and Afifi 1976; Lima et al. 2001; Fan and Sokorai 2008; Sarker et al. 2014) of which the latter two used fresh-cut or peeled and cut samples. Vitamin C content was similar in irradiated and control samples in one study (Fan and Sokorai 2008) and three studies that measured AA content generally found that levels were higher in irradiated samples.

Sweet potatoes
Three publications reported the effects of irradiation on sweet potato (Lu et al. 1986, 1989; Lim et al. 2013). Concentrations of AA was similar to controls in one study (Lu et al. 1986), and were similar or lower than controls in the study of different dose rates. Total vitamin C concentration in sweet potato varied compared to controls when stored for 0 – 8 weeks in a study by Lim et al. 2013.

Effect of irradiation on β-carotene in roots and tubers

Six studies reported the effects of irradiation on β-carotene or carotenoids levels in roots and

tubers, however a meta-analysis could not be undertaken as suitable statistics were not reported.

Some losses of β-carotene were observed in irradiated carrots, the extent of which varied with storage time and temperature following irradiation. In one study, β-carotene content was lower in irradiated carrots stored at either 2^{o} C or 25^{o} C immediately following irradiation, however following 2 – 4 days storage, levels were similar or slightly lower than controls (Ismail and Afifi 1976). Lima et al. (2001) and Sarker et al. (2014) also found that total carotenoid levels in carrots irradiated at 1 kGy were similar to or slightly lower than control samples.

In a study of two sweet potato varieties, total carotenoid concentration was similar to or higher than control samples following irradiation (Lu et al. 1986), while in another study by the same authors total carotenoid concentration was similar to or lower than controls depending on the dose rate when the dose was maintained at 1 kGy. In a third study of sweet potatoes, β-carotene levels were lower than controls immediately after irradiation but were similar to controls at all other time points over an eight week period (Lim et al. 2013). No data were available for the effect of irradiation on carotene levels in potato.

Effect of irradiation on vitamin E and thiamin in roots and tubers

Lee and Kim (1972) reported that thiamin concentrations were 11% lower in potatoes irradiated with 0.16 kGy compared to controls. Slight losses in thiamin concentrations in sweet potatoes following irradiation were observed in the study by Lim et al. (2013). No study measured the effect of irradiation on vitamin E concentration in roots and tubers.

4.2.5.4 Subgroup Analyses

In order to investigate the cause of heterogeneity between studies a range of subgroup analyses were performed.

Effect of individual vegetables on heterogeneity

Subgroup analysis was undertaken to determine the effect of 1 kGy irradiation on vitamin C or AA in three types of leafy vegetables, namely lettuce, spinach, and endive (Figure 6). In lettuce samples, irradiation followed by storage of 0 – 14 days caused a loss of 1 mg/100 g (95% CI [-2, 0], I^2 = 92%) vitamin C or AA compared to controls, with a similar loss in endive that was stored for up to 7 days: -1 mg/100 g (95% CI [-1, 0]) and I^2 = 96%. However, in spinach samples stored for up to 14 days losses were larger compared to controls: -10 mg/100 g (95% CI [-15, -6]) with a high level of heterogeneity I^2 = 90%, more than a three-fold loss compared to the overall effect for leafy vegetables. Differences between subgroups were statistically significant ($p < 0.05$).

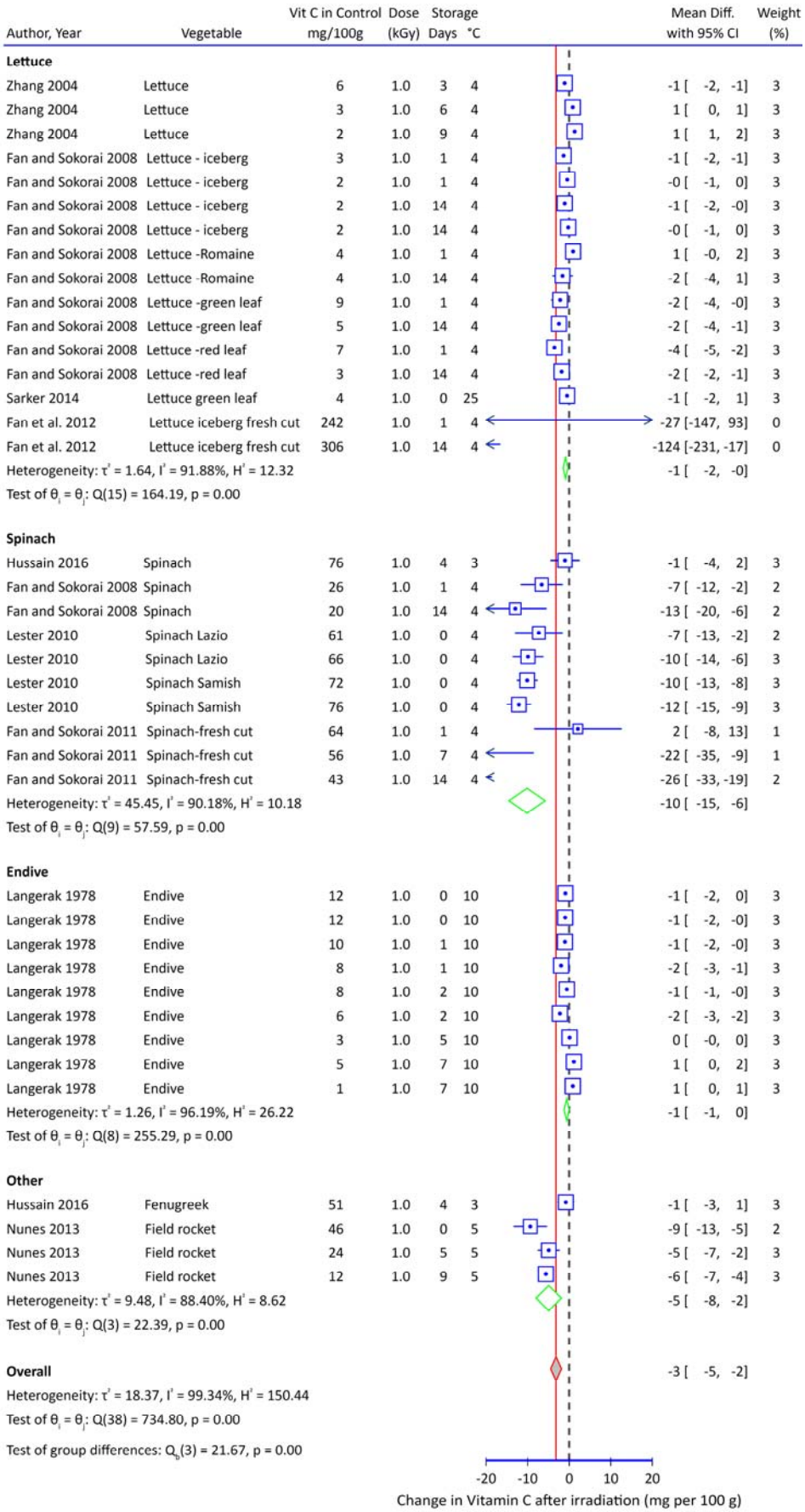

Figure 6: Forest plot of studies measuring the effect of irradiation on ascorbic acid or total vitamin C concentration in leafy vegetables by commodity

Effect of storage time on heterogeneity

Subgroup analysis was undertaken to determine the effect of storage time (no storage, up to 7 days, 8 – 14 days and > 14 days) on vitamin C/AA content (Figure 7) and β-carotene/total carotenoid content in Brassicas, leafy vegetables and roots and tubers compared to controls (Figure 8).

Vitamin C/AA

Across the three vegetable categories, the mean decrease in vitamin C or AA content due to phytosanitary irradiation was 2 mg/100 g (95% CI; -3 to -1), which represents a 5% loss, based on the mean vitamin C or AA content of control samples from studies in the Forest plot. Irradiation without storage caused a loss of 4 mg/100 g (95% CI [-7, -1]; I^2 = 98%) in vitamin C/AA compared to controls in the three categories of vegetables. Storage of up to 7 days caused a loss of 1 mg/100 g (95% CI [-2, 0]; I^2 = 95 %) in vitamin C/AA compared to controls; samples stored for 8 – 14 days observed losses of 3 mg/100 g (95% CI [-6, +1]; I^2 = 99%) compared to controls and samples stored for more than 14 days had a change of 0 mg/100 g (95% CI [-3, 2]; I^2 = 0%). Differences in the effect of storage time were not statistically significant between subgroups (p = 0.27).

β-Carotene/total carotenoid

In leafy vegetables, roots and tubers, the mean decrease in β-carotene or total carotenoid content due to phytosanitary irradiation was 3 mg/100 g (95% CI; -8 to 3), which represents a 3% loss. Irradiation without storage caused a loss of 2 mg/kg (95% CI [-4, 0]; I^2 = 57%) in β-carotene/total carotenoid compared to controls in the two categories of vegetables. Storage of up to 7 days caused a loss of 3 mg/100 g (95% CI [-22, 29]; I^2 = 97 %) in β-carotene/total carotenoid compared to controls; samples stored for 8 – 14 days observed losses of 9 mg/100 g (95% CI [-13, -4]; I^2 = 0%) compared to controls and samples stored for more than 14 days increased by 1 mg/100 g (95% CI [-9, +12]; I^2 = 0%). Differences in the effect of storage time were not statistically significant between subgroups (p = 0.09).

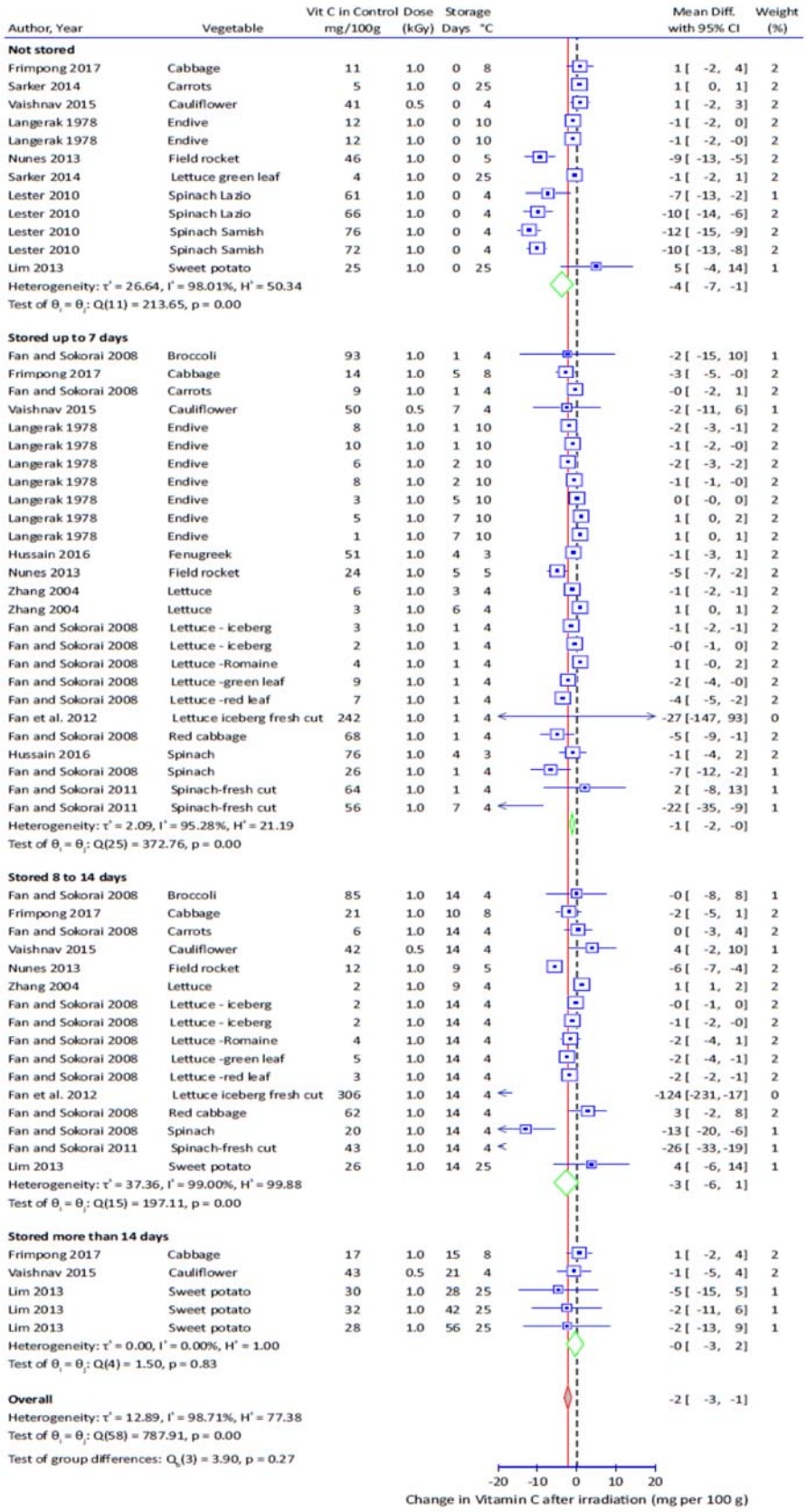

Figure 7: Forest plot of studies measuring the effect of irradiation on ascorbic acid or vitamin C concentration in Brassicas, leafy vegetables and roots and tubers by duration of storage

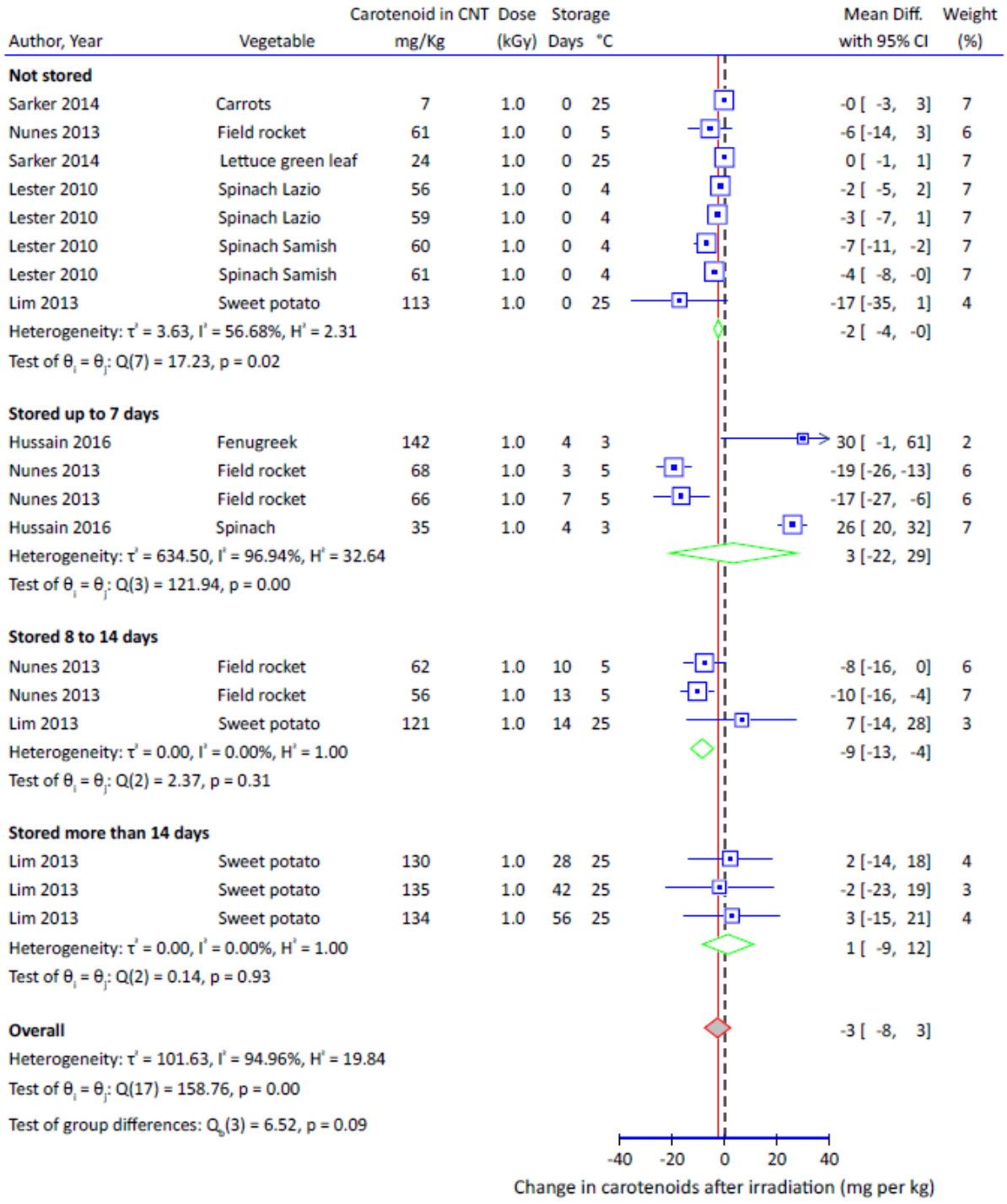

Figure 8: Forest plot of studies measuring the effect of irradiation on β-carotene or total carotenoid concentration in leafy vegetables and roots and tubers by duration of storage following 0.8 – 1 kGy irradiation

4.3 Nutrition discussion

The application seeks to permit the use of irradiation of fresh fruit and vegetables (not for further processing) for the purpose of pest disinfestation for a phytosanitary objective at doses of between 150 Gy – 1 kGy. The nutrition assessment considers the effect of the proposed irradiation on all fruit and vegetables up to a maximum dose of 1 kGy. In studies where multiple doses were tested, meta-analysis was conducted using the results from

1 kGy dose experiments or from the highest dose less than 1 kGy. Five micronutrients have been previously identified as sensitive to irradiation – Vitamins A, C, E, β-carotene and thiamin (Kilcast 1994). However vitamin A (as retinol) is found in foods of animal origin and in general fruit and vegetables are poor sources of thiamin and vitamin E.

FSANZ previously reviewed the effect of irradiation on the nutritional quality of a range of fruit and vegetables (FSANZ 2014) including fruit, fruiting vegetables and cucurbits and concluded that low dose irradiation (≤ 1 kGy) did not have an effect on carotene levels, and that vitamin C levels were not affected in the majority of fruit and vegetables. As part of the current assessment FSANZ undertook a literature review to identify additional studies that were published since the 2014 review was undertaken. Following the assessment of recent evidence, FSANZ remains confident in the conclusions from the 2014 review (Appendix 1).

Based on the nutritional assessments previously undertaken by FSANZ in five separate applications and the 2014 review of the nutritional impact of phytosanitary irradiation on selected fruit and vegetables, the present assessment focused on the nutritional impact of irradiation on Brassicas, leafy vegetables, and roots and tubers because irradiation of these vegetables has not been considered previously by FSANZ.

4.3.1 Effect of irradiation on vitamin C

Four publications were considered in the body of evidence for the effect of irradiation on the vitamin C or AA content of Brassicas including fresh-cut broccoli, white and red cabbage and ready-to-cook cauliflower. A meta-analysis of the effect of 0.5 – 1 kGy irradiation indicated that the vitamin C or AA concentration changed by 0 mg/100 g (95% CI [-2, +1]) compared to non-irradiated food with the confidence interval of most data points crossing the line of no effect. Three of the four studies measured AA which can be oxidised to DHAA over time. The most reliable measurement of the effects of irradiation on vitamin C content requires measurement of both AA and DHAA and losses of AA may overestimate vitamin C loss (Eitenmiller et al. 2008).

Twelve publications studied the effect of up to 1 kGy irradiation on a range of leafy vegetables including iceberg, green leaf, red leaf, Romaine, Lazio, and Samish lettuce varieties, spinach, arugula, fenugreek leaves, and endive. Eight publications observed the effects of irradiation on total vitamin C levels, and four measured changes in AA concentration (Zhang et al. 2004; Fan et al. 2012; Akhter 2013; Sarker 2014). In all studies vitamin C or AA content decreased in both control and irradiated samples during the storage period. Meta-analysis indicated a decrease in vitamin C or AA content in irradiated leafy vegetables compared to controls (-3 mg/100 g, 95% CI [-5, -2]), with losses varying depending on the commodity. Small losses relative to nutrient content were observed in lettuce (-1 mg/100 g 95% CI [-2, 0]); lettuce contains 4 – 13 mg/100 g and 0 – 12 mg/100 g vitamin C based on Australian and New Zealand data respectively. Vitamin C/AA content decreased by 1 mg/100 g (95% CI [-1, 0]) in endive. Vitamin C/AA content decreased by 10 mg/100 g in spinach (95% CI [-15, -6]); baby and mature spinach contains 25 and 27 mg/100 g respectively based on Australian data (Table 5).

Ten studies observed the effect of 0.15 Gy – 1kGy irradiation on vitamin C content in roots and tubers (Graham and Stevenson 1997; Fan and Sokorai 2008; Lim et al. 2013) or AA (Lee and Kim 1972; Ismail et al. 1976; Lu et al. 1986; Lu et al. 1989; Lima et al. 2004; Rezaee et al. 2011; Sarker et al. 2014). Meta-analysis of the available data indicated that 1 kGy irradiation did not deplete vitamin C or AA content in roots and tubers, with an effect size of 0 mg/100 g (95% CI [-1, +1]). Data from studies that were not included in the meta-analysis were inconsistent, with several studies reporting similar or higher levels of AA or vitamin C compared to control samples and some studies finding losses of vitamin C or AA.

Phytosanitary irradiation caused a mean decrease in vitamin C or AA content of approximately 5% in Brassicas, leafy vegetables and roots and tubers based on the mean vitamin C or AA content of control samples from studies in the Forest plot.

4.3.2 Effect of irradiation on carotenes

The effect of 1 kGy irradiation on β-carotene or carotenoid concentration in leafy vegetables was measured in four studies (Lester et al. 2010; Nunes et al. 2013; Sarker et al. 2014; Hussein et al. 2016). Meta-analysis of several leafy green vegetables including spinach (mature and baby), field rocket, lettuce and fenugreek indicated that β-carotene/carotenoid levels decreased by 3 mg/kg (95% CI [-10, +4]), with the 95% confidence interval crossing the line of no effect. Mature spinach contains 19 mg/kg and 24 mg/kg based on Australian and New Zealand data respectively (Table 6). Baby spinach contains 36 – 52 mg/kg β-carotene (Australian data), and lettuce contains 1 – 12 mg/kg and 3 – 5 mg/kg based on data from Australia and New Zealand.

In terms of roots and tubers, β-carotene levels generally increased during storage in both irradiated and control samples of carrots and sweet potatoes (Ismail and Afifi 1976; Lim et al. 2013). In both studies involving storage, irradiated samples had lower β-carotene concentrations compared to controls immediately after irradiation, however following storage differences were no longer observed. A number of studies that did not involve storage did not find differences in carotenoid levels between irradiated and control samples (Lu et al. 1986; Sarker et al. 2014); one study observed losses dependant on dose rate and another study a decrease in carotenoid content was observed in irradiated samples compared to controls (Lim et al. 2004). None of the studies in the body of evidence measured the effect of irradiation on carotenoid levels in Brassicas.

Phytosanitary irradiation caused a mean decrease in β-carotene or total carotenoid content of approximately 2% in leafy vegetables and roots and tubers based on the mean β-carotene or total carotenoid content of control samples from studies in the Forest plot.

4.3.3 Effect of irradiation on vitamin E and thiamin

Two studies measured the effects of irradiation on thiamin content, one reported an 11% decrease compared to controls (Lee and Kim 1972) and another study observed a small decrease depending on dose rate (Lu et al. 1989). However, vegetable products and dishes are not a major source of thiamin in the diet, contributing 6 – 9% of thiamin intake in Australian and New Zealand diets, and therefore this was not a focus of the assessment.

One study in the body of evidence (Lester et al. 2010) reported that 1 kGy irradiation resulted in a slight decrease (-5%; $p > 0.05$) in α-tocopherol concentration in two varieties of spinach stored under two conditions.

4.4 Nutrition assessment conclusions

In 2014 FSANZ undertook a review of the nutritional impact of phytosanitary irradiation on a range of fruit and vegetables including fruit, cucurbits, and fruiting vegetables. The review noted that irradiation at doses of up to 1 kGy does not affect the macronutrient or mineral content of fruit and vegetables; that 5 micronutrients – vitamins A, C, E, β-carotene and thiamin are potentially sensitive to irradiation; and that fruit, cucurbits, and fruiting vegetables are not major contributors of vitamin E or thiamin intake in the Australian and New Zealand diet. The review concluded that phytosanitary irradiation did not affect carotene content and did not decrease vitamin C content in the majority of fruit, cucurbits, and fruiting vegetables; however, these earlier reviews did not seek to calculate or estimate the average effect (i.e. effect size) or variability; therefore, it is not possible to judge the size of the ‘small’ or

‘negligible’ losses.

A literature review of additional studies that were published since the 2014 review was consistent with these findings and therefore FSANZ maintains its conclusion. However three categories of fruit and vegetables were not previously assessed by FSANZ including Brassicas, leafy vegetables and roots and tubers and an assessment of the effects of irradiation on these vegetables was undertaken.

Overall the evidence indicates that phytosanitary irradiation has a minimal effect on vitamin C concentration in Brassicas, leafy vegetables and roots and tubers. In the majority of cases vitamin C content was maintained following irradiation and when depletion was observed, in general losses were small relative to total vitamin C content, with an estimated loss of approximately 5%. The only exceptions across the eleven types of vegetables assessed were in spinach and rocket where losses of 18% and 34% respectively were observed. The contribution of these vegetables to nutrient intake are considered in Section 5 Dietary Intake Assessment.

The effect of irradiation on carotene levels was variable. For leafy vegetables sufficient data were available to undertake a meta-analysis. When analysed together a non-significant loss of carotenes was observed following irradiation. The effect on roots and tubers was variable, with some studies reporting a decrease in carotene levels compared to controls and several studies observing no effect, with an estimated loss of approximately 2%. Analysis of the contribution of Brassicas, leafy vegetables and roots and tubers to vitamin C and carotene intake in the Australian and New Zealand diet is discussed in Section 5 Dietary Intake Assessment.

FSANZ notes that the nutritional impact of irradiation on some commodities (e.g. onion) were not assessed due to a lack of data and the possibility exists for large losses in individual commodities that were not assessed.

FSANZ concludes that phytosanitary irradiation does not affect the macronutrient or mineral content of fruit and vegetables. Five vitamins or pro-vitamins are considered potentially sensitive to irradiation, of which vitamin C, β-carotene and vitamin E are most relevant for fruit and vegetables. Phytosanitary irradiation has little effect on the vitamin C content of most fruit and vegetables with only small depletion ranging from 1 to 3 mg per 100 g observed in a small number of vegetables; however, it did find larger losses in two foods – spinach and rocket. In general, β-carotene levels are stable in irradiated fruit, some inconsistency was observed across studies but the losses were always small. Very limited data were available on the effect of irradiation on the vitamin E content, with one study reporting a negligible effect (< 5%) on vitamin E content in spinach. Therefore losses of vitamin E in other commodities due to phytosanitary irradiation cannot be discounted. The effect of any potential losses of vitamin C or β-carotene are considered in Section 5 Dietary Intake Assessment.

5 Dietary intake assessment

5.1 Introduction

The aim of the dietary intake assessment was to determine whether the irradiation of fresh fruit and vegetables at the requested dose would have an impact on population dietary intakes of irradiation sensitive nutrients. This included whether there would be risks to any specific population sub groups or effects on the proportion of the population with inadequate intakes. In addition, it was to determine if the body of evidence available on the impact of irradiation on nutrient content for specific commodities was sufficient to make risk assessment conclusions for all fruit and vegetables.

The scope of the dietary intake assessment was driven by, and consistent with, that of the nutrition assessment described in Section 4 and the FSANZ 2014 review. Dietary intakes of thiamin and vitamin E were not considered in the dietary intake assessment as it was previously concluded in the FSANZ 2014 review, and confirmed with more recent nutrition survey data (Table 4), that fruit and vegetables were not major contributors to dietary intakes for these two nutrients. Therefore the dietary intake assessment focussed on vitamin C and β-carotene.

The hazard assessment did not identify any non-nutrient chemicals or compounds as a result of fruit or vegetables being irradiated for which a dietary exposure assessment was warranted. However, some information relating to furan concentrations in foods and estimates of dietary exposure were provided in Section 3.2.2.1.

5.2 Dietary intake assessment

As a result of the assessment for this application it was determined that detailed dietary intake assessments for vitamin C and β-carotene (and therefore also retinol equivalents (RE)) were not required. This was based on the combination of a number of different information sources including the:

- contribution of fruit and vegetables to dietary intake of these nutrients
- nutrient content in specific commodities for selected nutrients post-irradiation
- natural variation of nutrient content in specific commodities for these nutrients
- proportion of commodities to be potentially treated by irradiation
- proportion of the Australian and New Zealand populations with inadequate dietary intakes
- previous assessments on the impact of irradiation on nutrient content of other fruit and vegetables undertaken by FSANZ.

For the fruit and vegetable commodities where nutrient impact data from irradiation are available, an evaluation was also undertaken to determine how much of the contribution to specific nutrient intakes they represent. This was done to evaluate the degree of extrapolation of nutritional impacts to all fruit and vegetables.

Further information about this assessment is provided below.

5.2.1 Percent contribution of fruit and vegetables to intakes of irradiation sensitive nutrients

The contribution of fruit and vegetables to nutrient intakes from the most recent national nutrition survey data for Australia (2011-12 National Nutrition and Physical Activity Survey

(NNPAS)) and New Zealand (2002 National Children's Nutrition Survey and the 2008-09 Adult Nutrition Survey) was reviewed for specific nutrients. The range of contributions of all fruit and all vegetables to dietary intake for selected nutrients for Australian and New Zealand nutrition surveys are summarised in Table 4. More detailed contribution results are shown in Appendix 2.

For vitamin C, fruit including fruit products and dishes contributed almost one quarter of dietary intake (23 – 24%) across both countries. For vegetables including vegetable products and dishes, the contribution was between 19 – 39%, with the lowest end of the range being for New Zealand children. Specific types of vegetables with the highest contributions included potatoes and Brassica vegetables (Appendix 2, Table A2.1). The only other major food group that was a large contributor to vitamin C intakes was non-alcoholic beverages (25 – 36%), which was primarily from fruit and vegetable juices (10 – 23%).

For β-carotene, fruit including fruit products and dishes contributed less than one tenth of dietary intake (7 – 9%). For vegetables including vegetable products and dishes, the percent contribution was more than half the dietary intake (55 – 64%). When expressed as RE, the contribution of fruit was 4 – 5% and vegetables 33 – 35%. The vegetable that contributed the most to β-carotene intakes was carrots (19 – 37%), and likewise for RE (10 – 18%). No major food group had a higher contribution to the dietary intakes of β-carotene and RE than vegetables.

The nutrition survey results (Appendix 2) also indicate that there are dietary sources other than from fruit and vegetables that contribute to intakes of irradiation sensitive nutrients. This minimises the impact of irradiation of fruit and vegetables on total dietary intakes.

5.2.2 Nutrient content post-irradiation compared to natural variation

5.2.2.1 Approach to assessing nutrient content post-irradiation compared to natural variation

The vitamin C and β-carotene content and degree of loss observed in specific commodities post-irradiation (from data reviewed in the nutrition assessment – Section 4) was compared to the ranges in nutrient content due to natural variation obtained from food composition datasets. This was done to identify whether there are nutrient losses as a result of irradiation and whether these were likely to have an impact on population nutrient intakes. The outcome of this preliminary evaluation assisted in putting losses from irradiation into context, and in determining whether a detailed dietary intake assessment, which would estimate usual nutrient intakes, and compare intakes with Nutrient Reference Values (NRVs), would be required.

The data on the nutrient content post-irradiation was derived from the literature that was reviewed as part of the nutrition assessment (Section 4). The data on the naturally occurring concentrations (Appendix 4), which would capture any natural variation, was derived from food composition datasets in Australia, New Zealand, the USA and the UK. Whilst the food composition data came from four countries and all of these data were used in the evaluation, a comparison to the Australian and New Zealand data specifically was also undertaken to ensure the relevance of the conclusions regarding the dietary intake assessment approach for Australia and New Zealand.

The comparison of the nutrient content pre- and post-irradiation to the range of naturally occurring levels can be found in Appendix 6, Table A6.1 for vitamin C and Table A6.2 for β-carotene.

Consideration was also given to the conclusions of previous assessments undertaken by

FSANZ on the impact of irradiation on nutrient content of other fruit and vegetables to assist in determining the overall impact and potential for any impact on population intakes.

5.2.2.2 Vitamin C

For Brassicas, based on the nutrition assessment, there were no concerns with respect to irradiation causing any vitamin C losses. It was concluded that any loss of vitamin C content that may occur due to irradiation of Brassicas would be negligible. Vitamin C content post-irradiation (11 – 90 mg/100 g) is generally within naturally occurring levels (12 – 106 mg/100 g) (Table A6.1). In the two instances where the nutrient content post-irradiation was below the naturally occurring range noted in food composition datasets, the pre-irradiation content was also below showing the broad range of concentrations that can occur at baseline, and the change pre- to post-irradiation was negligible.

For leafy vegetables, around a 10 mg/100 g loss of vitamin C was observed in spinach and 7 mg/100 g in rocket. There were no concerns regarding losses in lettuce or endive. Leaf and stalk vegetables only contribute a combined total of 0.7 – 1.9% to vitamin C intakes in Australia and New Zealand, with spinach specifically 0.1 – 0.4% and rocket specifically 0.003-0.01%. Therefore, any impact of irradiation on nutrient content of leafy vegetables is likely to have a minimal impact total dietary intakes. When reviewing the nutrient content (Table A6.1), the post-irradiation concentration (1 – 215 mg/100 g) was within or higher than the naturally occurring range noted in food composition datasets (0 – 27 mg/100 g) showing the broad range of concentrations that can occur at baseline and that post-irradiation concentrations are not dissimilar.

For root and tuber vegetables, the nutrition assessment noted from some studies that there may be a loss of vitamin C in potatoes, however there were no concerns noted in relation to losses in carrots or sweet potatoes. Potatoes, potato products and potato dishes contribute 4.5% to vitamin C intakes in Australia, and 8.2 – 9.2% in New Zealand. When reviewing the nutrient content (Table A6.1), the post-irradiation vitamin C concentration in roots and tubers (3 – 39 mg/100 g) was within or higher than the naturally occurring range noted in food composition datasets (0 – 32 mg/100 g), again demonstrating the broad range of concentrations that can occur at baseline and that post-irradiation concentrations are not dissimilar.

In the FSANZ 2014 review, the majority of results show no statistically significant change in nutrient content with irradiation. However, there is imprecision and inconsistency in the results across the body of evidence with instances of larger losses. This inconsistency is not an important concern because it is expected that less than 5% of the fruit and vegetables in the food supply will be irradiated minimising any impact on population nutrient intakes from consuming irradiated produce.

5.2.2.3 β-Carotene

There were no data on the pre- and post-irradiation content of β-carotene in Brassicas. Total Brassicas only contribute 0.4 – 1.8% to β-carotene intakes in Australia and New Zealand. Therefore, any impact of irradiation on nutrient content is likely to have minimal impact on total dietary intakes.

For leafy green vegetables, the data from the nutrition assessment indicated a slight decrease in β-carotene content overall from irradiation (although in the meta analysis, the confidence intervals crossed the line of no effect). Leafy vegetables in total contribute 2.1% to β-carotene intakes in Australia and 4.1 – 7.4% in New Zealand. When reviewing the nutrient content (Table A6.2), the post-irradiation β-carotene concentration in leafy vegetables (6 – 17 mg/100 g) was within or higher than the naturally occurring range noted in

food composition datasets (1 – 5 mg/100 g) showing the broad range of concentrations that can occur at baseline and that post-irradiation concentrations are not dissimilar.

For root and tuber vegetables, there were no data on the effects of irradiation on the β-carotene content in potato. Levels in carrots were similar to or slightly lower than controls, and for sweet potato post-irradiation samples were similar to or either side of controls depending on the study. Carrots and similar root vegetables (including sweet potato, but not potato) contribute 32% to β-carotene intakes in Australia, with carrots alone contributing 24%, while potatoes contribute 0.1%. For New Zealand, 'potato, kumara and taro' contributed 0.6 – 0.9% of β-carotene intakes, and 'orange vegetables' (including carrot, pumpkin, yams) contributed 28.4 – 41.8% (carrots 19.0 – 37.2%). There is therefore the potential to have an effect on dietary intakes if there are demonstrated losses of β-carotene in root and tuber vegetables. However, when reviewing the nutrient content (Table A6.2) the post-irradiation concentration (7 – 137 mg/100 g) was within or higher than the naturally occurring range noted in food composition datasets (1 – 9 mg/100 g) again showing the broad range of concentrations that can occur at baseline and that post-irradiation concentrations are not dissimilar.

The FSANZ 2014 review, and update to the review (Appendix 1) noted that no losses of β-carotene were observed due to irradiation in a range of vegetables and fruit.

5.2.2.4 Other considerations by FSANZ

In addition to the FSANZ 2014 review, there have been other applications to FSANZ where the post-irradiation nutrient content of certain commodity groups, e.g. tropical fruit, was compared to naturally occurring levels. The findings from the assessments of previous applications are also consistent with those of this latest application. This is outlined in Section 4.1.2.

FSANZ has also assessed the changes that can occur in nutrient content as a result of post-harvest storage, processing and cooking, to also assist with putting post-irradiation changes into context. This information is outlined in Section 4.2.4, in the FSANZ 2014 review, the update to the review (Appendix 1), and in other irradiation applications (e.g. A1069 for tomatoes and capsicums). In terms of post-harvest storage, temperature and atmospheric conditions can have an impact. Vitamin C can be susceptible to post-harvest storage. For the commodities assessed, storage losses can differ based on length of time in storage and can be up to 90%. Warmer temperatures and high CO_2 causes higher losses. Processing such as freezing and canning can induce losses of vitamin C up to 75%. Cooking can cause losses of vitamin C up to 80%. For carotenoids, losses during storage, depending on time and commodity, have been reported to be up to 56% and cooking causes losses up to 20% (see Table 9). The losses noted as a result of storage, processing and cooking were often greater than losses determined as a result of irradiation.

It should also be noted that factors such as processing, storage, or variation across cultivars, are already accounted for when assessing nutrient intakes in a population as they are inherently included in the nutrient composition databases that form the basis of estimating dietary intakes. These factors affect day to day variability in intake but will not change mean population intakes over time. However, irradiation has the potential to change population intakes and the major part of the nutrition risk assessment focussed on the extent (i.e. magnitude) to which this may occur. This is then taken into consideration as part of the dietary intake assessment along with other factors to assist in making conclusions about impacts on population nutrient intakes.

5.2.3 Proportion of commodities to be potentially treated with irradiation

In assessing the nutritional impact of irradiation, it is important to consider the proportion of fruit and vegetables that will undergo irradiation treatment. The proportion of irradiated produce will vary depending on the fruit or vegetable type, season and geographic regions (e.g. state or territory). There will only be a proportion of crops available for consumption that are treated with irradiation, therefore there will only be a proportion of each commodity consumed over a period of time that is irradiated. This is another factor indicating that the impact on the dietary intake of irradiation sensitive nutrients would be minimal.

As noted in Section 2.4, the vast 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 within the same quarantine region. Therefore, the use of irradiation as a phytosanitary measure applies primarily to overseas imports and, for Australia, to interstate trade across different quarantine jurisdictions.

The applicant stated that in 2018, Australians consumed 1.8 million tonnes of fruit and 1.8 million tonnes of vegetables (apparent consumption), which was equivalent to the consumption of 71 kg of fruit and 71 kg of vegetables per capita per year excluding produce grown for processing (e.g. wine grapes, tomatoes, potatoes). It was estimated that 5% of fruit and 1% of vegetables are imported.

According to the applicant, out of 1.8 million tonnes of fruit consumed in Australia in 2018, 92,027 tonnes were imported from overseas and 145,517 tonnes were transferred interstate, indicating that 5% and 8% of fruit are imported from overseas or transferred interstate and, therefore, may be liable to require a phytosanitary treatment respectively. For vegetables, out of 1.8 million tonnes consumed in Australia, 25,266 tonnes were imported from overseas in 2018 and 58,168 tonnes were moved interstate. This shows that 1% of vegetables are from imported sources and 3% of vegetables are moved interstate, and have the potential to be irradiated. The applicant stated further that in a worst case scenario, only 3% of total fruit and 1.2% of total vegetables consumed in Australia (including domestically produced and imported) will be irradiated if Standard 1.5.3 is amended to allow phytosanitary irradiation of all fresh fruit and vegetables.

Within Australia, South Australia, Western Australia and Tasmania are the significant consumers of fresh produce from interstate. Tasmania is regarded as the worst-case scenario as it imports 76% of fruit from interstate and 12% of fruiting vegetables. The applicant proposed that a conservative estimate of 15% and 6% of fruit and vegetables imported to Tasmania respectively might be irradiated in the future.

According to the applicant, New Zealanders consumed 324,302 tonnes of fruit and 521,933 tonnes of vegetables in 2018 (apparent consumption), excluding 60% of potatoes and green vegetables that were grown for processing. The applicant stated further that when expressed per capita per year, New Zealanders consumed around 67 kg of fruit and 108 kg of fresh vegetables excluding consumption of processed foods. It was estimated that out of total fruit and vegetables consumed by New Zealanders, 46% of fruit and 2% of vegetables were imported.

The applicant also stated that currently New Zealand is practically self-sufficient in fresh vegetables. The applicant noted that only green and fruiting vegetable imports would need to be irradiated. In a worst case scenario, the applicant assumed that an estimate of 25% of green and fruiting vegetable imports may be irradiated and that an extra 25% may be imported as a result of new opportunities if Standard 1.5.3 was modified as requested. Therefore, 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 with the exception of Pome fruits which are produced locally. Therefore, the applicant assumed that as a worst case, approximately 17% of fruit imports and 8% of total fruit consumed might be irradiated in New Zealand in the future, if the requested permission was granted.

The proportion of fruit and vegetables that could potentially be irradiated is different for different commodities and is on case-by-case basis. For example, in Australia, the applicant noted that for tropical fruit, of 104,812 tonnes imports and interstate movement, 10% (10,481 tonnes) had the potential to be irradiated, and 2% could be irradiated as a share of total consumption. It was assumed that the largest volumes that are transported interstate are tropical fruit such as bananas, avocado and pineapple, which would not undergo irradiation treatment, while some mangoes and litchis may be irradiated. For soft fruit, 50% of grapes (31,067 out of 62,133 tonnes of soft fruit) may be irradiated.

The applicant proposed that root vegetables do not require any phytosanitary treatment, while for green vegetables, most imports and interstate transported produce would continue to use existing treatments (e.g. fumigation with MeBr and insecticides). No treatment is needed for potato from interstate and 50% of imports would continue to have alternate treatments such as those mentioned above. The applicant proposed the existing treatment for most green vegetable imports would continue, and the existing treatment for 50% of fruiting vegetables moved interstate would continue. The applicant assumed that 10% of green vegetables and 50% of fruiting vegetables imported into Australia and moved interstate would be irradiated.

The scope of the application covers all fresh fruit and vegetables with the exception of dried pulses and legumes, even though these are classified as vegetables in Schedule 22 of the Code. There were no other commodities requested to be exempt from the permission to irradiate. The application does note some commodities which are not likely to be, or would rarely be, irradiated under the requested permission. These include avocado, bananas, pineapples and root vegetables including potatoes. These individual commodities are amongst those that are most commonly consumed within their respective commodity group, therefore reducing any potential impact on nutrient intakes in the population.

In conclusion, the applicant has stated that the majority of fruit and vegetables produced in Australia and New Zealand do 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 the harvesting and processing procedures result in soil and pest free commodities. New Zealand has no need to irradiate produce consumed locally and there are no current plans for a commercial food irradiation facility in New Zealand. In summary, the total amount of fruit that could be potentially irradiated is estimated to be 3% in Australia and 8% in New Zealand and for vegetables less than 2% in both countries.

This information indicates that not all fruit and vegetables that the Australian and New Zealand populations will consume will be irradiated if the requested permission to irradiate is granted. There will only be a proportion of both imported and domestically produced crops that will be treated with irradiation as a phytosanitary measure, such that the dietary intake of nutrients will come from non-irradiated and potentially some irradiated produce over the course of a lifetime. Therefore, the impact of any effects of irradiation on nutrient intakes of the population is reduced due to the low proportion of commodities that will be treated.

5.2.4 Proportion of the population with inadequate nutrient intakes

The proportion of the Australian and New Zealand populations with inadequate intakes of

vitamin C and vitamin A (as RE) was reviewed to determine the current status in the populations. RE was reviewed as this is the NRV for vitamin A, and β-carotene contributes to RE. This was done to determine whether there are existing issues with the populations not meeting nutrient requirements before considering any subsequent potential impact of nutrient losses due to irradiation.

5.2.4.1 Vitamin C

For vitamin C, results for Australians from the 2011-12 NNPAS showed that between 1.4 and 5.5% of the population had intakes less than Estimated Average Requirement (EAR) across all the age/sex groups assessed (ABS & FSANZ 2015). The highest proportions were among children aged 2 – 3 years.

For New Zealand, the prevalence of inadequate vitamin C intakes was estimated to be very low for New Zealand children 5 – 14 years (0.1%) (based on the UK 1991 Dietary Reference Values) (Ministry of Health 2003). For adults 15 years and above, the estimated prevalence of inadequate intake of vitamin C was 2.4% (3.7% for males, 1.3% for females) (based on Australian and New Zealand NRVs) (University of Otago & Ministry of Health 2011).

5.2.4.2 Vitamin A

For RE, in Australia, less than 10% of children up to 13 years had dietary intakes less than EAR. For 14 years and above, there were between 11 and 33% with inadequate intakes (<EAR) (ABS & FSANZ, 2015).

For New Zealand, it is unlikely that vitamin A intakes are a concern for New Zealand children 5 – 14 years, but a proportion of Pacific children (19.7 – 37.4%) and Mäori males (12.9%) may be at risk of inadequate intakes (based on the UK 1991 Dietary Reference Values) (Ministry of Health 2003). Approximately half the vitamin A intake was from retinol (323 µg) and the remainder from carotenoids (Ministry of Health 2003). For New Zealand adults 15 years and above, the estimated prevalence of inadequate intake of RE was 17.2% (males 22.7%, females 12.1%), with a higher proportion in males and females aged 15 – 18 years (37.5% and 27.4% respectively) (based on Australian and New Zealand NRVs) (University of Otago & Ministry of Health 2011). The lower intakes of β-carotene by younger adults contributed to inadequate intakes of vitamin A.

While there was a proportion of the population with inadequate intakes of RE, both carotene and retinol sources contribute to vitamin A intakes. Carrot and other root vegetables contribute 19.8% to RE and 32% to β-carotene intakes in Australia (Tables A2.3 and A2.2). Therefore a slight loss (e.g. 10%) would only result in a slight decrease in RE levels.

Milk, meat and cereals contribute the most to retinol intakes (Table A2.4) and these are also major contributors to RE intakes (Table A2.3). This indicates that there is a reduced reliance on fruit and vegetables in providing adequate intakes of vitamin A. Overall, this factor also reduces any potential impacts of irradiation on the nutritional status of the Australian and New Zealand populations.

5.2.5 Impact on nutrient intakes estimated by the applicant

The applicant also provided some estimations of the likely impact on nutrient intakes due to irradiation of fruit and vegetables. The assessment was based on a number of factors including:

- firstly, the contribution of fresh produce to the intake of vitamins A, C, E and thiamin, then

- the total consumption (tonnes) of fresh fruit and vegetables sub-divided into major categories
- the tonnes and percentage of total consumption that involved produce imported across a border (either national for imports or state boundaries in Australia)
- the percentage of the imports that is likely to switch from an existing treatment to irradiation, which was used to calculate the percentage of total consumption that might be irradiated.

The applicant concluded that in the general population, the proportion of the intake of radiation-sensitive micronutrients derived from fresh fruit and vegetables that could be irradiated is less than 2% for vitamin C and less than 1% for vitamins A, E and thiamin.

This evaluation by the applicant, conducted in a different way to FSANZ, with conservative worst case assumptions, also shows the minimal impact likely on nutrient intakes as a result of irradiating fruit and vegetables.

5.2.6 Evaluation of the coverage of nutrient impact data against key commodities and nutrient intakes

The applicant requested a general permission to enable irradiation of all fruit and vegetables. Data on the effect of irradiation on the nutrient content of irradiation sensitive nutrients were only available for certain commodities for this application, previous applications and the 2014 review. FSANZ used the available data to make conclusions about nutritional impacts on the diet in terms of population nutrient intakes for all fruit and vegetables.

An evaluation was undertaken to determine the nutrient contribution from the commodities with available nutrient impact data (both qualitative and quantitative) compared to the contribution from all fruit and vegetables for vitamin C and β-carotene. This was done to evaluate if the extrapolation of the conclusions from certain commodities to all fruit and vegetables was based on a representative body of evidence.

A summary of the proportion of the dietary intake of vitamin C and β-carotene from the commodities for which there were nutrient impact data is summarised in Table 10 (details in Appendix 2, Table A2.9). For vitamin C, nutrient impact data were available for commodities that provided 69-85% of the contribution to dietary intakes from vegetables across Australia and New Zealand and 55-81% of the contribution from fruit. For β-carotene, nutrient impact data were available for commodities that provided 60-80% of the contribution to intakes from vegetables and 65-77% of the contribution from fruit.

FSANZ also reviewed the most commonly consumed commodities (i.e. commodities with the highest proportion of consumers) within each fruit and vegetable sub-group to assess whether the data on the effect of irradiation on nutrient content were available for these particular commodities (see Appendix 2, Table A2.10 for detailed results).

For vitamin C, data on the impact of irradiation on nutrient content was available for almost all commodities that were the most commonly consumed within their sub-group across Australia and New Zealand. For example, apples were the most commonly consumed Pome fruit and nutrient impact data were available for apples. The only fruit that was most commonly consumed for which there were no nutrient impact data for vitamin C was bananas within the tropical fruit category. In the application, Table 11 states "*Bananas are the greatest volume and do not suit phytosanitary irradiation at present*" and in Table 13 it says "*Largest volumes inter-state are bananas, avocado, pineapple and do not require treatment*". Therefore having no data on the nutrient impact of irradiation on bananas is not an issue for the risk assessment at this time.

For β-carotene, there were nutrient impact data for the most commonly consumed fruit apart from strawberries in the berry sub-group and bananas in the tropical fruit category. No data for bananas is not an issue as described above. Strawberries contribute < 0.005% of the intake of β-carotene for Australia and New Zealand, therefore having no data on the nutrient impact of irradiation for this commodity is not an issue for making conclusions for the risk assessment. For vegetables there were nutrient impact data for the three most commonly consumed fruiting vegetables (tomato, capsicum and cucumber) and for carrots, however for no other commonly consumed vegetables. Carrot was the vegetable that has the greatest contribution to β-carotene intakes (19 – 37% of total dietary intakes) well above other commodities, and there was nutrient impact data for this commodity.

There are no nutrient impact data for bulb vegetables for vitamin C or β-carotene. Onion is the commodity with the highest percent of consumers in this sub-group. However bulb vegetables only contribute a small amount to dietary intakes of vitamin C (<1%) and β-carotene (< 0.5%). There were also no nutrient impact data for stalk and stem vegetables for vitamin C or β-carotene. Celery is the commodity with the highest percent of consumers in this sub-group. Stalk and stem vegetables only contribute a small amount to dietary intakes of vitamin C (< 0.5%) and β-carotene (< 0.5%). Due to the low contribution to total dietary intakes for these two vegetable sub-groups, missing nutrient impact data has little impact on the ability to reliably predict the effect on population nutrient intakes.

Table 10: Summary of nutrient contribution from the commodities with available nutrient impact data[1] compared to the contribution from all fruits and vegetables for vitamin C and β-carotene

Food category	Vitamin C			β-carotene equivalents		
	Australia 2 years and above	New Zealand 5-14 years	New Zealand 15 years and above	Australia 2 years and above	New Zealand 5-14 years	New Zealand 15 years and above
Vegetables						
% contribution to total vitamin intake from vegetables with nutrient impact data[1]	17.2	16.4	31.1	43.9	51.2	36.1
% contribution from all vegetables to total vitamin intake	25.1	19.3	38.9	55.1	64.2	60.2
% of vegetables contribution with nutrient impact data[1]	69	85	80	80	80	60
Fruits						
% contribution to total vitamin intake from fruit with nutrient impact data[1]	18.8	18.8	13.3	6.6	5.1	4.7
% contribution from all fruit to total vitamin intake	23.1	24.3	24.2	8.5	7.9	6.8
% of fruit contribution with nutrient impact data[1]	81	78	55	77	65	69

[1] Vegetables or fruit for which some information was available about the effect of irradiation on nutrient composition.

In summary, there is a large proportion of the contribution to vitamin C and β-carotene

intakes from commodities that have nutrient impact data, and there are data for the most commonly consumed commodities (particularly where they contribute highly to nutrient intakes). Therefore, FSANZ's conclusions that irradiation of fruit and vegetables would have minimal impact on population nutrient intakes can be extrapolated to all fruit and vegetables, including those where no nutrient impact data are available.

5.2.7 Bioactives

Dietary intakes of non-vitamin bioactives were not estimated for this application. This was firstly because comprehensive datasets were not available for the bioactives of interest. In addition, there are no established HBGVs for bioactives. There would therefore be no value to which dietary intakes could be compared in order to characterise the risk associated with any estimated intakes.

The FSANZ 2014 review did assess the effect of irradiation on non-nutrient bioactives such as flavonoids and phenolics, where data were available. It was concluded in that review that phytosanitary doses of irradiation do not cause diminution of these compounds in fruit.

5.3 Dietary intake assessment conclusions

The focus of the dietary intake assessment was on vitamin C and β-carotene, consistent with the nutrition risk assessment and previous FSANZ 2014 review.

It was determined that a detailed dietary intake assessment was not required for these nutrients to assess potential decreases in population nutrient intakes or the proportion of the Australian and New Zealand populations with inadequate intakes. This was for a number of reasons including the contribution of fruit and vegetables to dietary intake of these nutrients; the changes in nutrient content post-irradiation; and the proportion of commodities potentially treated by irradiation, amongst others (see dot points at Section 5.2). Reasons are similar to those associated with the 2014 FSANZ assessment.

The nutrient content of the vegetables examined in this assessment post-irradiation, in combination with an evaluation of nutrient losses in other fruit and vegetables in previous FSANZ assessments, indicates that there would be little impact on dietary intakes from consuming irradiated produce. Where any small losses in nutrient content were identified in the nutrition risk assessment, the commodities in question made minor contributions to nutrient intakes. Therefore, any impact of nutrient losses due to irradiation on population nutrient intakes would be minimal.

Nutrient concentrations in fruit and vegetables vary naturally (e.g. between cultivars and by season) and can be decreased by storage, cooking and processing and these differences and losses usually exceed any changes caused by irradiation. To take account of these variations and losses when estimating population intakes of nutrients, food composition databases are based on nutrient analysis of foods that are cooked, processed, stored, from different seasons, and are composites of cultivars. In general, these factors do not affect population intakes of nutrients because they do not change from year to year. In the case of introducing irradiation this is not the case, therefore, the nutritional risk assessment has relied on evaluating the extent to which irradiation may alter population intakes.

There will only be a small proportion of both imported and domestically produced fruit and vegetables in Australia and New Zealand treated by irradiation, with some commodities not requiring irradiation due to localised consumption and technological reasons. There may be some variation by state in Australia. Therefore the dietary intake of nutrients is likely to come from a mix of non-irradiated and a small amount of irradiated produce over the course of a lifetime. This also minimises any impact on population nutrient intakes from consuming

irradiated produce.

There is a small proportion of the Australian and New Zealand populations currently with inadequate intakes of vitamin C (up to 5.5%) and a slightly higher proportion for vitamin A (as RE) (up to 37.5%, noting that both carotene and retinol sources contribute to vitamin A intakes). However, as the losses in nutrient content in fruit and vegetables due to irradiation are small and are for commodities that only contribute a small amount to total dietary intakes, and that only a small proportion of fruit and vegetables would be treated, the use of irradiation as a phytosanitary measure is unlikely to exacerbate this situation in either population.

There is a large proportion of the contribution to vitamin C and β-carotene intakes from commodities that have nutrient impact data (55-85% across fruit and vegetables for Australia and New Zealand), and there are data for the most commonly consumed commodities (particularly where they contribute highly to nutrient intakes). Therefore, FSANZ's conclusions that irradiation of fruit and vegetables would have minimal impact on population nutrient intakes can be extrapolated to all fruit and vegetables, including those where no nutrient impact data are available.

6 Risk characterisation

Phytosanitary irradiation of fruit and vegetables at the dose range of 0.15 – 1 kGy is an internationally accepted method for the control of fruit fly and other insect pests for quarantine purposes.

There are no significant toxic hazards associated with the formation of radiolytic compounds in irradiated fruit and vegetables. Fruit and vegetables have a low lipid content meaning that there is a low potential to generate 2-ACBs. The formation of furans resulting from irradiation of fresh fruit and vegetables is not of toxicological concern and will have minimal impact on total dietary exposures to furan.

Phytosanitary irradiation does not affect the macronutrient or mineral content of fruit and vegetables. A small number of vitamins are sensitive to irradiation, of which vitamin C and β-carotene are most relevant, and to a lesser extent vitamin E, for fruit and vegetables.

Vitamin C concentration was not depleted in the majority of fruit and vegetables, with a few notable exceptions. β-Carotene levels were not affected in fruit, fruiting vegetables and cucurbits, and the overall loss in leafy vegetables, roots and tubers was small. Irradiation did not affect vitamin E levels in one vegetable however no other data were available. Therefore the effects of irradiation on vitamin E levels in fruit and vegetables is uncertain. FSANZ considers that based on the available evidence the effect of irradiation on the nutritional quality of fruit and vegetables is likely to be low. Where nutrient losses due to irradiation were found in specific commodities, these contributed only small amounts to total dietary intakes. Therefore, the impact on population nutrient intakes would be minimal.

Only a small proportion of imported and domestically produced fruit and vegetables are to be irradiated for phytosanitary purposes. FSANZ concludes that there are no public health and safety concerns associated with the consumption of fresh fruit and vegetables which have been irradiated at doses of up to 1 kGy.

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Appendix 1: Update of FSANZ 2014 review

FSANZ previously reviewed the impact of phytosanitary irradiation on the nutritional content of several fruits, cucurbit and fruiting vegetables (FSANZ 2014). The majority of studies investigated the effects of irradiation on vitamin C content with some studies investigating the effect on β-carotene levels. The review noted that phytosanitary doses of irradiation did not decrease vitamin C levels in the majority of fruit and vegetables and had little effect on other non-vitamin bioactive compounds. The review also noted that irradiation did not affect the carotene content of fruit and vegetables.

As part of the current assessment, a literature search was conducted in Pubmed and EBSCO Discovery Service on 13 July 2020 to identify additional studies that may have been published since the FSANZ (2014) review using search terms described in Appendix 3. Twenty relevant studies were identified.

Tomato
Mendes (2020) evaluated the effect of up to 1 kGy gamma irradiation on the physicochemical properties of cherry tomatoes stored at room temperature during maturation for up to 28 days compared to non-irradiated samples. An increase of total carotenoids was observed as the irradiation dose increased. Following a 1 kGy irradiation dose, AA content was higher or similar to controls during the 28 day storage period and total carotenoid content was higher in irradiated samples.

Loro et al. (2018) investigated the effects of irradiation of up to 1.5 kGy on long life tomatoes (*Lycopersicon esculentum* Mill.) stored at 22° C for up to 21 days. AA content was similar in irradiated and control samples at each storage period.

Chilli
Chitravathi et al. (2020) reported that gamma irradiation of green chillies at doses of up to 0.5 kGy in combination with MAP caused a smaller loss of AA and carotenoids compared to untreated samples during storage of 14 – 42 days at 8° C.

Pumpkin
A study of the effect of 1 kGy irradiation on ready-to-cook pumpkin stored for 21 days at 10° C found that samples had lower vitamin C content compared to non-irradiated controls immediately following irradiation and during 14 days storage, however at 21 days irradiated samples had higher concentration than controls. Compared to control samples, β-carotene concentrations were stable immediately following irradiation, but were lower during the storage period (Tripathi et al. 2014).

Citrus
Jo et al. (2018) reported that, at doses of 0.5 and 1 kGy, vitamin C and total phenolic content of irradiated navel oranges was similar to non-irradiated controls.

Noh et al. (2016a, 2016b) reported that, following 1 kGy X-ray irradiation of navel oranges, vitamin C content was decreased immediately following irradiation but was higher than controls at most time points during a 12 day storage period at 20° C, but was lower at each time point compared to controls when stored at 3° C.

Two studies investigated the effects of low dose electron beam irradiation up to 1 kGy on navel oranges and noted a reduction in vitamin C content during storage in control samples and a greater reduction in irradiated samples compared to controls at most time points when stored at 20° C for 12 days (Cho et al. 2015a) or at 3° C for 45 days (Cho et al. 2015b).

Ornelas-Paz (2017) studied the effect of up to 1 kGy irradiation on seedless Kishu mandarins. AA concentration was higher in all irradiated samples compared to controls two days after irradiation, however concentrations were lower than controls when stored for 21 and 28 days at 6° C. Conversely, β-carotene content decreased compared to controls two days after irradiation in a dose-dependent manner however following 3 weeks of storage at 6° C, β-carotene levels were higher than controls at all doses.

Nam et al. (2019) found that irradiation of mandarin oranges with doses of 0.4 and 1 kGy followed by storage of up to 15 days did not affect AA or total phenolic content.

Zhang et al. (2014) found that irradiation up to 0.4 kGy followed by storage of up to 30 days at 4° C did not result in differences in AA content compared to controls but was lower than controls when stored for 30 days or when irradiated with 0.5 – 0.6 kGy and stored for 15 – 30 days.

Jo et al. (2018) reported that vitamin C concentration was stable following irradiation at doses of 0.4 or 1 kGy in two varieties of Korean citrus fruits (Jinjihyang and Chunggyun) stored for up to 20 days at 4° C.

Strawberry
Maraei and Elsawy (2017) reported that doses of up to 0.9 kGy gamma irradiation in strawberries followed by storage for 9 days at 10° C resulted in a decrease in AA concentration compared to controls, but did not affect total phenolic content.

Serapian and Prakash (2016) compared the effects of methyl bromide fumigation and phytosanitary irradiation of 400 Gy on the quality of fresh strawberries and reported that AA content was unchanged due to either treatments.

Filho et al. (2018) reported a decrease in AA content in strawberries irradiated with 1 kGy compared to controls.

Blueberry
Wang and Meng (2016) reported that blueberries irradiated with 1 kGy had lower vitamin C content compared to controls immediately following irradiation. However irradiated samples had higher vitamin C concentrations at all measured time points during the 35 day storage period at 0 ± 0.5^{o} C.

Guava
Zhao et al. (2014) reported that low-dose irradiation up to 600 Gy did not reduce vitamin C levels in guava fruit following storage at 1, 3 and 7 days.

Apple
Fante et al. (2015) reported that AA content of Eva apples was similar to or higher than controls when irradiated with up to 1 kGy and stored for 45 – 90 days but some losses were observed when stored for 135 days post-irradiation. Phenolic compound levels varied compared to controls at different storage times.

Pineapple
Jenjob et al. (2017) found that gamma irradiation of 400 Gy in Pattavia pineapple followed by storage of up to 14 days at 13^{o} C and 90% RH did not affect the AA or total phenolic content.

The recent evidence summarised above indicates that in general vitamin C and AA content is maintained in a variety of fruit and vegetables following irradiation at doses of up to 1 kGy. In addition, no consistent effect of irradiation on carotenes was observed. Therefore FSANZ maintains the conclusion that irradiation at doses of up to 1 kGy does not adversely affect

nutrient composition of fruit and vegetables.

Appendix 2: Contribution of food groups to nutrient intakes for Australia and New Zealand

Details of contribution of nutrients to vitamin intakes at the major food group level and fruit and vegetable sub-group level are provided in the tables; Table A2.1 for vitamin C, Table A2.2 β-carotene, Table A2.3 retinol equivalents (RE), Table A2.4 retinol, Table A2.5 thiamin, Table A2.6 vitamin E, Table A2.7 natural folate and Table A2.8 dietary folate equivalents (DFE).

Also in this appendix is information related to the contribution to nutrient intakes of vitamin C and β-carotene from commodities where data are available on the impact of irradiation on nutrient content (Table A2.9). The proportion of consumers for commodities that are the most commonly consumed within each fruit or vegetable sub-group are also presented (Table A2.10).

The national nutrition survey data used for these assessments were:

- The 2011-12 Australian National Nutrition and Physical Activity Survey (2011-12 NNPAS) (ABS 2014a and 2014b)
- The 2002 New Zealand National Children's Nutrition Survey (2002 NZ CNS) (Ministry of Health 2003; Ministry of Health 2005)
- The 2008-09 New Zealand Adult Nutrition Survey (2008 NZ ANS) (Ministry of Health 2011a; Ministry of Health 2011b).

The design of each of these surveys varies somewhat and key attributes of each are set out below. Further information is available on the FSANZ website on the national nutrition surveys used to conduct dietary exposure assessments.

The contribution of foods to nutrient intakes presented in this Appendix were obtained from both published sources and from FSANZ's dietary exposure assessment computer program Harvest. The majority of the contribution data for Australia came from the published reports from the 2011-12 NNPAS (ABS 2014a), however the data for β-carotene and retinol were from Harvest. All data for New Zealand were extracted from Harvest. All results are based on day 1 food consumption data only from each of the nutrition surveys. The data exclude any contribution to nutrient intakes from dietary supplements.

2011–12 Australian National Nutrition and Physical Activity Survey (2011-12 NNPAS)

The 2011–12 Australian National Nutrition and Physical Activity Survey (2011-12 NNPAS), undertaken by the Australian Bureau of Statistics (ABS) as part of the 2011-13 Australian Health Survey, is the most recent food consumption data for Australia. This survey includes food consumption data from a sample of 12,153 Australians aged from 2 years and above. The survey used a 24-hour recall method for all respondents, with 64% of respondents (n=7,735) also completing a second 24-hour recall on a second, non-consecutive day. The data were collected from May 2011 to June 2012 (with no enumeration between August and September 2011 due to the Census). Consumption and respondent data from the survey were incorporated into the Harvest program from the Confidentialised Unit Record Files (CURF) dataset (ABS 2014). These data were weighted during the calculations undertaken in Harvest.

2002 New Zealand National Children's Nutrition Survey (2002 NZ CNS)

The 2002 NZ CNS was a cross-sectional and nationally representative survey of 3,275 New Zealand children aged 5–14 years. The data were collected during the school year from February to December 2002. The survey used a 24-hour food recall and provided information on food and nutrient intakes, eating patterns, frequently eaten foods, physical activity patterns, dental health, anthropometric measures and nutrition-related clinical measures. It was also the first children's nutrition survey in New Zealand to include a second day diet recall data for about 15% of the respondents, and dietary intake from both foods (including beverages) and dietary supplements. These data were weighted during the calculations undertaken in Harvest.

2008-09 New Zealand Adult Nutrition Survey (2008 NZ ANS)

The 2008 NZ ANS provides comprehensive information on food consumption for a sample of 4,721 respondents aged 15 years and above. The survey was conducted on a stratified sample over a 12-month period from October 2008 to October 2009. The survey used a 24-hour recall methodology with 25% of respondents also completing a second 24-hour recall. The information collected in the 2008 NZ ANS included food and nutrient intakes, dietary supplement use, socio-demographics, nutrition related health, and anthropometric measures. These data were weighted during the calculations undertaken in Harvest.

Table A2.1: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of vitamin C

Major food group *Sub-group*	Contribution (%)**		
	Australia* 2 years and above	**New Zealand* 5-14 years**	**New Zealand* 15 years and above**
Non-alcoholic beverages	31.9	35.8	25.2
Cereals and cereal products	1.2	2.6	4.2
Cereal based products and dishes	6.2	0.6	0.6
Fats and oils	0	0	0
Fish and seafood products and dishes	0.4	0.1	0.3
Fruit products and dishes*	23.1	24.3	24.2
Berry fruit	*1.7*	*0.5*	*1.0*
Citrus fruit	*10.8*	*13.2*	*8.3*
Dried fruit, preserved fruit	*0.04*	*0.2*	*0.03*
Mixed dishes where fruit is the major component	*0.04*	*NR*	*NR*
Mixtures of two or more groups of fruit	*1.0*	*0.3*	*0.9*
Other fruit	*2.7*	*3.2*	*0.05*
Pome fruit	*2.2*	*4.5*	*3.0*
Stone fruit	*1.4*	*0.4*	*0.9*
Tropical and subtropical fruit	*3.2*	*2.1*	*10.0*
Egg products and dishes	0.1	0.0	0.03
Meat, poultry and game products and dishes	3.5	1.4	2.8
Milk products and dishes	0.7	2.5	0.7
Dairy & meat substitutes	0.1	NR	0
Soup	1.7	0.5	1.0
Seed and nut products and dishes	0.1	0.2	0.04
Sauces, dips and condiments	0.4	0.6	1.0
Vegetable products and dishes#	25.1	19.3	38.9
Potatoes	*4.5*	*8.7*	*11.0*
Cabbage, cauliflower and similar Brassicas	*3.4*	*3.5*	*7.3*
Carrot and similar root vegetables	*1.6*	*0.9*	*1.3*
Leaf and stalk vegetables	*0.8*	*0.7*	*1.9*
Peas and beans	*0.9*	*1.0*	*0.9*
Tomato and tomato products	*2.3*	*1.9*	*5.5*
Other fruiting vegetables	*3.2*	*1.0*	*5.1*
Other vegetables and vegetable combinations	*3.2*	*0.8*	*2.6*
Dishes where vegetable is the major component	*5.3*	*0.9*	*3.3*
Legume and pulse products and dishes	0.3	0.1	0.2
Snack foods	0.8	0.1	0.04
Sugar products and dishes	0.1	0.1	0.2
Confectionery and cereal/nut/fruit/seed bars	0.4	0.6	0.2
Alcoholic beverages	3.3	0.0	0.1
Special dietary foods	0.4	10.8	0.2

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.2: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of β-carotene equivalents

Major food group *Sub-group*	Contribution (%)**		
	*Australia 2 years and above	New Zealand* 5-14 years	New Zealand* 15 years and above
Non-alcoholic beverages	4.1	2.5	2.4
Cereals and cereal products	0.4	5.9	7.9
Cereal based products and dishes	8.8	2.4	2.2
Fats and oils	0.6	0.8	1.7
Fish and seafood products and dishes	0.8	0.2	0.3
Fruit products and dishes	8.5	7.9	6.8
Berry fruit	0.04	0.02	0.1
Citrus fruit	0.4	1.6	0.7
Dried fruit, preserved fruit	0.3	0.8	0.1
Mixed dishes where fruit is the major component	0.02	NR	NR
Mixtures of two or more groups of fruit	0.6	0.7	0.2
Other fruit	1.5	0.9	0.02
Pome fruit	0.2	1.5	0.6
Stone fruit	0.7	1.4	3.1
Tropical and subtropical fruit	4.7	1.1	1.9
Egg products and dishes	0.4	0.3	0.3
Meat, poultry and game products and dishes	8.1	3.4	6.5
Milk products and dishes	2.7	3.9	2.7
Dairy & meat substitutes	0.2	NR	0.0
Soup	8.2	4.0	5.4
Seed and nut products and dishes	0.03	0.2	0.03
Sauces, dips and condiments	0.8	1.2	2.2
Vegetable products and dishes#	55.1	64.2	60.2
Potatoes	*0.1*	*0.9*	*0.6*
Cabbage, cauliflower and similar Brassicas	*0.4*	*0.6*	*1.8*
Carrot and similar root vegetables	*32.1*	*41.8*	*28.4*
Leaf and stalk vegetables	*2.2*	*4.1*	*7.4*
Peas and beans	*0.6*	*1.2*	*1.0*
Tomato and tomato products	*0.9*	*2.8*	*5.0*
Other fruiting vegetables	*1.9*	*0.8*	*2.7*
Other vegetables and vegetable combinations	*8.6*	*9.3*	*7.1*
Dishes where vegetable is the major component	*8.4*	*2.7*	*6.3*
Legume and pulse products and dishes	0.9	0.4	0.6
Snack foods	0.3	0.8	0.4
Sugar products and dishes	0.03	0.4	0.2
Confectionery and cereal/nut/fruit/seed bars	0.2	0.2	0.04
Alcoholic beverages	0.01	0	0.01
Special dietary foods	0.02	0.8	0.04

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.3: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of retinol equivalents (RE)

Major food group *Sub-group*	Contribution (%)**		
	Australia 2 years and above	**New Zealand* 5-14 years**	**New Zealand* 15 years and above**
Non-alcoholic beverages	4.8	3.3	2.4
Cereals and cereal products	0.9	8.7	8.8
Cereal based products and dishes	10.4	7.1	4.8
Fats and oils	5.1	6.7	8.9
Fish and seafood products and dishes	1.0	1.6	1.7
Fruit products and dishes	5.3	3.8	3.7
Berry fruit	*0.02*	*0.01*	*0.1*
Citrus fruit	*0.3*	*0.8*	*0.4*
Dried fruit, preserved fruit	*0.2*	*0.4*	*0.1*
Mixed dishes where fruit is the major component	*0.04*	*NR*	*NR*
Mixtures of two or more groups of fruit	*0.3*	*0.3*	*0.1*
Other fruit	*0.9*	*0.4*	*0*
Pome fruit	*0.1*	*0.7*	*0.3*
Stone fruit	*0.5*	*0.7*	*1.7*
Tropical and subtropical fruit	*2.9*	*0.5*	*1.0*
Egg products and dishes	2.2	3.1	4.5
Meat, poultry and game products and dishes	10.6	4.5	12.1
Milk products and dishes	15.7	21.2	12.3
Dairy & meat substitutes	0.5	NR	0.1
Soup	5.4	2.1	3.1
Seed and nut products and dishes	0.02	0.1	0.02
Sauces, dips and condiments	0.9	1.3	1.8
Vegetable products and dishes[#]	34.9	32.8	33.6
Potatoes	*0.4*	*2.2*	*1.0*
Cabbage, cauliflower and similar Brassicas	*0.3*	*0.4*	*1.0*
Carrot and similar root vegetables	*19.8*	*20.1*	*15.4*
Leaf and stalk vegetables	*1.3*	*2.0*	*4.0*
Peas and beans	*0.4*	*0.6*	*0.5*
Tomato and tomato products	*0.6*	*1.3*	*2.8*
Other fruiting vegetables	*1.2*	*0.4*	*1.5*
Other vegetables and vegetable combinations	*5.3*	*4.5*	*3.8*
Dishes where vegetable is the major component	*5.6*	*1.4*	*3.6*
Legume and pulse products and dishes	0.5	0.2	0.3
Snack foods	0.2	0.4	0.2
Sugar products and dishes	0.1	0.8	0.5
Confectionery and cereal/nut/fruit/seed bars	0.6	0.1	0.1
Alcoholic beverages	0.1	0	0.1
Special dietary foods	0.8	1.1	0.3

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

[#] Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.4: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of retinol

Major food group *Sub-group*	Contribution (%)**		
	Australia* 2 years and above	**New Zealand* 5-14 years**	**New Zealand* 15 years and above**
Non-alcoholic beverages	6.1	4.0	2.4
Cereals and cereal products	1.7	11.2	9.9
Cereal based products and dishes	12.9	11.3	7.9
Fats and oils	12.3	12.2	17.4
Fish and seafood products and dishes	1.3	2.9	3.4
Fruit products and dishes	0.1	0.02	0.01
Berry fruit	*0*	*0*	*0*
Citrus fruit	*0*	*0*	*0*
Dried fruit, preserved fruit	*0*	*0*	*0*
Mixed dishes where fruit is the major component	*0.1*	*NR*	*NR*
Mixtures of two or more groups of fruit	*0*	*0*	*0*
Other fruit	*0*	*0*	*0*
Pome fruit	*0*	*0.02*	*0*
Stone fruit	*0*	*0*	*0*
Tropical and subtropical fruit	*0*	*0*	*0.01*
Egg products and dishes	5.2	5.6	9.4
Meat, poultry and game products and dishes	14.7	5.5	18.7
Milk products and dishes	36.8	37.0	23.5
Dairy & meat substitutes	0.9	NR	0.3
Soup	0.9	0.4	0.3
Seed and nut products and dishes	0.0	0.0	0
Sauces, dips and condiments	1.0	1.4	1.4
Vegetable products and dishes[#]	2.3	3.8	2.3
Potatoes	*1.0*	*3.4*	*1.4*
Cabbage, cauliflower and similar Brassicas	*0.02*	*0.2*	*0.1*
Carrot and similar root vegetables	*0.01*	*0.01*	*0.1*
Leaf and stalk vegetables	*0.01*	*0*	*0.01*
Peas and beans	*0.01*	*0*	*0.03*
Tomato and tomato products	*0.01*	*0.01*	*0.1*
Other fruiting vegetables	*0.03*	*0.03*	*0.1*
Other vegetables and vegetable combinations	*0.02*	*0.1*	*0.0*
Dishes where vegetable is the major component	*1.2*	*0.1*	*0.4*
Legume and pulse products and dishes	0.01	0.04	0.02
Snack foods	0.2	0.0	0.0
Sugar products and dishes	0.1	1.3	1.0
Confectionery and cereal/nut/fruit/seed bars	1.3	0.1	0.2
Alcoholic beverages	0.2	0	0.1
Special dietary foods	2.0	1.5	0.5

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

[#] Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.5: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of thiamin

Major food group *Sub-group*	Contribution (%)**		
	Australia 2 years and above	**New Zealand* 5-14 years**	**New Zealand* 15 years and above**
Non-alcoholic beverages	3.4	3.7	2.7
Cereals and cereal products	40.7	51.9	49.6
Cereal based products and dishes	11.5	4.0	3.7
Fats and oils	0.0	0.01	0.1
Fish and seafood products and dishes	1.0	0.5	1.3
Fruit products and dishes	2.9	2.8	2.9
Berry fruit	*0.1*	*0.01*	*0.2*
Citrus fruit	*1.1*	*0.9*	*0.6*
Dried fruit, preserved fruit	*0.2*	*0.1*	*0.2*
Mixed dishes where fruit is the major component	*0.02*	*NR*	*NR*
Mixtures of two or more groups of fruit	*0.1*	*0.1*	*0.1*
Other fruit	*0.2*	*0.1*	*0*
Pome fruit	*0.7*	*0.9*	*0.6*
Stone fruit	*0.1*	*0.05*	*0.1*
Tropical and subtropical fruit	*0.4*	*0.6*	*1.2*
Egg products and dishes	0.6	0.4	0.8
Meat, poultry and game products and dishes	11.4	7.1	11.2
Milk products and dishes	2.7	6.4	6.4
Dairy & meat substitutes	0.3	NR	0.2
Soup	2.9	0.3	0.7
Seed and nut products and dishes	1.3	0.4	0.9
Sauces, dips and condiments	0.4	4.8	6.8
Vegetable products and dishes[#]	6.2	8.2	9.4
Potatoes	*2.2*	*5.7*	*4.4*
Cabbage, cauliflower and similar Brassicas	*0.4*	*0.3*	*0.7*
Carrot and similar root vegetables	*0.4*	*0.3*	*0.5*
Leaf and stalk vegetables	*0.2*	*0.1*	*0.3*
Peas and beans	*0.4*	*0.8*	*0.8*
Tomato and tomato products	*0.2*	*0.2*	*0.5*
Other fruiting vegetables	*0.7*	*0.2*	*0.6*
Other vegetables and vegetable combinations	*0.6*	*0.4*	*0.8*
Dishes where vegetable is the major component	*1.1*	*0.2*	*0.8*
Legume and pulse products and dishes	0.4	0.3	0.6
Snack foods	0.5	1.1	0.5
Sugar products and dishes	0	0.4	0.4
Confectionery and cereal/nut/fruit/seed bars	0.8	0.7	0.5
Alcoholic beverages	0.2	0	0.8
Special dietary foods	1.0	6.6	0.3
Miscellaneous (yeast extracts)	11.7	4.3	6.1

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

[#] Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.6: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of vitamin E

Major food group *Sub-group*	Contribution (%)**		
	Australia 2 years and above	**New Zealand* 5-14 years**	**New Zealand* 15 years and above**
Non-alcoholic beverages	2.5	1.9	3.9
Cereals and cereal products	11.1	12.9	15.8
Cereal based products and dishes	19.1	12.1	7.0
Fats and oils	5.0	9.9	15.7
Fish and seafood products and dishes	5.0	1.7	4.3
Fruit products and dishes	5.1	7.7	6.9
Berry fruit	*0.2*	*0.1*	*0.3*
Citrus fruit	*0.4*	*1.5*	*0.7*
Dried fruit, preserved fruit	*0.4*	*0.4*	*0.2*
Mixed dishes where fruit is the major component	*0.1*	*NR*	*NR*
Mixtures of two or more groups of fruit	*0.2*	*0.1*	*0.1*
Other fruit	*0.4*	*1.1*	*0.01*
Pome fruit	*1.5*	*3.1*	*1.2*
Stone fruit	*1.0*	*0.8*	*1.2*
Tropical and subtropical fruit	*1.0*	*0.6*	*3.2*
Egg products and dishes	4.4	1.5	3.4
Meat, poultry and game products and dishes	14.1	9.0	9.3
Milk products and dishes	3.2	4.5	2.4
Dairy & meat substitutes	0.7	NR	0.3
Soup	1.9	0.9	1.1
Seed and nut products and dishes	5.4	3.2	3.5
Sauces, dips and condiments	6.1	5.1	4.2
Vegetable products and dishes[#]	10.0	16.4	17.4
Potatoes	*2.1*	*9.8*	*6.4*
Cabbage, cauliflower and similar Brassicas	*0.5*	*0.2*	*1.3*
Carrot and similar root vegetables	*1.0*	*1.9*	*2.3*
Leaf and stalk vegetables	*0.3*	*0.8*	*1.2*
Peas and beans	*0.1*	*0.5*	*0.2*
Tomato and tomato products	*0.6*	*1.3*	*2.4*
Other fruiting vegetables	*1.6*	*0.4*	*1.2*
Other vegetables and vegetable combinations	*0.7*	*0.6*	*0.9*
Dishes where vegetable is the major component	*3.2*	*0.9*	*1.5*
Legume and pulse products and dishes	0.4	0.6	0.5
Snack foods	2.9	4.5	1.1
Sugar products and dishes	0.1	1.3	1.2
Confectionery and cereal/nut/fruit/seed bars	1.8	1.2	0.7
Alcoholic beverages	0	0	0
Special dietary foods	1.0	5.0	0.5

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

[#] Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.7: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of natural folate

Major food group *Sub-group*	Contribution (%)**		
	Australia 2 years and above	New Zealand* 5-14 years	New Zealand* 15 years and above
Non-alcoholic beverages	16.8	NR	6.1
Cereals and cereal products	10.6	NR	23.3
Cereal based products and dishes	12.1	NR	4.1
Fats and oils	0.1	NR	0.1
Fish and seafood products and dishes	0.9	NR	2.3
Fruit products and dishes	8.9	NR	7.3
Berry fruit	0.5	NR	0.2
Citrus fruit	1.6	NR	3.5
Dried fruit, preserved fruit	0.1	NR	0.1
Mixed dishes where fruit is the major component	0.02	NR	NR
Mixtures of two or more groups of fruit	0.4	NR	0.1
Other fruit	0.4	NR	0.01
Pome fruit	2.2	NR	0.6
Stone fruit	0.01	NR	0.2
Tropical and subtropical fruit	3.7	NR	2.6
Egg products and dishes	3.9	NR	6.0
Meat, poultry and game products and dishes	6.9	NR	5.8
Milk products and dishes	13.8	NR	9.6
Dairy & meat substitutes	0.5	NR	1.1
Soup	1.6	NR	1.0
Seed and nut products and dishes	1.4	NR	1.4
Sauces, dips and condiments	0.9	NR	4.8
Vegetable products and dishes[#]	17.1	NR	17.5
Potatoes	2.9	NR	6.4
Cabbage, cauliflower and similar Brassicas	3.3	NR	2.6
Carrot and similar root vegetables	1.1	NR	0.8
Leaf and stalk vegetables	1.2	NR	3.2
Peas and beans	1.1	NR	1.4
Tomato and tomato products	0.7	NR	1.4
Other fruiting vegetables	1.8	NR	2.3
Other vegetables and vegetable combinations	1.8	NR	1.9
Dishes where vegetable is the major component	3.3	NR	2.1
Legume and pulse products and dishes	1.3	NR	1.9
Snack foods	1.0	NR	0.6
Sugar products and dishes	0.1	NR	0.5
Confectionery and cereal/nut/fruit/seed bars	1.0	NR	0.5
Alcoholic beverages	0.3	NR	0.9
Special dietary foods	0.3	NR	0.1

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

[#] Two categories for New Zealand data were combined which were ‘vegetables’ and ‘potatoes, kumara and taro’.

Table A2.8: Major food group contributions, and contributions of specific fruits and vegetables to dietary intakes of dietary folate equivalents

Major food group Sub-group	Contribution (%)**		
	Australia 2 years and above	New Zealand^ 5-14 years	New Zealand* 15 years and above
Non-alcoholic beverages	8.3	4.6	4.6
Cereals and cereal products	46.5	49.1	39.1
Cereal based products and dishes	10.5	3.9	3.0
Fats and oils	0	0	0
Fish and seafood products and dishes	0.6	0.8	1.7
Fruit products and dishes	4.1	5.5	5.5
Berry fruit	0.2	0.1	0.2
Citrus fruit	0.7	3.0	2.6
Dried fruit, preserved fruit	0.05	0.1	0.1
Mixed dishes where fruit is the major component	0.01	NR	NR
Mixtures of two or more groups of fruit	0.2	0.1	0.1
Other fruit	0.2	0.2	0.01
Pome fruit	1.0	0.9	0.5
Stone fruit	0.01	0.1	0.2
Tropical and subtropical fruit	1.7	0.9	1.9
Egg products and dishes	1.8	1.3	4.5
Meat, poultry and game products and dishes	4.1	4.5	4.3
Milk products and dishes	6.3	5.7	7.1
Dairy & meat substitutes	0.3	0	0.5
Soup	0.7	0.5	0.7
Seed and nut products and dishes	0.6	1.9	1.1
Sauces, dips and condiments	0.4	5.6	6.5
Vegetable products and dishes#	7.9	8.5	13.0
Potatoes	1.3	6.0	4.8
Cabbage, cauliflower and similar Brassicas	1.5	1.6	1.9
Carrot and similar root vegetables	0.5	0.2	0.5
Leaf and stalk vegetables	0.5	1.0	2.4
Peas and beans	0.5	1.8	1.1
Tomato and tomato products	0.3	0.6	1.0
Other fruiting vegetables	0.8	0.6	1.7
Other vegetables and vegetable combinations	0.8	0.9	1.4
Dishes where vegetable is the major component	1.6	0.6	1.6
Legume and pulse products and dishes	0.6	0.9	1.4
Snack foods	0.4	1.5	0.4
Sugar products and dishes	0.1	0.4	0.4
Confectionery and cereal/nut/fruit/seed bars	0.7	1.4	0.6
Alcoholic beverages	0.1	0	0.7
Special dietary foods	0.6	0.9	0.6

NR: Not reported.

* Extracted from Harvest.

** Data are presented on an all respondents basis and data for day 1 are presented for all surveys.

Two categories for New Zealand data were combined which were 'vegetables' and 'potatoes, kumara and taro'.

^ Expressed as '*Total folates, equated*' in the 2002 New Zealand children survey; extracted values from the Harvest.

Table A2.9: Amount of contribution of vitamin C and beta carotene to commodities with nutrition impact data for irradiation

Categories of fruit and vegetables*	Commodities for which nutrient impact data was available for Vitamin C	Vitamin C % contribution			Commodities for which nutrient impact data was available for β-carotene	β- carotene % contribution			Project in which the data was considered
		Australia 2+ years	New Zealand 5-14 years	New Zealand 15+years		Australia 2+ years	New Zealand 5-14 years	New Zealand 15+years	
Vegetables									
Potatoes	Potatoes	4.49	8.2	9.24	ND	NA	NA	NA	A1193
Cabbage, cauliflower and similar Brassicas	Cabbage	0.36	0.64	0.78	ND	NA	NA	NA	A1193
	Cauliflower, broccoli	2.68	2.69	6.15	ND	NA	NA	NA	A1193
Carrot and similar root vegetables	Carrot	0.42	0.58	0.41	Carrot	24.42	37.2	19.01	A1193
	Sweet potato	1.05	0.4	1.56	Sweet potato or kumara	7.62	0.08	0.19	A1193
Leaf and stalk vegetables	Field rocket	0.01	0	0.003	Field rocket	0.17	0	0.05	A1193
	Spinach	0.19	0.09	0.4	Spinach	0.63	0.74	2.08	A1193
	Fenugreek	0	0	0	Fenugreek	0	0	0	A1193
	Endive	0	0	0		0	0	0	A1193
	Lettuce - iceberg, non-defined variety, red-leaf, romaine	0.35	0.28	0.56		0.82	0.28	0.62	A1193
Tomato and tomato products	Tomato	2.30	1.90	5.53	Tomato	0.91	2.77	5.03	A1069, FSANZ 2014 review
Other fruiting vegetables	Capsicum	1.65	0.62	4.13	Capsicum	0.42	0.22	1.56	A1069, A1092, FSANZ 2014 review
	Corn	0.21	0.26	0.14	Corn	0.11	0.37	0.12	A1069, A1092, FSANZ 2014 review
Other vegetables and vegetable combinations	Zucchini (courgette)	0.25	0	0	Zucchini	0.11	0.17	0.47	A1092, FSANZ 2014 review
	Cucumber	0.27	0.08	0.23	Cucumber	0.18	0.02	0.04	A1092, FSANZ 2014 review
Mixtures of 2 or more vegetables		2.97	0.67	1.99	Mixtures of 2 or more vegetables	8.51	9.31	6.97	

Categories of fruit and vegetables*	Commodities for which nutrient impact data was available for Vitamin C	Vitamin C % contribution			Commodities for which nutrient impact data was available for β-carotene	β- carotene % contribution			Project in which the data was considered
		Australia 2+ years	New Zealand 5-14 years	New Zealand 15+years		Australia 2+ years	New Zealand 5-14 years	New Zealand 15+years	
Fruits									
Pome fruit	Apple	1.69	4.26	2.75	Apple	0.17	1.42	0.55	A1092, FSANZ 2014 review
Berry fruit	Strawberry, blueberry, raspberry	1.52	0.501	0.60	ND	NA	NA	NA	A1092, A1115, FSANZ 2014 review
Citrus fruit	Orange, blood orange	5.99	6.40	4.10	Orange	0.28	0.90	0.37	FSANZ 2014 review
	Grapefruit	0.15	0.14	0.12	Grapefruit	0.002	0	0	FSANZ 2014 review
	Lemon, lime	0.21	0.1	0.02	Lemons, lime	0	0.001	0.0002	FSANZ 2014 review
	Mandarin	4.38	6.48	3.88	Mandarin	0.13	0.62	0.24	FSANZ 2014 review
Stone fruit	Nectarine, peach	1.26	0.31	0.49	Nectarine, peach	0.55	1.05	1.14	A1092, FSANZ 2014 review
	Apricot, cherry, plum	0.18	0.08	0.39	Apricot, cherry, plum	0.19	0.36	1.99	A1092, FSANZ 2014 review
Tropical and subtropical fruit	Mango	1.47	0.07	0.07	Mango	4.13	0.17	0.13	FSANZ 2014 review
	Pineapple	0.23	0.26	0.29	Pineapple	0.01	0.03	0.02	FSANZ 2014 review
	Papaya	0.56	0	0.03	Papaya	0.28	0	0.02	FSANZ 2014 review
	Guava	0.01	0.08	0.04	Guava	0.0004	0.003	0.002	FSANZ 2014 review
	Litchi	0.08	0.004	0	Litchi	0	0	0	FSANZ 2014 review
	Custard apple	0.01	0	0.02	Custard apple	0.00003	0	0.0001	FSANZ 2014 review
Other fruit	Persimmon	0.02	0.09	0.04	Persimmon	0.05	0.55	0.16	FSANZ 2014 review
	Grape	0.19	0.02	0.33	Grape	0.13	0.02	0.05	FSANZ 2014 review
	Honeydew melon	0.01	0	0.01	Honeydew melon	0.001	0	0.0003	FSANZ 2014 review
	Rockmelon	0.85	0.04	0.08	Rockmelon	0.65	0.01	0.02	FSANZ 2014 review

ND: no data
NA: not applicable to include in the sum of contributions as no nutrient impact data available.
* Extracted from ABS 2014 Australian Health Survey: Users' Guide, 2011-13 — Food and Supplement Classification.

Table A2.10: Individual commodities with the highest proportion of consumers for fruit and vegetable sub-food categories and cross check if nutrient loss data is available

Food category	Sub-group	Commodity (% consumers)			Were nutrient loss data for this commodity available?	
		Australia 2 years and above	**New Zealand 5-14 years**	**New Zealand 15 years and above**	**Vitamin C**	**β-carotene**
Fruit	Berry fruit	Strawberry (3.9)	Strawberry (1.8)	Strawberry (1.6)	Yes	No
	Citrus fruit	Mandarin (7.8) Orange (6.8)	Orange (12.2) Mandarin (11.0)	Mandarin (7.3) Orange (7.1)	Yes	Yes (Orange only)
	Pome fruit	Apple (22.7)	Apple (31.9)	Apple (21.6)	Yes	Yes
	Stone fruit	Peach (3.7)	Peach (3.6)	Peach (4.8)	Yes	Yes
	Tropical and subtropical fruit	Banana (17.5)	Banana (18.3)	Banana (28.6)	No	No
Vegetables	Brassica vegetables	Broccoli (6.5)	Broccoli (8.6)	Broccoli (9.7)	Yes[1]	No
	Bulb vegetables	Onion (8.0)	Onion (13.7)	Onion (19.5)	No	No
	Fruiting vegetables	Tomato (18.4) Cucumber (6.1) Corn (4.5)	Tomato (9.5) Cucumber (7.8) Corn (5.2)	Tomato (19.5) Capsicum (6.7) Cucumber (5.5)	Yes	Yes
	Leafy vegetables	Lettuce (12.9)	Lettuce (11.3)	Lettuce (15.1)	Yes	No
	Root and tuber vegetables	Potatoes (31.4) Carrot (13.5)	Potato (52.0)* Carrot (20.9)	Potato (46.5)* Carrot (17.5)	Yes	Yes (Carrot only)
	Stalk and stem vegetables	Celery (0.9)	Celery (1.6)	Celery (2.3)	No	No

* Excludes potato crisps in this case.

Notes:
1. Three commodities with highest proportion of consumers in Brassicas are broccoli, cabbage and cauliflower, and vitamin C data are available for all of these.
2. Legumes were not included in the scope of the application.

Appendix 3: Search strategies

1. Search strategies for the effect of phytosanitary irradiation on Brassicas, leafy vegetables, and roots and tubers

PubMed portal
Database was searched on 14 January 2020 and 52 articles were identified. Search strategy included “vegetable name” AND “nutrient” AND “irradiation”.

#1	**Search:** ((((((((((((((((((("spinacia oleracea"[MeSH Terms] OR ("spinacia"[All Fields] AND "oleracea"[All Fields]) OR "spinacia oleracea"[All Fields] OR "spinach"[All Fields]) OR ("lettuce"[MeSH Terms] OR "lettuce"[All Fields])) OR rocket[All Fields]) OR ("brassica"[MeSH Terms] OR "brassica"[All Fields] OR "kale"[All Fields])) OR (("plant leaves"[MeSH Terms] OR ("plant"[All Fields] AND "leaves"[All Fields]) OR "plant leaves"[All Fields] OR "leaf"[All Fields]) AND ("vegetables"[MeSH Terms] OR "vegetables"[All Fields] OR "vegetable"[All Fields]))) OR ("daucus carota"[MeSH Terms] OR ("daucus"[All Fields] AND "carota"[All Fields]) OR "daucus carota"[All Fields] OR "carrot"[All Fields])) OR ("ipomoea batatas"[MeSH Terms] OR ("ipomoea"[All Fields] AND "batatas"[All Fields]) OR "ipomoea batatas"[All Fields] OR ("sweet"[All Fields] AND "potato"[All Fields]) OR "sweet potato"[All Fields])) OR ("solanum tuberosum"[MeSH Terms] OR ("solanum"[All Fields] AND "tuberosum"[All Fields]) OR "solanum tuberosum"[All Fields] OR "potato"[All Fields])) OR (("plant roots"[MeSH Terms] OR ("plant"[All Fields] AND "roots"[All Fields]) OR "plant roots"[All Fields] OR "root"[All Fields]) AND ("vegetables"[MeSH Terms] OR "vegetables"[All Fields] OR "vegetable"[All Fields]))) OR ("colocasia"[MeSH Terms] OR "colocasia"[All Fields] OR "taro"[All Fields])) OR yam[All Fields]) OR ("brassica napus"[MeSH Terms] OR ("brassica"[All Fields] AND "napus"[All Fields]) OR "brassica napus"[All Fields] OR "turnip"[All Fields])) OR ("raphanus"[MeSH Terms] OR "raphanus"[All Fields] OR "radish"[All Fields])) OR ("manihot"[MeSH Terms] OR "manihot"[All Fields] OR "cassava"[All Fields])) OR ("brassica"[MeSH Terms] OR "brassica"[All Fields] OR "broccoli"[All Fields])) OR ("brassica"[MeSH Terms] OR "brassica"[All Fields] OR "cabbage"[All Fields])) OR ("brassica"[MeSH Terms] OR "brassica"[All Fields] OR "cauliflower"[All Fields])) OR ("brassica"[MeSH Terms] OR "brassica"[All Fields]))
#2	**Search:** (((((((((ascorbate[All Fields] OR ("ascorbic acid"[MeSH Terms] OR ("ascorbic"[All Fields] AND "acid"[All Fields]) OR "ascorbic acid"[All Fields])) OR ascorbic[All Fields]) OR ("ascorbic acid"[MeSH Terms] OR ("ascorbic"[All Fields] AND "acid"[All Fields]) OR "ascorbic acid"[All Fields] OR "vitamin c"[All Fields])) OR ("carotenoids"[MeSH Terms] OR "carotenoids"[All Fields] OR "carotene"[All Fields])) OR ("carotenoids"[MeSH Terms] OR "carotenoids"[All Fields] OR "carotenoid"[All Fields])) OR ("vitamin a"[MeSH Terms] OR "vitamin a"[All Fields])) OR ("vitamin e"[MeSH Terms] OR "vitamin e"[All Fields])) OR ("tocopherols"[MeSH Terms] OR "tocopherols"[All Fields] OR "tocopherol"[All Fields])) OR ((thiamin) OR (thiamin)) OR (mononitrate, thiamin[MeSH Terms])
#3	**Search:** ("radiotherapy"[MeSH Terms] OR "radiotherapy"[All Fields] OR "irradiation"[All Fields])
#4	Search (#1) AND (#2) AND (#3)

EBSCO Discovery

Database was searched on 14 January 2020 and 85 articles were identified. Search strategy included “vegetable name” AND “nutrient” AND “irradiation”.

S1	**Search:** ((((((((((((((((((((spinach) OR lettuce) OR rocket) OR kale) OR leaf vegetable) OR carrot) OR sweet potato) OR potato) OR root vegetable) OR taro) OR yam) OR turnip) OR radish) OR cassava) OR broccoli) OR cabbage) OR cauliflower) OR brassica))
S2	**Search:** ((((((((((ascorbate) OR ascorbic acid) OR ascorbic) OR vitamin C) OR carotene) OR carotenoid) OR vitamin a) OR vitamin e) OR tocopherol) OR thiamine) OR thiamin))
S3	**Search:** irradiation
S4	Search (#1) AND (#2) AND (#3)
Limiters	Scholarly (Peer Reviewed) Journals; Publication Date: 19900101-20191231
Expanders	Also search within the full text of the articles; Apply equivalent subjects
Narrow by Subject	irradiation
Search modes	Find all my search terms

2. Search strategies for the update of the FSANZ 2014 Review

PubMed portal
Database was searched on 13 July 2020 using the search strategies as outlined in the 2014 review and limited by date since 2014. 16 articles were identified. The search strategy included “vegetable name” AND “nutrient” AND “irradiation”.

#1	**Search:** ((((((((((((((((((((((((((((((((((stone fruit) OR (nectarine)) OR (peach)) OR (cherry)) OR (plum)) OR (apricot)) OR (berry fruit)) OR (blueberry)) OR (strawberry)) OR (raspberry)) OR (citrus)) OR (orange)) OR (mandarin)) OR (grapefruit)) OR (lemon)) OR (lime)) OR (tropical fruit)) OR (pineapple)) OR (mango)) OR (papaya)) OR (litchi)) OR (guava)) OR (melon)) OR (watermelon)) OR (grape)) OR (kiwifruit)) OR (persimmon)) OR (cucurbit)) OR (zucchini)) OR (cucumber)) OR (pumpkin)) OR (capsicum)) OR (tomato)) OR (chilli)) OR (eggplant)) OR (corn)))
#2	**Search:** (((((((((ascorbate[All Fields] OR ("ascorbic acid"[MeSH Terms] OR ("ascorbic"[All Fields] AND "acid"[All Fields]) OR "ascorbic acid"[All Fields])) OR ascorbic[All Fields]) OR ("ascorbic acid"[MeSH Terms] OR ("ascorbic"[All Fields] AND "acid"[All Fields]) OR "ascorbic acid"[All Fields] OR "vitamin c"[All Fields])) OR ("carotenoids"[MeSH Terms] OR "carotenoids"[All Fields] OR "carotene"[All Fields])) OR ("carotenoids"[MeSH Terms] OR "carotenoids"[All Fields] OR "carotenoid"[All Fields])) OR ("vitamin a"[MeSH Terms] OR "vitamin a"[All Fields])) OR ("vitamin e"[MeSH Terms] OR "vitamin e"[All Fields])) OR ("tocopherols"[MeSH Terms] OR "tocopherols"[All Fields] OR "tocopherol"[All Fields])) OR ((thiamin) OR (thiamin)) OR (mononitrate, thiamin[MeSH Terms])
#3	**Search:** ("radiotherapy"[MeSH Terms] OR "radiotherapy"[All Fields] OR "irradiation"[All Fields] OR "food irradiation"[MeSH Terms])
#4	Search (#1) AND (#2) AND (#3)
Filters:	from 2014 – 2020

EBSCO Discovery
Database was searched on 13 July 2020 using the search strategies as outlined in the 2014 review and limited by date since 2014. 250 articles were identified. The search strategy included “vegetable name” AND “nutrient” AND “irradiation”. 250 titles were retrieved and 34 articles reviewed.

S1	(ascorbic acid or vitamin c) OR ascorbate OR carotene OR carotenoid OR vitamin a OR thiamin OR thiamin OR vitamin e OR tocopherol OR nutrient OR micronutrient OR vitamin
S2	(pome fruit OR apple OR pear OR stone fruit OR nectarine OR peach OR cherry OR plum OR apricot OR berry fruit OR blueberry OR strawberry OR raspberry OR citrus OR orange OR mandarin OR grapefruit OR lemon OR lime OR tropical fruit OR pineapple OR mango OR papaya OR lychee OR guava OR melon OR watermelon OR grapes OR kiwifruit OR persimmons OR cucurbit OR zucchini OR cucumber OR pumpkin OR capsicum OR tomato OR chilli OR eggplant OR corn)
S3	food irradiation
S4	(S1 AND S2 AND S3)
Limiters	Scholarly (Peer Reviewed) Journals; Publication Date: 19900101-20200713

Appendix 4: Naturally occurring concentration of vitamins in raw vegetables

Table A4: Concentration range of selected irradiation sensitive vitamins in raw vegetables from various nutrient reference tables

Vegetable#	ß-carotene (µg/100 g)				Vitamin C† (mg/100 g)				Thiamin (mg/100 g)				Vitamin E (mg/100 g)			
	AUS*	NZ^	USAδ	UKφ	AUS*	NZ^	USAδ	UKφ	AUS*	NZ^	USAδ	UKφ	AUS*	NZ^	USAδ	UKφ
Roots and tubers																
Potato	0	0	1–6	0	12–25	3–12	7–12	7–14	0.07–0.09	0.04–0.12	0.06–0.10	0.15–0.20	n/a	0–0.08	0–0.01	0.01–0.06
Sweet potato	6600	118–3530	4030–16000	3960	31	2–32	0–5	23	0.03	0.07–0.10	0.07–0.10	0.17	0.7	0.07–0.6	0.04–0.48	0.28
Taro, flesh	20	11	35	37	16	4	5	13	0.06	0.1	0.095	0.08	2.38	1.61	2.38	n/a
Taro, leaves	n/a	3410	2895	6980	n/a	90	52	52	n/a	0.15	0.21	0.21	n/a	2.3	2.02	n/a
Carrot	5700–9900	4300–8900	1990–21000	6115–9149	3–7	0–2	1–9	2–4	0.02–0.04	0.03–0.04	0.02–0.09	0.04–0.13	n/a	0.20–0.67	0.25–1.46	0.09–0.56
Brassicas																
Broccoli	285	630	54–118	578–675	106	99	57–105	79–100	0.08	0.08	0.06–0.10	0.1–0.15	0.18	0.98	0.04–0.22	1.30–1.72
Cauliflower	n/a	n/a	20-166	n/a	12–55	36	46–118	56	0.04	0.04	0.02–0.09	0.06	n/a	n/a	n/a	0.09
Brussels sprout	160	19	340–530	215	110	9	85	115	0.09	0.15	0.14	0.15	0.88	0.11	0.88	1
Cabbage	5–1550	6–670	21–1800	0–70	20–100	13–60	29–45	21–55	0.01-0.09	0.03–0.06	0.04–0.07	0.02–0.33	0–0.14	0.16–0.20	0.09–0.27	0.05–0.20
Bok choy/choy sum	545	1030–1160	2681	n/a	17	8	45	n/a	0.11	0.01–0.11	0.04	n/a	0.14	0.1	0.09	n/a
Leafy greens																
Lettuce	115–1210	267–506	57–8746	60	4–13	0–12	1–13	1	0.01–0.09	0.02–0.09	0.01–0.09	0.14	0.04–0.21	0.08–0.77	0.03–0.37	0.64
Spinach, baby	3600–5200	n/a	n/a	1559	25	n/a	n/a	29	0.07	n/a	n/a	0.09	1.62	n/a	n/a	0.48
Spinach, mature English	1920	2410	3970–8900	8295	27	3	28	26	0.06	n/a	0.08	0.07	1.3	n/a	1.41–2.70	1.71
Silverbeet/Swiss Chard	1540	1900	2725–4568	4569	21	5	30	30	0.03	0.06	0.04	0.04	0.16	0.3	1.89	n/a
Rocket	1900–4100	2660	1424	1132	16–150	2	15	20	0.07	0.04	0.04	0.19	1.3	0.35	0.43	0.22
Parsley	3810–4740	7000	4523–5600	n/a	95–132	150	133	190	0.15–0.16	0.15	0.09	0.23	0.80–0.90	0.75	0.75	1.7

* Australian Food Composition Database (AFCD) Release 1
^ New Zealand FOODfiles™ 2018 Version 01
δ USDA Food Data Central
φ McCance and Widdowson's The Composition of Foods integrated dataset
n/a – not analysed
Where values are provided for different varieties a range is given
† Vitamin C refers to the two related compounds that have vitamin C activity: ascorbic acid and dehydroascorbic acid.

Appendix 5: Included studies

Properties of studies included in the assessment of the effects of irradiation on radiation-sensitive nutrients in Brassica, roots and tubers and leafy vegetables

Brassicas

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
Frimpong et al. 2015	Cabbage – cut	Ascorbic acid – titration method **Effect of irradiation on AA content in cut cabbage (mean ± SD mg/100 g)** **Storage period (days)** **Dose (kGy) 0 5 10 15** 0 10.94 ± 2.12 14.40 ± 1.40 20.82 ± 2.12 17.02 ± 2.07 1 11.77 ± 1.95 11.66 ± 1.84 18.86 ± 1.90 17.69 ± 1.84 % Change +7.6% -19.03% -9.4% +3.94%	0, 1, (2 and 3) kGy Three replicates analysed. Post-irradiation storage 0, 5, 10, 15 days at 8 ± 2° C	AA was higher in irradiated samples immediately after irradiation. Losses were observed between 5-10 days and at 15 days concentrations were higher in irradiated samples. Differences were not significantly different at any time point ($p > 0.05$).
Vaishnav et al. 2015	Cauliflower – cut	Ascorbic acid – titration method **Effect of irradiation on AA content in cut cauliflower (mean ± SD mg/100 g)** **Storage period (days)** **Dose (kGy) 0 7 14 21** 0 41.23 ± 1.5 50.22 ± 6.88 42.13 ± 3.69 42.72 ± 2.70 0.5 42.13 ± 1.6 47.72 ± 3.1 46.12 ± 3.79 42.03 ± 2.60 % Change +2.18% -5.0% +9.5% -1.62%	0.5 kGy at 27°C ^{60}Co irradiation Three replicates analysed per sample. Post-irradiation storage 0, 7, 14, 21 days at 4° C	AA levels were similar or higher than controls at all time points.
Banerjee et al. 2016	Cabbage – cut and packaged	Ascorbic acid – titration method	2 kGy Nine replicates per sample.	AA concentrations were stable over time in non-irradiated and

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
		Effect of irradiation on AA content in cut cabbage (mean ± SD mg/100 g) **Storage period (days)** **4ºC** / **Dose (kGy)** / **0** / **5** / **8** / **13** / **16** / **21** 0 / 18.73 ± 2.89 / 17.77 ± 2.01 / 17.20 ± 3.06 / 17.87 ± 2.01 / 17.84 ± 2.17 / 16.88 ± 1.05 2 / 17.85 ± 2.09 / 18.57 ± 3.14 / 17.93 ± 2.89 / 17.63 ± 2.01 / 18.17 ± 2.57 / 16.72 ± 2.01 % Change / -4.3% / +4.52% / +4.21% / -1.3% / +1.8% / -0.95% **10ºC** 0 / 18.65 ± 2.97 / 16.96 ± 1.13 / 17.28± 1.13 / 16.88 ± 1.53 / 17.92 ± 1.84 / ND 2 / 17.85 ± 2.01 / 17.69 ± 1.85 / 17.20 ± 1.29 / 18.17 ± 1.45 / 18.17 ± 1.13 / ND % Change / -4.3% / +4.3% / -0.47% / +7.62% / +1.8%	Post-irradiation storage 0, 5, 8, 13, 16, 21 days Data extracted using Webplot digitizer	control samples. AA concentration in irradiated samples was similar or higher than controls at all time points, with no statistically significant differences at any time point (P > 0.05).

Leafy vegetables

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
Langerak et al. (1978)	Endive – minimally processed and packaged	Total vitamin C – titration method with reduction of DHAA **Effect of irradiation on total vitamin C (mg/100 g) of fresh-cut endive** **Storage time (days)** **Dose (kGy)** / **0** / **1** / **2** / **5** / **7** **Perforated bags** 0 / 12.22 ± 0.97 / 8.20 ± 0.73 / 6.09 ± 0.17 / 2.69 ± 0.14 / 1.48 ± 0.35 1 / 11.31 ± 0.98 / 6.25 ± 0.39 / 3.86 ± 0.25 / 2.79 ± 0.09 / 2.36 ± 0.18 % Change / -7.5 / -23.8 / -36.7 / +3.8 / +59.3 **Non-perforated bags** 0 / 11.77 ± 0.79 / 9.68 ± 0.55 / 7.62 ± 0.38 / No data / 5.03 ± 0.80 1 / 10.81 ± 0.39 / 8.66 ± 0.62 / 7.05 ± 0.32 / No data / 6.16 ± 0.36 % Change / -8.1 / -10.5 / -7.6 / No data / +22.6	1 kGy Four replicates per treatment. Post-irradiation storage 0, 1, 2, 5, 7 days at 10º C	Total vitamin C decreased over time in both irradiated and control samples. Losses in Vitamin C were observed following irradiation and up to 2 days post-storage after which time irradiated samples had higher concentrations than controls. No statistical analysis undertaken.

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr>
<td>Fan and Sokorai (2002)</td>
<td>Iceberg lettuce</td>
<td>Total vitamin C – HPLC (data not shown for AA)

Effect of irradiation on total vitamin C (µg/g*) of iceberg lettuce
Storage time (days)
<table>
<tr><th>Dose (kGy)</th><th>0</th><th>3</th><th>7</th><th>14</th></tr>
<tr><td>0</td><td>51.3</td><td>26.1</td><td>15.6</td><td>10</td></tr>
<tr><td>1</td><td>No data</td><td>21.2</td><td>14.8</td><td>9.6</td></tr>
<tr><td>% Change</td><td>No data</td><td>-18.8</td><td>-5.1</td><td>-4.0</td></tr>
</table>
*No SD provided</td>
<td>0, 1, (2, 3, 4) kGy ^{137}Cs

Four replicates per treatment.

Randomised design for treatment and lettuce pieces were placed in film bags.

Post-irradiation storage 3, 7, 14 days at 3° C</td>
<td>Vitamin C concentration decreased in test and control samples during storage. Non-significant differences in Vitamin C were observed between samples and controls at each time point.</td>
</tr>
<tr>
<td>Fan et al. (2003)</td>
<td>Fresh-cut iceberg lettuce</td>
<td>Total vitamin C – ion exchange chromatography, (data not shown for total antioxidant analysis, phenolics)

Effect of irradiation on vitamin C (µg/g) in fresh-cut lettuce *
Storage time (days)
<table>
<tr><th>Dose (kGy)</th><th>1</th><th>7</th><th>14</th><th>21</th></tr>
<tr><td>Pre-treatment at 4° C</td><td></td><td></td><td></td><td></td></tr>
<tr><td>0</td><td>26.5</td><td>7.17</td><td>5.39</td><td>7.03</td></tr>
<tr><td>0.5</td><td>29.1</td><td>2.82</td><td>3.25</td><td>6.33</td></tr>
<tr><td>1</td><td>22.6</td><td>3.05</td><td>4.69</td><td>4.8</td></tr>
<tr><td>% change (1kGy vs 0 kGy)</td><td>-14.7</td><td>-57.5</td><td>-13.0</td><td>-31.7</td></tr>
<tr><td>Pre-treatment at 47° C</td><td></td><td></td><td></td><td></td></tr>
<tr><td>0</td><td>17.42</td><td>4.52</td><td>5.07</td><td>7.25</td></tr>
<tr><td>0.5</td><td>18.73</td><td>6.11</td><td>3.31</td><td>4.32</td></tr>
<tr><td>1</td><td>18.01</td><td>7.33</td><td>3.78</td><td>9.24</td></tr>
</table></td>
<td>0, 0.5, 1, (2) kGy

Four replicates per treatment.

Fresh-cut iceberg lettuce dipped in 5° C or 47° C for 2 min packaged in MAP and irradiated 0-2 kGy.

Data extracted using Webplot digitiser

Post-irradiation storage 1, 7, 14, 21 days at 3° C</td>
<td>Vitamin C concentration decreased in test and control samples during storage, with greater losses observed in samples pre-treated at 47° C. Greater losses observed in irradiated samples pre-treated at 4° C. Irradiation had mixed effect over time compared to irradiated samples pre-treated at 47° C.</td>
</tr>
</table>

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
		% change (1kGy vs 0 kGy) +3.4 +62.2 -25.4 +27.5 *No SD provided		
Zhang et al. (2004)	Fresh-cut lettuce	Ascorbic acid – titration (data not shown for polyphenoloxidase activity) **Effect of irradiation on ascorbic acid content (mg/100 g ±SD) of fresh-cut lettuce*** **Storage time (days)** **Dose (kGy)** 0 3 6 9 0 10.04 ± 0.24 5.50^{a} ± 0.31 3.30^{b} ± 0.31 1.98^{b} ± 0.40 0.5 10.04 ± 0.24 4.62^{b} ± 0.31 2.42^{c} ± 0.31 1.10^{C} ± 0.16 1.0 10.04 ± 0.24 4.40^{b} ± 0.00 4.16^{a} ± 0.34 3.30^{a} ± 0.20 % change (1kGy vs 0 kGy) NA** -20.0 +26.0 +66.7 * Column values with different letters are significantly different ($p < 0.05$) ** baseline value same for all samples, most likely only measured for one of doses. Not used for meta-analysis	0, 0.5, 1, (1.5) kGy Irradiation performed at ~15 ° C Three replicates per treatment. Green and damaged leaves were removed and samples were cut into 2 cm squares, washed and placed in polyethylene bags. Post-irradiation storage 0, 3, 6, 9 days at 4° C	AA concentration decreased in test and control samples during storage. 1 kGy irradiation had a variable effect on AA concentration compared to controls, significantly lower at 3 and 9 days storage and significantly higher at 6 days.
Lester et al. (2010)	Packaged baby-leaf spinach (Lazio and Samish cultivars)	Total vitamin C – spectrophotometry, α-tocopherol – HPLC, β-carotene – HPLC (data not shown for vit K, B9, xanthophylls, phylloquinone) **Effect of irradiation on total vitamin C content (mean ± SD mg/100 g) in spinach*** **Dose (kGy)** **Lazio air** **Lazio N_2** **Samish air** **Samish N_2** 0 66.3 ± 2.4^{a} 61.2 ± 2.5^{a} 71.9 ± 1.8^{a} 76.3 ± 2.5^{a} 0.5 56.0 ± 2.4^{b} 55.8 ± 2.7^{b} 63.5 ± 4.7^{b} 72 $\pm 3.5^{b}$ 1 56.4 ± 2.8^{b} 53.9 ± 5.2^{b} 61.8 ± 1.7^{b} 64.2 ± 1.5^{c} %Change 1kGy vs 0 kGy -14.9 -11.9 -14.1 -15.9	0, 0.5, 1,(1.5, 2) kGy 25 g leaf tissue (baby leaves ≤ 5cm width removed from plant) were placed in sealable bag with air or N_2 atmosphere. Four replicates per	Vitamin C content decreased significantly ($p < 0.05$) in irradiated samples in both cultivars and storage conditions compared to control samples. B carotene content was similar in one

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr><td></td><td></td><td>
Effect of irradiation on β-carotene content (mean ± SD µg/g FW) in spinach*
<table>
<tr><th>Dose (kGy)</th><th>Lazio air</th><th>Lazio N_2</th><th>Samish air</th><th>Samish N_2</th></tr>
<tr><td>0</td><td>55.9 ± 1.7^{a}</td><td>59.1 ± 2.6^{a}</td><td>61.3 ± 2.7^{a}</td><td>59.7 ± 3.7^{a}</td></tr>
<tr><td>0.5</td><td>54.9 ± 3.5^{a}</td><td>60.2 ± 2.7^{a}</td><td>57.7 ± 2.3^{ab}</td><td>53.6 ± 2.3^{b}</td></tr>
<tr><td>1</td><td>54.3 ± 3.0^{a}</td><td>56.4 ± 3.0^{a}</td><td>57.4 ± 2.5^{b}</td><td>52.9 ± 2.7^{b}</td></tr>
<tr><td>%Change 1kGy vs 0 kGy</td><td>-2.9</td><td>-4.6</td><td>-6.4</td><td>-11.4</td></tr>
</table>
Effect of irradiation on α-tocopherol content (mean ± SD µg/g FW) in spinach*
<table>
<tr><th>Dose (kGy)</th><th>Lazio air</th><th>Lazio N_2</th><th>Samish air</th><th>Samish N_2</th></tr>
<tr><td>0</td><td>13.2 ± 1.3^{a}</td><td>13.4 ± 1.5^{a}</td><td>13.5 ± 0.6^{a}</td><td>12.9 ± 0.7^{a}</td></tr>
<tr><td>0.5</td><td>12.6 ± 1.5^{a}</td><td>12.8 ± 1.2^{a}</td><td>13.2 ± 1.0^{a}</td><td>12.8 ± 0.8^{a}</td></tr>
<tr><td>1</td><td>12.5 ± 1.2^{a}</td><td>12.7 ± 1.3^{a}</td><td>13.0 ± 1.5^{a}</td><td>12.7 ± 1.0^{a}</td></tr>
<tr><td>%Change 1kGy vs 0 kGy</td><td>-5.3</td><td>-5.2</td><td>-3.7</td><td>-1.5</td></tr>
</table>
* Results with a different letter are significantly different ($p < 0.05$; two way t test; n=24)
</td><td>treatment. Irradiation was performed using ^{137}Cs at 21^{o} C. Samples were either frozen and stored at -80^{o} C for < 30 days or lyophilized.

No storage</td><td>cultivar irradiated with 1 kGy and lower in the second cultivar compared to control samples. Vitamin E content was similar in test and control samples ($p > 0.05$).</td></tr>
<tr><td>Fan and Sokorai (2011)</td><td>Fresh-cut spinach</td><td>
Total vitamin C – ion exclusion chromatography (data not shown for antioxidant capacity, total phenolic content)
Effect of irradiation on total vitamin C content (mean ± SD µg/g FW) of fresh-cut spinach
<table>
<tr><th></th><th colspan="3">Storage time (days)</th></tr>
<tr><th>Dose (kGy)</th><th>1</th><th>7</th><th>14</th></tr>
<tr><td>0</td><td>645 ± 94</td><td>557 ± 111</td><td>432 ± 42</td></tr>
<tr><td>1</td><td>666 ± 91</td><td>341 ± 120*</td><td>175 ± 78*</td></tr>
<tr><td>% Change 1 kGy vs 0 kGy</td><td>+3.2</td><td>-38.80</td><td>-59.5</td></tr>
</table>
</td><td>0, 1, (2, 3, 4) kGy

Post-irradiation storage 1, 7, 14 day storage at 4^{o} C

Experiments were randomised. Six replicates per treatment.</td><td>Vitamin C content was similar after irradiation but decreased compared to controls after 7 and 14 days storage ($p < 0.05$).</td></tr>
</table>

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr><td></td><td></td><td>* Data are significantly different to controls (p< 0.05)</td><td></td><td></td></tr>
<tr><td>Fan et al. 2012</td><td>Fresh-cut iceberg lettuce</td><td>Ascorbic acid – HPLC
Effect of irradiation on AA content in iceberg lettuce (mg/g FW mean ± SD)
<table><tr><th></th><th colspan="2">Storage period (days)</th></tr><tr><th>Dose (kGy)</th><th>1</th><th>14</th></tr><tr><td>0</td><td>2.42 ± 1.21</td><td>3.06 ± 0.93</td></tr><tr><td>1</td><td>2.15 ± 0.19</td><td>1.82 ± 0.58*</td></tr><tr><td>% Change</td><td>-11.16</td><td>-40.52</td></tr></table>* Data are significantly different to controls (p < 0.05)</td><td>0, 1, (2, 3, 4) kGy ^{137}Cs

Rate 0.09 Gy/min

Four replicates per treatment.

Samples cut in 1 inch squares, flushed with nitrogen and sealed in film bags.

Post-irradiation storage 1, 14 days at 4° C</td><td>AA content decreased compared to controls when stored for 1 and 14 days, reaching significance at day 14 (p < 0.05).</td></tr>
<tr><td>Akhter et al. (2013)</td><td>Spinach leaves</td><td>Ascorbic acid – titration
Effect of irradiation on AA content (mean mg/100 g) in spinach*
<table><tr><th></th><th colspan="5">Storage time (days)</th></tr><tr><th>Dose (kGy)</th><th>0</th><th>3</th><th>6</th><th>9</th><th>12</th></tr><tr><td>0</td><td>13.37</td><td>11.82</td><td>11.72</td><td>11.37</td><td>7.56</td></tr><tr><td>0.5</td><td>17.39</td><td>11.15</td><td>8.59</td><td>7.87</td><td>5.23</td></tr><tr><td>1</td><td>17.39</td><td>9.19</td><td>8.59</td><td>7.87</td><td>3.49</td></tr><tr><td>%change 1 vs 0 kGy</td><td>+30</td><td>-22</td><td>-27</td><td>-45</td><td>-54</td></tr></table></td><td>0.5 and 1 kGy

Undamaged leaves were selected and placed in polythene bags. Mean of 2 replicates, 2 units per replicate. Analysis undertaken at 12° C

Post-irradiation storage 0, 3, 6, 9,</td><td>AA content decreased in test and control samples during storage. AA content was higher after irradiation but decreased during storage compared to controls.</td></tr>
</table>

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr><td></td><td></td><td>*No SD or statistical analysis for individual time points provided</td><td>12 day at 12º C and 60% RH</td><td></td></tr>
<tr><td>Nunes et al. (2013)</td><td>Minimally processed arugula (field rocket)</td><td>Total vitamin C (HPLC), provitamin A carotenoids including all-trans β-cryptoxanthin, all-trans-α-carotene and all-trans-β-carotene (HPLC) (data not shown for DHAA, all trans β-carotene, all-trans-α-carotene, cis- β-carotene)

Effect of irradiation on total vitamin C content in aragula (mg/100 g)

Storage time (days)
Dose (kGy) 0 5 9 12 16
0 46.07 ± 1.5 23.82 ± 1.0 12.46 ± 1.09 7.36 ± 1.25 0.08 (no SD)
1 36.71 ± 3.14* 18.90 ± 2.01* 6.86 ± 0.67 3.09 (no SD) nd
%Change -20% -21% -45% -58% -

Effect of irradiation on provitamin A carotenoids content in arugula (µg/g)

Storage time (days)
Dose (kGy) 0 3 7 10 13
0 61.1 ± 3.24 67.93 ± 3.17 65.57 ± 7.23 61.99 ± 6.25 56.45 ± 3.46
1 55.54 ± 6.52 48.58 ± 5.06** 49.0 ± 5.92 54.34 ± 3.22 46.13 ± 4.18
%Change -9 -29 -25 -12 -18

*significant difference between 1 kGy and control ($p < 0.05$)
nd: not detected</td><td>0, 1, (2) kGy ^{60}Co irradiation

Damaged leaves were removed and leaves and stalks were rinsed and sanitized in ozone treated water.
Three replicates per dose.

Post-irradiation storage (days)
Total carotenoids: 0*, 3, 7, 10, 13

AA: 0*, 5, 9, 12, 16

* Day 0: 24 hr after irradiation.

Samples stored at 5 ± 1º C after irradiation

Data extracted using Webplotdigitizer</td><td>Vitamin C content decreased in control and test samples during storage.
Provitamin A carotenoids were similar or higher than pre-storage levels.
Vitamin C and carotenoid content was lower than control samples during storage period.</td></tr>
<tr><td>Hussain et al. (2016)</td><td>Spinach and fenugreek</td><td>Total vitamin C – HPLC, total carotenoids – HPLC*; (data not shown for AA, total phenols, total flavonoids)

Effect of irradiation on total vitamin C content (mg/100 g, stored for 4 days)

Dose (kGy) Spinach Fenugreek</td><td>0.25, 0.5, 0.5, 0.75, 1, (1.25, 1.5 kGy)

Randomised design, three replicates per</td><td>Irradiation did not affect total vitamin C content in spinach or fenugreek. B carotene levels</td></tr>
</table>

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
		0 75.6 ± 2.1[a] 51.4 ± 1.2[a] 0.25 75.4 ± 2.2[a] 51.2 ± 1.4[a] 0.5 75.1 ± 2.2[a] 50.8 ± 1.5[a] 0.75 74.8 ± 2.4[a] 50.6 ± 1.4[a] 1.0 74.6 ± 2.2[a] 50.6 ± 1.2[a] %Change 1 vs 0kGy -1.3 -1.6 **Effect of irradiation on β-carotene content (mg/100 g stored for 4 days)** **Dose (kGy) Spinach Fenugreek** 0 3.5 ± 0.21[a] 14.2 ± 1.5[a] 0.25 3.9 ± 0.22[a] 14.4 ± 1.3[a] 0.5 4.4 ± 0.25[b] 15.3 ± 1.7[b] 0.75 5.1 ± 0.31[b] 16.4 ± 2.2[c] 1.0 6.1 ± 0.45[c] 17.2 ± 2.3[d] %Change 1 vs 0kGy +74.3 +21.1	treatment. Samples were washed, leaves were detached from the stems, dried, placed in perforated bags and sealed. Experiments were repeated over two consecutive years. Irradiation at 10 ± 2° C and samples stored for 4 days at 3 ±1° C prior to analysis.	were higher in irradiated samples than control samples.

Roots and tubers

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
Lee and Kim (1972)	Potato – whole variety Irish Cobbler	AA – titration , thiamin – thichrome fluorescence (riboflavin) **Effect of irradiation on vitamins in Irish Cobbler potato** **AA** mg/100 g fresh weight **Thiamin** µg/100 g fresh weight **Dose (kGy)** 0 9.9 15.7 0.16 12.1* 14 % Difference +22.22 -10.83 * significantly different to control Tukey's procedure, $p < 0.05$ No SD provided	0, (0.02, 0.04,0.08), 0.16 kGy. Isotope not described. Dose rate 551-2010 rad/hr Storage 4.5 months at 5° C pre-irradiation and for 2 months at room temp (RT) prior to analysis	Irradiated potatoes contained significantly higher levels of AA compared to controls ($p < 0.05$). Thiamin concentration decreased in irradiated samples compared to controls ($p > 0.05$).

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr><td></td><td></td><td></td><td>Randomised complete block design with 4 replicates per treatment.</td><td></td></tr>
<tr><td>Ismail and Afifi (1976)</td><td>Carrot – whole variety Chantenay</td><td>AA – DNPH, β-carotenes – method not provided, (data not shown for α carotene, total acids, sugars)

Effect of irradiation on AA content in carrot (mg/100 g)
Storage time (days)
<table><tr><th></th><th colspan="5">Storage temp 2° C ± 0.5° C</th><th colspan="5">Storage temp 25° C ± 5° C</th></tr><tr><th>Dose kGy</th><th>2</th><th>4</th><th>8</th><th>16</th><th>32</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr><tr><td>0</td><td>14.5</td><td>16.4</td><td>14.9</td><td>15.8</td><td>14.2</td><td>13.7</td><td>16</td><td>15.5</td><td>16.9</td><td>15.7</td></tr><tr><td>0.75</td><td>13.7</td><td>15.1</td><td>17.2</td><td>16.5</td><td>17.9</td><td>14.5</td><td>16.4</td><td>14.9</td><td>15.8</td><td>14.2</td></tr><tr><td>% change</td><td>-5.52</td><td>-7.93</td><td>15.44</td><td>4.43</td><td>26.06</td><td>5.84</td><td>2.5</td><td>-3.87</td><td>-6.51</td><td>-9.55</td></tr></table>
Effect of irradiation on β-carotene content in carrot (mg/kg)
Storage time (days)
<table><tr><th></th><th colspan="5">Storage temp 2° C ± 0.5° C</th><th colspan="5">Storage temp 25° C ± 5° C</th></tr><tr><th>Dose kGy</th><th>2</th><th>4</th><th>8</th><th>16</th><th>32</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr><tr><td>0</td><td>42</td><td>49.8</td><td>47</td><td>54.2</td><td>44.8</td><td>66.4</td><td>135.8</td><td>98</td><td>102.4</td><td>104.8</td></tr><tr><td>0.75</td><td>30.2</td><td>42.5</td><td>47</td><td>48.8</td><td>44.6</td><td>59.7</td><td>114.3</td><td>99.8</td><td>99.8</td><td>92.8</td></tr><tr><td>% change</td><td>-28.10</td><td>-14.66</td><td>0</td><td>-9.96</td><td>-0.45</td><td>-10.1</td><td>-15.83</td><td>1.84</td><td>-2.54</td><td>-11.45</td></tr></table>
No statistical analysis for the effect of irradiation on nutrient content was provided. No SDs provided</td><td>0, 0.75 kGy ^{60}Co gamma irradiation

Storage 12 hr 2° C 95-100% RH prior to irradiation and same conditions or RT (25-30° C and 50-60% RH) post-irradiation</td><td>In samples stored at 2° C AA decreased compared to controls for 4 days however longer storage resulted in an increase in AA concentration compared to controls. The effect was reversed when stored at 25° C.

β-carotene concentration decreased initially after irradiation, but losses decreased over time.</td></tr>
<tr><td>Lu et al. 1986</td><td>Sweet potato – Georgia Jet and Jewel</td><td>AA – titration, total carotenoids (Lanier and Sistrunk 1979)

Effect of irradiation on AA and carotenoid content in sweet potato (mean mg/100 g)</td><td>0, (0.1), 0.5, 0.8, (1.5, 2) kGy ^{60}Co gamma irradiation

Cured 1 week post-harvest (27-</td><td>Slight losses of AA and total carotenoids in Jewel variety but not in Georgia set following irradiation ($p > 0.05$).</td></tr>
</table>

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><th></th><th colspan="2">AA</th><th colspan="2">Total carotenoids</th></tr>
<tr><th>Dose (kGy)</th><th>Jewel</th><th>Georgia Set</th><th>Jewel</th><th>Georgia Set</th></tr>
<tr><td>0</td><td>18.6</td><td>10.5</td><td>11.2</td><td>7.5</td></tr>
<tr><td>0.5</td><td>20.9</td><td>10.5</td><td>12.4</td><td>8.8</td></tr>
<tr><td>0.8</td><td>17.3</td><td>10.3</td><td>10.7</td><td>9.3</td></tr>
<tr><td>% Change 0.8KGy</td><td>-6.99</td><td>-1.90</td><td>-4.46</td><td>+24.00</td></tr>
</table>
</td><td>33º C and 80-90% RH), 2 weeks (15º C and 85% RH) pre- and post-irradiation

Randomisation was not discussed

No SDs provided</td><td></td></tr>
<tr><td>Lu et al. 1989</td><td>Sweet potato</td><td>AA – titration, total carotenoids – spectrophotometer, thiamin – fluorometric method, (riboflavin)

Effect of dose rate of 1 kGy irradiation on vitamins in sweet potato (mean mg/100 g fresh weight)
<table>
<tr><th>Dose rate kGy/hr</th><th>AA</th><th>Total carotenoids</th><th>Thiamin</th></tr>
<tr><td>0</td><td>17.3</td><td>12.61</td><td>0.018</td></tr>
<tr><td>1</td><td>14.65*</td><td>7.55*</td><td>0.017</td></tr>
<tr><td>4.94</td><td>15.05*</td><td>8.58*</td><td>0.016</td></tr>
<tr><td>7.44</td><td>16.93</td><td>7.74*</td><td>0.017</td></tr>
<tr><td>10.4</td><td>16.34</td><td>12.93</td><td>0.015</td></tr>
<tr><td>15.3</td><td>16.43</td><td>11.4</td><td>0.016</td></tr>
<tr><td>Largest % difference to control</td><td>-15.32</td><td>-40.13</td><td>-16.67</td></tr>
<tr><td>Smallest % difference to control</td><td>-2.14</td><td>2.54</td><td>-5.56</td></tr>
</table>
* significantly different to control $p < 0.05$ Duncan’s Multiple Range test.</td><td>0, 1 kGy ^{60}Co gamma irradiation

5-10 roots per dose rate

Cured 1 week post-harvest (27-30º C and 85-90% RH), stored for one month (15º C and 85% RH) prior to irradiation. AA measured immediately after irradiation, and other nutrients soon after irradiation..
No SDs provided</td><td>In general higher dose rates caused only slight losses of AA or total carotenoids. Thiamin levels were similar to controls at each dose rate.</td></tr>
<tr><td>Graham and Stevenson 1997</td><td>Potato var Pentland Dell (data for strawberry not shown)</td><td>Total vitamin C – ion exclusion HPLC (data not shown for AA and DHAA)

Effect of irradiation on total vitamin C content in potato (mean mg/100 g fresh wt)
<table>
<tr><th>Storage (months)</th><th>Dose (kGy)</th><th>Raw</th><th>% Change</th><th>Boiled</th><th>% Change</th><th>Baked</th><th>% Change</th></tr>
<tr><td>0</td><td>0</td><td>13.06</td><td>-7.17</td><td>10.04</td><td>-21.70</td><td>8.08</td><td>-21.51</td></tr>
</table>
</td><td>0, 0.15 kGy ^{60}Co gamma irradiation
Potatoes for analysis were randomly selected from each treatment group.</td><td>Vitamin C content decreased in all irradiated and control potato groups during the storage period. Greater losses were observed in baked,</td></tr>
</table>

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
		0 0.15 12.13 7.86 6.34 **1** 0 9.79 -37.32 7.69 -34.44 5.71 -33.01 **1** 0.15 6.13 5.04 3.83 **2** 0 8.62 -29.89 6.66 -30.77 3.68 -16.58 **2** 0.15 6.04 4.61 3.07 **5** 0 7.87 +2.38 6.06 -1.41 3.68 +12.06 **5** 0.15 8.05 5.98 4.12	Analysis was performed on raw, boiled or baked samples. Potatoes were stored for 1 month at 12° C prior to irradiation. Storage for 0, 1, 2, or 5 months. Storage temperature not provided.	boiled and raw potatoes.
Lima et al. 2004	Carrot – ready to eat	Total carotenoids- spectrophotometer, and ascorbic acid – titration (total soluble solids, total titratable acidity, volatiles) **Effect of irradiation on AA and total carotene content in carrot (mean mg/100 g fresh wt)** **Dose (kGy)** / **Ascorbic acid** / **Total carotenes** 0 8.21 10.47 0.25 8.20 10.14 0.5 8.04 9.64 0.75 8.05 9.42 1 8.29 9.27 % Change 1 vs 0 kGy +0.96 -11.45	0, 0.25, 0.5, 0.75,1.0 kGy ^{137} Cs irradiation	No significant difference between test and control at any dose ($p > 0.05$) No further details available – full text in Portuguese.
Rezaee et al. (2011)	Potato – whole Agria	Ascorbic acid – spectrophotometer **Percentage loss of AA compared to recently harvested potatoes** **Days storage prior to irradiation** **Dose (Gray)** / **Storage Temp (°C)** / **10** / **30** / **50**	0, (50, 100), 150 Gy ^{60}Co gamma irradiation 10, 30 or 50 days storage pre-irradiation,	AA losses increased over time with potatoes irradiated with 150 Gy and stored at 16° C but losses were variable over time when stored at 8° C.

<table>
<tr><th>Study</th><th>Vegetable</th><th>Nutrient – Method of analysis and results</th><th>Experimental details</th><th>Outcome</th></tr>
<tr><td></td><td></td><td>
<table>
<tr><td>0</td><td>8</td><td>9.96</td><td>NA</td><td>NA</td></tr>
<tr><td>150</td><td>8</td><td>20.80</td><td>12.65</td><td>29.67</td></tr>
<tr><td>0</td><td>16</td><td>16.95</td><td>NA</td><td>NA</td></tr>
<tr><td>150</td><td>16</td><td>21.09</td><td>31.20</td><td>38.55</td></tr>
</table>
The authors reported that date, irradiation and temperature affected ascorbic acid loss ($p < 0.01$) using ANOVA. No further details provided.
</td><td>5 month storage at 8° C or 16° C post-irradiation, 80-90% RH

Random selection of potatoes for storage at 8° C or 16° C. Three replicates of each treatment.</td><td></td></tr>
<tr><td>Lim et al. (2013)</td><td>Sweet potato roots (Ipomea batatas Lam. cv. Annobeny)</td><td>
Vitamin C – dinitrophenylhydrazine method, β-carotene – HPLC

Effect of irradiation on vitamin C in sweet potato*
Storage period (weeks)
<table>
<tr><th>Dose (kGy)</th><th>0</th><th>2</th><th>4</th><th>6</th><th>8</th></tr>
<tr><td>0</td><td>24.8 ± 2.8</td><td>25.6 ± 3.8</td><td>30.3 ± 3.0</td><td>31.9 ± 2.8</td><td>28.5 ± 3.5</td></tr>
<tr><td>0.2</td><td>27.4 ± 4.0</td><td>30.2 ± 4.2</td><td>28.4 ± 4.0</td><td>29.0 ± 3.7</td><td>29.3 ± 3.2</td></tr>
<tr><td>0.4</td><td>25.4 ± 3.5</td><td>33.8 ± 3.4</td><td>30.9 ± 3.8</td><td>28.9 ± 3.2</td><td>25.1 ± 3.7</td></tr>
<tr><td>1</td><td>29.8 ± 4.2</td><td>29.4 ± 3.2</td><td>25.6 ± 4.2</td><td>29.4 ± 3.6</td><td>26.1 ± 4.3</td></tr>
<tr><td>% Change 1 vs 0 kGy</td><td>20.16</td><td>14.84</td><td>-15.51</td><td>-7.84</td><td>-8.42</td></tr>
</table>
Effect of irradiation on β-carotene in sweet potato*
Storage period (weeks)
<table>
<tr><th>Dose (kGy)</th><th>0</th><th>2</th><th>4</th><th>6</th><th>8</th></tr>
<tr><td>0</td><td>113.4 ± 10.2</td><td>121.2 ± 15.5</td><td>130.2 ± 11.4</td><td>135.4 ± 14.2</td><td>134.3 ± 12.4</td></tr>
<tr><td>0.2</td><td>107.4 ± 10.2</td><td>118.6 ± 10.8</td><td>124.2 ± 14.5</td><td>137.2 ± 14.2</td><td>125.4 ± 11.4</td></tr>
<tr><td>0.4</td><td>109.2 ± 16.5</td><td>125.4 ± 13.2</td><td>120.4 ± 12.8</td><td>133.2 ± 11.2</td><td>130.4 ± 11.5</td></tr>
<tr><td>1</td><td>96.2 ± 12.4</td><td>127.8 ± 10.2</td><td>132.4 ± 8.4</td><td>133.4 ± 11.5</td><td>137.2 ± 10.4</td></tr>
</table>
</td><td>0, (0.1), 0.2, 0.5, 1 kGy

^{60}Co gamma irradiation

Analysis conducted using 100 sweet potato roots for each treatment. Analysis conducted in triplicate.</td><td>Vitamin C content was higher in samples irradiated at 1 kGy immediately and 2 days after irradiation. Some losses were observed over extended storage periods.

β-carotene levels were lower immediately after irradiation but similar following storage.</td></tr>
</table>

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
		% Change 1 vs 0 kGy: -15.17 5.45 1.66 -1.48 2.16 *mean ± SE of three replicates. Units not given and attempts to contact author were unsuccessful. Vitamin C values were consistent with mg/100 g conc in Australian Food Composition tables and used as such, β-carotenes were not clear and not used in meta-analysis		

Multiple categories

Study	Vegetable	Nutrient – Method of analysis and results	Experimental details	Outcome
Fan and Sokorai (2008)	Packaged fresh-cut broccoli (MAP), red cabbage (MAP), red leaf lettuce (air), romaine lettuce (MAP), spinach (MAP), iceberg lettuce (MAP and air), carrot (MAP)	Total vitamin C -ion exclusion chromatography **Effect of irradiation on total vitamin C (mean ± SD μg/g) content in vegetables** **Storage time (days)** **Dose (kGy) 1 14** Broccoli (MAP) 0 925.9 ± 71.7 854.9 ± 76.1 1 902.3 ± 101.3 854.8 ± 11.2 %Change -2.55 -0.01 Red cabbage (MAP) 0 681.3 ± 31.8 623.9 ± 44.2 1 632.1 ± 29.9 652.8 ± 21.9 %Change -7.2 4.6 Green leaf lettuce (air) 0 88.8 ± 14.2 52.8 ± 10.1 1 67.1±15.9* 28.2 ± 8.2* %Change -24.4 -46.6 Iceberg lettuce MAP 0 30.3 ± 2.8 15.2 ± 3.6 1 16.8 ± 5.0* 12.9 ± 4.5 %Change -44.6 -15.1	1 kGy Packaged fresh-cut broccoli, shredded carrot, red cabbage, iceberg, romaine lettuce and spinach were used as purchased. Whole iceberg, red and green leaf lettuce were cut into 3cm square pieces and dipped in chlorine. Four replicates per sample. 1 and 14 day post-irradiation storage at 4° C	Irradiated leaf vegetables observed higher losses of vitamin C compared to other vegetables, in many cases reaching statistical significance ($p < 0.05$).

Study	Vegetable	Nutrient – Method of analysis and results				Experimental details	Outcome
		Iceberg lettuce (air)	0	20.7 ± 3.6	21.7 ± 6.9		
			1	16.1 ± 3.8	10.9 ± 2.6*		
		%Change		-22.2	-49.8		
		Red leaf lettuce (air)	0	74.5 ± 9.1	33.7 ± 6.3		
			1	39.1 ± 5.9*	15.7 ± 1.2*		
		%Change		-47.5	-53.4		
		Romaine lettuce (MAP)	0	38.1 ± 14.3	44.8 ± 17.9		
			1	47.6 ± 3.5	28.9 ± 15.8		
		%Change		24.9	-35.5		
		Spinach (MAP)	0	264.8 ± 37.9	198.2 ± 55.8		
			1	198.7 ± 34.1	68.6 ± 51.5*		
		%Change		-25	-64		
		Carrots (MAP)	0	92.6 ± 11.7	55.4 ± 36.1		
			1	88.6 ± 3.9	59.1 ± 5.3		
		%Change		-4.3	6.7		
		* denotes significant difference (least square difference $p < 0.05$)					
Sarker et al. 2014	Processed vegetables Green leaf lettuce Carrot	Ascorbic acid – titration, total carotenoid – spectrophotometry **Effect of irradiation on AA** (mean ± SD mg/100 g fresh wt) | **Effect of irradiation on Total carotenoid** (mean ± SD µg/g fresh wt)				0, 1, (2, 2.5, 3) kGy ^{60}Co No storage of samples	AA content decreased but total carotenoid content was unchanged in green leaf lettuce.

Study	Vegetable	Nutrient – Method of analysis and results							Experimental details	Outcome
	Cucumber Tomato Green capsicum	**Dose (kGy)**	0	1	%Change	0	1	%Change	3 replicates of each treatment. Statistical analysis: 1 way ANOVA	AA content was higher in carrot and total carotenoid content was maintained in carrots.
		Green leaf lettuce	3.79 ± 0.77	3.28 ± 0.0	-13%	24.5 ± 0.71	24.5 ± 0.71	0%		
		Cucumber	6.49 ± 0.37	5.74 ± 0.10	-12%	0.33 ± 0.06	0.25 ± 0.02	-24%		
		Carrot	4.64 ± 0.22	5.38 ± 0.27	+16%	6.87 ± 2.5	6.67 ± 0.62	-3%		

Appendix 6: Nutrient concentrations in irradiated commodities and naturally occurring levels

Table A6.1: Vitamin C content in selected commodities pre- and post-irradiation and naturally occurring levels

Food	mg/100 g (unless otherwise stated)		Source[!]	Naturally occurring nutrient content (mg/100 g)	
	Pre-irradiation (0 kGy)[#]	Post - irradiation (1 kGy unless otherwise stated)[#]		AUS* & NZ^ data range	Other countries**
Roots and tubers					
Potato – whole variety Irish Cobbler	9.9	12.1 (0.16 kGy)	Lee and Kim (1972)	3–25	7–14
Potato var Pentland Dell (raw)	7.87–13.06	6.04–12.13 (0.15 kGy)	Graham and Stevenson (1997)	3–25	7–14
Potato var Pentland Dell (boiled)	6.06–10.04	4.61–7.86 (0.15 kGy)	Graham and Stevenson (1997)	3–25	7–14
Potato var Pentland Dell (baked)	3.68–8.08	3.07–6.34 (0.15 kGy)	Graham and Stevenson (1997)	3–25	7–14
Potato – whole Agria	9.96–16.95	12.65–38.55	Rezaee et al. (2011)	3–25	7–14
Sweet potato – Georgia Jet and Jewel	10.5–18.6	10.3–17.3 (0.8 kGy)	Lu et al. (1986)	2–32	0–23
Sweet potato	17.3	14.65–16.43	Lu et al. (1989)	2–32	0–23
Sweet potato roots (Ipomea batatas Lam. cv. Annobeny)	24.8–31.9	25.6–29.8	Lim et al. (2013)	2–32	0–23
Carrot –whole variety Chantenay	13.7–16.9	13.7–17.9 (0.75 kGy)	Ismail and Afifi (1976)	0–7	1–9
Carrot – ready to eat	8.21	8.29	Lima et al. (2004)	0–7	1–9
Carrots (MAP), day 1 to 14 storage	55.4–92.6 (µg/g)	59.1–88.6 (µg/g)	Fan and Sokorai (2008)	0–7	1–9
Carrot	4.64	5.38	Sarker et al. (2014)	0–7	1–9
Brassicas					
Cabbage – cut	10.94–20.82	11.66–18.86	Frimpong et al. (2015)	20–100	21–55
Red cabbage (MAP) day 1 to 14 storage	623.9–681.3 (µg/g)	632.1–652.8 (µg/g)	Fan and Sokorai (2008)	20–100	21–55
Cauliflower – cut	41.23–50.22	42.03–47.72 (0.5 kGy)	Vaishnav et al. (2015)	12–55	46–118
Packaged fresh-cut broccoli (MAP) day 1 to 14	854.9–925.9 (µg/g)	854.8–902.3 (µg/g)	Fan and Sokorai (2008)	99–106	57–105

Food	mg/100 g (unless otherwise stated)		Source[!]	Naturally occurring nutrient content (mg/100 g)	
	Pre-irradiation (0 kGy)[#]	Post - irradiation (1 kGy unless otherwise stated)[#]		AUS* & NZ^ data range	Other countries**
Leafy vegetables					
Endive – minimally processed & packaged	1.48–12.22	2.36–11.31	Langerak et al. (1978)	N/A	N/A
Iceberg lettuce	10–51.3 (µg/g)	9.6–21.2 (µg/g)	Fan and Sokorai (2002)	0–13	1–13
Fresh-cut iceberg lettuce	4.52–26.5 (µg/g)	3.05–22.6 (µg/g)	Fan et al. (2003)	0–13	1–13
Fresh-cut lettuce	1.98–10.04	3.3–10.04	Zhang et al. (2004)	0–13	1–13
Fresh-cut iceberg lettuce	2.42–3.06 (mg/g FW)	1.82–2.15 (mg/g FW)	Fan et al. (2012)	0–13	1–13
Green leaf lettuce (air), day 1 to 14 storage	52.8–88.8 (µg/g)	28.2–67.1 (µg/g)	Fan and Sokorai (2008)	0–13	1–13
Iceberg lettuce MAP, day 1 to 14 storage	15.2–30.3 (µg/g)	12.9–16.8 (µg/g)	Fan and Sokorai (2008)	0–13	1–13
Iceberg lettuce (air), day 1 to 14 storage	20.7–21.7 (µg/g)	10.9–16.1 (µg/g)	Fan and Sokorai (2008)	0–13	1–13
Red leaf lettuce (air), day 1 to 14 storage	33.7–74.5 (µg/g)	15.7–39.1 (µg/g)	Fan and Sokorai (2008)	0–13	1–13
Romaine lettuce (MAP), day 1 to 14 storage	38.1–44.8 (µg/g)	28.9–47.6 (µg/g)	Fan and Sokorai (2008)	0–13	1–13
Green leaf lettuce	3.79	3.28	Sarker et al. (2014)	0–13	1–13
Packaged baby-leaf spinach (Lazio and Samish cultivars)	61.2–76.3	53.9–64.2	Lester et al. (2010)	25	29
Fresh-cut spinach	432–645 (µg/g FW)	175–666 (µg/g FW)	Fan and Sokorai (2011)	3–27	26–28
Spinach leaves	7.56–13.37	3.49–17.39	Akhter et al. (2013)	3–27	26–28
Spinach	75.6	74.6	Hussain et al. (2016)	3–27	26–28
Spinach (MAP), day 1 to 14 storage	198.2–264.8 (µg/g)	68.6–198.7 (µg/g)	Fan and Sokorai (2008)	3.0–27	26–28
Minimally processed arugula (field rocket)	0.08–46.07	3.09–36.71	Nunes et al. (2013)	2–15	15–20
Fenugreek	51.4	50.6	Hussain et al. (2016)	N/A	N/A

MAP = modified atmosphere package.
* Australian Food Composition Database (AFCD) Release 1.
^ New Zealand FOODfiles™ 2018 Version 01.
**Other countries dataset include USDA Food Data Central & McCance and Widdowson's The Composition of Foods integrated dataset.
Where values are provided for different varieties a range is given.
N/A: no data available.
! source of pre and post irradiation data.

Table A6.2: β-Carotene or total carotenoid content in selected commodities pre- and post-irradiation and naturally occurring levels

Food	mg/100 g (unless otherwise stated)		Source[!]	Naturally occurring nutrient content (µg/100 g)	
	Pre-irradiation (0 kGy)[#]	Post-irradiation (1 kGy unless otherwise stated)[#]		AUS* & NZ^ data range	Other countries**
Roots and tubers					
Sweet potato	7.5–11.2	9.3–10.7 (0.8 kGy)	Lu et al. (1986)	118–6600	3960–16000
Sweet potato	12.61	7.55	Lu et al. (1989)	118–6600	3960–16000
Sweet potato	113.4–135.4	96.2–137.2	Lim et al. (2013)	118–6600	3960–16000
Carrot	42–135.8	30.2–114.3 (0.75 kGy)	Ismail and Afifi (1976)	4300–9900	1990–21000
Carrot	10.5	9.3	Lima et al. (2001)	4300–9900	1990–21000
Carrot	6.9	6.7	Sarker et al. (2014)	4300–9900	1990–21000
Leafy vegetables					
Spinach	3.5	6.1	Hussain et al. (2016)	3600–5201	1559
Spinach	55.9–61.3 (µg/g FW)	52.9–57.4 (µg/g FW)	Lester et al. (2010)	3600–5201	1559
Fenugreek	14.2	17.2	Hussain et al. (2016)	N/A	N/A
Arugula (field rocket)	56.5–61.1 (µg/g)	46.13–55.5 (µg/g)	Nunes et al. (2013)	1900–4100	1132–1424
Green leaf lettuce	24.5 (µg/g FW)	24.5 (µg/g FW)	Sarker et al. (2014)	115–1210	57–8746

FW = fresh weight.
* Australian Food Composition Database (AFCD) Release 1.
^ New Zealand FOODfiles™ 2018 Version 01.
**Other countries dataset include USDA Food Data Central & McCance and Widdowson's The Composition of Foods integrated dataset.
Where values are provided for different varieties a range is given.
N/A: no data available.
! source of pre and post irradiation data.

Table A6.1 and Table A6.2 show the vitamin C and β-carotene concentrations in selected commodities pre- and post-irradiation along with naturally occurring levels.

To study the effect of irradiation on vitamin C and β-carotene contents in vegetables, vitamin C and β-carotene concentration data from studies reviewed in the nutrition risk assessment were reviewed along with the naturally occurring nutrient contents from food composition tables. The nutrient content of vegetables pre- and post-irradiation and naturally occurring levels were summarised for Brassicas, leafy greens, and roots and tubers. The naturally occurring nutrient concentrations were summarised to show the range of Australian and New Zealand values from the lowest to the highest. The concentrations were for raw vegetables.

The concentration data for vitamin C and β-carotene for the pre- and post-irradiated vegetables at 1 kGy dosage were extracted from meta-analysis results of nutrient risk assessment. The foods with β-carotene values available in the meta-analysis were spinach, arugula (field rocket), carrot, sweet potato and green lettuce. In the Australian Food Composition Database (AFCD), the β-carotene values in rocket are exactly the same as the provitamin carotenoids. The study in the meta-analysis used pro-carotenoids. No data were available for fenugreek. Data with no units were not included in the meta-analyses.

Appendix 7: Abbreviations

2-ACB	2-alkylcyclobutanone
AA	Ascorbic acid
β-carotene	pro-vitamin A carotenoid
β-carotene equivalents	Estimated using the following formula: β-carotene (µg) + α-carotene/2 (µg) + β-cryptoxanthin/2 (µg)
Carotene	Non-oxygenated carotenoid
Carotenoid	Hydrocarbon pigments synthesised by plants
DHAA	Dehydroascorbic acid (oxidised ascorbic acid)
EAR	Estimated Average Requirement
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
Gy	Gray
HPLC	High pressure liquid chromatography
IAEA	International Atomic Energy Agency
kGy	KiloGray
MAP	modified atmosphere packaging
MeBr	Methyl bromide
NonMR	non-midrib
NNPAS	The 2011-12 Australian National Nutrition and Physical Activity Survey
NRV	Nutrient reference value
Retinol equivalents[7] (RE)	Calculation of total vitamin A activity of a food. Estimated using the formula: retinol (µg)+(β-carotene/6 + α- carotene/12+β-cryptoxanthin/12(µg))
RH	Relative humidity
RT	Room temperature
SCF	European Commission Scientific Committee on Food
WHO	World Health Organization

[7] For an alternate approach, calculating Retinol Activity Equivalents (RAE), please see the "DRI Essential Guide to Nutrient Requirements" (2006), available at http://www.nap.edu/openbook.php?record_id=11537&page=170