Nutritional profile of irradiated summerfruit, vegetables and melons

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Effect of irradiation on the nutritional profile and postharvest quality of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon

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MT10057 Final Report

This report investigates the effects of low doses of gamma (γ)-irradiation applied as a quarantine disinfestation method on the nutrition (Part A) and quality (Part B) of a selection of fruit commodities, both before and after a recommended cold storage period.

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1. Report summary

This study examines the radio-tolerance of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at doses at and below 1kGy for the purposes of quarantine disinfestation. The effects of low dose gamma (γ)-irradiation on the proximate and nutritional profile and postharvest fruit quality attributes of these selected fruits were investigated.

The study provides an analysis of the six commodities irradiated with 0Gy, 150Gy, 600Gy and 1000Gy and then assessed at two times, being within 24 hours after being irradiated and after a recommended cold storage period of up to 21 days. The nutritional profile of each produce was analysed at these two times for ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, ascorbic acid (vitamin C) and beta-carotene. Fruit physico-chemical measurements were also conducted at the same times.

The results showed that applications of gamma irradiation of ≤ 1kGy did not induce any significant deleterious effects on the chemical and proximate components of tomato, green capsicum, zucchini, nectarine and rockmelon. Beta-carotene levels in honeydew melon however were initially affected by irradiation (within 24 hours), being significantly lower in the ≥ 600Gy treatment (12μg/100g) compared with control fruit (17μg/100g), although by the end of the storage period no differences were detected across any of the treatments (mean 12.3μg/100g). Treatment doses at below 600Gy can therefore be applied safely without inducing any deleterious effects on the nutritional components in honeydew melon.

In regards to fruit quality, irradiation applied up to 1kGy overall had little to no effect on a range of quality attributes measured in tomato, capsicum, zucchini and rockmelon. These commodities were instead impacted more by storage time than by irradiation itself, undergoing the typical senescent-related processes (e.g. deterioration through aging) often observed under storage conditions, such as changes in skin and/or flesh colour, flesh softening and weight loss.

The irradiation treatment did however have a significant effect on the quality of honeydew melon and, to a lesser extent, nectarine fruit. In both cases, the incidence and severity of symptoms (namely skin browning and pitting) increased with dose level; being observed only at the end of the recommended storage period. Specifically, symptoms in honeydew melon occurred only when treated to a dose of 600Gy and above, with up to 51% of the skin surface area being affected. In contrast, irradiation damage in nectarine fruit was comparatively low across all the treatments (< 1cm^2 skin area affected), with only a small proportion of fruit (3%) affected at 150Gy. However, this increased significantly to greater than 13% of fruit affected at a dose of 600Gy and above.

In conclusion, the overall findings of this study suggest that an application of up to 1kGy will not result in any significant detrimental damage to the nutritional and postharvest quality of fruit such tomato, capsicum, zucchini or rockmelon. An irradiation dose of 600Gy or above, however, would not be recommended for honeydew melon or nectarine fruit given the potential for adverse affects on fruit quality. Further studies on both commodities looking at factors such as, postharvest handling, storage, the particular cultivar, production system, maturity and environmental conditions prior to harvest is recommended. All factors listed above have been reported to impact on the radio-tolerance of a wide range of commodities.

2. Part A – Effect of low dose gamma (γ)-irradiation on the nutritional profile of selected fruit commodities

2.1 Summary

This report examines the radio-tolerance of tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at doses at and below 1kGy for the purposes of quarantine disinfestation. The study provides an analysis of data on the nutritional profile of the six commodities that have been irradiated with 0Gy, 150Gy, 600Gy and 1000Gy and assessed on two occasions.

The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety ‘Gourmet Swanson’; green capsicum (*Capsicum annuum*), variety ‘Plato’; dark skin zucchini (*Cucurbita pepo*), variety ‘Blackjack’; firm white flesh nectarine (*Prunus persica var. nucipersica*), variety ‘Arctic Snow’; rockmelon (*Cucumis melo*), variety ‘Triumph’ and white skin honeydew melon (*Cucumis melo*), variety ‘Galaxy’.

The nutritional profile of each produce was analysed and included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. Overall, our results show that tomato, capsicum, zucchini, nectarine and rockmelon can tolerate 1kGy radiation without significant deterioration in the majority of nutrient components investigated. The nutritional components of these fresh commodities tested were not negatively affected by low dose irradiation.

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

Specifically, a main effect of dose was not detected in Vitamin C (ascorbic acid) in tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon. No main effect of dose was detected in beta-carotene in tomato, capsicum, zucchini, nectarine and rockmelon. However, beta-carotene content in honeydew melon was significantly affected with doses ≥ 600Gy immediately after irradiation treatment. An interaction of time and dose was observed in Vitamin C (ascorbic acid) and beta-carotene in honeydew melon.

While each commodity responded differently when exposed to ionising low dose gamma (γ)-irradiation, overall, the effect of storage time was greater than by irradiation itself in many of the nutrients investigated and the changes generally appeared to be associated with the ripening or senescence processes during storage.

In this study, the fresh fruits studied are high in water content, and low in protein and fat with moisture contents frequently greater than 86%. Compositions of fruit vary according to variety, cultivation practices, environment and weather, but also change with the degree of maturity prior to harvest, the condition of ripeness, postharvest handling, transport and storage conditions.

Applications of gamma irradiation treatments of ≤ 1kGy can be considered as a phytosanitary method without inducing significant deleterious effects to the chemical and proximate components of tomato, green capsicum, zucchini, nectarine and rockmelon. Honeydew melon however, was less tolerant to doses > 600Gy with respect to beta-carotene content just after irradiation treatment. Treatment with 150Gy could be safely applied without inducing any deleterious effects in honeydew melon.

Research studies and simulated transport are still needed in which irradiation is included as part of the supply chain system or combination treatments involving irradiation and modified atmosphere packaging or edible coatings to reduce postharvest rots and extend shelf life.

2.2 Introduction

As soon as fruits are harvested, some undergo higher rates of respiration, in association with moisture loss, deterioration of fruit quality, nutrition and potential microbial spoilage. Fruits will also lose some vitamins quite rapidly and can deteriorate if they are stored in warmth and light. More than likely, fruit will also be picked at a slightly immature stage to reduce mechanical damage during harvesting and transportation. The literature indicates that by the time they are consumed, fresh, frozen and canned fruits may be nutritionally similar, depending on the post harvest handling and processing treatments.

It is known that respiration by fruit and other tissues are affected as a result of exposure to ionising radiation however, these responses can vary. It has also been shown that irradiation can delay the ripening of some fruits or the sprouting of certain bulbs and tubers, thereby extending shelf life.

While there is literature available on the effect of irradiation on the nutrition and quality of tropical fruits in general, there is sometimes discrepancy reported as well. The differences have been reported to be due to the commodity, postharvest handling, storage, the particular cultivar, production system, maturity, environmental conditions, soil type, growing and weather conditions during growth.

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

Export quality fresh whole produce were sourced for this study. Treatment doses were 0Gy, 150Gy, 600Gy and 1000Gy.

The Australia New Zealand Food Standards Coded 1.5.3 (Australian Government Com Law website, 2011) permits irradiation of food for the purposes of pest disinfestation for a phytosanitary objective; the minimum is 150Gy and the maximum of 1kGy.

Irradiation treatment for fruit flies of the family Tephritidae (generic) (ISPM No.28, Annex 7, 2009) provides for the irradiation of fruits and vegetables at 150Gy minimum absorbed dose to prevent the emergence of adults of fruit flies at the stated efficacy. Approved new minimum doses for certain fruit flies are reviewed and re-evaluated as required and would facilitate the use of irradiation to neutralise more pests at lower doses, potentially minimising any adverse affects on commodity quality.

The effect of low dose gamma (γ)-irradiation was also examined after a period of cold storage following treatment. This approach provides data on the effect of irradiation treatment however, limited to only the particular variety. Other researchers have obtained samples from the supermarket, measuring what the consumer has available, but this can increase nutrient variability due to cultivar, growing conditions, maturity and handling practices.

2.3 Materials and methods

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

Irradiation treatment of tomatoes and capsicum were carried out on 28 February - 2 March 2011. Zucchini and nectarine were treated between 14-16 March 2011and rockmelon and honeydew melon on 9-10 May 2011.

A second set of produce (tomato, capsicum, zucchini, rockmelon and honeydew melon) were purchased and treated 18 July 2011 and sent for beta-carotene analysis as the previous analysis was done in error. The same varieties were purchased and treated in the same way using the same experimental design. Nectarine for beta-carotene analysis was irradiated 28 March 2012.

Control produce and treatment produce were stored pre and post irradiation in a coldroom set at 10°C. The fruits were carefully placed in cardboard boxes which fitted into the stainless steel irradiation chamber for treatment. The produce did not receive any sanitizing or washing before treatment. The fruits were not graded.

There were three replications for each dose treatment (0Gy, 150Gy, 600Gy and 1000Gy) and the effects of irradiation were measured at two stages: before storage (Time 1; one day after irradiation treatment) and after a period of storage (Time 2). The storage times and conditions for each commodity are listed in Table 1.

Table 1. Storage conditions for tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon.

Commodity	Set storage temperature	Duration
Tomato (red)	10°C	14 days
Capsicum (green)	8°C	21 days
Zucchini	8°C	7 days
Nectarine	4°C	21 days
Rockmelon	7°C	14 days
Honeydew melon	7°C	14 days

For tomato and nectarine, each replicate consisted of ten pieces of fruit per treatment dose per assessment time. For capsicum, each replicate consisted of five pieces of produce per treatment dose per assessment time. For zucchini, each replicate consisted of eight pieces of fruit per treatment dose per assessment time. For rockmelon and honeydew melon, each replicate consisted of three pieces of fruit per treatment dose per assessment time.

Following irradiation treatment, the fruits were sorted, packed and sent for chemical analysis and fruit quality assessment. Time 2 fruits were placed in cold storage at their respective set conditions until testing commenced (Table 1).

2.3.1 Cultivars

Export quality fresh fruits were selected. The cultivars studied were: firm ripe tomato (*Lycopersicon esculentum*), variety ‘Gourmet Swanson’; green capsicum (*Capsicum annuum*), variety ‘Plato’; dark skin zucchini (*Cucurbita pepo*), variety ‘Blackjack’; firm white flesh nectarine (*Prunus persica var. nucipersica*), variety ‘Arctic Snow’; rockmelon (*Cucumis melo*), variety ‘Triumph’ and white skin honeydew melon (*Cucumis melo*), variety ‘Galaxy’. To minimise variation, each commodity was sourced from only one producer.

2.3.2 Irradiation treatment

The samples were exposed to target irradiation doses of 0Gy, 150Gy, 600Gy and 1000Gy from a Co^{60} source of gamma irradiation. There were three replications of each treatment dose undertaken. The irradiation temperature in the chamber during treatment was around 22-25°C, varying with the commodity. The boxes of produce were positioned on a rig parallel to the plaque source (Figure 1). Control and treatment produce were stored pre and post irradiation in a coldroom set at 10°C.

Figure 1. **Boxes of produce positioned for irradiation. Dosimeters attached on the outside of boxes of packed produce.**
Source: Radiation Technology, ANSTO.

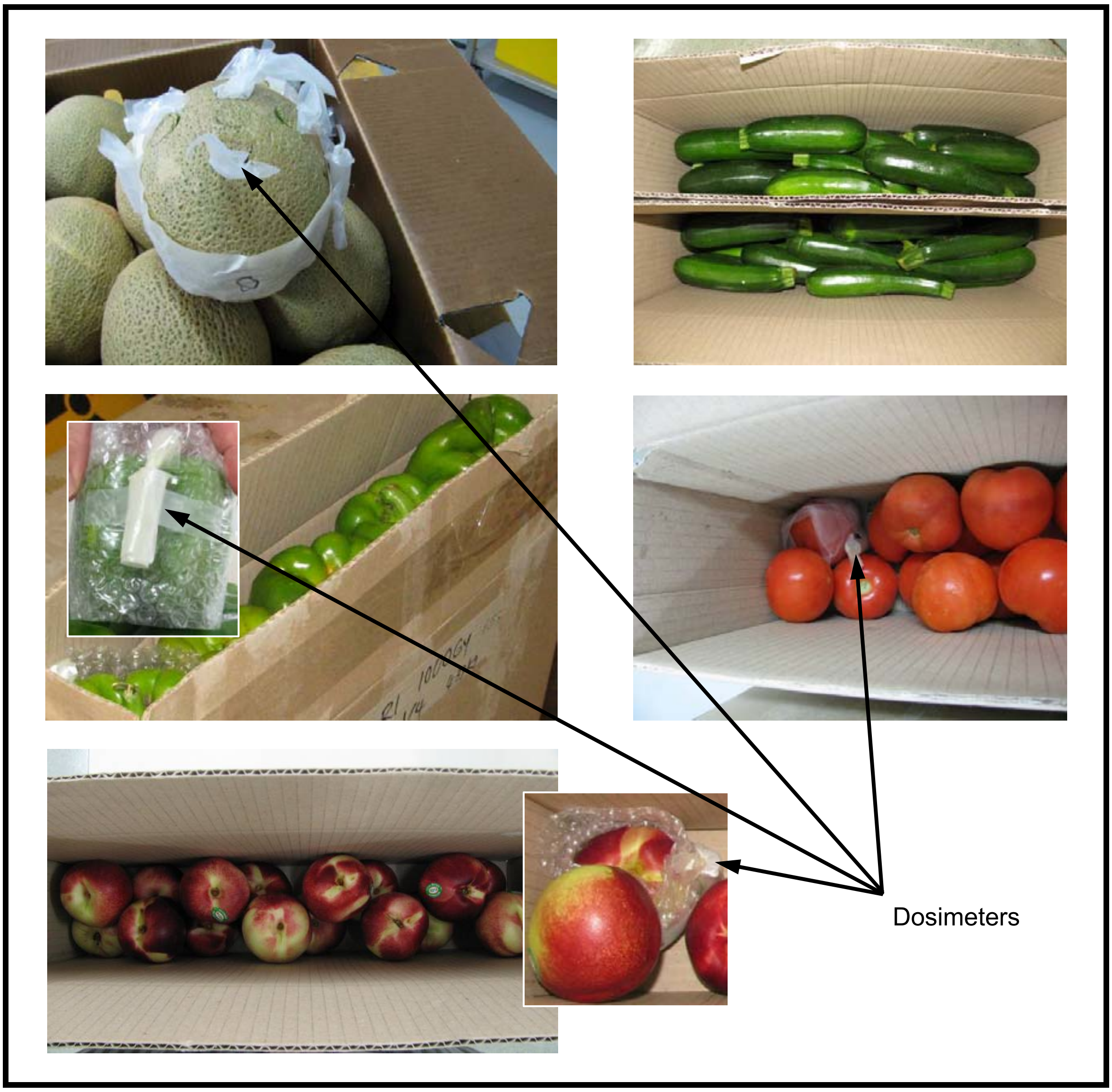

Figure 2. **Rockmelon, zucchini, capsicum, tomato and nectarine arranged in a cardboard box ready for irradiation. Dosimeter(s) attached to a piece of produce for monitoring doses received within the box.**
Source: Radiation Technology, ANSTO.

Radiation Technology, ANSTO maintains a quality management system that complies with ISO9001:2008 and ISO17025 and ISO/ASTM standards for dosimetry for radiation processing (ANSTO, 2011).

The irradiation doses were confirmed by dosimeters. Dosimeters (Frickes) were placed throughout the array of produce at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were situated at the front, the back and between fruits (Figure 2). Additional dosimeters were attached to the outside of each package for monitoring and to provide references to the minimum and maximum doses (Figure 1).

2.3.3 Chemical analysis

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

The samples were analysed at two occasions, after treatment and after a period in cold storage. The first assessment was a day after mean irradiation treatment and the second analysis at the end of the storage period (Table 1).

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

2.3.3.1 Moisture. Reference method AS2300.1.1

The moisture content is the percentage decrease in mass obtained on drying the material. This method is used to determine the percentage of water in a sample by drying the sample to a constant weight.

- Place homogenised sample in pre-dried, weighed dish.
- Include sand and a small rod in the dish, if necessary.
- Add sample. Macerate with the sand, if using.
- Dry at 102°C for 4 hours.
- Cool in a desiccator. Weigh.
- Return to the oven for one hour.
- Cool in a desiccator. Weigh.
- Repeat the drying process until constant weight is obtained.
- Calculate moisture (or total solids).

2.3.3.2 Ash. Reference method AS2300.1.5

Ash is determined as the percentage by mass of residue obtained after thorough ignition.

- Weigh sample into a clean crucible
- Dry and then burn off organic matter
- Ignite to 550°C, to a pale grey ash.
- Cool in a desiccator. Weigh.

2.3.3.3 Protein. Reference method AOAC 928.08

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

- Digest sample with sulphuric acid and catalyst.
- Add caustic to neutralise.
- Distil and collect the ammonia.
- Titrate ammonia and calculate as protein.

2.3.3.4 Dietary fibre. Reference Method AOAC 985.29

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

- The digested sample is treated with alcohol to precipitate soluble dietary fibre before filtering and residue is washed with alcohol and acetone, dried and weighed.
- The residue is corrected for protein and ash and calculated as dietary fibre.

2.3.3.5 Fat. Reference method AOAC 922.06

Fat was determined using the acid hydrolysis method. Crude fat was determined by extracting the fat from the sample using a solvent, then determining the weight of the fat recovered.

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

2.3.3.6 Fatty acid profile. Reference method AOAC 963.22

The fatty acid composition can contain a complex mixture of saturated, monounsaturated, and polyunsaturated fatty acids, each with a variety of carbon chain lengths. The analysis of fatty acids was performed by gas chromatography following the conversion of the fatty acids into their corresponding Methyl Esters (FAME).

- Cold extract fat from sample.
- Saponify fat.
- Methylate with boron trifluoride.
- Extract into heptane.
- Dry with anhydrous sodium sulphate.
- Inject onto gas chromatograph.
- Compare to standards for peak identification.
- Correct low molecular weight fats, if appropriate.
- Calculate area percent of FAME.

2.3.3.7 Sugars. Reference method AOAC 982.14

Sucrose, glucose, maltose and fructose were analysed by high performance liquid chromatography (HPLC), using refractive index detector.

- Run sugar standards and control.
- Extract sample into water.
- Calculate sugar levels from standards.
- Clarify with Carrez Reagents.
- Filter.
- Inject onto HPLC.
- Calculate sugar levels from standards.

2.3.3.8 Sodium. Reference method AOAC 985.35

Sodium was determined using the Atomic Absorption Spectrophotometer (AAS) Method.

- Homogenise sample.
- Ash sample at 560°C for 8 hours.
- Dissolve ash in 1:1 nitric cid, dry, re-ash.

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

2.3.3.9 Vitamin C (ascorbic acid). Reference method AOAC 985.33

The method used for Vitamin C (ascorbic acid) was by titration with coloured oxidation-reduction indicator 2, 6-Dichloroindophenol.

- Prepare standard.
- Standardise indophenol solution.
- Pipette aliquot of sample into conical flask.
- Complex sulphur dioxide, if necessary, with acetone.
- Add metaphosphoric acid solution and swirl.
- Titrate with the indophenol solution.
- Calculate ascorbic acid level.

2.3.3.10 Carbohydrates. Reference Method Food Standard Code 1.2.8

Carbohydrates are determined by difference.

2.3.3.11 Energy. Reference Method Food Standard Code 1.2.8

By calculation.

- Levels of individual components of the analysis are multiplied by the factors listed in Standard 1.2.8 of the Australian Food Standard code to establish the total energy level.

2.3.3.12 Beta-carotene. Reference Method VL292_alpha and beta Carotene in Foodstuffs

Determination by HPLC. Carotenes are sensitive to degradation caused by exposure to oxygen, heat and light.

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

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

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

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

2.3.4 Statistical analysis of chemical components

The chemical measurements for each commodity at Time 1 and at Time 2 after receiving irradiation doses of 0Gy, 150Gy, 600Gy and 1000Gy were analysed using analysis of variance (ANOVA). All statistical tests were performed at a 5% significance level.

To determine the effect of irradiation on the nutritional components for the fruits, each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD). A factorial analysis investigating the time by dose interaction has also been made using a 2-way ANOVA with time and dose as the main factors.

For some components, where all or the majority of data was censored (below the level of detection) the data have not been analysed. Where there were a minority of values censored, the analysis used the method of Taylor (1973). This procedure estimates the censored values iteratively using the information from the other observations in the experiment. A $\log_{10}$ transformation was required for several censored variables to improve the assumptions underlying the ANOVA and ensure sensible estimates of the censored values were obtained. The estimated values for the censored data are included in the calculation of the standard deviation to ensure it is not under-estimated.

The lower limits of detection were: for fat, saturated fat, mono-unsaturated fat, poly-unsaturated fat and trans fat and dietary fibre < 0.1g/100g; for sucrose < 0.2mg/100g; maltose and lactose were < 0.5g/100g and; beta-carotene was < 0.5μg/100g.

2.4 Results

2.4.1 Irradiation treatment – dosimetry

The results of dosimetry indicate that the doses received by each produce were as required. The average irradiation dose absorbed complies with the required specifications. The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2%.

Details for the irradiation treatment for the six commodities are provided in Appendices 1 and 2.

2.4.2 Tomato

High quality, oblate and firm tomatoes, variety 'Gourmet Swanson' were treated and the samples were analysed at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 14 days storage in a cold room set at 10°C.

Irradiation at all test doses did not affect the nutritional quality of tomato. The nutritional components of fresh whole tomato were not negatively affected by low dose irradiation (150Gy, 600Gy and 1000Gy) compared with the control sample, before storage and after 14 days storage. The effects of irradiation dose on the components at each time are summarised in Tables 2 and 3.

No significant dose effects on the nutritional components tested were found at either Time 1 (before storage) (Table 2) or Time 2 (fourteen days cold storage) (Table 3). Irradiation had no significant effects on ash, carbohydrates, dietary fibre, energy, fat profile, moisture, sodium, protein, total sugar, fructose, glucose and Vitamin C (ascorbic acid) and beta-carotene.

In the control sample, mean Vitamin C (ascorbic acid) detected after irradiation was 18.3mg/100g while the irradiated samples ranged between 17.0-18.0mg/100g (Table 2). After 14 days storage, mean Vitamin C (ascorbic acid) ranged between 16.3-25.0mg/100g (Table 3).

Fresh untreated tomato, variety 'Gourmet Swanson' contained a mean of 180.0μg/100g of beta-carotene, the 150Gy and 1000Gy irradiated samples contained means of 196.7μg/100g and 600Gy tomato contained a mean of 210.0μg/100g.

Table 2. Mean chemical measurements in 'Gourmet Swanson' tomato after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.57 (0.058)	0.57 (0.058)	0.50 (0.000)	0.53 (0.058)	0.455	0.045
Carbohydrates (g/100g)	3.27 (0.153)	3.07 (0.058)	3.23 (0.321)	3.40 (0.265)	0.426	0.187
Dietary fibre (g/100g)	0.73 (0.208)	1.00 (0.173)	0.93 (0.115)	0.93 (0.153)	0.263	0.125
Energy (kJ/100g)	80.7 (3.22)	79.7 (5.69)	84.0 (4.58)	88.3 (2.08)	0.210	3.87
Moisture (g/100g)	94.43 (0.115)	94.43 (0.208)	94.27 (0.153)	94.07 (0.153)	0.106	0.138
Protein (g/100g)	0.83 (0.058)	0.80 (0.173)	0.83 (0.058)	0.93 (0.058)	0.349	0.071
Sodium (mg/100g)	16.7 (2.89)	18.3 (2.89)	18.3 (2.89)	15.0 (5.00)	0.613	2.81
Fat (g/100g)	0.12 (0.067)	0.17 (0.058)	0.20 (0.000)	0.20 (0.000)	0.188	0.034
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	2.93 (0.058)	2.90 (0.173)	2.97 (0.058)	2.90 (0.173)	0.918	0.112
Fructose (g/100g)	1.57 (0.058)	1.53 (0.058)	1.60 (0.000)	1.53 (0.058)	0.455	0.045
Glucose (g/100g)	1.37 (0.058)	1.37 (0.115)	1.40 (0.000)	1.37 (0.115)	0.950	0.071
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	18.3 (5.03)	18.0 (1.00)	17.7 (1.53)	17.0 (1.73)	0.952	2.45
Beta-carotene (μg/100g)	180.0 (26.46)	196.7 (5.77)	210.0 (26.46)	196.7 (5.77)	0.475	17.85

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

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

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.47 (0.058)	0.57 (0.153)	0.53 (0.058)	0.47 (0.058)	0.455	0.071
Carbohydrates (g/100g)	3.07 (0.058)	2.80 (0.173)	2.93 (0.462)	3.17 (0.208)	0.202	0.156
Dietary fibre (g/100g)	0.90 (0.100)	0.90 (0.100)	0.70 (0.173)	0.77 (0.153)	0.133	0.085
Energy (kJ/100g)	84.3 (5.51)	85.7 (3.22)	77.3 (6.11)	77.7 (2.52)	0.065	3.03
Moisture (g/100g)	94.57 (0.153)	94.80 (0.346)	94.87 (0.551)	94.80 (0.173)	0.403	0.174
Protein (g/100g)	0.73 (0.058)	0.93 (0.321)	0.83 (0.058)	0.67 (0.115)	0.379	0.149
Sodium (mg/100g)	18.3 (2.89)	21.7 (2.89)	18.3 (2.89)	20.0 (5.00)	0.613	2.81
Fat (g/100g)	0.33 (0.153)	0.40 (0.173)	0.20 (0.100)	0.17 (0.058)	0.227	0.112
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total Sugars (g/100g)	2.87 (0.115)	2.70 (0.173)	2.70 (0.265)	2.90 (0.100)	0.396	0.139
Fructose (g/100g)	1.53 (0.058)	1.47 (0.115)	1.53 (0.115)	1.53 (0.058)	0.730	0.071
Glucose (g/100g)	1.30 (0.100)	1.23 (0.058)	1.20 (0.200)	1.33 (0.058)	0.482	0.089
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	25.0 (6.00)	19.3 (2.08)	16.3 (2.08)	16.7 (1.53)	0.108	3.19
Beta-carotene (μg/100g)	303.3 (58.60)	336.7 (47.26)	310.0 (17.32)	298.0 (80.57)	0.882	52.27

Standard deviations are presented in brackets below each mean.

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

Potentially there could be a time by dose interaction and a full factorial analysis is shown in Table 4. Exploration of the variation of treatment effect over time to partly understand the changes is presented.

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

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Ash (g/100g)	1	0.57	0.57	0.50	0.53	0.54	Day	0.288	0.030
	14	0.47	0.57	0.53	0.47	0.51	Irrad.	0.460	0.043
	Mean	0.52	0.57	0.52	0.50		Day x Irrad.	0.416	0.060
Carbohydrates (g/100g)	1	3.27	3.07	3.23	3.40	3.24a	Day	0.025	0.100
	14	3.07	2.80	2.93	3.17	2.99 b	Irrad.	0.136	0.141
	Mean	3.17	2.93	3.08	3.28		Day x Irrad.	0.986	0.199
Dietary fibre (g/100g)	1	0.73	1.00	0.93	0.93	0.90	Day	0.221	0.065
	14	0.90	0.90	0.70	0.77	0.82	Irrad.	0.448	0.092
	Mean	0.82	0.95	0.82	0.85		Day x Irrad.	0.191	0.130
Energy (kJ/100g)	1	80.7abc	79.7 bc	84.0abc	88.3a	83.2	Day	0.302	1.79
	14	84.3abc	85.7ab	77.3 c	77.7 c	81.2	Irrad.	0.794	2.53
	Mean	82.5	82.7	80.7	83.0		Day x Irrad.	0.014	3.58
Moisture (g/100g)	1	94.43	94.43	94.27	94.07	94.30 b	Day	<0.001	0.088
	14	94.57	94.80	94.87	94.80	94.76a	Irrad.	0.502	0.124
	Mean	94.50	94.62	94.57	94.43		Day x Irrad.	0.126	0.176
Protein (g/100g)	1	0.83	0.80	0.83	0.93	0.85	Day	0.346	0.060
	14	0.73	0.93	0.83	0.67	0.79	Irrad.	0.768	0.085
	Mean	078	0.87	0.83	0.80		Day x Irrad.	0.163	0.120
Sodium (g/100g)	1	16.7	18.3	18.3	15.0	17.1	Day	0.075	1.30
	14	18.3	21.7	18.3	20.0	19.6	Irrad.	0.502	1.84
	Mean	17.5	20.0	18.3	17.5		Day x Irrad.	0.575	2.60
Vitamin C (ascorbic acid) (mg/100g)	1	18.3	18.0	17.7	17.0	17.8	Day	0.259	1.35
	14	25.0	19.3	16.3	16.7	19.3	Irrad.	0.080	1.90
	Mean	21.7	18.7	17.0	16.8		Day x Irrad.	0.203	2.69
Beta-carotene (μg/100g)	1	180.0	196.7	210.0	196.7	195.8 b	Day	<0.001	18.18
	14	303.3	336.7	310.0	298.0	312.0a	Irrad.	0.758	25.71
	Mean	241.7	266.7	260.0	247.3		Day x Irrad.	0.841	36.36
Total sugars (g/100g)	1	2.93	2.90	2.97	2.90	2.92a	Day	0.042	0.060
	14	2.87	2.70	2.70	2.90	2.79 b	Irrad.	0.566	0.084
	Mean	2.90	2.80	2.83	2.90		Day x Irrad.	0.405	0.119

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Fructose (g/100g)	1	1.57	1.53	1.60	1.53	1.56	Day	0.169	0.029
	14	1.53	1.47	1.53	1.53	1.52	Irrad.	0.428	0.041
	Mean	1.55	1.50	1.57	1.53		Day x Irrad.	0.818	0.057
Glucose (g/100g)	1	1.37	1.37	1.40	1.37	1.37a	Day	0.016	0.040
	14	1.30	1.23	1.20	1.33	1.27 b	Irrad.	0.758	0.056
	Mean	1.33	1.30	1.30	1.35		Day x Irrad.	0.482	0.079
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.10	0.17	0.20	0.20	0.17 b	Day	0.018	0.040
	14	0.33	0.40	0.20	0.17	0.28a	Irrad.	0.350	0.057
	Mean	0.22	0.28	0.20	0.18		Day x Irrad.	0.055	0.080
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

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

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

Energy was the only component that showed a significant time by dose interaction in tomato. No significant differences were found over time for 0Gy, 150Gy and 600Gy samples, but a significant decrease in energy was observed for 1000Gy. However, no dose was significantly different to the control within each time.

Table 4 also presents results where the interaction of time and dose was not significant but there was a significant main effect of time. Significant main effect of time was found for beta-carotene, carbohydrates, moisture, fat, total sugars and glucose.

Mean beta-carotene increased from 195.8μg/100g to 312.0μg/100g after 14 days cold storage at 10°C.

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

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

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

Ripening in tomato harvested when mature is accompanied by a rapid rise in respiration rate, followed by a slowing down as the fruit ripens and develops good eating quality. Ripeness is followed by senescence and breakdown of the fruit, which is the normal aging of produce. These changes in mean values are thought to be responses from general fruit senescence.

2.4.3 Capsicum

Medium dark green, firm, blocky capsicum fruit, variety 'Plato' were treated on 1 March 2011. The samples were analysed on two occasions; the first analysis (Time 1) one day after irradiation treatment and the second analysis (Time 2) after 21 days storage in a cold room set at 8°C.

Overall, there was no significant effect of dose on all the nutritional components in capsicum one day after irradiation (Table 5). Irradiation had no significant effects on ash, carbohydrates, dietary fibre, energy, fat profile, moisture, sodium, protein, total sugar, fructose, glucose, Vitamin C (ascorbic acid) and beta-carotene.

A significant dose effect at Time 2 was found for moisture, poly-unsaturated fat and fructose after 21 days in cold storage (Table 6). For moisture, the mean after exposure to 1000Gy (93.97g/100g) was significantly lower than the control mean (94.30mg/100g). The mean poly-unsaturated fat content was significantly lower after exposure to 150Gy compared to 600Gy and 1000Gy, but no irradiation treatments were significantly different to the control mean.

Mean Vitamin C (ascorbic acid) in the control sample was 82.7mg/100g one day after irradiation while mean Vitamin C (ascorbic acid) in the irradiated samples ranged between 61.0-76.3mg/100g (Table 5). This decrease in mean Vitamin C in the irradiated samples is not significantly different to the control sample.

Table 7 shows the means for the time by dose interactions for capsicum. Significant interactions were found for carbohydrates, energy, moisture, sodium, total sugars, fructose and glucose. In each case a significant difference was found between the controls at Time 1 and Time 2, but no significant difference was found between the 1000Gy measurements at Time 1 and Time 2. This suggests the mean level of these compounds changed significantly for untreated fruit after storage, but not for capsicums treated with a "higher" dose.

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

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.37 (0.058)	0.50 (0.100)	0.47 (0.058)	0.50 (0.000)	0.181	0.059
Carbohydrates (g/100g)	3.43 (0.115)	3.30 (0.200)	3.33 (0.058)	3.20 (0.100)	0.339	0.116
Dietary fibre (g/100g)	1.60 (0.100)	1.57 (0.208)	1.57 (0.115)	1.43 (0.058)	0.322	0.087
Energy (kJ/100g)	95.3 (3.06)	91.7 (4.16)	92.7 (1.53)	88.0 (3.00)	0.089	2.29
Moisture (g/100g)	93.43 (0.208)	93.47 (0.379)	93.50 (0.200)	93.77 (0.252)	0.370	0.193
Protein (g/100g)	0.97 (0.058)	0.93 (0.058)	0.87 (0.115)	0.87 (0.058)	0.362	0.062
Sodium (mg/100g)	8.3 (2.89)	16.7 (2.89)	16.7 (2.89)	15.0 (5.00)	0.070	2.81
Fat (g/100g)	0.200 (0.0000)	0.200 (0.0000)	0.220 (0.0346)	0.203 (0.0058)	0.517	0.0147
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	0.10 (0.000)	0.13 (0.058)	0.12 (0.073)	0.10 (0.000)	0.795	0.039
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	2.93 (0.058)	2.83 (0.115)	2.73 (0.153)	2.60 (0.200)	0.122	0.118
Fructose (g/100g)	1.43 (0.058)	1.40 (0.000)	1.40 (0.100)	1.30 (0.100)	0.349	0.071
Glucose (g/100g)	1.47 (0.058)	1.40 (0.100)	1.37 (0.058)	1.30 (0.100)	0.204	0.068
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	82.7 (35.80)	61.0 (26.85)	62.7 (11.59)	76.3 (0.58)	0.701	21.26
Beta-carotene (μg/100g)	62.0 (19.93)	47.7 (15.28)	48.7 (25.15)	52.0 (17.69)	0.831	17.17

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

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

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.40 (0.000)	0.40 (0.000)	0.30 (0.100)	0.37 (0.058)	0.216	0.047
Carbohydrates (g/100g)	2.90 (0.100)	3.07 (0.153)	3.00 (0.200)	3.23 (0.153)	0.218	0.141
Dietary fibre (g/100g)	1.27 (0.153)	1.27 (0.058)	1.23 (0.208)	1.27 (0.058)	0.990	0.122
Energy (kJ/100g)	82.7 (3.51)	84.3 (0.58)	86.3 (2.08)	89.7 (5.13)	0.123	2.50
Moisture (g/100g)	94.30a (0.100)	94.20ab (0.100)	94.40a (0.173)	93.97b (0.208)	0.046	0.118
Protein (g/100g)	0.90 (0.000)	0.80 (0.000)	0.83 (0.058)	0.87 (0.058)	0.070	0.030
Sodium (mg/100g) #	18.9 (8.66)	7.3 (3.55)	11.4 (2.89)	11.4 (2.89)	0.122	0.14
Fat (g/100g)	0.243 (0.0351)	0.230 (0.0265)	0.267 (0.0208)	0.270 (0.0361)	0.477	0.0279
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	0.16ab (0.067)	0.10 b (0.000)	0.20a (0.000)	0.20a (0.000)	0.032	0.028
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	1.73 (0.306)	2.37 (0.058)	2.10 (0.608)	2.70 (0.173)	0.057	0.275
Fructose (g/100g)	0.83 c (0.208)	1.27ab (0.058)	1.13 bc (0.379)	1.53a (0.058)	0.022	0.156
Glucose (g/100g)	0.90 (0.100)	1.10 (0.000)	0.97 (0.231)	1.23 (0.058)	0.070	0.105
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	127.7 (39.94)	97.0 (1.73)	109.3 (30.67)	132.0 (21.07)	0.449	22.86
Beta-carotene (μg/100g)	143.3 (15.28)	136.7 (15.28)	130.0 (20.00)	130.0 (10.00)	0.718	13.26

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different (p>0.05).

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

 # Analysed on the log_{10} scale. Reported means are back-transformed. SED is on the log_{10} scale.

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

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Ash (g/100g)	1	0.37	0.50	0.47	0.50	0.46a	Day	0.003	0.025
	14	0.40	0.40	0.30	0.37	0.37 b	Irrad.	0.178	0.035
	Mean	0.38	0.45	0.38	0.43		Day x Irrad.	0.062	0.050
Carbohydrates (g/100g)	1	3.43a	3.30ab	3.33a	3.20abc	3.32a	Day	<0.001	0.061
	14	2.90 d	3.07 bcd	3.00 cd	3.23abc	3.05 b	Irrad.	0.929	0.087
	Mean	3.17	3.18	3.17	3.22		Day x Irrad.	0.038	0.123
Dietary fibre (g/100g)	1	1.60	1.57	1.57	1.43	1.54a	Day	<0.001	0.056
	14	1.27	1.27	1.23	1.27	1.26 b	Irrad.	0.747	0.079
	Mean	1.43	1.42	1.40	1.35		Day x Irrad.	0.688	0.112
Energy (kJ/100g)	1	95.3a	91.7abc	92.7ab	88.0 bcde	91.9a	Day	<0.001	1.35
	14	82.7 e	84.3 de	86.3 cde	89.7abcd	85.8 b	Irrad.	0.885	1.91
	Mean	89.0	88.0	89.5	88.8		Day x Irrad.	0.017	2.70
Moisture (g/100g)	1	93.43 d	93.47 d	93.50 d	93.77 cd	93.54 b	Day	<0.001	0.088
	14	94.30ab	94.20ab	94.40a	93.97 bc	94.22a	Irrad.	0.813	0.125
	Mean	93.87	93.83	93.95	93.87		Day x Irrad.	0.049	0.177
Protein (g/100g)	1	0.97	0.93	0.87	0.87	0.91a	Day	0.041	0.026
	14	0.90	0.80	0.83	0.87	0.85 b	Irrad.	0.157	0.037
	Mean	0.93	0.87	0.85	0.87		Day x Irrad.	0.346	0.052
Sodium (g/100g)	1	8.3 cd	16.7ab	16.7ab	15.0abc	14.2	Day	0.410	1.79
	14	20.0a	7.3 d	11.7 bcd	11.7 bcd	12.6	Irrad.	0.798	2.53
	Mean	14.2	12.0	14.2	13.3		Day x Irrad.	0.005	3.58
Vitamin C (ascorbic acid) (mg/100g)	1	82.7	61.0	62.7	76.3	70.7 b	Day	<0.001	10.31
	14	127.7	97.0	109.3	132.0	116.5a	Irrad.	0.230	14.59
	Mean	105.2	79.0	86.0	104.2		Day x Irrad.	0.926	20.63
Beta-carotene (µg/100g)	1	62.0	47.7	48.7	52.0	52.6 b	Day	<0.001	7.12
	14	143.3	136.7	130.0	130.0	135.0a	Irrad.	0.558	10.07
	Mean	102.7	92.2	89.3	91.0		Day x Irrad.	0.955	14.24
Total sugars (g/100g)	1	2.93a	2.83ab	2.73ab	2.60ab	2.77	Day	<0.001	0.111
	14	1.73 d	2.37 bc	2.10 cd	2.70ab	2.22	Irrad.	0.189	0.157
	Mean	2.33	2.60	2.42	2.65		Day x Irrad.	0.008	0.222

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Fructose (g/100g)	1	1.43a	1.40ab	1.40ab	1.30ab	1.38a	Day	0.012	0.066
	14	0.83 c	1.27ab	1.13 b	1.53a	1.19 b	Irrad.	0.052	0.093
	Mean	1.13	1.33	1.27	1.42		Day x Irrad.	0.005	0.132
Glucose (g/100g)	1	1.47a	1.40ab	1.37ab	1.30ab	1.38a	Day	<0.001	0.043
	14	0.90 e	1.10 cd	0.97 de	1.23 bc	1.05 b	Irrad.	0.314	0.061
	Mean	1.18	1.25	1.17	1.27		Day x Irrad.	0.008	0.086
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.20	0.20	0.22	0.20	0.21 b	Day	<0.001	0.011
	14	0.24	0.23	0.27	0.27	0.25a	Irrad.	0.252	0.015
	Mean	0.22	0.22	0.24	0.24		Day x Irrad.	0.681	0.021
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	0.10	0.13	0.12	0.10	0.11 b	Day	0.010	0.017
	14	0.16	0.10	0.20	0.20	0.17a	Irrad.	0.274	0.024
	Mean	0.13	0.12	0.16	0.15		Day x Irrad.	0.067	0.034
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

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

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

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

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

In this study, Vitamin C (ascorbic acid) increased for all capsicum samples after storage. A significant effect of time was found for Vitamin C (ascorbic acid), increasing from a mean of 70.7mg/100g to 116.5g/100g after storage at 8°C for three weeks. The mean Vitamin C (ascorbic acid) in the control increased from 82.7mg/100g to 127.7mg/100g.

Mean beta-carotene ranged between 47.7-62.0µg/100g before storage and increased levels were observed across all irradiated samples (130.0-136.7µg/100g) and the control sample (143.3µg/100g) after three weeks storage (Tables 5 and 6). Mean beta-carotene in capsicum increased in storage from 52.6µg/100g to 135.0µg/100g, with the relative increase in irradiated samples being greater than in the control sample (Table 7).

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

2.4.4 Zucchini

Green skin zucchini, variety 'Blackjack' were treated and analysed at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2), after seven days storage in a coldroom set at 8°C.

Irradiation at all test doses did not affect the nutritional quality of zucchini. The nutritional components of fresh whole zucchini were not negatively affected by low dose irradiation (150Gy, 600Gy and 1000Gy) compared with the control sample at one day after irradiation. The effects of irradiation dose on the components are summarised in Table 8.

No significant dose effects were found in ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars, Vitamin C (ascorbic acid) and beta-carotene one day after treatment (Table 8). Significant differences between doses however, were found after seven days for carbohydrates, dietary fibre and total sugars (Table 9). In all cases, the mean values were higher for the treated samples than the untreated control.

There were no significant differences in mean Vitamin C (ascorbic acid) levels detected between irradiated zucchini samples and the untreated control. At Time 1 mean Vitamin C (ascorbic acid) was 6.20mg/100g in the control sample compared to 12.60mg/100g, 8.90mg/100g and 8.37mg/100g in the 150Gy, 600Gy and 1000Gy samples, respectively (Table 8). After seven days storage, mean Vitamin C (ascorbic acid) was 7.03mg/100g for the control sample and the values varied between 8.53mg/100g and 11.13mg/100g in the irradiated zucchini samples.

Beta-carotene of the irradiated samples was not significantly different to the control sample just after treatment and after seven days in cold storage (Table 8 and Table 9). Time in storage however did affect these levels. In all cases, mean beta-carotene increased, with the greatest increase observed in the 150Gy sample (Table 10).

Dietary fibre was significantly higher after storage for doses 150, 600 and 1000Gy, and also higher for the control samples but not significantly so.

Table10 presents results where the interaction of time and dose was significant. Significant interactions were found for dietary fibre, total sugars and fructose. The changes in means of total sugars and fructose were greater for the untreated fruit after storage than for treated zucchini.

Table 8. Mean chemical measurements in zucchini, variety 'Blackjack' after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.57 (0.115)	0.67 (0.058)	0.63 (0.058)	0.60 (0.100)	0.244	0.045
Carbohydrates (g/100g)	1.53 (0.208)	1.57 (0.058)	1.60 (0.100)	2.00 (0.557)	0.255	0.233
Dietary fibre (g/100g)	0.30 (0.100)	0.23 (0.058)	0.30 (0.100)	0.23 (0.058)	0.519	0.059
Energy (kJ/100g)	66.7 (5.86)	64.7 (2.52)	64.7 (3.22)	69.7 (7.37)	0.455	3.34
Moisture (g/100g)	95.73 (0.404)	95.87 (0.153)	95.93 (0.153)	95.63 (0.569)	0.498	0.201
Protein (g/100g)	1.33 (0.058)	1.20 (0.173)	1.13 (0.153)	1.07 (0.058)	0.094	0.087
Sodium (mg/100g)	25.0 (5.00)	25.0 (8.66)	31.7 (10.41)	26.7 (2.89)	0.739	6.80
Fat (g/100g)	0.43 (0.058)	0.43 (0.058)	0.43 (0.058)	0.43 (0.058)	1.000	0.041
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	0.20 (0.000)	0.20 (0.000)	0.17 (0.058)	0.27 (0.058)	0.138	0.036
Saturated fat (g/100g)	0.23 (0.058)	0.20 (0.000)	0.23 (0.058)	0.20 (0.000)	0.455	0.027
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	1.37 (0.058)	1.30 (0.200)	1.33 (0.115)	1.63 (0.231)	0.214	0.152
Fructose (g/100g)	0.77 (0.058)	0.70 (0.100)	0.73 (0.058)	0.87 (0.115)	0.256	0.077
Glucose (g/100g)	0.67 (0.058)	0.60 (0.100)	0.67 (0.058)	0.77 (0.115)	0.297	0.078
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	6.20 (8.404)	12.60 (2.816)	8.90 (2.326)	8.37 (1.210)	0.303	3.052
Beta-carotene (μg/100g)	216.7 (32.15)	200.0 (10.00)	200.0 (30.06)	146.7 (28.87)	0.140	26.28

Standard deviations are presented in brackets below each mean.

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

Table 9. Mean chemical measurements in untreated and irradiated zucchini, variety 'Blackjack' after seven days (Time 2) cold storage at 8°C.

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.67 (0.058)	0.60 (0.000)	0.63 (0.058)	0.60 (0.000)	0.189	0.030
Carbohydrates (g/100g)	0.83 b (0.153)	1.30a (0.100)	1.13a (0.058)	1.10ab (0.173)	0.040	0.119
Dietary fibre (g/100g)	0.37 b (0.058)	0.37 b (0.058)	0.53a (0.058)	0.57a (0.058)	0.015	0.053
Energy (kJ/100g)	46.0 (4.36)	52.0 (2.65)	50.7 (3.22)	49.3 (3.51)	0.366	3.23
Moisture (g/100g)	96.53 (0.289)	96.27 (0.231)	96.23 (0.252)	96.27 (0.231)	0.539	0.222
Protein (g/100g)	1.57 (0.115)	1.37 (0.058)	1.37 (0.153)	1.30 (0.100)	0.129	0.097
Sodium (mg/100g)	18.3 (5.77)	41.7 (17.56)	30.0 (5.00)	31.7 (10.41)	0.237	9.91
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	0.41 b (0.165)	0.90a (0.173)	0.77a (0.115)	0.73a (0.115)	0.042	0.129
Fructose (g/100g)	0.30 (0.100)	0.53 (0.058)	0.43 (0.058)	0.47 (0.058)	0.055	0.065
Glucose (g/100g)	0.16 (0.123)	0.40 (0.100)	0.33 (0.058)	0.30 (0.100)	0.144	0.089
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	7.03 (9.419)	8.53 (2.470)	9.63 (1.124)	11.13 (3.308)	0.850	4.778
Beta-carotene (μg/100g)	230.0 (30.00)	310.0 (52.92)	226.7 (55.08)	176.7 (5.77)	0.062	37.74

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different (p>0.05).

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

Table 10. Mean chemical measurements in untreated and irradiated zucchini (150Gy, 600Gy and 1000Gy), variety 'Blackjack' before storage (Time 1) and after seven days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Ash (g/100g)	1	0.57	0.67	0.63	0.60	0.62	Day	0.699	0.021
	14	0.67	0.60	0.63	0.60	0.62	Irrad.	0.644	0.030
	Mean	0.62	0.63	0.63	0.60		Day x Irrad.	0.090	0.042
Carbohydrates (g/100g)	1	1.53	1.57	1.60	2.00	1.67a	Day	<0.001	0.095
	14	0.83	1.30	1.13	1.10	1.09 b	Irrad.	0.095	0.135
	Mean	1.18	1.43	1.37	1.55		Day x Irrad.	0.149	0.191
Dietary fibre (g/100g)	1	0.30 bc	0.23 c	0.30 bc	0.23 c	0.27 b	Day	<0.001	0.027
	14	0.37 b	0.37 b	0.53a	0.57a	0.46a	Irrad.	0.028	0.039
	Mean	0.33 bc	0.30 c	0.42a	0.40ab		Day x Irrad.	0.020	0.055
Energy (kJ/100g)	1	66.7	64.7	67.7	69.7	66.4a	Day	<0.001	1.70
	14	46.0	52.0	50.7	49.3	49.5 b	Irrad.	0.624	2.41
	Mean	56.3	58.3	57.7	59.5		Day x Irrad.	0.257	3.41
Moisture (g/100g)	1	95.73	95.87	95.93	95.63	95.79 b	Day	<0.001	0.111
	14	96.53	96.27	96.23	96.27	96.33a	Irrad.	0.698	0.158
	Mean	96.13	96.07	96.08	95.95		Day x Irrad.	0.410	0.223
Protein (g/100g)	1	1.33	1.20	1.13	1.07	1.18 b	Day	<0.001	0.044
	14	1.57	1.37	1.37	1.30	1.40a	Irrad.	0.005	0.062
	Mean	1.45a	1.28 b	1.25 b	1.18 b		Day x Irrad.	0.930	0.087
Sodium (g/100g)	1	25.0	25.0	31.7	26.7	27.1	Day	0.421	4.02
	14	18.3	41.7	30.0	31.7	30.4	Irrad.	0.243	5.69
	Mean	21.7	33.3	30.8	29.2		Day x Irrad.	0.240	8.04
Vitamin C (ascorbic acid) (mg/100g)	1	6.20	12.60	8.90	8.37	9.02	Day	0.973	1.921
	14	7.03	8.53	9.63	11.13	9.08	Irrad.	0.519	2.716
	Mean	6.62	10.57	9.27	9.75		Day x Irrad.	0.641	3.841
Beta-carotene (μg/100g)	1	216.7	200.0	200.0	146.7	190.8 b	Day	0.010	15.09
	14	230.0	310.0	226.7	176.7	235.8a	Irrad.	0.005	21.34
	Mean	223.3a	255.0a	213.3a	161.7 b		Day x Irrad.	0.144	30.18
Total sugars (g/100g)	1	1.37 cd	1.30 c	1.33 c	1.63 d	1.41a	Day	<0.001	0.066
	14	0.41a	0.90 b	0.77 b	0.73 b	0.70 b	Irrad.	0.046	0.094
	Mean	0.89 b	1.10a	1.05ab	1.18a		Day x Irrad.	0.030	0.133

Variable	Day	Irradiation dose (Gy) 0	150	600	1000	Mean	ANOVAs Factor	p-value	SED
Fructose (g/100g)	1	0.77ab	0.70 b	0.73ab	0.87a	0.77a	Day	<0.001	0.033
	14	0.30 d	0.53 c	0.43 cd	0.47 c	0.43 b	Irrad.	0.075	0.047
	Mean	0.53	0.62	0.58	0.67		Day x Irrad.	0.033	0.066
Glucose (g/100g)	1	0.67	0.60	0.67	0.77	0.68a	Day	<0.001	0.039
	14	0.17	0.40	0.33	0.30	0.30 b	Irrad.	0.247	0.056
	Mean	0.42	0.50	0.50	0.53		Day x Irrad.	0.067	0.078
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.43	0.43	0.43	0.43		Day		
	14	C	C	C	C		Irrad.	1.000	0.041
	Mean						Day x Irrad.		
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	0.20	0.20	0.17	0.27		Day		
	14	C	C	C	C		Irrad.	0.138	0.036
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	0.23	0.20	0.23	0.20		Day		
	14	C	C	C	C		Irrad.	0.455	0.027
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

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

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

Mean carbohydrates ranged from 1.53-2.00g/100g before storage, decreasing to 0.83-1.30g/100g after seven days in storage. The decrease in carbohydrates was greater in the untreated zucchini sample. The control carbohydrates mean after seven days storage (0.83g/100g) was significantly lower than the means for 150Gy and 600Gy.

While there were no significant differences in mean total sugars between doses before storage (1.30-1.63g/100g), the mean total sugar content for the control (0.41g/100g) after seven days was found to be significantly lower than the means for all other doses (150Gy, 600Gy and 1000Gy). A significant main effect of time on total sugars was observed; decreasing from a mean of 1.41g/100g to 0.70g/100g (Table 10).

Storage time had a significant effect on carbohydrates, dietary fibre, energy, moisture, protein, beta-carotene and total sugars (both fructose and glucose decreased in storage). All components increased with storage except for carbohydrates, total sugars (both fructose and glucose) and energy.

2.4.5 Nectarine

White flesh, medium-large, rounded nectarine, variety ‘Arctic Snow’ were analysed at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 21 days storage in a coldroom set at 4°C.

Nectarine fruit investigated in this study were very firm. The skin surface was white with a red blush and a hint of green. Nectarine (like honeydew and rockmelon) can ripen in appearance but not in sweetness after picking. The samples were free from defects. The flesh was firm and white, some with a hint of green. Fruit are often delivered in the less mature stage for longer shelf life.

Irradiation had no significant effect on the majority of nutritional components in nectarine analysed in this study one day after treatment, except for fat, poly-unsaturated fat and sugar profile (fructose, glucose and sucrose) (Table 11). For fat, poly-unsaturated fat and sucrose the mean for the 1000Gy was significantly lower than the control dose (0Gy) and lower doses. On the other hand, mean glucose and fructose was significantly higher for fruit treated at 1000Gy than untreated nectarine and the lower doses.

After 21 days storage, no significant differences were detected in ash, carbohydrates, energy, dietary fibre, moisture, protein, fat, total sugars, glucose, sucrose and Vitamin C (ascorbic acid) between untreated nectarine and irradiated nectarine (Table 12). The censored values for mono-unsaturated fat, poly-unsaturated fat and trans fat are <0.1g/100g and < 0.5μg/100g for beta-carotene.

Mean sodium content in untreated nectarine (21.7mg/100g) was significantly lower than the 600Gy (40.0mg/100g) and 1000Gy (43.3mg/100g) irradiated nectarine (Table 12).

Mean fructose was significantly lower in the control fruit compared to all other doses (Table 12).

There was a significant time effect detected in Vitamin C (ascorbic acid). Untreated and treated nectarines contained 1.37-2.00mg/100g Vitamin C (ascorbic acid) before storage whereas after 21 days, increased values for Vitamin C (ascorbic acid) were detected (4.37-6.33mg/100g). However, no significant differences were detected between untreated and irradiated samples within each time.

Table 13 presents the analysis investigating the time by dose interaction using a 2-way ANOVA with time and dose as the main factors.

There was no time by dose interaction, main dose or time effect on total sugars but there were some changes in fructose, sucrose and glucose. Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher with irradiated nectarine after 21 days.

Table 11. Mean chemical measurements in nectarine, variety 'Arctic Snow' one day after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.50 (0.100)	0.50 (0.100)	0.43 (0.058)	0.50 (0.000)	0.538	0.053
Carbohydrates (g/100g)	10.17 (0.723)	10.20 (0.173)	9.97 (0.603)	9.60 (0.361)	0.351	0.339
Dietary fibre (g/100g)	1.67 (0.289)	1.73 (0.115)	1.70 (0.100)	1.57 (0.058)	0.673	0.139
Energy (kJ/100g)	222.3 (13.32)	216.7 (2.89)	214.0 (11.36)	201.1 (7.81)	0.077	6.54
Moisture (g/100g)	86.13 (1.026)	86.37 (0.208)	86.67 (0.777)	87.23 (0.416)	0.222	0.481
Protein (g/100g)	1.10 (0.436)	0.77 (0.058)	0.80 (0.100)	0.70 (0.100)	0.278	0.196
Sodium (mg/100g)	30.0 (8.66)	30.0 (5.00)	33.3 (7.64)	31.7 (7.64)	0.913	5.49
Fat (g/100g)	0.47a (0.058)	0.43a (0.058)	0.47a (0.058)	0.37 b (0.058)	0.016	0.024
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	0.20a (0.000)	0.17a (0.058)	0.12ab (0.070)	0.05 b (0.043)	0.037	0.038
Saturated fat (g/100g)	0.23 (0.058)	0.20 (0.100)	0.30 (0.173)	0.27 (0.115)	0.742	0.093
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	8.33 (0.451)	8.37 (0.306)	8.43 (0.473)	7.80 (0.100)	0.212	0.290
Fructose (g/100g)	1.03 b (0.153)	1.00 b (0.000)	1.07 b (0.153)	1.50a (0.100)	0.001	0.073
Glucose (g/100g)	0.87 b (0.153)	0.83 b (0.058)	0.93 b (0.115)	1.20a (0.100)	0.005	0.065
Sucrose (g/100g)	6.40a (0.200)	6.53a (0.321)	6.43a (0.208)	5.17 b (0.115)	0.002	0.208
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	1.37 (0.252)	1.67 (0.306)	2.00 (0.854)	2.00 (0.656)	0.594	0.521
Beta-carotene (μg/100g)	C	C	C	C		

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different ($p>0.05$).

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

Table 12. Mean chemical measurements in untreated and irradiated nectarine, variety 'Arctic Snow' after 21 days cold storage (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.50 (0.000)	0.53 (0.115)	0.57 (0.058)	0.53 (0.058)	0.714	0.056
Carbohydrates (g/100g)	9.93 (0.651)	9.90 (1.136)	9.17 (0.551)	9.67 (1.595)	0.842	0.956
Dietary fibre (g/100g)	1.70 (0.100)	1.67 (0.321)	1.57 (0.058)	1.53 (0.231)	0.619	0.141
Energy (kJ/100g)	196.3 (7.23)	199.7 (19.35)	188.7 (11.06)	194.3 (27.47)	0.907	15.44
Moisture (g/100g)	87.17 (0.462)	86.97 (1.210)	87.63 (0.611)	87.43 (1.858)	0.907	0.980
Protein (g/100g)	0.60 (0.346)	0.77 (0.153)	0.90 (0.100)	0.73 (0.058)	0.481	0.181
Sodium (mg/100g)	21.7 c (5.77)	28.3 bc (10.41)	40.0ab (5.00)	43.3a (2.89)	0.017	5.09
Fat (g/100g)	0.049 (0.0449)	0.133 (0.0252)	0.110 (0.0466)	0.118 (0.0598)	0.234	0.0380
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	8.13 (0.764)	8.80 (1.058)	8.37 (0.473)	8.40 (1.229)	0.887	0.856
Fructose (g/100g)	1.40 b (0.100)	1.90a (0.173)	1.80a (0.100)	1.83a (0.115)	0.010	0.103
Glucose (g/100g)	1.17 (0.153)	1.37 (0.153)	1.30 (0.000)	1.33 (0.115)	0.233	0.090
Sucrose (g/100g)	5.57 (0.757)	5.57 (0.907)	5.23 (0.321)	5.23 (1.097)	0.941	0.764
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	4.37 (0.945)	5.57 (1.823)	6.00 (2.138)	6.33 (1.106)	0.518	1.324
Beta-carotene (μg/100g)	C	C	C	C		

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different (p>0.05).

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

Table 13. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) nectarine, variety 'Arctic Snow' before storage (Time 1) and after 21 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Ash (g/100g)	1	0.50	0.50	0.43	0.50	0.48	Day	0.073	0.026
	14	0.50	0.53	0.57	0.53	0.53	Irrad.	0.935	0.036
	Mean	0.50	0.52	0.50	0.52		Day x Irrad.	0.328	0.052
Carbohydrates (g/100g)	1	10.17	10.20	9.97	9.60	9.98	Day	0.356	0.332
	14	9.93	9.90	9.17	9.67	9.67	Irrad.	0.614	0.469
	Mean	10.05	10.05	9.57	9.63		Day x Irrad.	0.830	0.664
Dietary fibre (g/100g)	1	1.67	1.73	1.70	1.57	1.67	Day	0.463	0.066
	14	1.70	1.67	1.57	1.53	1.62	Irrad.	0.408	0.094
	Mean	1.68	1.70	1.63	1.55		Day x Irrad.	0.843	0.133
Energy (kJ/100g)	1	222.3	216.7	214.0	201.0	213.5a	Day	0.004	5.50
	14	196.3	199.7	188.7	194.3	164.8 b	Irrad.	0.412	7.78
	Mean	209.3	208.2	201.3	197.7		Day x Irrad.	0.582	11.00
Moisture (g/100g)	1	86.13	86.37	86.67	87.23	86.60	Day	0.071	0.358
	14	87.17	86.97	87.63	87.43	87.30	Irrad.	0.452	0.506
	Mean	86.65	86.67	87.15	87.33		Day x Irrad.	0.834	0.716
Protein (g/100g)	1	1.10	0.77	0.80	0.70	0.84	Day	0.334	0.092
	14	0.60	0.77	0.90	0.73	0.75	Irrad.	0.678	0.129
	Mean	0.85	0.77	0.85	0.72		Day x Irrad.	0.126	0.183
Sodium (g/100g)	1	30.0	30.0	33.3	31.7	31.2	Day	0.421	2.51
	14	21.7	28.3	40.0	43.3	33.3	Irrad.	0.013	3.56
	Mean	25.8 c	29.2 bc	36.7ab	37.5a		Day x Irrad.	0.061	5.03
Vitamin C (ascorbic acid) (mg/100g)	1	1.37	1.67	2.00	2.00	1.76 b	Day	<0.001	0.497
	14	4.37	5.57	6.00	6.33	5.57a	Irrad.	0.297	0.702
	Mean	2.87	3.62	4.00	4.17		Day x Irrad.	0.804	0.993
Beta-carotene (µg/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Total sugars (g/100g)	1	8.33	8.37	8.43	7.80	8.23	Day	0.528	0.296
	14	8.13	8.80	8.37	8.40	8.43	Irrad.	0.689	0.419
	Mean	8.23	8.58	8.40	8.10		Day x Irrad.	0.739	0.592

Variable	Day	Irradiation dose (Gy) 0	150	600	1000	Mean	ANOVAs Factor	p-value	SED
Fructose (g/100g)	1	1.03 c	1.00 c	1.07 c	1.50 b	1.15 b	Day	<0.001	0.043
	14	1.40 bc	1.90abc	1.80abc	1.83a	1.73a	Irrad.	<0.001	0.061
	Mean	1.22 c	1.45 b	1.43 b	1.67a		Day x Irrad.	<0.001	0.086
Glucose (g/100g)	1	0.87 c	0.83 c	0.93 c	1.20ab	0.96 b	Day	<0.001	0.039
	14	1.17 b	1.37a	1.30ab	1.33ab	1.29a	Irrad.	0.004	0.055
	Mean	1.02 b	1.10 b	1.12 b	1.27a		Day x Irrad.	0.021	0.078
Sucrose (kJ/100g)	1	6.40	6.53	6.43	5.17	6.13a	Day	0.014	0.261
	14	5.57	5.57	5.23	5.23	5.40 b	Irrad.	0.131	0.369
	Mean	5.98	6.05	5.83	5.20		Day x Irrad.	0.370	0.521
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	0.467abcd	0.433abc	0.467abcd	0.367 b	0.433a	Day	<0.001	0.0178
	14	0.051 d	0.133 c	0.107 cd	0.123 cd	0.104 b	Irrad.	0.325	0.0252
	Mean	0.259	0.283	0.287	0.245		Day x Irrad.	0.023	0.0357
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

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

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

2.4.6 Rockmelon

Round, firm, green skin rockmelon with brown netting, variety 'Triumph' were treated and analysed for nutritional components at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 14 days storage in a coldroom set at 7°C.

Rockmelon fruit appear to be able to tolerate up to 1000Gy irradiation without significant dose effects on the nutritional attributes investigated.

No significant dose effects were found at either Time 1 or Time 2 (Tables 14 and 15), where each time has been analysed separately. Irradiation had no significant effect on ash, carbohydrates, energy, dietary fibre, fat profile, moisture, sodium, protein, sugars and Vitamin C (ascorbic acid) either before storage or after cold storage for 14 days. The main effect of irradiation on beta-carotene could be considered marginally significant as it was just outside the 0.05 level of significance at Time 1.

Mean Vitamin C (ascorbic acid) ranged from 17.60-27.33mg/100g one day after irradiation treatment and between 17.80-23.07mg/100g after 14 days in storage. No significant dose effects were detected in beta-carotene in the control samples and the treated rockmelon fruit one day after irradiation treatment (986.7-1600.0μg/100g) and after 14 days storage (1026.7-1266.7μg/100g).

Only fructose showed a significant time by dose interaction (Table 16) however, the changes were variable with the control decreasing significantly after storage, 150Gy samples increasing significantly after storage, and 600Gy and 1000Gy showing no significant difference between Time 1 and Time 2.

Where the interaction of time and dose was not significant, a significant main effect of time was detected in ash, carbohydrates, sodium and glucose. Mean values for carbohydrates, glucose and sodium decreased with storage whereas there was a significant increase in ash.

2.4.7 Honeydew melon

Firm, smooth and white skin honeydew melon fruit, variety 'Galaxy' were treated and analysed for nutritional components at two occasions; the first analysis (Time 1) one day after mean irradiation treatment and the second analysis (Time 2) after 14 days storage in a coldroom set at 7°C.

There was a significant dose effect detected in beta-carotene and not in the other nutritional components measured at Time 1 (Table 17). In general, beta-carotene was lower in irradiated samples than in the control sample, being significantly lower to the control samples for 600Gy and 1000Gy samples.

Significant differences between the doses were found after 14 days in cold storage (Time 2) for protein, fructose and glucose (Table 18). For each of these components, the mean for dose 600Gy was higher.

Mean protein after 14 days was 0.40-0.57g/100 for the control, 150Gy and 1000Gy fruit and 0.67g/100g for the 600Gy irradiated fruit. No significant differences in protein were found between the control fruit and the treated samples.

One day after irradiation treatment, fructose ranged between 2.27-2.83g/100g while glucose was 2.13-2.60g/100g. After 14 days storage, fructose ranged between 2.57-2.77g/100g for the control, 150Gy and 1000Gy fruit and 3.37g/100g for the 600Gy irradiated fruit. Glucose ranged between 2.30-2.53g/100g for the control, 150Gy and 1000Gy fruit and 3.07g/100g for the 600Gy irradiated fruit.

No significant dose effect was detected in Vitamin C (ascorbic acid) at Time 1 and Time 2 between the irradiated samples and corresponding controls. Vitamin C (ascorbic acid) ranged between 11.90-16.90mg/100g one day after treatment. After 14 days in cold storage mean Vitamin C (ascorbic acid) ranged between 9.20-13.10mg/100g.

Table 14. Mean chemical measurements in rockmelon, variety 'Triumph' after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.60 (0.100)	0.63 (0.115)	0.60 (0.100)	0.63 (0.058)	0.919	0.068
Carbohydrates (g/100g)	5.40 (1.300)	4.03 (0.321)	4.27 (0.551)	4.40 (0.520)	0.255	0.644
Dietary fibre (g/100g)	0.40 (0.100)	0.43 (0.252)	0.37 (0.058)	0.37 (0.058)	0.931	0.119
Energy (kJ/100g)	110.7 (22.01)	91.3 (6.66)	92.3 (8.08)	95.0 (5.57)	0.303	10.36
Moisture (g/100g)	92.80 (1.400)	93.97 (0.462)	93.93 (0.493)	93.70 (0.436)	0.372	0.691
Protein (g/100g)	0.70 (0.100)	0.90 (0.200)	0.77 (0.252)	0.80 (0.200)	0.748	0.183
Sodium (mg/100g)	50.0 (21.79)	36.7 (20.21)	33.3 (11.55)	38.3 (7.64)	0.729	15.35
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	5.07 (1.358)	3.90 (0.458)	3.93 (0.462)	4.13 (0.473)	0.330	0.655
Fructose (g/100g)	2.53 (0.306)	1.97 (0.058)	2.17 (0.058)	2.23 (0.208)	0.083	0.174
Glucose (g/100g)	1.93 (0.651)	1.50 (0.100)	1.50 (0.100)	1.53 (0.208)	0.473	0.307
Sucrose (g/100g) #	0.51 (0.296)	0.36 (0.384)	0.29 (0.322)	0.33 (0.072)	0.734	0.220
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	26.97 (13.353)	27.33 (11.511)	21.73 (3.356)	17.60 (1.609)	0.563	7.604
Beta-carotene (μg/100g)	1333.3 (208.17)	1366.7 (208.17)	1600.0 (100.00)	986.7 (287.29)	0.051	165.04

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

 # Analysed on the log_{10} scale. Reported means are back-transformed. SED is on the log_{10} scale.

Table 15. Mean chemical measurements in untreated and irradiated rockmelon, variety 'Triumph' after 14 days cold storage (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.90 (0.265)	0.77 (0.058)	0.73 (0.058)	0.77 (0.208)	0.683	0.145
Carbohydrates (g/100g)	4.00 (0.346)	4.23 (0.513)	3.97 (0.569)	3.47 (0.306)	0.369	0.407
Dietary fibre (g/100g)	0.53 (0.058)	0.40 (0.000)	0.37 (0.231)	0.43 (0.058)	0.527	0.112
Energy (kJ/100g)	91.7 (9.29)	94.3 (10.21)	86.7 (8.15)	82.0 (3.61)	0.407	7.25
Moisture (g/100g)	93.63 (0.723)	93.60 (0.529)	94.20 (0.458)	94.27 (0.058)	0.343	0.434
Protein (g/100g)	0.93 (0.208)	0.90 (0.100)	0.73 (0.115)	0.93 (0.115)	0.323	0.113
Sodium (mg/100g)	33.3 (15.28)	18.3 (5.77)	16.7 (12.58)	28.3 (18.93)	0.271	8.74
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	3.73 (0.586)	4.07 (0.551)	3.77 (0.252)	3.37 (0.153)	0.438	0.397
Fructose (g/100g)	2.07 (0.153)	2.30 (0.173)	2.07 (0.115)	2.00 (0.173)	0.245	0.138
Glucose (g/100g)	1.23 (0.115)	1.50 (0.173)	1.27 (0.058)	1.20 (0.173)	0.165	0.124
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	23.07 (3.661)	17.80 (2.800)	20.07 (1.793)	20.27 (5.358)	0.421	2.917
Beta-carotene (μg/100g)	1153.3 (323.32)	1266.7 (208.17)	1103.3 (167.43)	1026.7 (237.56)	0.729	212.93

Standard deviations are presented in brackets below each mean.

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

Table 16. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) rockmelon, variety 'Triumph' before storage (Time 1) and after 14 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Ash (g/100g)	1	0.60	0.63	0.60	0.63	0.62 b	Day	0.008	0.057
	14	0.90	0.77	0.73	0.77	0.79a	Irrad.	0.778	0.080
	Mean	0.75	0.70	0.67	0.70		Day x Irrad.	0.663	0.113
Carbohydrates (g/100g)	1	5.40	4.03	4.27	4.40	4.52a	Day	0.036	0.263
	14	4.00	4.23	3.97	3.47	3.92 b	Irrad.	0.235	0.372
	Mean	4.70	4.13	4.12	3.93		Day x Irrad.	0.196	0.526
Dietary fibre (g/100g)	1	0.40	0.43	0.37	0.37	0.39	Day	0.477	0.057
	14	0.53	0.40	0.37	0.43	0.43	Irrad.	0.666	0.081
	Mean	0.47	0.42	0.37	0.40		Day x Irrad.	0.741	0.114
Energy (kJ/100g)	1	110.7	91.3	92.3	95.0	97.3	Day	0.072	4.45
	14	91.7	94.3	86.7	82.0	88.7	Irrad.	0.219	6.29
	Mean	101.2	92.8	89.5	88.5		Day x Irrad.	0.367	8.90
Moisture (g/100g)	1	92.80	93.97	93.93	93.70	93.60	Day	0.273	0.285
	14	93.63	93.60	94.20	94.27	93.92	Irrad.	0.193	0.403
	Mean	93.22	93.78	94.07	93.98		Day x Irrad.	0.505	0.570
Protein (g/100g)	1	0.70	0.90	0.77	0.80	0.79	Day	0.269	0.072
	14	0.93	0.90	0.73	0.93	0.87	Irrad.	0.508	0.102
	Mean	0.82	0.90	0.75	0.87		Day x Irrad.	0.555	0.145
Sodium (g/100g)	1	50.0	36.7	33.3	38.3	39.6a	Day	0.026	6.19
	14	33.3	18.3	16.7	28.3	24.2 b	Irrad.	0.276	8.76
	Mean	41.7	27.5	25.0	33.3		Day x Irrad.	0.965	12.39
Vitamin C (ascorbic acid) (mg/100g)	1	26.97	27.33	21.73	17.60	23.41	Day	0.311	2.954
	14	23.07	17.80	20.07	20.27	20.30	Irrad.	0.534	4.178
	Mean	25.02	22.57	20.90	18.93		Day x Irrad.	0.546	5.909
Beta-carotene (μg/100g)	1	1333.3	1366.7	1600.0	986.7	1321.7	Day	0.070	94.00
	14	1153.3	1266.7	1103.3	1026.7	1137.5	Irrad.	0.083	132.94
	Mean	1243.3	1316.7	1351.7	1006.7		Day x Irrad.	0.268	188.00
Total sugars (g/100g)	1	5.07	3.90	3.93	4.13	4.26	Day	0.069	0.266
	14	3.73	4.07	3.77	3.37	3.73	Irrad.	0.362	0.377
	Mean	4.40	3.98	3.85	3.75		Day x Irrad.	0.246	0.533

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Fructose (g/100g)	1	2.53a	1.97 c	2.17 bc	2.23abc	2.23	Day	0.140	0.075
	14	2.07 bc	2.30ab	2.07 bc	2.00 bc	2.11	Irrad.	0.275	0.105
	Mean	2.30	2.13	2.12	2.12		Day x Irrad.	0.014	0.149
Glucose (g/100g)	1	1.93	1.50	1.50	1.53	1.62a	Day	0.013	0.112
	14	1.23	1.50	1.27	1.20	1.30 b	Irrad.	0.496	0.158
	Mean	1.58	1.50	1.38	1.37		Day x Irrad.	0.214	0.224
Sucrose # (kJ/100g)	1	0.51	0.31	0.26	0.33	0.34	Day	0.415	0.181
	14	0.30	0.17	0.34	0.20	0.24	Irrad.	0.836	0.256
	Mean	0.39	0.23	0.30	0.26		Day x Irrad.	0.878	0.362
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

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

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

 # Analysed on the log_{10} scale. Reported means are back-transformed. SED is on the log_{10} scale.

Table 17. Mean chemical measurements in honeydew melon, variety 'Galaxy' after irradiation treatment (Time 1).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.33 (0.058)	0.40 (0.000)	0.37 (0.115)	0.30 (0.100)	0.507	0.065
Carbohydrates (g/100g)	6.10 (1.375)	5.63 (0.351)	6.73 (1.704)	5.67 (1.940)	0.767	1.166
Dietary fibre (g/100g) #	0.19 (0.448)	0.20 (0.301)	0.25 (0.174)	0.20 (0.301)	0.970	0.294
Energy (kJ/100g)	116.7 (24.01)	108.7 (3.79)	130.0 (31.19)	108.7 (36.75)	0.727	21.23
Moisture (g/100g)	92.80 (1.323)	93.17 (0.153)	92.00 (2.107)	93.27 (2.146)	0.743	1.248
Protein (g/100g)	0.43 (0.153)	0.43 (0.058)	0.50 (0.265)	0.40 (0.265)	0.941	0.167
Sodium (mg/100g)	38.3 (17.56)	26.7 (2.89)	33.3 (2.89)	33.3 (14.43)	0.754	10.61
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	5.50 (1.179)	5.37 (0.351)	6.37 (1.716)	5.27 (1.940)	0.752	1.112
Fructose (g/100g)	2.43 (0.231)	2.57 (0.153)	2.83 (0.404)	2.27 (0.208)	0.233	0.246
Glucose (g/100g)	2.27 (0.252)	2.40 (0.200)	2.60 (0.265)	2.13 (0.252)	0.306	0.229
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	11.90 (3.176)	16.90 (3.381)	14.83 (4.430)	14.00 (1.997)	0.488	3.059
Beta-carotene (μg/100g)	17.0a (2.65)	16.0ab (1.00)	12.0c (1.73)	13.7bc (3.22)	0.027	1.27

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

 # Analysed on the $\log_{10}$ scale. Reported means are back-transformed. SED is on the $\log_{10}$ scale.

Table 18. Mean chemical measurements in untreated and irradiated honeydew melon, variety 'Galaxy' after 14 days cold storage (Time 2).

Parameter	Dose				p-value	SED
	0Gy	150Gy	600Gy	1000Gy		
Ash (g/100g)	0.60 (0.000)	0.40 (0.100)	0.57 (0.058)	0.53 (0.115)	0.085	0.065
Carbohydrates (g/100g)	7.30 (1.058)	5.57 (0.473)	8.33 (0.115)	6.83 (2.013)	0.159	1.033
Dietary fibre (g/100g)	0.17 (0.058)	0.33 (0.208)	0.27 (0.058)	0.27 (0.115)	0.455	0.097
Energy (kJ/100g)	138.3 (19.09)	107.7 (6.66)	159.0 (2.00)	129.0 (31.43)	0.108	16.97
Moisture (g/100g)	91.27 (1.210)	93.17 (0.306)	90.13 (0.208)	91.90 (1.931)	0.125	1.056
Protein (g/100g)	0.57ab (0.115)	0.40 b (0.000)	0.67a (0.058)	0.40 b (0.173)	0.024	0.072
Sodium (mg/100g)	33.3 (7.64)	21.7 (2.89)	26.7 (5.77)	25.0 (13.23)	0.315	5.73
Fat (g/100g)	C	C	C	C		
Mono-unsaturated fat (g/100g)	C	C	C	C		
Poly-unsaturated fat (g/100g)	C	C	C	C		
Saturated fat (g/100g)	C	C	C	C		
Trans fat (g/100g)	C	C	C	C		
Total sugars (g/100g)	7.10 (1.044)	5.30 (0.500)	8.13 (0.058)	6.30 (1.682)	0.095	0.923
Fructose (g/100g)	2.77 b (0.351)	2.77 b (0.153)	3.37a (0.153)	2.57 b (0.153)	0.032	0.201
Glucose (g/100g)	2.53 b (0.351)	2.50 b (0.200)	3.07a (0.115)	2.30 b (0.173)	0.050	0.213
Sucrose (g/100g)	C	C	C	C		
Lactose (g/100g)	C	C	C	C		
Maltose (g/100g)	C	C	C	C		
Vitamin C (ascorbic acid) (mg/100g)	12.87 (2.454)	7.33 (1.595)	9.20 (2.402)	13.10 (2.651)	0.062	1.939
Beta-carotene (μg/100g)	7.72 (0.075)	9.67 (2.082)	11.67 (2.887)	10.33 (2.309)	0.559	2.677

Standard deviations are presented in brackets below each mean.

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

Means in a row followed by the same letter are not significantly different (p>0.05).

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

Table 19 presents results of the interaction of dose and time. Significant time and dose interactions were detected in ash, Vitamin C (ascorbic acid) and beta-carotene. In each case, there was no significant main effect of dose.

Mean ash levels increased significantly with storage, except in the 150Gy sample where it remained unchanged. Mean ash content was 0.35g/100g at Time 1 and was 0.52g/100g at Time 2.

Mean Vitamin C (ascorbic acid) decreased significantly after 14 days storage for doses 150Gy and 600Gy, while no significant differences were found for the control samples and the 1000Gy samples.

In beta-carotene significant decreases were observed in the control sample and 150Gy honeydew melon sample. Overall, a fall in beta-carotene was observed with time in storage, from 14.7μg/100g to 9.9μg/100g.

Table 19 shows where the interaction of dose and time was not significant but there was a significant main effect of time and/or dose. There was a significant time of storage effect in total sugars and significant dose and time effects on fructose and glucose.

2.5 Discussion

The chemical measurements for each commodity at Time 1 (one day after mean irradiation treatment) and at Time 2 after receiving irradiation doses of 0Gy, 150Gy, 600Gy and 1000Gy were analysed. Time 2 is the number of days in cold storage; 7 days for zucchini, 14 days for tomato, rockmelon and honeydew melon; 21 days for nectarine and capsicum. All irradiation treatments were applied on three separate occasions, representing three replicate blocks.

The cultivars studied were: firm ripe tomato, variety 'Gourmet Swanson' ; fresh green capsicum, variety 'Plato'; dark skin zucchini, variety 'Blackjack'; firm white flesh nectarine, variety 'Arctic Snow'; firm rockmelon, variety 'Triumph' and firm white skin honeydew melon, variety 'Galaxy'.

The nutritional profile analysed included ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene. Each time has been analysed separately and where a significant dose effect was found, pair-wise comparisons have been made using the 95% least significant difference (LSD). Time and dose interactions, at the four doses and measured on the two occasions were also investigated.

The results show that at Time 1, low dose irradiation (≤ 1kGy) had minor or no statistical effect on the range of nutritional and proximate components measured in tomato, capsicum, zucchini, nectarine and rockmelon. While each commodity responded differently when exposed to ionising low dose gamma (γ)-irradiation, overall, tomato, capsicum, zucchini, nectarine and rockmelon can tolerate low doses without significant negative effects on the nutritional measurements reported.

This was also found in an early study by Mitchell *et al.* (1992) where no loss in nutritional composition was found with zucchini irradiated at 300Gy.

Some of the Vitamin C (ascorbic acid) and beta-carotene levels detected in these varieties were different to published data and will be discussed further. In particular, no significant main effect of dose was detected in Vitamin C (ascorbic acid) in tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at Time 1. There was no main effect of dose detected in beta-carotene in tomato, capsicum, zucchini and rockmelon. Beta-carotene in nectarine was below the detection level (< 0.5μg/100g).

A significant dose effect in beta-carotene in honeydew melon, variety 'Galaxy' was detected at Time 1. Lower mean beta-carotene levels were found in the 600Gy and 1000Gy samples. However, after 14 days in cold storage the beta-carotene levels were higher, although not significantly so, in the 600Gy and 1000Gy samples than in the control and 150Gy honeydew samples.

Table 19. Mean chemical measurements in untreated and irradiated (150Gy, 600Gy and 1000Gy) honeydew melon, variety 'Galaxy' before storage (Time 1) and after 14 days cold storage (Time 2).

Variable	Day	Irradiation dose (Gy)					ANOVAs		
		0	150	600	1000	Mean	Factor	p-value	SED
Ash (g/100g)	1	0.33 b	0.40 b	0.37 b	0.30 b	0.35 b	Day	<0.001	0.030
	14	0.60a	0.40 b	0.57a	0.53a	0.52a	Irrad.	0.315	0.043
	Mean	0.47	0.40	0.47	0.42		Day x Irrad.	0.032	0.060
Carbohydrates (g/100g)	1	6.10	5.63	6.73	5.67	6.03	Day	0.090	0.535
	14	7.30	5.57	8.33	6.83	7.01	Irrad.	0.121	0.756
	Mean	6.70	5.60	7.53	6.25		Day x Irrad.	0.717	1.069
Dietary fibre (g/100g)	1	0.24	0.23	0.27	0.23	0.24	Day	0.810	0.085
	14	0.17	0.33	0.27	0.27	0.26	Irrad.	0.833	0.121
	Mean	0.20	0.28	0.27	0.25		Day x Irrad.	0.839	0.171
Energy (kJ/100g)	1	116.7	108.7	130.0	108.7	116.0	Day	0.082	9.35
	14	138.3	107.7	159.0	129.0	133.5	Irrad.	0.086	13.23
	Mean	127.5	108.2	144.5	118.8		Day x Irrad.	0.704	18.71
Moisture (g/100g)	1	92.80	93.17	92.00	93.27	92.81	Day	0.053	0.563
	14	91.27	93.17	90.13	91.90	91.62	Irrad.	0.101	0.797
	Mean	92.03	93.17	91.07	92.58		Day x Irrad.	0.668	1.127
Protein (g/100g)	1	0.43	0.43	0.50	0.40	0.44	Day	0.335	0.067
	14	0.57	0.40	0.67	0.40	0.51	Irrad.	0.234	0.094
	Mean	0.50	0.42	0.58	0.40		Day x Irrad.	0.662	0.133
Sodium (g/100g)	1	38.3	26.7	33.3	33.3	32.9	Day	0.146	4.06
	14	33.3	21.7	26.7	25.0	26.7	Irrad.	0.287	5.74
	Mean	35.8	24.2	30.0	29.2		Day x Irrad.	0.989	8.12
Vitamin C (ascorbic acid) (mg/100g)	1	11.90abc	16.90a	14.83a	14.00ab	14.41a	Day	0.008	1.231
	14	12.87ab	7.33 c	9.20 bc	13.10ab	10.62 b	Irrad.	0.804	1.741
	Mean	12.38	12.12	12.02	13.55		Day x Irrad.	0.037	2.462
Beta-carotene (μg/100g)	1	17.0a	16.0ab	12.0 bcd	13.7abc	14.7a	Day	<0.001	1.03
	14	7.8 d	9.7 cd	11.7 bcd	10.3 cd	9.9b	Irrad.	0.902	1.46
	Mean	12.4	12.8	11.8	12.0		Day x Irrad.	0.048	2.07
Total sugars (g/100g)	1	5.50	5.37	6.37	5.27	5.62 b	Day	0.047	0.497
	14	7.10	5.30	8.13	6.30	6.71a	Irrad.	0.083	0.703
	Mean	6.30	5.33	7.25	5.78		Day x Irrad.	0.571	0.995

Variable	Day	Irradiation dose (Gy) 0	150	600	1000	Mean	ANOVAs Factor	p-value	SED
Fructose (g/100g)	1	2.43	2.57	2.83	2.27	2.52 b	Day	0.006	0.105
	14	2.77	2.77	3.37	2.57	2.87a	Irrad.	0.003	0.149
	Mean	2.60 b	2.67 b	3.10a	2.42 b		Day x Irrad.	0.726	0.210
Glucose (g/100g)	1	2.27	2.40	2.60	2.13	2.35 b	Day	0.029	0.103
	14	2.53	2.50	3.07	2.30	2.60a	Irrad.	0.006	0.145
	Mean	2.40 b	2.45 b	2.83a	2.22 b		Day x Irrad.	0.621	0.205
Sucrose (kJ/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Maltose (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Mono-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Poly-unsaturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Saturated fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		
Trans fat (g/100g)	1	C	C	C	C		Day		
	14	C	C	C	C		Irrad.		
	Mean						Day x Irrad.		

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

Parameter labels which are italicised mean that a minority of values were censored and have been estimated using the method of Taylor (1973).

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

These components were analysed again at Time 2, after a recommended period of cold storage. No significant main effect of dose was found in the nutritional components in tomato and rockmelon after 14 days storage however, differences in response to the main effect of dose were detected for various components in capsicum, zucchini, nectarine and honeydew melon.

Overall after a period in cold storage, fresh ripe tomato, green capsicum, zucchini, nectarine and rockmelon tolerated low irradiation dose (≤ 1kGy) without significant losses in nutritional composition. In particular, no significant main effect of dose was detected in Vitamin C (ascorbic acid) in tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon at Time 2. There was no main effect of dose detected in beta-carotene in tomato, capsicum, zucchini, rockmelon and honeydew melon.

In nectarine, there was no interaction of time and dose, or main effect of dose or time on total sugars but there were some changes in fructose, sucrose and glucose. Time in storage resulted in a significant decrease in sucrose while mean glucose and fructose increased. Fructose was significantly higher with irradiated nectarine after 21 days. Wall (2007) observed these changes in bananas as dose increased to 800Gy and attributed these differences to an acceleration of sucrose hydrolysis in treated bananas.

Castell-Perez *et al.* (2004) found no significant effect on the sugars content of whole cantaloupe (rockmelon) fruits irradiated at 1000Gy but sugars content decreased significantly by the fourth day of storage at 10°C. They also reported no changes in beta-carotene content of whole cantaloupes over the storage period.

The effect of storage time was greater than by irradiation itself in many of these cases and the changes generally appeared to be associated with the ripening process during storage.

Although irradiation is known to destroy vitamins in pure and unadulterated systems, in food the damage may not be significant due the mutually protective action or shielding effect of various chemical constituents on each other (Diehl 1990).

The absorbed dose, commodity maturity and physiological state at harvest, pre and post handling, transportation, presence of microorganisms, storage environment and storage time all interact to affect product quality and shelf life. Different outcomes in nutritional quality after similar treatments can occur between different varieties of the same fruit, as noted by Thomas (1988) and Morris and Jessup (1994). It is a well-known fact that the nutritional components measured depends upon the degree of ripeness of the fruit, and quite different results would no doubt have been obtained had unripe or over-ripe fruits been analysed.

2.5.1 Vitamin C and beta-carotene

2.5.1.1 Tomato

In tomato, mean Vitamin C (ascorbic acid) in the control sample after irradiation was 18.3mg/100g while the means for the irradiated samples ranged between 17.0-18.0mg/100g. These figures are comparable with the reference data in the Food Standard Australia New Zealand (FSANZ) nutrient database of 18mg/100g (FSANZ, 2011 website) and 13.7mg/100g in the United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference (US Dept Agric, 2011 website). In the FSANZ database, Vitamin C refers to total Vitamin C activity:to ascorbic acid and dehyroascorbic acid while the USDA database refers to total ascorbic acid for red ripe tomato.

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

Time and dose interactions were not detected in Vitamin C (ascorbic acid) or beta-carotene in tomato however, a significant time effect was found in beta-carotene. There was in increase in mean beta-carotene from 195.8μg/100g to 312.0μg/100g after 14 days in cold storage at 8°C.

An increase in mean fat in tomato has no biological significance in this study although Heureux *et al.* (1993) found increasing electrolyte leakage or membrane permeability and fatty acid unsaturation of tomato during storage at 1°C. Yasia *et al.* (1987) studied the loss of firmness of tomatoes and linked this to the breakdown of pectic fractions at doses > 1000Gy.

2.5.1.2 Capsicum

In capsicum, irradiation had no significant effects on Vitamin C (ascorbic acid). The mean Vitamin C (ascorbic acid) in the control sample was 82.7mg/100g one day after irradiation compared to the reference data of 98mg/100g of total Vitamin C activity (ascorbic acid and dehyroascorbic acid) in the FSANZ nutrient database (FSANZ, 2011 website) and 80.4mg/100g total ascorbic acid in the USDA nutrient database (US Dept Agric, 2011 website). Topuz and Ozdemir (2007) reported values for Vitamin C of 63.1-64.9mg/100g in wet basis in two Turkish capsicum varieties.

An early study also showed that irradiation at low doses (≤ 300Gy) had no significant effects on total Vitamin C (ascorbic acid plus dehydroascorbic acid), Vitamin C as dehydroascorbic acid or sugars in green capsicum shortly after irradiation or after storage at 5°C for 3.5 weeks (Mitchell *et al.* 1992).

In this study, Vitamin C (ascorbic acid) increased for all capsicum samples after storage. A significant effect of time was found for Vitamin C (ascorbic acid), increasing from a mean of 70.7mg/100g to 116.5g/100g after storage at 10°C for three weeks. The mean Vitamin C (ascorbic acid) in the control increased from 82.7mg/100g to 127.7mg/100g. Mitchell *et al.* (1992) also reported increasing total Vitamin C and dehydroascorbic acid with storage. In their study, total Vitamin C for untreated green capsicum increased from 56.5mg/100g to 83.8mg/100 g and for dehydroascorbic acid, this increased from 7.7mg/100g to 10.0g/100g after storage at 5°C for 3.5 weeks.

The FSANZ nutrient database (FSANZ, 2011 website) records a mean of 161μg/100g for beta-carotene in green, raw capsicum whereas it is 208μg/100g in the USDA database (US Dept Agric, 2011 website). Our results for beta-carotene were much lower than these immediately at Time 1 (47.7-62.0μg/100g) and increased with storage (130.0-143.3μg/100g).

In a study with red capsicum, the beta-carotene levels were roughly four times higher (Mitchell *et al.* 1990) and increased slightly during three weeks storage at 5°C. The study also showed there was no significant effect of dose (≤ 300Gy) in beta-carotene in red capsicum.

The increase in Vitamin C (ascorbic acid) and decrease in glucose and fructose found in green capsicum during storage appear to be metabolic events occurring during senescence in fruit. The ratio of fructose to glucose is nearly 1:1. The same results were observed in green capsicum treated at doses ≤ 300Gy and stored at 5°C for 3.5 weeks (Mitchell *et al.* 1992).

This study supports the data previously established by other studies (Kader 1986; Mitchell *et al.* 1990, 1992). Kader (1986) in his list of relative tolerance of fresh fruit and vegetables to irradiation doses below 1000Gy indicated that tomato suffered minimal detrimental effects.

Although doses were lower, ≤ 300Gy, in Mitchell *et al.*'s studies (1990, 1992), they reported parallel findings in beta-carotene and Vitamin C activity before and after storage for a period of 3-3.5 weeks. They also showed that time in storage had a greater effect on physio-chemical components in tomato and capsicum than irradiation. Ramamurthy *et al.* (2004) found small reductions in Vitamin C and carotenoids in capsicums at doses between 1000-3000Gy.

2.5.1.3 *Zucchini*

At Time 1 in zucchini, mean Vitamin C (ascorbic acid) ranged between 6.20-12.60mg/100g and at Time 2 ranged from 7.03-11.13mg/100g. The mean detected in the control sample at Time 1 was low (6.2mg/100g) compared with the reference data in the FSANZ Nutrient Database of 22mg/100g and 17.9mg/100g in the USDA Database.

Lee and Kader (2000) in their review indicated that preharvest and postharvest factors, such as genotypes, climatic conditions, cultural practices, maturity at harvest, harvesting method and postharvest handling can influence Vitamin C content of horticultural crops.

Fresh untreated zucchini contained a mean of 216.7μg/100g of beta-carotene at Time 1. The value recorded in the FSANZ nutrient database is 243μg/100g while the recorded beta-carotene value is 120μg/100g in the USDA database. While there was no time by dose interaction, there was an effect of dose and time in storage in the beta-carotene levels in zucchini.

2.5.1.4 *Nectarine*

At Time 1 mean Vitamin C (ascorbic acid) in the control nectarine sample (1.37mg/100g) was low compared with the reference data in the FSANZ Nutrient Database of 12mg/100g and 5.4mg/100g in the USDA Database. The irradiated samples ranged from 1.67-2.00mg/100g. There was no significant time and dose interaction but a significant time effect was detected. Mean Vitamin C (ascorbic acid) increased after 21 days in cold storage to 4.37mg/100g in the control and 5.57-6.33mg/100g in the irradiated samples.

The lower Vitamin C (ascorbic acid) may be that the nectarine variety tested was a late-season variety. In a study in grapefruit, Patil *et al.* (2004) found an interaction between harvest season and irradiation dose on production of bioactive compounds of grapefruit irradiated up to 700Gy. The study demonstrated that irradiation doses of up to 700Gy had no significant effect on Vitamin C content of early-season grapefruit while late season fruit showed lower Vitamin C when exposed to doses ≥ 200Gy after 35 days storage. The authors indicated that this was a result of stress by irradiation above 200Gy, coupled with low temperature stress that may be harmful to the late season crop.

Data for beta-carotene in nectarine was below the detection level of 0.5μg/100g. The value recorded in the FSANZ nutrient database is 65μg/100g while the recorded beta-carotene value is 150μg/100g in the USDA Database.

The lower Vitamin C (ascorbic acid) and beta-carotene values observed in this study may be a result of the nectarine samples being immature. The study by Lester and Dunlap (1985) showed that the major compositional changes in developing and ripening in muskmelon were sucrose, glucose, fructose and beta-carotene; beta-carotene increased from 0.3% (w/w) at 10 days post-pollination to 2.7% (w/w) in 50-day old melons.

Similarly, in a study with tomato, the advance ripening rate of ethylene treated fruit was indicated by increased carotenoid concentrations as the fruit ripened (Boe and Salunkhe 1967).

2.5.1.5 *Rockmelon*

In this study, no significant dose effect, time or time and dose interaction were observed in Vitamin C (ascorbic acid) and beta-carotene in rockmelon, variety ‘Triumph’, although the effect of dose at Time 1 on beta-carotene could be considered marginally significant.

The Vitamin C (ascorbic acid) level in the control sample was 26.9 7mg/100g compared with a Vitamin C value of 41mg/100g in the FSANZ Nutrient Database, 36.7mg/100g in the USDA Database.

Beaulieu and Lea (2007) found total Vitamin C (combined dehydroascorbic acid and ascorbic acid) in rockmelon peaked at 35 days after anthesis (47.3mg/100g) and started declining independent of fruit maturity. The loss was attributed to transport, handling and natural senescence.

Castell-Perez *et al.* (2004) reported no changes in beta-carotene content of whole cantaloupes over the storage period of 0, 4, 8 and 12 days at 10°C irradiated at 1000Gy.

Fresh untreated rockmelon contained a mean of 1333.3µg/100g of beta-carotene, the irradiated samples contained means of 986.7-1600.0µg/100g. The value recorded in the FSANZ nutrient database is 836µg/100g while the recorded beta-carotene value is 2020µg/100g in the USDA Database.

2.5.1.6 Honeydew melon

No significant main effect of dose was detected in Vitamin C (ascorbic acid) in Time 1 and Time 2. The control sample at Time 1 recorded a value of 11.90mg/100g compared with a value of 20mg/100g in the FSANZ Nutrient Database and 18.0mg/100g in the USDA Database. At Time 2, mean Vitamin C (ascorbic acid) for the control samples was 12.87mg/100g. A significant time and dose interaction was found. Mean vitamin C levels for doses 150 and 600Gy decreased significantly over time, while no significant changes were detected in the mean levels for the control samples and 1000Gy.

For beta-carotene, a significant main effect of dose was detected at Time 1 but not at Time 2. Our results for beta-carotene were lower than the FSANZ Nutrient Database and USDA Database record of 30µg/100g for beta-carotene. A significant time and dose interaction was detected. The mean beta-carotene levels decreased significantly after storage for the control samples and 150Gy. Decreases were also observed for 600 and 1000Gy but the decrease was not significant.

2.6 Recommendations

Tomato, capsicum, zucchini, nectarine, rockmelon and honeydew melon are potential fruit fly hosts and are subject by regulation to plant quarantine treatments against fruit fly and other regulated pests as a condition of entry and/or movement into certain plant quarantine jurisdictions. This applies to both domestic and international markets.

In this study, applications of gamma irradiation treatments of ≤ 1kGy can be considered as a phytosanitary method. While components in each commodity responded differently when exposed to ionising low dose gamma (γ)-irradiation the overall findings of this study suggest that an application of up to 1kGy will not induce any significant detrimental effects to the chemical and proximate components of tomato, green capsicum, zucchini, nectarine and rockmelon. Honeydew melon however, showed lower tolerance to doses > 600Gy with respect to beta-carotene content at Time 1. There were no treatments between 150Gy and 600Gy applied in this study. Treatment with 150Gy could be safely applied without inducing any deleterious effects in honeydew melon.

2.7 References

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2.8 Appendix 1 – Irradiation reports

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15 March 2011

Irradiation Report

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

ANSTO Ref: G11142 SRT F 004

Prepared CB Authorised JD Date 18·3·11 Page 1 of 5

Connie Banos Justin Davies

Product Details

Product	Capsicums and Tomatoes
Quantity	7, 10kg boxes Tomatoes 14, 8kg boxes Capsicums

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	28 February 2011 to 2 March 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Capsicum Approx. 8.3 $Gy.min^{-1}$ & Tomatoes Approx. 7.9 $Gy.min^{-1}$
Dosimeter Type	Fricke
Dosimeter Batches	F219
Storage Conditions	Pre & post irradiation 10 °C
Irradiation temperature	22.7 to 24.5 °C

The samples of tomatoes and capsicums that were received for processing were repacked into cardboard boxes. The boxes for each produce were divided into **four** lots and identified for each target dose of 150, 600 & 1000 Gy.

A pair of dosimeters were sited on the outside of one box at the monitoring position, as per previous dose mapping (ANSTO Ref G11139). The boxes were positioned on a rig parallel to the plaque source for processing.

Results for Capsicums

Target dose (Gy)	**Lot**	**Minimum Dose (Gy)**	**Maximum Dose (Gy)**	**Average dose (Gy)**
150	Capsicums R1&R2	144 ± 7	152 ± 7	148 ± 5
600	Capsicums R1&R2	560 ± 19	594 ± 19	577 ± 14
1000	Capsicums R1&R2	936 ± 23	993 ± 24	964 ± 17
150	Capsicums R3	146 ± 7	155 ± 7	151 ± 5
600	Capsicums R3	564 ± 19	599 ± 20	582 ± 14
1000	Capsicums R3	941 ± 23	999 ± 24	970 ± 17
150	Capsicums R4	146 ± 7	155 ± 7	150 ± 5
600	Capsicums R4	573 ± 20	609 ± 20	591 ± 14
1000	Capsicums R4	955 ± 24	1013 ± 24	984 ± 17

Results for Tomatoes

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Tomatoes R1&R2	148 ± 7	159 ± 8	154 ± 5
600	Tomatoes R1&R2	584 ± 21	628 ± 22	606 ± 15
1000	Tomatoes R1&R2	969 ± 25	1042 ± 26	1006 ± 18
150	Tomatoes R3	147 ± 7	158 ± 8	152 ± 5
600	Tomatoes R3	566 ± 20	609 ± 21	588 ± 15
1000	Tomatoes R3	953 ± 24	1026 ± 26	990 ± 18
150	Tomatoes R4	148 ± 7	159 ± 8	154 ± 5
600	Tomatoes R4	580 ± 20	624 ± 22	602 ± 15
1000	Tomatoes R4	964 ± 25	1037 ± 26	1001 ± 18

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

ANSTO Ref: G11142 SRT F 004

Prepared CLB Authorised JD Date 18.3.11 Page 4 of 5

Connie Banos Justin Davies

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement.*

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

Prepared [signature] Authorised [signature] Date 18.3.11

Connie Banos Justin Davies

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24 March 2011

Irradiation Report

ANSTO Reference	G11145
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	PO 4550047094

Prepared
Sohil Sheth

Authorised
Justin Davies

Date 24.3.11

Product Details

Product	Nectarines and Zucchinis
Quantity	10 × 10 kg boxes Nectarines 9 × 10 kg boxes Zucchinis

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	14 March 2011 to 16 March 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Nectarines Approx. 8.1 $Gy.min^{-1}$ & Zucchinis Approx. 7.8 $Gy.min^{-1}$
Dosimeter Type	Fricke
Dosimeter Batches	F219 & F220
Storage Conditions	Pre & post irradiation 10 °C
Irradiation temperature	23.3 to 24.0 °C

Prepared Authorised Date 24-3-11

Sohil Sheth Justin Davies

The samples of nectarines and zucchinis that were received for processing were repacked into cardboard boxes. The boxes for each produce were divided into three lots and identified for each target dose of 150, 600 & 1000 Gy.

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited at the front, the back and in between nectarines and zucchinis. Additional dosimeters were attached to the outside of one box to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy samples from the first lot were used to carry out a dosemapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dosemapping repeated twice with dosimeters at those locations. This dosemapping information was used to process the remaining boxes of nectarines to their target doses. The dosemapping exercise was repeated for the zucchinis.

Figure 1: Boxes of nectarines and zucchinis for irradiation.

Figure 2: Boxes positioned for irradiation.

Results for Nectarines

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Nectarines R1	145 ± 11	163 ± 13	154 ± 8
600	Nectarines R1	575 ± 7	645 ± 7	610 ± 5
1000	Nectarines R1	953 ± 32	1069 ± 38	1011 ± 25
150	Nectarines R2	139 ± 10	156 ± 12	148 ± 8
600	Nectarines R2	539 ± 29	604 ± 34	572 ± 23
1000	Nectarines R2	911 ± 36	1021 ± 42	966 ± 27
150	Nectarines R3	139 ± 10	155 ± 12	147 ± 8
600	Nectarines R3	545 ± 30	611 ± 35	578 ± 23
1000	Nectarines R3	910 ± 36	1020 ± 42	965 ± 28

Results for Zucchinis

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Zucchinis R1	145 ± 8	154 ± 7	150 ± 6
600	Zucchinis R1	584 ± 7	617 ± 7	600 ± 5
1000	Zucchinis R1	972 ± 26	1028 ± 22	1000 ± 17
150	Zucchinis R2	148 ± 9	157 ± 8	152 ± 6
600	Zucchinis R2	578 ± 24	612 ± 21	595 ± 16
1000	Zucchinis R2	968 ± 29	1024 ± 26	996 ± 19
150	Zucchinis R3	147 ± 9	155 ± 7	151 ± 6
600	Zucchinis R3	576 ± 24	610 ± 21	593 ± 16
1000	Zucchinis R3	965 ± 29	1021 ± 26	993 ± 20

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

Prepared Authorised Date 24.3.11

Sohil Sheth Justin Davies

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement*.

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

Prepared Authorised Date 24.3.11

Sohil Sheth Justin Davies

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31 March 2011

Irradiation Report

ANSTO Reference	G11146
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	PO 4550047094

Prepared Connie Banos
Authorised Justin Davies
Date 31.3.11

Product Details

Product	Rockmelons (for dose mapping)
Quantity	6 boxes (8 melons/box)

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	22 March 2011 to 23 March 2011
Required Doses	N/A (dose mapping only)
Dosimeter Type	Fricke
Dosimeter Batch	F220

Six boxes each containing 8 rockmelons were received for dose mapping in preparation for targetted irradiations.

An initial experiment (Experiment A) looked at the dose distribution through three melons. Holes were bored into these melons of diameter sufficient to snugly fit a Fricke dosimeter container (approx. 15 mm diameter). Three dosimeters were placed inside each melon; one in the centre, and one behind and one in front through the flesh. These melons were placed in a box with other melons such that the dosimeters lined up with the source. The box was sited such that only one layer of melons faced the source. In this setup the melons were irradiated to approx. 200 Gy. The dosimeters were measured to determine depth dose profiles. This experiment was repeated with the irradiation interrupted to rotate the box 180° at 100 Gy and then irradiated for a further 100 Gy (Experiment B).

In a separate experiment (Experiment C), four boxes of melons were prepared for dose mapping. Dosimeters were sited on the front and back of every melon. A pair of dosimeters were attached to the outside of one melon to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source.

The rockmelons were irradiated to approximately 200 Gy. The locations of minimum and maximum doses were found and dosemapping repeated twice with dosimeters at those locations. Factors were then calculated that relate the dose at the monitoring position to the minimum and maximum doses.

Results – Experiment A (one-sided irradiation)

Displayed in Figure 1 is a plot of the average depth dose profiles measured in three rockmelons when each melon has been irradiated from one side. This result indicates approximately half of the gamma radiation intensity is attenuated through a rockmelon.

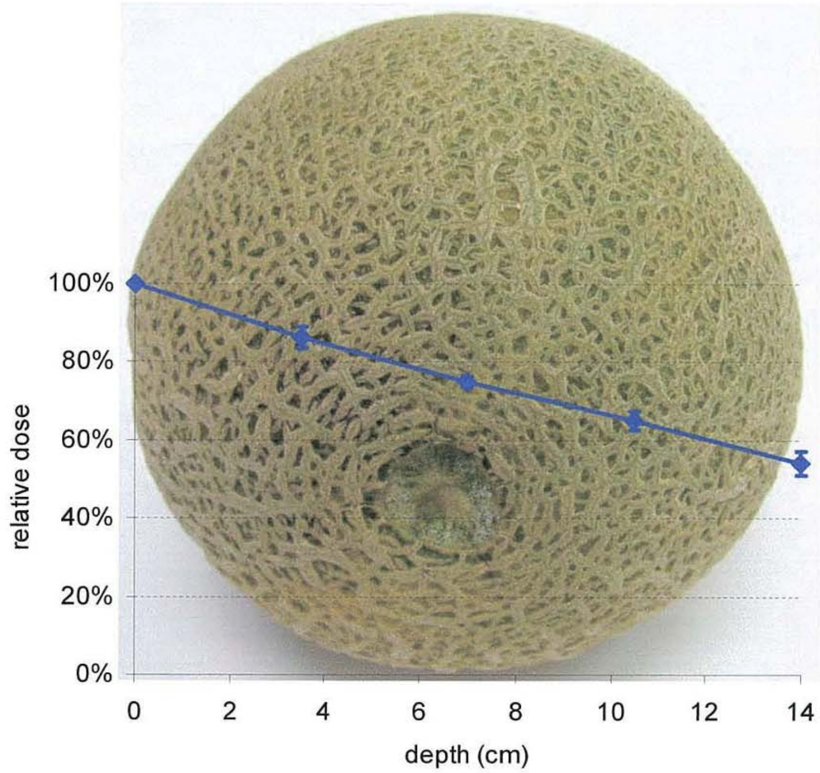

Figure 1: The average of three depth dose profiles from a one-sided irradiation (irradiated from the left-hand side). The doses are relative to the dose measured at the left-hand side. Error bars indicate the precision of the measurement (one standard deviation of three readings).

Results – Experiment B (two-sided irradiation)

Displayed in Figure 2 is a plot of the average depth dose profiles measured in three rockmelons when each melon has been irradiated approximately equally from both sides (i.e. the irradiation was interrupted at 100 Gy, the box of melons rotated 180°, and irradiated for a further 100 Gy). This result indicates that when the rockmelons are given a two-sided irradiation, the dose delivered inside is approximately the same as the outside (within measurement error).

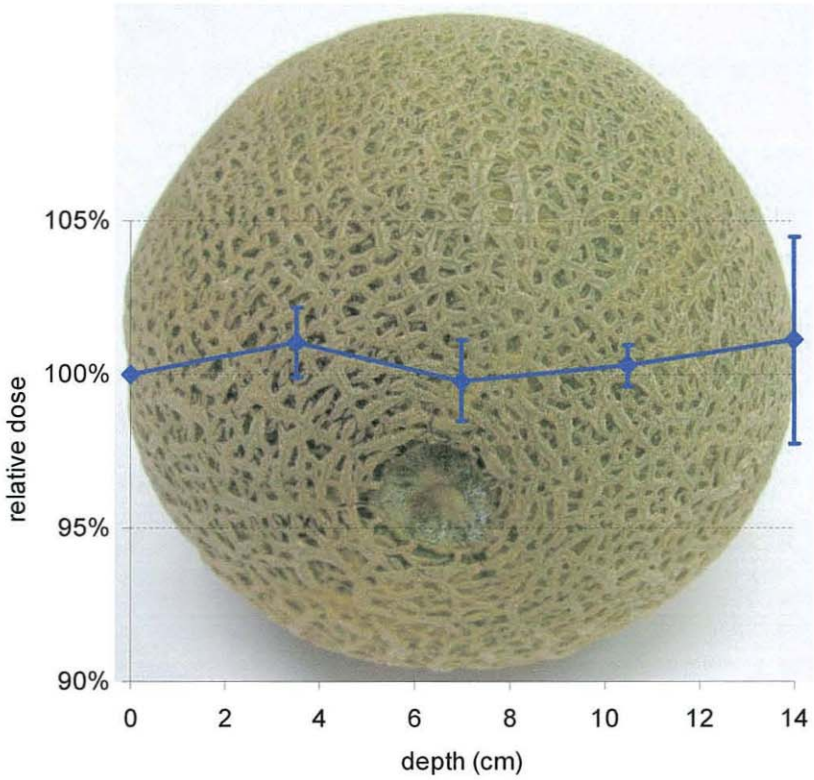

Figure 2: The average of three depth dose profiles from a two-sided irradiation. The doses are relative to the dose measured at the left-hand side. Error bars indicate the precision of the measurement (one standard deviation of three readings).

Results – Experiment C (dose map)

The factors that relate the dose at the monitoring position to the minimum and maximum doses are the Minimum and Maximum Dose Factors, respectively. The Uniformity Ratio is the ratio of the maximum to minimum doses.

Minimum Dose Factor	0.925 ± 0.039
Maximum Dose Factor	1.014 ± 0.043
Uniformity Ratio	1.096 ± 0.066

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement.*

Conclusion

This dose mapping information may be used in subsequent targetted irradiations.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

ANSTO Ref: G11146 SRT F 004

Prepared [signature] Authorised [signature] Date 31.3.11 Page 6 of 6

Connie Banos Justin Davies

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23 May 2011

Irradiation Report

ANSTO Reference	G11160
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	4550047094

ANSTO Ref: G11160 SRT F 004

Prepared Authorised Date 23·5·11 Page 1 of 4

Sohil Sheth Justin Davies

Product Details

Product	Honeydew & Rock Melons
Quantity	24, 13 kg boxes Honeydew Melons 24, 15 kg boxes Rock Melons

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	9 May 2011 to 10 May 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 7.5 $Gy.min^{-1}$
Dosimeter Type	Fricke
Dosimeter Batch	F221
Storage Conditions	Pre & post irradiation 7 °C to 8 °C
Irradiation temperature	20.9 to 21.5 °C

The samples of Honeydew and Rock Melons that were received for processing were divided into **four** lots and identified for each target dose of 0 (control), 150, 600 & 1000 Gy.

A pair of dosimeters were sited on a melon inside one box at the pre-determined monitoring position, as per previous dose mapping (ANSTO Ref G11146). The boxes were positioned on a rig parallel to the plaque source for processing. The dose at each replicate represented an irradiation of two boxes of Honeydew and two boxes of Rock Melons.

Results for Honeydew & Rock Melons

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	139 ± 6	152 ± 7	145 ± 5
600	Replicate 1	553 ± 14	607 ± 16	580 ± 11
1000	Replicate 1	915 ± 22	1003 ± 24	959 ± 16
150	Replicate 2	143 ± 6	156 ± 7	150 ± 5
600	Replicate 2	570 ± 18	625 ± 20	598 ± 13
1000	Replicate 2	940 ± 22	1031 ± 24	985 ± 16
150	Replicate 3	144 ± 6	158 ± 7	151 ± 5
600	Replicate 3	561 ± 18	615 ± 20	588 ± 13
1000	Replicate 3	945 ± 22	1036 ± 24	991 ± 17

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement.*

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

Prepared [signature] Authorised [signature] Date 23.5.11

Sohil Sheth Justin Davies

2.9 Appendix 2 – Irradiation reports for beta-carotene analysis

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3 August 2011

Irradiation Report

ANSTO Reference	11-1806
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	4550047974

ANSTO Ref: 11-1806 SRT F 004

Prepared Authorised Date 3-8-11 Page 1 of 4

Sohil Sheth Justin Davies

Product Details

Product	Capsicums, Tomatoes & Zucchinis
Quantity	12 Boxes Capsicums 12 Boxes Tomatoes 6 Boxes Zucchinis

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	18 July 2011 to 19 July 2011
Required Doses	150, 600 & 1000 Gy
Dose rate	Capsicums Approx. 7.8 $Gy.min^{-1}$ & Tomatoes & Zucchinis Approx. 7.5 $Gy.min^{-1}$
Dosimeter Type	Fricke
Dosimeter Batches	F221
Storage Conditions	Pre & post irradiation 8 °C
Irradiation temperature	20.0 to 21.0 °C

Capsicums and tomatoes were repacked into 12 cardboard boxes, and zucchinis into 6 cardboard boxes for processing. The boxes for each produce were divided into three lots and identified for each target dose of 150, 600 & 1000 Gy.

Dosimeters were sited in a position that provides reference to the minimum and maximum doses within the irradiated volume based on previous dosemapping (refer to G11139, G11142 & G11145). Two dosimeters were sited at the reference position. The product was then irradiated for a time expected to give the required dose.

Results

Tomatoes

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	147 ± 7	158 ± 8	153 ± 5
600	574 ± 20	618 ± 21	596 ± 15
1000	967 ± 24	1040 ± 25	1004 ± 17

Zucchinis

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	148 ± 9	156 ± 8	152 ± 6
600	576 ± 24	609 ± 21	592 ± 16
1000	970 ± 28	1025 ± 25	998 ± 19

Capsicums

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	141 ± 7	150 ± 7	145 ± 5
600	558 ± 19	592 ± 19	575 ± 13
1000	977 ± 24	1038 ± 24	1007 ± 17

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement.*

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

Prepared	Authorised	Date 3.8.11	Page 4 of 4
Sohil Sheth	Justin Davies		

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9 August 2011

Irradiation Report

ANSTO Reference	11-1826
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay
Customer Reference	4550047974

Prepared	Authorised	Date 9.8.11	Page 1 of 4
Sohil Sheth	Justin Davies		

Product Details

Product	Honeydew & Rock Melons
Quantity	12 boxes Honeydew Melons 12 boxes Rock Melons

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	8 August 2011
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 7.4 $Gy.min^{-1}$
Dosimeter Type	Fricke
Dosimeter Batch	F222
Storage Conditions	Pre & post irradiation 7 °C to 8 °C
Irradiation temperature	21.2 to 22.7 °C

ANSTO Ref: 11-1826 SRT F 004

Prepared Authorised Date 9.8.11 Page 2 of 4

Sohil Sheth Justin Davies

The samples of Honeydew and Rock Melons that were received for processing were divided into **four** lots and identified for each target dose of 0 (control), 150, 600 & 1000 Gy.

A pair of dosimeters was sited on one box at the pre-determined monitoring position, as per previous dose mapping (ANSTO Ref G11146). The boxes were positioned on a rig parallel to the plaque source for processing. Four boxes were sited on one side and two boxes on other side of the plaque source for each irradiation representing all three replicates for Honeydew and Rock Melons for each dose.

Results for Honeydew & Rock Melons

Target dose (Gy)	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	142 ± 6	156 ± 7	149 ± 5
600	556 ± 18	609 ± 19	582 ± 13
1000	935 ± 21	1026 ± 23	980 ± 16

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement.*

Prepared Authorised Date 9-8-11

Sohil Sheth Justin Davies

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

Prepared	Authorised	Date 9.8.11	Page 4 of 4
Sohil Sheth	Justin Davies		

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20 April 2012

Irradiation Report

ANSTO Reference	12-2040 A (Apples) & B (Nectarines)
Customer	QLD DEEDI
Address	21-23 Redden Street, Portsmith, QLD – 4870
Contact	Patricia Chay

Prepared Authorised Date 26.4.12

Connie Banos Justin Davies

Product Details

Product	Red Delicious Apples and White Flesh Nectarines
Quantity	7 × boxes Apples 3 × 10kg boxes Nectarines

Irradiation Conditions

Irradiation Facility	Gamma Technology Research Irradiator (GATRI)
Radiation type	Gamma radiation (cobalt-60)
Irradiation Dates	26 - 27 March 2012
Required Doses	0, 150, 600 & 1000 Gy
Dose rate	Approx. 9.7 $Gy.min^{-1}$
Dosimeter Type	Fricke
Dosimeter Batches	F228
Storage Conditions	Pre & post irradiation 0 °C
Irradiation temperature	23.0 to 24.0 °C

The apples and nectarines that were received for processing were repacked into boxes. The boxes for each produce were divided into four lots and identified for each target dose of 0, 150, 600 & 1000 Gy. Each lot was further divided for 3 replicates at each dose (R1, R2 & R3).

Dosimeters were sited throughout the array at the expected minimum and maximum dose zones, taking into consideration previous dose mapping and locations of inhomogeneous product distribution. Dosimeters were sited within the boxes at the front of apples and nectarines (Figure 1). Additional dosimeters were attached to the outside of one tray to provide a reference to the minimum and maximum doses (the monitoring position). The boxes were positioned on a rig parallel to the plaque source (Figure 2).

Since the dosimeters used (Fricke) are calibrated for readings 50 – 350 Gy, the 600 & 1000 Gy (R2) samples from the first lot were used to carry out a dosemapping exercise at approximately 200 Gy intervals. The locations of minimum and maximum doses were found and dosemapping repeated twice with dosimeters at those locations. This dosemapping information was used to process the remaining boxes of apples and nectarines to their target doses.

Figure 1: Dosimeter positioned on apple.

Figure 2: Boxes positioned for irradiation.

Results for Apples and Nectarines

Target dose (Gy)	Lot	Minimum Dose (Gy)	Maximum Dose (Gy)	Average dose (Gy)
150	Replicate 1	143 ± 7	158 ± 7	151 ± 5
600	Replicate 1	573 ± 7	631 ± 7	602 ± 5
1000	Replicate 1	953 ± 21	1049 ± 21	1001 ± 15
150	Replicate 2	144 ± 7	158 ± 7	151 ± 5
600	Replicate 2	541 ± 18	595 ± 19	568 ± 13
1000	Replicate 2	921 ± 23	1014 ± 23	967 ± 16
150	Replicate 3	139 ± 7	153 ± 7	146 ± 5
600	Replicate 3	562 ± 19	618 ± 19	590 ± 14
1000	Replicate 3	937 ± 23	1032 ± 24	985 ± 17

Measurement Traceability & Uncertainty

ANSTO's dosimeters are calibrated in a cobalt-60 radiation field, in which the dose rate has been determined from reference dosimeter measurements made under similar conditions. The reference dosimeter measurements are traceable to the Australian standard for absorbed dose.

The overall uncertainty associated with an individual dosimeter reading includes both the uncertainty of calibration of the batch of dosimeters and the uncertainty due to variation within the batch and is calculated to be 2.0 %. The above results include the uncertainties in the dosemapping undertaken to calculate the minimum and maximum doses. Where incremental doses have been delivered, the uncertainty in each dose fraction has been propagated to calculate the total uncertainty. Where results have been collated, the uncertainty in each run has been propagated to calculate the total uncertainty.

This expanded uncertainty is based on the standard uncertainty multiplied by a coverage factor of two, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with the *ISO Guide to the Expression of Uncertainty in Measurement.*

Conclusion

The dose absorbed by both products complies with the required specifications.

Radiation Technology maintains a quality management system that complies with ISO 9001:2008 and adheres to the principles of international best practice for dosimetry (ISO 17025 and ISO/ASTM standards for dosimetry for radiation processing).

Prepared Authorised Date 26-4-12

Connie Banos Justin Davies

3. Part B – Effect of gamma irradiation on postharvest quality of selected fruit commodities

3.1 Summary

Fruit quality evaluations were conducted on six commodities, comprising tomato, capsicum, nectarine, zucchini, honeydew and rockmelon, after being treated with gamma irradiation and following a recommended cold storage period of up to 21 days. For each commodity, treatments consisted of a gamma irradiation dose of 0Gy (control), 150Gy, 600Gy or 1000Gy applied sequentially on up to three sets of fruit with each representing a statistical replicate block. Fruit evaluations consisted of physico-chemical measurements conducted immediately after an irradiation treatment (within 24 hours), during and after removal from their recommended storage period.

For the majority of commodities tested, fruit quality was primarily impacted more by the effects of storage duration than that of irradiation per se. In this case, changes in skin and flesh colour, along with fruit softening and moisture loss rates were primarily associated with the typical senescence or ripening processes that can occur during storage. For some fruit, the use of high doses of irradiation (600-000Gy) resulted in minor changes in quality, such as a slight increase in moisture loss and Brix levels in capsicum fruit, while in zucchini Brix levels decreased. Overall, these effects were minor and did not detract from the integrity or overall visual appeal of the fruit.

Irradiation however had a significant impact on the quality of honeydew melon and to a lesser extent on nectarine fruit, although its effects were not expressed until the end of their recommended storage period. In both cases, the level of skin pitting and browning was related to the intensity of the dose, with initial symptoms first being expressed in nectarine and honeydew melon at 150Gy and 600Gy respectively. In nectarine, the disorder expressed at 150Gy was very low with only 3% of fruit exhibiting skin pitting/browning on < $1cm^2$ of the total fruit surface area. At 1000Gy, this increased to 20% of fruit affected despite the severity remaining low. In contrast, treatment doses from 600-1000Gy in honeydew melon resulted in up to 86% of fruit expressing symptoms of pitting on 26% of their skin surface area.

In conclusion, the overall findings of the study suggest that an application of up to 1000Gy will not result in any detrimental damage to the quality of tomato, capsicum, zucchini or rockmelon fruit. In contrast, the quality of honeydew melon and to a lesser extent nectarine fruit showed little to no defects following a 150Gy irradiation dose. However, a dose of 600Gy or above would not be recommended for either produce type given the severity of irradiation damage expressed.

3.2 Introduction

The current study serves to compliment the nutritional component of this report, where the focus is primarily directed towards an examination of the effects of irradiation on fruit quality in tomato, capsicum, nectarine, zucchini, honeydew melon and rockmelon. The work was undertaken using a similar corresponding set of fruit as used in the nutritional study, which included the same postharvest irradiation treatments and subsequent storage duration conditions.

Fruit quality assessments in this study specifically entailed measurements of physico-chemical properties of each commodity, with evaluations conducted immediately (within 24 hours) after each irradiation event, and after a recommended cold storage period. The findings of this study are therefore anticipated to contribute to our overall understanding of the impact of relatively low to moderate doses of gamma irradiation (≤ 1000Gy) on fruit storage life and on overall quality maintenance. The study will provide recommendations on the irradiation dose limits for ensuring product integrity.

3.3 Materials and methods

3.3.1 Experimental layout

Six fruit commodities (Table 1) were sourced from the Sydney Markets, NSW between February and May 2011. Fruit were transported over to the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, NSW, where each commodity was irradiated over three sequential times (blocking factor) with target doses of 150Gy, 600Gy and 1000Gy. A corresponding set of untreated fruit (0Gy) served as a control group. For each fruit commodity, replication consisted of ten replicate fruit per block per irradiation treatment per assessment time (two times), except for both melons which consisted of five replicate fruit.

Following the irradiation treatment, each commodity was immediately transported by air to the DAFF postharvest laboratory in Cairns. Within 24 hours, a subset of fruit was destructively assessed for quality determination (Day 1) while a second subset was placed immediately into cold storage and, depending on the commodity type, stored for up to 21 days and then destructively assessed (Table 20). Over the storage period, fruit were also assessed for any visual defects and weighed at seven day intervals. Storage condition and duration for each commodity was based on the postharvest storage and handling guidelines recommended by the University of California, Davis Postharvest Technology Center, California, USA (UC Davis, 2011). During storage, ambient conditions (air temperature and relative humidity) were also monitored to ensure they remained within the specifications of the trial.

Table 20. Description of fruit type and storage conditions applied in the present study.

Commodity	Variety	Storage temperature (°C)	Storage relative humidity (%)	Storage duration (days)
Tomato	‘Gourmet Swanson’	10.0	90-95%	14
Capsicum (green)	‘Plato’	7.5	> 95%	21
Zucchini	‘Blackjack’	7.0	95%	7
Nectarine	‘Arctic Snow’	1.0	90-95%	21
Honeydew melon	‘Galaxy’	7.0	90-95%	14
Rockmelon	‘Triumph’	7.0	85-90%	14

3.3.2 Fruit quality assessments

Fruit quality measurements conducted before and after storage included a measure of fresh weight, fruit firmness, skin and/or flesh colour, biochemical analyses (determination of soluble solids and titratable acidity), and record of the incidence and severity of disorders and disease types. Both fruit weight and disorder/disease measurements were recorded every seven days during the storage period. A description of each assessment method is described below.

3.3.2.1 Fruit colour

Fruit skin and/or flesh colour was assessed using a Minolta digital colorimeter (model CR300) fitted with an 8mm orifice and a 0° observer. A colour measurement was collected on each individual replicate fruit for lightness, chroma and hue angle (L*, C*, H° units). On some fruit types, an internal colour measurement was taken on the cut flesh surface taken from an equatorial transection of fruit.

3.3.2.2 Moisture loss and whole fruit softness

Fruit were weighed on each specified evaluation day. Percent moisture loss was calculated by determining the proportion of moisture lost from each assessment day compared to the initial assessment date (Day 1). A measure of fruit firmness was also conducted for each fruit using a desk-mounted Chatillon penetrometer (DFIS 50) fitted with a 12mm spherical probe. Compression on the equatorial region of each fruit was undertaken using a rate of 20mm per minute until 2mm of fruit tissue was displaced, with results expressed in Newton (N).

3.3.2.2 Biochemical analyses

Total soluble solids (TSS) and titratable acidity (TA) were determined by destructively assessing a subset of fruit before and after their storage period. TSS was determined using an Atago bench refractometer using extracted juice obtained by compressing tissue through a fine mesh cloth. Results were expressed as degree (°) Brix. Samples were also blended to a fine slurry and the extracted juice sample was used to determine TA. Samples were titrated to pH 8.1 with 0.1N NaOH and expressed as % citric acid (Mettler Toledo T50 autotitrator).

3.3.2.3 Fruit disorders and pathogens

The incidence and severity of physiological disorders and diseases were scored on individual fruit. Incidence was based on the proportion of fruit within a treatment expressing symptoms. A severity rating scale using a score from 0 to 5 was based on the surface area affected, where **0** = nil, **1** = < 1cm, **2** = 1-2cm, **3** = 2.1-3cm, **4** = 3.1cm to 25% and **5** = > 25%. A severity rating scale on the larger fruit, specifically both melon types, was based on the proportion (%) of surface area affected.

3.3.3 Statistical analysis

Biometrical analyses of fruit quality were conducted using the statistical package Genstat version 11.1 (VSN International Ltd.). For each crop, a general ANOVAs was performed to test the main and interactive effects of irradiation dose and storage time on each fruit quality attribute. Blocking was represented by each irradiation event for a given commodity. A significant result occurred when $p \leq 0.05$, and not significant findings were reported as “ns”. Differences between treatment levels were determined using a least square difference (LSD) test at 5%.

3.4 Results

3.4.1 Tomato

The effects of irradiation and storage duration on tomato fruit quality attributes are summarised in Table 21. Over the storage period, tomato fruit firmness decreased significantly by 19% from 3.2N to 2.6N, although it still remained highly saleable in regards to overall fruit firmness. This was associated with an approximate 3% loss in moisture content of individual fruit over this period. The irradiation treatment however had no effect on either fruit firmness or on moisture loss rates.

Small, although significant, changes in tomato skin colour occurred over the 14 day storage period. These were primarily attributed to the time in storage and less so to the effects of irradiation. Skin colour, therefore, over this period transitioned to a slightly deeper shade of red. Visually, irradiation, therefore, had no detrimental effect on skin quality (Appendix 3).

TSS in tomato flesh remained relatively constant over the storage period, showing only a 0.1° difference from the mean (~4.9° Brix) across most of the irradiation levels. Percent citric acid was not affected by irradiation but did increase with storage time, equating to an average increase of 0.04% from an initial value of 0.39% (Day 0).

Table 21. Effect of irradiation dose and storage duration on tomato quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (10°C) for 14 days (Day 14).

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Firmness (N)	1	3.3	3.2	3.1	3.0	3.2a	Day	<0.001
	14	2.8	2.5	2.6	2.5	2.6 b	Irrad.	ns
	Mean	3.1	2.9	2.9	2.8		Day x Irrad.	ns
Skin lightness	1	38.9	38.9	39.3	39.4	39.1a	Day	<0.001
	14	37.2	37.1	37.5	37.0	37.2 b	Irrad.	ns
	Mean	38.1	38.0	38.4	38.2		Day x Irrad.	ns
Skin chroma	1	34.0	32.7	34.0	33.8	33.6a	Day	<0.01
	14	36.1	34.9	35.7	33.6	35.1 b	Irrad.	ns
	Mean	35.1	33.8	34.8	33.7		Day x Irrad.	ns
Skin hue angle	1	44.2	45.7	44.69	45.7	45.0a	Day	<0.001
	14	43.0	43.4	43.20	43.2	43.2 b	Irrad.	<0.05
	Mean	43.6a	44.6 b	43.90ab	44.4 b		Day x Irrad.	ns
TSS (° Brix)	1	4.9	4.8	5.0	4.9	4.9	Day	ns
	14	4.9	4.7	4.9	4.9	4.9	Irrad.	<0.05
	Mean	4.9a	4.8 b	4.9a	4.9a		Day x Irrad.	ns
TA (% citric acid)	1	0.39	0.38	0.40	0.38	0.39 b	Day	<0.001
	14	0.44	0.44	0.43	0.42	0.43a	Irrad.	ns
	Mean	0.42	0.41	0.42	0.40		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

3.4.2 Capsicum

The effects of irradiation and storage duration on green capsicum quality attributes are summarised in Table 22. Both storage time and irradiation dose independently affected fruit firmness levels, resulting in fruit becoming softer (up to 1.6N) after 21 days of storage and with increasing doses of irradiation. Fruit softening was also associated with significantly higher rates of moisture loss rates in 1kGy treated fruit compared with all other treatments ($p<0.05$) (Figure 3).

The development of red pigments in capsicum skin (degreening) was not affected by irradiation but did occur over the 21 storage period. Only a mean surface area of 2% per fruit expressed this red pigment. According to skin colour analyses, background green colour also changed as a result of storage time, showing only a slight shift towards a darker green shade by 21 days (Table 22). Fruit treated to 600Gy and above were also slightly darker than 0Gy and 150Gy treated fruit, although this was not visually detectable (Appendix 3).

Internal quality, such as TSS and TA levels, were both affected independently by storage time and irradiation dose (Table 22). TSS levels increased from 4.1° to 4.5° Brix over the 21 day storage period and between the 0Gy and 1kGy irradiation treatment. TA levels exhibited very small but significant changes over the storage period and between irradiation doses. Generally, TA levels decreased (by 0.02 to 0.13%) with storage time, whereas irradiation exposure resulted in a slight increase in TA levels (range 0.13 to 0.15%).

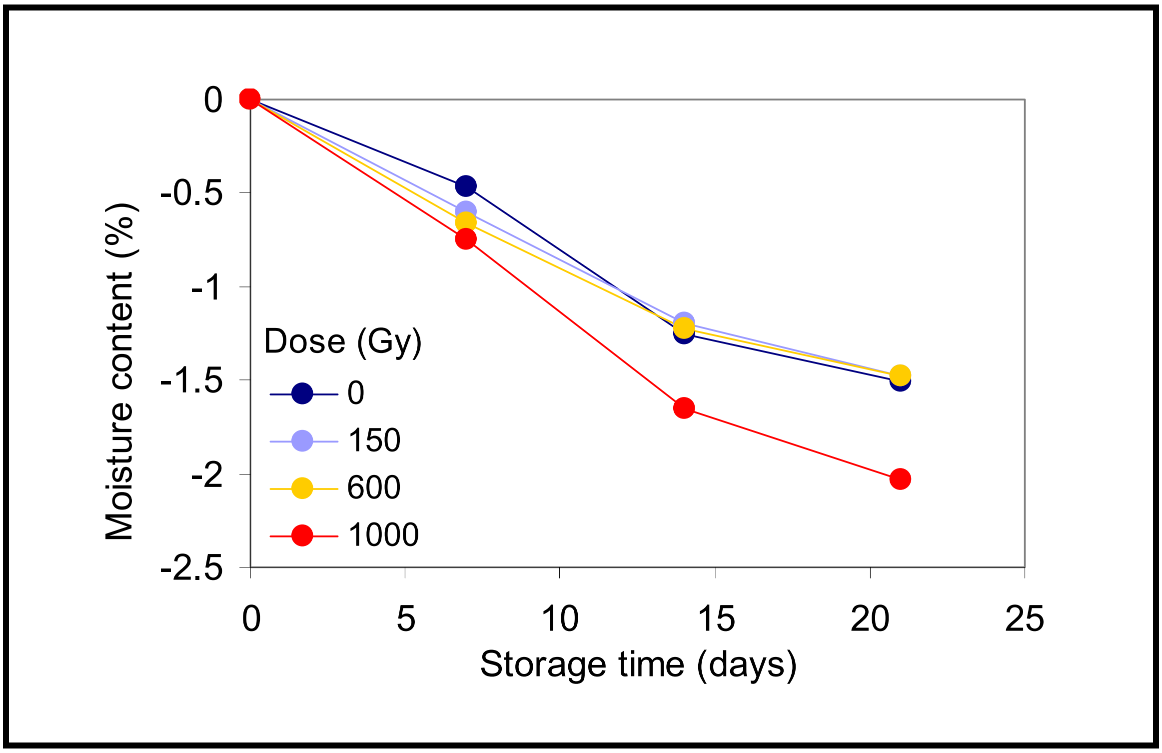


Figure 3. Effect of irradiation dose on fruit moisture content during cold (7.5°C) storage of green capsicum.

Table 22. Effect of irradiation dose and storage duration on green capsicum quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.5°C) for 21 days (Day 21).

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Firmness (N)	1	7.9	7.1	6.6	5.8	6.9a	Day	<0.001
	14	5.8	5.6	5.2	4.8	5.3 b	Irrad.	<0.01
	Mean	6.9a	6.3ab	5.9 bc	5.3 c		Day x Irrad.	ns
Degreen (%)	1	1.0	0.3	0.0	0.3	0.4 b	Day	<0.001
	14	3.0	2.3	7.5	3.3	4.0a	Irrad.	ns
	Mean	2.0	1.3	3.8	1.8		Day x Irrad.	ns
Skin lightness	1	35.9	36.2	36.0	36.4	36.1a	Day	<0.001
	14	33.7	33.4	33.4	34.1	33.7 b	Irrad.	ns
	Mean	34.8	34.8	34.7	35.3		Day x Irrad.	ns
Skin chroma	1	16.2	16.8	17	17.1	16.8a	Day	<0.01
	14	14.9	14.3	14.6	15.2	14.7 b	Irrad.	ns
	Mean	15.5	15.5	15.8	16.2		Day x Irrad.	ns
Skin hue angle	1	129.5	128.2	127.7	128	128.4 b	Day	<0.01
	14	131	130.8	129.5	128.7	130.0a	Irrad.	<0.01
	Mean	130.2a	129.5ab	128.6 b	128.4 b		Day x Irrad.	ns
TSS (° Brix)	1	3.9	3.9	4.2	4.5	4.1 b	Day	<0.001
	14	4.3	4.5	4.6	4.5	4.5a	Irrad.	<0.05
	Mean	4.1 c	4.2 bc	4.4ab	4.5a		Day x Irrad.	ns
TA (% citric acid)	1	0.14	0.15	0.16	0.15	0.15a	Day	<0.001
	14	0.11	0.13	0.14	0.13	0.13 b	Irrad.	<0.001
	Mean	0.13 b	0.14a	0.15a	0.14a		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

3.4.3 Zucchini

Fruit moisture loss rates between treatments remained unchanged over the seven day storage duration, averaging a 3% loss over that period. Similarly, fruit firmness also remained relatively similar between treatments and evaluation dates (Table 23). Biochemically, TA was not affected by any treatments although fruit TSS increased significantly with storage time (from 2.8° to 3.5° Brix) although decreased with an irradiation dose above 600Gy (mean of 3.3° down to 2.7° Brix).

Zucchini colour properties changed over the seven day storage period, with the skin becoming a lighter green and the flesh a darker yellow colour with time (Table 23). Only small changes in internal flesh colour (chroma values) were attributed to the effects of irradiation, resulting in flesh tissue becoming slightly duller in colour by Day 7, particularly with doses at and above 600Gy. These changes however were not visually detectable (Appendix 3).

3.4.4 Nectarine

Changes in fruit colour properties are shown in Table 24. With exception to skin chroma values, irradiation and storage time had no effect on skin colour properties. Changes in chroma values were associated with a slight decrease in skin colour intensity, particularly in the control and the lowest dose treatment. Small changes in internal flesh colour also occurred, although storage time had more of an affect on colour properties than did the irradiation treatment itself. In this case, fruit flesh colour became a lighter yellow colour with time, with the colour becoming more intense with higher doses of irradiation (Appendix 3).

All fruit lost approximately 1.4% of their initial weight by the end of the 21 day storage period, although there was no effect of irradiation. There was also no significant difference in fruit firmness levels between irradiation doses or assessment times. Internal quality such as TSS and TA were also unaffected by the irradiation treatment, although storage time did affect fruit flavour. Over this period, TSS increased significantly from 11.4° to 12.3° Brix while TA decreased from 0.38 to 0.29% (Table 24).

The irradiation treatments resulted in fruit developing a mild form of pitting along with browning of the skin surface (Figure 4 and Table 24). This was expressed only after 21 days of storage, occurring in a small percentage of fruit (3%) at 150Gy although this increased significantly with higher doses with up to 20% of fruit affected at 1kGy. The severity of symptoms however was low with on average less than 1cm² of their surface area being affected.

Figure 4. Nectarine fruit with symptoms of irradiation damage following treatment to 1kGy occurring after 21 days in cold (1.0°C) storage. Symptoms consisted of mild pitting associated with browning on the skin surface.

Table 23. Effect of irradiation dose and storage duration on zucchini fruit quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for seven days (Day 7).

Variable	Day	Irradiation dose (Gy) 0	150	600	1000	Mean	ANOVAs Factor	p-value
Firmness (N)	1	7.1	8.0	8.2	8.1	7.8	Day	ns
	14	7.6	8.2	7.2	6.3	7.3	Irrad.	ns
	Mean	7.4	8.1	7.7	7.2		Day x Irrad.	ns
TSS (° Brix)	1	3.3	2.9	2.7	2.3	2.8 b	Day	<0.01
	14	3.6	3.7	3.6	3.1	3.5a	Irrad.	<0.05
	Mean	3.4a	3.3a	3.2a	2.7 b		Day x Irrad.	ns
TA (% citric acid)	1	0.15	0.16	0.17	0.17	0.16	Day	ns
	14	0.17	0.17	0.17	0.16	0.17	Irrad.	ns
	Mean	0.16	0.16	0.17	0.17		Day x Irrad.	ns
Skin lightness	1	28.1	28.2	27.5	27.2	27.7 b	Day	<0.05
	14	31.5	32.4	32.3	31.0	31.8a	Irrad.	ns
	Mean	29.8	30.3	29.9	29.1		Day x Irrad.	ns
Skin chroma	1	16.2	15.3	14.8	14.6	15.2 b	Day	<0.05
	14	17.0	18.6	18.3	16.7	17.6a	Irrad.	ns
	Mean	16.6	16.9	16.6	15.6		Day x Irrad.	ns
Skin hue angle	1	126.1	126.3	126.9	127	126.6a	Day	<0.05
	14	128.7	128.1	128.5	129	128.6 b	Irrad.	ns
	Mean	127.4	127.2	127.7	128.0		Day x Irrad.	ns
Flesh lightness	1	86.4	87.3	88.0	87.5	87.3a	Day	<0.05
	14	85.3	85.0	85.0	82.5	84.5 b	Irrad.	ns
	Mean	85.8	86.1	86.5	85.0		Day x Irrad.	ns
Flesh chroma	1	23.6a	22.2ab	20.0 bc	22.2ab	22.0	Day	ns
	14	22.1ab	23.1a	21.9abc	20.0 c	21.8	Irrad.	<0.05
	Mean	22.8a	22.6ab	21.0 c	21.1 bc		Day x Irrad.	<0.05
Flesh hue angle	1	102.3	105.5	105.8	104.9	105.4a	Day	<0.001
	14	104.4	103.9	103.8	103.4	103.9 b	Irrad.	ns
	Mean	104.8	104.7	104.8	104.2		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

Table 24. Effect of irradiation dose and storage duration on nectarine fruit quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (1.0°C) for 21 days (Day 21).

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Firmness (N)	1	6.4	5.8	6.4	6.1	6.2	Day	ns
	14	6.8	6.2	7.0	7.6	6.9	Irrad.	ns
	Mean	6.6	6.0	6.7	6.8		Day x Irrad.	ns
TSS (° Brix)	1	11.5	11.1	11.6	11.4	11.4 b	Day	<0.05
	14	12.3	12.3	12.6	12.2	12.3a	Irrad.	ns
	Mean	11.9	11.7	12.1	11.8		Day x Irrad.	ns
TA (% citric acid)	1	0.39	0.37	0.36	0.40	0.38a	Day	<0.001
	14	0.3	0.28	0.28	0.29	0.29 b	Irrad.	ns
	Mean	0.35	0.33	0.32	0.35		Day x Irrad.	ns
Skin lightness	1	79.8	79.5	78.5	77.9	78.9	Day	ns
	14	79.3	80.1	80.6	79.3	79.8	Irrad.	ns
	Mean	79.6	79.8	79.5	78.6		Day x Irrad.	ns
Skin chroma	1	29.8ab	30.3a	30.2a	30.5a	30.2	Day	<0.01
	14	26.0 c	28.4 b	30.0a	31.0a	28.8	Irrad.	<0.001
	Mean	27.9	29.3	30.1	30.8		Day x Irrad.	<0.01
Skin hue angle	1	100.1	98.9	92.4	91.4	95.7	Day	ns
	14	99.6	98.5	97.3	97.1	98.1	Irrad.	ns
	Mean	99.8	98.7	94.8	94.2		Day x Irrad.	ns
Flesh lightness	1	78.5	78.1	79.5	78.6	78.7 b	Day	<0.001
	14	79.4	79.8	80.1	80.2	79.9a	Irrad.	ns
	Mean	78.9	79.0	79.8	79.4		Day x Irrad.	ns
Flesh chroma	1	12.3 d	13.4 c	14.6 b	13.9 bc	13.6	Day	ns
	14	12.2 d	13.1 cd	14.5 b	15.9a	13.9	Irrad.	<0.001
	Mean	12.2 c	13.2 b	14.6a	14.9a		Day x Irrad.	<0.05
Flesh hue angle	1	88.1	87.2	93.2	91.2	89.9 b	Day	<0.05
	14	98.0	99.8	99.5	99.2	99.1a	Irrad.	<0.001
	Mean	93.0 b	93.5 b	96.3a	95.2ab		Day x Irrad.	ns

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Skin browning/ pitting incidence (%)	1	0 b	0.0 b	0.0 b	0.0 b	9.2a	Day	<0.05
	14	0 b	3.3 b	13.3ab	20.0a	0.0 b	Irrad.	<0.01
	Mean	0 b	1.7 b	6.7ab	10.0a		Day x Irrad.	<0.05
Skin browning/ pitting severity (0-5)	1	0	0.0	0.0	0.0	0.0 b	Day	<0.01
	14	0	0.1	0.4	0.4	0.2a	Irrad.	ns
	Mean	0	0.0	0.2	0.2		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

3.4.5 Rockmelon

The effects of irradiation and storage duration on rock melon quality attributes are summarised in Table 25. Rockmelon fruit became softer during storage but was unaffected by the irradiation treatment. By Day 14, fruit had lost approximately 5% of their initial mean fresh weight (1.7kg), although this was not influenced by the irradiation treatment. Aside from a few small spots of mould on the skin surface (Day 14), there was no affect of irradiation or storage time on the overall visual appearance of the fruit (Appendix 3), nor on the internal flesh colour. TSS and TA were also unaffected by any of the irradiation treatments, although storage time did result in a small but significant decline in Brix levels and a slight increase in citric acid levels.

3.4.6 Honeydew

In Table 26 the effects of irradiation and storage duration on honeydew melon quality attributes are presented. Honeydew melon fruit lost approximately 1.6% in fresh weight during the storage period, although no differences in firmness levels were detected between irradiation treatments and before or after storage. TSS and TA were also unaffected by any of the irradiation treatments, although did decline slightly during storage.

By the end of the 14 day storage period, some honeydew fruit treated with irradiation developed pitting on the skin surface (Table 26; Figure 5; Appendix 3). Those affected were 60% and 80% of fruit treated with 600Gy and 1kGy, respectively. The proportion of skin surface area affected was also associated with the intensity of the dose, increasing from 8% (600Gy) to 51% (1kGy).

Figure 5. Honeydew melon expressing symptoms of irradiation damage following treatment to 1kGy occurring after 14 days in cold (7.0°C) storage. Symptoms consisted of pitting and browning on the skin surface.

Table 25. Effect of irradiation dose and storage duration on rockmelon quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for 14 days (Day 14).

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Firmness (kg force)	1	21.9	18.3	17.3	18.8	19.1a	Day	<0.001
	14	14.1	15.1	15.4	15.4	15.0 b	Irrad.	ns
	Mean	18.0	16.7	16.4	17.1		Day x Irrad.	ns
Flesh lightness	1	67.8	68.7	68.2	68.9	68.4	Day	ns
	14	67.6	67.8	68.2	67.9	67.9	Irrad.	ns
	Mean	67.7	68.3	68.2	68.4		Day x Irrad.	ns
Flesh chroma	1	35.5	35.6	36.7	34.7	35.6	Day	ns
	14	35.7	36.1	36.0	36.4	36.1	Irrad.	ns
	Mean	35.6	35.9	36.4	35.6		Day x Irrad.	ns
Flesh hue angle	1	79.1	79.3	77.7	79.4	78.9	Day	ns
	14	77.9	77.7	78.0	78.1	77.9	Irrad.	ns
	Mean	78.5	78.5	77.9	78.7		Day x Irrad.	ns
TSS (° Brix)	1	7.7	7.5	7.1	7.7	7.5a	Day	<0.05
	14	6.7	7.1	7.1	7.0	7.0 b	Irrad.	ns
	Mean	7.2	7.3	7.1	7.3		Day x Irrad.	ns
TA (% citric acid)	1	0.06	0.06	0.07	0.06	0.06 b	Day	<0.001
	14	0.08	0.08	0.07	0.08	0.08a	Irrad.	ns
	Mean	0.07	0.07	0.07	0.07		Day x Irrad.	ns

Means followed by the same letter are not significantly different.

ns = not significant

Table 26. Effect of irradiation dose and storage duration on honeydew melon quality attributes. Fruit were gamma irradiated (Irrad.) up to 1kGy and then assessed within 24 hours (Day 1) and after cold storage (7.0°C) for 14 days (Day 14).

Variable	Day	Irradiation dose (Gy)					ANOVAs	
		0	150	600	1000	Mean	Factor	p-value
Firmness (kg force)	1	21.9	24.4	25.7	24.3	24.1	Day	ns
	14	25.6	26.7	26.5	23.6	25.6	Irrad.	ns
	Mean	23.7	25.5	26.1	24.0		Day x Irrad.	ns
Flesh lightness	1	63.4	62.1	60.5	60.6	61.7 b	Day	<0.001
	14	64.7	63.6	63.4	65.5	64.3a	Irrad.	<0.05
	Mean	64.0a	62.9ab	62.0 b	63.1ab		Day x Irrad.	ns
Flesh chroma	1	25.8	25.4	27.4	26.9	26.4	Day	ns
	14	25.9	25.7	24.9	24.4	25.2	Irrad.	ns
	Mean	25.9	25.5	26.1	25.7		Day x Irrad.	ns
Flesh hue angle	1	117.4	117.1	117.1	117.4	117.2	Day	ns
	14	117.8	117.2	117.1	116.6	117.2	Irrad.	ns
	Mean	117.6	117.2	117.1	117.0		Day x Irrad.	ns
TSS (° Brix)	1	8.5	9.6	9.5	9.6	9.3a	Day	<0.05
	14	8.1	9.2	7.7	7.8	8.2 b	Irrad.	ns
	Mean	8.3	9.4	8.6	8.7		Day x Irrad.	ns
TA (% citric acid)	1	0.10	0.09	0.10	0.10	0.10a	Day	<0.05
	14	0.08	0.09	0.09	0.09	0.09 b	Irrad.	ns
	Mean	0.09	0.09	0.09	0.10		Day x Irrad.	ns
Skin pitting incidence (%)	1	0 c	0 c	0.0 c	0.0 c	0.0 b	Day	<0.001
	14	0 c	0 c	60.0 b	86.7a	40.0a	Irrad.	<0.001
	Mean	0 c	0 c	30.0 b	43.3a		Day x Irrad.	<0.001
Skin pitting severity (%)	1	0 c	0 c	0.0 c	0.0 c	0.0 b	Day	<0.001
	14	0 c	0 c	7.5 b	51.3a	15.2a	Irrad.	<0.001
	Mean	0 c	0 c	3.7 b	25.7a		Day x Irrad.	<0.001

Means followed by the same letter are not significantly different.

ns = not significant

3.5 Discussion

This study contributes towards further enhancing our baseline knowledge of the effects of irradiation on fruit quality. In this study, irradiation applied up to 1kGy overall had little to no effect on a range of fruit quality attributes measured in tomato, capsicum, zucchini and rockmelon. These commodities were instead primarily impacted more by storage time than by irradiation itself. This comprised small changes in skin and flesh colour along with moisture loss and fruit softening; being overall typical ripening or senescence responses that occur while in storage.

As a result of irradiation, capsicum and zucchini fruit, in particular, exhibited small although statistically significant changes in fruit quality. At high doses of irradiation (0.6-1kGy), a slight increase in moisture loss and Brix levels were observed in capsicum fruit, while Brix levels in zucchini decreased. These effects overall were minor and did not visually detract from the integrity or overall appearance of the fruit. Mitchell *et al.* (1992) also reported similar findings in a study which included irradiated green capsicum and zucchini fruit stored at 5°C and 7°C for 3.5 weeks and 3 weeks, respectively. Although they only applied doses up to 300Gy, they found that storage duration had a greater impact on physico-chemical components in these crops than did the effect of irradiation itself. These effects included decreases in soluble solids, acidity and fruit colour properties.

Application of irradiation however had a significant impact on the quality of honeydew melon and, to a lesser extent, nectarine fruit. In both commodities, irradiation damage was only expressed by the end of the storage period, with the development of skin pitting and browning being positively related to the dose intensity. The overall severity of symptoms in nectarine fruit however was very low across all treatment doses, with only a few (3%) fruit expressing very mild symptoms at 150Gy. Mitchell *et al.* (1992) also assessed the effects irradiation on nectarine, yet found no effects on fruit physico-chemical properties up to 300Gy. Similarly, reports on melon fruit have also shown that treatment with gamma irradiation (≤ 1000Gy) resulted in little to no damage to fruit (Kader 1986; Castell-Perez *et al.* 2004). According to Kader (1986), nectarine and melon fruit are generally regarded as having a relatively high stress tolerance to ionizing radiation (up to 1kGy), although acknowledges that various pre and postharvest factors can influence their susceptibility, including climatic growing conditions, cultural field practices, and handling and storage conditions.

3.6 Recommendations

In this study, applications of gamma irradiation treatments of ≤ 1kGy can be used as a disinfestation measure without inducing any deleterious effects on quality in tomato, green capsicum, zucchini and rockmelon fruit. In contrast, honeydew melon, and to a lesser extent, nectarine fruit both expressed a lower tolerance to irradiation, with doses predominately at 600Gy and above resulting in skin pitting and browning. In regards to honeydew melon, as this study did not define the threshold between 150 and 600Gy where these disorders could be expressed, applications of gamma irradiation of up to 150Gy could therefore be safely employed without any negligible impacts on quality. In nectarine, treatment with 150Gy could also be considered a safe limit given the overall incidence and severity of symptoms at this dose level was extremely low.

3.7 References

Castell-Perez E, Moreno M, Rodriguez O and Moreira RG (2004). Electron beam irradiation treatment of cantaloupes: effect on product quality. *Food Science & Technology International 10 (6):* 383-390.

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

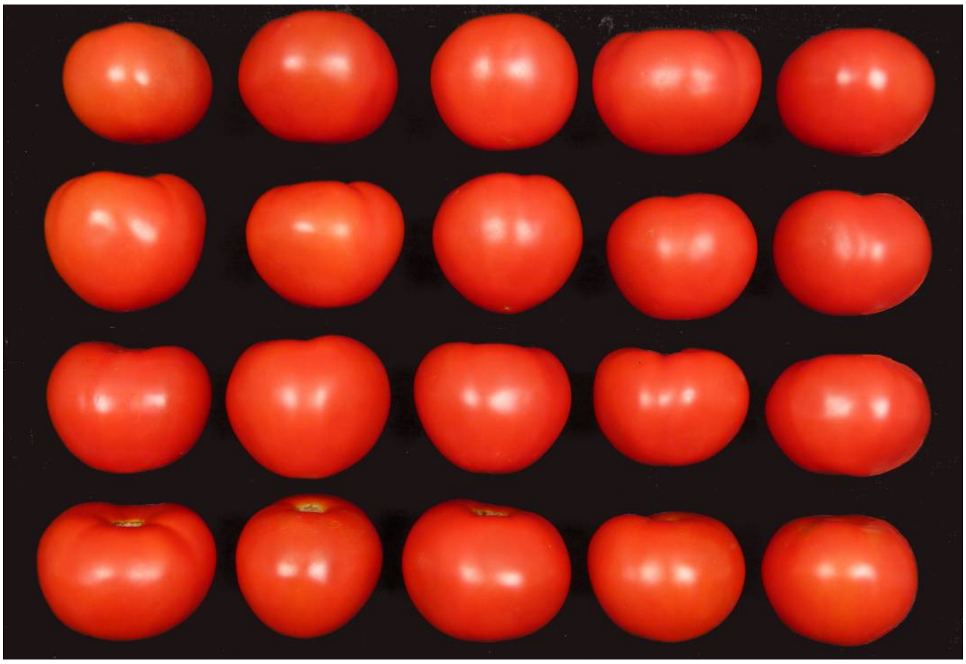
Mitchell GE, McLauchlan RL, Isaacs AR, Williams DJ, Nottingham SM (1992). Effect of low dose irradiation on composition of tropical fruits and vegetables. J*ournal of Food Composition and Analysis 5:* 291-311.

UC Davis (2011). Postharvest Technology Produce Fact Sheets. Agriculture and Natural Resources, University of Southern California, USA website viewed 15 August, 2011. http://postharvest.ucdavis.edu/producefacts/

3.8 Appendix 3 – Photographs of each fruit type gamma irradiated with a dose between 0Gy to 1000Gy taken before cold storage (Day 1) and up to a maximum of 21 days

3.8.1 Tomato (var. Gourmet Swanson)

Day 1



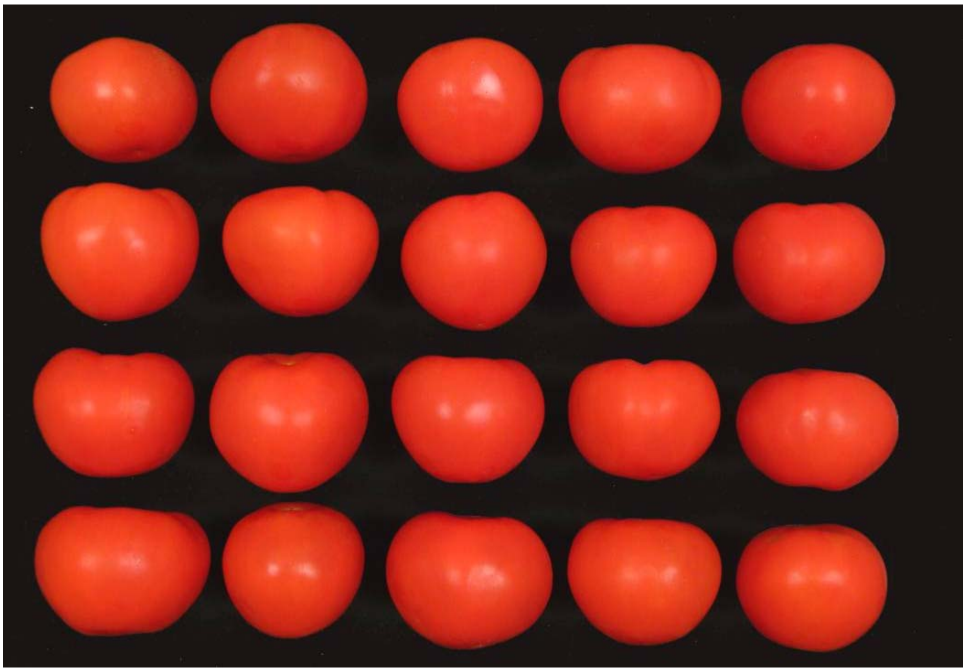
0Gy

150Gy

600Gy

1000Gy

Day 7



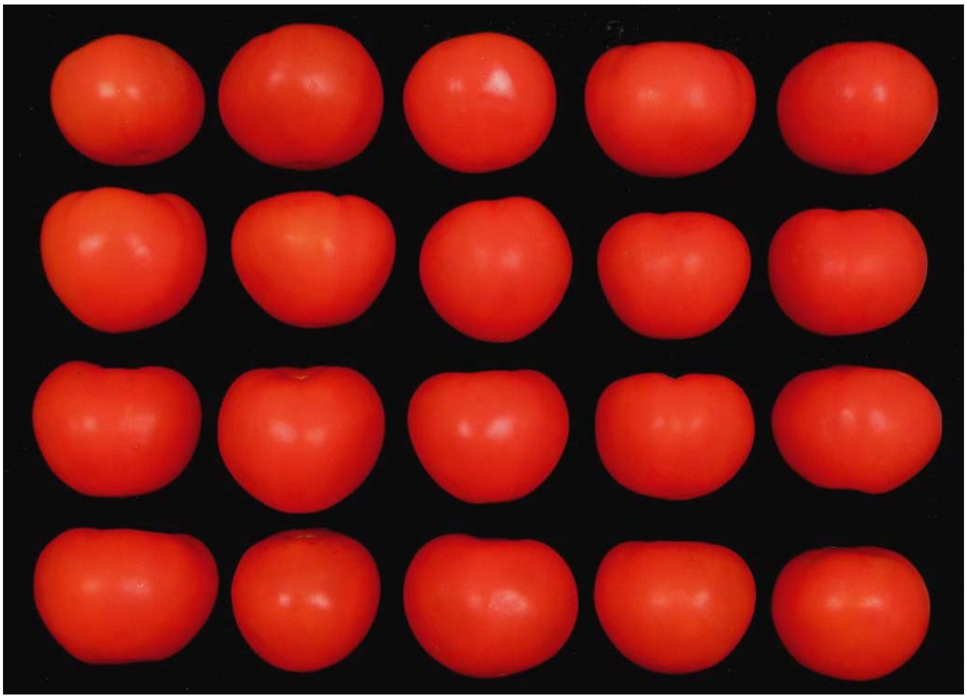
0Gy

150Gy

600Gy

1000Gy

Day 14



0Gy
150Gy
600Gy
1000Gy

3.8.2 Capsicum (var. Plato)

Day 1

0Gy
150Gy
600Gy
1000Gy

Day 7

0Gy

150Gy

600Gy

1000Gy

Day 14

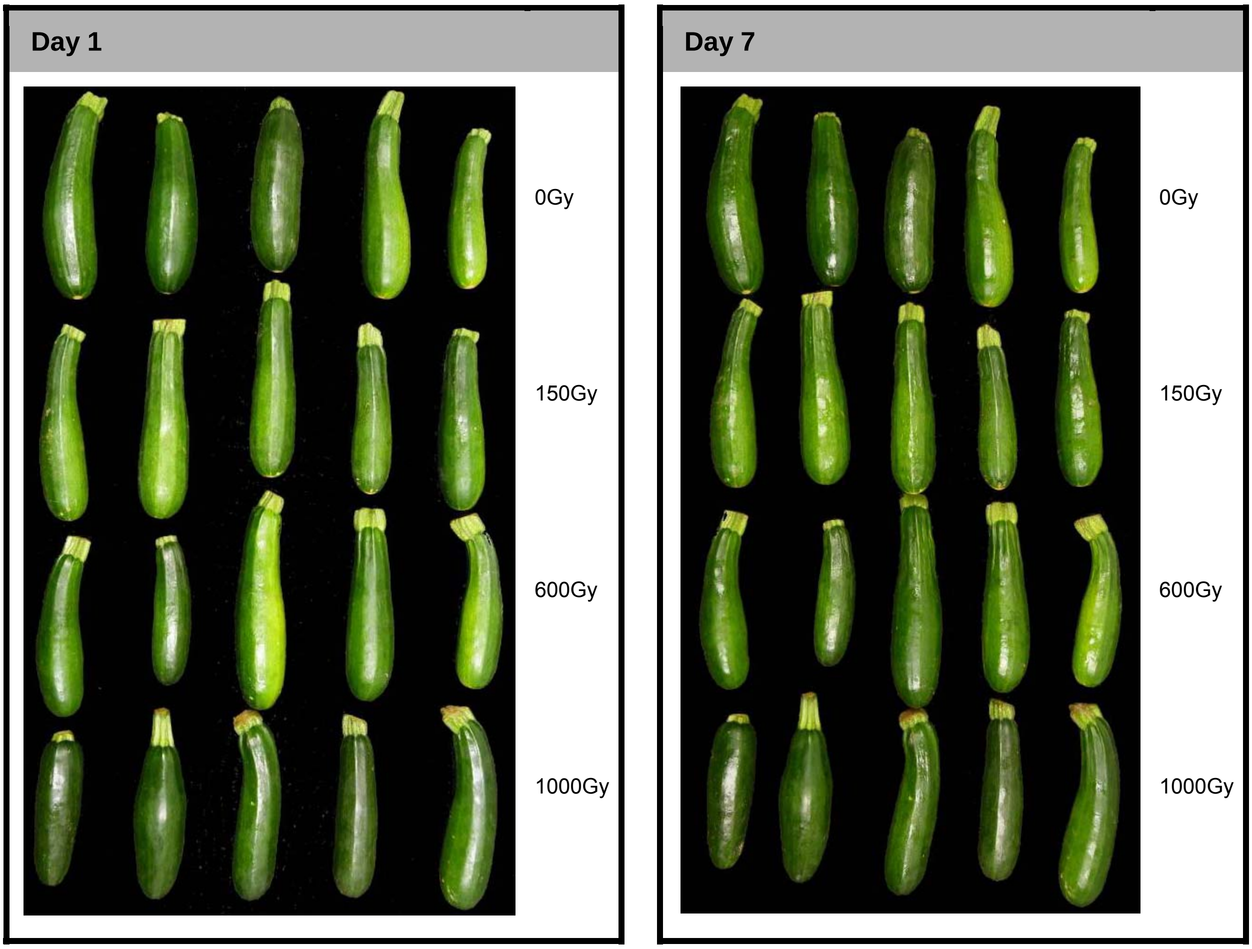
0Gy

150Gy

600Gy

1000Gy

3.8.3 Zucchini (var. Blackjack)



3.8.4 Nectarine (var. Arctic Snow)

Day 1

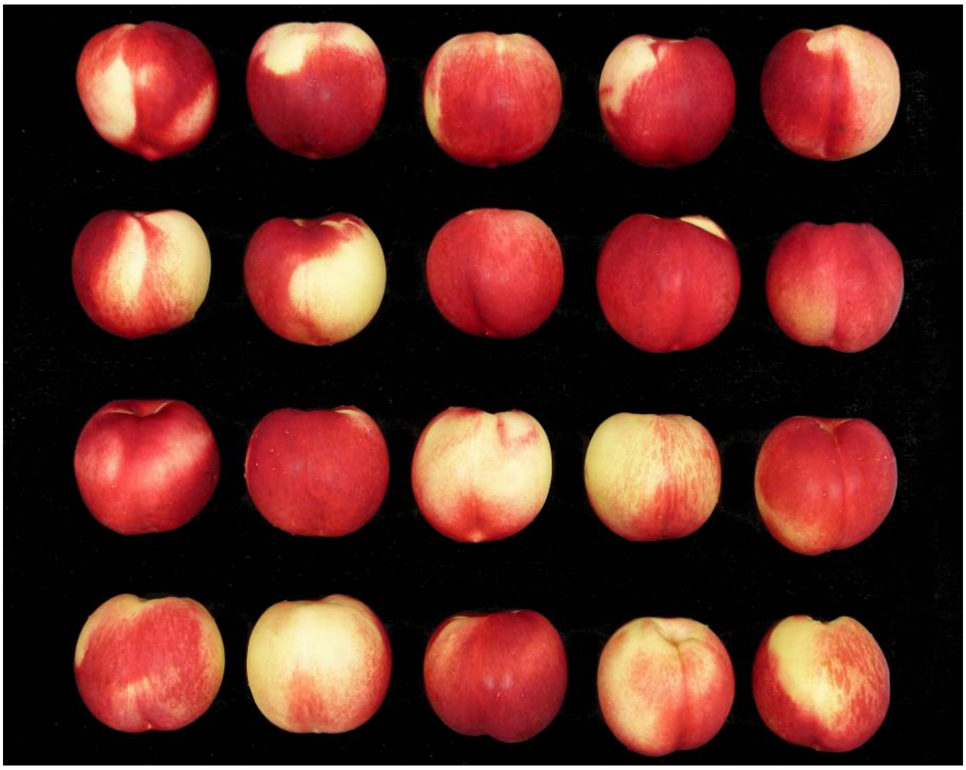
0Gy

150Gy

600Gy

1000Gy

Day 7



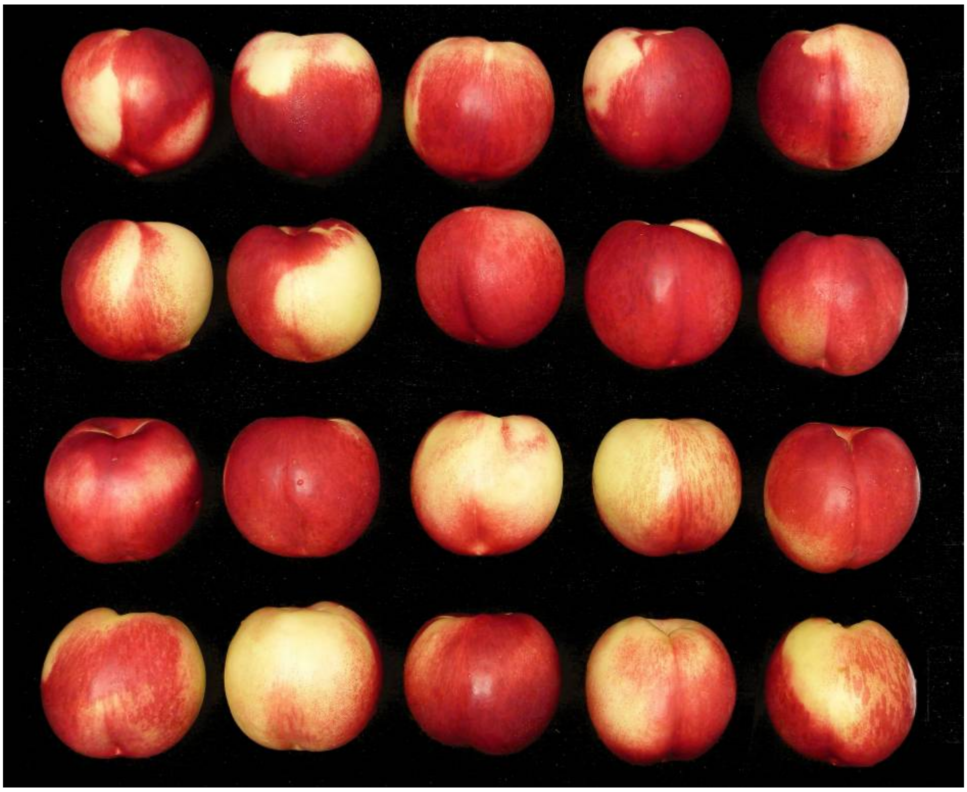
0Gy

150Gy

600Gy

1000Gy

Day 14



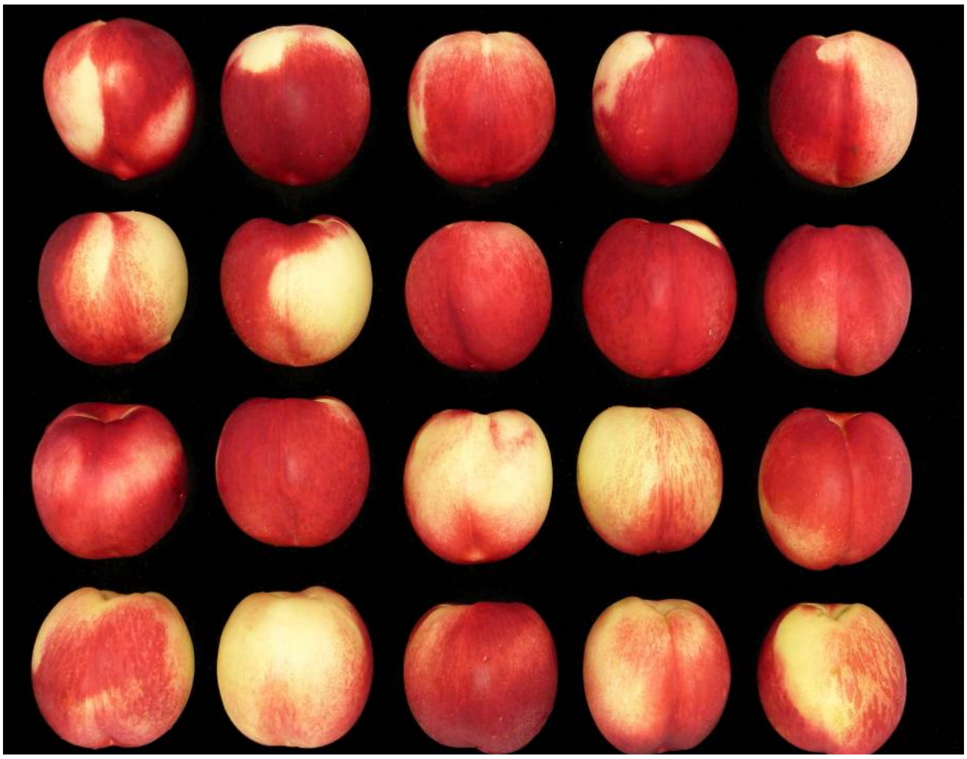
0Gy

150Gy

600Gy

1000Gy

Day 21



0Gy

150Gy

600Gy

1000Gy

3.8.5 Honeydew (var. Galaxy)

Day 1

0Gy

150Gy

600Gy

1000Gy

Day 7

0Gy

150Gy

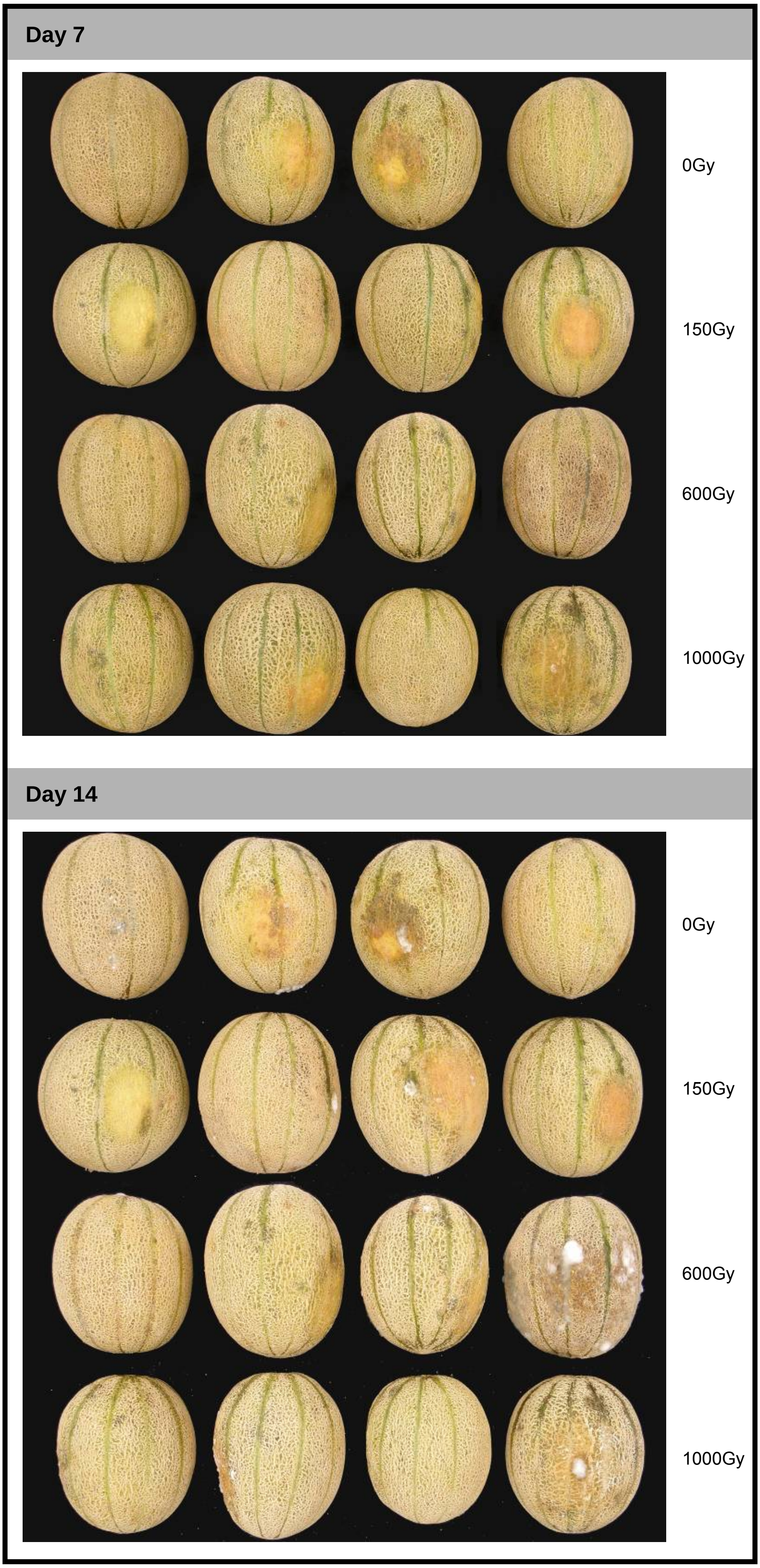
600Gy

1000Gy

Day 14

3.8.6 Rockmelons (var. Triumph)

Day 1


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