AM19002 Building Capacity in Irradiation

Post phytosanitary treatment quality testing for selected commodities aligned to transit times

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Author(s):

Dr. John Golding. NSW Department of Primary Industries, Australia

Dr. Thuy Pham. NSW Department of Primary Industries, Australia

Glenn Hale. Agriculture Victoria, Australia

Jung Cho. Plant and Food Research, New Zealand

Dr Allan Woolf. Plant and Food Research, New Zealand

Collaborators:

Dr. Anuradha Prakash. Chapman University, United States

Dr. Penta Pristijono. University of Newcastle, Ourimbah, Australia

Dr. Apiradee Uthairatanakij. King Mongkut's University of Technology Thonburi, Thailand

Dr. Baogang Wang. Beijing Academy of Agriculture and Forestry Sciences, China

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Contents

EXECUTIVE SUMMARY 4
INTRODUCTION 5
Research Objectives 5
METHOD 6
RESULTS 7
1.3b Product quality and tolerance 7
CONCLUSION 9
APPENDICES 10
Appendix A: Hass avocado 11
Appendix B: Dekopon citrus 41
Appendix C: Afourer mandarin 51
Appendix D: Broccoli 62
Appendix E: Persimmon 70
Appendix F: Plum 77
Appendix G: Asparagus 82
Appendix H: Nectarine out-turns 89
Appendix I: Cherry out-turns 91

EXECUTIVE SUMMARY

Phytosanitary irradiation is a relatively new market access tool for Australian horticulture where industry and the market needs further confidence to successfully use this technology to open new markets and increase exports.

This subcomponent of the research project began to fill gaps in our knowledge regarding the effective use of phytosanitary irradiation with a series of product tolerance trials and retail surveys on a range of fruit and vegetables. Fruit quality trials were conducted on Hass avocado, Dekopon citrus, Afourer mandarin, broccoli, persimmon, plum and asparagus and in-country retail observations of nectarine and cherry were conducted on irradiated produce in Vietnam. The results of the trials were consistent with the literature, in that phytosanitary irradiation had few effects on the internal quality of most products, but there were minor issues identified with the external appearance in some commodities. But it should be noted that these trials were a 'snap-shot' at one time and more work is required to confirm the findings and rectify any issues. Indeed, understanding and overcoming the inconsistency in product tolerance in response to phytosanitary irradiation will be key to the continued growth of the use of phytosanitary irradiation in Australia.

INTRODUCTION

This research was conducted as part of the '*Building Capacity in Irradiation'* project (AM19002), where the objectives of this component (1.3b) were to:

- Fill gaps in our knowledge regarding the effective use of phytosanitary irradiation

Research Objectives

The research objectives of this component were to:

1.3b Post phytosanitary treatment quality testing for selected commodities aligned to transit times

This sub-component will be led by Dr. John Golding (NSW DPI) in collaboration with Glenn Hale (Agriculture Victoria). Based on the GAP analysis and recommendations of the desk top review (1.3a), a range of postharvest trials were conducted by the project team for selected commodities and export markets:

- Hass avocado
- Dekopon citrus
- Afourer mandarin
- Broccoli
- Persimmon
- Plum
- Asparagus
- In-country retail observations of nectarine and cherry

This work quantified fruit tolerance and quality issues following phytosanitary irradiation treatment and simulated export assessment.

METHOD

1.3b Post phytosanitary treatment quality testing for selected commodities aligned to transit times

As identified in the Literature Review (1.3a), a range of fresh fruit and vegetables were selected for some preliminary studies on their tolerance to phytosanitary irradiation. These products were:

- Hass avocado
- Dekopon citrus
- Afourer mandarin
- Broccoli
- Persimmon
- Plum
- Asparagus
- In-country retail observations of nectarine and cherry

Each of these commodities were treated with phytosanitary irradiation at the Steritech treatment facility in Melbourne and stored at different temperatures and times to simulate air and sea fright with different export supply chain scenarios.

The Materials and Methods of the different individual trials are presented in the Commodity Technical Reports and attached as individual Appendices (A-I).

RESULTS

1.3b Product quality and tolerance

Post-phytosanitary treatment quality testing for selected commodities aligned to transit times

As identified in the Literature Review, it was recommended to explore *Recommendation 1* to give industry confidence in the use of phytosanitary treatment. A range of fresh fruit and vegetables were selected for preliminary studies on their tolerance to phytosanitary irradiation. In consultation with industry, these products were:

- Hass avocado
- Dekopon citrus
- Afourer mandarin
- Broccoli
- Persimmon
- Plum
- Asparagus
- In-country retail observations of nectarine and cherry

The major research findings for each commodity and corresponding reference to the full technical report is presented in the Summary Table (below).

Summary Table of product tolerance and quality following phytosanitary irradiation and export supply chain simulation

Commodity	Main observations	Appendix
Hass avocado	In both storage trials with fruit from different orchards, the quality of the fruit coming into phytosanitary treatment was not ideal, however these preliminary observations showed that Hass avocado treated with phytosanitary irradiation retained green skin colour and maintained fruit firmness thus increasing shelf life. There were minor differences in other fruit physiology and quality parameters response to phytosanitary irradiation between fruit from different orchards.	A
Dekopon citrus	Phytosanitary irradiation caused damage to the peel of treated fruit, which was characterised by damage to the oil glands, particularly around the neck of the fruit which reduced consumer appeal. Apart from the cosmetic appearance of the fruit there were few differences between the phytosanitary treated and non-treated fruit. There were no or few consistent differences in fruit weight loss, development of rots, fruit firmness, juice content, TSS, TA and vitamin C content between the treated and non-treated fruit.	B
Afourer mandarin	Treated fruit had phyto-toxic damage to the peel and higher levels of damage to the fruit calyx. However, there were no consistent differences in fruit quality observed between the different sizes of fruit or from different orchards. There were few consistent differences between treated and non-treated fruit, although treated fruit had higher respiration rates after treatment indicating fruit damage.	C
Broccoli	Phytosanitary irradiation had little effect on broccoli head quality at the early stages of storage and marketing, but differences in quality were observed during storage. Phytosanitary irradiation is a suitable market access treatment for short term marketing, but less so for long term storage or sea freight.	D

Persimmon	In two experiments, the effects of irradiation on persimmon quality were minimal. Storage temperature had a large effect on fruit quality and there were few differences between treated and non-treated fruit.	E
Plum	Irradiation treatment had minor effects on plum fruit maturity, flesh firmness or soluble solids concentrations however treated plums were slightly softer, had lower flesh juice, and inconsistent texture beyond six weeks of cool storage.	F
Asparagus	Phytosanitary irradiation had no effect on asparagus quality compared to asparagus in open cartons after one week of cool storage simulating air freight export conditions. Irradiated asparagus packed in relative humidity liners had higher marketability after 14 and 21 days of cool storage compared to spears packed in either relative humidity liner without irradiation, or in an open crates whether irradiated or untreated.	G
Nectarine out-turns	Irradiation appeared to have little negative impact of nectarine quality following treatment, transport and retail in Vietnam. Nectarines were very ripe at time of purchase.	H
Cherry out-turns	Treated and untreated cherry quality was highly variable in fruit purchased from different points in the supply chain in Vietnam.	I

CONCLUSION

Phytosanitary irradiation is a relatively new market access tool for Australian horticulture and industry needs confidence to successfully use this technology to open new markets and increase exports.

The results of the trials were consistent with the literature, in that phytosanitary irradiation had few effects on the internal quality of most products, but there were some issues identified with the external appearance in some commodities. In general there are few effects of irradiation on fruit quality, for example in persimmon and plum fruit there were only minor differences in quality between treated and untreated fruit. While differences in product quality are sometimes observed at the end of a long storage times between treated and untreated produce (e.g. broccoli, asparagus and plum), the major use of phytosanitary irradiation is its use in short term marketing and air-freight transport, where long term storage is not required. Furthermore phytosanitary irradiation had some potential beneficial effects in slowing the effects of ripening in Hass avocado, i.e. maintaining green skin colour retention and fruit firmness during storage. This observation could be of some benefit to maintaining fruit quality during transport and marketing. However in the two trials conducted with citrus fruit, while there were few differences in internal eating quality following phytosanitary irradiation, the treatment also resulted in unacceptable damage to the peel following treatment in Dekapon citrus and Afourer mandarins. It should be noted that these observations were made on fruit from single batches of fruit, and that other commercial batches of citrus fruit often show no damage symptoms. It is this variability in fruit quality out-turn which is one of the main issues with the commercial application of phytosanitary irradiation and the study of the effects of irradiation on fruit quality. For the commercial application of phytosanitary irradiation, it is essential that these potential fruit quality issues are successfully managed and minimized. However it is not known what causes this variability in response to irradiation. More systematic research is required identify the pre- and postharvest factors that affect fruit responses to postharvest phytosanitary irradiation. Indeed more research is required to also understand the underlying mechanisms of the effects of irradiation on produce quality.

APPENDICES

Appendix A	Hass avocado
Appendix B	Dekapon citrus
Appendix C	Afourer mandarin
Appendix D	Broccoli
Appendix E	Persimmon
Appendix F	Plum
Appendix G	Asparagus
Appendix H	Nectarine out-turns
Appendix I	Cherry out-turns

Appendix A: Hass avocado

Introduction

Increasing market access for Australian avocados is critical for the Australian avocado industry. Should irradiation serve as a viable phytosanitary measure for avocados, the pathway can be negotiated alongside new market access applications and provide an alternative access point for Australian fruit to both domestic and international markets.

The adoption of phytosanitary irradiation is dependent on its effects on fruit quality. However the effects of irradiation on avocado fruit quality is not clear. Various studies have evaluated the sensitivity of different avocados to irradiation and generally showed there is some sensitivity of avocado fruit to irradiation (Barkai-Golan and Follet, 2017). However most of this research was conducted with less modern treatment facilities and dosimetry where the results and conclusions from these early studies should be evaluated accordingly. There is also no agreement regarding the minimum level of irradiation that causes damage to the fruit therefore more research is required. Lizarazo-Pena et al. (2022) recently showed the sensitivity of Hass avocado fruits to gamma irradiation particularly in the visual quality of the mesocarp which would limit consumer acceptability. Indeed, browning of the vascular tissue within the avocado flesh has been regularly reported (Arevalo et al., 2002). This damage is observed principally in the parenchyma tissue where the cell membranes are broken and a red colour is observed due to the development of phenolic compounds (Arevalo et al., 2002). They also showed an increase in the size of xylem and phloem cells in the vascular tissue even at the minimum dose of 150 Gy. However Arevalo et al. (2002) showed that these changes were not perceived by panellists in a sensory test. Irradiated fruits were accepted by panellists as well as control fruit as regards parameters of taste, internal colour and external colour.

Researchers in South Africa investigated the effect of gamma irradiation (Co60) at three different dose levels, 100 Gy, 200 Gy and 400 Gy on two cultivars of avocado, 'Carmen' and 'Hass' (early , mid- and late season) (De Run et al. 2010). They showed in terms of external quality, only few differences were detected between the non-irradiated control fruit and the irradiated fruit (100 Gy, 200 Gy and 400 Gy). However, the internal quality of irradiated avocado compared to non-irradiated avocado was poor and concluded that avocados are sensitive to Gamma irradiation and therefore are not suitable for use of irradiation as a quarantine treatment (De Run et al. 2010). However the effects of the application of low dose irradiation on Australian avocados in the export supply chain are not known particularly with the commercial X-ray treatment and handling systems.

Two trials were conducted to examine the effects of phytosanitary irradiation on avocado fruit tolerance experiments using Hass avocados:

1) Avocado experiment 1 (x 2 orchards – SA and NSW)
2) Avocado experiment 2 (x 1 orchard - WA)

Methods

Avocado Experiment 1

Hass avocados from two separate orchards (SA and NSW) were treated with 150 Gy (X-ray) irradiation at Steritech and arrived at NSW DPI on 12 December 2022. Fruit from both orchards were over-ripe and soft. However fruit from Orchard 1 (SA) was better quality fruit (i.e. less ripe and greener) than fruit from Orchard 2 (NSW) (Figure 4). Non-treated fruit were considered the control. Four replicates within each treatment were allocated where each treatment unit was 1 tray of fruit. Fruit were assessed upon receipt from Steritech, and after 1 week at 6^{o}C storage and one day at 20^{o}C.

Avocado Experiment 2

Hass avocados from WA were harvested 4 January 2023 and packed the next day. Fruit were treated by Steritech on 12 January and arrived at NSW DPI on 20 January 2023. While a total of 24 trays arrived, some of the labels were missing. We could only confidentially allocate 3 replicates to each treatment, rather than the planned four replicates. Therefore 3 replicates were allocated and each treatment unit was a tray of fruit.

Fruit quality assessments were conducted; (a) upon receipt of fruit (i.e. 2 days after treatment), (b) after 2 weeks storage at 6^{o}C and one day at 20^{o}C, and (c) after 3 weeks storage at 6^{o}C and one day at 20^{o}C.

Fruit quality assessments

The following fruit quality attributes were assessed at each sampling time: weight loss, respiration (CO_2) and ethylene production rates, external colour (subjective and objective assessment), fruit firmness colour (subjective and objective assessment), tissue breakdown and rots, stem end rots, uneven ripening, vascular browning and flesh browning.

Weight loss of the fruit in Experiment 2 was assessed using an electronic balance (Model Kean & Sohn GmbH, D-72336, Germany), where individual fruit weight of each treatment unit was recorded each assessment day. Weight change was expressed as a percentage value determined by deducting the initial weights (W1) from the final weights (W2) divided by the initial weights and multiplied by hundred percent (%). Ten fruit from each replicate were used to measure weight loss for each replicate.

Skin colour was assessed using a Minolta colourimeter (Konica Minolta CR-400, Tokyo, Japan). Instrument calibrated was performed using a white porcelain reference plate, on the initial and final days of the experiment. The L*, a*, b* axes (from white to black, green to red and blue to yellow, respectively) were scored on the equatorial zone of all fruit within each tray and the results were the means of two points of the fruit surface and expressed as skin lightness (L8), chroma and Hue angle = arc tangent (b*/a*).

Endogenous ethylene production and the respiration rate by the fruit was determined by sealing a single fruit in a 2 L glass jar for 3 h to accumulate ethylene and CO_2 in the headspace (Figure 1). Gas samples were then withdrawn from the headspace of the container and analysed as previously described by Huque et al. (2013). The concentration of endogenous ethylene production rate was expressed as mL L kg^{-1} h^{-1}. Carbon dioxide (CO_2) concentration in the jar was determined by withdrawing a 1 mL gas sample from the headspace and injecting into gas chromatograph. Respiration rate of avocado fruit was calculated according to the method of Huque et al. (2013). In Experiment 1, four fruit per replicate were used to measure ethylene production and the respiration rate, and in Experiment 2, six fruit per replicate were measured per replicate.

Figure 1. Measurement of headspace CO_2 and ethylene produced by Hass avocado in sealed glass jars to measure fruit respiration and ethylene production rates.

Fruit firmness was measured on the equator of individual avocado fruits using a texture analyser (Lloyd Instrument Ltd, Fareham, UK). Each fruit was compressed 2.5 mm at a rate of 10 $mm \cdot s^{-1}$ with a trigger of 0.05 kgf. Two sides of the fruit were measured at the equator with measurements at 90º orientation. The maximum force developed during the test was recorded and expressed as Newton (N). In Experiment 1, Orchard 1 ten fruit were measured for each replicate and for Orchard 2, 20 fruit were measured for each replicate. In Experiment 2, 5 fruit per replicate was used to measure fruit firmness.

Subjective fruit quality assessments:

For all subjective assessments, all fruit in each tray were assessed in each replicate.

- Hand firmness score was subjectively assessed using a 7-point scale: score 7 = hard avocado, 5 = optimal firmness, 1 = soft avocado fruit.
- Ripeness skin colour – The subjective colour of the avocado skin was given a visual rating: 1 = emerald green; 2 = forest green; 3 = 20% coloured black/purple on green; 4 = 60% coloured black/purple on green; 5 = purple over 100% of peel surface; 6 = black over 100% of peel surface.
- Body rots – rots entering through the skin. Count how many had body rots (incidence) and then score each one (severity).
- Stem end rots – rots entering through fruit peduncle. Count how many had stem rots (incidence) and then score each one (severity).
- Vascular browning – browning of the vascular stands running longitudinally through the fruit tissue (Figure 2 and 3) were subjectively scored using the following scale: 1 = no occurrence, 2 = some possible incidence of vascular browning, 3 = slight incidence of vascular browning, 4 – noticeable and commercially unacceptable, 5 = moderate – high levels of vascular browning, 6 = high levels of vascular browning, 7 = severe levels of vascular browning.

Figure 2. Vascular tissue browning in the flesh of Hass avocado fruit. Note the brown / red ends of the vascular tissue with run though the fruit flesh.

Figure 3. Assessing Hass avocado fruit quality at NSW Department of Primary Industries.

Results

Experiment 1

As the fruit from the different orchard sources were very different (i.e. SA and NSW), the results of the two different orchards are discussed separately.

Orchard 1 (SA)

Upon arrival of fruit at NSW Department of Industries, the fruit were ripe to over-ripe in all treatments (Figure 4 and 5). Fruit were stored for 1 week in cold storage before a final assessment was conducted. After storage, the untreated fruit were not acceptable with large numbers of rots, but the treated fruit were more acceptable (Figure 6).

Upon arrival

Figure 4. Phytosanitary irradiation treated (left) and untreated (right) Hass avocados from Orchard 1 (SA) upon arrival at NSW DPI.

Figure 5. Phytosanitary irradiation treated (left) and untreated (right) Hass avocados from Orchard 1 (SA) upon arrival at NSW DPI.

After 1 week in cold

Treated | Untreated

Figure 6. Phytosanitary irradiation treated (left) and untreated (right) Hass avocados from Orchard 1 (SA) after one week in cold storage.

Avocado Experiment 1 - Observations from Hass avocado from Orchard 1

The fruit from Orchard 1 was from South Australia and overall the general fruit quality was good. The fruit arrived in relatively good condition, but riper than expected (Figure 4).

Treated fruit from Orchard 1 tended to retain external green skin colour as measured by the Minolta (hue angle, chroma, L* colour values) and was supported with the subjective colour assessment where the treated fruit maintained green colour upon arrival and after storage (Figure 9). The phytosanitary irradiation treatment also maintained fruit firmness as measured by the texture analyser, as compared to the untreated control fruit (Figure 8).

Treated fruit had no difference in fruit respiration rates as compared to untreated control fruit however treated fruit tended to have higher ethylene production rates, but these ethylene rates were relatively minor (Figure 7). This indicates that the physiological ripening was similar between the treatments.

There were few no differences in the level of rots, but treated fruit tended to have lower body rots during storage (Figure 11). Treated fruit had more vascular browning than untreated fruit (Figure 13).

The level of body rots in treated fruit were similar upon arrival of fruit after treatment, but was lower in treated fruit after 1 week storage in cold. There was no difference in the severity of body rots in both treatments (Figure 11). However for stem end rots, there were few differences between treated and non-treated fruit (Figure 12).

The levels of vascular browning increased during storage and was higher in treated fruit as compared to non-treated fruit (Figure 13).

In summary, the results of fruit from Orchard 1 showed the treated fruit maintained the green skin colour and were firmer than the untreated control fruit. However the treated fruit also had higher levels of vascular browning in the flesh. These results suggest that the treatment delayed or slowed ripening as shown by slowing the rate of fruit softening and loss of skin green colour in Hass avocado from Orchard 1.

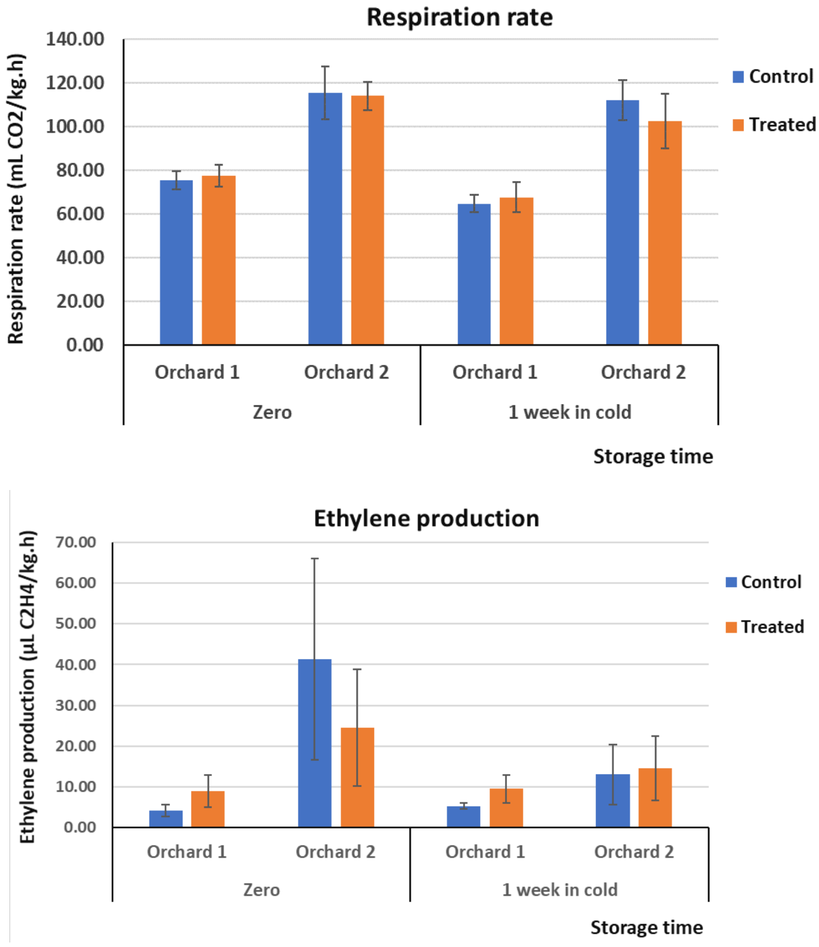
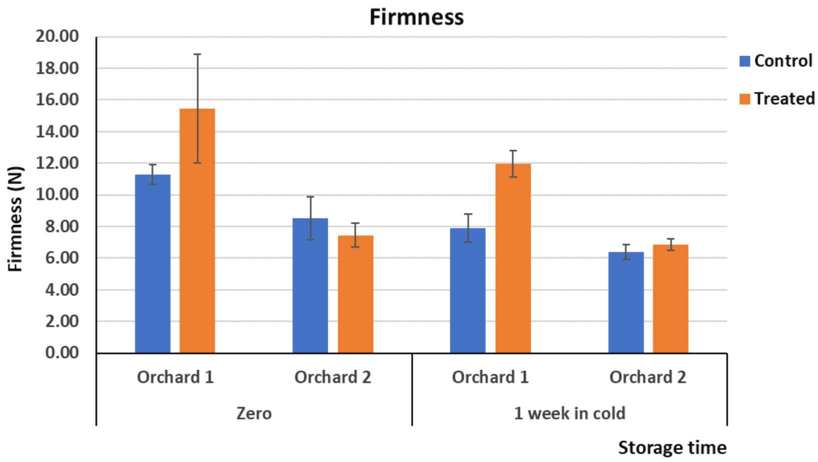


Figure 7. Effect of phytosanitary irradiation treatment on fruit respiration rate (mL CO_2.kg.hr $^{-1}$) (top) and ethylene production rate (mL ethylene.kg.hr $^{-1}$) (lower) in Hass avocado fruit from two different orchards. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage. Bars are standard deviation bars around the mean (*n*=4).



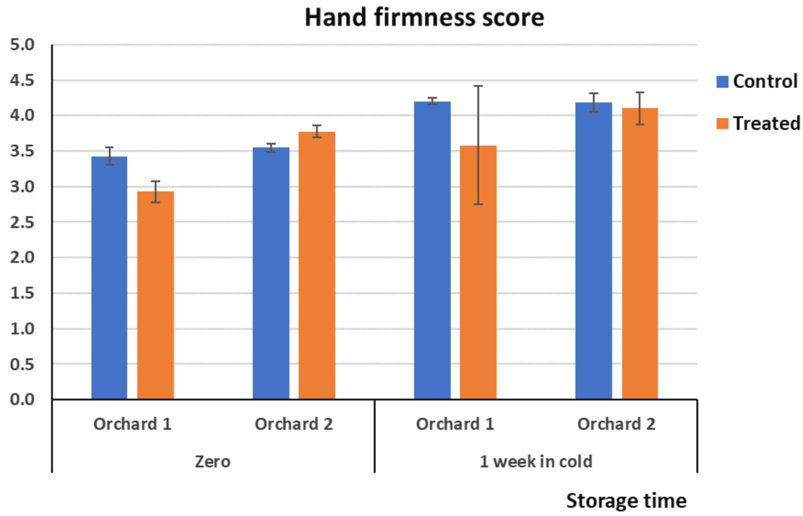


Figure 8. Effect of phytosanitary irradiation treatment on fruit firmness as objectively measured with texture analyser (N) (top) and subjectively assessing with a 6 point scale (lower) in Hass avocado fruit from two different orchards. The subjective firmness score was assessed by hand on 10 fruit where score 7 = hard avocado, 5 = optimal firmness, 1 = soft avocado. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage.
Bars are standard deviation bars around the mean (*n*=4).

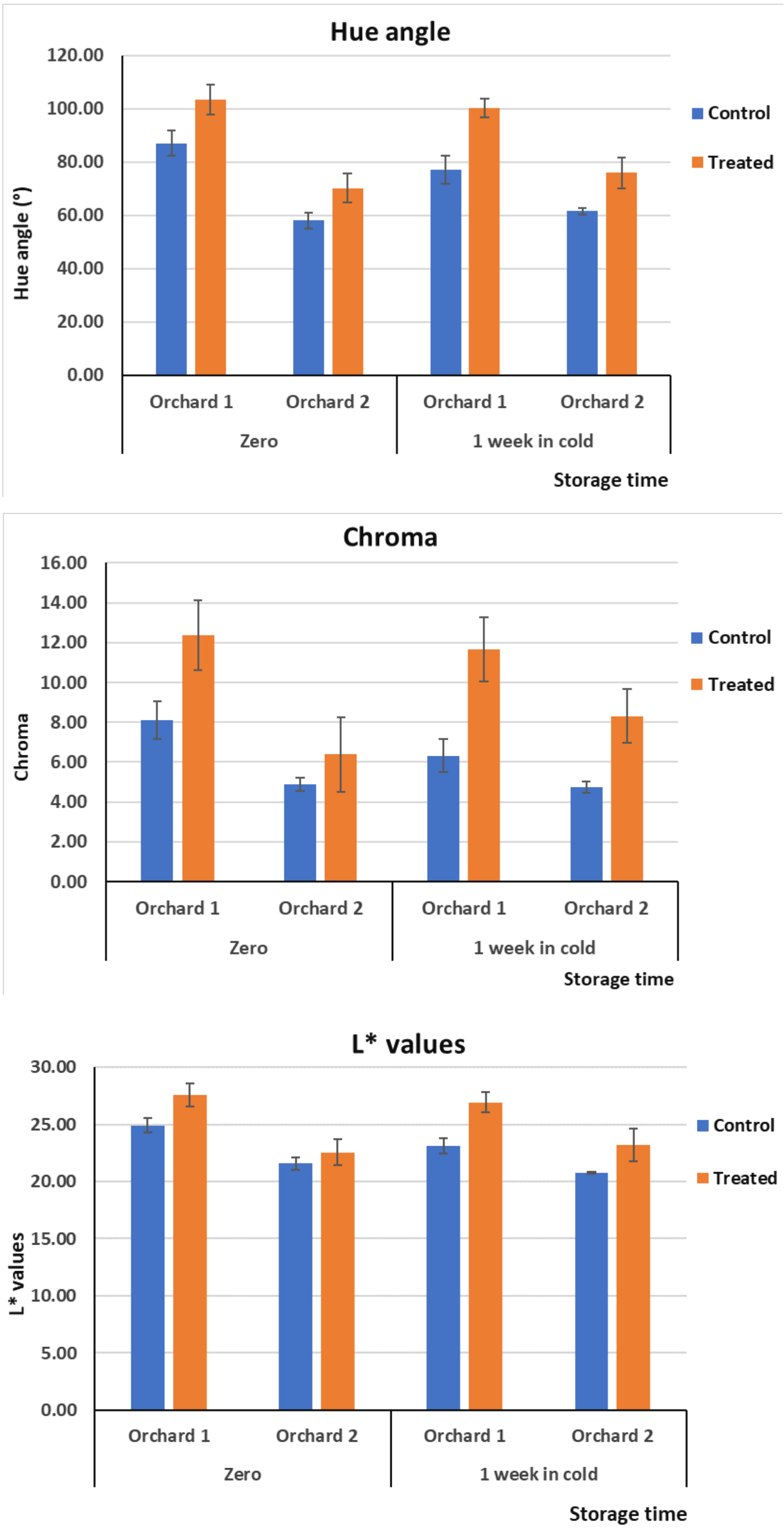


Figure 9. Effect of phytosanitary irradiation treatment on external fruit colour as subjectively measured with Minolta colour meter. Hue angle (top), chroma (middle) and L* value (lower) on Hass avocado fruit from two different orchards. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage. Bars are standard deviation bars around the mean (*n*=4).

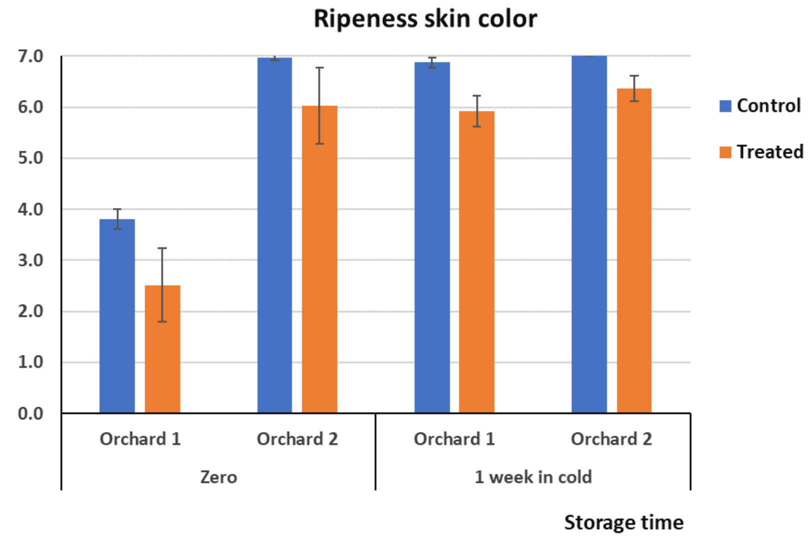
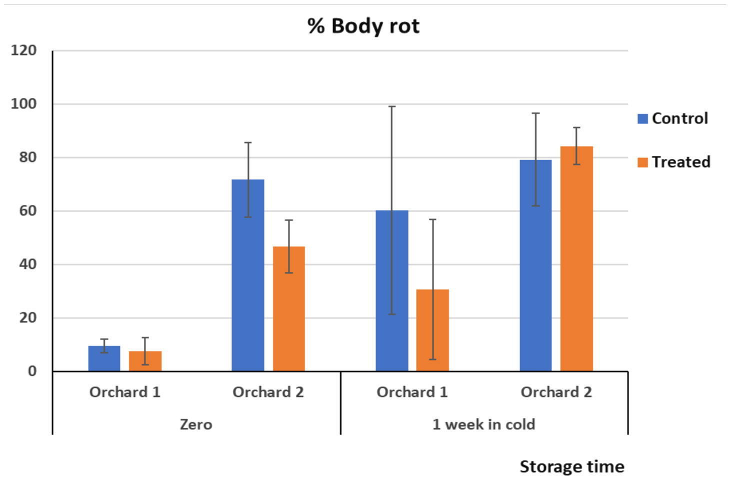


Figure 10. Effect of phytosanitary irradiation treatment on external fruit colour as objectively assessed on a 7-point scale where; 1 = emerald green; 2 = forest green; 3 = 20% coloured black/purple on green; 4 = 60% coloured black/purple on green; 5 = purple over 100% of peel surface; 6 = black over 100% of peel surface. Hass avocado fruit from two different orchards. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage. Bars are standard deviation bars around the mean (*n*=4).



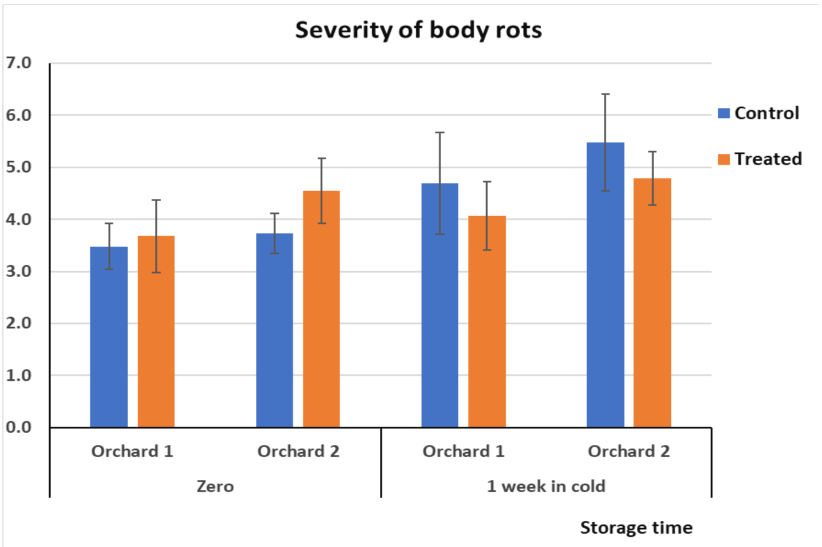


Figure 11. Effect of phytosanitary irradiation treatment on percentage of fruit with body rots (top) and severity of fruit with body rots (lower) where; 1 – no rots, 2 – start of some rot, 3 – slight incidence, 4 – definite rot and unacceptable, 5 – moderate level of rots, 6 – many rots present, and 7 – severe. Hass avocado fruit from two different orchards. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage.
Bars are standard deviation bars around the mean (*n*=4).

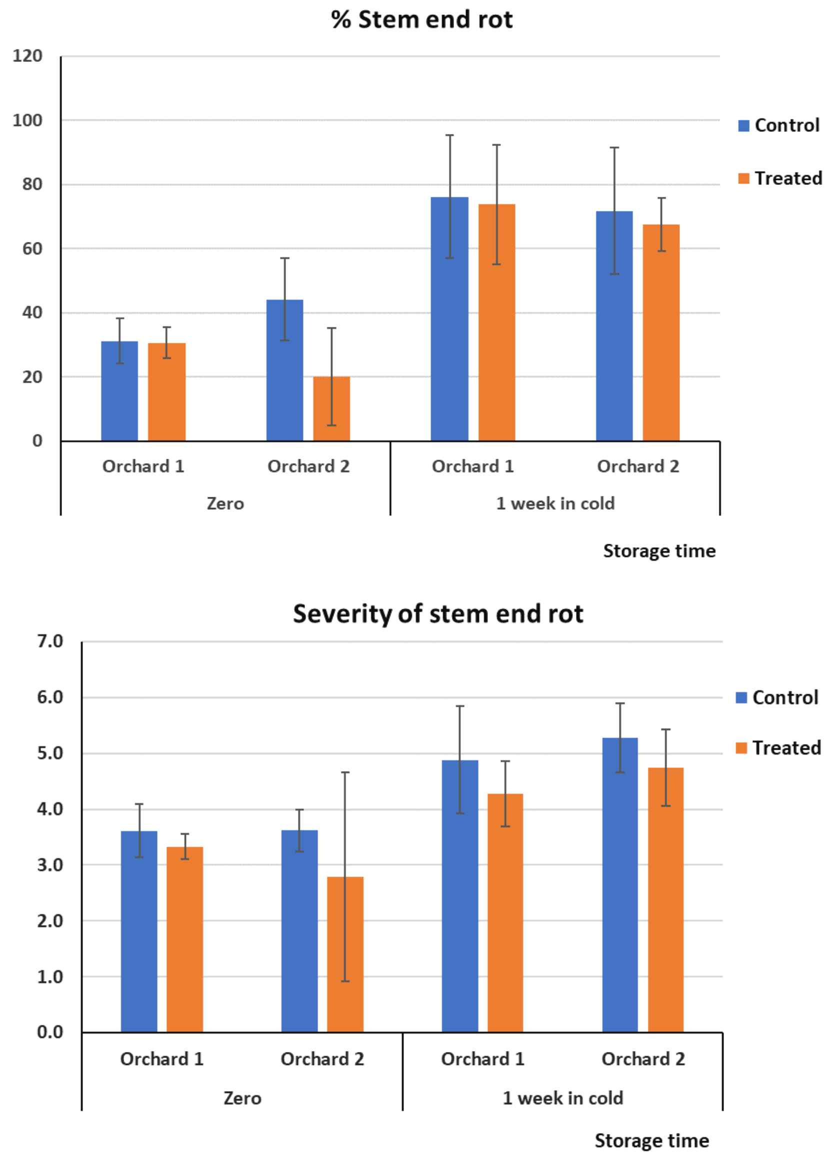
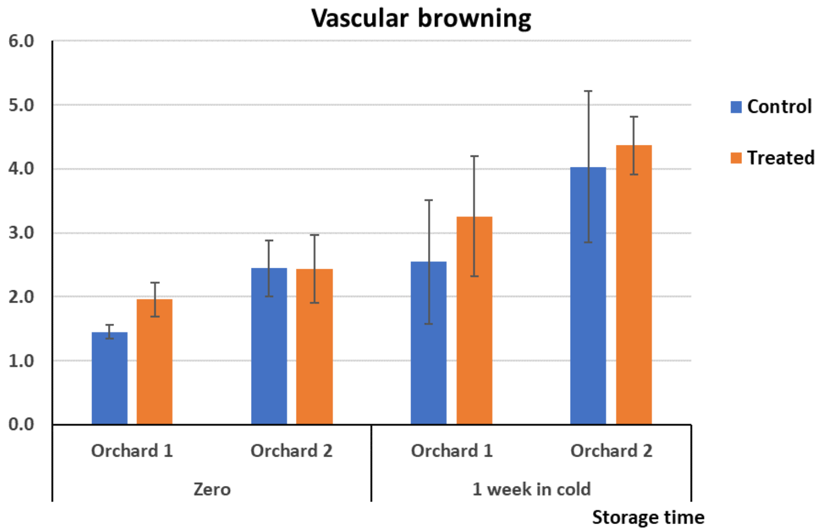


Figure 12. Effect of phytosanitary irradiation treatment on percentage of fruit with stem end rots (top) and severity of fruit with stem end rots (lower) where; 1 – no rots, 2 – start of some rot, 3 – slight incidence, 4 – definite rot and unacceptable, 5 – moderate level of rots, 6 – many rots present, and 7 – severe. Hass avocado fruit from two different orchards. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage.
Bars are standard deviation bars around the mean (*n*=4).



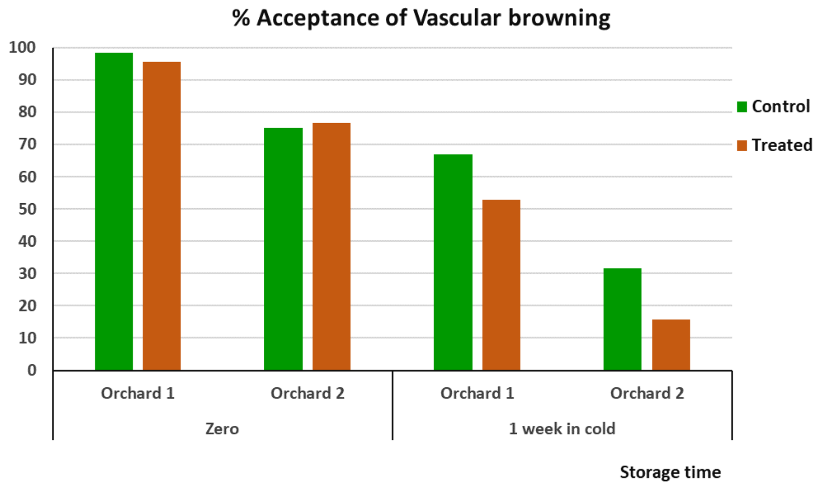


Figure 13. Effect of phytosanitary irradiation treatment on the severity and % acceptability of fruit with vascular browning. The levels of vascular browning was objectively assessed on a 7-point scale where; ; 1 = no occurrence, 2 = some possible incidence of vascular browning, 3 = slight incidence of vascular browning, 4 – noticeable and commercially unacceptable, 5 = moderate – high levels of vascular browning, 6 = high levels of vascular browning, 7 = severe levels of vascular browning. Hass avocado fruit were from two different orchards. Fruit were assessed upon arrival at NSW DPI (Zero) and after one week storage. Bars are standard deviation bars around the mean (*n*=4).

Avocado Experiment 1 - Orchard 2 (NSW)

Upon arrival all fruit in both treatments were over-ripe (Figure 14 and 15) and considerably more unacceptable after the additional one week cold storage (Figure 16).

Upon arrival

Figure 14. Phytosanitary irradiation treated (left) and untreated (right) Hass avocados from Orchard 2 (NSW) upon arrival at NSW DPI.

Figure 15. Phytosanitary irradiation treated (left) and untreated (right) Hass avocados from Orchard 2 (NSW) upon arrival at NSW DPI.

After 1 week in cold storage

Treated Untreated

Figure 16. Phytosanitary irradiation treated (left) and untreated (right) Hass avocados from Orchard 2 (NSW) after one week storage.

Avocado Experiment 1 - Observations from Hass avocado from Orchard 2

The fruit from Orchard 2 was from New South Wales and fruit quality in both control and treated fruit was poor. The fruit were over-ripe and senescent and beyond commercial acceptability (Figures 14 – 23).

There were very few differences between the treated and non-treated fruit from Orchard 2. There was no difference between treated and non-treated fruit in respiration rate (Figure 24), ethylene production rate (Figure 24), fruit firmness (Figure 25) and the incidence of vascular browning (Figure 31). Treated fruit maintained green skin colour with higher (hue, chroma, L* colour attributes) and greener subjective appearance (Figure 26). The levels of body rots were lower in the treated fruit upon arrival of fruit at NSW DPI, but after storage, the levels of body rots were similar between treated and non-treated (Figure 29). There were no differences in stem end rots between the treatments (Figure 30).

Overall there were few differences detected between the treatments as the fruit were very ripe / senescent and beyond commercial acceptability. However treated fruit tended to remain greener after treatment and storage.

Avocado Experiment 2

All fruit arrived in good condition and commercially acceptable, i.e. green and firm. However all fruit had noticeable vascular tissue / fibre within flesh even at arrival.

In addition, different replicate trays appeared to behave differently to treatment / storage. Although all fruit were treated in the same batch for treatment, there were some observable effects on ripening / colour / softening between different trays within the treated samples / replicates (Figure A).

Treated Replicate 1 **Untreated**

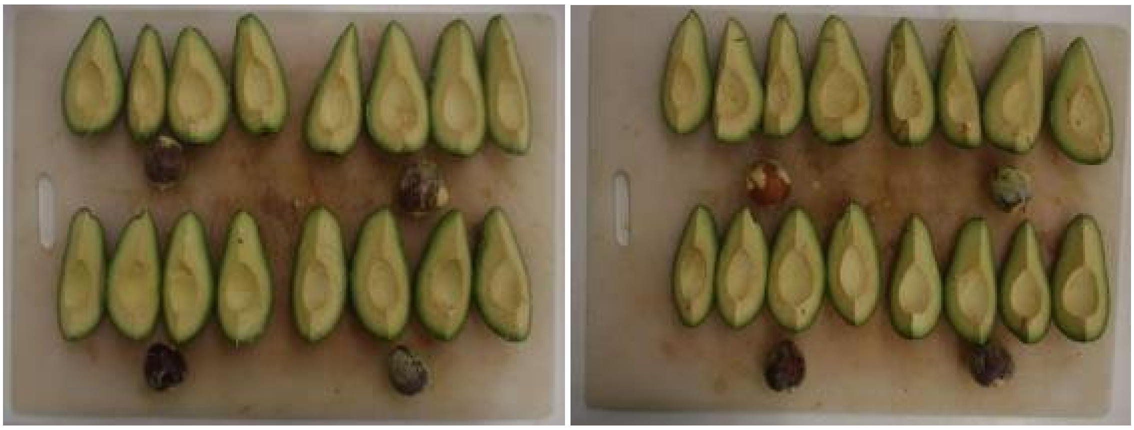
Replicate 2

Replicate 3

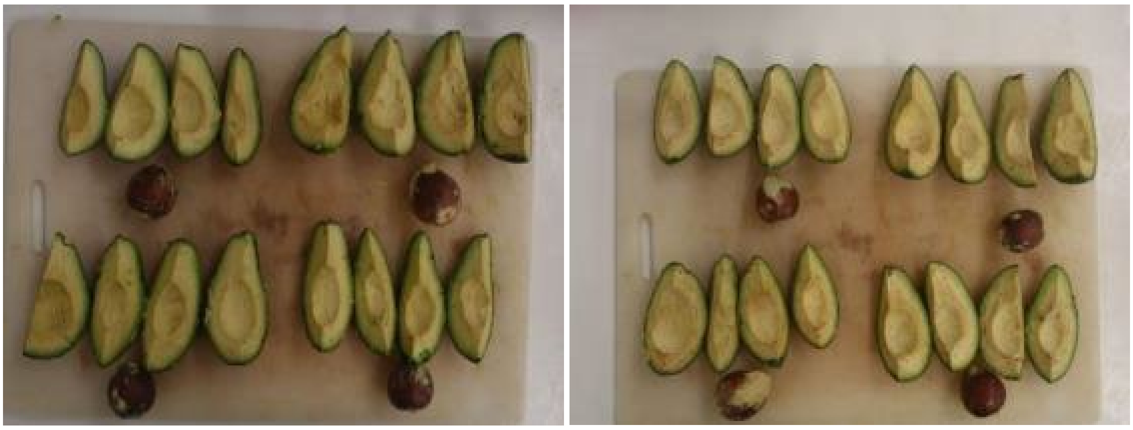
Figure 17. External appearance of Hass avocados treated with phytosanitary irradiation upon arrival at NSW DPI. Three separate trays / replicates are shown.

Figure 18. Internal appearance of Hass avocados treated with phytosanitary irradiation upon arrival at NSW DPI. Three separate trays / replicates are shown

Treated Replicate 1 **Untreated**



Replicate 2



Replicate 3

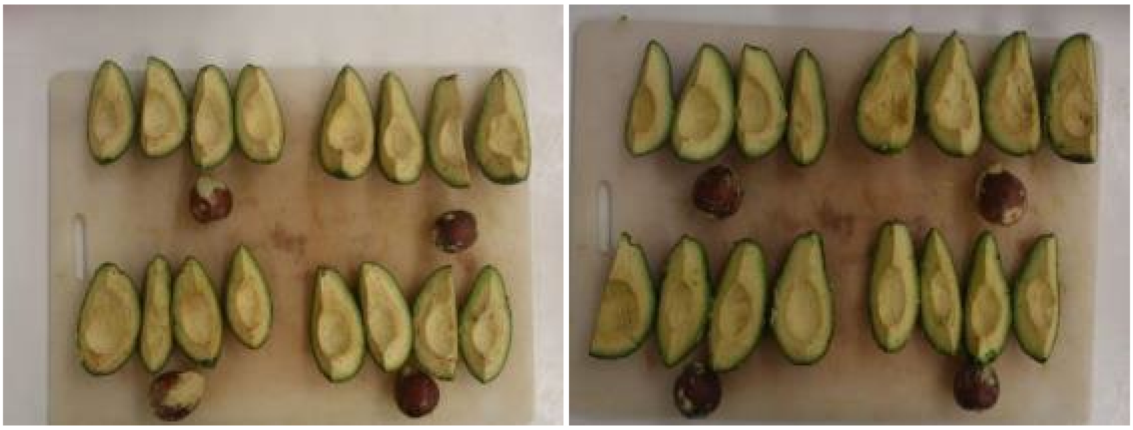


Figure 19. Internal appearance of Hass avocados treated with phytosanitary irradiation upon arrival at NSW DPI. Three separate trays / replicates are shown.

Replicate 1. Treated Untreated

Replicate 2. Treated Untreated

Replicate 3. Treated Untreated

Figure 20. External appearance of Hass avocados treated with phytosanitary irradiation after 2 weeks in cold storage at NSW DPI. Three separate trays / replicates are shown.

Treated Replicate 1 **Untreated**

Treated Replicate 2 **Untreated**

Treated Replicate 3 **Untreated**

Figure 21. Internal appearance of Hass avocados treated with phytosanitary irradiation after 2 weeks in cold storage at NSW DPI. Three separate trays / replicates are shown.

Replicate 1. Treated Untreated

Replicate 2. Treated Untreated

Replicate 3. Treated Untreated

Figure 22. External appearance of Hass avocados treated with phytosanitary irradiation after 3 weeks in cold storage at NSW DPI. Three separate trays / replicates are shown.

Treated Replicate 1 **Untreated**

Treated Replicate 2 **Untreated**

Treated Replicate 3 **Untreated**

Figure 23. Internal appearance of Hass avocados treated with phytosanitary irradiation after 3 weeks in cold storage at NSW DPI. Three separate trays / replicates are shown.

Given the different replicates apparently behaved differently, overall there the treated fruit had higher respiration rates than the untreated fruit upon arrival and after 3 weeks in cold storage (Figure 24). But there was no difference in ethylene production rates (Figure 24). As objectively measured by the texture analyser, treated fruit were firmer at the beginning of the trial and after 2 weeks storage (Figure 25). However with the subjective hand assessment, there was no difference between treated and untreated fruit, except after 3 weeks storage where treated fruit appeared firmer (Figure 25).

Weight loss was measured over time and showed there was no difference between the treatments at 2 weeks in cold storage, but after 3 weeks in storage, the untreated fruit had higher weight loss than the treated fruit (Figure 28).

The appearance of the fruit skin between the treatments were similar upon arrival of the fruit after treatment, but during storage the treated fruit retained greenness (higher chroma, hue angle. L value) more than the untreated control fruit (Figure 26). Similarly the fruit 'ripeness colour' was subjectively assessed as similar upon arrival but the treated fruit remained 'greener' during storage (Figure 27).

The level of rots increased with time but no difference in body rots between the treatments (Figure 27). However the numbers of stem end rots was higher in treated fruit, but the severity was the same between the treated and untreated fruit (Figure 30).

The levels of vascular browning was high and increased during storage (Figure 31). There was no difference in vascular browning between the treatments during storage.

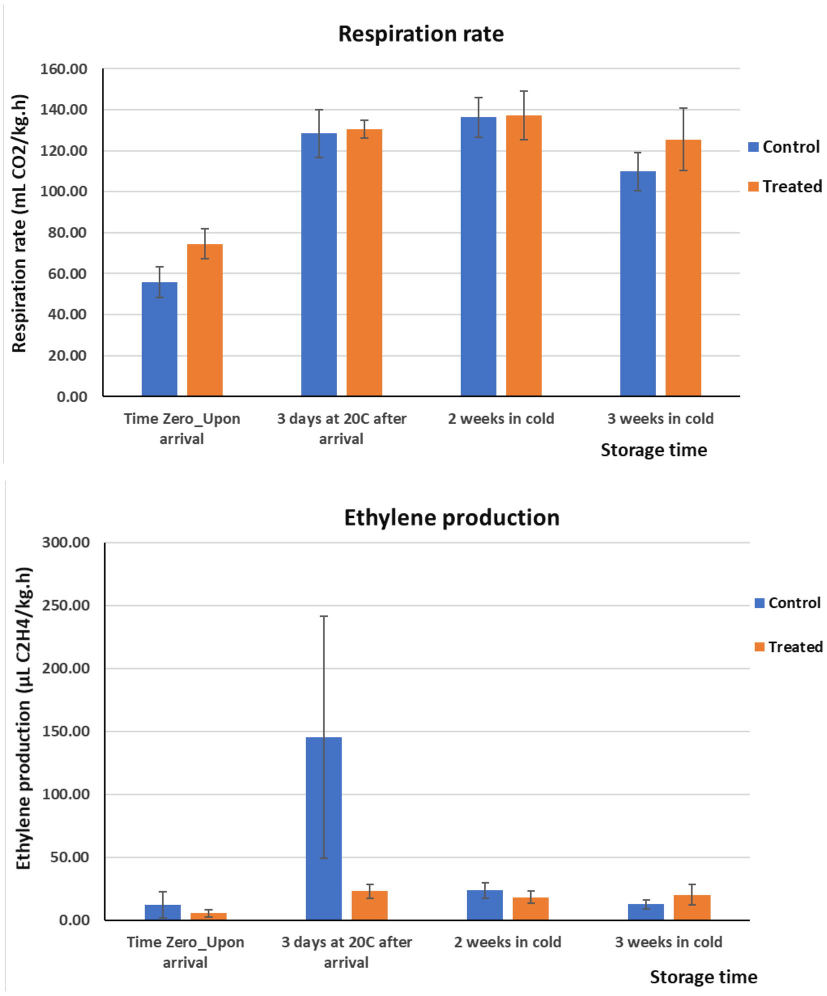
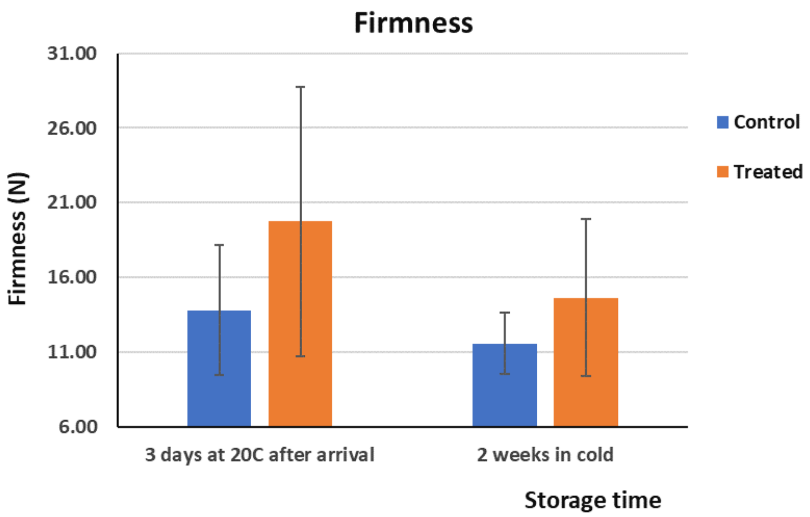


Figure 24. Effect of phytosanitary irradiation treatment on fruit respiration rate (mL CO_2.kg.hr $^{-1}$) (top) and ethylene production rate (mL ethylene.kg.hr $^{-1}$) (lower) in Hass avocado fruit from WA. Fruit were assessed upon arrival at NSW DPI (Zero) and during storage for up to 3 weeks. Bars are standard deviation bars around the mean (*n*=3).



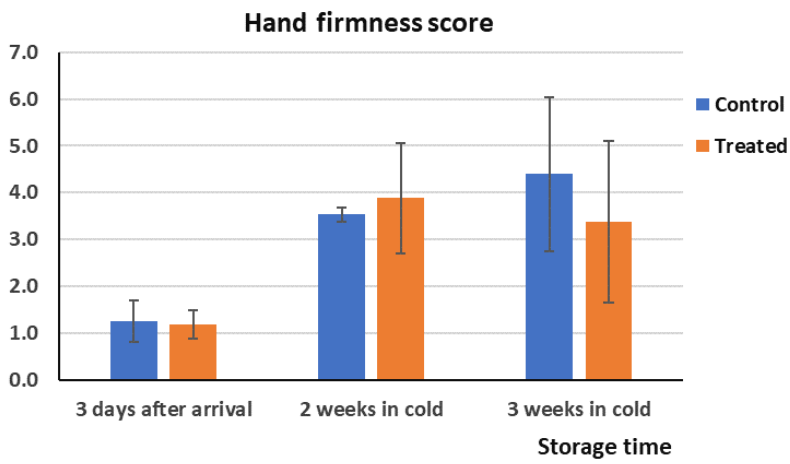


Figure 25. Effect of phytosanitary irradiation treatment on fruit firmness as objectively measured with texture analyser (N) (top) and subjectively assessing with a 6 point scale (lower) in Hass avocado fruit from WA. The subjective firmness score was assessed by hand on 10 fruit where score 7 = hard avocado, 5 = optimal firmness, 1 = soft avocado. Fruit were assessed upon arrival at NSW DPI (Zero) and during cold storage for up to 3 weeks. Bars are standard deviation bars around the mean (*n*=3).

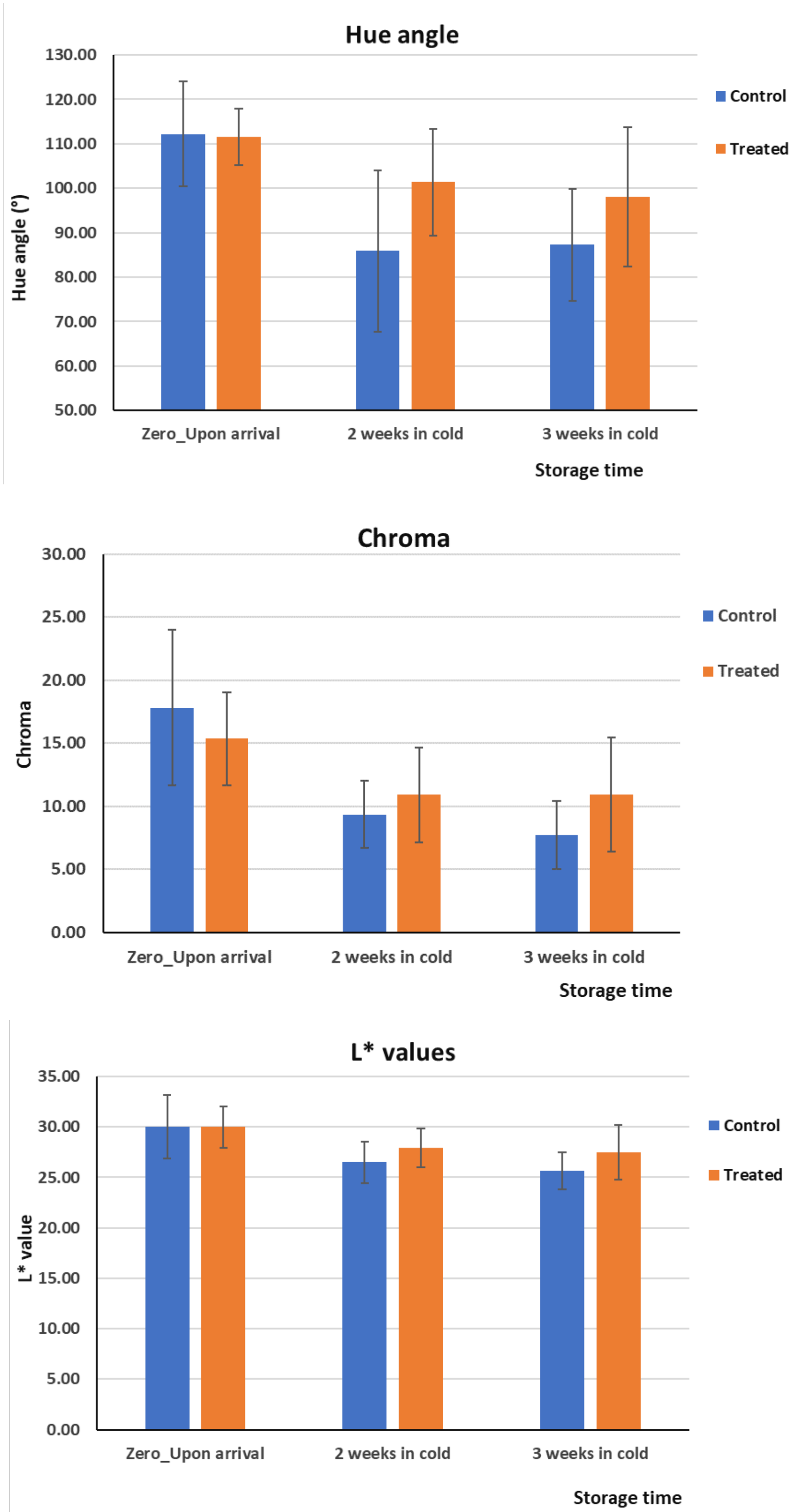


Figure 26. Effect of phytosanitary irradiation treatment on external fruit colour as subjectively measured with Minolta colour meter. Hue angle (top), chroma (middle) and L* value (lower) on Hass avocado fruit from WA. Fruit were assessed upon arrival at NSW DPI (Zero) and during 3 weeks cold storage.
Bars are standard deviation bars around the mean (*n*=3).

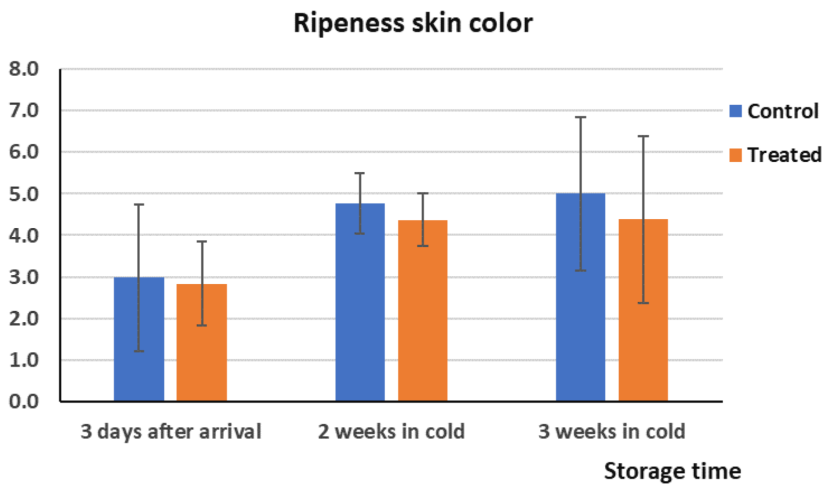


Figure 27. Effect of phytosanitary irradiation treatment on external fruit colour as objectively assessed on a 7-point scale where; 1 = emerald green; 2 = forest green; 3 = 20% coloured black/purple on green; 4 = 60% coloured black/purple on green; 5 = purple over 100% of peel surface; 6 = black over 100% of peel surface. Hass avocado fruit from WA. Fruit were assessed upon arrival at NSW DPI (Zero) and during storage for up to 3 weeks. Bars are standard deviation bars around the mean (*n*=3).

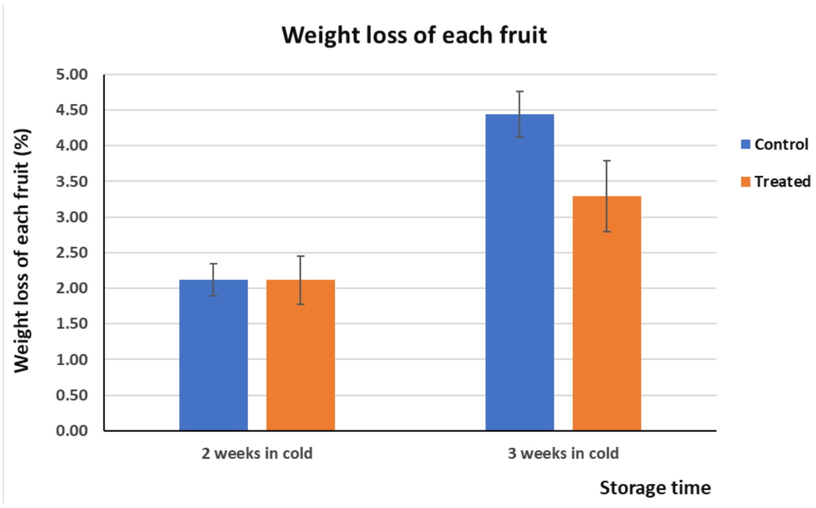
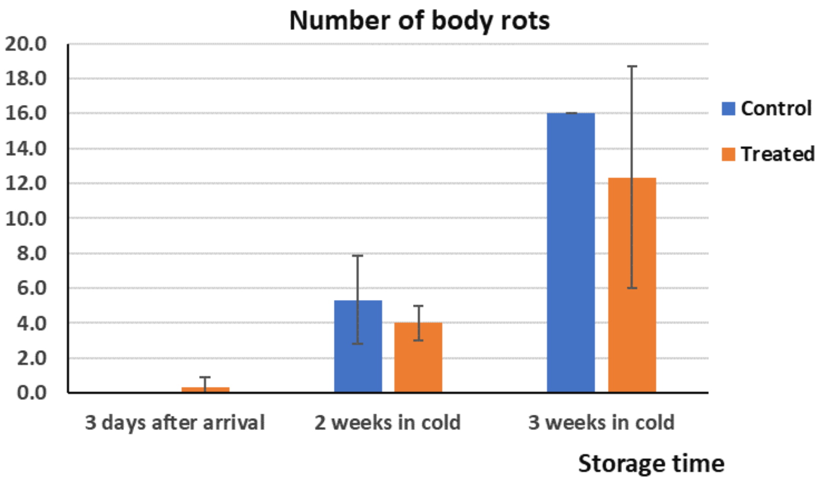


Figure 28. Effect of phytosanitary irradiation treatment on weight loss of Hass avocado fruit from WA. Initial weights were made upon arrival at NSW DPI and weight loss was measuring during cold storage for up to 3 weeks. Bars are standard deviation bars around the mean (*n*=3).



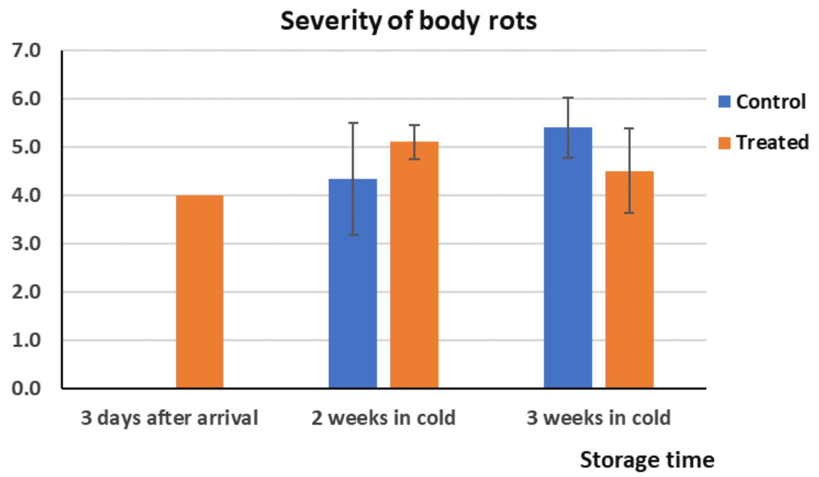


Figure 29. Effect of phytosanitary irradiation treatment on the number of fruit in each tray (replicate) with body rots (top) and severity of fruit with body rots (lower) where; 1 – no rots, 2 – start of some rot, 3 – slight incidence, 4 – definite rot and unacceptable, 5 – moderate level of rots, 6 – many rots present, and 7 – severe. Hass avocado fruit from WA. Fruit were assessed upon arrival at NSW DPI (Zero) and during storage for up to 3 weeks. Bars are standard deviation bars around the mean (*n*=3).

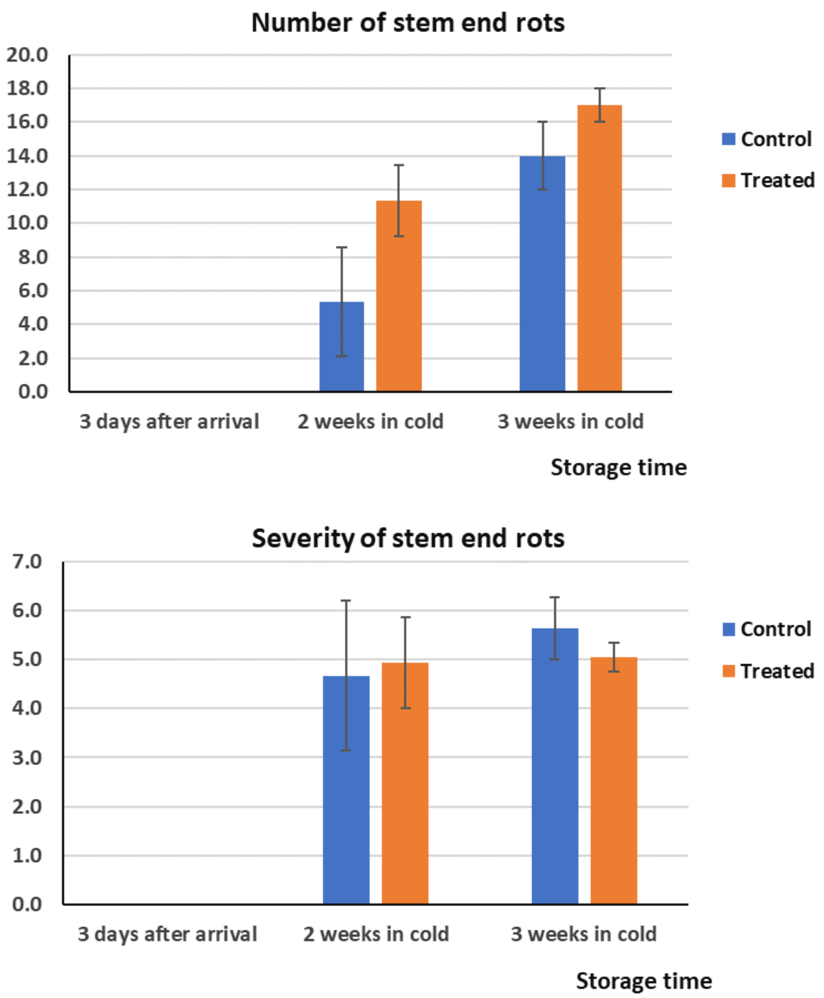
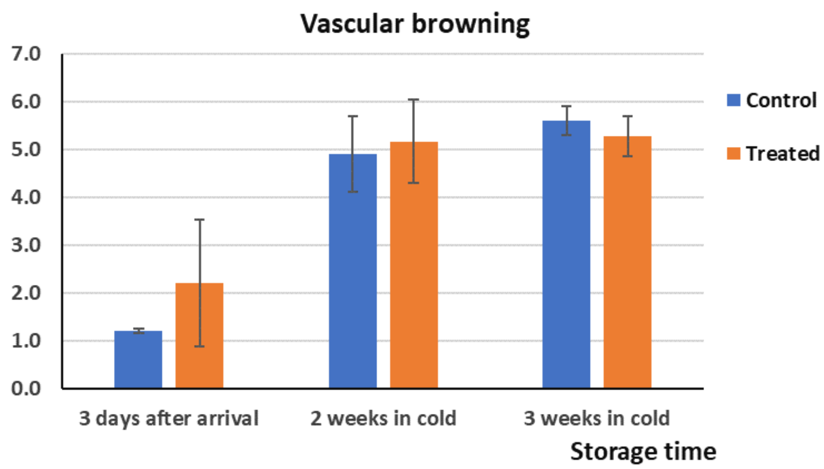


Figure 30. Effect of phytosanitary irradiation treatment on the number of fruit in each tray (replicate) with stem end rots (top) and severity of fruit with stem end rots (lower) where; 1 – no rots, 2 – start of some rot, 3 – slight incidence, 4 – definite rot and unacceptable, 5 – moderate level of rots, 6 – many rots present, and 7 – severe. Hass avocado fruit from WA. Fruit were assessed upon arrival at NSW DPI (Zero) and during storage for up to 3 weeks. Bars are standard deviation bars around the mean (*n*=3).



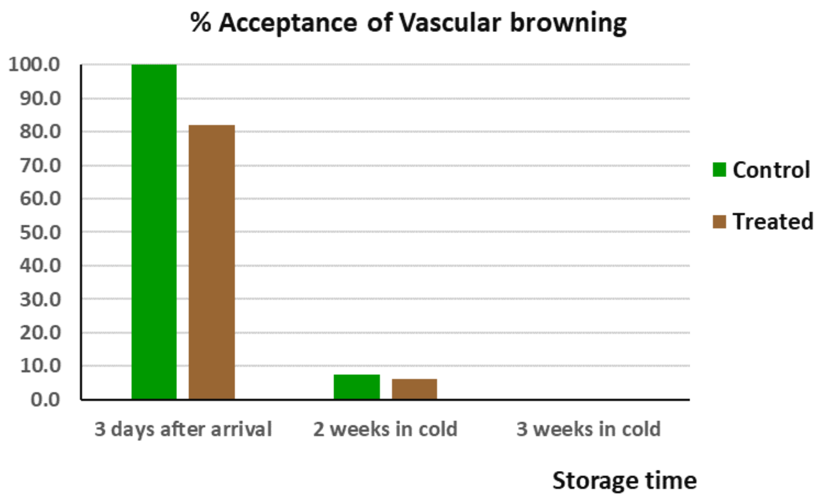


Figure 31. Effect of phytosanitary irradiation treatment on the severity and % acceptability of fruit with vascular browning. The levels of vascular browning was objectively assessed on a 7-point scale where; 1 = no occurrence, 2 = some possible incidence of vascular browning, 3 = slight incidence of vascular browning, 4 – noticeable and commercially unacceptable, 5 = moderate – high levels of vascular browning, 6 = high levels of vascular browning, 7 = severe levels of vascular browning. Hass avocado fruit were from WA. Fruit were assessed upon arrival at NSW DPI (Zero) and during 3 weeks cold storage. Bars are standard deviation bars around the mean (*n*=3).

Summary

Avocado fruit have been reported to be susceptible to low dose irradiation (Barkai-Golan and Follet, 2017) but the fruit tolerance limits of this phytosanitary treatment on Hass avocados are not known. These two experiments examined the effects of 150 Gy phytosanitary irradiation treatment on quality of Hass avocados. Fruit were subject to commercial treatment and handling at the Steritech x-ray facility in Melbourne.

In both experiments, the quality of the fruit coming into treatment was not ideal, however these preliminary observations showed that Hass avocado treated with phytosanitary irradiation retained green skin colour and maintained fruit firmness thus increasing shelf life. There were minor differences in other fruit physiology and quality parameters response to phytosanitary irradiation between fruit from different orchards. These differences and their consistency of phytosanitary irradiation on avocado fruit quality need to be more fully explored with additional research.

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Appendix B: Dekopon citrus

Introduction

The literature review undertaken in the first stage 'Review of phytosanitary irradiation pathways and product quality tolerance' identified several potential issues with the application of phytosanitary irradiation on citrus fruit (Golding and Hale, 2022). While some citrus types such as Navel oranges are relatively tolerant to low dose phytosanitary treatment, some other citrus types are more sensitive to irradiation. This trial examined the effect of commercial market access phytosanitary irradiation treatment (150 Gy target) on the shelf life and quality of dekopon (Sumo®) mandarins. Due to their delicate nature, these fruit are difficult to grow and market due to their inherent storage issues (Obenland and Arpaia, 2023). But these fruit also demand high returns therefore developing a market access pathway for dekopon mandarins would be of great benefit to growers.

Methods

Dekopon mandarins from a commercial orchard in NSW were treated with 150 Gy (180-420 Gy actual absorbed dose) at the X-ray treatment facility at Steritech in Melbourne. Non-treated fruit were considered the control. Four replicates within each treatment were allocated where each treatment unit was 1 box / tray (Count 25, 6kg).

Fruit quality was assessed at the following times after treatment:

1. Time Zero upon receipt of fruit – 4 days after treatment
2. Time Zero + 1 week at 20^{o}C
3. Two weeks storage at 8^{o}C - upon removal
4. Two weeks storage at 8^{o}C plus one week at 20^{o}C
5. Four weeks storage at 8^{o}C - upon removal
6. Four weeks storage at 8^{o}C plus one week at 20^{o}C

Fruit quality assessments

At each assessment time the following quality attributes were measured:

Subjective assessments

Calyx senescence was visually evaluated with changes in colour of the calyxes from green to brown and scored on a 5-point scale where; 1 green – fresh green, 2 - slightly yellow (<25% yellow / brown), 3 moderately yellow (25-50% brown / yellow), 4 yellow (50-75% yellow / brown) and 5 brown (>75% brown). The number of calyxes that had detached from the fruit was recorded and the percentage of fruit with calyxes still attached was calculated.

Damage (browning / bronzing) of the skin was rated on a 5-point scale where; 1 No browning, 2 trace / some detectable (0-5% of the surface area has browning) – still acceptable, 3 moderate (5-25% surface area has browning symptoms) – not acceptable, 4 high levels (35-50% browning), and 5 very high levels (>50% browning).

The number of rots / decay in each tray were recorded and expressed as percentage of total fruit.

Weight loss

Weight loss of the fruit was assessed using an electronic balance (Model Kean & Sohn GmbH, D-72336, Germany), where fruit weight of each treatment unit was recorded each assessment day. Weight change was expressed as a percentage value determined by deducting the initial weights (W1) from the final weights (W2) divided by the initial weights and multiplied by hundred percent (%).

Fruit firmness

A texture analyser (Lloyd Instrument LTD, Fareham, UK) was used to determine firmness of ten fruit per replicate after the fruit had conditioned to 20˚C. The maximum force (N) was measured by compressing the fruit in the equatorial zone between two flat surfaces closing together at the rate of 1 mm min^{-1} to a depth of 2 mm. The average of two reading points from each side of the fruit was recorded.

Respiration rate

Respiration rate (mL CO_2 kg^{-1} h^{-1}) was measured on five fruit from each replicate. Fruit were sealed into an airtight 2 L glass jars fitted with a septum for 3 hours to accumulate respiratory gases. Carbon dioxide (CO_2) concentration in the jar was determined by withdrawing a 1 mL gas sample from the headspace and injecting into a gas chromatograph (Gow-Mac, Bridgewater NJ) fitted with two stainless steel columns (60 cm × 1 mm i.d.) connected in series. Operating temperatures for the detector, injector, and column were 110˚C, 50˚C and 110˚C respectively. The carrier gas used was high purity argon (BOC Gases, Sydney) at a flow rate of 25 mL min^{-1}.

Internal fruit quality assessments

Fruit from each replicate were manually juiced and sieved through two layers of cheesecloth. TSS content of the juice was determined using a digital refractometer (Atago Co., Ltd., Tokyo Atago, Japan) and expressed as °Brix. TA was determined by titrating 5 mL of the juice with 0.1 M NaOH to pH 8.2 with an automatic titrator (Mettler Toledo, Switzerland) and data were expressed as percentage citric acid. For ethanol accumulation, 10 mL of juice was transferred into a 20 mL glass vial with crimp-top caps sealed with silicone septa. The sealed sample was then incubated in a water bath of 30˚C for 10 minutes before analysis. Ethanol accumulation was determined by headspace analysis using a gas chromatograph (Model 580, Gow-Mac-Bethlehem, PA, USA) with a flame ionization detector and a column (Carbwax, GowMac, USA). The injector was set at 190°C, the column at 68°C, the detector (FID) at 190°C with gas flow rates of 30, 30 and 300 mL min^{-1} for nitrogen, hydrogen and air respectively. After incubating the samples, 1 mL of the headspace gas sample was drawn from the vials and injected into the GC. Ethanol accumulation was calculated and expressed as g L^{-1}.

The juice content of 10 fruit per replicate was determined. The percent juice contents were calculated by using the following formula; % juice contents = juice weight ÷ fruit weight x 100

The levels of Vitamin C were measured using a modified method of Zaaroor-Presman et al. (2020). In summary the juice from 10 fruit were titrated using the iodometric titration method (Zaaroor-Presman et al., 2020) and expressed as parts per million (ppm, µL L^{-1}).

Results

The phytosanitary treated Sumo® mandarins had significant superficial damage to the peel upon arrival of fruit at NSW DPI (Figure 1) which remained during storage (Figure 2).

Figure 1. Phytosanitary irradiation treated (left) and untreated (right)
Sumo® mandarins upon arrival at NSW DPI.

Figure 2. Phytosanitary irradiation treated (left) and untreated (right)
Sumo® mandarins after 4 weeks storage plus shelf life.

The damage to the peel in irradiated treated fruit was apparent after treatment and continuously deteriorated during storage. The initial damage appeared to be damage to the oil glands in the peel which caused browning of the adjacent peel tissue to form a spotty brown appearance (Figure 3). However as time progressed in cold storage some of the peel damage around the equator of the fruit developed more continuous browning symptoms with darker desiccation symptoms (Figure 3).

There was some non-phytosanitary irradiation damage observed in non-treated fruit (Figure 4), but this was general senescent browning on the peel and was generally within commercial acceptability (i.e. less than Damage Score 2 - Figure 3).

Figure 3. Damage to the peel of phytosanitary irradiation treated Sumo® mandarins after 4 weeks storage plus shelf life. Typical damage to the oil glands, particularly around the fruit collar and neck (top) and later senescent browning damage on the peel of late stored fruit (4 weeks) (lower).

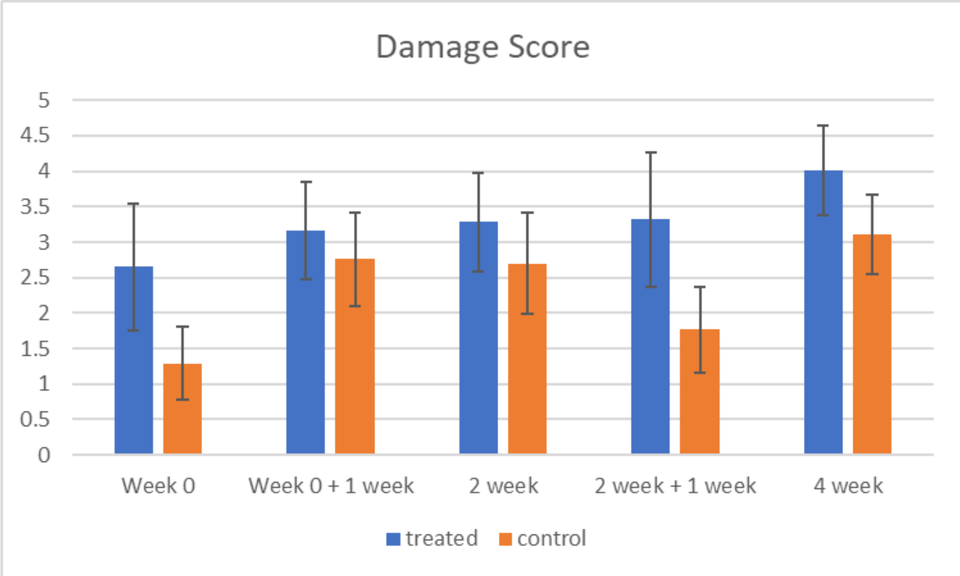

Figure 4. Effect of phytosanitary irradiation on the level of peel damage on Sumo® mandarins during storage and shelf life. Damage score: 1 No browning, 2 trace / some detectable (0-5% of the surface area has browning) – still acceptable, 3 moderate (5-25% surface area has browning symptoms) – not acceptable, 4 high levels (35-50% browning), and 5 very high levels (>50% browning).Bars are standard deviation bars around the mean (*n*=4).

The calyx (button) on citrus fruit are an indicator of fruit 'freshness'. The results in Figure 5 show that treated fruit had lower calyx score, i.e. yellower / browner and more senescent.

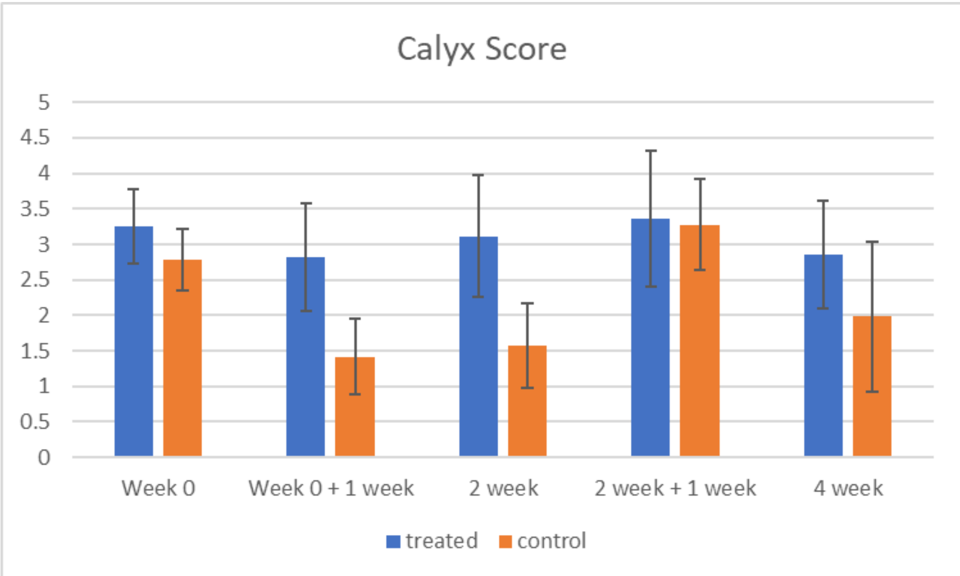

Figure 5. Effect of phytosanitary irradiation on the comparative health of the calyx (button) on Sumo® mandarins during storage and shelf life. Calyx score: 1 green – fresh green, 2 - slightly yellow (<25% yellow / brown), 3 moderately yellow (25-50% brown / yellow), 4 yellow (50-75% yellow / brown) and 5 brown (>75% brown).
Bars are standard deviation bars around the mean (*n*=4).

As the fruit had been commercially treated with fungicides, the level of rots in in Sumo® mandarins during storage and shelf life were low (Figure 6) with no consistent differences between treated and non-treated fruit.

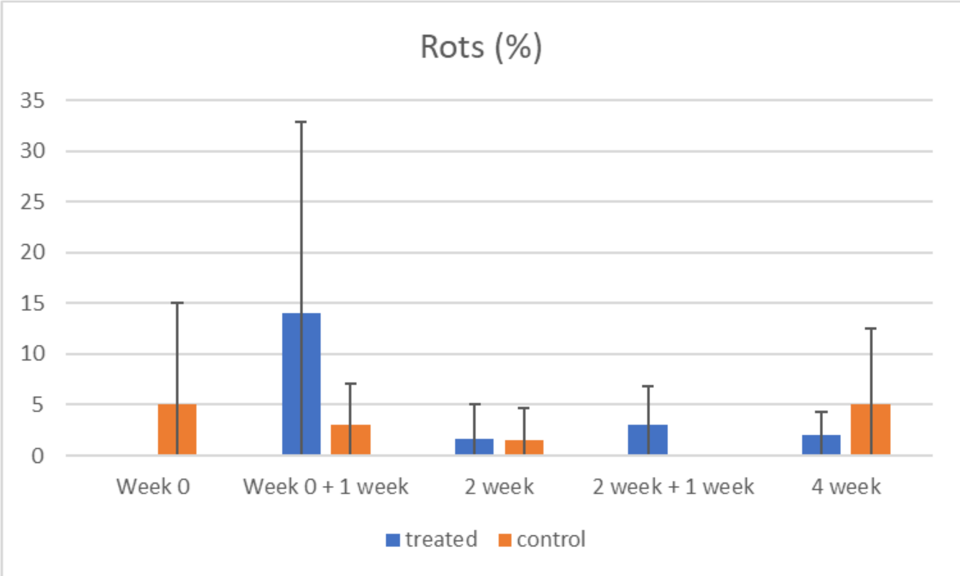

Figure 6. Effect of phytosanitary irradiation treatment on the percentage of fruit rots (%) in Sumo® mandarins during storage and shelf life. Bars are standard deviation bars around the mean (*n*=4).

There was no difference in the levels of weight loss from the treated and untreated fruit after 4 weeks storage and 1 week shelf life at 20°C (Figure 7).

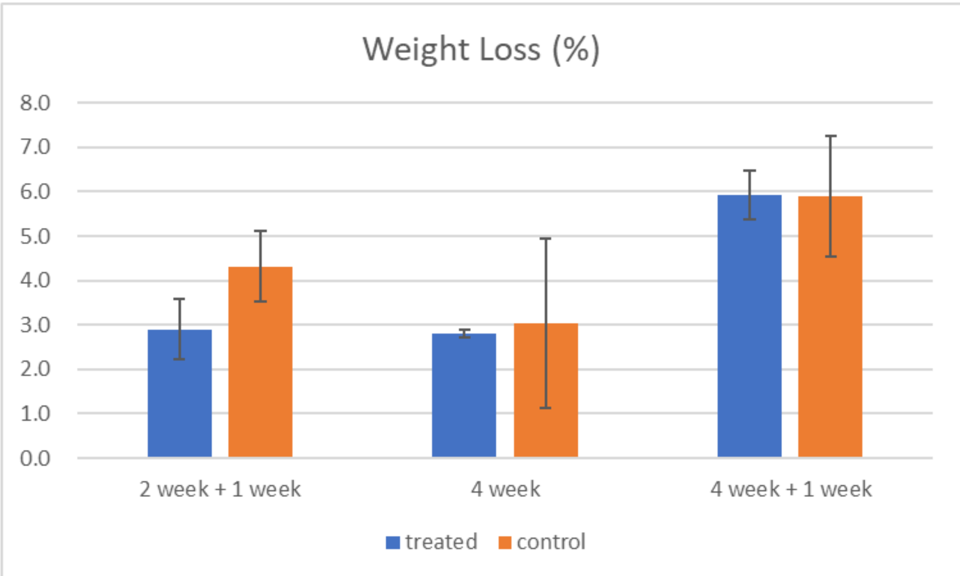

Figure 7. Effect of phytosanitary irradiation treatment on fruit weight loss (%) in Sumo® mandarins during storage and shelf life. Bars are standard deviation bars around the mean (*n*=4).

There were no consistent differences in fruit firmness (Figure E), TSS, TA, vitamin C (Figure 8) between the treated and non-treated Sumo® mandarins.

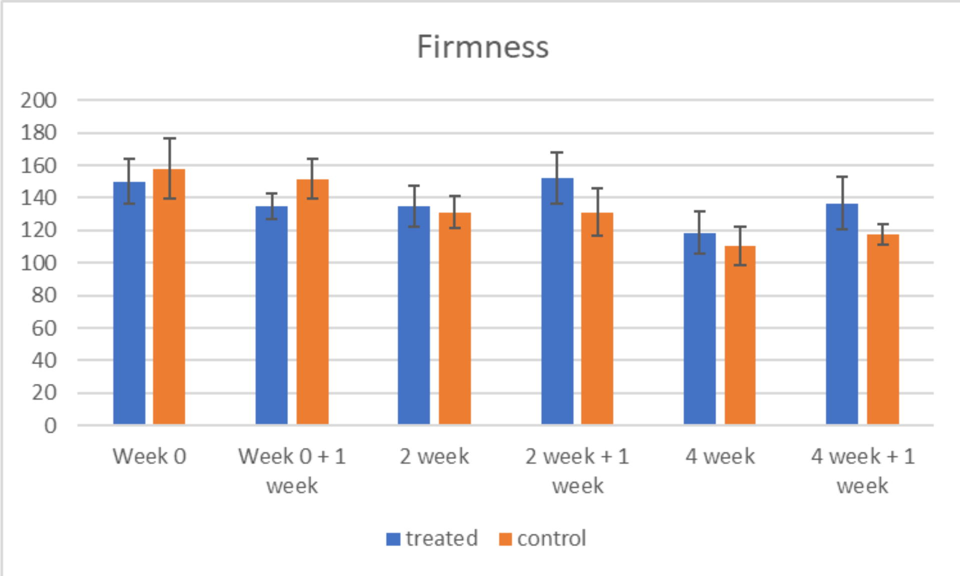

Figure 8. Effect of phytosanitary irradiation treatment on fruit firmness as objectively measured with texture analyser (N) Bars are standard deviation bars around the mean (*n*=4).

The percentage of juice extracted from the fruit during storage and shelf life is presented in Figure 9 and shows there were few differences between treated and untreated fruit.

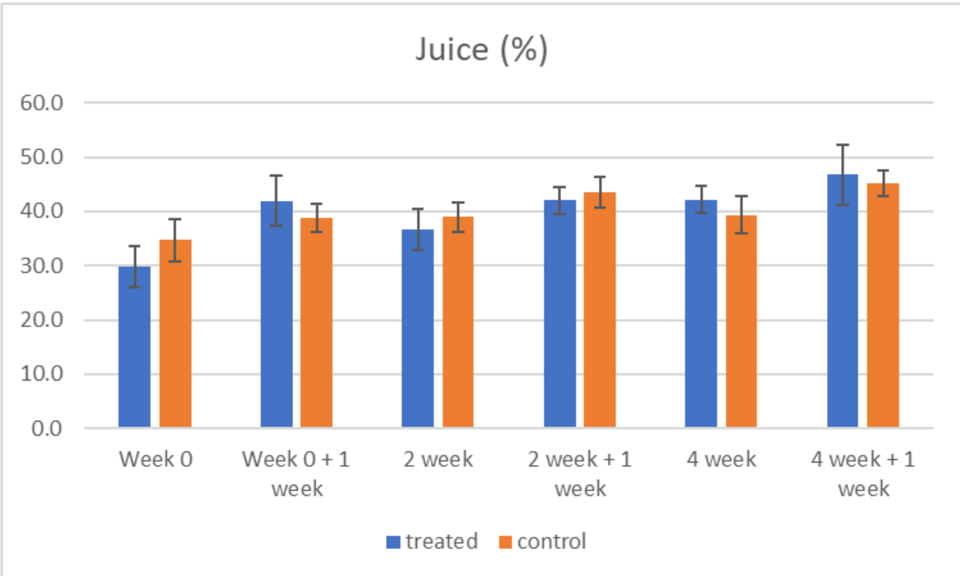

Figure 9. Effect of phytosanitary irradiation treatment on the percentage juice extracted from Sumo® mandarins during storage and shelf life. Bars are standard deviation bars around the mean (*n*=4).

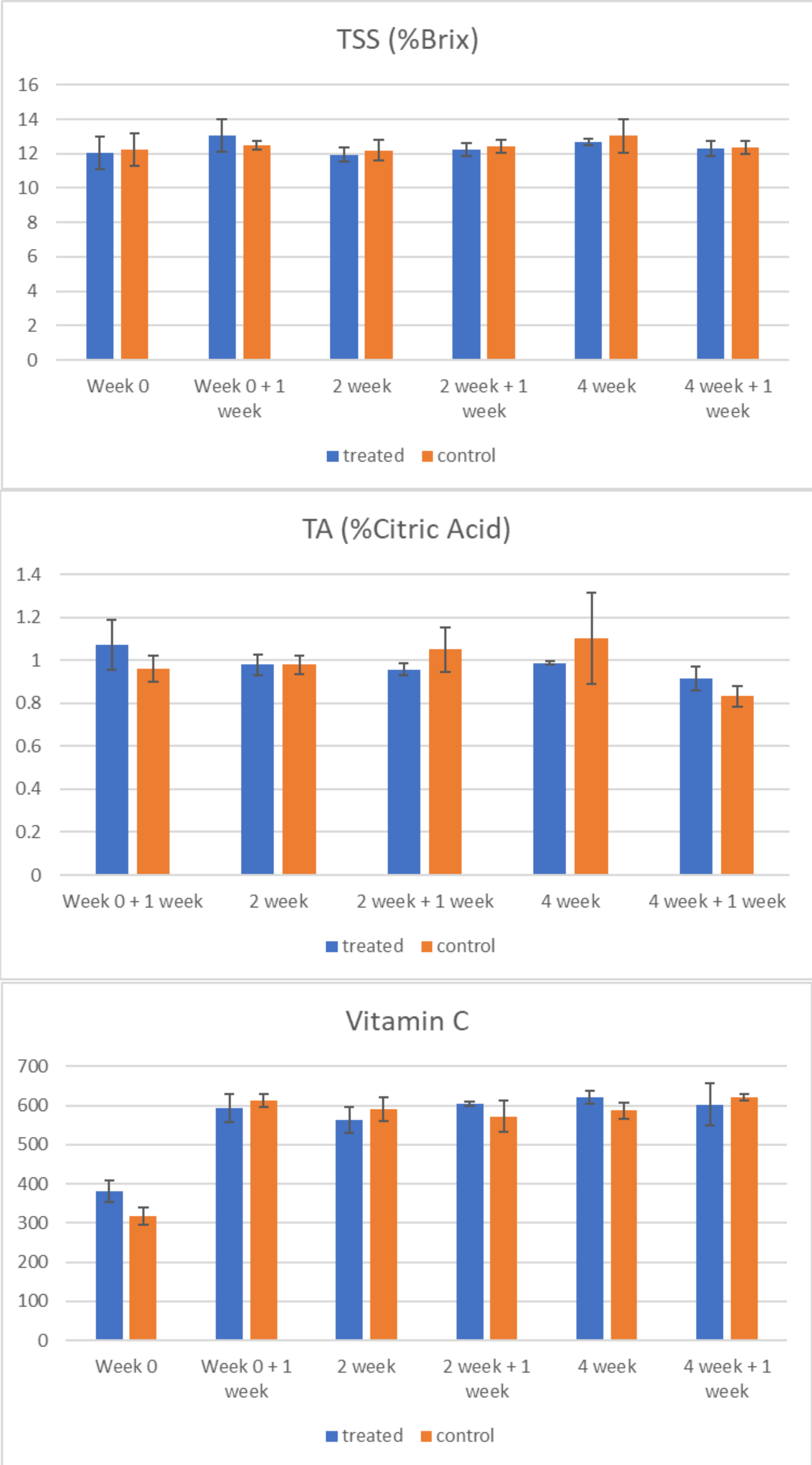

Figure 10. Effect of phytosanitary irradiation treatment on total soluble solids (TSS,SSC% Brix%), titratable acidity (TA, % citric acid) and vitamin C content (ppm) in Sumo® mandarins. Bars are standard deviation bars around the mean (*n*=4).

The rates of respiration in Sumo® mandarins were generally not affected by irradiation treatment, but when there were differences between treatments, treated fruit had higher levels of respiration than untreated fruit (Figure 11).

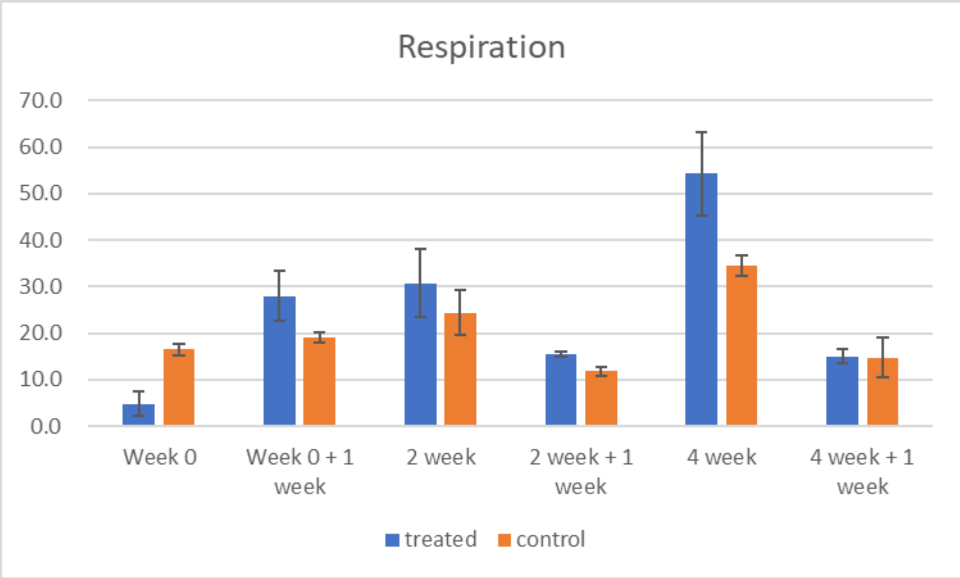

Figure 11. Effect of phytosanitary irradiation treatment on fruit respiration rate (mL CO_2.kg.hr $^{-1}$) in Sumo® mandarins during storage and shelf life.
Bars are standard deviation bars around the mean (*n*=4).

Treated Sumo® mandarins tended to have higher levels of ethanol in the headspace of the juice (Figure 12). High levels of ethanol in the juice are associated with off-flavours and dekopon mandarins are very prone to developing off-flavour in storage (Obenland and Arpaia, 2023). These results suggest irradiation increases the level of ethanol during storage and may contribute to more off-flavours.

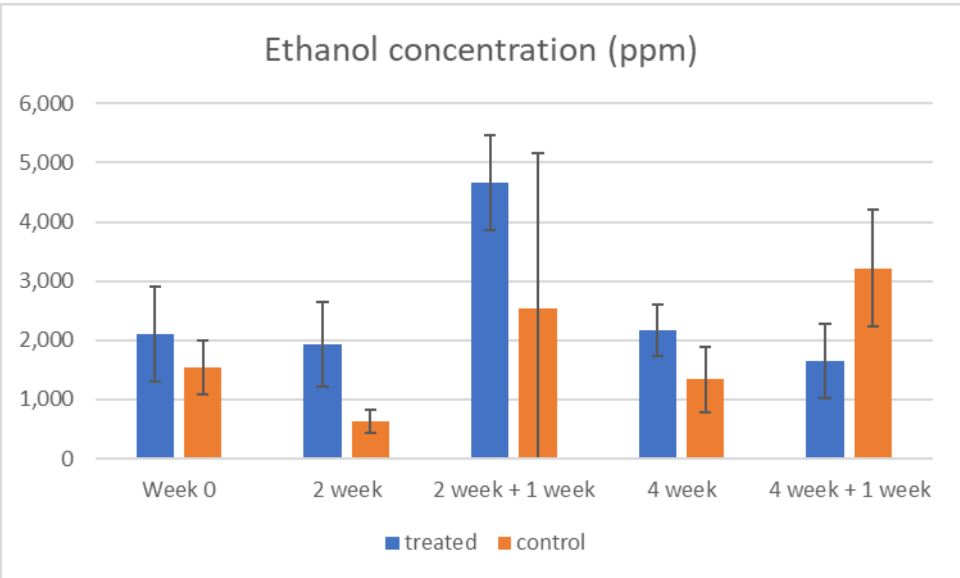

Figure 12. Effect of phytosanitary irradiation treatment on the concentration of juice ethanol (ppm) in Sumo® mandarins during storage and shelf life. Bars are standard deviation bars around the mean (*n*=4).

Summary

Dekopon mandarins are inherently difficult to handle, store and market (Obenland and Arpaia, 2023). In this trial, Sumo® mandarins were treated with phytosanitary irradiation and stored for up to 4 weeks. The results showed that the phytosanitary irradiation caused damage to the peel of treated fruit. This damaged was characterised by damage to the oil glands, particularly around the neck of the fruit which reduced consumer appeal. In addition the calyx of treated fruit were generally browner than on the untreated fruit.

Apart from the cosmetic appearance of the fruit there were few differences between the phytosanitary treated and non-treated fruit. The results showed there were no or few consistent differences in fruit weight loss, development of rots, fruit firmness, juice content, TSS, TA and vitamin C content between the treated and non-treated Sumo® mandarins. However there were differences in respiration rates, where higher respiration rates were detected in treated fruit at some assessment times. In addition there were higher ethanol levels in the juice of irradiated fruit. Dekopon mandarins are susceptible to the development of off-flavours in storage (Obenland and Arpaia, 2023). In this experiment, the significant cosmetic peel damage, higher respiration rates and accumulation of ethanol indicate damage to the fruit by the treatment. While the other internal quality parameters were not generally affected by irradiation, the external damage to the peel as a result of irradiation treatment is a significant issue for consumer acceptance. More work is required to investigate the consistency of this damage across other batches of Sumo® mandarins during the season and develop management strategies to overcome this issue.

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Appendix C: Afourer mandarin

Introduction

Afourer mandarins are an growing segment of the Australian citrus industry and new markets are required for increasing volumes of Afourer mandarins. This trial examined the effects of commercial phytosanitary irradiation on the external and internal quality of Afourer mandarins.

There were four smaller observational sub-trails within this experiment to examine the effects of phytosanitary irradiation on different orchard and fruit size factors:

Sub -trial 1	medium fruit from different orchards
Sub -trial 2	fruit predisposed to rind damage
Sub -trial 3	medium and large fruit
Sub -trial 4	medium fruit from the same orchard

Methods

Table 1. Experimental design for Afourer mandarin trial (including sub-trials)

Box number	Sub -trial	Treated/Control	Fruit size	Harvest date	Orchard number
1	Trial 1	Control	Medium	19-09-2022	1
2	Trial 1	Control	Medium	19-09-2022	1
3	Trial 1	Control	Medium	03-10-2022	18
4	Trial 1	Treated	Medium	19-09-2022	1
5	Trial 1	Treated	Medium	03-10-2022	18
6	Trial 1	Treated	Medium	03-10-2022	18
7	Trial 2	Control	Rind breakdown	04-10-2022	5
8	Trial 2	Control	Rind breakdown	03-10-2022	14
9	Trial 2	Treated	Rind breakdown	03-10-2022	14
10	Trial 2	Treated	Rind breakdown	03-10-2022	5
11	Trial 3	Control	Medium	03-10-2022	18
12	Trial 3	Control	Large	03-10-2022	14
13	Trial 3	Control	Large	03-10-2022	14
14	Trial 3	Control	Medium	03-10-2022	18
15	Trial 3	Treated	Large	03-10-2022	14
16	Trial 3	Treated	Medium	03-10-2022	18
17	Trial 3	Treated	Medium	03-10-2022	18
18	Trial 3	Treated	Large	03-10-2022	14
19	Trial 4	Control	Medium	03-10-2022	18
20	Trial 4	Control	Medium	03-10-2022	18
21	Trial 4	Control	Medium	03-10-2022	18
22	Trial 4	Control	Medium	03-10-2022	18
23	Trial 4	Treated	Medium	03-10-2022	18
24	Trial 4	Treated	Medium	03-10-2022	18
25	Trial 4	Treated	Medium	03-10-2022	18
26	Trial 4	Treated	Medium	03-10-2022	18

The treatment and storage methods are similar to those conducted in the previous experiment (Appendix C – Dekapon citrus) and fruit were stored at 20^{o}C shelf-life for up to 10 days after treatment.

Results

In all the different sub-trials, irradiation treatment had a significant negative effect on the levels of skin blemish of Afourer mandarins, where treatment resulted in high levels of browning and damage to the skin (Figures 1 and 2). Treatment also results in higher fruit respiration rates and was particularly evident when observed when the fruit had arrived at NSW DPI (Time Zero), but these treatment differences became lower during storage at 20 °C (Figure 3). Conversely there were few differences in the ethanol content in fruit from Trial 2, 3 and 4 at the beginning of the trial, but after 10 days at 20 °C, the ethanol content of treated fruit were higher (Figure 4). The juice content (%), TSS, TA, TSS/TA ratio, Vitamin C content and fruit firmness were not consistently affected by treatment (Figures 5-10). However calyx (button) browning and loss were higher in treated fruit (Figure 11-12). The fruit colour observations, as measured with Minolta colour meter, reflect the observations of the blemish whereby the treated fruit were darker in colour (lower L* value, chroma and overall hue angle)(Figures 13-15).

Overall, treatment resulted in higher levels of skin blemish and higher levels of damage to the fruit calyx in the Afourer mandarins tested in this experiment. However, there were no consistent differences in fruit quality observed between the different sizes of fruit or from different orchards. There were few consistent differences between treated and non-treated fruit, although treated fruit had higher respiration rates after treatment indicating fruit damage following treatment.

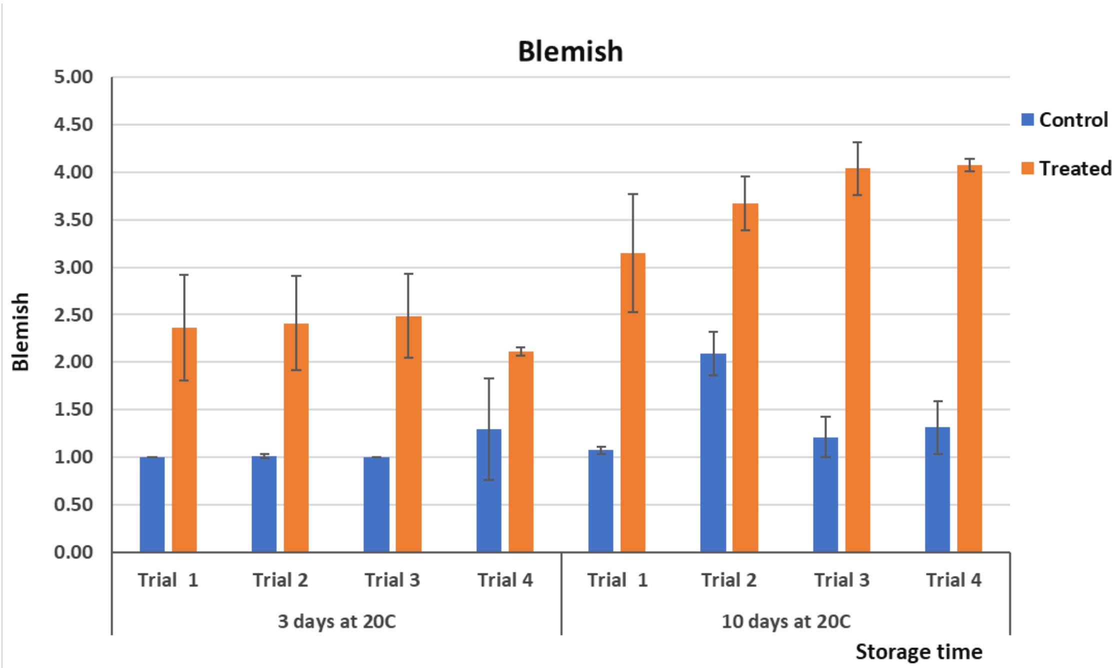

Figure 1. Effect of phytosanitary irradiation on Afourer mandarin blemish with different trials following storage at 20 °C for up to 10 days.

Time Zero

Trial 1 Untreated (Control) (Left) Treated (Right)

Trial 2 Untreated (Control) (Left) Treated (Right)

Trial 3 Untreated (Control) (Left) Treated (Right)

Trial 4 Untreated (Control) (Left) Treated (Right)

Figure 2. Effect of phytosanitary irradiation on Afourer mandarin blemish with different trials at the beginning of the storage trial.

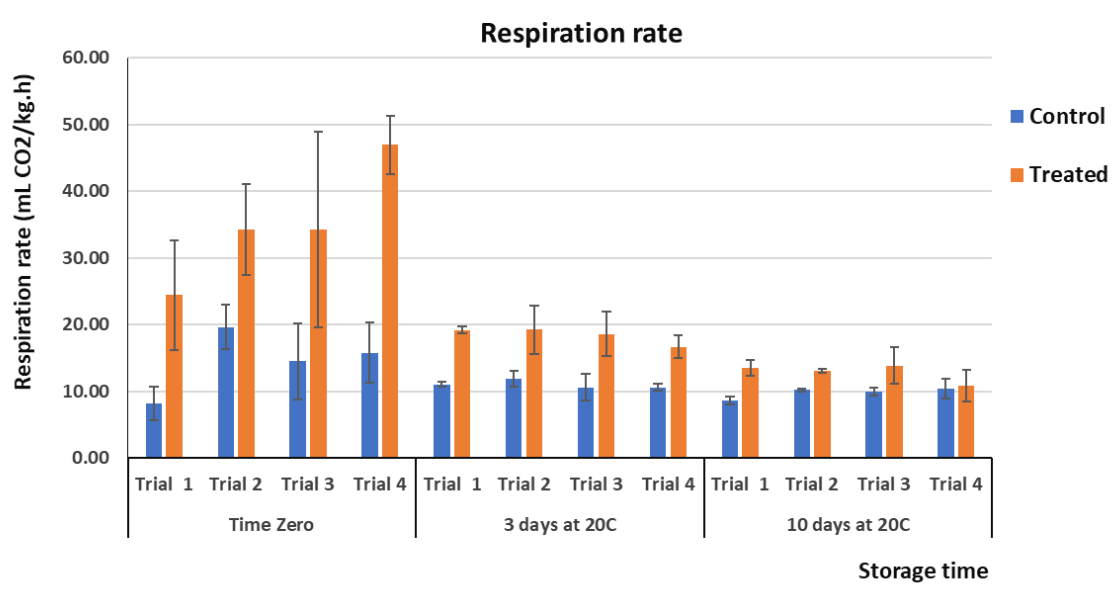

Figure 3. Effect of phytosanitary irradiation on Afourer mandarin respiration rate (mL CO_2/kg.h) with different trials following storage at 20 °C for up to 10 days.

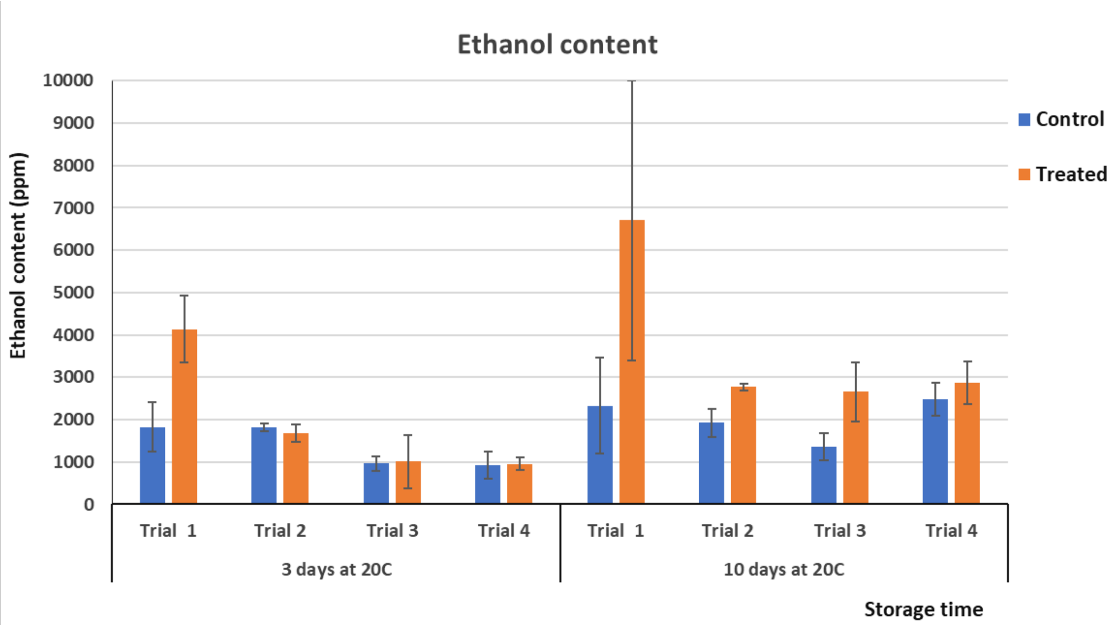

Figure 4. Effect of phytosanitary irradiation on Afourer mandarin ethanol content (ppm) with different trials following storage at 20 °C for up to 10 days.

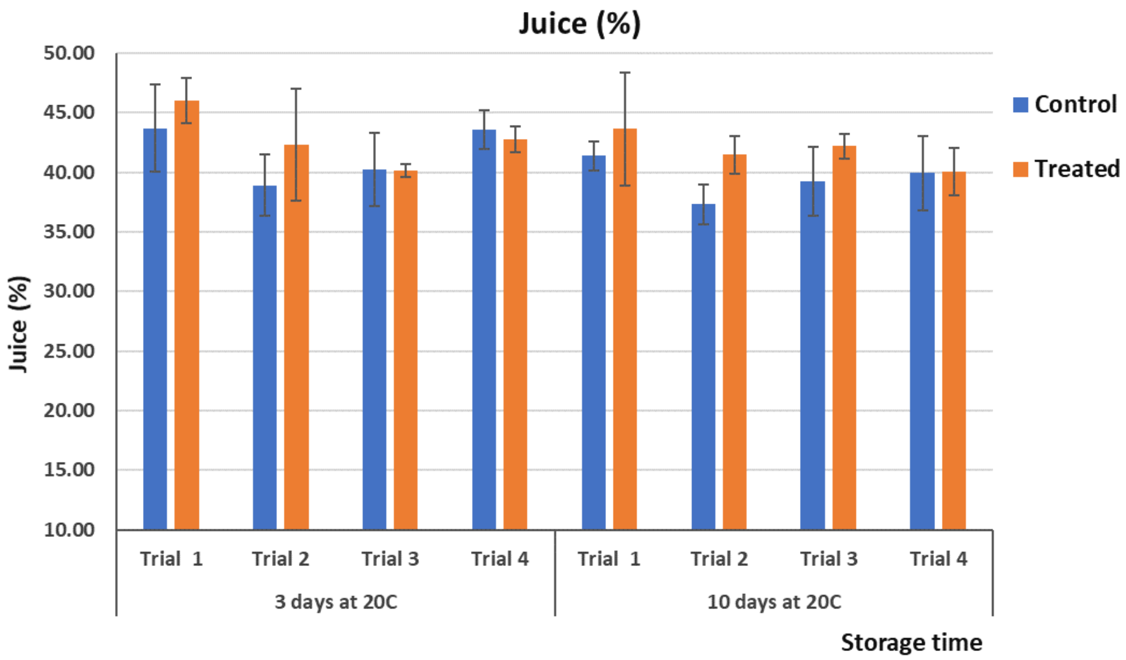

Figure 5. Effect of phytosanitary irradiation on Afourer mandarin juice (%) with different trials following storage at 20 °C for up to 10 days.

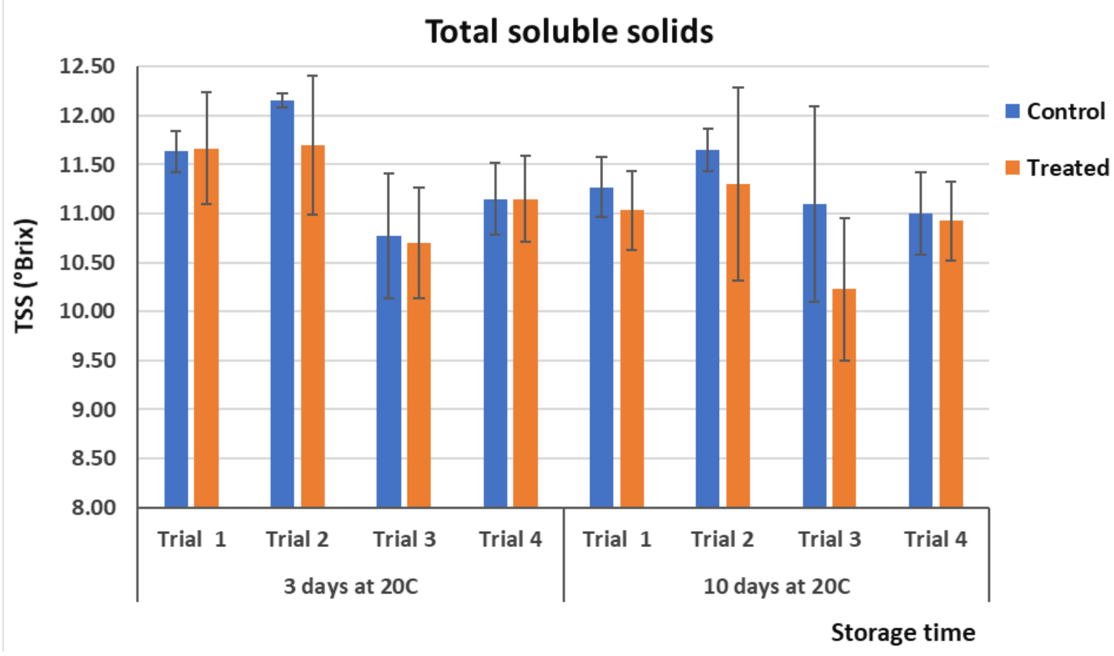

Figure 6. Effect of phytosanitary irradiation on Afourer mandarin total soluble solids (°Brix) with different trials following storage at 20 °C for up to 10 days.

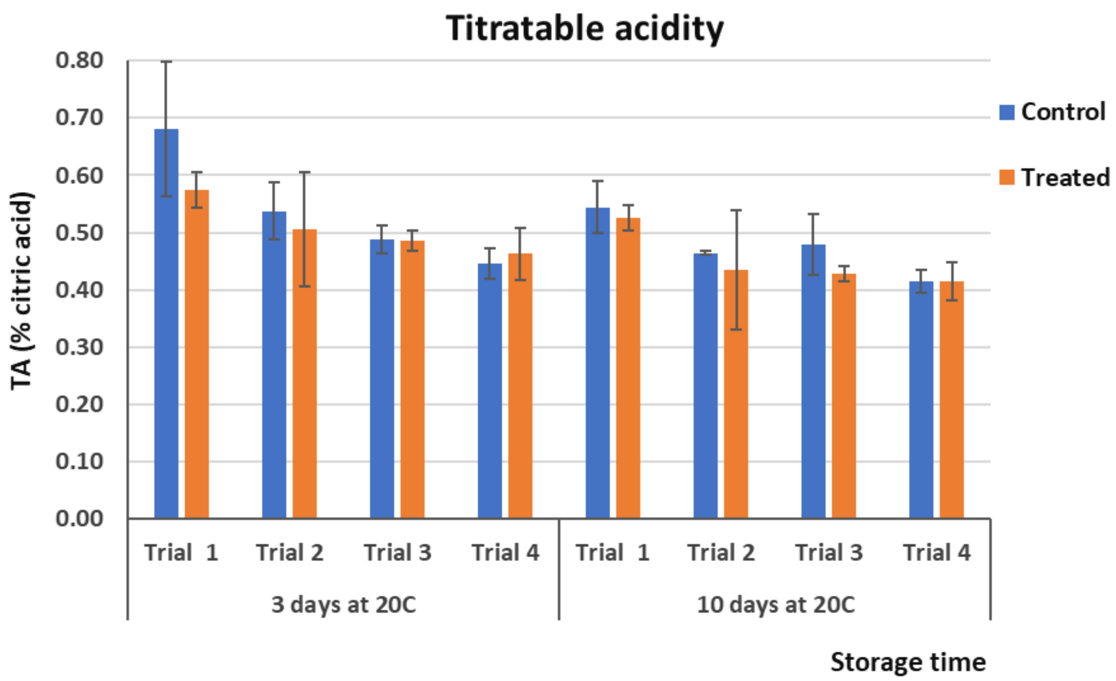

Figure 7. Effect of phytosanitary irradiation on Afourer mandarin titratable acidity (% citric acid) with different trials following storage at 20 °C for up to 10 days.

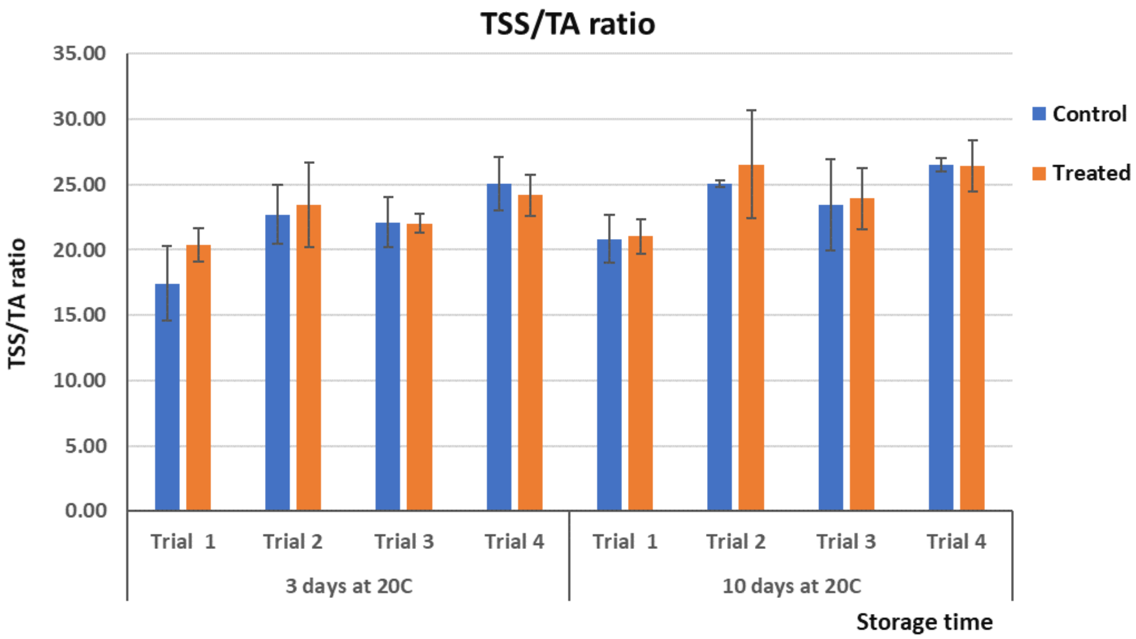

Figure 8. Effect of phytosanitary irradiation on Afourer mandarin TSS/TA with different trials following storage at 20 °C for up to 10 days.

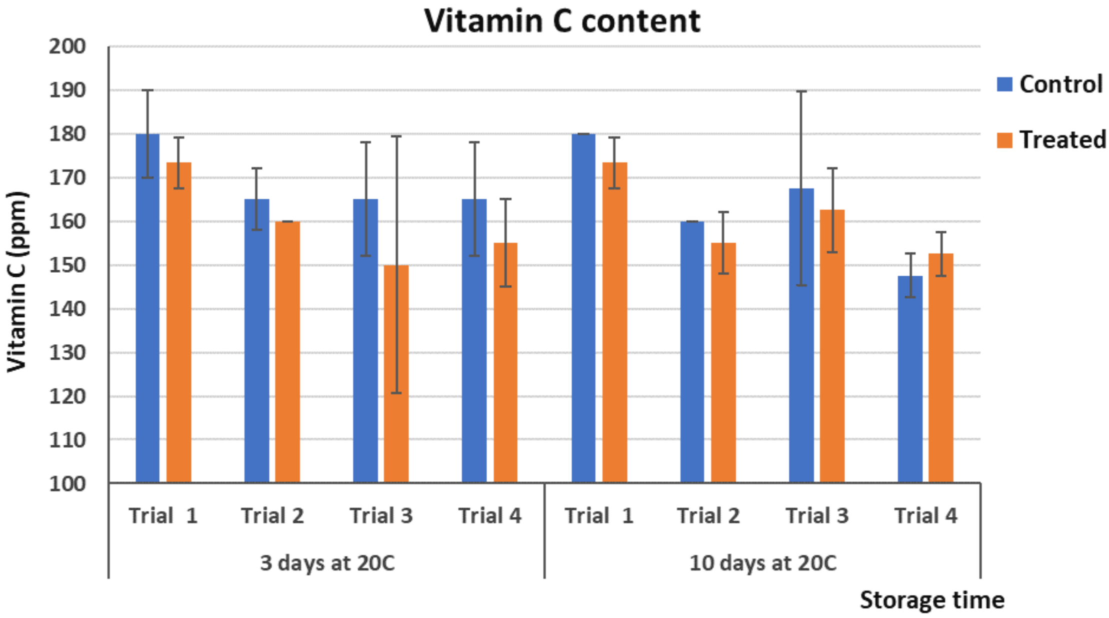

Figure 9. Effect of phytosanitary irradiation on Afourer mandarin vitamin C content (ppm) with different trials following storage at 20 °C for up to 10 days.

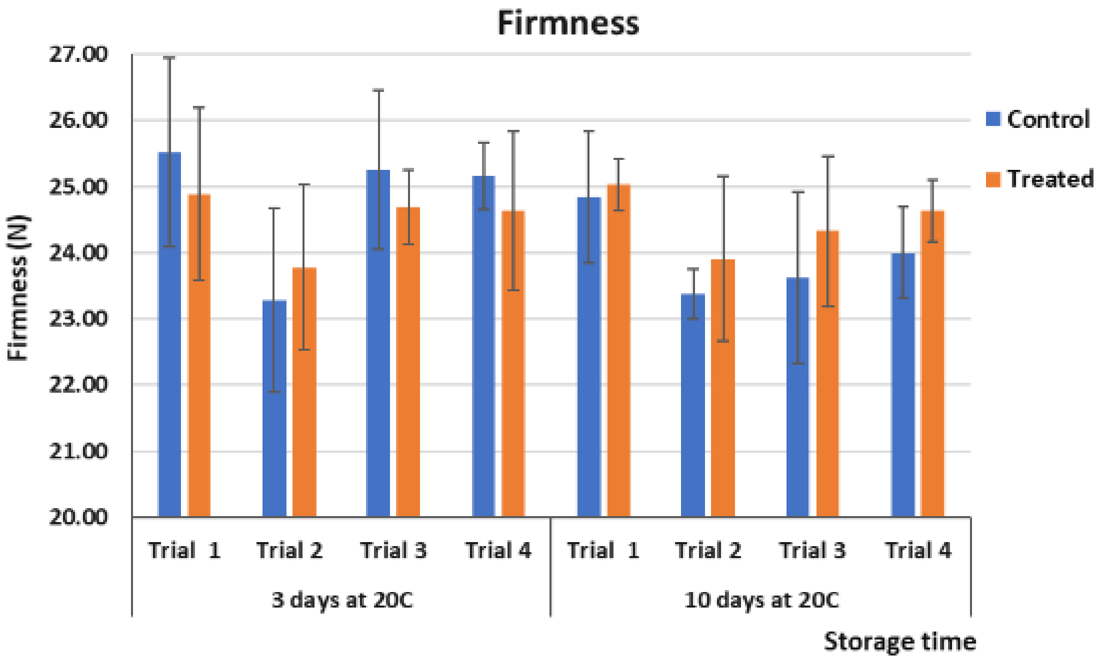

Figure 10. Effect of phytosanitary irradiation on Afourer mandarin firmness (N) with different trials following storage at 20 °C for up to 10 days.

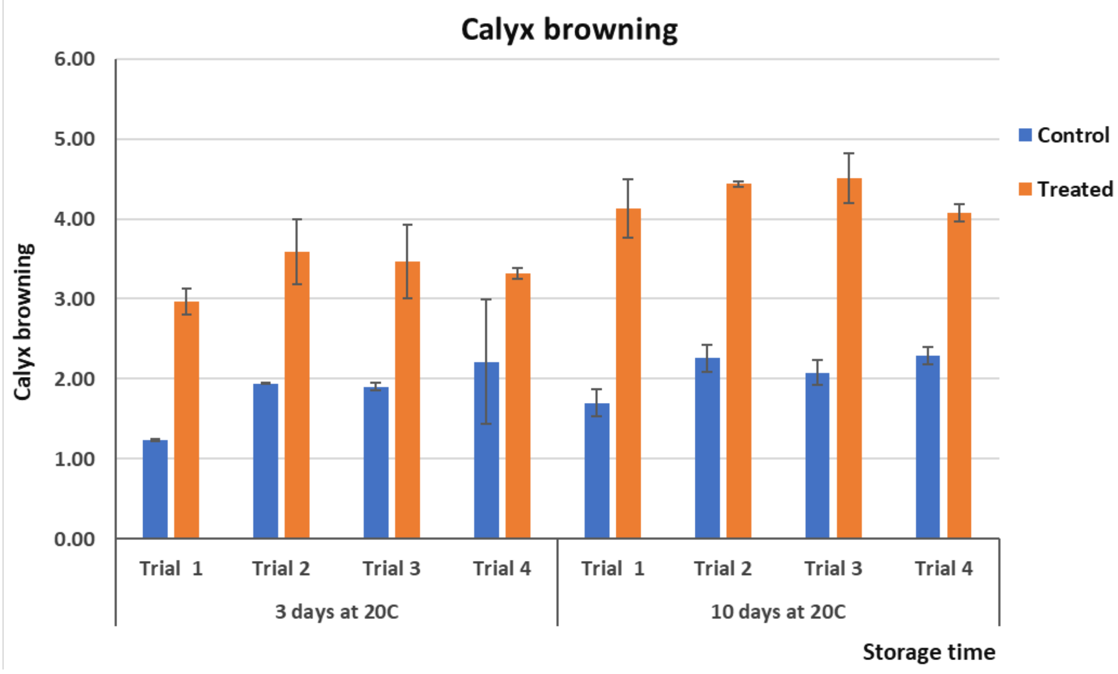

Figure 11. Effect of phytosanitary irradiation on Afourer mandarin calyx browning with different trials following storage at 20 °C for up to 10 days.

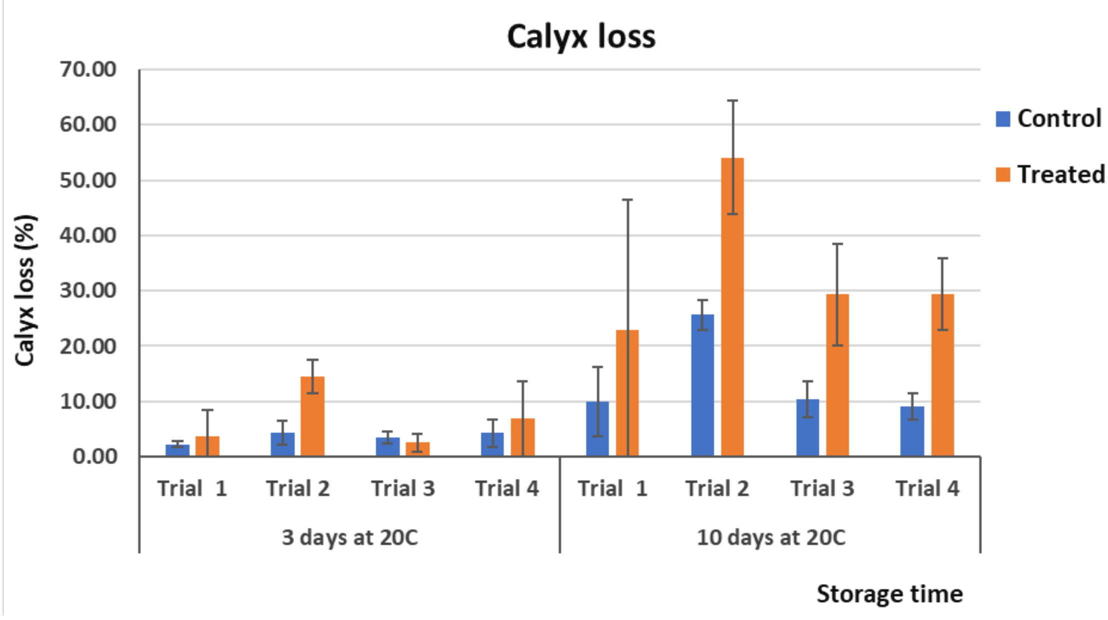

Figure 12. Effect of phytosanitary irradiation on Afourer mandarin calyx loss (%) with different trials following storage at 20 °C for up to 10 days.

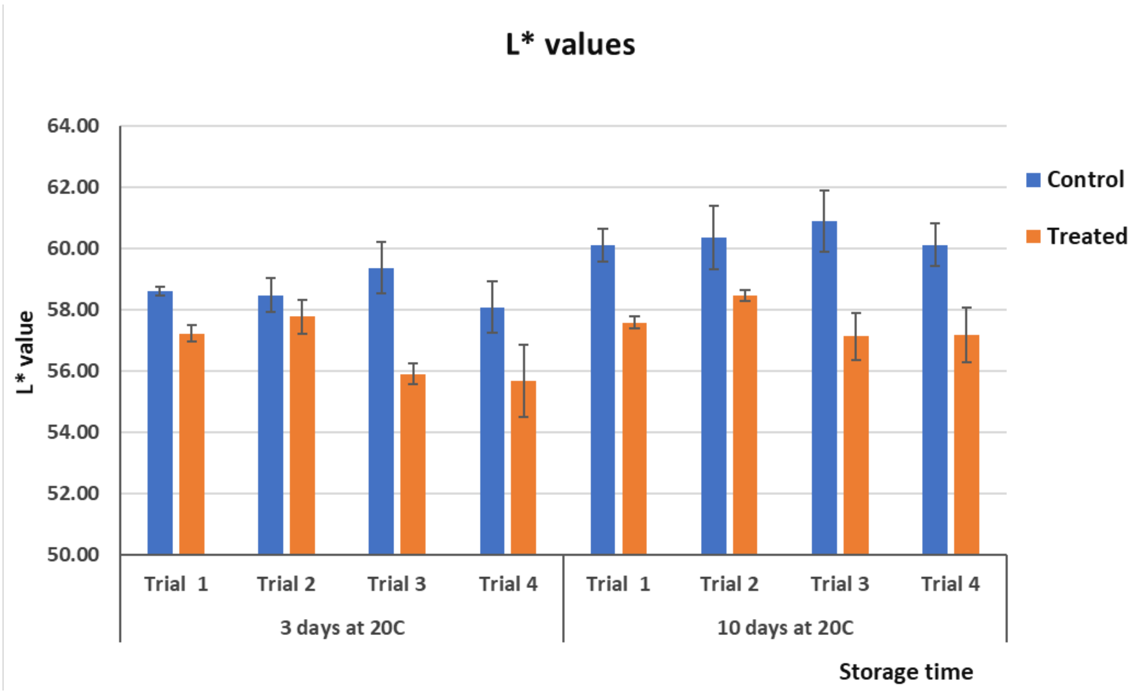

Figure 13. Effect of phytosanitary irradiation on Afourer mandarin L* values with different trials following storage at 20 °C for up to 10 days.

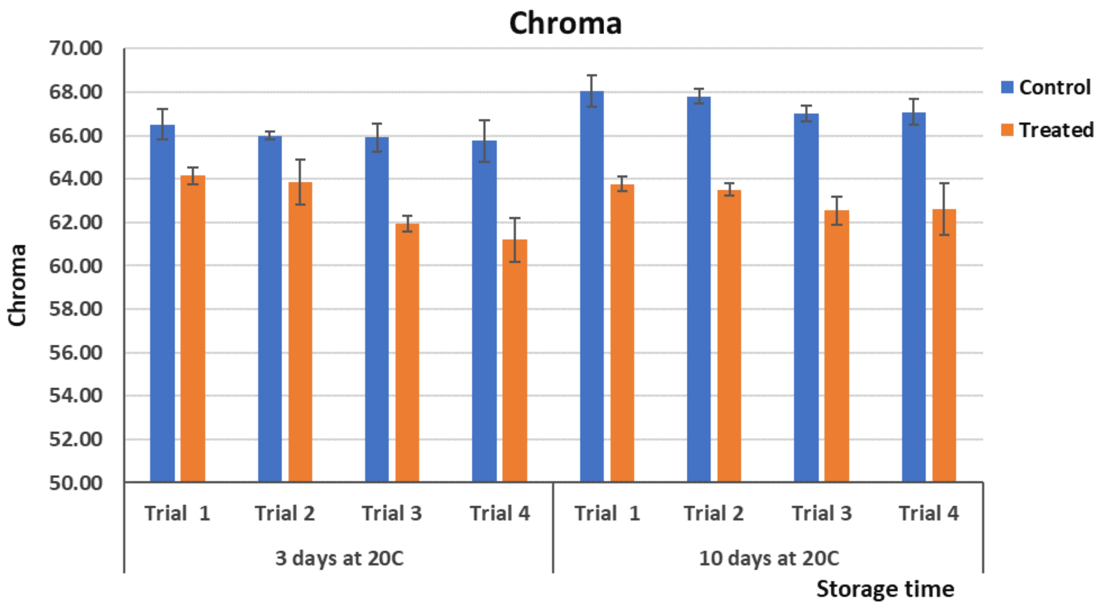

Figure 14. Effect of phytosanitary irradiation on Afourer mandarin chroma with different trials following storage at 20 °C for up to 10 days.

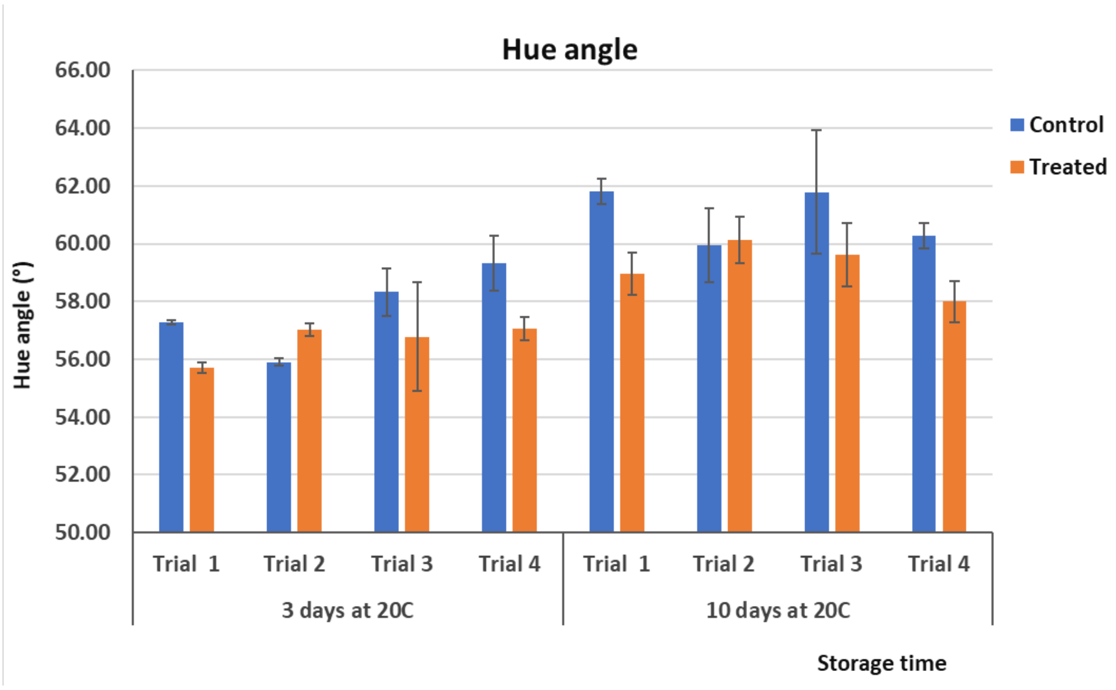

Figure 15. Effect of phytosanitary irradiation on Afourer mandarin hue angle (°) with different trials following storage at 20 °C for up to 10 days.

Appendix D: Broccoli

Two storage trials were conducted by Agriculture Victoria to assess the effects of phytosanitary irradiation on broccoli during simulated export.

Broccoli Trial 1

Key findings

- Water loss during long-term storage was higher from broccoli heads stored in MA liners compared to HH liners.
- An effect of increased head weight loss due to irradiation treatment was observed among broccoli stored in HH liners but not in head stored within the MAL liner.
- Yellowing of broccoli heads increased during the 11-day marketing period with clearer differences in head colour between irradiated and untreated broccoli treatments with increasing shelf-life duration.
- After 5 weeks of cool storage broccoli would need to be sold before a marketing period of 7 days due to course beading and opening of florets affecting the visual appearance of heads.

Introduction

Twenty crates of fresh broccoli (cv. 'Blackjack') were sourced from a commercial grower in Werribee South, transported back to Agribio centre, heads tagged, and quality assessed. Broccoli was repacked into either Life Pack™ modified atmosphere (MA) liners or high humidity (HH) liners and irradiation disinfestation treatment five days after harvest. Broccoli quality on ten tagged heads per five crates containing either the MA or HH liner were assessed after simulated sea freight for 38 days at 1 °C and marketing at 8 °C for 0, 4, 7 or 11 days.

Disinfestation treatment	Package type	Marketing period after cool storage at 1 °C for 38 days
Control	Life pack® modified atmosphere liner	0, 4, 7 or 11 days for 8 °C
Irradiation		
Control	Micro-perforated high humidity liner	
Irradiation		

Tagged broccoli heads (n=10 per replicate crate) prior to cool storage (left) and broccoli packed in a sealed modified atmosphere (MA) liner and perforated high humidity liner (right).

Results

Irradiation treatment had minimal effect on broccoli head weight loss when produce was packed in an MA liner compared to untreated heads, with water loss from heads above acceptable levels in both treatments during marketing after storage in MA liners and increasing weight loss observed with extended marketing periods (Fig. 1). Head weight loss was significantly lower in HH liners compared to MA liners at all marketing periods in both irradiated and untreated broccoli, with acceptable weight loss after 7 and 11 days of marketing only observed among untreated heads stored in HH liners. Irradiation significantly increased head weight loss in HH liners after marketing for 0, 4 or 7 days compared to untreated heads stored in the same liner.

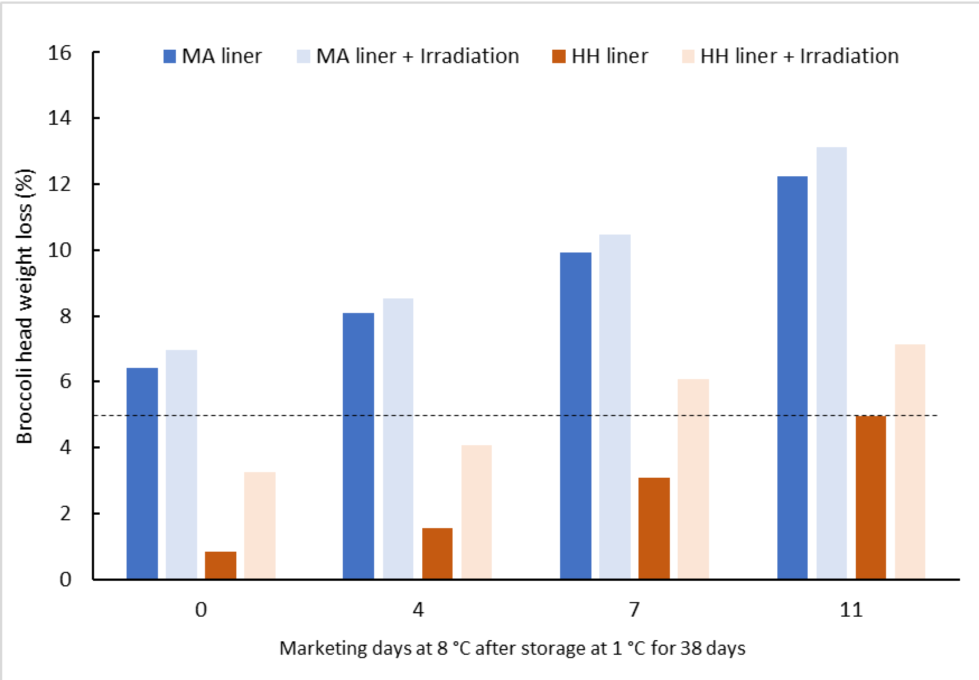

Figure 1. Effect of package type, irradiation treatment and marketing period after storage at 1 °C on broccoli head weight loss. Dashed line is the minimum commercially acceptable head weight loss.

Little difference in broccoli head colour was observed during marketing for 0, 4 or 7 days at 8 °C after cool storage as measured by CIELAB b* value where a higher value indicates greater head yellowing, although at each marketing period irradiated heads stored in HH liners were slightly more yellow than heads in other treatments (Fig. 2). Irradiated heads stored in HH liners had significantly more yellowing than other treatments after 11 days of marketing, whilst untreated heads stored in the MA liner had the lowest b* value, indicating the least yellowing of heads among treatments, and was the only treatment to keep head yellowing below the limit of commercial acceptability after 11 days of marketing.

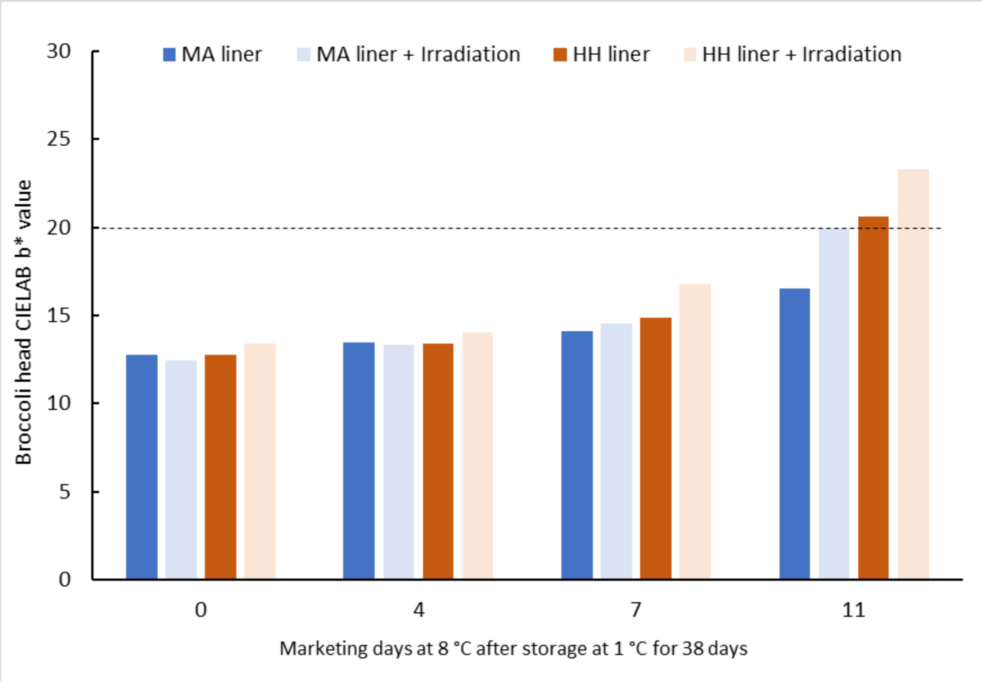

Figure 2. Effect of package type, irradiation treatment and marketing period after storage at 1 °C on broccoli head b* value that represents the blue–yellow axis of the CIELAB colour space, with higher values indicating greater yellow colour. Dashed line is the minimum commercially acceptable degree of head yellowing.

Broccoli head texture score was very good among all treatments during cool storage and marketing for 0 and 4 days at 8 °C with fine to coarse beading of heads observed, indicating commercially acceptable head texture regardless of irradiation treatment or package type (Fig. 3). After marketing for 7 days commercially unacceptable head texture was only observed among irradiated heads stored in HH liners with coarse beading and little difference in texture observed on heads within remaining treatments. After 11 days of marketing all treatments, except non-irradiated heads stored in MA liners resulted in commercially unacceptable head texture scores, due to irregular beading and open florets with the highest score observed in irradiated heads stored in HH liners.

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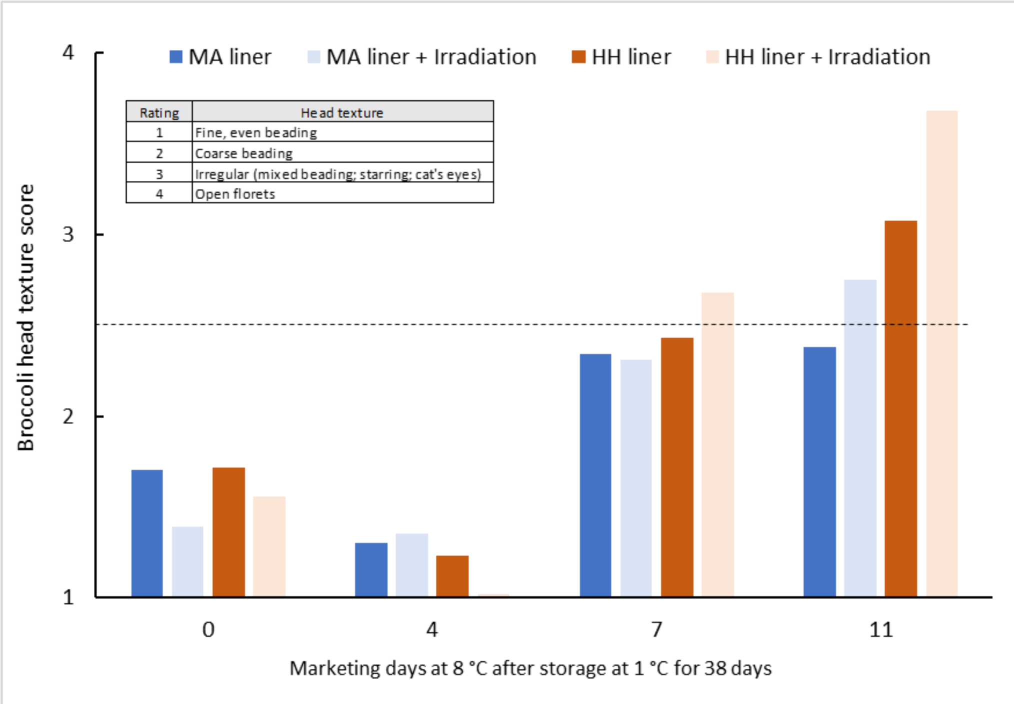


Figure 3. Effect of package type, irradiation treatment and marketing period after storage at 1 °C on broccoli head texture score. Dashed line is the minimum commercially acceptable head texture score.

Commercial implications

- After cool storage for 38 days at 1 °C to simulate sea freight and 7 or 11 days of marketing at 8 °C, non-irradiated broccoli heads in Life pack MA liners were generally of higher quality than heads within other treatments due to less head yellowing and less coarse texture, but head weight loss was greater than observed within HH liners, both in irradiated and untreated heads, due to a higher moisture transmission rate through the MA liner.
- Broccoli weight loss only remained below commercially acceptable levels after 11 days of marketing among untreated heads stored within HH liners, whilst irradiation increased weight loss in heads within both MA and HH liners during the marketing phase.
- Irradiation treatment or liner type had little effect on broccoli head colour during marketing for 0, 4 or 7 days at 8 °C after cool storage whilst irradiated heads stored in HH liners had significantly more yellowing than other treatments after 11 days of marketing, whilst the MA liner without head irradiation was the only treatment to keep head yellowing below the limit of commercial acceptability.
- After marketing for 7 days commercially unacceptable head texture was only observed among irradiated heads stored in HH liners, whilst after 11 days of marketing all treatments except storage in the MA liner resulted in commercially unacceptable head texture.
- Irradiation treatment generally decreased broccoli quality based on weight loss, loss of green colour and head texture, beyond 4 days of marketing at 8 °C within both liner types after simulated sea freight indicating that this disinfestation treatment may be incompatible with long-term storage or sea freight.
- The commercial Life pack MA liner tested in this trial was generally effective in reducing quality loss in broccoli up to 7 days of marketing regardless of disinfestation treatment, but relatively high weight loss in heads stored in this liner highlights the importance of comprehensive testing of commercial MA liners under a variety of postharvest storage and marketing scenarios.

Broccoli Trial 2

Key findings

- No difference in visual appearance of broccoli between treatments after 10 days storage at 1 °C.
- Irradiation treatment accelerated yellowing of florets during the 4-day marketing period at 12 °C after storage compared to untreated heads.
- At a marketing temperature of 12 °C all broccoli was unsaleable after 7 days of shelf-life due to poor visual quality that included opening and yellowing of florets and minor rot development.

Introduction

Eight crates of fresh broccoli packed in macro-perforated high humidity liners were sourced from a commercial grower and transported back to Agribio centre, five heads tagged per replicate crate and initial quality assessed. Heads were stored for 8 days at 1 °C prior to irradiation disinfestation treatment of four crates and remaining four crates left untreated. Broccoli quality of untreated and irradiated heads was assessed after short-term storage at 1 °C for 10 days and marketing at 12 °C for 0, 4 and 7 days.

Disinfestation treatment	Packaging type	Marketing period after cool storage at 1 °C for 10 days
Control	Commercially available perforated high humidity liner (black)	0, 4 or 7 days @ 12 °C
Irradiation		

Broccoli was stored in perforated high humidity liners (left) and tagged heads (middle) were assessed prior to storage at 1 °C for 10 days and after marketing at 12 °C for up to 7 days (right).

Results

Overall water loss of tagged broccoli was similar among both treatments with untreated heads losing 8.2 % in weight, and irradiated heads losing 7.9 % weight, after short-term storage for 10 days and a marketing period of 4 days (Table 1).

Table 1. Fresh broccoli weight at each stage of storage and marketing assessments for both control and irradiated treatments during.

Storage days at 1 °C	Marketing days at 12 °C	Treatment*	Fresh weight (g) ± SD	Change (%)
0	**0**	**Control**	340.8 ± 70.9	0
		Irradiation	324.0 ± 35.4	0
	4	**Control**	NA	NA
		Irradiation	NA	NA
10	**0**	**Control**	331.4 ± 66.1	2.8
		Irradiation	316.2 ± 36.4	2.4
	4	**Control**	312.9 ± 61.2	8.2
		Irradiation	298.3 ± 36.1	7.9

NA=no assessment; *N=20 heads per treatment

Yellowing in broccoli head colour was more prominent in irradiated produce at both marketing periods after storage for 10 days at 1 °C (Figure 1). A higher b-value indicates greater head yellowing, with the difference between treatments increasing with shelf-life days at 12 °C. Interestingly, all broccoli was showing signs of yellowing by day 7 which suggests fresh produce needs to be sold quickly or offered for sale at ambient temperatures below 12 °C to minimise wastage.

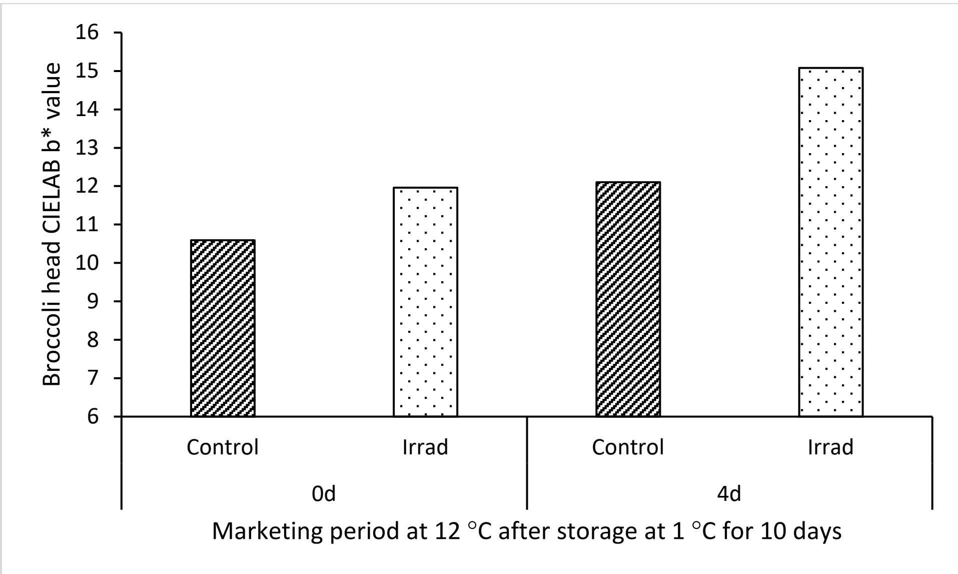


Figure 1. Effect of irradiation treatment and marketing period after 10 days storage at 1 °C on broccoli head b* value that represents the blue–yellow axis of the CIELAB colour space, with higher values indicating greater yellow colour.

Marketable quality describes the limit of acceptable produce specifications such as colour, overall visual appearance, shape, size and maturity of broccoli heads. Fresh broccoli was in very good condition and all heads fully marketable in both treatments directly after short-term storage for 10 days (Fig. 2). Marketable head quality decreased in both treatments after 4 days of shelf-life at 12 °C with 70 % of untreated broccoli and 65 % of irradiated broccoli still marketable (Fig. 2 and 4).

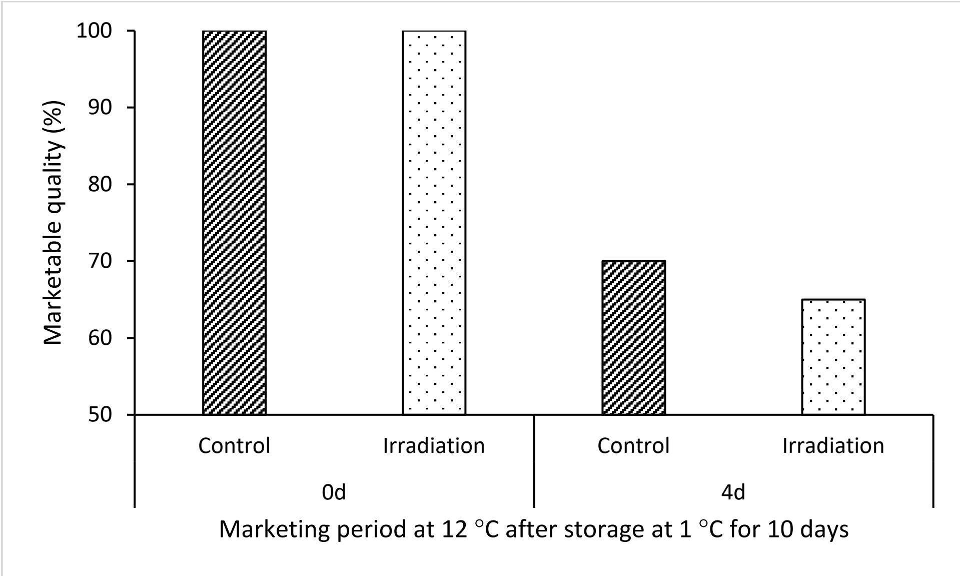


Figure 2. Effect of irradiation treatment and marketing period after 10 days storage at 1 °C on broccoli head b* value that represents the blue–yellow axis of the CIELAB colour space, with higher values indicating greater yellow colour.

The majority of broccoli were unmarketable after 7 days of shelf life at 12 °C mainly due to opening and yellowing of florets, minor water staining and the slight rot development in some broccoli heads, among both treatments and hence the storage and shelf-life trial was ended (Fig. 3). Furthermore, bolting in several florets was more obvious in the irradiated broccoli which suggests higher physiological stress due to irradiation treatment compared to untreated broccoli (Fig. 3). No further quality assessments were conducted beyond 7 days of shelf-life.

Figure 3. Effect of no treatment (left) and irradiation treatment (right) on marketable quality of broccoli heads after 10 days storage at 1 °C and 7 days at 12 °C. Floret bolting as a stress response in irradiated broccoli (white circles).

Control Irradiation

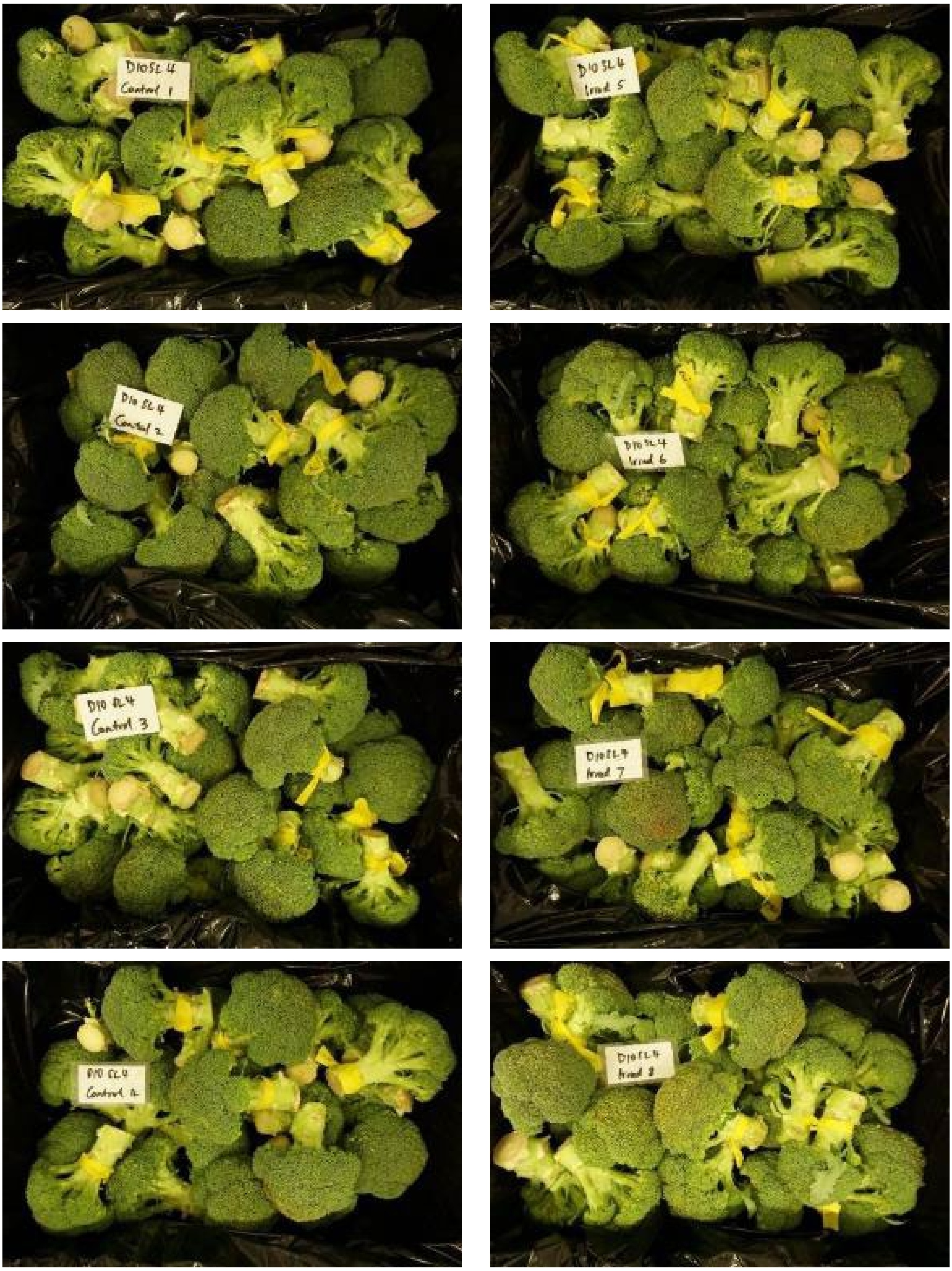


Figure 4. Effect of no treatment (left) and irradiation treatment (right) on visual quality of broccoli heads after 10 days of storage at 1 °C and 4 days at 12 °C.

Appendix E: Persimmon

Two trials were conducted on the effects of irradiation on persimmon fruit quality:

1. **Impact of irradiation treatment and cool storage temperature on persimmon quality (Ag Vic), and**
2. **Response of New Zealand 'Fuyu' persimmon to X-ray treatment (New Zealand Institute for Plant and Food Research)**

Persimmon Trial 1. Impact of irradiation treatment and cool storage temperature on persimmon quality (Ag Vic)

Key findings from persimmon quality assessments

- Due to higher moisture loss fruit stored at 15 ° C had lower mean weight compared to fruit stored at 1 ° C.
- The higher storage temperature of 15 °C increased softening and redness, an indicator of greater ripeness, particularly among irradiated fruit, compared to both irradiated and control fruit stored at 1 °C.
- Storage at 1 °C reduced the rate of ripening in persimmon compared to storage at 15 °C and was found to have a more important impact on ripening than irradiation treatment.

Methods

Two trays of sweet persimmons containing 20 fruit each were delivered by Steritech to Agriculture Victoria (AVR) consisting with one tray of irradiated fruit and the other non-irradiated as the control. Post-treatment ten fruit from each tray were stored for 10 days at either 1 ° C or 15 °C, and >70 % RH (Fig. 1). Fruit quality was assessed on all fruit directly out of storage after warming to a temperature of 18 °C.

Figure 1. Visual quality of persimmons stored for 10 days at 1 °C after irradiation (top left) and after no treatment (bottom left) and stored at 15 °C after irradiation (top right) and after no treatment (bottom right).

Fresh weight was measured to one decimal place using a benchtop scale. Skin colour was measured in four central locations on the fruit surface with a hand-held Nix™ Pro 2 colour sensor (Ontario, Canada) prior to destructive measurements, and the mean value recorded. Figure 2 shows the Hunter Lab colour space and values measured by the Nix™ Pro 2. Fruit flesh firmness was evaluated in four central locations using a Fruit Texture Analyzer (FTA) (Guss Manufacturing Ltd., Strand, SA) fitted with an 8 mm plunger and the mean value recorded after removing a small slice of skin from each location on fruit. Soluble solids concentration (SSC) was evaluated from four central locations and a composite juice sample measured with a pocket PAL-1 refractometer (Atago, Tokyo, Japan).

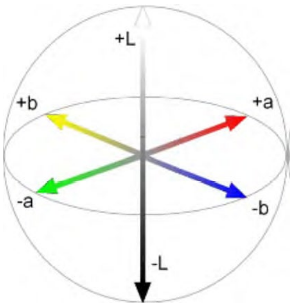


Figure 2. Hunter Lab *L.a.b.* colour space where the L value for each scale indicates the degrees of lightness or darkness, the a* value refers to the red - green colour axis, and the b* value to yellow – blue colour axis. All three values are required to completely describe an objects colour, and among persimmons, required to describe the range of orange to red hues encountered during ripening.

Results

Persimmons stored for 10 days at 1 °C were on average 5 to 7 g heavier than fruit stored 15 °C with similar increases in weight loss among both irradiated and untreated fruit (Fig. 3). It is well understood that higher cool storage temperatures result in greater water loss from fresh produce which explains the observed reduction in mean fruit weight among persimmon fruit.

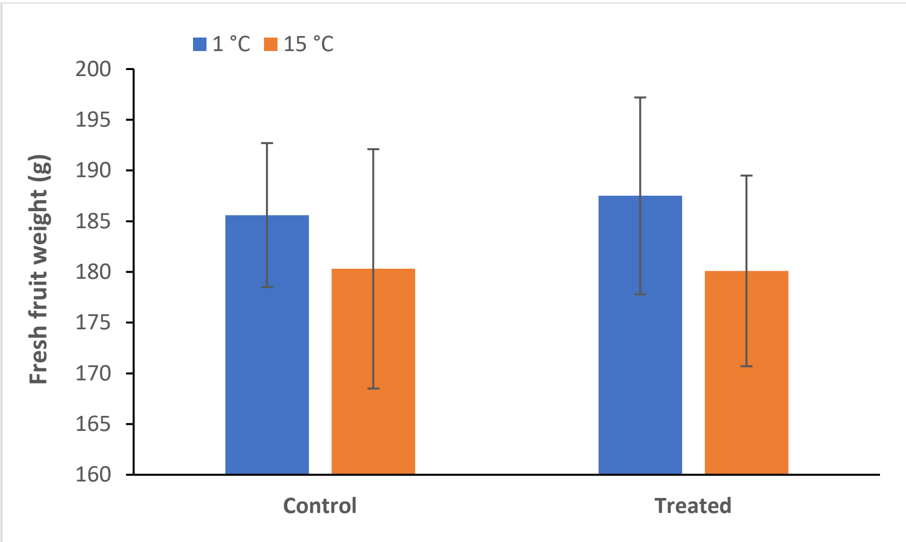


Figure 3. Mean fresh weight of untreated and treated persimmons after storage for 10 days at either 1 °C or 15 °C where each error bar is the standard deviation of the mean.

Flesh of persimmons stored for 10 days at 1 °C were significantly firmer compared to fruit stored at 15 °C among both irradiated and untreated fruit (Fig. 4). Untreated fruit stored at 1 °C were approximately 1 kg/cm^2 firmer than equivalent fruit stored at 15 °C whereas irradiated fruit stored at 1 °C were more than 1.6 kg/cm^2 firmer than fruit stored at 15 °C. Among fruit stored at the same temperature irradiation had a greater effect on the rate of flesh firmness loss at 15 °C than at 1 °C with a reduction in flesh firmness of 0.5 kg/cm^2 observed between control fruit stored at the two temperatures, and of 1.2 kg/cm^2 between irradiated fruit stored at the 15 and 1 °C.

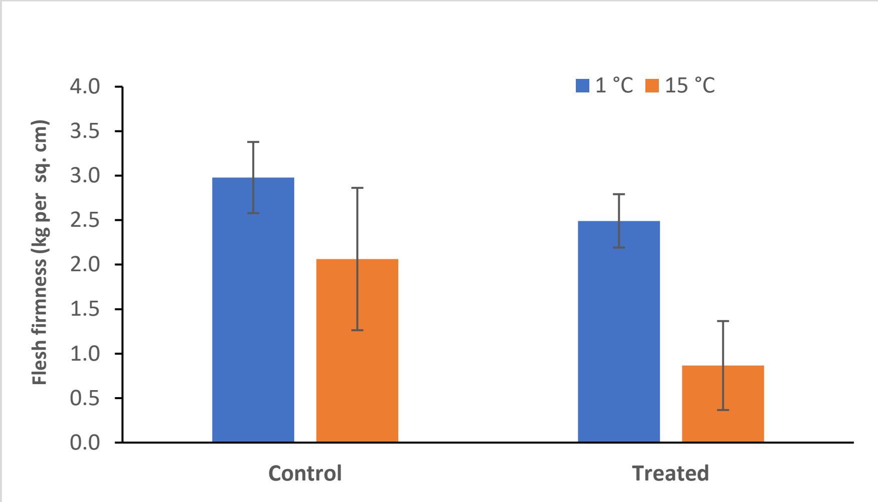


Figure 4. Mean flesh firmness of untreated and treated persimmons after storage for 10 days at either 1 °C or 15 °C where each error bar is the standard deviation of the mean.

Persimmons stored at 15 °C had greater red skin colour compared to when stored at 1 °C within both irradiated and untreated fruit whilst irradiation treatment increased redness of skin colour, associated with higher ripeness, compared to untreated fruit when stored at 15 °C, but with little difference in a* value between irradiated and untreated fruit stored at 1 °C (Fig. 5). This effect suggests that commercially important differences in the rate of skin colour change from orange to red, and associated ripening, between irradiated and untreated fruit are only likely to be observed at higher and sub-optimum storage temperatures.

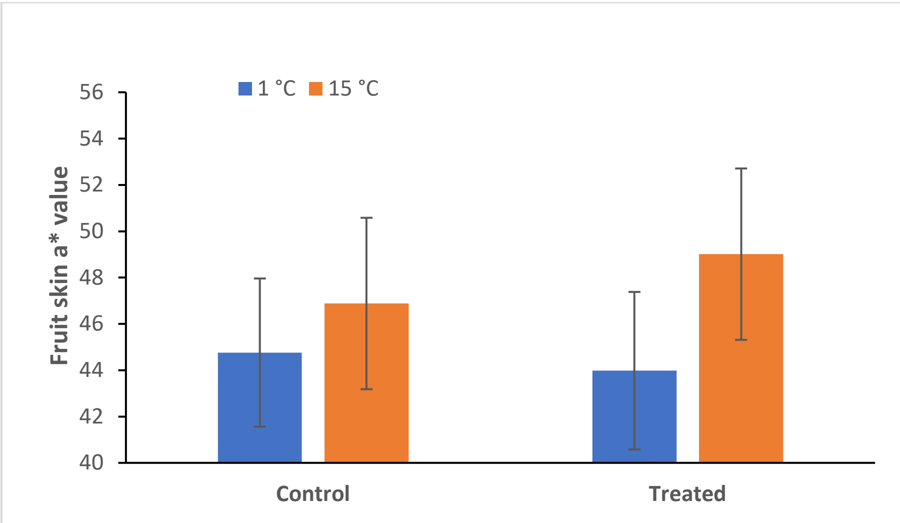


Figure 5. Mean persimmon skin a* value of untreated and treated persimmons after storage for 10 days at either 1 °C or 15 °C where each error bar is the standard deviation of the mean.

Persimmon Trial 2. Response of New Zealand 'Fuyu' persimmon to X-ray treatment (New Zealand Institute for Plant and Food Research)

Jung Cho[1], Terry Rudge[2], Lisa Jamieson[1] and Allan Woolf[1]

[1] The New Zealand Institute for Plant and Food Research Limited, Private Bag 92169, Auckland Mail Centre, Auckland 1142, New Zealand.

[2] Rudge Produce Systems, PO Box 4032, Essendon Fields VIC 3041, Australia

Introduction

Australia has removed the offshore pre-shipment inspection programme (OPI) that enabled New Zealand persimmons to receive a phytosanitary inspection in New Zealand by the Australian Department of Agriculture Fisheries and Forestry inspectors before shipment. Now persimmons are inspected in Australia and a failed phytosanitary inspection requires expensive and undesirable processes to mitigate the intercepted risk, such as methyl bromide treatment, reshipment to an alternative destination, or destruction of fruit.

A potential solution for continued market access to Australia is an alternative remedial treatment should a consignment fail phytosanitary inspection. Australia accepts irradiation as a phytosanitary treatment for persimmons, however, the current regulations only allow irradiation treatment to be carried out before shipment and New Zealand does not have a treatment facility.

Steritech has built a new X-ray irradiation facility in Melbourne and is interested in collaborating to explore the potential for X-ray treatment as an onshore remedial treatment.

Aim

Determine whether New Zealand grown 'Fuyu' persimmons (*Diospyros kaki*) can tolerate a phytosanitary X-ray treatment with an insect phytosanitary dose after arrival in Australia without reducing fruit quality or subsequent storage life.

Materials and methods

Fruit were harvested on 14 May and treated with VAPORMATE™ (16.7% ethyl formate with 83.3% carbon dioxide) to ensure fruit complied with quarantine standards for export to Australia. They were then packed in the standard commercial manner, in to 4 kg trays with a plastic pocket pack and an industry standard MA bag (80 µm LDPE), palletised, and stored at 0°C.

A generic insect treatment dose of ≥400 Gy is accepted by the United States Department of Agriculture – Animal and Plant Health Inspection Service (USDA–APHIS) as a generic treatment for all insects except the pupae and adults of Lepidoptera (USDA–APHIS 2006). However, in a commercial treatment fruit would be exposed to a range of doses higher than the target while all dosimeters reach ≥400 Gy. Depending on the dose uniformity ratio (DUR), the dose that some fruit receive in a 400 Gy treatment may be as high as 800 Gy.

On 14 July (after 8 weeks of storage), one pallet of fruit was treated three times for dose mapping by placing 60 dosimeters across five pallet layers (1 (bottom of pallet), 5, 10, 15 and 22 (top of pallet)) before X-ray treatment. The mean minimum dose received was 603 Gy and maximum was 970 Gy, with calculated DURs of each run of 1.52, 1.53 and 1.74. After the first X-ray treatment, trays of fruit were removed (single-dose treatment) and replaced with trays from a second half-pallet that was provided for the trial. The minimum and maximum dose of the fruit used for assessments were 613 and 929 Gy.

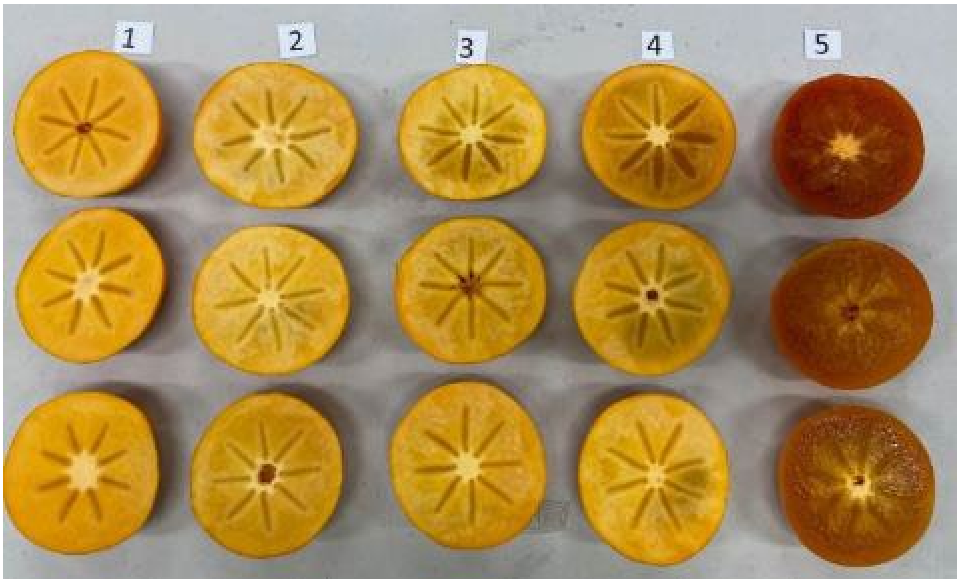
Following treatment, fruit were stored for a further 3, 7 and 14 days at 1-3°C to simulate various supply chain scenarios. Trays of fruit were then removed from the coolstore, MA bags removed, external quality assessed 1 day after treatment, and external and internal quality assessed after 3 days at 20°C.

Unfortunately, fruit from the second half-pallet was later discovered to be from a different grower. This resulted in the single dose treated trays being of a different grower (G1/X-ray) to the control (G2/UTC; Untreated Control), limiting the analysis. Trays of fruit from the second grower, which were X-ray treated twice as part of the dose-mapping, were also included in the analysis to compare fruit quality responses to X-ray from the two growers.

Fruit firmness was measured using a Bareiss densimeter and the presence or absence of stem-end breakdown was determined. External skin blemishes were rated on a 0 to 3 scale, while chilling injury (internal gelling) was rated on a 1 (none) to 5 scale (Figure 1).

External blemish at calyx/distal end

Stem-end breakdown



Chilling injury/gelling rating scale

Figure 1. External and internal disorders observed in the control and X-ray treated New Zealand ‘Fuyu’ persimmons exported to Australia.

Results and discussion

The key factor that limits storage life of persimmons is chilling injury (flesh gelling). The chilling injury rating scale used in this experiment is shown in Figure 1. The levels of unacceptable flesh gelling (ratings of 3–5; Figure 2) showed no obvious consistent treatment effects following 3 (20/07), 7 (24/07) and 14 days (31/07) storage after treatment. This included a double dose of X-ray treatment (2X-ray), which was only included to determine grower differences. Increased gelling with longer time is indicated (all three treatments over 50% by day 14). This result is similar to that found in ‘Jiro’ persimmons (Golding et al. 2020).

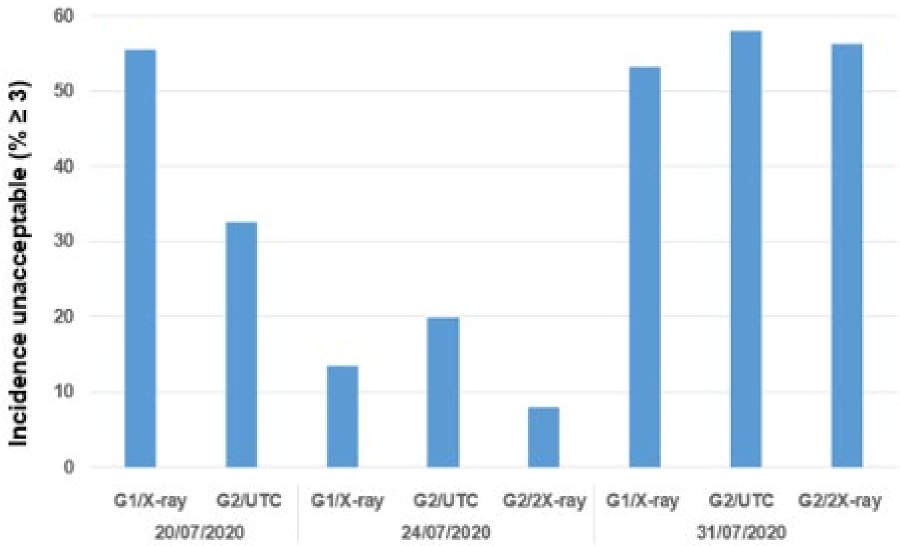


Figure 2. Proportion of unacceptable internal chilling injury – flesh gelling (rating of 3–5) in New Zealand 'Fuyu' persimmons 3 (20/7), 7 (24/7) and 14 days (31/7) after X-ray treatment. G1 and G2 = Growers 1 and 2, UTC = untreated control, X-ray = one dose of X-ray, and 2X-ray = double X-ray treatment.

Fruit firmness showed no significant treatment effect and minor reduction over storage and shelf-life times (Figure 3).

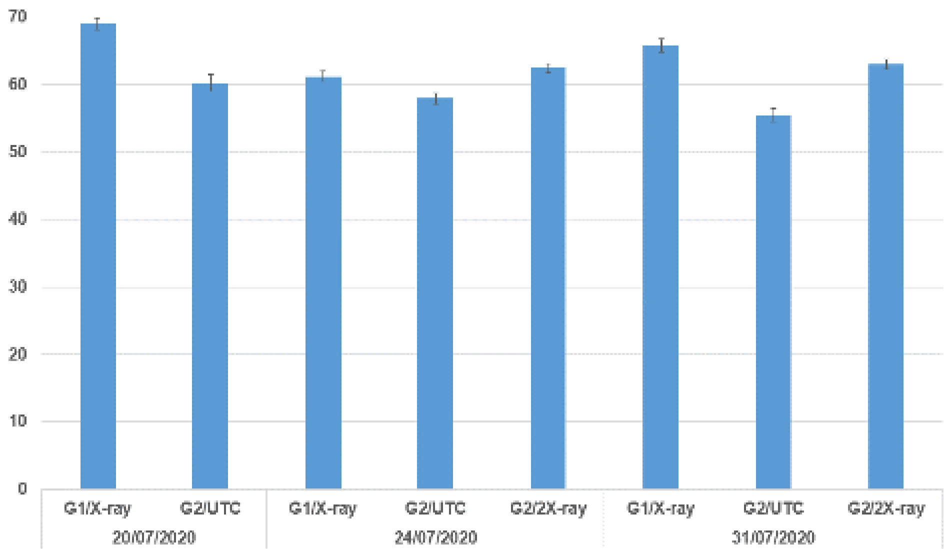


Figure 3. Fruit firmness after 3 days of shelf life for New Zealand 'Fuyu' persimmons 3 (20/7), 7 (24/7) and 14 days (31/7) after X-ray treatment. G1 and G2 = Growers 1 and 2, UTC = untreated control, X-ray = one dose of X-ray, and 2X-ray = double X-ray treatment.

Two external damage symptoms were observed – stem-end breakdown, and external blemish, though neither showed any consistency with treatment or grower effects (data not shown). While the former resembled freezing or high CO_2 damage, the storage conditions should not result in either of these effects. Work in New Zealand examining ethyl formate treatments with a range of CO_2 concentrations up to 18% showed no damage (Woolf, unpublished). It is unlikely that freezing damage occurred during transit from Sydney to Melbourne or in Steritech coolstore.

Conclusion

Although some external disorders were observed following X-ray treatment, these were not related to X-ray dose, and flesh gelling and softening was not affected by X-ray dose nor a double X-ray treatment. While this gives reasonable confidence in the tolerance of 'Fuyu' persimmons to X-ray treatments applied after storage, it is important to repeat this work with fruit from a range of growers, regions, times in the season and for different storage durations.

Acknowledgements

Ian Turk from Persimmon Industry Council, First Fresh NZ Ltd, and Steritech staff.

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Golding J.B., Pristijono P. and Wang B. (2020) Effect of Phytosanitary Irradiation Treatment on the Storage Life of 'Jiro' Persimmons at 15 °C. Horticulturae 6(4):92. DOI: 10.3390/horticulturae6040092

Appendix F: Plum

Impact of irradiation treatment, cool storage duration and marketing on plum quality

Key findings from plum quality assessments

- Little difference in fruit maturity, flesh firmness or soluble solids concentrations (SSC) was observed between irradiated and untreated plums during cool storage or after ripening.
- Irradiated plums were slightly softer, had lower flesh juice, and inconsistent texture beyond six weeks of cool storage.
- Plum SSC increased marginally during cool storage and ripening with a corresponding reduction in sourness judged via tasting over fruit.

Introduction

In February 2022 phytosanitary irradiation was approved as a market access protocol for Victorian grown peaches and nectarines exported to Vietnam. Plums were not included in the initial application so in a meeting with Summerfruit Australia in January 2023 it was agreed that Agriculture Victoria would collect initial data on the effect of irradiation on plum quality during cool storage. In February 2023 Agriculture Victoria Research (AVR) sourced a mid-season plum from a commercial grower in Swan Hill for an irradiation and cool storage experiment utilising cold room facilities at Agribio centre in Melbourne.

Methods

Twelve cartons of a mid-season plum cultivar packed in Poly Wrap modified atmosphere (MA) liners were sourced from a commercial grower in Swan Hill and transported to Agribio in Melbourne in and stored at 2 °C for 3 days (Fig. 1). After an initial quality assessment where 20 fruits in each carton were numbered, all cartons were transported to Steritech, six cartons were irradiated whilst the other untreated six cartons remained were placed in cool storage. Post-treatment, all cartons were returned to the 2 ° C cool room at Agribio and stored for up to 7 weeks. Fruit weight and quality assessments were conducted on 1 to 2 cartons (i.e., 20 to 40 fruit) after 1, 5, 6 and 7 weeks and after 3 days ripening at 18 °C, subsequent to removal from cool storage. Oxygen (O_2) and carbon dioxide (CO_2) concentrations within sealer MA liners were measured weekly with a PBI Checkpoint Dansensor.

Figure 1. Twelve cartons of mid-season plum sourced from a commercial grower and transported to Agribio (left) prior to conducting an initial quality assessment (middle), measurement of liner atmospheres (right), and tagging cartons for irradiation treatment (pink ribbon).

Results

There was effective reduction in O_2 and increase in CO_2 concentrations within MA liners in both irradiated and untreated cartons (Fig. 2). Oxygen concentration decreased to between 9 and 13 % in untreated fruit, and to between 9 and 15 % among irradiated fruit. Carbon dioxide concentrations increased up to 4 to 5 % in both treatments over seven weeks of storage at 2 ° C which suggests all fruit were responding similarly to atmosphere modification, and that irradiated fruit were not overly stressed due to treatment, which would have been indicated by higher CO_2 and lower O_2 concentrations.

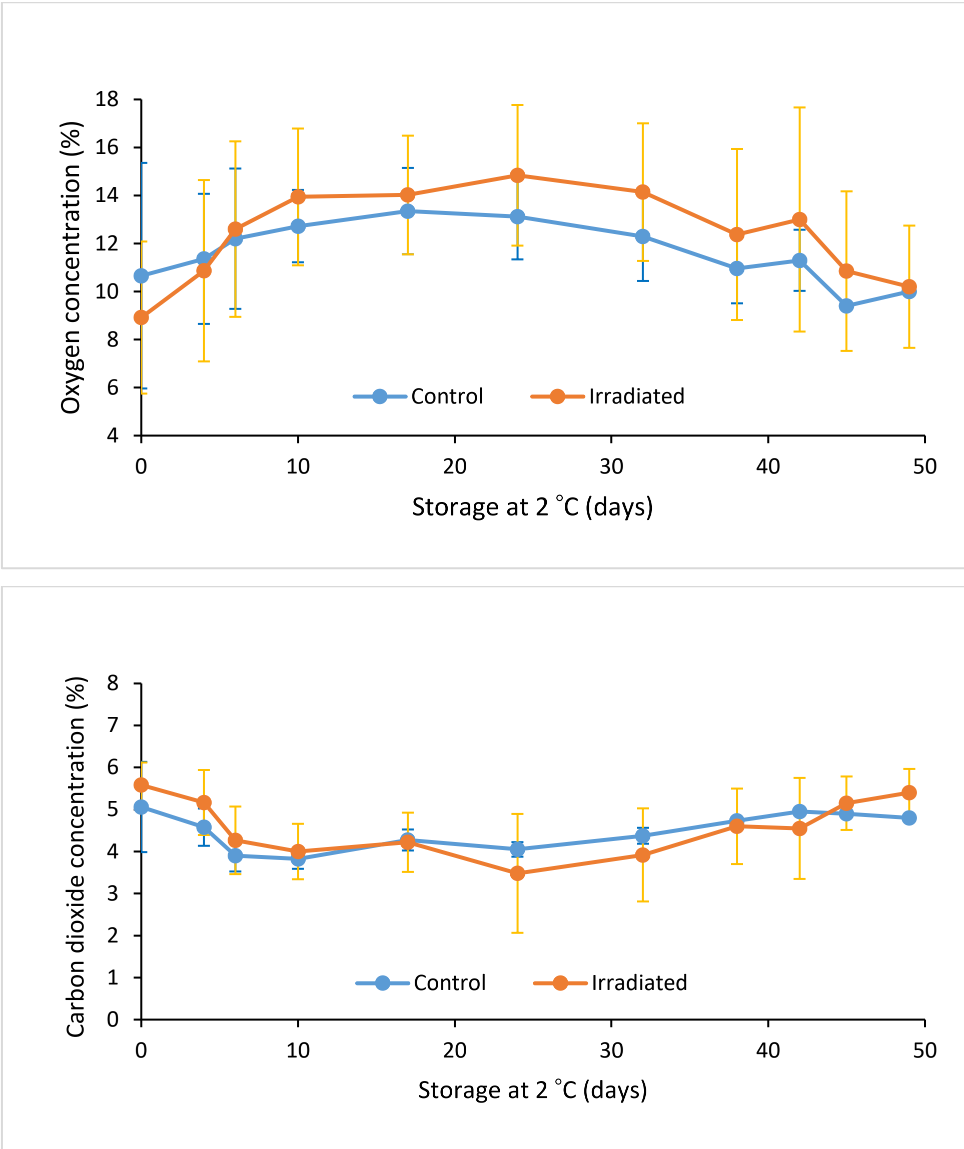

Figure 2. Mean oxygen (O_2) (top) and carbon dioxide (CO_2) concentrations (bottom) in irradiated and untreated fruit during 7 weeks of storage at 2 ° C; error bar is the standard deviation of each mean.

Both treatments contained fruit of similar size with a mean weight of between 51 and 57 g with relatively low water loss during cool storage and subsequent ripening for 3 days at 18 ° C among individual tagged fruit within both treatments (Fig. 3). Weight loss was consistent among removals and the ripening period which suggests that irradiation had minimal impact on fruit weight loss relative to untreated fruit.

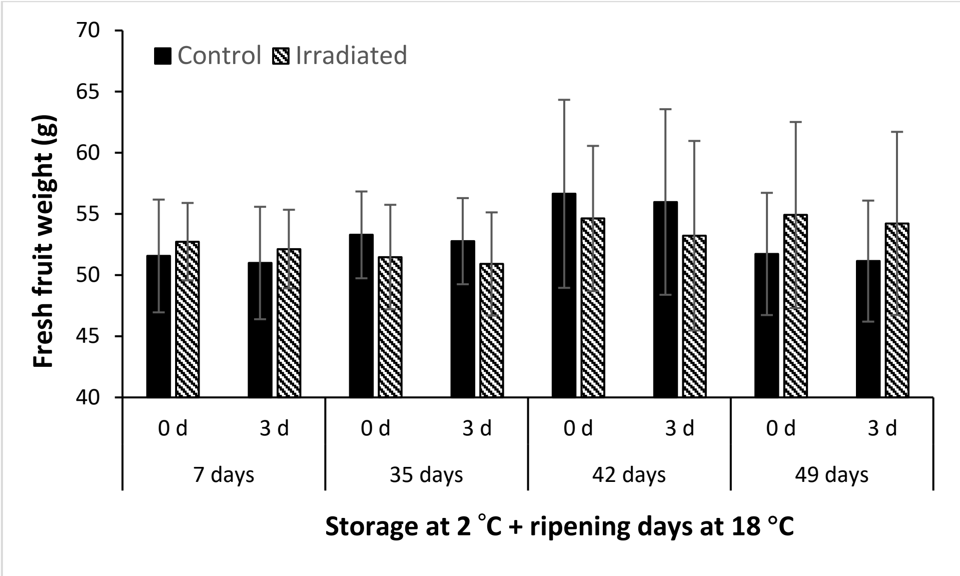

Figure 3. Change in fruit weight from the beginning of cool storage until removal for a mid-season plum stored for 7 weeks at 2 ° C followed by 3 days of ripening at 18 ° C; error bar is the standard deviation of each mean.

A DA meter (Turoni, Italy) was used to measure I_{AD} index, an indicator of physiological maturity in plums that correlates relatively well with fruit ethylene production. Little difference in I_{AD} value was observed between treatments at each removal and ripening period (Figure 4). Lower values were found more so in fruit that had been stored for at least five weeks and then ripened however similar trends were observed among both treatments.

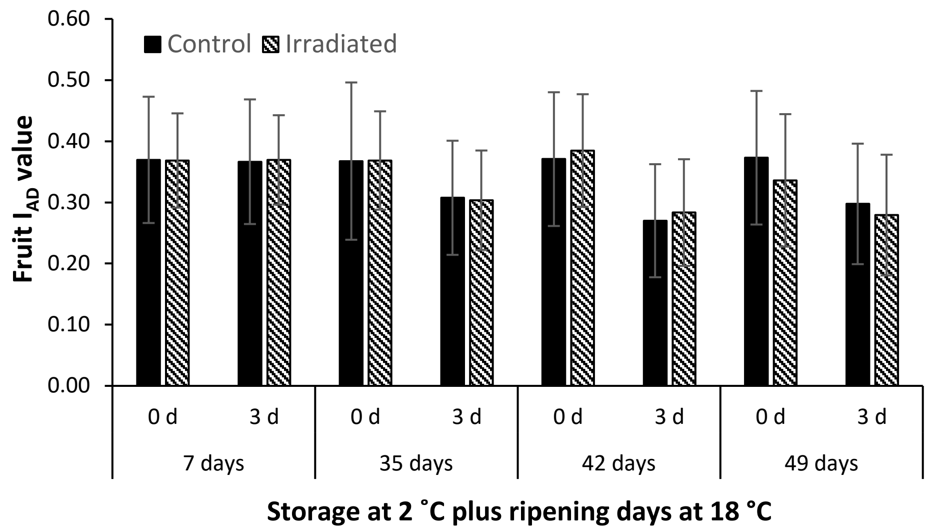

Figure 4. Change in fruit maturity (I_{AD}) for a mid-season plum stored for 7 weeks at 2 ° C followed by 3 days of ripening at 18 ° C; error bar is the standard deviation of each mean.

Fruit firmness as measured non-destructively with an Agrosta®100 USB was similar at all removals among both treatments however fruit softened more rapidly at all ripening periods after 5 weeks of storage indicating that fruit would need to be sold rapidly during marketing (Fig. 5). Little difference in non-destructive fruit firmness was found between the two treatments after 7 days of storage and a ripening period, a storage duration likely to simulate air freight conditions to Vietnam.

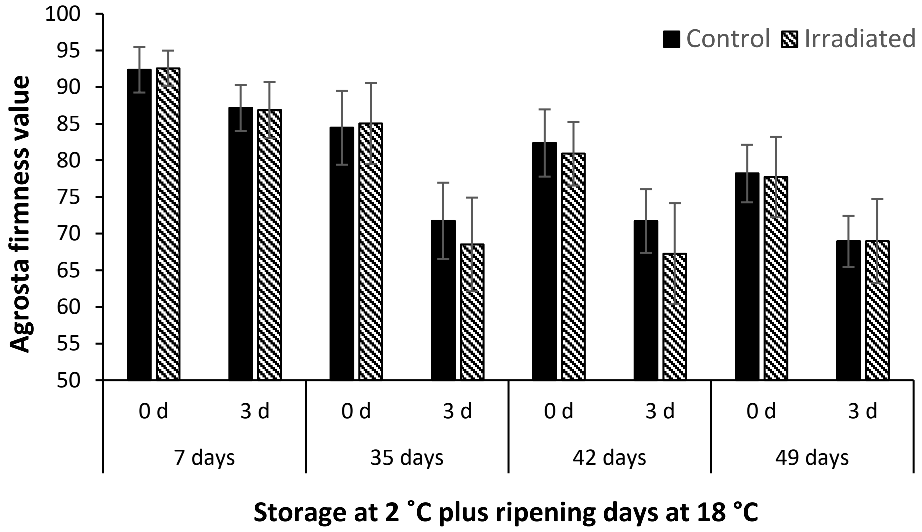

Figure 5. Change in Agrosta fruit firmness for a mid-season plum stored for 7 weeks at 2 ° C followed by 3 days of ripening at 18 ° C; error bar is the standard deviation of each mean.

A fruit texture analyser (FTA) with an effegi penetrometer was used to destructively measure fruit flesh firmness. Flesh firmness was slightly higher in irradiated fruit than control fruit after short-term storage of one week, however this trend was reversed during longer-term storage of 5 to 7 weeks, and ripening (Fig. 6). Plums among both treatments had similar flesh firmness after long term storage and ripening although irradiated fruit were consistently softer than control fruit after ripening by approximately 0.5 kg/cm^2.

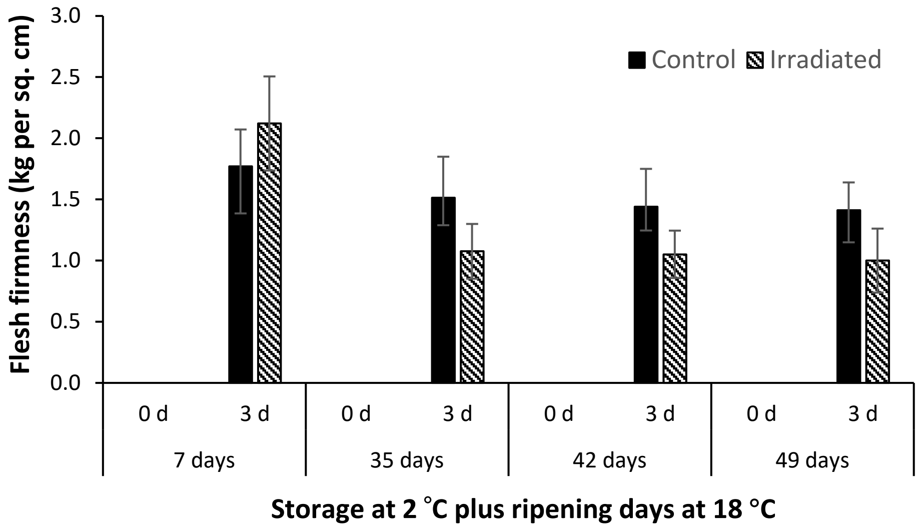

Figure 6. Change in fruit firmness (FTA) for a mid-season plum stored for 7 weeks at 2 ° C followed by 3 days ripening at 18 ° C; error bar is the standard deviation of each mean.

As with other fruit quality parameters there was little difference in soluble solids concentration (SSC) after each removal and ripening period which suggests that irradiation had a minimal effect on sweetness of irradiated fruit compared untreated plums (Fig. 7). Interestingly the eating quality of plums changed by the end of the storage period even though the SSC remained relatively constant at approximately 14 ° Brix. Tasting of fruit suggest that flesh acid concentrations must have substantially decreased among both treatments as all plums were less sour after long-term storage.

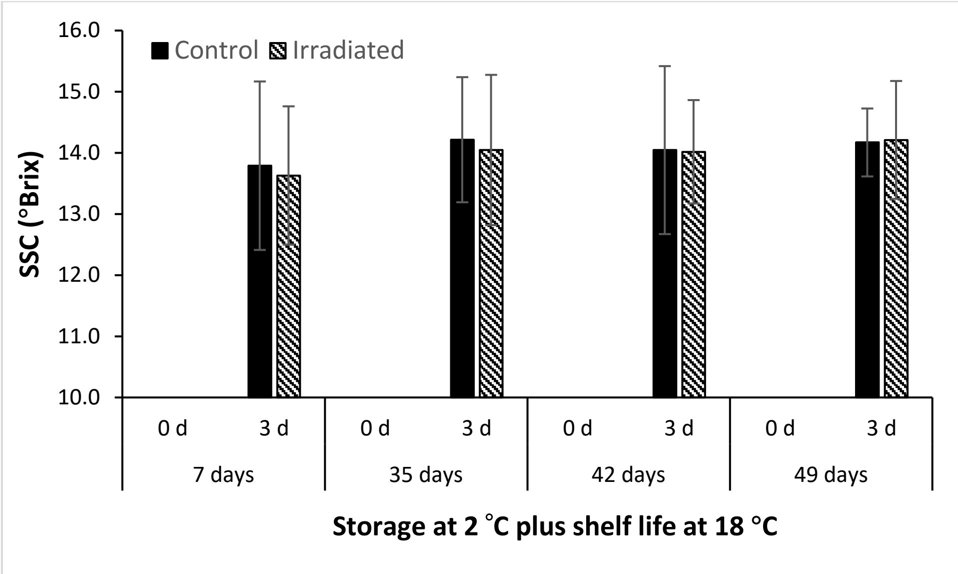

Figure 7. Change in soluble solids concentration (SSC) for a mid-season plum stored for 7 weeks at 2 ° C followed by 3 days of ripening at 18 ° C; error bar is the standard deviation of each mean.

Appendix G: Asparagus

Two storage trials were conducted to examine the effects of phytosanitary irradiation on asparagus in commercial export supply chains.

Asparagus Trial 1

Key findings

- No effect of irradiation or liner packaging on asparagus quality compared to asparagus in open cartons after one week of cool storage simulating air freight export conditions.
- Irradiated asparagus packed in relative humidity (RH) liners had higher marketability after 14 and 21 days of cool storage compared to spears packed in either RH liner without irradiation, or in an open crates whether irradiated or untreated.
- Under current commercial postharvest handling and packaging conditions, a storage duration of up to 21 days at 1 °C as required for sea freight export is possible for Victorian-grown asparagus.

Introduction

An asparagus irradiation and cool storage experiment was conducted in collaboration with a major Victorian exporter, to gather preliminary data on the impact if irradiation disinfestation treatment on spear market quality during simulated sea freight export and marketing. Irradiation may be an effective and efficient disinfestation procedure that could supersede methyl bromide fumigation in both domestic and some export markets in the future as well as helping to reduce quality loss due to fungal rot development. The main objectives of this study were to:

- Understand the effect of irradiation treatment on asparagus market quality during simulated air and sea freight and marketing.
- Determine the storage life of Victorian grown mid-season asparagus handled under current commercial postharvest practices.
- Determine if relative humidity micro-perforated liners are a viable technology to extend asparagus storage life for sea freight export compared to current open-air crates.

Methods

Packaging treatments used in the asparagus sea freight simulation and marketing experiment;
Open crate in air - control (left) and Lifespan® micro-perforated relative humidity liner (right).

Results and discussion

Scoring of asparagus market quality (MQ) was based on a combination of quality factors that reduce overall spear appearance (i.e., visual quality), and thus their commercial marketability, and included spear shrivel, yellowing, and rot development. Spears with a MQ score below 2 would be unmarketable at retail level based on the scoring scale used in this experiment.

Longer storage at 1 °C reduced MQ of spears among all packaging treatments with little difference in marketability after 7 days of cool storage (Fig. 1). After 14 days of cool storage, significantly higher MQ was observed in irradiated RH treatments compared to air-stored spears, whereas MQ was very similar between irradiated-Air asparagus and non-irradiated asparagus in RH. Similar differences between packaging treatments were observed after 21 days of cool storage although spear MQ score for Ir-RH was only significantly greater than the Ir-Air treatment and marginally higher than both non-irradiated asparagus in Air and RH treatments. After 28 days of cool storage, there was no difference in spear MQ between all four treatments and were at the limit of marketability (Fig. 1). After 28 days of cool storage, irradiated and non-irradiated spears in high humidity liners did not significantly improve MQ compared to air-stored asparagus.

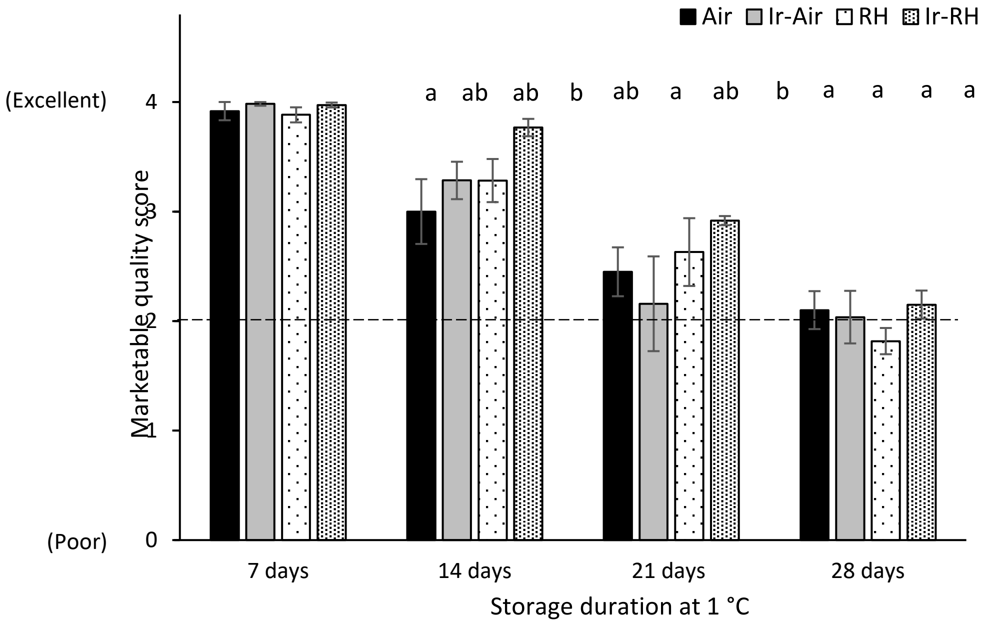

Figure 1. Effect of package type, treatment, and storage duration at 1 °C, on asparagus marketable quality score (where 0=poor and 4=excellent). Dashed line is the score at the limit of marketability, error bars show ± standard error of each mean, and different letters within a storage duration indicates significant differences between packaging treatments at $P < 0.05$.

Asparagus Trial 2

Key findings

- Asparagus spear weight and length decreased consistently throughout the storage and marketing period.
- Spear tip feathering increased during storage but more-so during marketing due to elevated temperatures.
- Spear tip feathering and shrivel was only an issue after 3 weeks storage and marketing.
- Spears remained relatively green with slight yellowing occurring over time.
- Storage of asparagus in air limited to 2 to 3 weeks at 2 °C plus a short marketing period at low temperatures.

Methods

Nine crates of fresh asparagus (5 kg) were sourced from a commercial grower in SE Melbourne on 6 December 2022 and transported back to Agribio and stored overnight at 1 °C. The spears (N=10 per crate) were tagged with coloured rubber bands, initial quality assessed, and irradiation disinfestation treatment conducted on 8 December 2022. Asparagus spear quality was assessed weekly up to 21 days at 2 °C and marketing at 18 °C for 0 and 4 days.

Disinfestation treatment	Package type	Marketing period after cool storage at 2 °C for up to 21 days
Irradiation	Open 5 kg crate in air	0 or 4 days @ 18 °C

Packaging treatment (open crate in air) used in the asparagus air and sea freight simulation and marketing experiment.

Quality assessments were conducted weekly over 3 weeks storage on 16/12/22, 23/12/22 and 30/12/22 (weeks 1, 2 and 3) at 2 °C followed by a marketing phase of 0 and 4 days at 18 °C.

16/12/22 - W1D0

20/12/22 - W1D4

23/12/22 - W2D0

27/12/22 - W2D4

30/12/22 - W3D0

3/1/23 - W3D4

Results

The aim of the second asparagus irradiation trial was to observe quality changes in spears over a three-week storage period that would represent air freight (e.g., 1 week) and sea freight (e.g., 2 to 3 weeks) conditions utilizing current packaging methods consisting of a waxed corrugated crate with 5 kg of asparagus spears standing upright in air. Three crates of asparagus were assessed weekly over a 21-day storage period and within each crate, ten asparagus spears were assessed after a marketing period of 0 and 4 days at 18 °C.

Asparagus continues to develop after harvest hence low post-harvest temperatures are important to reduce changes in asparagus spear quality. The average spear weight and length varied between individual crates and consistently decreased after storage at each of the three marketing periods. Fresh weight of spears decreased at each assessment period on average between 1.4 and 1.6 g after 4 days marketing at 18 °C (Fig. 1). Similarly, asparagus spears decreased consistently by 4 mm during each of the four-day marketing periods (Fig. 2).

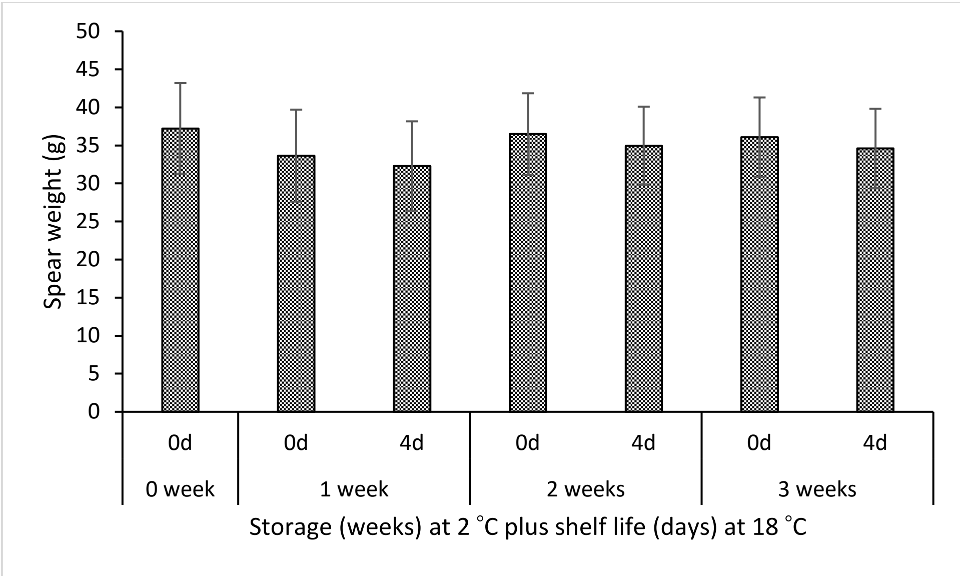

Figure 1. Change in asparagus spear weight during three weeks storage at 2 °C and 4 days marketing at 18 °C. Error bars show ± standard error of each mean.

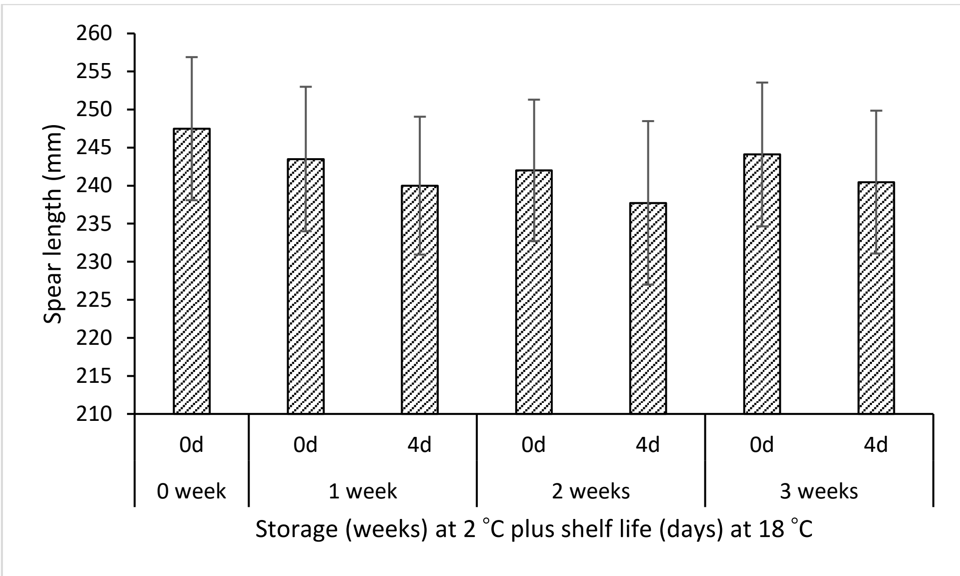

Figure 2. Change in asparagus spear length during three weeks storage at 2 °C and 4 days marketing at 18 °C. Error bars show ± standard error of each mean.

Feathering or expansion and opening of spear tips increased not only after each storage period but also during the marketing phase at higher temperatures (Fig. 3). Spear tip-feathering remained at acceptable levels (Rating score ≤2) up until the marketing period after 3 weeks storage at 2 °C. After 4 days marketing, spear tips opened which resulted in poor visual appearance and is a strong indicator of senescence (plant flowering).

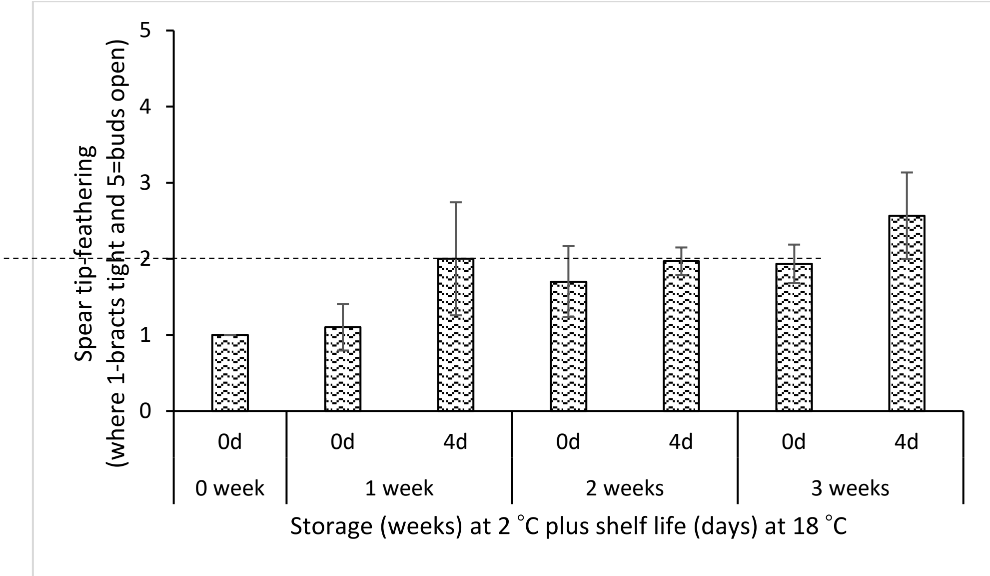

Figure 3. Change in asparagus spear tip-feathering during three weeks storage at 2 °C and 4 days marketing at 18 °C. Dashed line is the score at the limit of acceptability, error bars show ± standard error of each mean.

Similar to spear tip-feathering, shrivel or wilting in the lower to mid stem of spears remained low for most of the trial (Figure 4). Shrivel is a natural response to dehydration or moisture loss and only became an issue (score = 2 which corresponds to slight wrinkle on the stem) during the marketing phase after three weeks storage at 2 °C (Fig. 4).

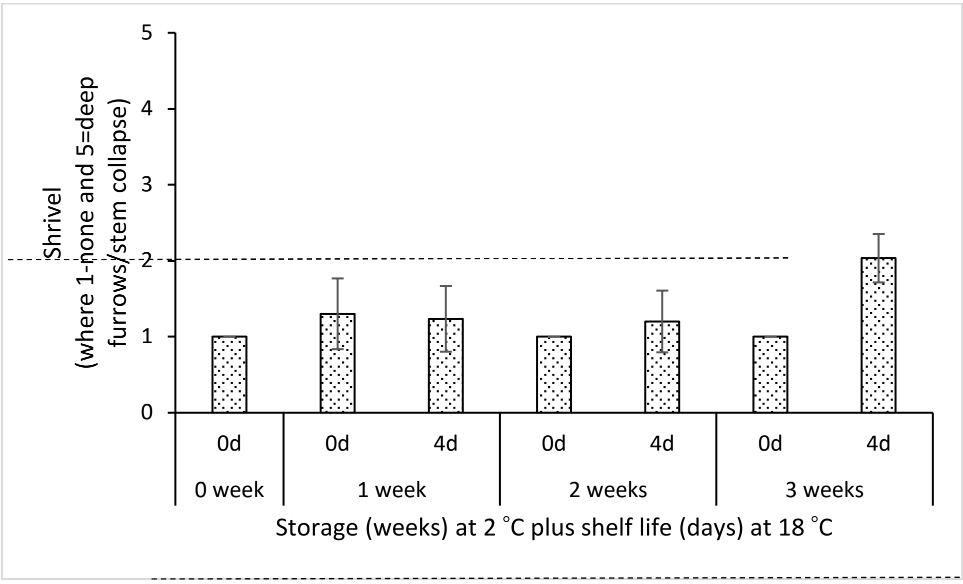

Figure 4. Change in asparagus shrivel score during three weeks storage at 2 °C and 4 days marketing at 18 °C. Dashed line is the score at the limit of acceptability, error bars show ± standard error of each mean.

Colour is one of the most important characteristics used in postharvest quality assessments of vegetables. The b* value which is an indication of spear yellowing increased throughout the storage trial from an initial reading of 31.5 to 35.5 after three weeks storage at 2 °C (Fig. 5). Generally, the b* value increased during the marketing period, especially after two to three weeks storage which is a sign of slight degradation in quality.

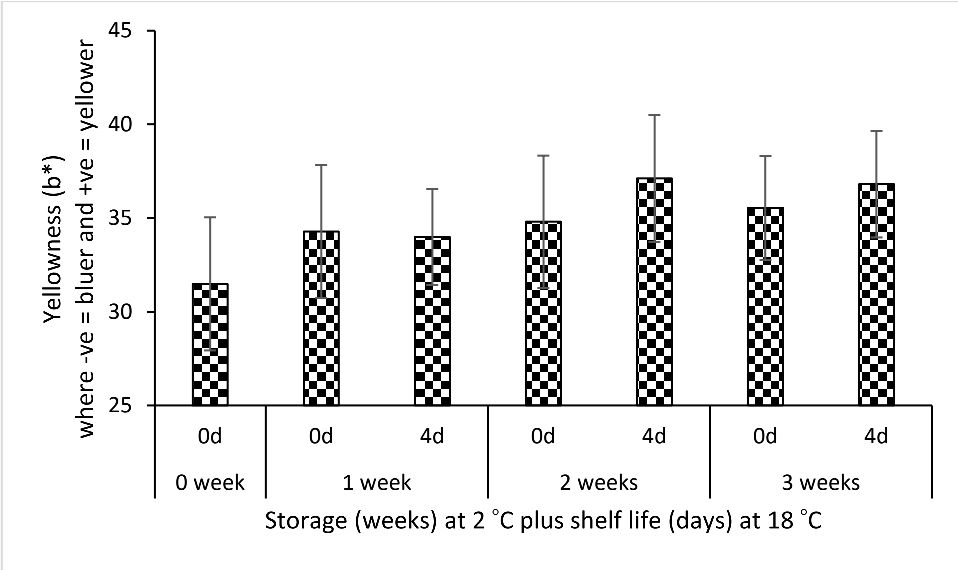

Figure 5. Change in asparagus colour (yellowing) during three weeks storage at 2 °C and 4 days marketing at 18 °C. Error bars show ± standard error of each mean.

Marketable quality of asparagus spears remained high at 100% throughout the storage trial when stored at 2 °C (Fig. 6). Overall quality decreased to 57% and 83% during the marketing phase after one and two weeks, respectively. All asparagus were unmarketable after three weeks storage and 4 days marketing due to a combination of factors such as shrivel, slight yellowing, development of stem lesions but mainly tip feathering and calcification or cell drying on the cut surface of the base.

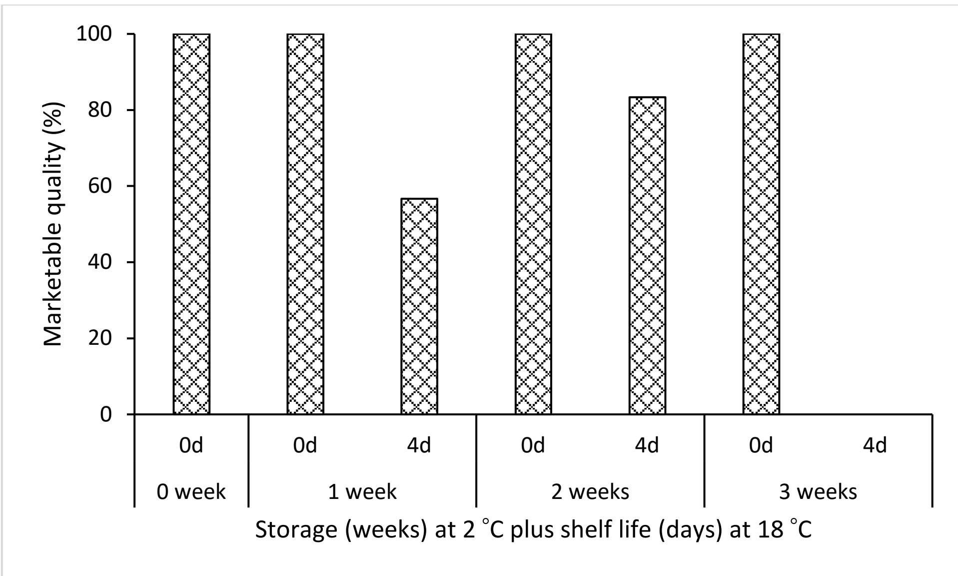

Figure 6. Change in asparagus marketable quality during three weeks storage at 2 °C and 4 days marketing at 18 °C. Error bars show ± standard error of each mean.

Appendix H: Nectarine out-turns

Impact of irradiation treatment on Australian nectarine quality retailed in Vietnam

Key findings

- Plastic clamshell packaging did not identify the nectarine cultivars.
- Irradiation appeared to have little negative impact of nectarine quality at retail.
- Nectarines were large, visually appealing, and fully coloured.
- Nectarines were very ripe (ie., very high maturity) and so would need to be consumed immediately after purchase.
- Fruit had good eating quality with soft flesh, juicy and of acceptable sweetness.
- Fresh Australian peaches were not stocked by retail outlets or markets.

Background

Agriculture Victoria (AVR) staff travelled to Ho Chi Minh city, Vietnam in January 2023 to inspect irradiated stone fruit imported from Australia and marketed at retail outlets. A small sample of irradiated nectarines were purchased from two major retailers and fruit quality assessed.

Results

AVR staff purchased a small sample of irradiated nectarines for approximately A$2.50 each from two major retail outlets in Vietnam (Fig. 1 and 2). Interestingly eMart were conducting in-store promotions of Australian grown nectarines however brand ambassadors possessed little information on the origins of the fruit, cultivar, date of harvest or export supply chain duration. Fresh produce was re-packed by retailers into plastic clamshells containing between 4 and 6 fruit and sold in open refrigerated shelves within the fresh produce section of the store.

Quality assessments were conducted on each fruit within a clamshell container at each retail outlet. Fresh weight of nectarines varied between 130 g and 150 g (data not shown), with all fruit of high physiological maturity as measured via index of absorbance difference (I_{AD}) using a DA meter, with mean I_{AD} values of 0.08 and 0.09, in nectarines purchased from EMart and Co-Op Mart, respectively (Table 1). Mean fruit flesh firmness of 0.7 and 1.2 kg/cm^2 respectively indicated that fruit was at ripe eating quality resulting in customers needing to consume the fruit immediately after purchase, with little shelf life remaining among all nectarines assessed. Fruits were of expected and acceptable sweetness for an early-to-mid season cultivar with mean soluble solids concentration (SSC) of 11.6 °Brix measured in fruit from the eMART retailer, and 11.4 °Brix, and higher variability in sweetness, among fruit purchased from Co-op Mart. In general, all nectarines assessed were very-to-over ripe and had soft flesh which is unlikely to appeal to local consumers who prefer to eat crunchy and firm nectarines. No peaches were being sold in the fresh fruit market or at the retail level whilst AVR staff were visiting Vietnam in mid-January 2023.

Table 1. Mean I_{AD} value, flesh firmness and soluble solids concentration (SSC) among irradiated Australian nectarines at two Vietnamese retailers; SD = standard deviation of each mean.

		Mean fruit quality ± SD		
Retail outlet	**Fruit sample size**	**I_{AD} value**	**Flesh firmness (kg/cm^2)**	**SSC (°Brix)**
eMart	6	0.08 ± 0.03	0.7 ± 0.1	11.6 ± 0.7
Co-Op Mart	4	0.09 ± 0.02	1.2 ± 0.1	11.4 ± 1.2

Figure 1. Retail packaging and in-store promotion of Australian nectarines at eMart supermarket in Vietnam in January 2023.

Figure 2. Retail packaging of Australian nectarines at Co-Op Mart supermarket in Vietnam in January 2023.

Appendix I: Cherry out-turns

Impact of irradiation treatment on Australian cherry quality retailed in Vietnam

Key findings

- Cherries purchased from different points in the supply chain were highly variable in quality.
- Cherries grown in Victoria were generally firmer, sweeter, and had higher eating quality than NZ cherries.
- Cherry stems became brown very rapidly out of cold storage during shelf-life assessment.

Introduction

Agriculture Victoria Research (AVR) staff travelled to Ho Chi Minh city, Vietnam in January 2023 to inspect irradiated cherries exported from Australia. Two Victorian exporters were consulted, and their produce sourced directly from one importer, and the other purchased from a retailer, with fruit quality assessed at pick up or purchase, and after a shelf life of up to 4 days at 20 °C. Fresh cherries were also purchased from other retail outlets and local markets to compare quality of irradiated cherries grown in Victoria to untreated cherries exported from Tasmania and New Zealand (NZ).

Results

Figure 1. Cherries purchased from Ben Thanh market in Ho Chi Minh city, Vietnam in January 2023.

Figure 2. Cherries purchased from an importer in Ho Chi Minh city, Vietnam in January 2023.

Figure 3. Cherries purchased from Grove Fresh supermarket in Ho Chi Minh city, Vietnam in January 2023.

Figure 4. Cherries purchased form US Mart supermarket in Ho Chi Minh city, Vietnam in January 2023.

Twelve batches of cherries were sourced from 11 different retail outlets in Ho Chi Minh city, Vietnam including two consignments from Victorian exporters. The results for four quality assessments (Fig. 1 to 4 and Table 1), and a single shelf-life trial (Fig. 5) are included in this report. Overall, the appearance, price, packaging type and fruit quality in terms of fresh weight, size, colour, and maturity was highly variable between sources (i.e., retail outlets, markets, importer) and state or country of origin (i.e., Victoria, Tasmania, Chile, or New Zealand). Irradiated fruit from Victoria was significantly firmer, sweeter by >3 °brix, and of higher eating quality than cherries from NZ. Unlike in previous years stems were less green on cherries purchased from Ben Thanh market, even though produce was stored on-site in a refrigerator.

A 4-day shelf-life trial conducted on one batch of irradiated cherries from the Yarra Valley in Victoria showed a similar loss of fruit weight each day. Over the full 4-days of shelf-life cherries lost 5 % fresh weight, and 6 % in flesh firmness, whereas maturity based on I_{AD} (Index of absorbance difference) measured with a DA meter increased by 10 %. Cherry stems browned very quickly during daily shelf-life assessments which highlights the importance of storing cherries at close to optimum temperature and never above 4 °C.

Whilst in Vietnam, Agriculture Victoria (AV) staff visited the fruit and vegetable wholesale market and observed only one stand selling fresh cherries. AV also collaborated with Jenny Margetts (P2P Business Solutions) who was conducting a similar audit on cherry quality for Cherry Growers Australia with selected data being shared between AV and P2P.

Table 1. Retail information and quality assessment of cherries purchased from four different sources in Ho Chi Minh city, Vietnam in January 2023.

Date	11/01/2023	12/01/2023	13/01/2023	16/01/2023
Store	Stall	Bato AuSales	Grove Fresh	US Mart
Type	Market	Importer	Retail	Retail
District	Ben Thanh	Phu Nhuan	Thi Minh Khai	Co Giang
City	Ho Chi Minh	Ho Chi Minh	Ho Chi Minh	Ho Chi Minh
Origin	Victoria	Victoria	NZ	Victoria
Area	Yarra Valley	Yarra Valley	45 South	Central VIC.
Pack	Clamshell/loose	Carton	Carton	Carton
Size (kg)	0.5	2	1	2
Price:				
Per unit (VND)	330,000	NA	500,000	1,528,626
Per kg (VND)	660,000	NA	1,000,000	759,000
Per kg (AUD)	$41.96	NA	$40.55	$47.15
Quality:				
Av Fresh weight (g)	11.0	12.8	12.2	10.8
Size (CGA Card)	30	32	30	30
Colour (CGA Card)	three to six (Av 5.6)	five to six (Av 6.0)	four to six (Av 5.5)	three to six (Av 5.6)
I_{AD} (DA meter)	2.08	1.74	1.59	1.35
Agrosta Firmness Units	78.2 Extremely firm	79.8 Extremely firm	65.5 Very/firm	76.1 Very firm+

Nix colour:				
L*	10.37	8.6	10.40	12.9
a*	13.98	16.4	18.08	25.6
b*	-0.07	1.1	1.94	2.1
Stem colour (where 1=brown and 4=green)	1.7	3.2	3.5	3.2
Eating quality (where 1=poor and 5=excellent)	4.0	4.5	3.5	4.0
SSC (° Brix)	17.6 to 25.0 (Av 21.0) = Super sweet	17.2 to 22.8 (Av 19.9) = Very sweet+	11.8 to 21.8 (Av 16.4) = Moderately/sweet	16.2 to 23.6 (Av 19.7) = Very sweet
Quality assessment (N)	18	24	18	18
Comments	Dark red and shiny fruit, very sweet and juicy, mixed firmness. Stored in fridge.	Picked up directly from importer. Cv. 'Regina' 30mm.All dark red fruit with green stems. Large and firm fruit, very shiny.	Limited fresh produce on shelves, lots of cherries with green stems, slightly soft on shoulders, lacking flavour and 1 major rot.	Cv. 'Lapin' 28-30mm (BATCH: XXX), mixed colours, firm, reasonably juicy, with green stems, minimal amount of pitting compared to others.

NA=Not applicable

Cherry shelf-life trial in Vietnam

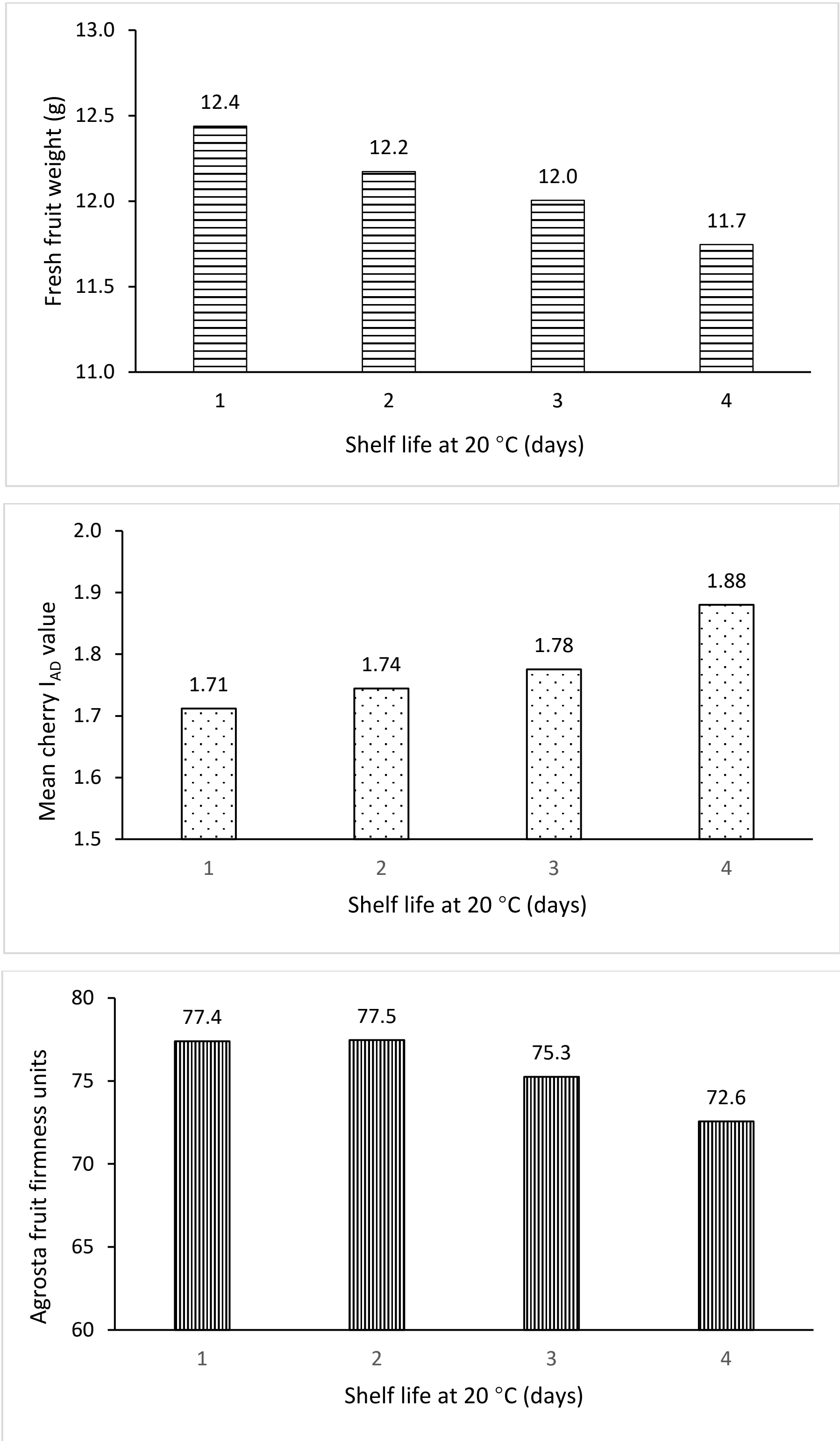

Figure 5. Results of shelf-life trial for 'Regina' cherry (N=24) stored at 20 °C for four days – fresh weight (top), I_{AD} value (middle) and fruit firmness (bottom).