Final report

Project title:

Evaluation of irradiation as a postharvest phytosanitary measure for Australian avocados

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AV22008

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Contents

Public summary

Market access is crucial for the long-term profitability and sustainability of the Australian avocado industry. With an increasing supply of avocados, there is a need to increase the export opportunities for Australian avocados to improve grower returns and profitability. These new export opportunities are limited by phytosanitary quarantine barriers which require treatment of fruit to ensure control of pests (such as Queensland fruit fly) and there are limited market access treatment options for the Australian avocado industry.

Phytosanitary irradiation is a technologically proven, viable and scientifically sound disinfestation treatment. However, the adoption of phytosanitary irradiation is dependent on its effects on fruit quality. There have been various studies which have evaluated the sensitivity of avocado to irradiation where some of these studies have shown there is some sensitivity of avocado fruit to irradiation. This project evaluated the effects of low dose phytosanitary irradiation on the two major Australian avocado cultivars (Hass and Shepard) from major growing regions around Australia at different times of the year. Phytosanitary irradiation treatment was conducted at Steritech, the commercial X-ray treatment facility in Melbourne, and the fruit was handled to simulate the export supply chain.

Hass and Shepard avocados were sourced from four main growing regions (north Queensland, Bundaberg, southeast Queensland and Victoria) and the effects of phytosanitary irradiation on fruit quality were evaluated. The results showed treated fruit were not commercially acceptable after treatment and storage. High levels of vascular browning were consistently found in the flesh of treated fruit, irrespective of variety, growing region or storage time. There were also higher levels of flesh and stem rots in treated fruit which resulted in all fruit being unacceptable. Phytosanitary treatment also affected the ripening behaviour of the fruit, with irradiation treatment causing fruit to remain greener and firmer for longer.

This study demonstrated that phytosanitary irradiation resulted in a significant and unacceptable decrease in fruit quality, mainly through increased vascular browning within the flesh. These results show phytosanitary irradiation is not suitable as a market access treatment for avocados and other potential market access treatments (such as methyl bromide fumigation) are required for Australian avocados.

Technical summary

Market access is crucial for the long-term profitability and sustainability of the Australian avocado industry. There is increasing over-supply of avocados within Australia which is reducing grower returns. There is an urgent need to increase the export opportunities for Australian avocados to improve grower returns and profitability. These new export opportunities are limited by phytosanitary quarantine barriers which require treatment of fruit to ensure control of pests (e.g. Queensland fruit fly) and there are limited market access treatment options for the Australian avocado industry. This project examined the impacts of contemporary phytosanitary irradiation technology on avocado fruit quality.

Irradiation is a technologically proven, viable and scientifically sound disinfestation treatment. However, the adoption of phytosanitary irradiation is dependent on its effects on fruit quality where the effects of irradiation on avocado fruit quality are 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.

This project evaluated the effects of low dose phytosanitary irradiation (150 Gray (Gy) treatment) on the two major Australian avocado cultivars (Hass and Shepard) from major growing regions around Australia at different times of the year. Phytosanitary irradiation treatment was conducted at Steritech, the commercial X-ray treatment facility in Melbourne, and the fruit was handled to simulate the export supply chain.

Hass and Shepard avocados were sourced from four main growing regions (north Queensland, Bundaberg, southeast Queensland and Victoria) and the effects of commercial phytosanitary irradiation on fruit quality were assessed. All fruit used in these experiments were above the standard commercial dry matter limits.

Fruit quality was assessed after treatment (i.e. before any cold storage) and also after a period of cold storage and shelf life. The results showed that when the fruit were assessed after treatment, there were few consistent differences between treated and untreated fruit except there was an increase in vascular browning in the flesh of most treated fruit. Fruit quality was also assessed after storage and shelf life (2 weeks at 7 °C + 4 days at 20 °C) and the results showed high levels of vascular browning in the flesh for all treated samples. Treated fruit also had higher levels of body and stem rots which resulted in all treated fruit being unacceptable. Treatment also affected the ripening behaviour of the fruit where phytosanitary treatment resulted in altered ripening patterns, where the fruit were firmer with a greener skin colour.

This study demonstrated that phytosanitary irradiation resulted in a significant and unacceptable decrease in fruit quality, mainly through increased vascular browning within the flesh. These results show phytosanitary irradiation is not suitable as a market access treatment for avocados and other potential market access treatments (such as methyl bromide fumigation) are required for Australian avocados.

Keywords

avocado, market access, phytosanitary irradiation, quality

Introduction

Market access is crucial for the long-term profitability and sustainability of the Australian avocado industry. With increased supply of avocados occurring, there is a need to increase the export opportunities for Australian avocados to improve grower returns and profitability. These new export opportunities are limited by phytosanitary quarantine barriers which require treatment of fruit to ensure control of pests (e.g. Queensland fruit fly) and there are limited market access treatment options for the Australian avocado industry. This project examined the impacts of contemporary phytosanitary irradiation technology on avocado fruit quality.

Irradiation is a technologically proven, viable and scientifically sound disinfestation treatment. Irradiation has recently been approved as a market access treatment for all fruit and vegetables in Australia and New Zealand (Golding et al., 2024). Irradiation has been approved for use in Australia and New Zealand in some commodities for 20 years and internationally since the 1950's. Indeed, the use of phytosanitary irradiation treatment as a market access treatment to facilitate trade has been increasing. Phytosanitary irradiation as a market access treatment has been endorsed by two internationally recognised standards-setting agencies for human and plant health; Codex Alimentarius (Codex) and the International Plant Protection Convention (IPPC). Irradiation as a market access treatment has been approved in several export markets such as Indonesia and Vietnam.

However, the adoption of phytosanitary irradiation is dependent on its effects on fruit quality and the effects of irradiation on avocado fruit quality are not clear. Some studies have evaluated the sensitivity of different avocados to irradiation and 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. They concluded that as doses greater than 100 Gy are required for phytosanitary treatment that none of their evaluated radiation treatments could be used as a phytosanitary treatment in fresh Hass avocado fruits. 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 was observed due to the development of phenolic compounds (Arevalo et al., 2002). Arevalo et al. (2002) also showed an increase in the size of xylem and phloem cells in the vascular tissue even at the minimum dose of 150 Gy required for phytosanitary treatment. However, they further 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 (Arevalo et al., 2002).

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) (Du Rand 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 (Du Rand 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.

When this project was commencing, the results of the Hort Frontiers market access project, '*Phytosanitary irradiation: Building stronger pathways for domestic and international trade'* (AM19002) (Hort Innovation) were concluding. This Hort Frontiers project conducted fruit tolerance work on Hass avocado fruit (Golding et al., 2023). The results from 3 different

growers from 2 different states showed that Hass avocado treated with phytosanitary irradiation retained green skin colour and maintained fruit firmness thus increasing shelf life. However, there were some differences in fruit physiology and quality parameters response to phytosanitary irradiation between fruit from different orchards (Golding et al., 2023). This was followed up in this Hort Innovation fruit tolerance project (AV22008).

This project evaluated the effects of low dose phytosanitary irradiation on the two major Australian avocado cultivars (Hass and Shepard) from major growing regions around Australia at different times of the year. Phytosanitary irradiation treatment was conducted at Steritech, the commercial X-ray treatment facility in Melbourne and the fruit handled to simulate the export supply chain.

Methodology

A series of fruit tolerance trials were conducted with avocados from different growing regions at different times of the year:

1. Hass avocado (Sunraysia) Avocados (Hass) – November 2023 (x 3 growers)
2. Shepard avocado (North Queensland) – March 2024 (x 1 grower)
3. Hass avocado (North Queensland and Central Queensland) - June 2024 (x 2 growers)
4. Hass avocado (SE Queensland, Central Queensland and North Queensland) - July 2024 (x 3 growers)
5. Hass avocado (SE Queensland, Central Queensland and North Queensland) - September 2024 (x 3 growers)
6. Shepard avocado (North Queensland) – March 2025 (x 4 growers)

The following fruit quality attributes were assessed at each sampling time: weight loss, respiration (mL CO_2. kg^{-1} hr^{-1}) and ethylene production rates (mL ethylene kg^{-1} h^{-1}), external colour (subjective and objective assessment), fruit firmness colour (subjective and objective assessment), body and stem-end rots, vascular browning and flesh browning. The detailed methods are presented in Appendix 1. The dry matter in all fruit used in these trials was above the industry standard.

Results and discussion

A total of 16 comparisons of treated and non-treated fruit were conducted from four main growing regions (north Queensland, Bundaberg, southeast Queensland and Victoria) over 16 months. All fruit for all experiments were above the standard dry matter limits. A total of 11 Hass assessments and 5 Shepard fruit assessments were conducted. A summary of the effects of phytosanitary irradiation on Australian avocados are presented in Tables 1 and 2.

The results in Table 1 summarise the effects of phytosanitary irradiation (150 Gy) on Hass and Shepard avocados after treatment (i.e. before any cold storage) on the main fruit quality parameters (fruit firmness, skin colour, ripening) and the development of negative attributes such as body and stem rots and vascular browning within the flesh. The results showed there were few other consistent effects of treatment immediately after treatment, except Hass fruit were firmer and greener than the untreated control. However, there was a significant increase in the levels of vascular browning in most fruit (13 of the 16 comparisons) after treatment (i.e. before storage) resulting in unacceptable fruit.

The effects of treatment on fruit quality after an additional storage and shelf life (2 weeks at 7 °C + 4 days at 20 °C) are presented in Table 2. The results showed high levels of vascular browning in all treated samples which also had higher levels of body and stem rots resulting in all fruit being unacceptable. Treatment also affected the ripening behaviour of the fruit with treated fruit having altered ripening. This resulted in treated fruit being firmer and having a greener skin colour than non-treated fruit. But overall, treated fruit were not commercially acceptable after treatment and storage. In addition, a small informal taste test showed treated fruit tasted ‘chalky’ and dry, as compared to the untreated fruit.

These results showed that phytosanitary irradiation caused significant and unacceptable decrease in fruit quality, mainly through increased vascular browning within the flesh.

Figure 1. Effect of phytosanitary irradiation on the internal quality of Shepard (left) and Hass (right) avocado fruit. Untreated fruit are on the top and treated fruit are on the bottom, showing extensive vascular browning within the flesh.

Figure 2. Treated Shepard (left) and Hass (right) avocado fruit showing extensive vascular browning. Stem end rots also apparent in the Shepard fruit (left).

Table 1. Effects of phytosanitary irradiation on quality attributes of avocados after treatment and **before** storage.

Variety	Date	Grower	Region	Flesh firmness	Skin colour	Ripening	Vascular browning	Rots (body + stem	Overall effect
Hass	Nov 2023	Grower 1	Victoria	-	-	N/A	Y	N	negative
Hass	Nov 2023	Grower 2	Victoria	-	-	N/A	Y	N	negative
Hass	Nov 2023	Grower 3	Victoria	firmer	greener	N/A	Y	N	negative
Shepard	Mar 2024	Grower 1	North Qld	-	-	N/A	N	N	no
Hass	June 2024	Grower 1	North Qld	-	-	N/A	Y	N	negative
Hass	June 2024	Grower 2	Bundaberg	-	-	N/A	Y	N	negative
Hass	July 2024	Grower 1	SE Qld	firmer	-	N/A	Y	N	negative
Hass	July 2024	Grower 2	Bundaberg	firmer	-	N/A	Y	N	negative
Hass	July 2024	Grower 3	North Qld	-	-	N/A	Y	N	negative
Hass	Sept 2024	Grower 1	SE Qld	firmer	greener	N/A	Y	N	negative
Hass	Sept 2024	Grower 2	Bundaberg	firmer	greener	N/A	Y	N	negative
Hass	Sept 2024	Grower 3	North Qld	firmer	greener	N/A	Y	N	negative
Shepard	Mar 2025	Grower 1	North Qld	-	-	N/A	N	N	no
Shepard	Mar 2025	Grower 2	North Qld	-	-	N/A	N	N	no
Shepard	Mar 2025	Grower 3	North Qld	-	-	N/A	Y	N	negative
Shepard	Mar 2025	Grower 4	North Qld	-	-	N/A	Y	N	negative

- no difference

N/A not applicable. Fruit assessed before storage and shelf life

Y yes – presence of disorder / rot

N no – absence of disorder / rot

Table 2. Effects of phytosanitary irradiation on quality attributes of avocados **after** storage and shelf life (2 weeks at 7 °C + 4 days at 20 °C).

Variety	Date	Grower	Region	Flesh firmness	Skin colour	Ripening	Vascular browning	Rots (body + stem	Overall effect
Hass	Nov 2023	Grower 1	Victoria	firmer	greener	N	Y	Y	negative
Hass	Nov 2023	Grower 2	Victoria	firmer	greener	N	Y	Y	negative
Hass	Nov 2023	Grower 3	Victoria	firmer	greener	N	Y	Y	negative
Shepard	Mar 2024	Grower 1	North Qld	firmer	-	N	Y	Y	negative
Hass	June 2024	Grower 1	North Qld	firmer	greener	N	Y	Y	negative
Hass	June 2024	Grower 2	Bundaberg	firmer	greener	N	Y	Y	negative
Hass	July 2024	Grower 1	SE Qld	firmer	greener	N	Y	Y	negative
Hass	July 2024	Grower 2	Bundaberg	firmer	greener	N	Y	Y	negative
Hass	July 2024	Grower 3	North Qld	firmer	greener	N	Y	Y	negative
Hass	Sept 2024	Grower 1	SE Qld	firmer	greener	N	Y	N	negative
Hass	Sept 2024	Grower 2	Bundaberg	firmer	greener	N	Y	N	negative
Hass	Sept 2024	Grower 3	North Qld	firmer	greener	N	Y	N	negative
Shepard	Mar 2025	Grower 1	North Qld	firmer	lighter	N	Y	Y	negative
Shepard	Mar 2025	Grower 2	North Qld	firmer	-	N	Y	Y	negative
Shepard	Mar 2025	Grower 3	North Qld	firmer	-	N	Y	Y	negative
Shepard	Mar 2025	Grower 4	North Qld	firmer	-	N	Y	Y	negative

- no difference

Y yes – presence of disorder / rot

N no – absence of abnormal ripening / disorder / rot

Outputs

The project outcomes are summarized in Table 3, as described in the project M&E plan.

Table 3. Output summary

Output	Description	Detail
Project updates to industry	Presentations and updates to various industry and avocado research panels	Regular project updates were given to the Project Reference Group (PRG) which included growers, key export businesses and Avocados Australia. Updates were also given to industry panels / reviews. As requested, Fresh and Secure Trade Alliance (FASTA) (AM22000) Avocado Research Forum (December 2023), Avocado Market Development Panel (October 2024)
Report on the storage trials of the effects of irradiation on avocado fruit quality	Report on the effects of phytosanitary irradiation on avocado fruit quality	The full report on the effects of phytosanitary irradiation on avocado fruit quality is presented in Appendices 2 - 7. The full results from a series of different fruit tolerance studies are presented and discussed. This report will be made publicly available on the Hort Innovation website.
Industry article	Extension article to *'Talking Avocados'* industry magazine. Target audience - avocado growers, packers and exporters	Extension article "*The effects of phytosanitary irradiation as a market access treatment on fruit quality*" submitted to *Talking Avocados* industry magazine for general industry distribution of the project outcomes. This is appended in Appendix 8.
Presentation of results to industry	Poster of project outcomes presented at Avocado Australia regional forums and meetings	"*Improving avocado market access*" poster presented at Avocados Australia regional forums and meetings x 6 regional forums (approximately 50 attendees per event), AvoConnections (June 2025) (approximately 110 attendees) and R&D Forum (September 2025) (approximately 70 attendees). This will be facilitated by Mary Burton – Avocados Australia RD&E Coordinator. The poster is appended in Appendix 9.

Outcomes

A summary of the project's outcomes is presented in Table 4.

Table 4. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
The avocado industry has a better understanding of the effects of irradiation on Australian avocados.	This project contributed to the Avocado Strategic Investment Plan 2022-2026 Outcome 1, Strategy 4 – Improve technical access to high-value markets as identified within the export strategy.	The project examined the effects of phytosanitary irradiation on the Hass and Shepard avocados from different growers, growing regions and times of the year.	A full report on the effects of phytosanitary irradiation is presented in Appendices 2-7.
Deliver recommendations on the feasibility of contemporary phytosanitary irradiation technology as a market	This project contributed to the Avocado Strategic Investment Plan 2022-2026 Outcome 1, Strategy 4 – Improve technical access to	Recommendations from the results of the fruit tolerance trials were made (Recommendations - below).	Recommendations for more work and the next steps are provided (Recommendations – below).

access treatment for Australian avocados.	high-value markets as identified within the export strategy		

Monitoring and evaluation

The project performance as outlined in the project M&E plan and referenced to Key Evaluation Questions is presented in Table 5.

Table 5. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
1. To what extent has the project achieved its expected outcomes?	The project comprehensively evaluated the effect of irradiation as a postharvest phytosanitary measure for Australian avocados with range of fruit tolerance trials on Shepard and Hass avocado fruit from different growing regions at different times of the year.	The impacts of on-farm management upon fruit quality post irradiation treatment could be evaluated.
2. How relevant was the project to the needs of intended beneficiaries?	The project met the needs of the Australian Avocado Industry by providing robust data and fruit tolerance studies on the effects of phytosanitary irradiation on fruit quality. Are there any gaps or additional opportunities for research?	Undertake the assessment of multiple phytosanitary treatments on fruit quality within the same grower / region to identify any contributing factors.
3. How well have intended beneficiaries been engaged in the project?	Regular PRG meetings were conducted and reported. In addition, the results of the trials were frequently sent to PRG members (between PRG meetings). Updates to industry and research panels have been provided. An extension article in '*Talking Avocados'* has been produced.	Invite a representative from Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) to join future PRG's to increase awareness of market access research findings.
4. To what extent were engagement processes appropriate to the target audience/s of the project?	The project engaged with the project PRG and other stakeholders. Research update was provided with an article in '*Talking Avocados'* and a project summary poster printed for Avocados Australia RD&E Coordinator (Mary Burton) for presentation at regional forums and the annual conference.	Links between research projects and the avocado industry extension and communications projects were established to increase industry awareness.
5. What efforts did the project make to improve efficiency?	The project sourced fruit from a range of different growers, regions and times of the year. This demonstrated the robustness of the project's outcomes.	Undertake comprehensive assessments to understand and manage treatment responses.

Recommendations

- Explore opportunities to reduce the development of irradiation-induced vascular browning.
- Conduct applied R&D for new market access opportunities. For example:
    - Develop optimum methyl bromide fumigation treatment conditions for insect mortality and maintaining fruit quality,
    - Explore physical treatments such as heat and low pressure to kill quarantine insects,
    - Develop combination treatments using low dose irradiation (e.g. lower dose phytosanitary irradiation) and

'cold' treatment combinations,

- To facilitate potential cold treatment, develop and apply practical treatments to overcome fruit chilling damage (e.g. controlled atmosphere storage, heat etc.)

Refereed scientific publications

Request submission for article for peer review and scientific publication:

Tentative title and journal - '*Effects of phytosanitary irradiation on the storage life of Hass and Shepard avocado fruit'* - for submission / publication in New Zealand Journal of Crop and Horticultural Science. (https://www.tandfonline.com/journals/tnzc20)

The reporting of the results of this project to the wider scientific community will enhance Australia's R&D status and improve industry knowledge of the effects of phytosanitary irradiation on avocado fruit quality.

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Intellectual property

No project IP or commercialisation to report.

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Appendices

Appendix 1. Experimental summary and methods

Summary of Experiments

A series of fruit tolerance trials were conducted:

1. Hass avocado (Sunraysia) Avocados (Hass) – November 2023 (x 3 growers)
2. Shepard avocado (North Queensland) – March 2024 (x 1 grower)
3. Hass avocado (North Queensland and Central Queensland) - June 2024 (x 2 growers)
4. Hass avocado (SE Queensland, Central Queensland and North Queensland) - July 2024 (x 3 growers)
5. Hass avocado (SE Queensland, Central Queensland and North Queensland) - September 2024 (x 3 growers)
6. Shepard avocado (North Queensland) – March 2025 (x 4 growers)

Materials and methods

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), body and stem-end rots, vascular browning and flesh browning.

Fruit weight loss 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.

Dry matter was determined based on the industry guidelines. Firstly, skin of 10 fruits was peeled off. Then, the fruits were cut into quarter sections of flesh from either side of the fruits and the seed coat was removed. Secondly, the flesh of quarter sections was shredded by hand and weighed about 100 g of shredded flesh per one treatment unit. The shredded flesh sample was dried in a food dehydrator at 60 – 65 ^{o}C for 24h. Dry matter (%) was calculated = (final weight/start weight) *100.

Endogenous ethylene production and the respiration rate by the fruit was determined as previously described by Huque et al. (2013) (Figure 1). Ethylene production was determined from a gas sample (1 mL) which was taken for analysis after two fruits were placed in the jar and sealed for 1 hour. Ethylene was measured by injecting the gas sample into a flame ionization gas chromatograph (Gow-Mac 580, Bridgewater, NJ, USA) fitted with a stainless steel column (2 m x 3.2 mm outer diameter x 2.2 mm internal diameter) packed with Porapak Q (80-100 mesh) (Altech, Sydney, Australia) with 110,

90 and 70 °C as the operating temperatures of the detector, column and the injector, respectively. Nitrogen, hydrogen and air were used as carrier and combustion gases at flow rates of 30, 30 and 300 mL/min, respectively. The ethylene concentration was calculated with reference to the concentration of an ethylene standard and expressed as µL C_2H_4/kg/h.

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.

External colour (objective and subjective assessment)

Objective assessment: Objective external skin colour was measured 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, chroma and Hue angle = arc tangent (b*/a*).

Subjective assessment: Subjective external skin colour for Hass was scored on a 5-point scale based on QDAF guidelines where 1 = emerald-green, 2 = forest green, 3 = 1 – 25% coloured, 4 = 25 – 75% coloured and 5 = purple.

Subjective external skin colour for Shepard was scored on a 5-point scale according to Arioli et al. (2023) where 1 = unripe (emerald green and shiny), 2 = onset ripe (forest green and < 20% dark), 3 = ripe (black on green and 20 to 30% dark), 4 = eating ripe (green on black and 60 to 70% dark), and 5 = over-ripe (mostly black and > 70% dark).

Fruit firmness (objective and subjective assessment)

Objective assessment: Fruit firmness was measured on the equator of individual avocado fruits using an automatic penetrometer (Wel penetrometer) with 11 mm tip, measurement depth of 8.0 mm, trigger threshold of 50 g, down speed of 20 mm/sec, measurement speed of 20 mm/sec, up speed of 25 mm/sec and return distance of 25.0 mm was applied on peeled fruits. Each fruit was measured at two positions 90 degrees apart at equator.

Subjective assessment: Subjective firmness was scored on a 5-point scale based on QDAF criteria where 1 = hard (no give with strong thumb pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2 – 3 mm with moderate thumb pressure), 4 = firm ripe (deforms 2 – 3 mm with light thumb pressure) and 5 = medium – soft ripe (deforms with moderate hand pressure).

Other subjective assessments of fruit conditions including flesh bruising, stem end rots, vascular browning, diffuse discolouration and body rots were determined based on QDAF criteria where 1 = 0% flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume.

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

Subjective fruit quality assessments:

- Body rots – rots entering through the skin. The number of body rots (incidence) and the severity of each rot was scored on each fruit (as above).
- Stem end rots – rots entering through fruit peduncle. The number of stem-end rots (incidence) and the severity of each rot was scored on each fruit (as above).
- Vascular browning – browning of the vascular stands running longitudinally through the fruit tissue (Figure 2 and 3) were subjectively scored using the subjective scale above.

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 and Regional Development.

Reference

Huque R., Wills R.B.H., Pristijono P. and Golding J.B. (2013) Effect of nitric oxide (NO) and associated control treatments on the metabolism of fresh-cut apple slices in relation to development of surface browning. *Postharvest Biology and Technology* 78, 16–23. doi:10.1016/j.postharvbio.2012.12.006

Appendix 2. Experiment 1. Hass x3

Effects of phytosanitary irradiation on Hass avocado from 3 Victorian growers

Aim. Examine the effects of phytosanitary irradiation on quality of Hass avocados from three growers.

Methods. Export-grade Hass avocados were sourced from three commercial growers in Victoria (Robinvale, Tol Tol and Irakk, Victoria). Fruit were transported to Steritech in Melbourne and treated with 150 Gy X-ray treatment on 6 November 2023. The other half of the fruit were untreated (control) which were handled the same way. After treatment, fruit were transported to NSW Department of Primary Industries at Ourimbah where fruit quality was assessed at two assessment times; upon receipt of fruit (2 days after treatment, time zero), and after 17 days storage at 7 °C and 4 days at 20 °C. Four replicates were allocated from each treatment and each treatment unit was a tray of fruit.

Results.

Firmness. The results presented in Figures 1 and 2 show that all Hass avocado fruit were still firm upon arrival except for fruit from Grower 3 were softer than the treated fruit. After storage and shelf-life, treated fruit remained firmer than untreated fruit.

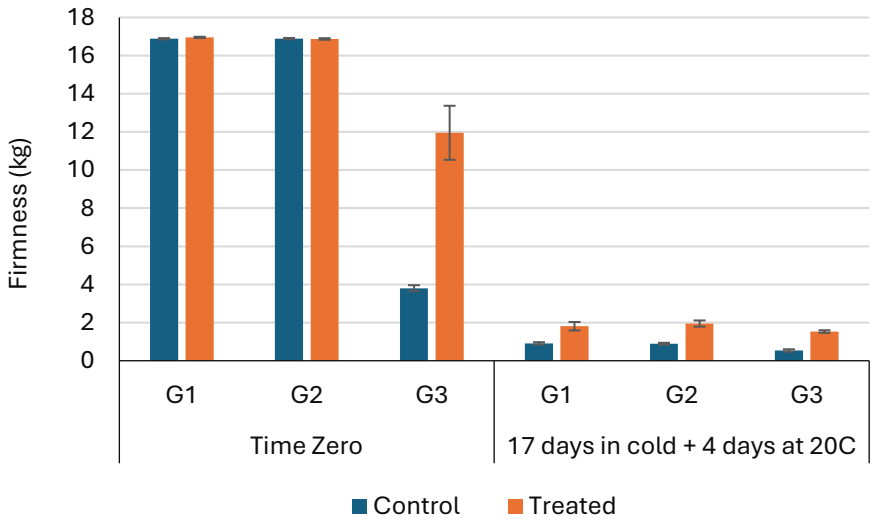


Figure 1. Firmness (kg) of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

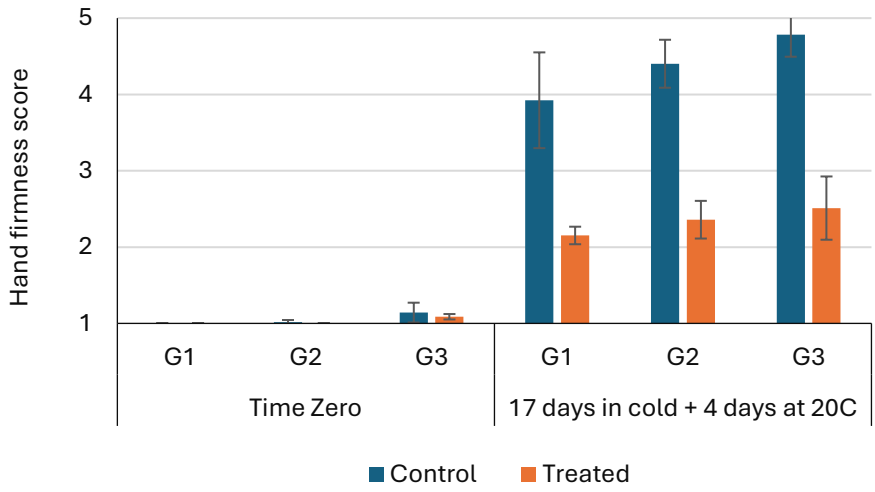


Figure 2. Subjective hand firmness score of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective hand firmness score: 1 = hard (no give with strong thump pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2-3 mm with moderate thump pressure), 4 = firm ripe (deforms 2-3 mm with slight thumb pressure) and 5 = medium-soft ripe (deforms with moderate hand pressure).
Bars are standard deviations around the means, *n* = 4.

Ethylene production. The levels of endogenous ethylene production were generally lower in treated fruit immediately upon arrival of fruit at NSW DPI, but after 17 days in cold storage and an addition 4 days at 20 °C shelf life, treated fruit had higher levels of ethylene than non-treated fruit.

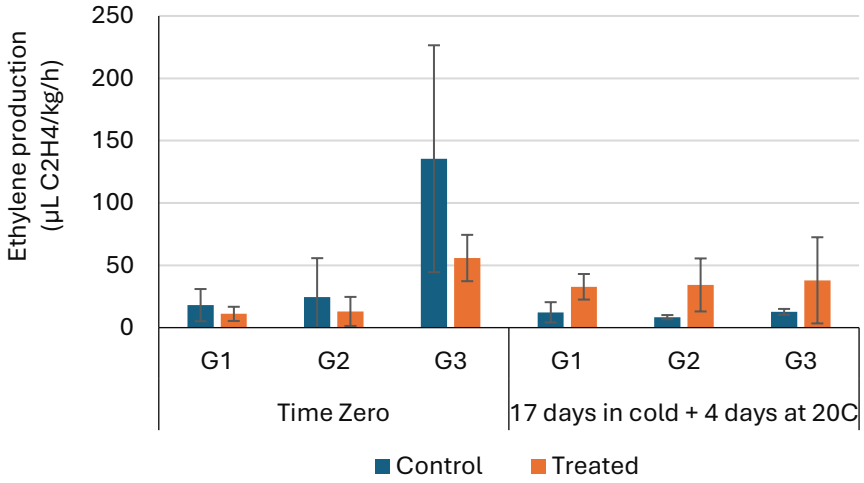


Figure 3. Ethylene production (µL C_2H_4/kg/h) of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at the assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Respiration rate. The respiration rates of treated fruit tended to be higher in all growers at all times (upon arrival and after 17 days in cold storage and an addition 4 days at 20 °C) (Figure 4).

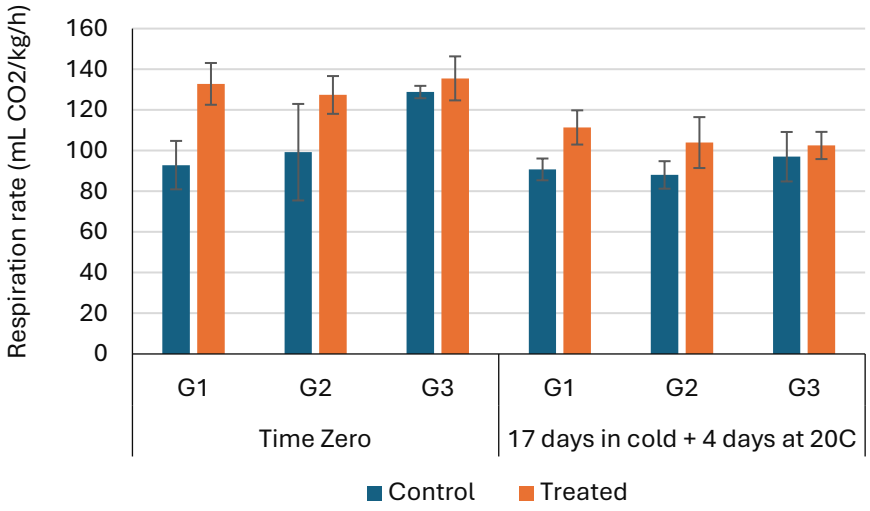


Figure 4. Respiration rate (mL CO_2/kg/h) of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Dry matter. The levels of dry matter in all growers were above the recommended 23% dry matter (Figure 5).

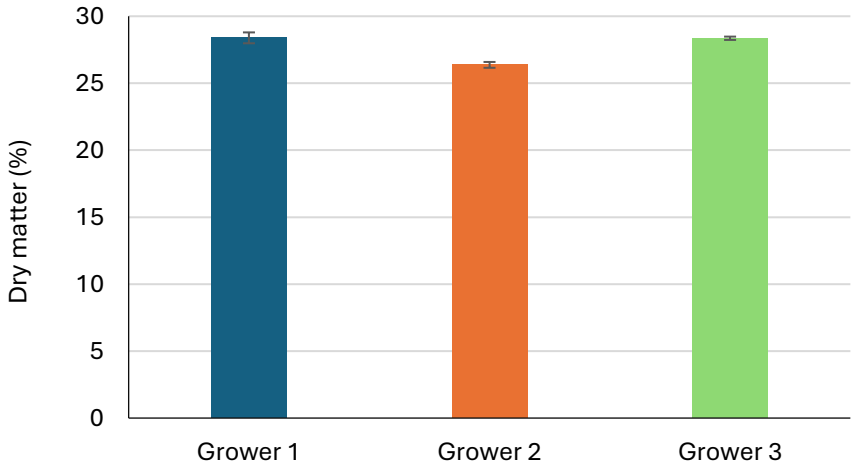


Figure 5. Dry matter (%) of avocados at Time Zero from three growers.
Bars are standard deviations around the means, *n* = 3.

Fruit colour. The results of the objective colour assessment as measured with the Minolta colour meter are presented in Figures 6-8 and show while there were few differences in fruit colour upon arrival, treated fruit retained their green colour (higher hue angle) after 17 days in cold storage and an addition 4 days at 20 °C (Figure 8).

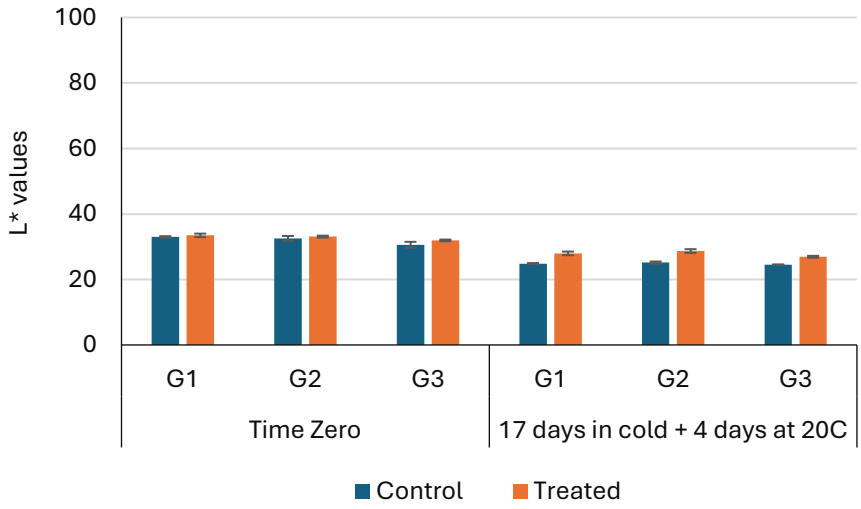


Figure 6. L* values of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

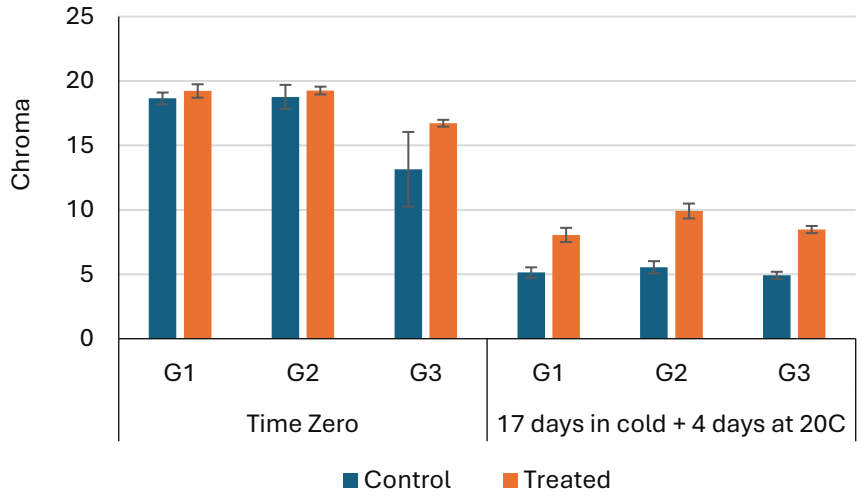


Figure 7. Chroma values of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

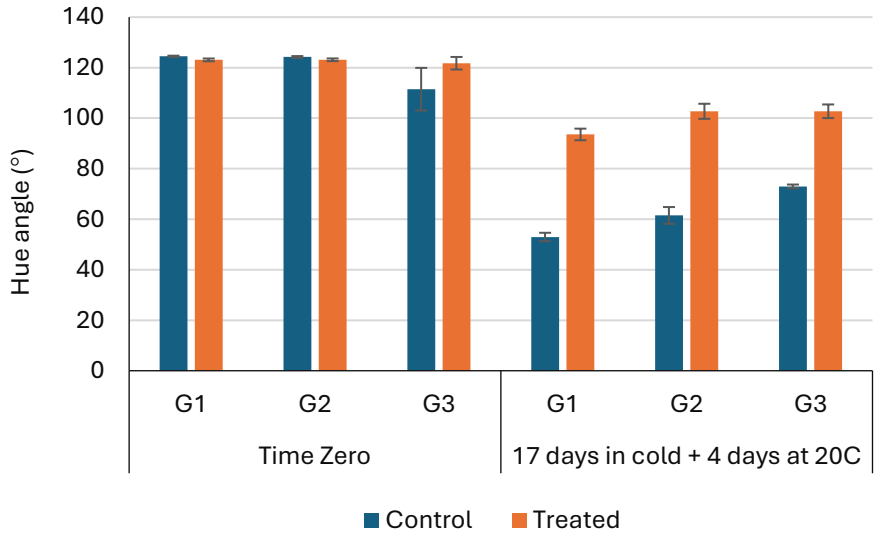


Figure 8. Hue angles (°) of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

Skin colour. The subjective colour score presented in Figure 9 reflects the objective Minolta results (Figures 6-8) and show the treated fruit retained its greener colour, as compared to the untreated fruit which were more purple.

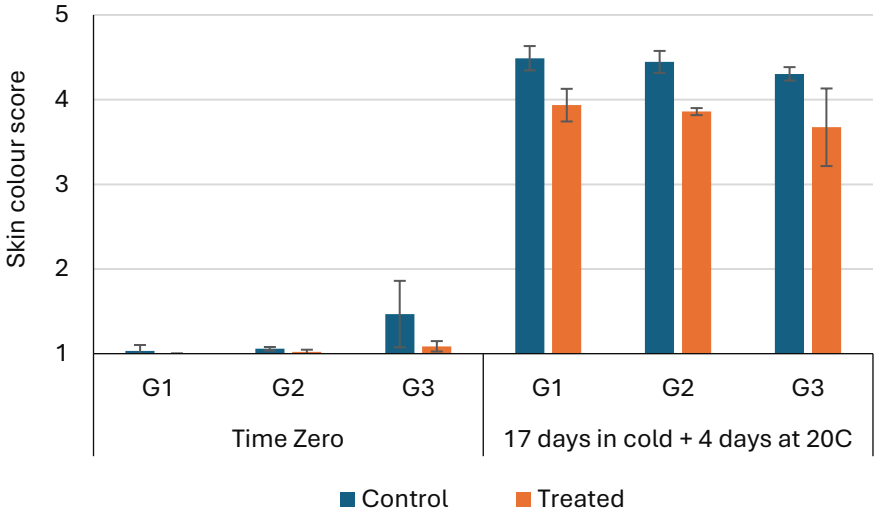


Figure 9. Subjective skin colour score of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective skin colour score: 1 = emerald green, 2 = forest green, 3 = 1 – 25% coloured, 4 = 25 – 75% coloured and 5 = purple.
Bars are standard deviations around the means, *n* = 4.

Skin spotting. The percentage of acceptable fruit (%) with skin spotting and the subjective levels of skin spotting are presented in Figures 10 and 11 and show that treatment did not affect the levels of skin spotting immediately after harvest. No assessment of skin spotting was made after storage, as all the fruit had ripened and become purple.

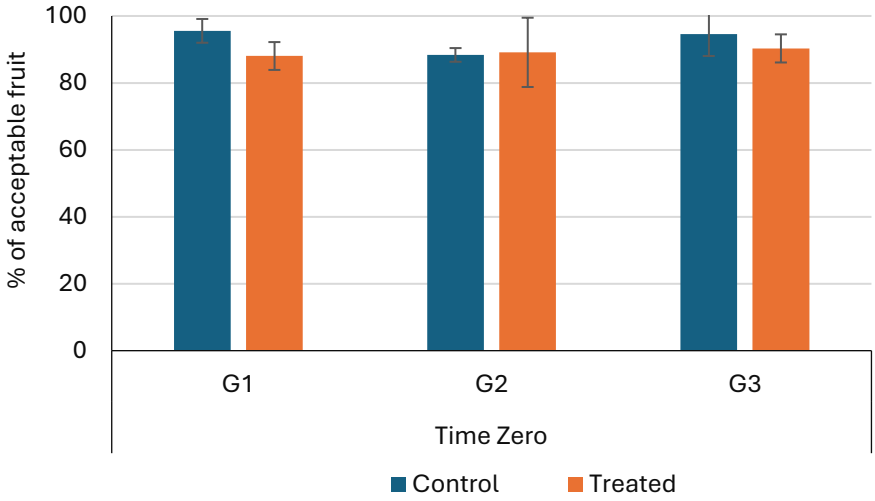


Figure 10. Percentage of acceptable fruit (%) with skin spotting of the control and irradiated (treated) avocados of three growers (G) at Time Zero. Bars are standard deviations around the means, *n* = 4.

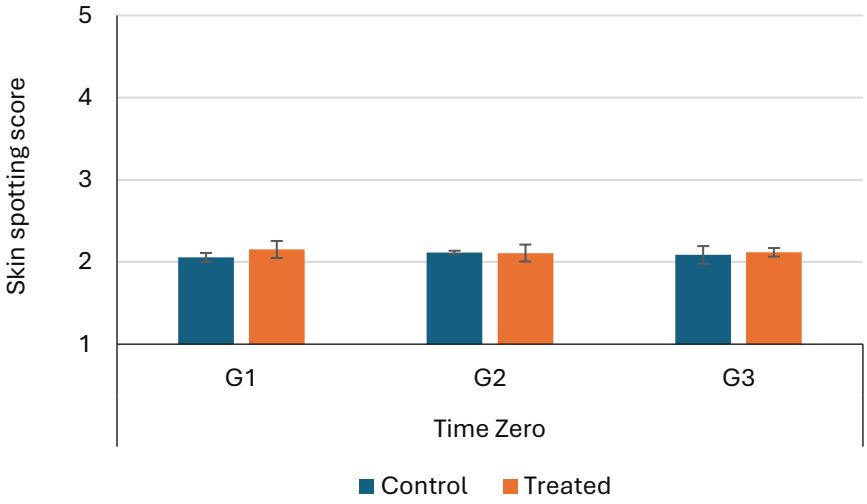


Figure 11. Subjective skin spotting score of the control and irradiated (treated) avocados of three growers (G) at Time Zero. Subjective skin spotting score: 1 = 0% of fruit surface, 2 = 1 – 5% of fruit surface, 3 = 5 – 10% of fruit surface, 4 = 10 – 25% of fruit surface and 5 = >25% of fruit surface.
Bars are standard deviations around the means, *n* = 4.

Flesh bruising. There were no fruit with flesh bruising at either assessment time (Figure 12 and 13).

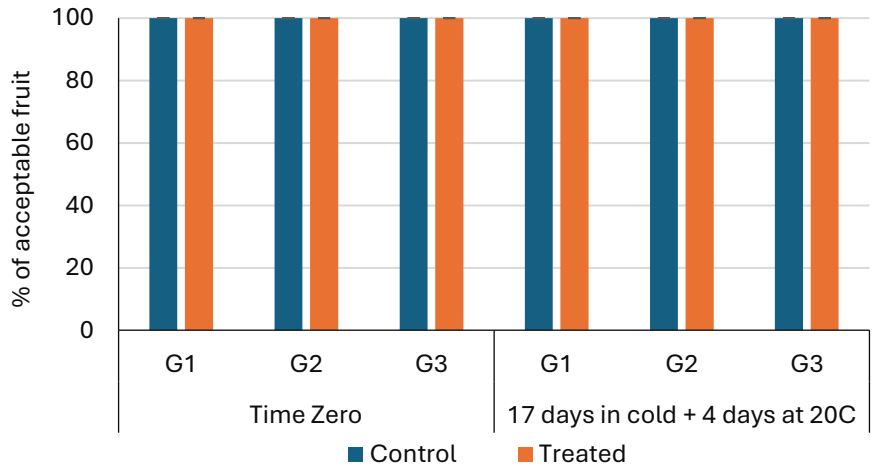


Figure 12. Percentage of acceptable fruit (%) with flesh bruising of the control and irradiated (treated) avocados of three growers (G) at Time Zero and assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

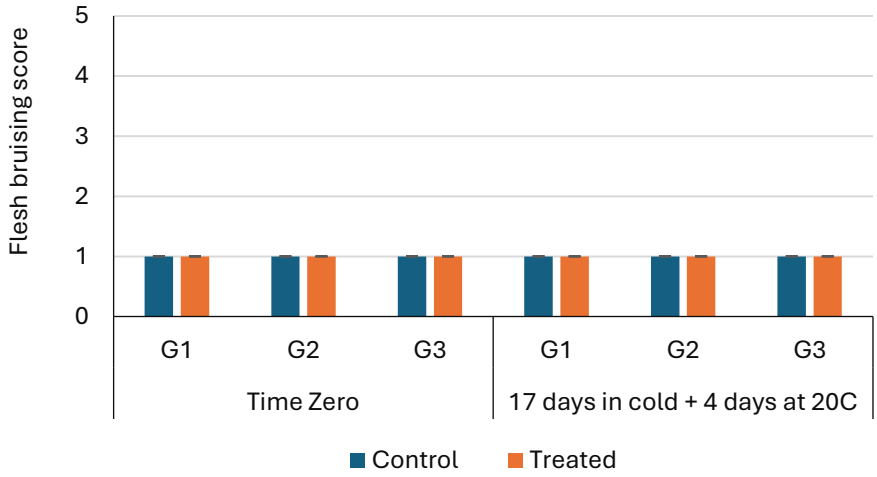


Figure 13. Subjective flesh bruising score of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective flesh bruising score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Stem end rots. The percentage of fruit (%) with stem end rot levels and the levels of stem end rots are presented in Figures 14-16 and show there were no stem end rots at Assessment 1 (upon arrival). However, after 17 days at 7 °C + 4 days at 20 °C, treated fruit had more stem end rots and were less acceptable.

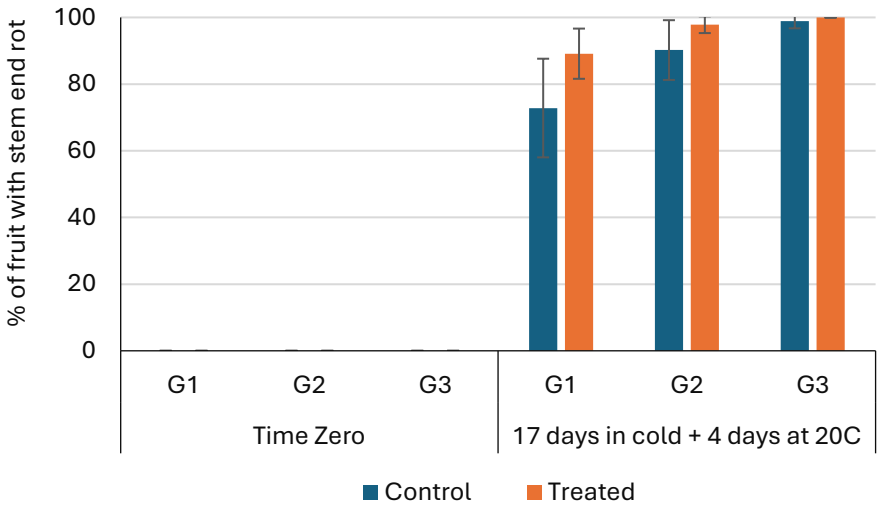


Figure 14. Percentage of fruit (%) with stem end rot of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

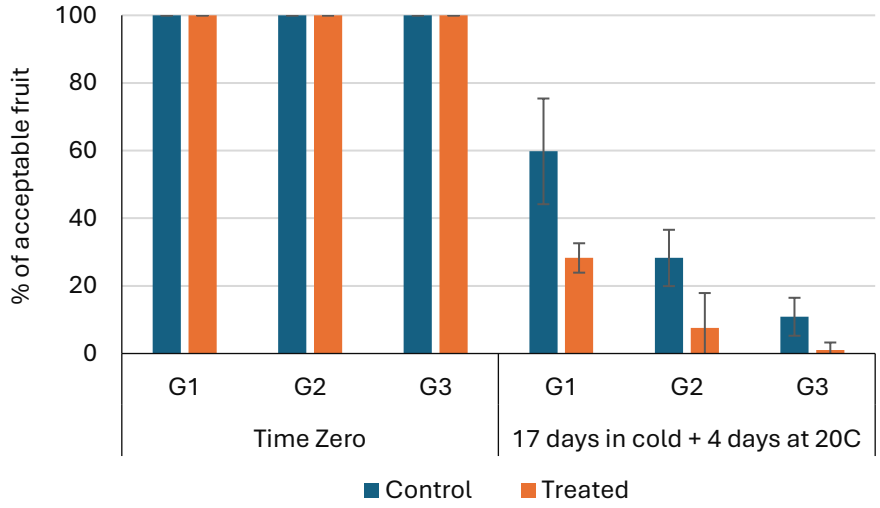


Figure 15. Percentage of acceptable fruit (%) with stem end rot of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

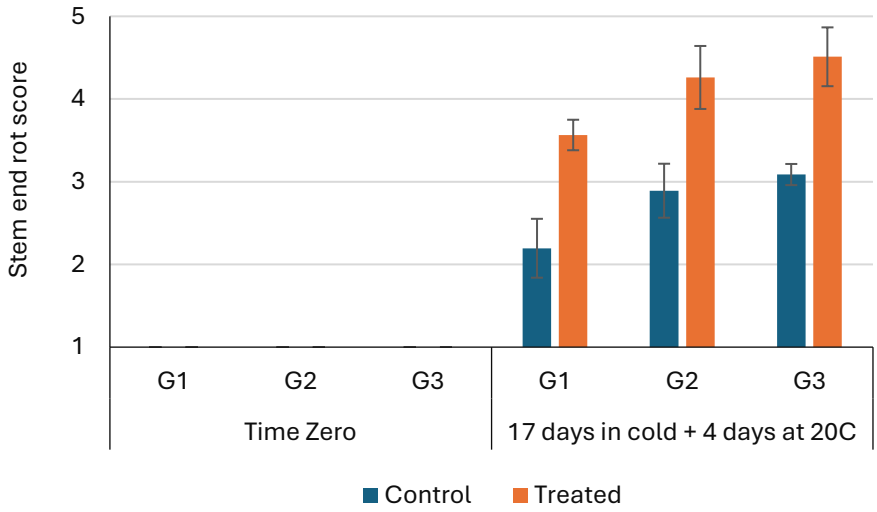


Figure 16. Subjective stem end rot score of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective stem end rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Vascular browning. Phytosanitary treatment had an adverse effect on the levels of vascular browning in treated fruit (Figures 17-19). Percentage of fruit (%) with vascular browning was higher in treated fruit compared to the background level of vascular browning (Figure 17). Due to the presence of vascular browning, there were no / little fruit that were acceptable following treatment (Figure 18), where the levels of vascular browning increased during storage and shelf life (Figure 19).

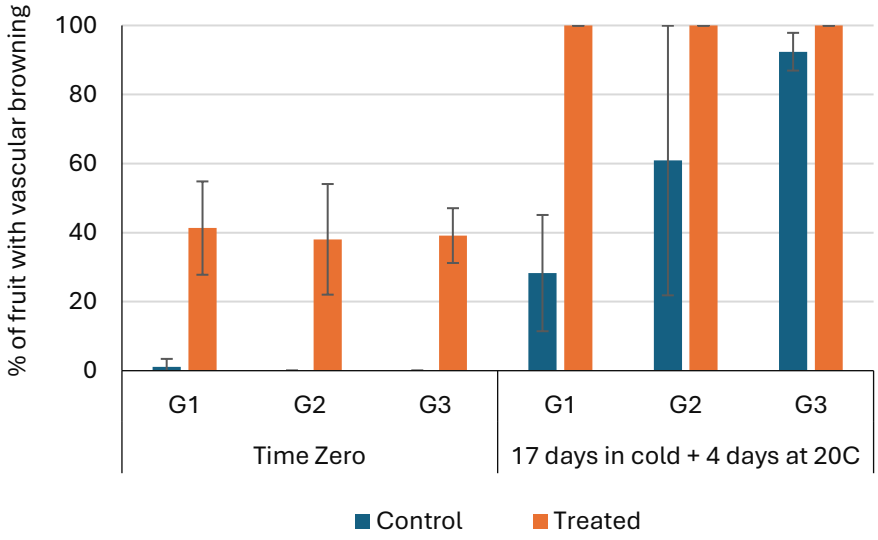


Figure 17. Percentage of fruit (%) with vascular browning of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

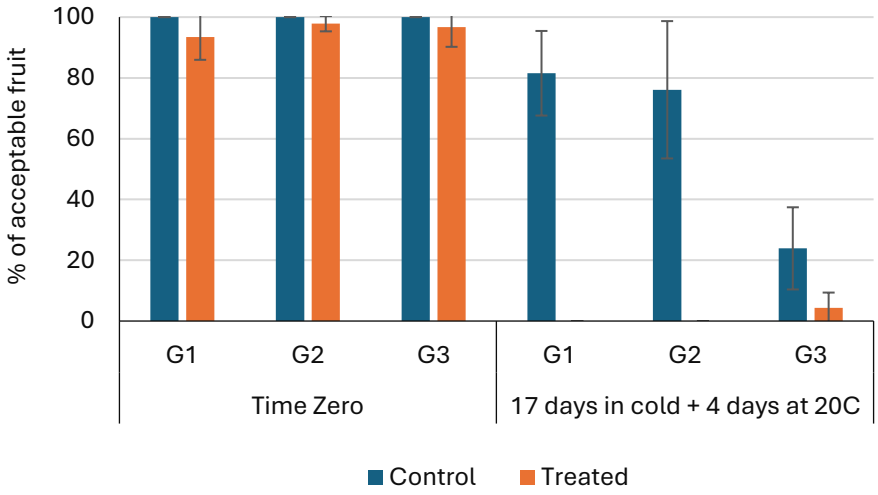


Figure 18. Percentage of acceptable fruit (%) with vascular browning of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

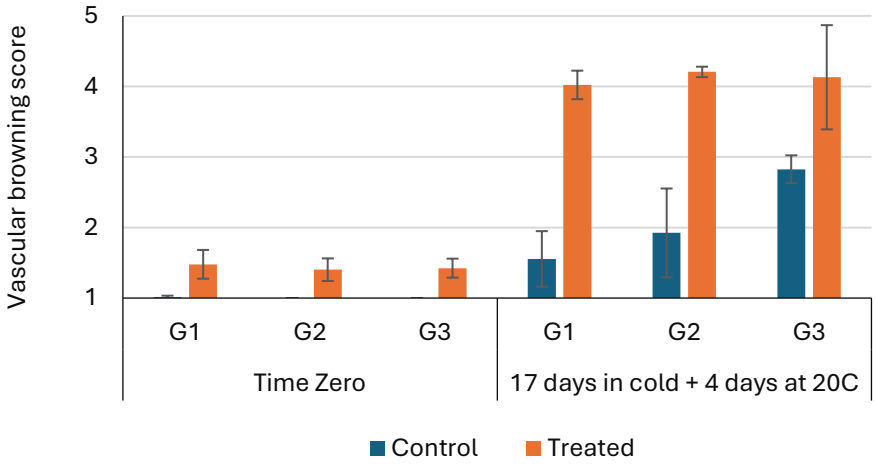


Figure 19. Subjective vascular browning score of the control and irradiated (treated) avocados of three growers (G) at Time Zero at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective vascular browning score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 –25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Diffuse discolouration. The levels of fruit with diffuse flesh discolouration were higher in treated fruit particularly in fruit stored for 17 days at 7 °C and an additional 4 days at 20 °C (Figures 20-22).

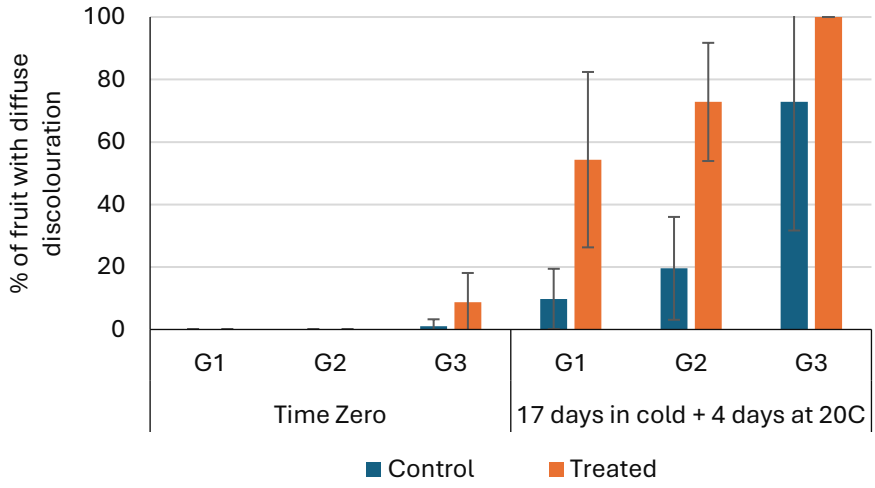


Figure 20. Percentage of fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

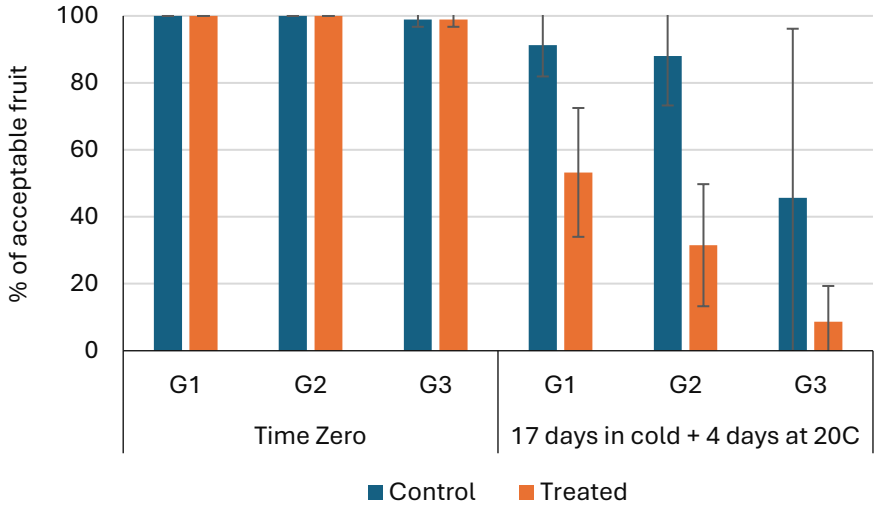


Figure 21. Percentage of acceptable fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

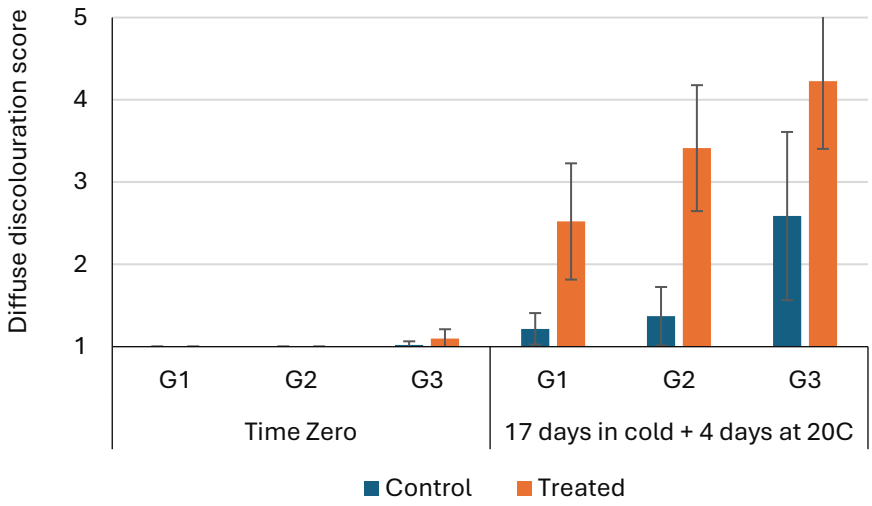


Figure 22. Subjective diffuse discolouration score of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective diffuse discolouration score: 1 = 0% of flesh volume, 2 = 1 – 5 % of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Body rots. The numbers of fruit with body rots were higher in treated fruit, particularly after storage and shelf life (Figures 23-25). There were some differences between the different grower lots, but the irradiation treatment resulted in higher numbers and severity of body rots.

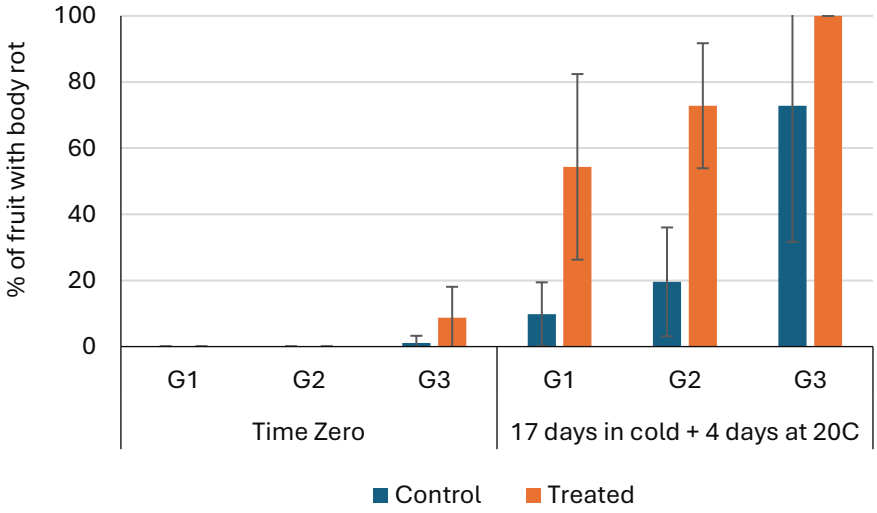


Figure 23. Percentage of fruit (%) with body rot of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

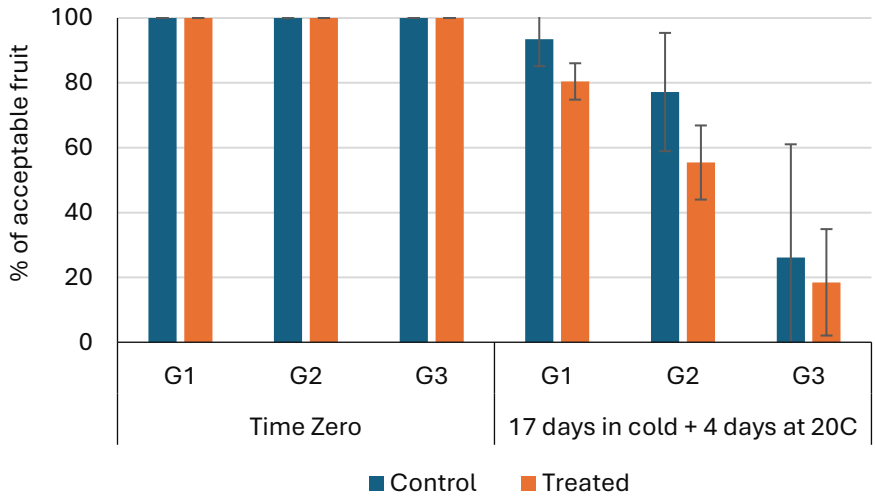


Figure 24. Percentage of acceptable fruit (%) with body rots of the control and irradiated (treated) avocados of three growers (G) at Time Zero and at assessment 2 (17 days at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

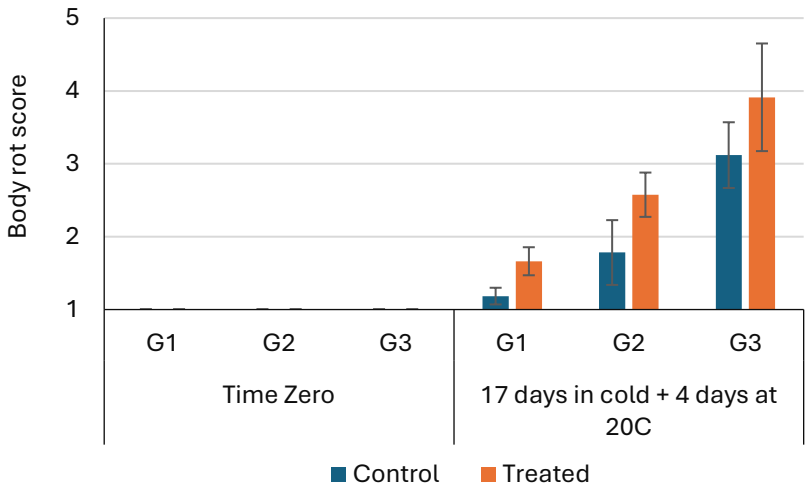


Figure 25. Subjective body rot score of the control and irradiated (treated) avocados of three growers (G) at Time Zero at assessment 2 (17 days at 7 °C + 4 days at 20 °C). Subjective body rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Photos from Grower 1 at: Time Zero, upon removal from cold storage after 17 days in cold storage and an additional 4 days at 20 °C following cold storage.

Time Zero

Untreated

Rep 1

Rep 2

Rep 3

Rep 4

Time Zero

Treated

Rep 1

Rep 2

Rep 3

Rep 4

Time Zero

Untreated

Rep 1

Rep 2

Rep 3

Rep 4

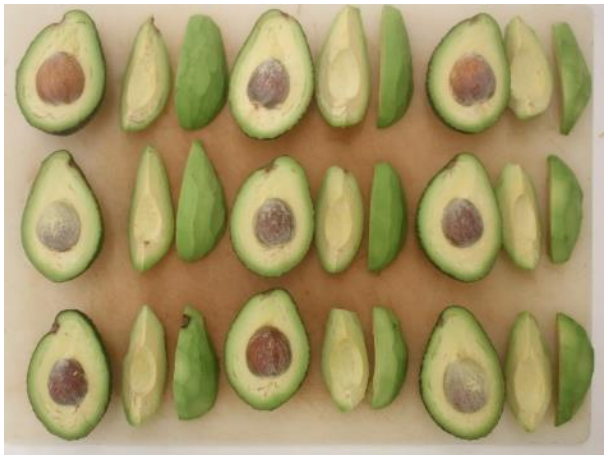
Time Zero

Treated

Rep 1

Rep 2

Rep 3



Rep 4

Time Zero

Untreated

Treated

Assessment 2: Upon removal (17 days in cold)

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2: Upon removal (17 days in cold)

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2: Upon removal (17 days in cold) + 4 days at 20 °C

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2: Upon removal (17 days in cold) + 4 days at 20 °C

Rep 3 Untreated Treated

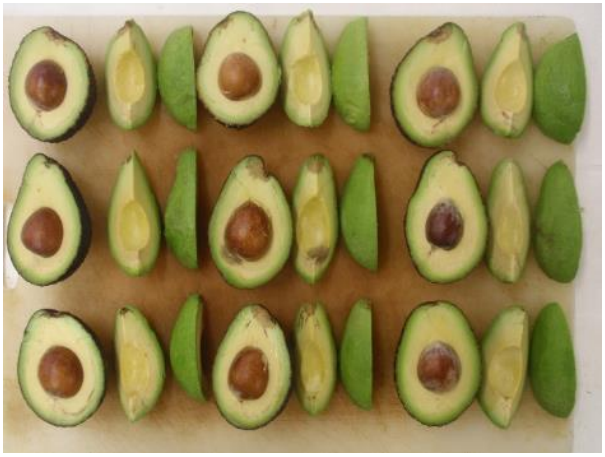
Rep 4 Untreated Treated

Assessment 2: Upon removal (17 days in cold) + 4 days at 20 °C

Untreated

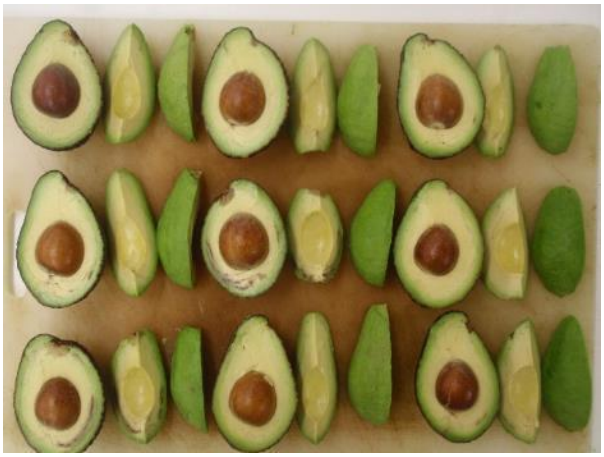
Rep 1

Rep 2



Rep 3

Rep 4



Assessment 2: Upon removal (17 days in cold) + 4 days at 20 °C

Treated

Rep 1

Rep 2

Rep 3

Rep 4

Assessment 2: 17 days in cold + 4 days at 20 °C

Grower 1 Untreated Treated

Grower 2 Untreated Treated

Grower 3 Untreated Treated

Appendix 3. Experiment 2 – Shepard x1

Effects of phytosanitary irradiation on Shepard avocado from 1 North Queensland grower

Aim. Examine the effects of phytosanitary irradiation on quality of Shepard avocados from one North Queensland grower.

Methods. Export-grade Shepard avocados were sourced from one commercial grower in North Queensland (Mareeba). Fruit were transported to Steritech in Melbourne and treated with 150 Gy X-ray treatment on 22 March 2024. The other half of the fruit were untreated (control) and handled the same way. After treatment, fruit were transported to NSW Department of Primary Industries at Ourimbah where fruit quality was assessed at two assessment times; upon receipt of fruit (2 days after treatment, time zero), and after 14 days storage at 7 °C and 4 days at 20 °C. Four replicates were allocated from each treatment and each treatment unit was a tray of fruit.

Results.

Fruit firmness. There were no differences in fruit firmness immediately after treatment, but as the fruit ripened and softened, the treated fruit was firmer (Figures 1 and 2).

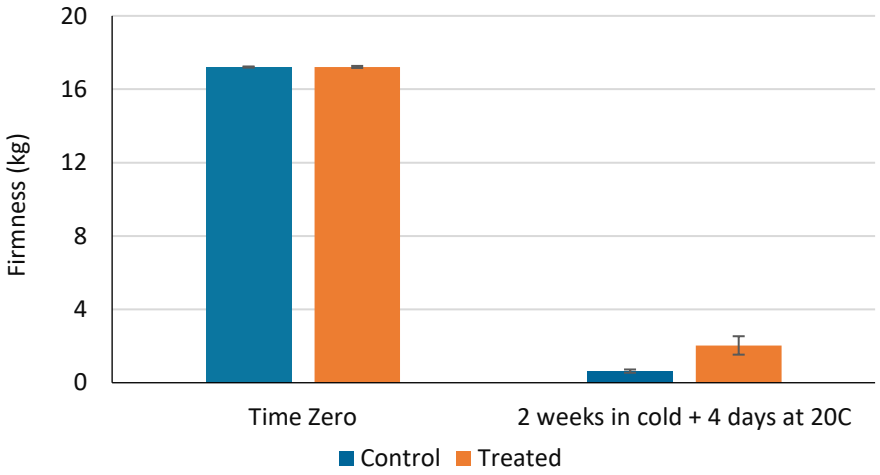


Figure 1. Objective firmness (kg) of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

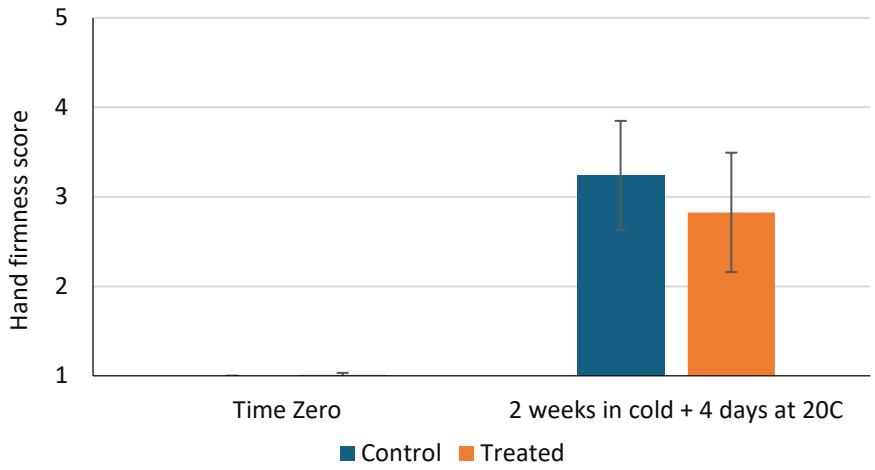


Figure 2. Subjective hand firmness score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective hand firmness score: 1 = hard (no give with strong thump pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2-3 mm with moderate thump pressure), 4 = firm ripe (deforms 2-3 mm with slight thumb pressure) and 5 = medium-soft ripe (deforms with moderate hand pressure). Bars are standard deviations around the means, *n* = 4.

Ethylene production. The levels of ethylene production were higher in the treated fruit (Figure 3), particularly after 2 weeks at 7 °C + 4 days at 20 °C.

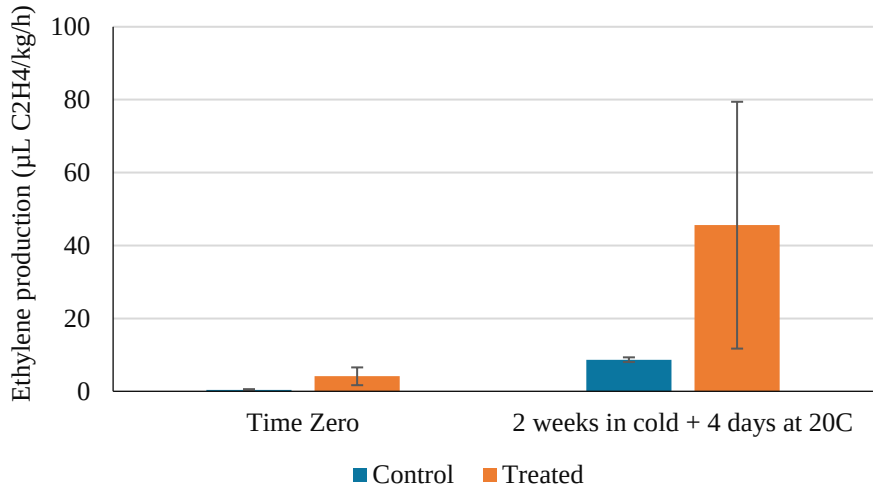


Figure 3. Ethylene production (µL C_2H_4/kg/h) of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

Respiration rate. The respiration rates in treated fruit were higher than in untreated fruit (Figure 4) at both assessment times.

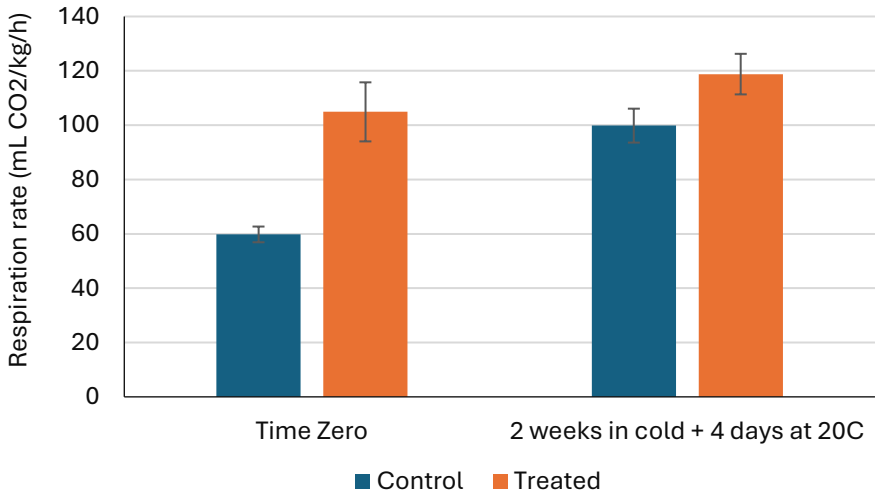


Figure 4. Respiration rate (mL CO_2/kg/h) of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

Dry matter. The dry matter in Shepard fruit used in this experiment were above the standard 21% dry matter (Figure 5).

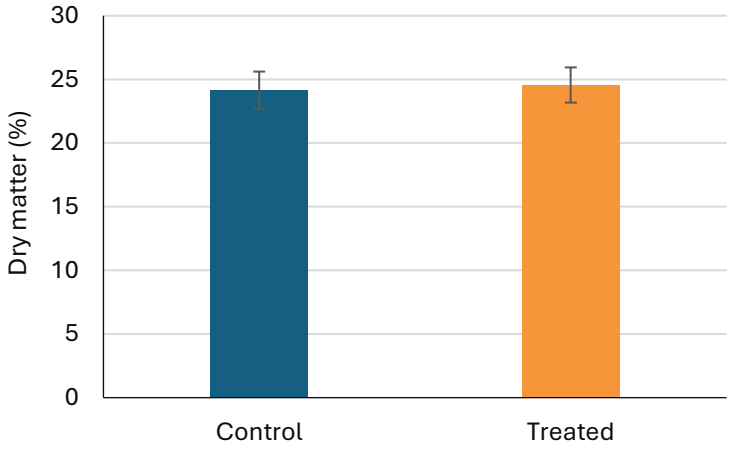


Figure 5. Dry matter (%) of the control and irradiated (treated) avocados at Time Zero. Bars are standard deviations around the means, *n* = 4.

Weight loss. The results in Figure 6 show that water loss was higher in treated fruit at both assessment times.

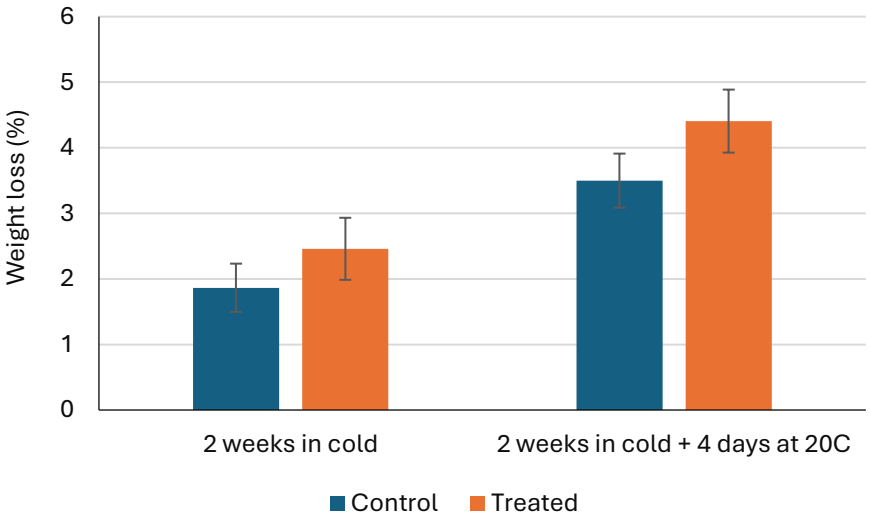


Figure 6. Percentage of weight loss (%) of the control and irradiated (treated) avocados after 2 weeks at 7 °C and 2 weeks at 7 °C plus 4 days at 20 °C. Bars are standard deviations around the means, *n* = 4.

Fruit colour. The results of the objective measurement of fruit skin colour with the Minolta colour meter are presented in Figures 7-9 and the subjective assessment of skin colour score is presented in Figure 10. The results show few differences between treated and non-treated fruit.

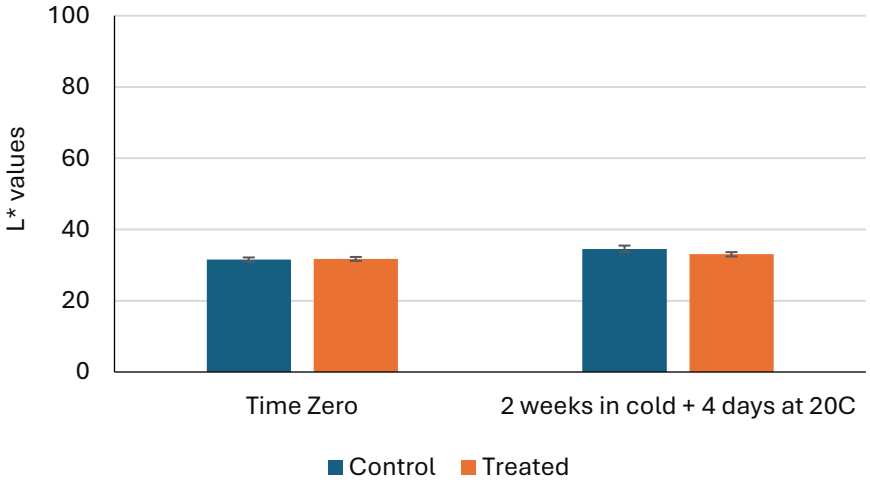


Figure 7. L* values of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

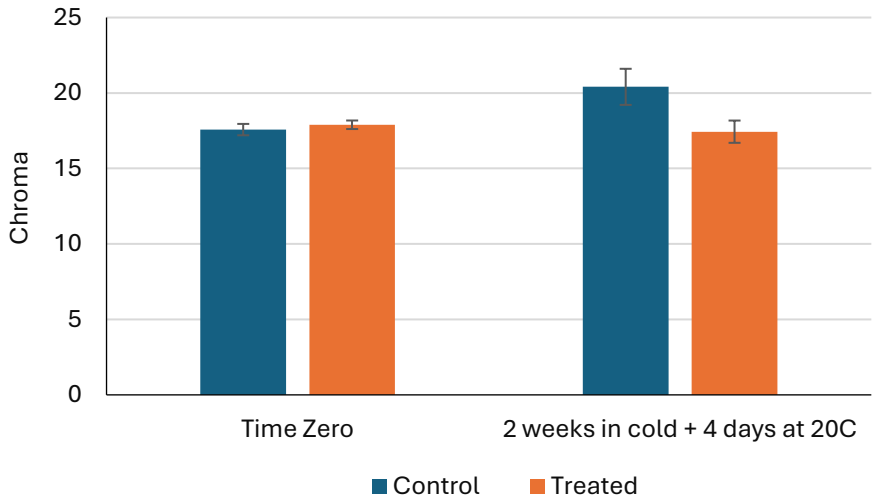


Figure 8. Chroma values of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

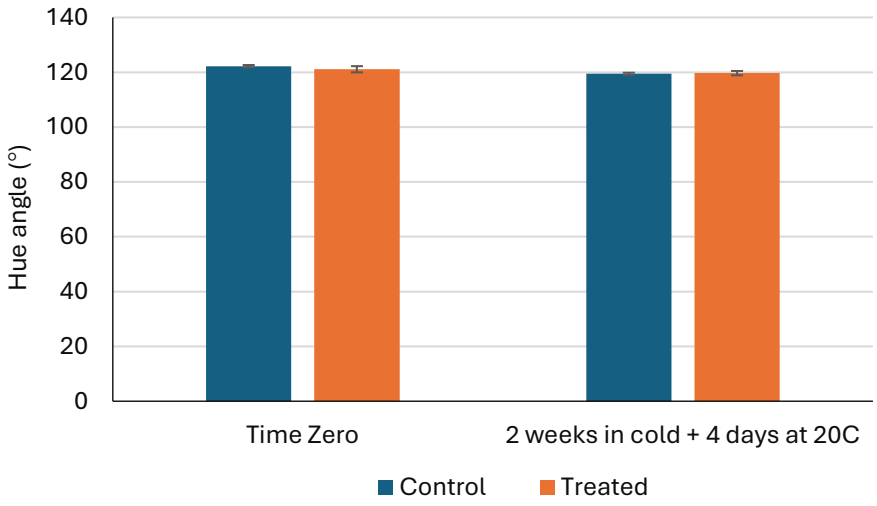


Figure 9. Hue angle (°) of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

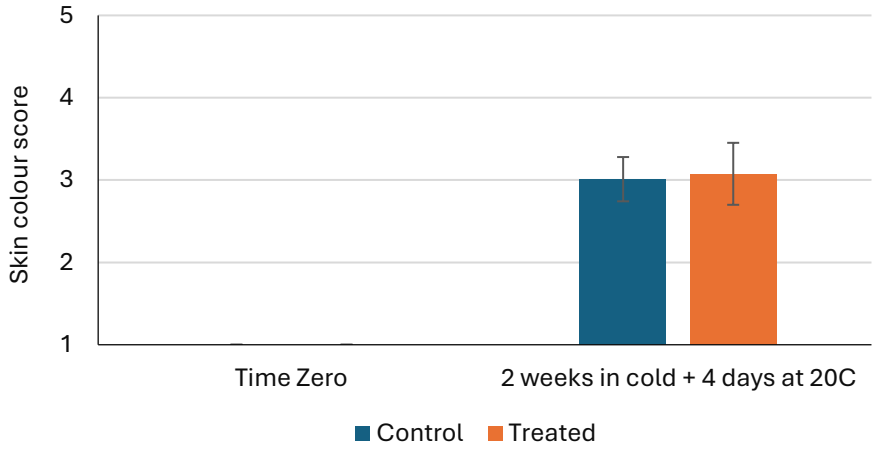


Figure 10. Subjective skin colour score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective skin colour score: 1 = unripe (emerald green and shiny), 2 = onset ripe (forest green and < 20% dark), 3 = ripe (black on green and 20 to 30% dark), 4 = eating ripe (green on black and 60 to 70% dark), and 5 = over-ripe (mostly black and > 70% dark). Bars are standard deviations around the means, *n* = 4.

Skin spotting. There were low levels of skin spotting on Shepard avocados and no difference between treated and non-treated fruit.

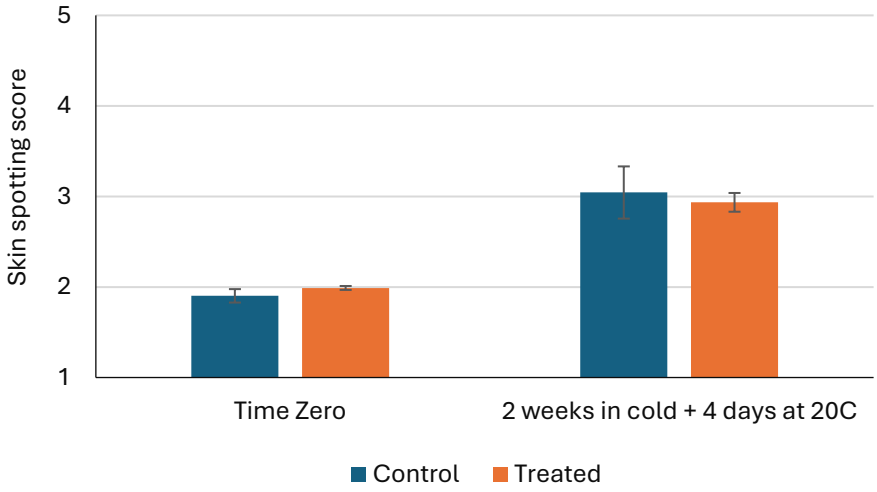


Figure 11. Subjective skin spotting score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective skin spotting score: 1 = 0% of fruit surface, 2 = 1 – 5% of fruit surface, 3 = 5 – 10% of fruit surface, 4 = 10 – 25% of fruit surface and 5 = >25% of fruit surface. Bars are standard deviations around the means, *n* = 4.

Flesh bruising. There was no flesh bruising in any fruit or treatment (Figures 12 and 13).

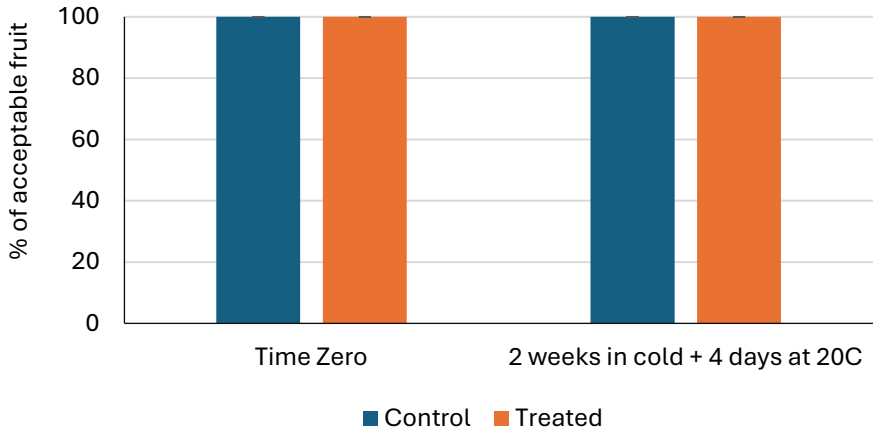


Figure 12. Percentage of acceptable fruit (%) with flesh bruising of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

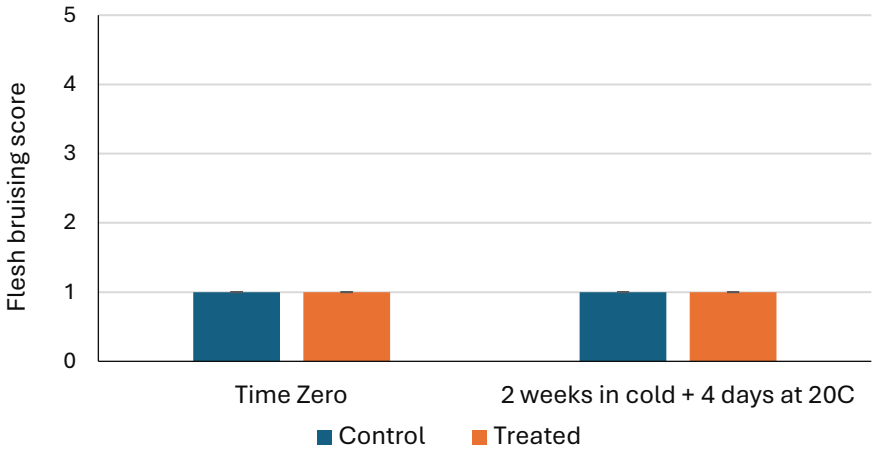


Figure 13. Subjective flesh bruising score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective flesh bruising score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Stem end rots. There were no stem end rots immediately after treatment, but after 2 weeks at 7 °C + 4 days at 20 °C, the treated fruit had higher numbers of fruit with more severity of stem end rots (Figures 14-16).

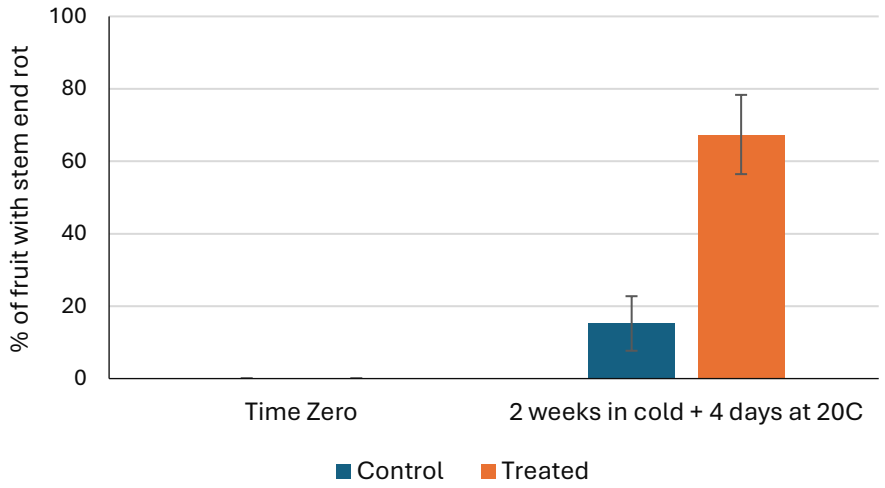


Figure 14. Percentage of fruit (%) with stem end rot of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

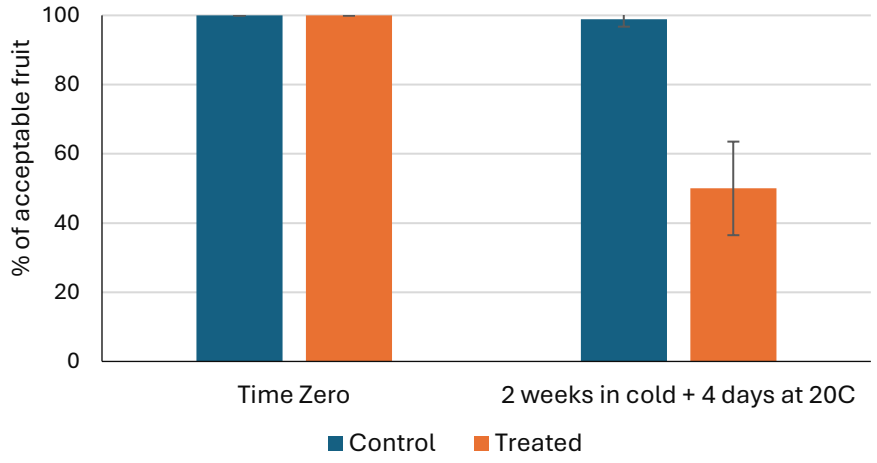


Figure 15. Percentage of acceptable fruit (%) with stem end rot of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

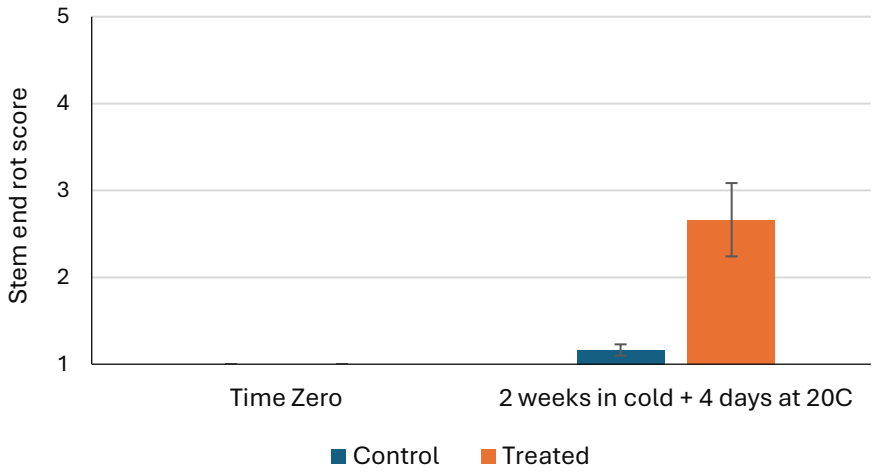


Figure 16. Subjective stem end rot score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective stem end rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Vascular browning. There was little vascular browning in any treatment immediately after treatment, but after storage and shelf life the levels and severity of vascular browning in the flesh of treated fruit was very high and unacceptable, while the untreated fruit remained acceptable (Figures 17-19).

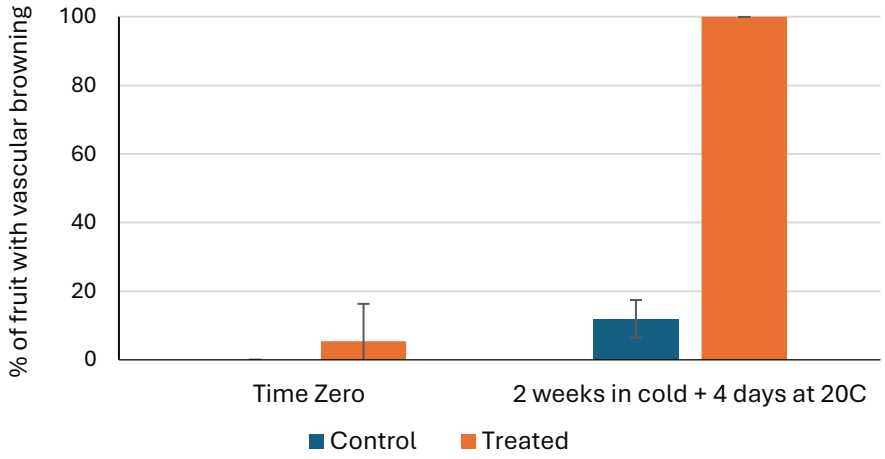


Figure 17. Percentage of fruit (%) with vascular browning of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

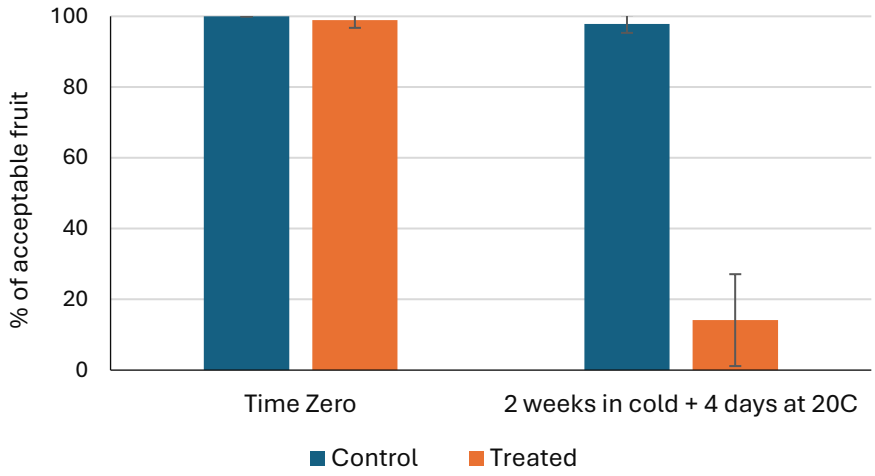


Figure 18. Percentage of acceptable fruit (%) with vascular browning of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

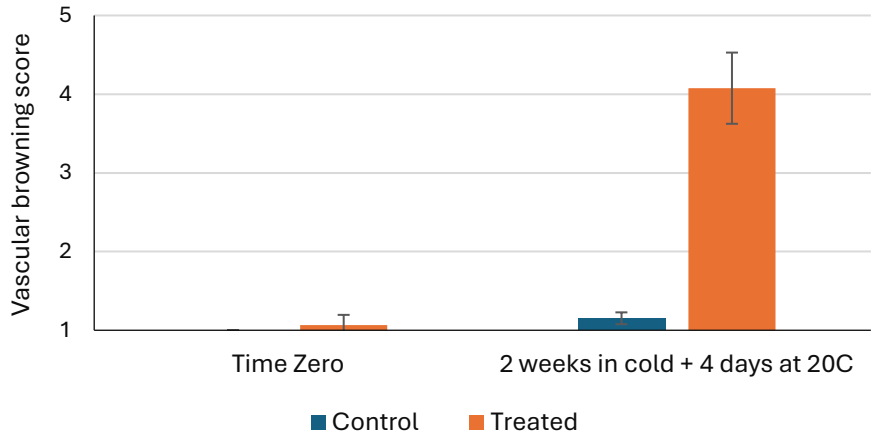


Figure 19. Subjective vascular browning score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective vascular browning score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 –25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Diffuse discolouration. The levels of flesh diffuse discolouration were higher in treated fruit, particularly after storage and shelf life (Figures 20-22).

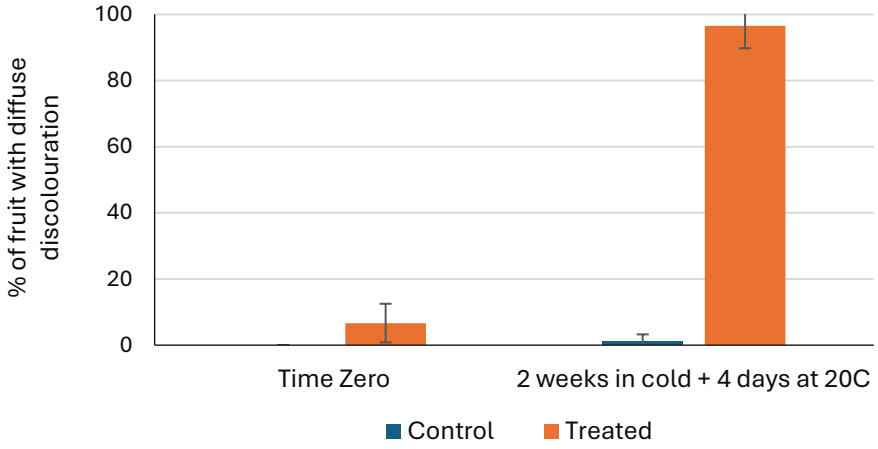


Figure 20. Percentage of fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

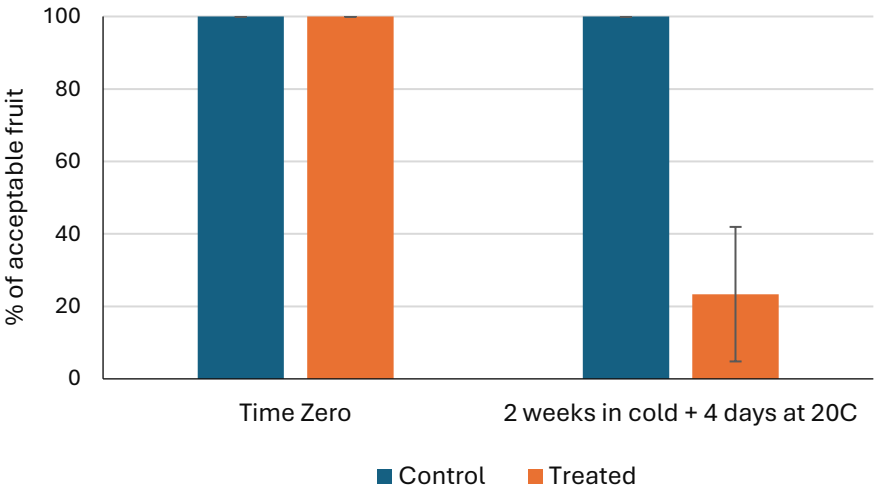


Figure 21. Percentage of acceptable fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

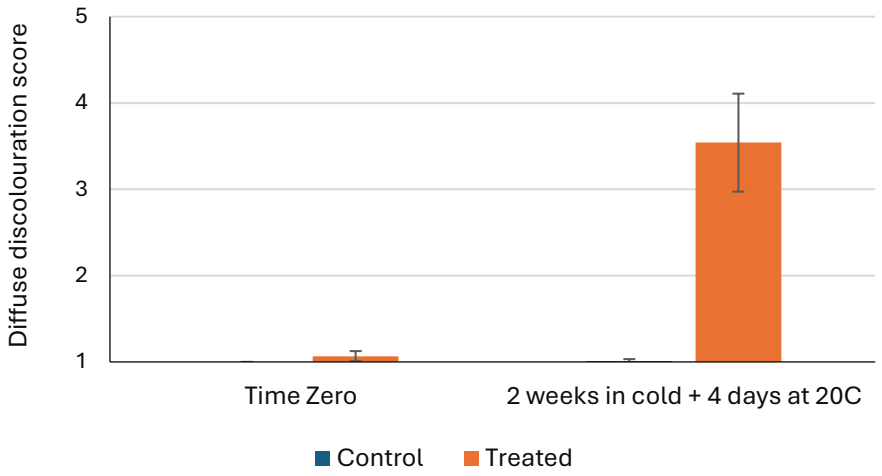


Figure 22. Subjective diffuse discolouration score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective diffuse discolouration score: 1 = 0% of flesh volume, 2 = 1 – 5 % of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Body rots. There were no body rots in any fruit upon arrival of the fruit (assessment 1), but after 2 weeks at 7 °C + 4 days at 20 °C, the treated fruit had higher numbers and greater severity of body rots than the untreated fruit (Figures 23-25).

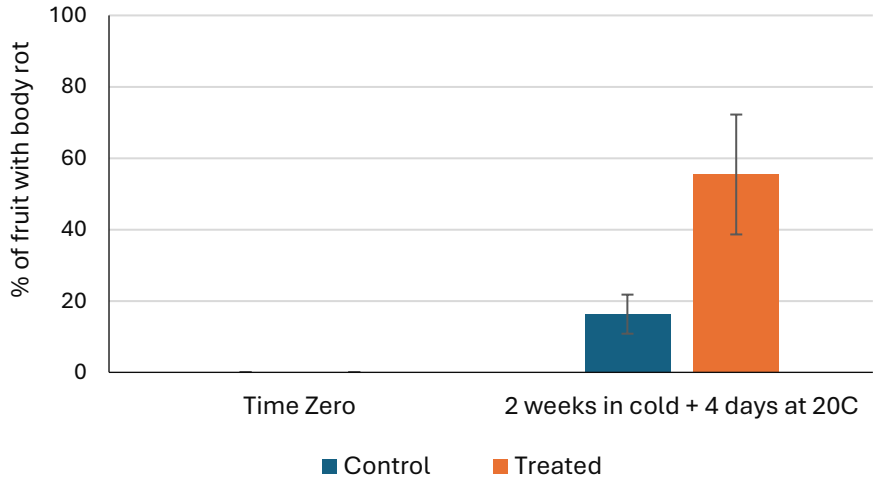


Figure 23. Percentage of fruit (%) with body rot of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

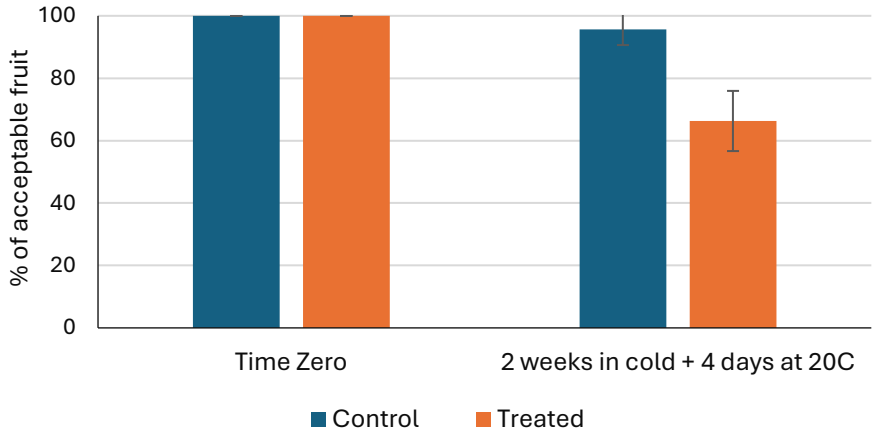


Figure 24. Percentage of acceptable fruit (%) with body rot of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

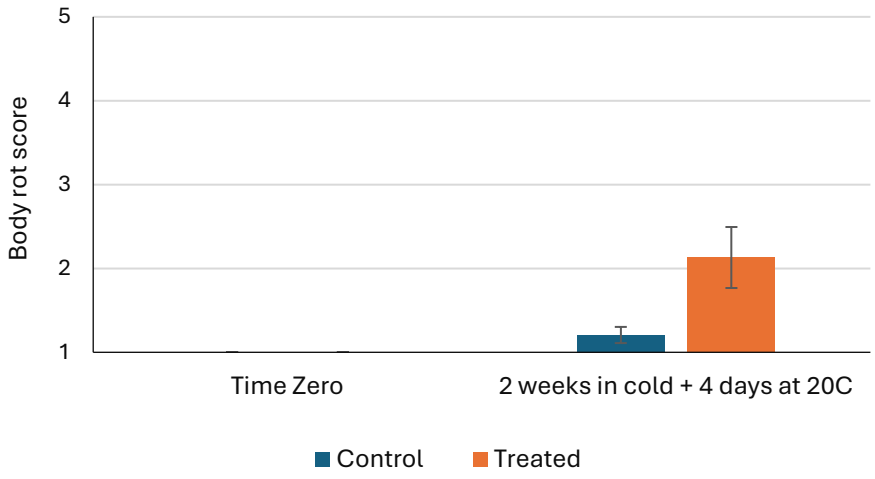


Figure 25. Subjective body rot score of the control and irradiated (treated) avocados at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective body rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume.
Bars are standard deviations around the means, *n* = 4.

Taste testing. An informal untrained taste test was conducted at the assessment 2 (avocado stored for 2 weeks at 7 ^{o}C and 4 days at 20 ^{o}C) to evaluate how the untreated and treated Shepard avocado tasted. The tasters / assessors were asked to describe the texture of both untreated and treated avocado (Table 1). The results show the treated fruit were not acceptable for consumers.

Table 1. Informal consumer assessment of texture and flavour of treated and untreated Shepard avocado following treatment and storage at 2 weeks at 7 ^{o}C and 4 days at 20 ^{o}C.

Taster / assessor	**Untreated**	**Treated**
1	Soft, good creaming texture, tasting like avocado, maybe a little watery but good	No favour, very dry, not avocado taste/texture, Poor texture, chalky
2	Moist, creamy and flavoured	Firm, dry and less flavour
3	Creamy and soft	Dry tasting, taste like potato and leave a strange taste in mouth
4	Soft, creamy and good flavour	Dry and starchy like cooked potato

Photos of treated and untreated Shepard avocados after treatment (Time Zero), upon removal from 2 weeks in cold storage and also after an additional 4 days at 20 °C.

Time Zero

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Time Zero

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Time Zero

Untreated

Treated

Untreated

Treated

Time Zero

Untreated

Treated

Untreated

Treated

Assessment 2: Upon removal (2 weeks in cold)

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2: Upon removal (2 weeks in cold)

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2: 2 weeks in cold + 4 days at 20 °C

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2: 2 weeks in cold + 4 days at 20 °C

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2: 2 weeks in cold + 4 days at 20 °C

Untreated Rep 1

Rep 2

Rep 3

Rep 4

Assessment 2: 2 weeks in cold + 4 days at 20 °C

Treated Rep 1 Rep 2

Rep 3 Rep 4

Untreated Treated

Assessment 2: 2 weeks in cold + 4 days at 20 °C

Untreated

Treated

Untreated

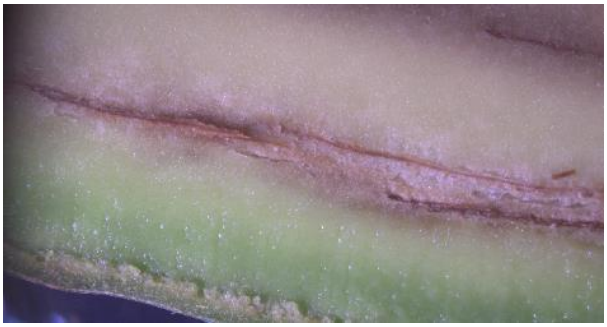
Treated

Untreated (Top)

Treated (Lower)

Assessment 2: 2 weeks in cold + 4 days at 20 °C

Under light microscope

Untreated	Treated
	
	
	
	

Appendix 4. Experiment 3 – Hass x2

Effects of phytosanitary irradiation on Hass avocado from 2 Queensland growers

Aim. Examine the effects of phytosanitary irradiation on quality of Hass avocados from North Queensland and Central Queensland growers.

Methods. Export-grade Hass avocados were sourced from two commercial growers (North Queensland (Atherton) and Central Queensland (Isis). Fruit were transported to Steritech in Melbourne and treated with 150 Gy X-ray treatment on 19 June 2024. The other half of the fruit were untreated (control) and handled the same way. After treatment, fruit were transported to NSW Department of Primary Industries at Ourimbah where fruit quality was assessed at two assessment times; upon receipt of fruit (2 days after treatment, time zero), and after 14 days storage at 7 °C and 4 days at 20 °C. Four replicates were allocated from each treatment and each treatment unit was a tray of fruit. A batch of Shepard avocados were planned for this trial but were not included as the quality of the fruit were poor and unacceptable for export storage trials.

Results.

Fruit firmness. The effects of treatment and storage time on fruit firmness of Hass avocados is presented in Figures 1 and 2 and show the fruit softened during storage and shelf life. Treated fruit tended to be firmer than untreated fruit.

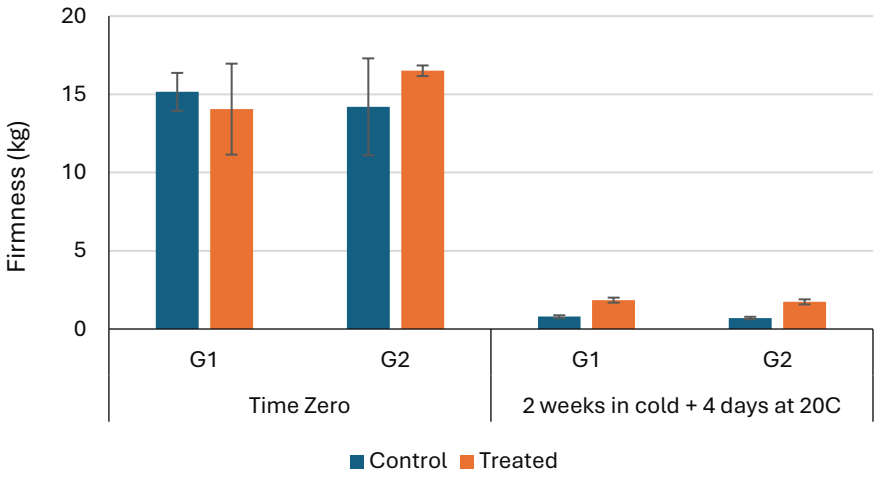


Figure 1. Objective firmness (kg) of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

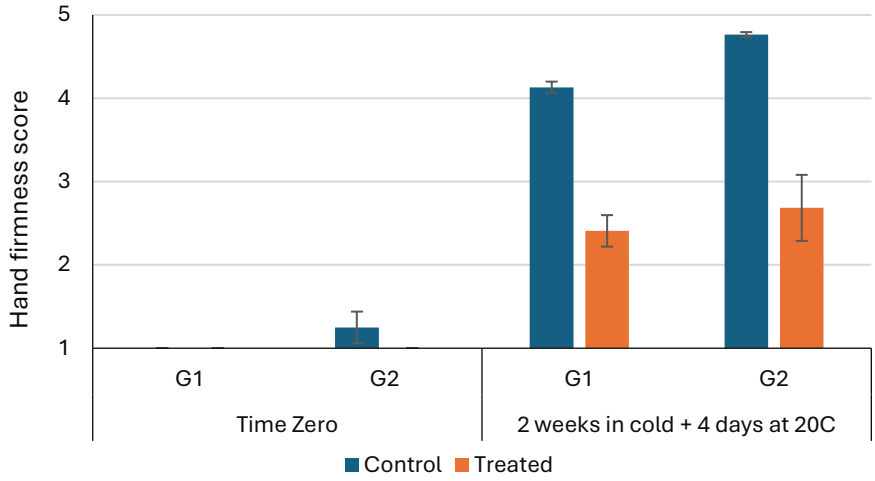


Figure 2. Subjective hand firmness score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective hand firmness score: 1 = hard (no give with strong thump pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2-3 mm with moderate thump pressure), 4 = firm ripe (deforms 2-3 mm with slight thumb pressure) and 5 = medium-soft ripe (deforms with moderate hand pressure).
Bars are standard deviations around the means, *n* = 4.

Ethylene production. The levels of ethylene production increased during storage and there were no consistent differences between treated and untreated fruit (Figure 3).

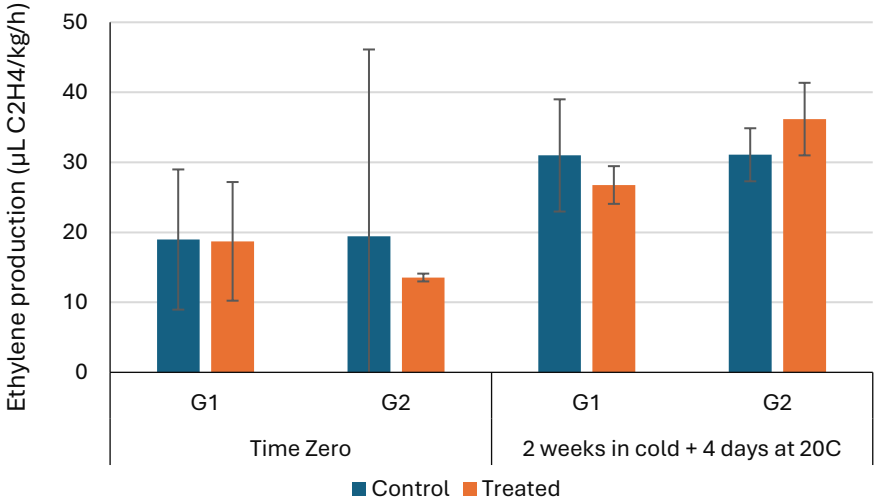


Figure 3. Ethylene production (µL C_2H_4/kg/h) of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Respiration rate. The fruit respiration rates increased during storage and there were no consistent differences between treated and untreated fruit (Figure 4).

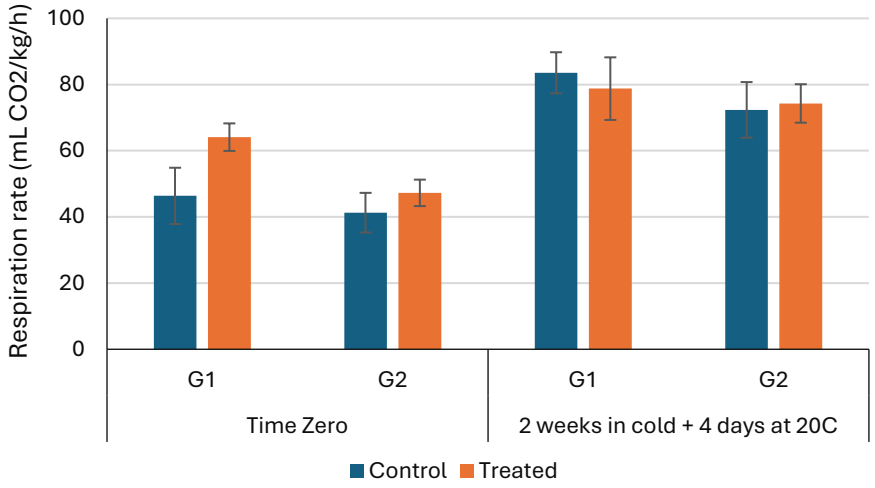


Figure 4. Respiration rate (mL CO_2/kg/h) of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

Dry matter. The levels of dry matter in the trial Hass avocados from the 2 growers were well above the dry matter standard (Figure 5).

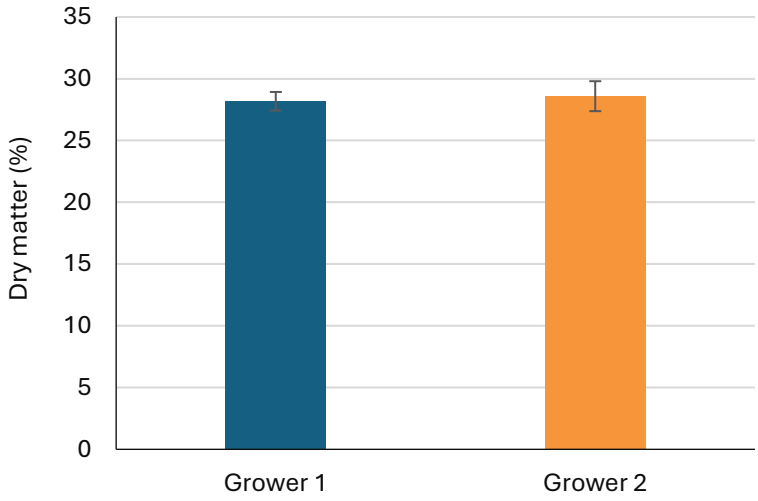


Figure 5. Dry matter (%) of avocados of 2 growers/regions (G) at Time Zero. Bars are standard deviations around the means, *n* = 4.

Weight loss. The levels of weight loss from the fruit are presented in Figure 6 and shows increasing fruit weight loss with storage time, where treated fruit tended to have slightly higher weight loss than untreated fruit.

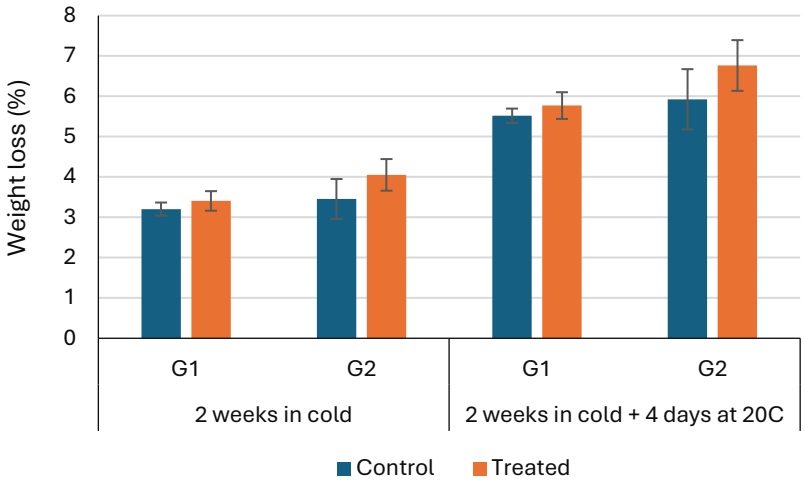


Figure 6. Percentage of weight loss (%) of the control and irradiated (treated) avocados of 2 growers/regions (G) after 2 weeks at 7 °C and 2 weeks at 7 °C plus 4 days at 20 °C.
Bars are standard deviations around the means, *n* = 4.

Skin fruit colour. The objective colour of the Hass skin as measured with the Minolta colour meter is presented in Figures 7-9 and show treated fruit had higher chroma and hue angles after storage and shelf life. The results of the subjective skin colour score validated these measurements with treated fruit having delayed green colour development after storage and shelf life.

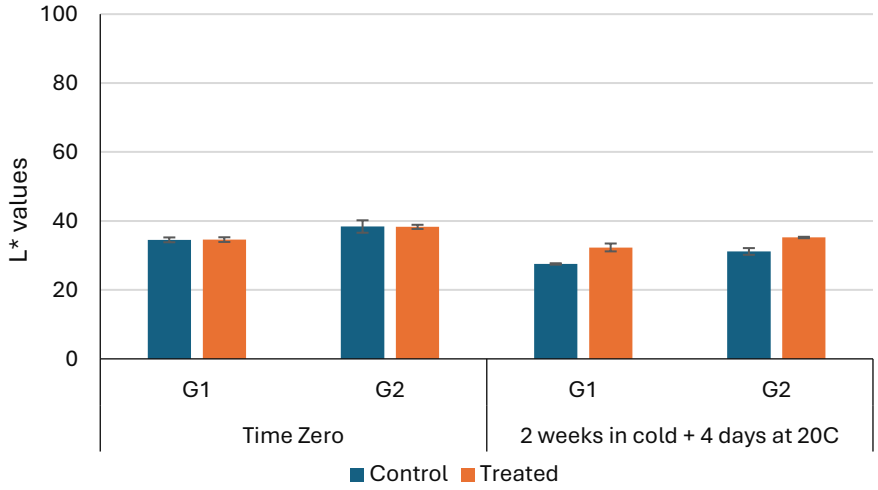


Figure 7. L* values of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

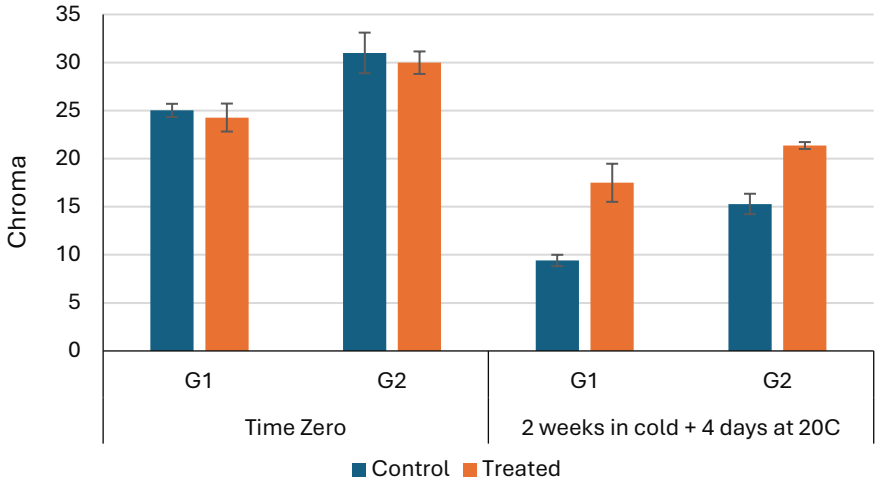


Figure 8. Chroma values of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

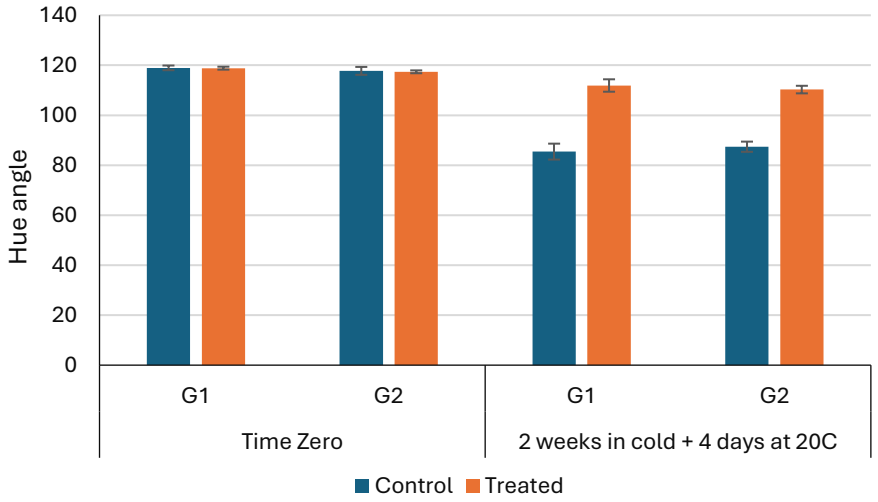


Figure 9. Hue angles (°) of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

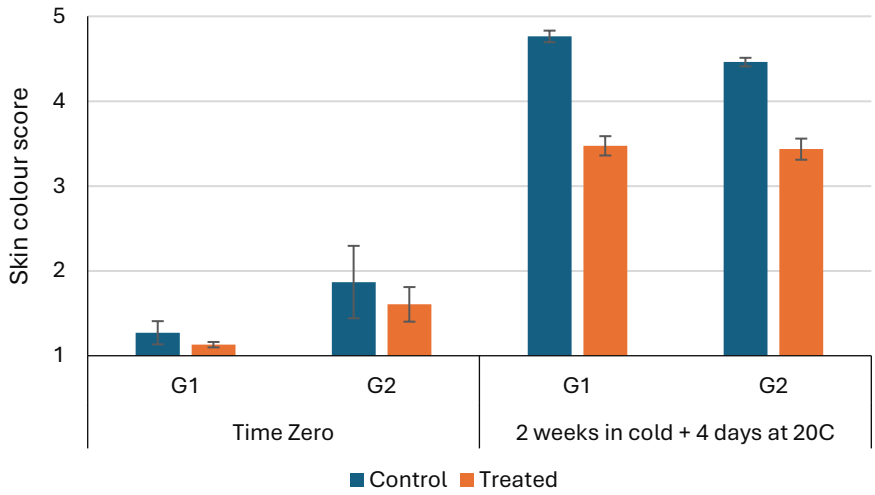


Figure 10. Subjective skin colour score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective skin colour score: 1 = emerald green, 2 = forest green, 3 = 1 – 25% coloured, 4 = 25 – 75% coloured and 5 = purple.
Bars are standard deviations around the means, *n* = 4.

Skin spotting. Treatment increased the levels of skin spotting (Figure 11) immediately after treatment. Due to the progression of ripening (purple colour development in the skin), skin spotting was not visible after storage.

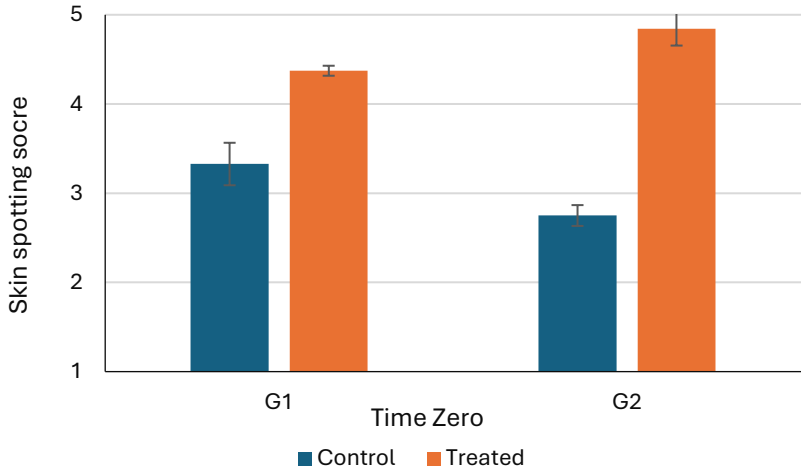


Figure 11. Subjective skin spotting score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero. Subjective skin spotting score: 1 = 0% of fruit surface, 2 = 1 – 5% of fruit surface, 3 = 5 – 10% of fruit surface, 4 = 10 – 25% of fruit surface and 5 = >25% of fruit surface.
Bars are standard deviations around the means, *n* = 4.

Flesh bruising. The levels of fruit bruising were low but were slightly higher in the untreated fruit (Figures 12 - 14).

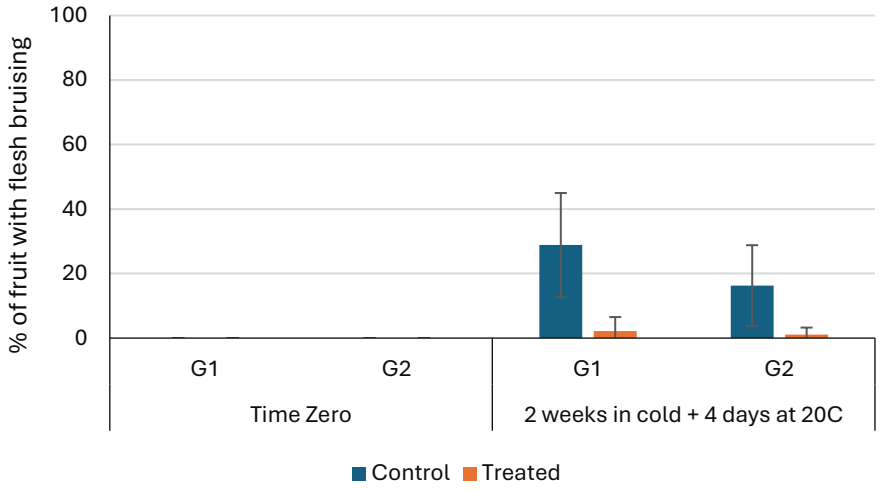


Figure 12. Percentage of fruit with flesh bruising (%) of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

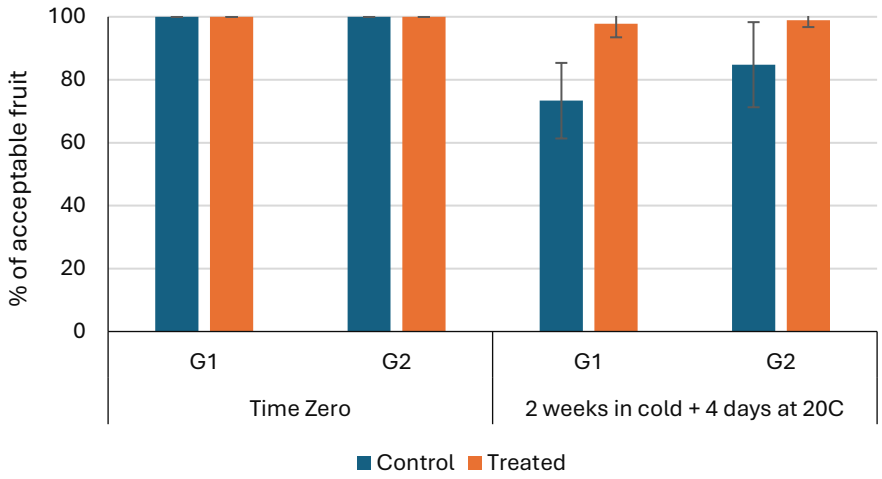


Figure 13. Percentage of acceptable fruit with flesh bruising (%) of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

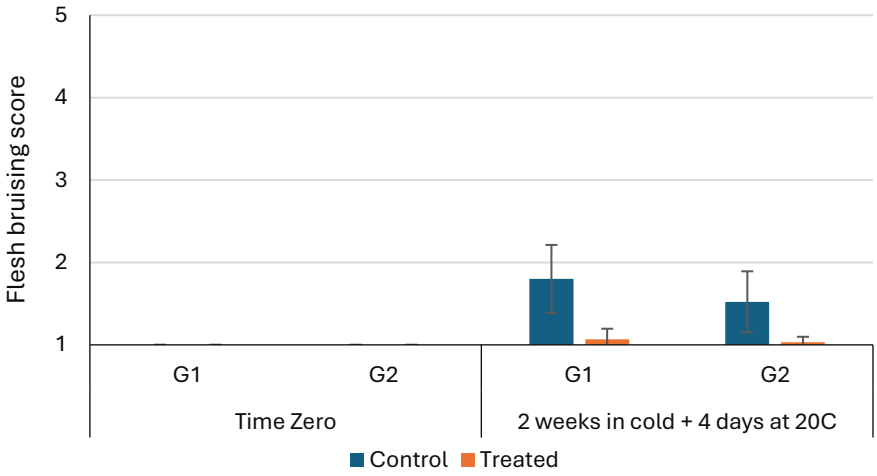


Figure 14. Subjective flesh bruising score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective flesh bruising score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Stem end rots. The number of fruit with stem end rots were higher in treated fruit after storage and shelf life (Figure 15), and the severity of rots were also higher in treated fruit (Figure 16). There were no stem end rots detected at assessment 1 (time zero – upon arrival).

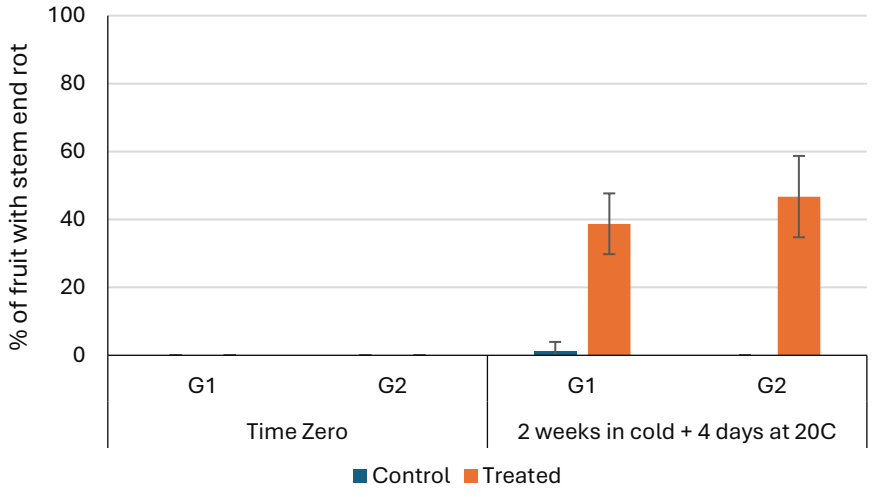


Figure 15. Percentage of fruit (%) with stem end rot of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

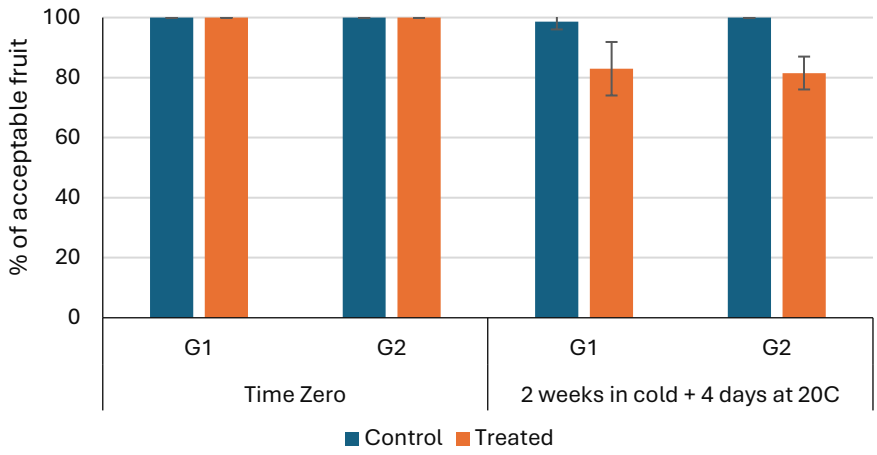


Figure 16. Percentage of acceptable fruit (%) with stem end rot of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

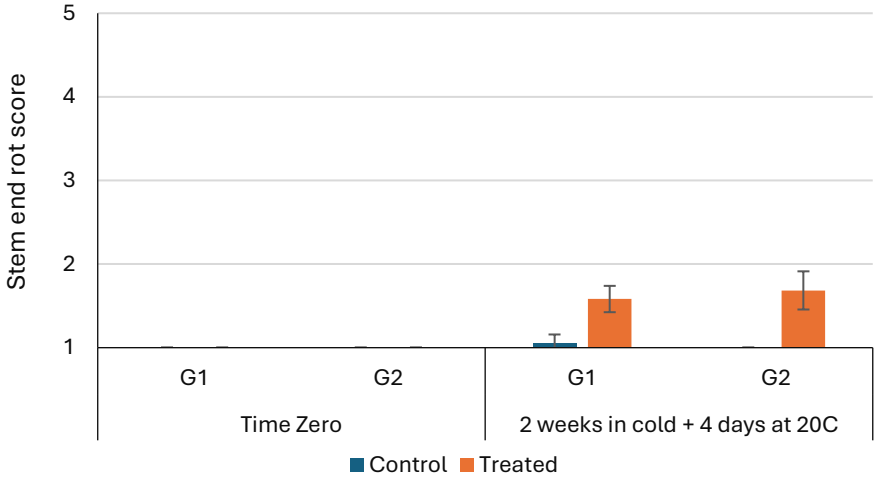


Figure 17. Subjective stem end rot score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective stem end rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Vascular browning. The levels of vascular browning were higher in treated fruit (Figure 18 and 20). This was observed after treatment (time zero) and after storage and shelf life. The severity of vascular browning in treated fruit was high which resulted in high levels of unacceptable fruit (Figure 19).

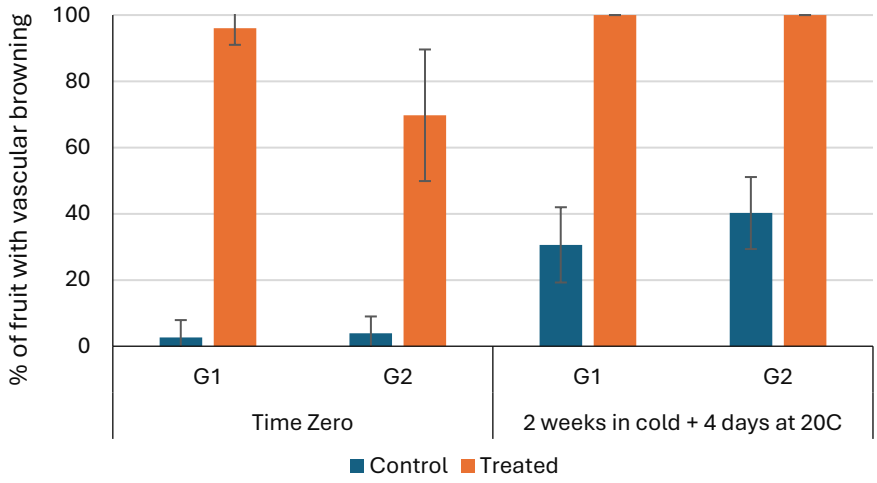


Figure 18. Percentage of fruit (%) with vascular browning of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

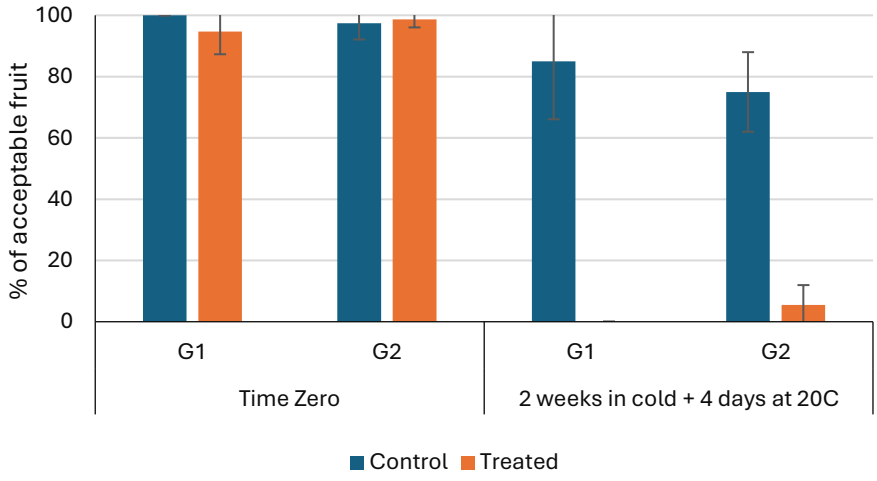


Figure 19. Percentage of acceptable fruit (%) with vascular browning of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

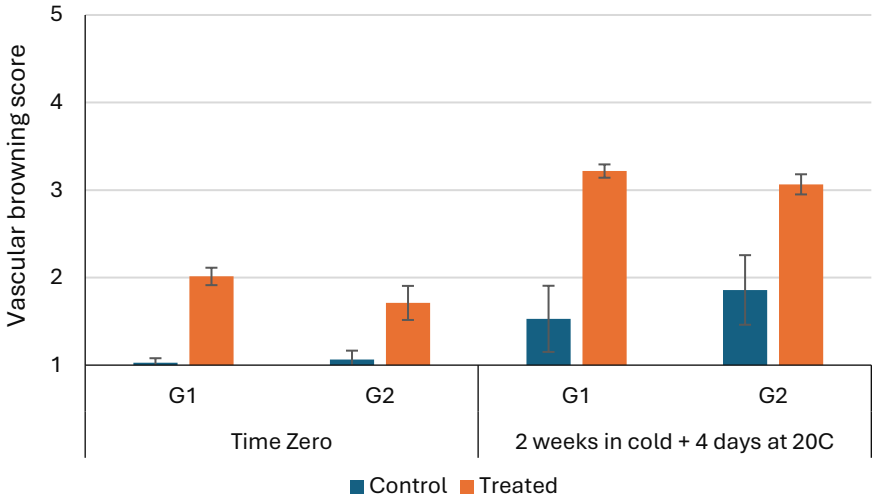


Figure 20. Subjective vascular browning score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective vascular browning score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 –25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Diffuse discolouration. The levels of diffuse discolouration were higher in treated fruit at all assessment times (Figure 21 and 23). No diffuse discolouration was observed in the untreated fruit at assessment 1, but with significant levels observed in treated fruit from Grower 2 at this time. These levels increased during storage and shelf life.

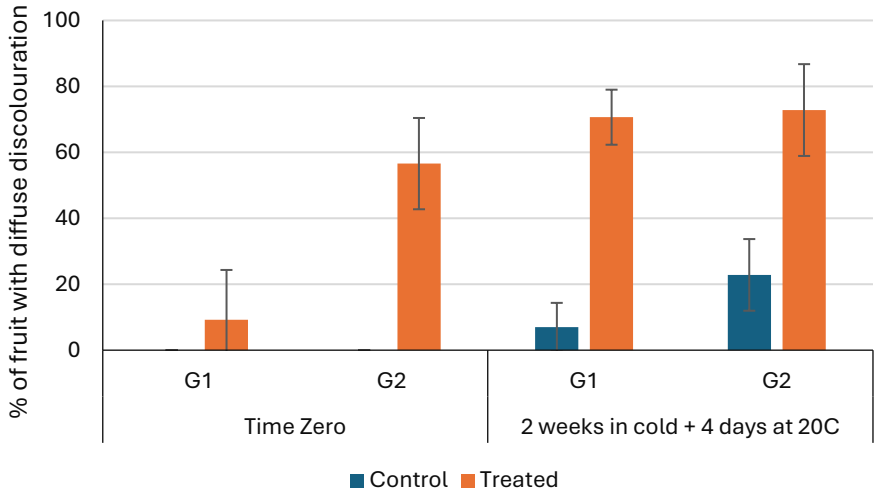


Figure 21. Percentage of fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

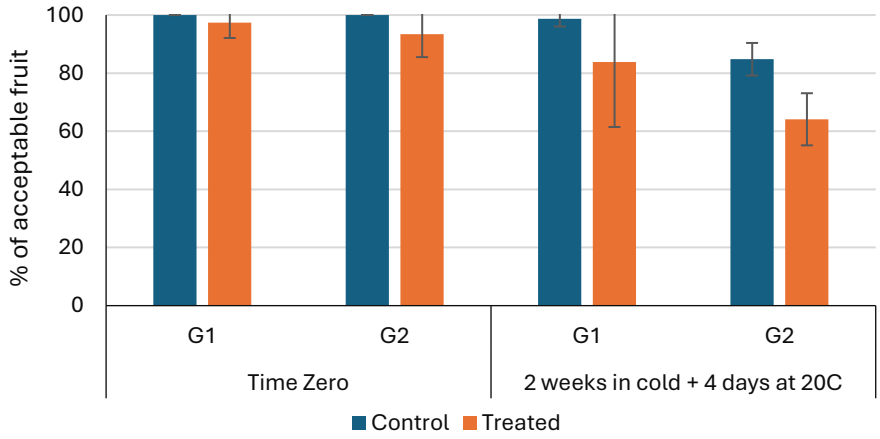


Figure 22. Percentage of acceptable fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

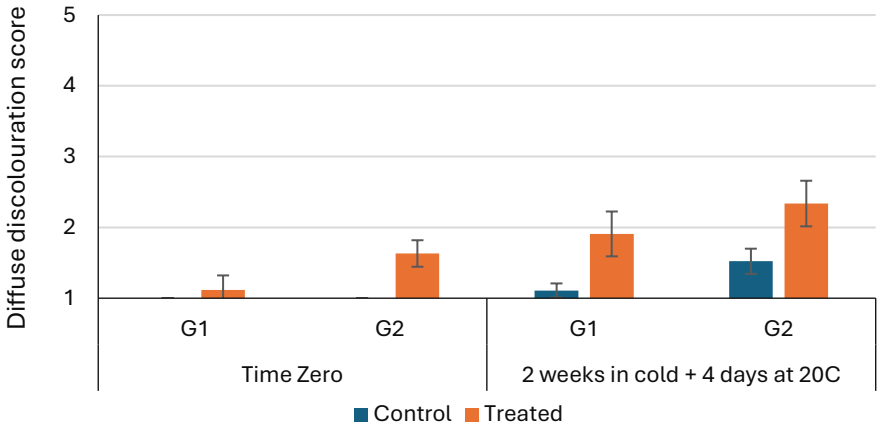


Figure 23. Subjective diffuse discolouration score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective diffuse discolouration score: 1 = 0% of flesh volume, 2 = 1 – 5 % of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume.
Bars are standard deviations around the means, *n* = 4.

Body rots. There were no body rots detected at assessment 1 (time zero) in any treatment, but after storage and shelf life, treated fruit had higher levels of body rots than untreated fruit resulting in more unacceptable fruit (Figures 24-26).

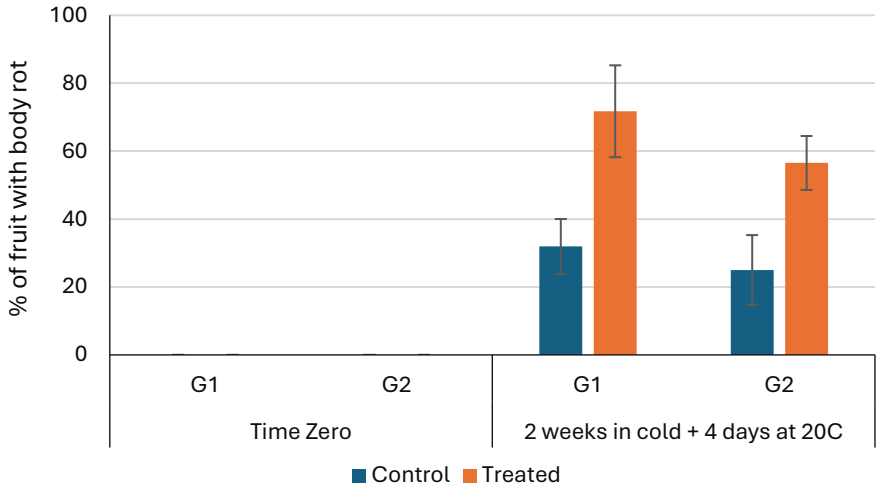


Figure 24. Percentage of fruit (%) with body rot of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

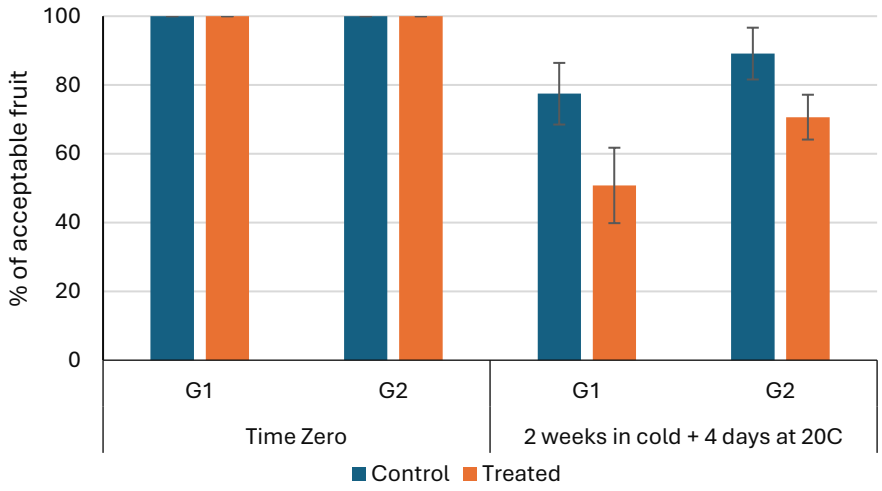


Figure 25. Percentage of acceptable fruit (%) with body rots of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

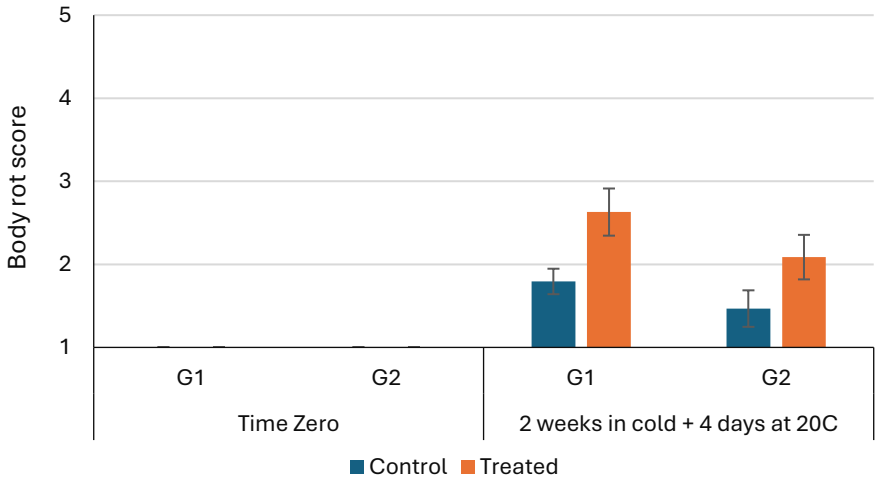


Figure 26. Subjective body rot score of the control and irradiated (treated) avocados of 2 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective body rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Time Zero. Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Time Zero

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Time Zero

Grower 1

Untreated Rep 1 Rep 2

Rep 3 Rep 4

Time Zero

Grower 1

Treated Rep 1 Rep 2

Rep 3 Rep 4

Time Zero

Grower 1 Untreated Treated

Grower 1 Untreated Treated

Assessment 2. 2 weeks in cold + 4 days at 20 °C

Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2. 2 weeks in cold + 4 days at 20 °C

Grower 1

Rep 3 Untreated Treated

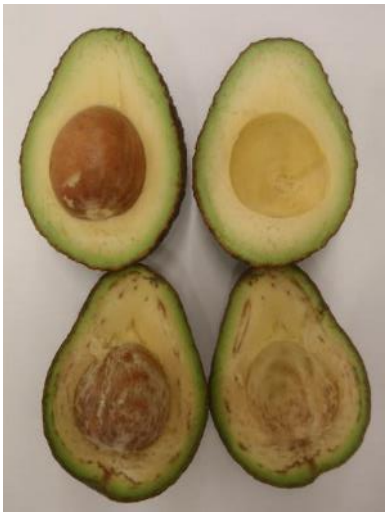
Rep 4 Untreated Treated

Assessment 2. 2 weeks in cold + 4 days at 20 °C

Grower 1

Untreated (Top)

Treated (Lower)



Untreated (Top)

Treated (Lower)

Untreated

Treated

Appendix 5. Experiment 4 – Hass x3

Effects of phytosanitary irradiation on Hass avocado from 3 Queensland growers

Aim. Examine the effects of phytosanitary irradiation on quality of Hass avocados from North Queensland, Central Queensland and South-East Queensland growers.

Methods. Export-grade Hass avocados were sourced from three commercial growers (North Queensland (Atherton), Central Queensland (Isis) and South-East Queensland (Ravensbourne). Fruit were transported to Steritech in Melbourne and treated with 150 Gy X-ray treatment on 3 July 2024. The other half of the fruit were untreated (control) and handled the same way. After treatment, fruit were transported to NSW Department of Primary Industries at Ourimbah where fruit quality was assessed at two assessment times; upon receipt of fruit (2 days after treatment, time zero), and after 14 days storage at 7 °C and 4 days at 20 °C. Four replicates were allocated from each treatment and each treatment unit was a tray of fruit.

Results.

Fruit firmness. The effects of treatment on Hass fruit firmness on 3 different grower lines are presented in Figures 1 and 2. The results show that the treated fruit retained higher firmness at both assessment times, even after the fruit had ripened, the treated fruit were subjectively firmer (Figure 2).

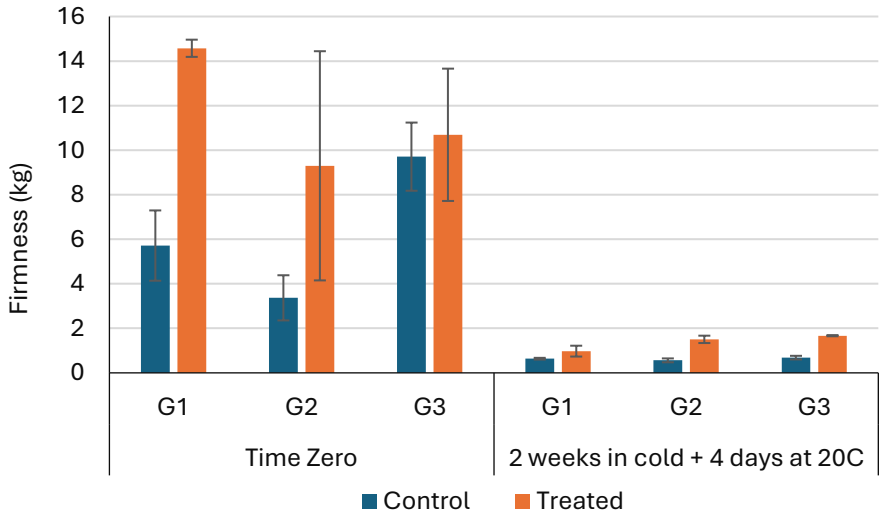


Figure 1. Objective firmness (kg) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

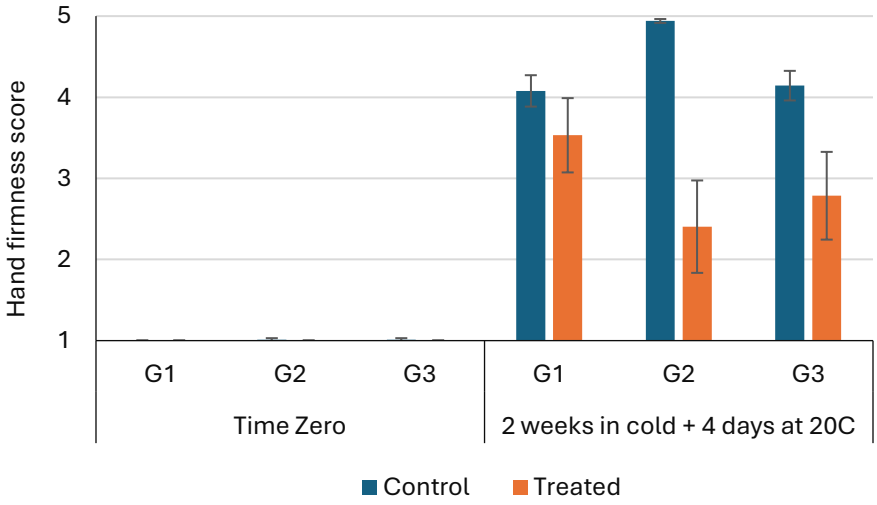


Figure 2. Subjective hand firmness score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective hand firmness score: 1 = hard (no give with strong thump pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2-3 mm with moderate thump pressure), 4 = firm ripe (deforms 2-3 mm with slight thumb pressure) and 5 = medium-soft ripe (deforms with moderate hand pressure).
Bars are standard deviations around the means, *n* = 4.

Ethylene production. The ethylene production rates between the treated and untreated fruit were similar (Figure 3), and the fruit in the second assessment (after storage) had lower ethylene production rates.

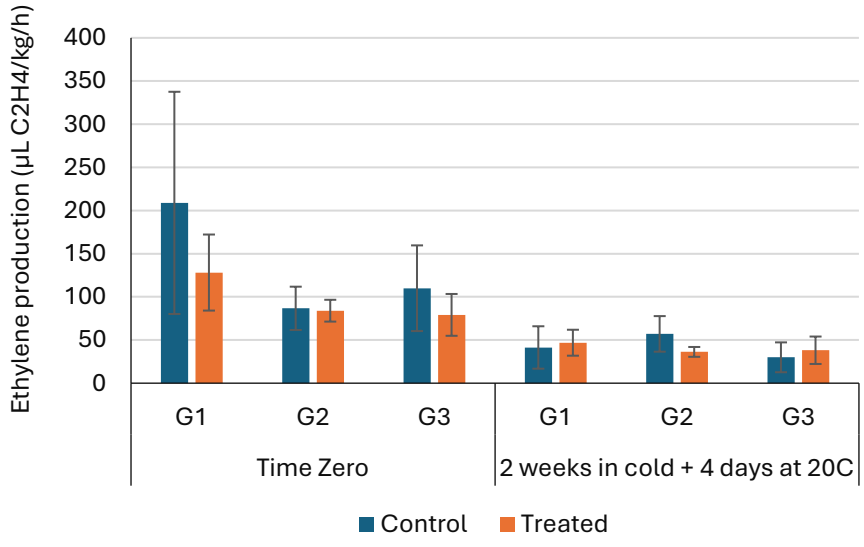


Figure 3. Ethylene production (µL C_2H_4/kg/h) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Respiration rate. There were few consistent differences in fruit respiration rates between treated and untreated avocados at each of the assessment times (Figure 4).

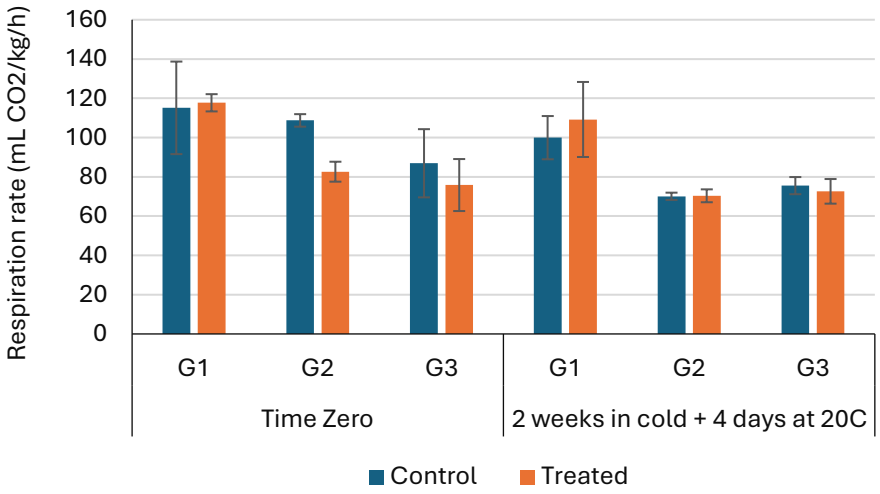


Figure 4. Respiration rate (mL CO_2/kg/h) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Dry matter. The dry matter of the Hass avocados from the 3 growers were all above the standard dry matter (Figure 5).

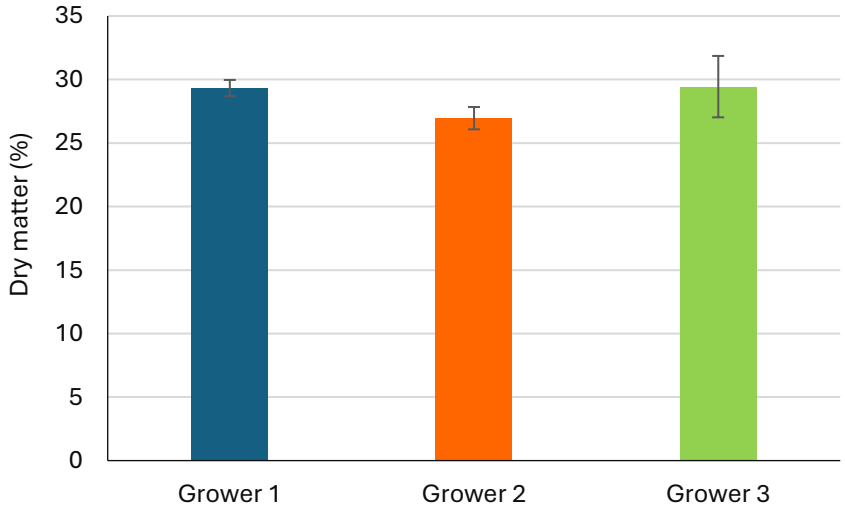


Figure 5. Dry matter (%) of avocados of 3 growers/regions (G) at Time Zero.
Bars are standard deviations around the means, *n* = 4.

Weight loss. As expected, fruit weight loss increased with storage time and shelf life, but there were no consistent differences between treatments (Figure 6).

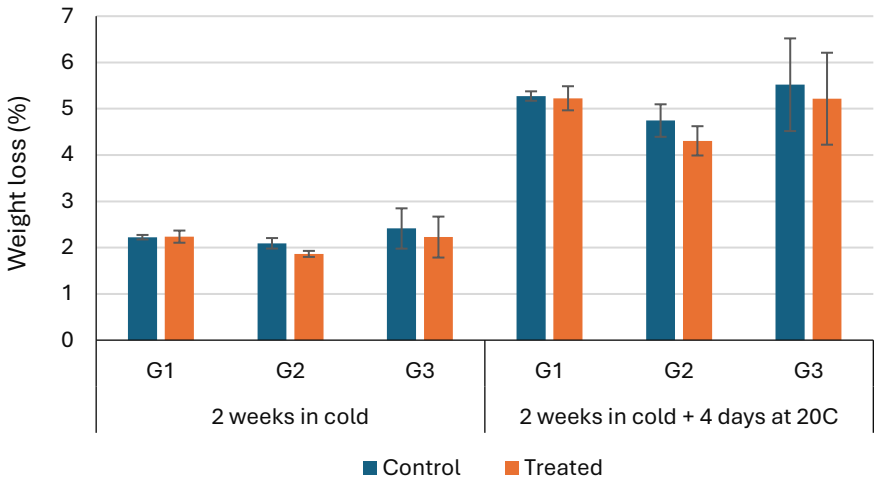


Figure 6. Percentage of weight loss (%) of the control and irradiated (treated) avocados of 3 growers/regions (G) after 2 weeks at 7 °C and 2 weeks at 7 °C plus 4 days at 20 °C.
Bars are standard deviations around the means, *n* = 4.

Fruit skin colour. The objective colour of the Hass skin in the 3 grower batches as measured with the Minolta colour meter are presented in Figures 7-9 and show treated fruit had higher L*, chroma and hue angles after storage and shelf life. The results of the subjective skin colour score validated these measurements with treated fruit having delayed colour development after storage and shelf life (Figure 10).

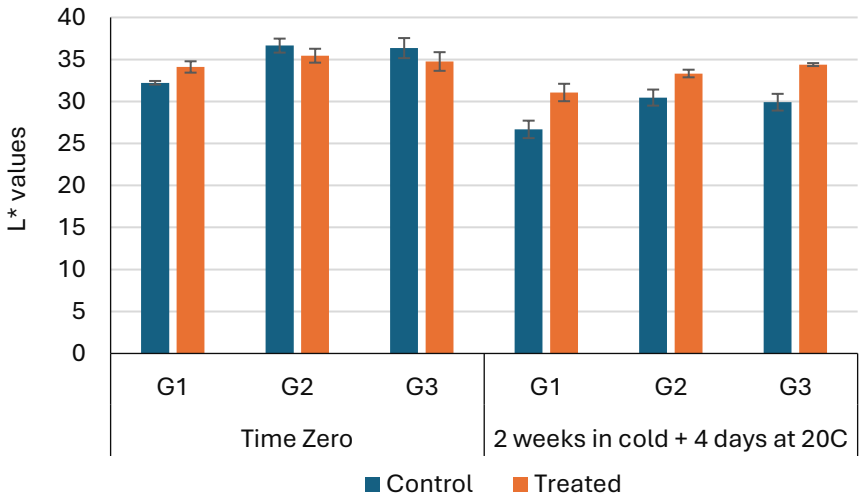


Figure 7. L* values of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

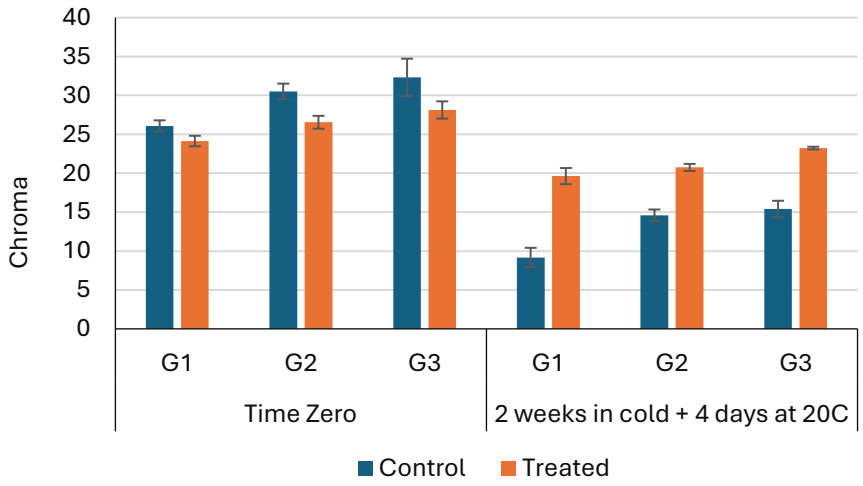


Figure 8. Chroma values of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

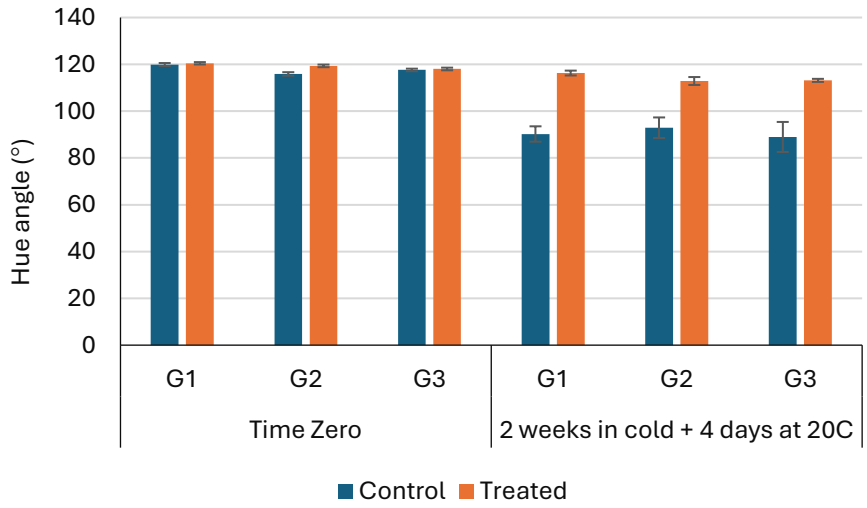


Figure 9. Hue angle (°) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

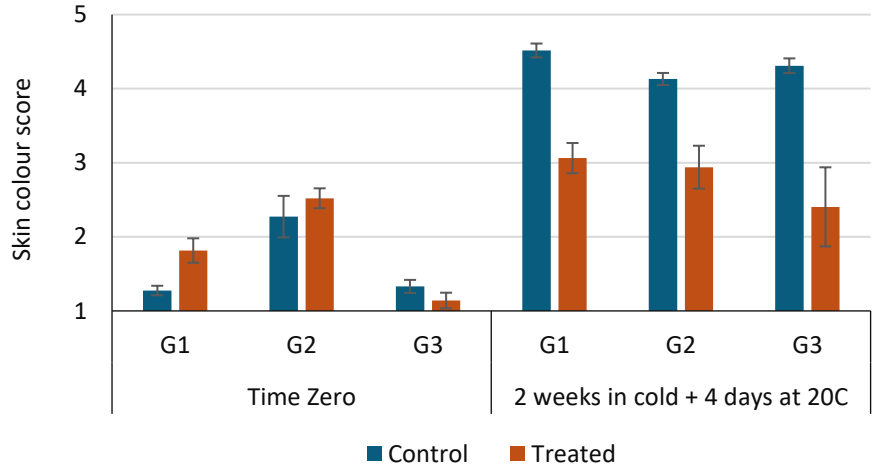


Figure 10. Subjective skin colour score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective skin colour score: 1 = emerald green, 2 = forest green, 3 = 1 – 25% coloured, 4 = 25 – 75% coloured and 5 = purple.
Bars are standard deviations around the means, *n* = 4.

Skin spotting. There were moderate levels of fruit spotting observed in all fruit at the beginning of the trial (time zero) (Figure 11). As the fruit ripened and the skin turned purple during storage, it was not possible to observe skin spotting in the second assessment time.

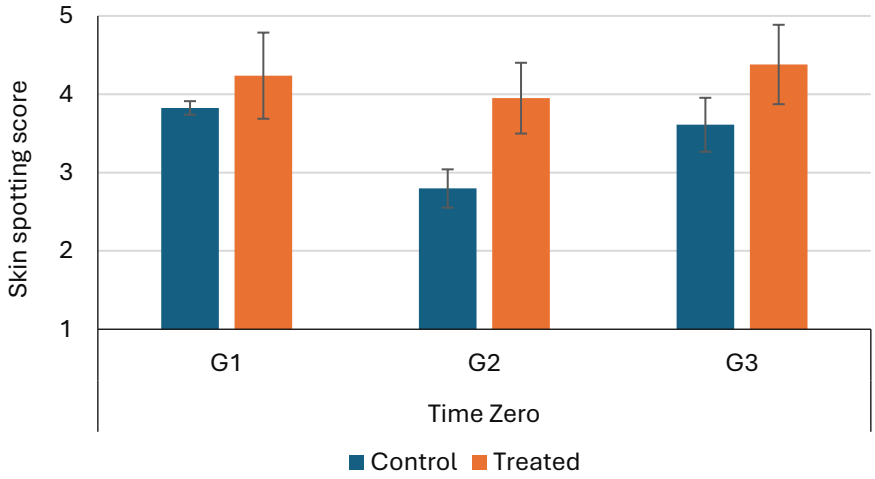


Figure 11. Subjective skin spotting score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero. Subjective skin spotting score: 1 = 0% of fruit surface, 2 = 1 – 5% of fruit surface, 3 = 5 – 10% of fruit surface, 4 = 10 – 25% of fruit surface and 5 = >25% of fruit surface.
Bars are standard deviations around the means, *n* = 4.

Flesh bruising. There were very low levels of flesh bruising in all fruit both treatments, and all fruit were acceptable (Figures 12-14).

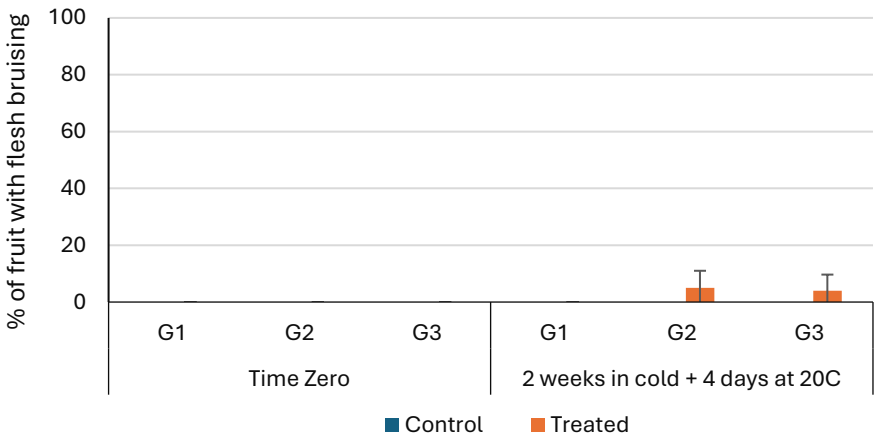


Figure 12. Percentage of fruit with flesh bruising (%) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

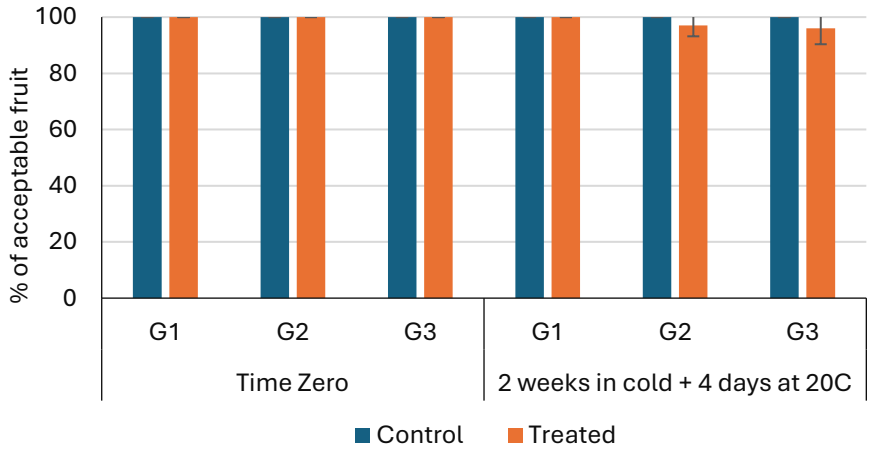


Figure 13. Percentage of acceptable fruit with flesh bruising (%) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

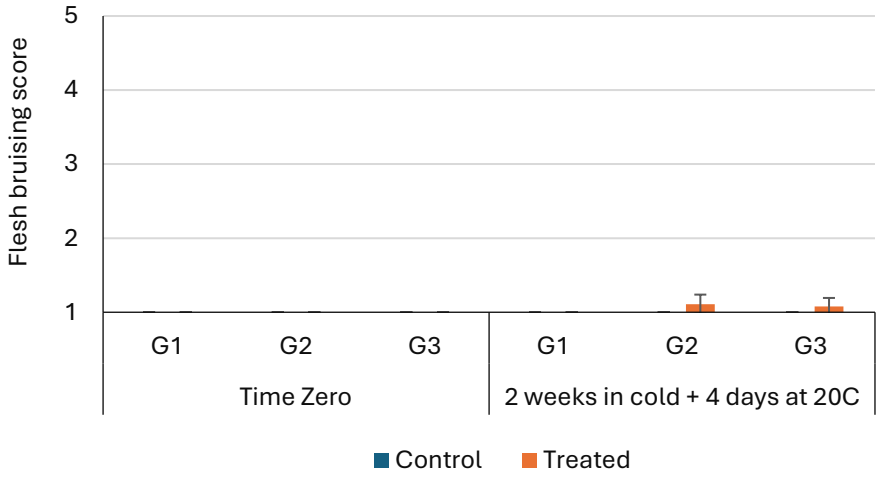


Figure 14. Subjective flesh bruising score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective flesh bruising score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Stem end rots. There were no stem end rots observed at the beginning of the experiment, but in the second assessment (2 weeks at 7 °C + 4 days at 20 °C), there was an increase in the number and severity of fruit with stem end rots (Figures 15-17). There were few differences between treated and untreated fruit, except for Grower 1, where the treated fruit had higher incidence and severity of stem end rots.

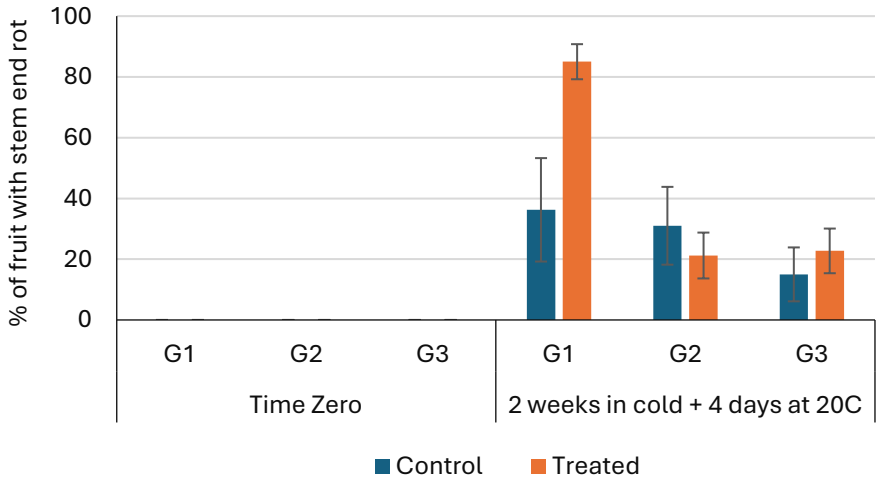


Figure 15. Percentage of fruit (%) with stem end rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

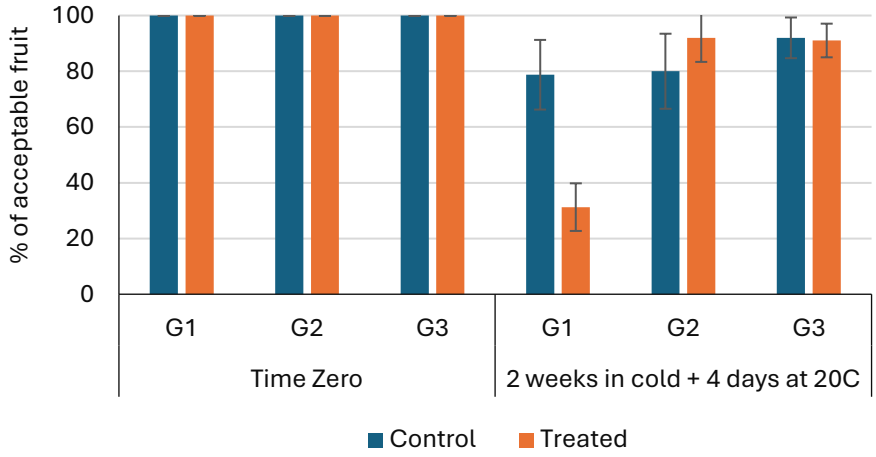


Figure 16. Percentage of acceptable fruit (%) with stem end rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

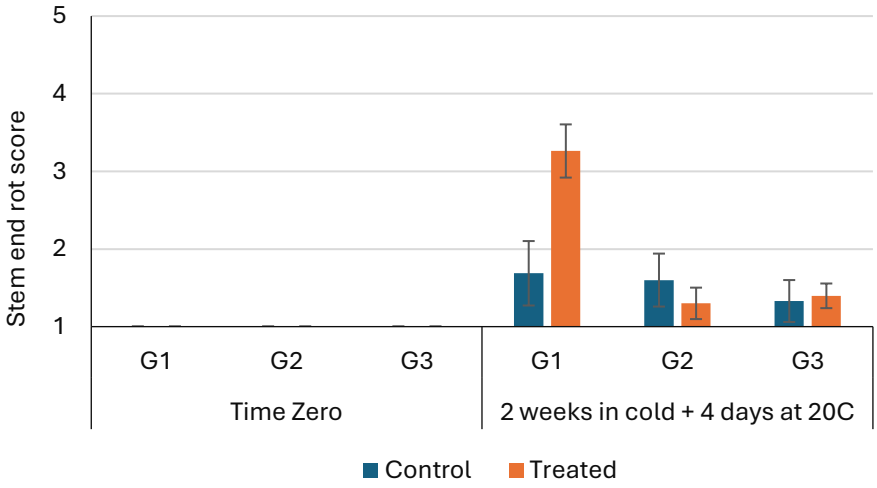


Figure 17. Subjective stem end rot score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective stem end rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Vascular browning. The levels of vascular browning were very high in treated fruit from Grower 1 at the beginning of the trial, whilst these levels were much lower in untreated fruit at the same time (Figure 18). Similar differences were observed in fruit from Grower 2 and 3, but these initial levels of vascular browning were lower in the treated fruit. All fruit had vascular browning after 2 weeks at 7 °C + 4 days at 20 °C. While there were similar levels of vascular browning severity between treated and untreated fruit (Figure 20), the percentage of unacceptable fruit was lower in the treated fruit after storage and shelf-life (Figure 19)

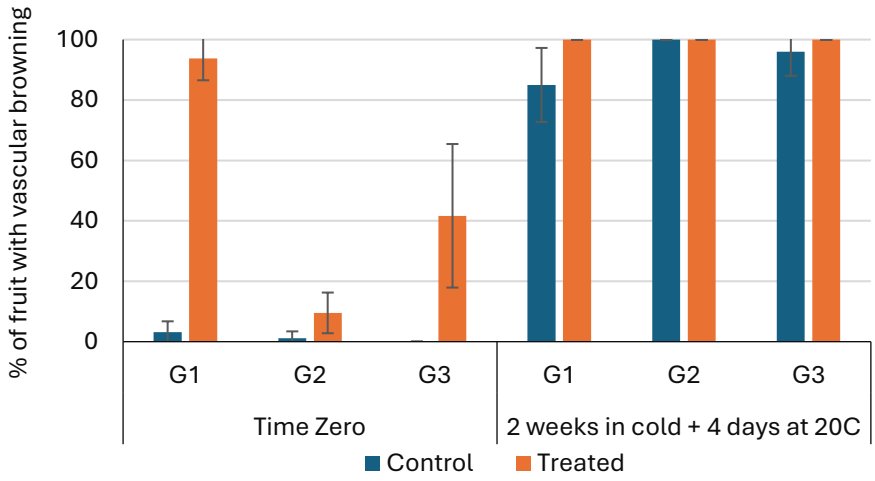


Figure 18. Percentage of fruit (%) with vascular browning of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

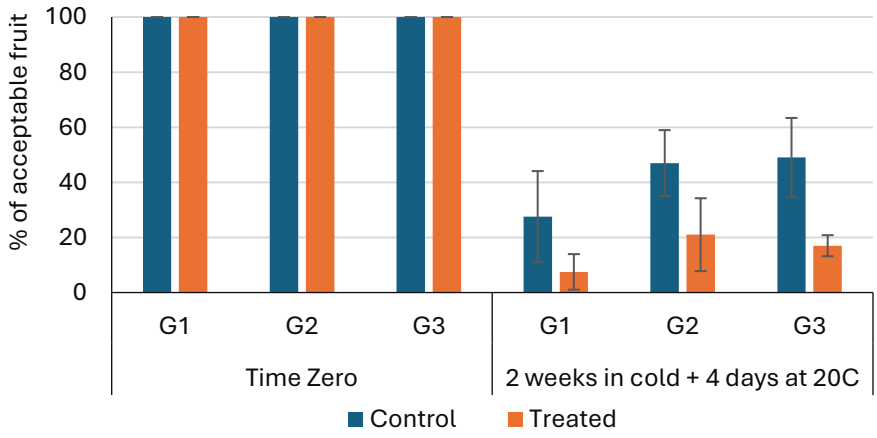


Figure 19. Percentage of acceptable fruit (%) with vascular browning of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

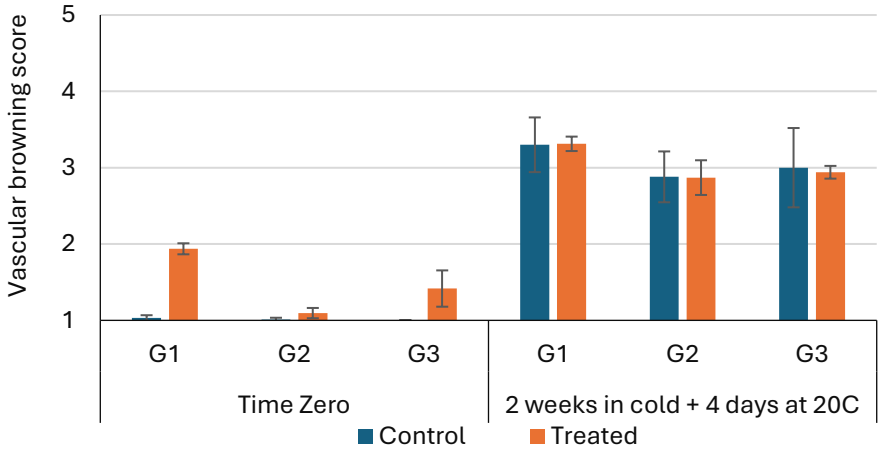


Figure 20. Subjective vascular browning score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective vascular browning score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 –25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Diffuse discolouration. Similar to the results of vascular browning (above), Hass avocado fruit from Grower 1 had higher levels of diffuse flesh discolouration at time zero in the treated fruit, with little / no diffuse discolouration in the untreated fruit at the beginning of the experiment. However, after 2 weeks storage at 7 °C and 4 days at 20 °C, the levels of diffuse discolouration increased in number (Figure 21) and severity (Figure 23).

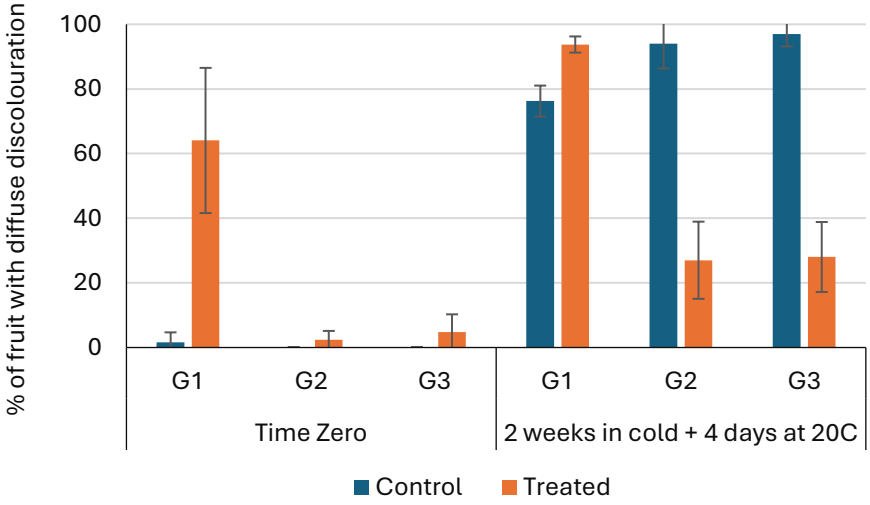


Figure 21. Percentage of fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

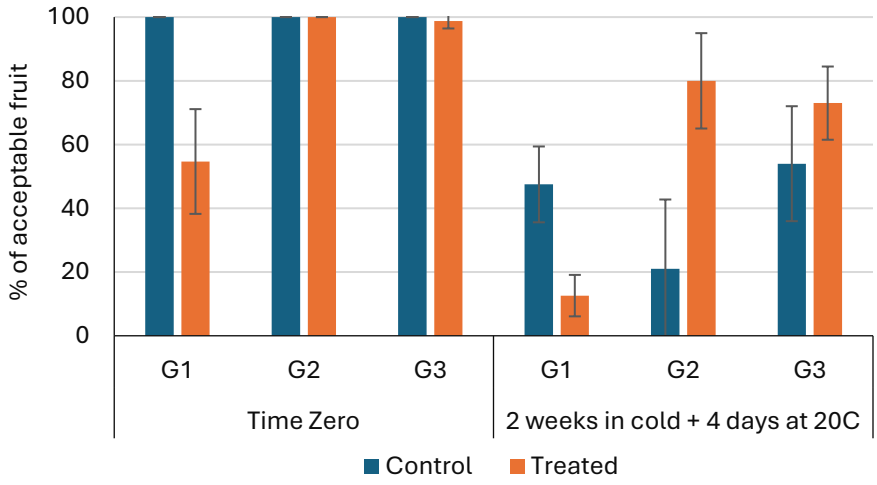


Figure 22. Percentage of acceptable fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

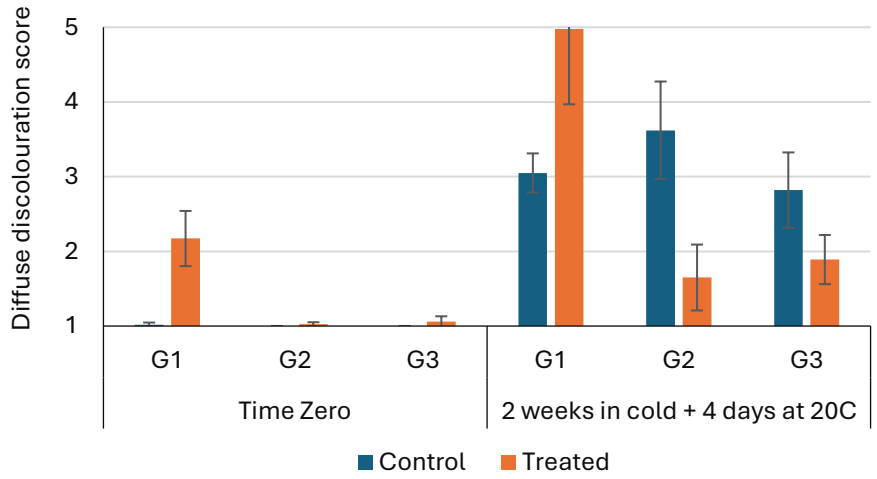


Figure 23. Subjective diffuse discolouration score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective diffuse discolouration score: 1 = 0% of flesh volume, 2 = 1 – 5 % of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Body rots. There were no body rots observed in any fruit at the beginning of the trial, but significant rots developed during storage and shelf life (Figures 24-26). There was high variability in the levels of rots, with different growers having different responses to treatment.

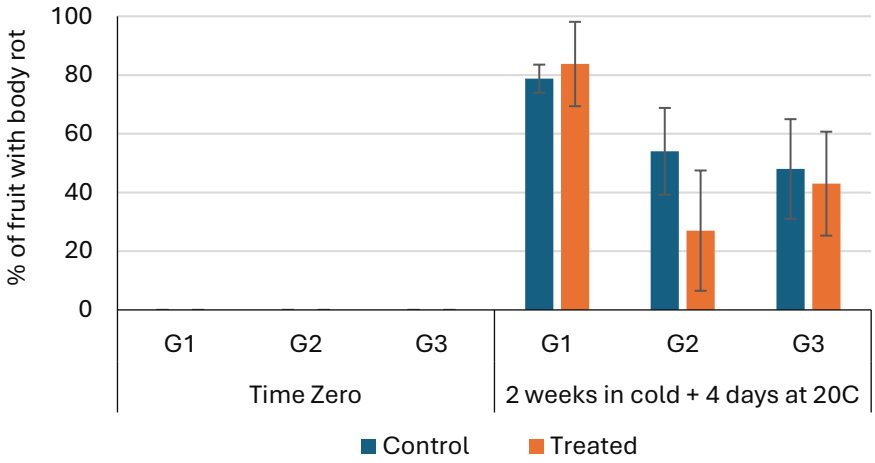


Figure 24. Percentage of fruit (%) with body rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

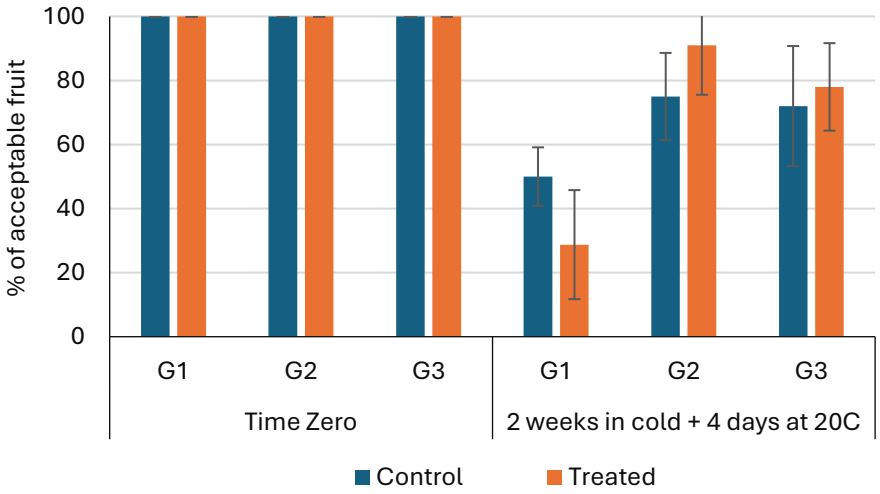


Figure 25. Percentage of acceptable fruit (%) with body rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

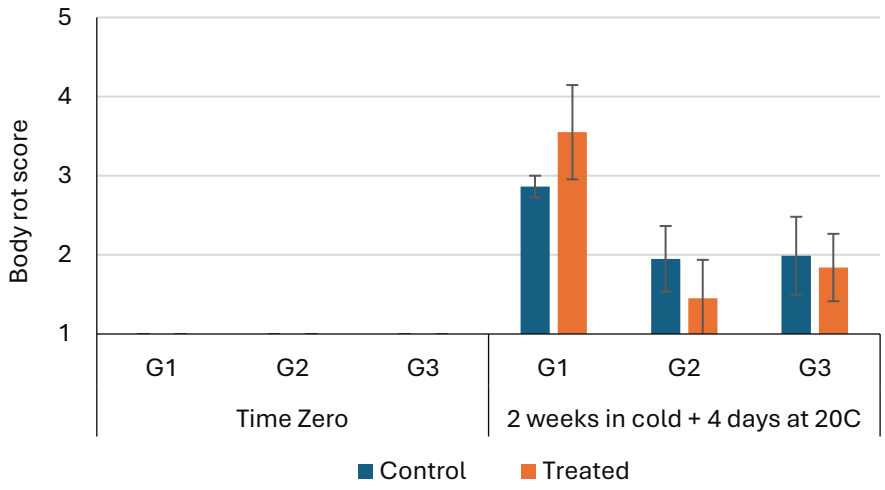


Figure 26. Subjective body rot score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective body rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Photos from Grower 1 of treated and untreated Hass avocados after treatment (Time Zero), and also from 2 weeks in cold storage with an additional 4 days at 20 ^{o}C.

Time Zero. Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Time Zero

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Time Zero

Grower 1

Untreated Rep 1 Rep 2

Rep 3 Rep 4

Time Zero

Grower 1

Treated Rep 1 Rep 2

Rep 3 Rep 4

Time Zero

Grower 1 Untreated Treated


Grower 2 Untreated Treated


Grower 3 Untreated Treated


Assessment 2. 2 weeks in cold + 4 days at 20 °C

Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2. 2 weeks in cold + 4 days at 20 °C

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2. 2 weeks in cold + 4 days at 20 °C

Grower 1

Untreated (Top)

Treated (Lower)

Untreated (Top)

Treated (Lower)

Untreated

Treated

Appendix 6. Experiment 5 – Hass x3

Effects of phytosanitary irradiation on Hass avocado from 3 Queensland growers

Aim. Examine the effects of phytosanitary irradiation on quality of Hass avocados from North Queensland, Central Queensland and South-East Queensland growers.

Methods. Export-grade Hass avocados were sourced from three commercial growers (North Queensland (Atherton), Central Queensland (Isis) and South-East Queensland (Ravensbourne). Fruit were transported to Steritech in Melbourne and treated with 150 Gy X-ray treatment on 9 September 2024. The other half of the fruit were untreated (control) and handled the same way. After treatment, fruit were transported to NSW Department of Primary Industries at Ourimbah where fruit quality was assessed at two assessment times: upon receipt of fruit (2 days after treatment, time zero), and after 7 days storage at 7 °C and 2 days at 20 °C. Upon arrival at NSW DPI, all fruit were more ripe than previous trials and therefore the storage time was reduced to 7 days storage at 7 °C and 2 days at 20 °C. Four replicates were allocated from each treatment, and each treatment unit was a tray of fruit.

Results.

Fruit firmness. The effects of treatment and storage on the fruit firmness in Hass avocados from 3 different growers are presented in Figures 1 and 2. The results show that the treated fruit retained fruit firmness, particularly at the first assessment time (Time Zero).

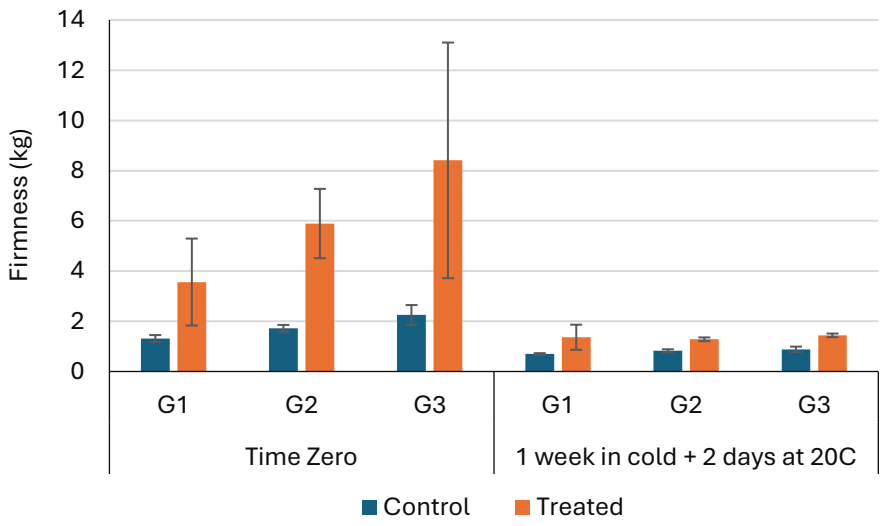


Figure 1. Objective firmness (kg) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

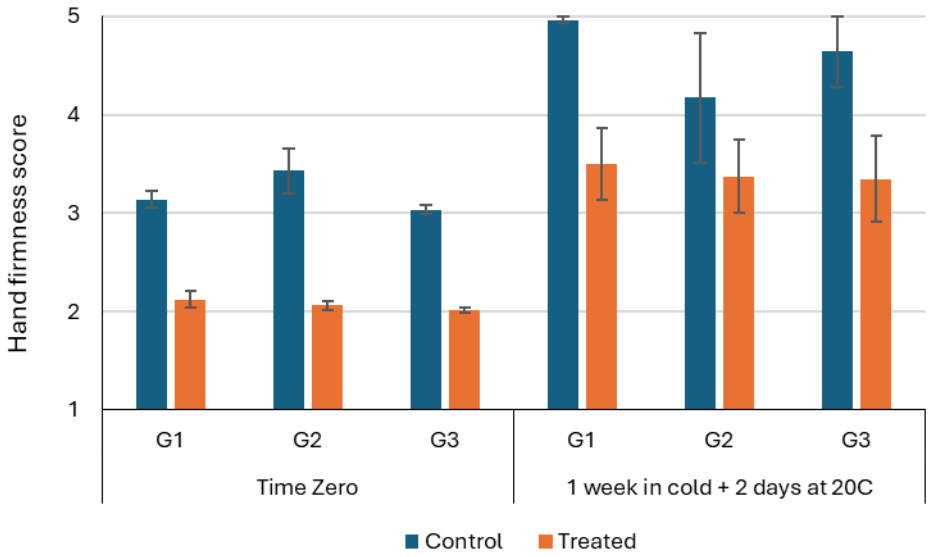


Figure 2. Subjective hand firmness score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective hand firmness score: 1 = hard (no give with strong thump pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2-3 mm with moderate thump pressure), 4 = firm ripe (deforms 2-3 mm with slight thumb pressure) and 5 = medium-soft ripe (deforms with moderate hand pressure).
Bars are standard deviations around the means, *n* = 4.

Ethylene production. Fruit ethylene production rates were relatively high in the fruit upon arrival (time zero) and lower after storage and shelf life (Figure 3). There were no consistent differences between treated and non-treated fruit.

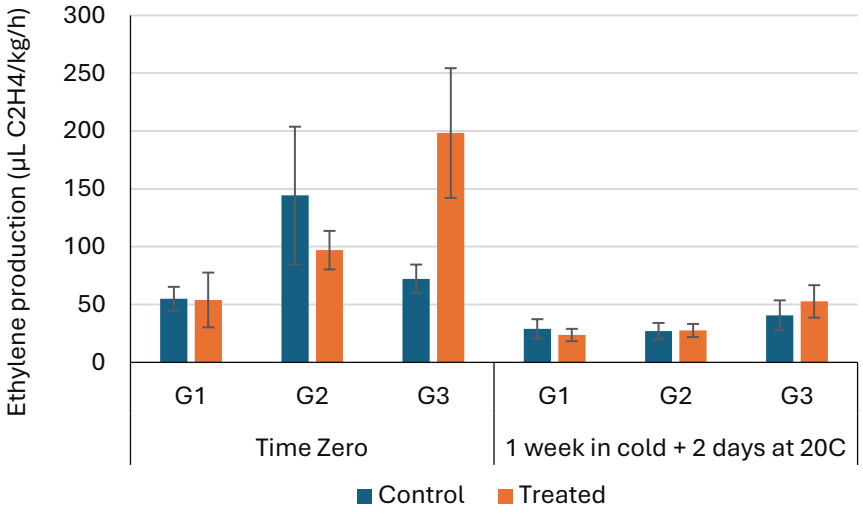


Figure 3. Ethylene production (µL C_2H_4/kg/h) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Respiration rate. The respiration rates were relatively high in all treatments and assessment times, with no consistent effects of treatment on fruit respiration rate (Figure 4).

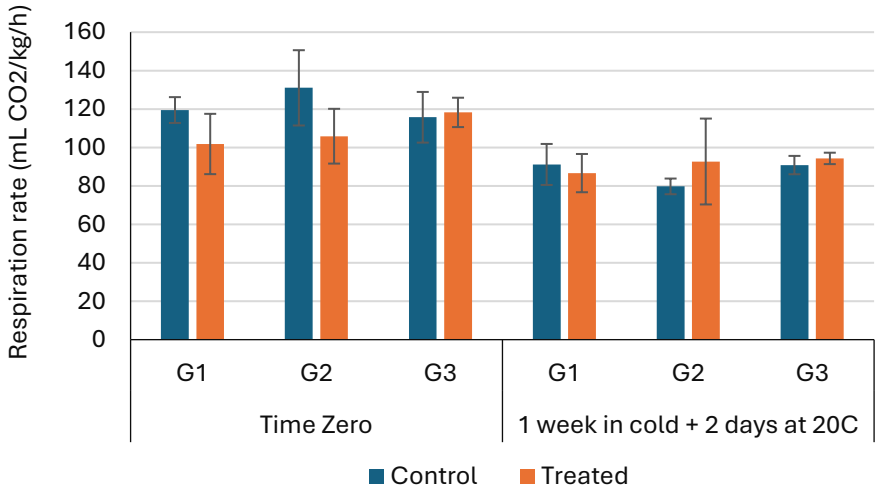


Figure 4. Respiration rate (mL CO_2/kg/h) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Dry matter. Fruit dry matter for all samples were within the standard limits (Figure 5).

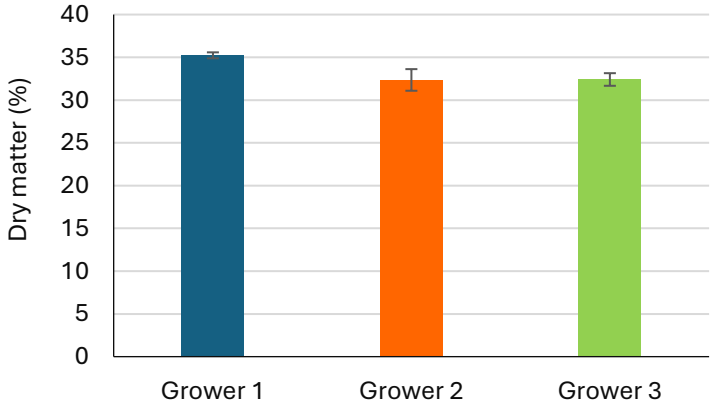


Figure 5. Dry matter (%) of avocados of 3 growers/regions (G) at Time Zero.
Bars are standard deviations around the means, *n* = 4.

Weight loss. Fruit weight loss increased with shelf life (Figure 6). There were no consistent effects of treatment on weight loss in all grower lines.

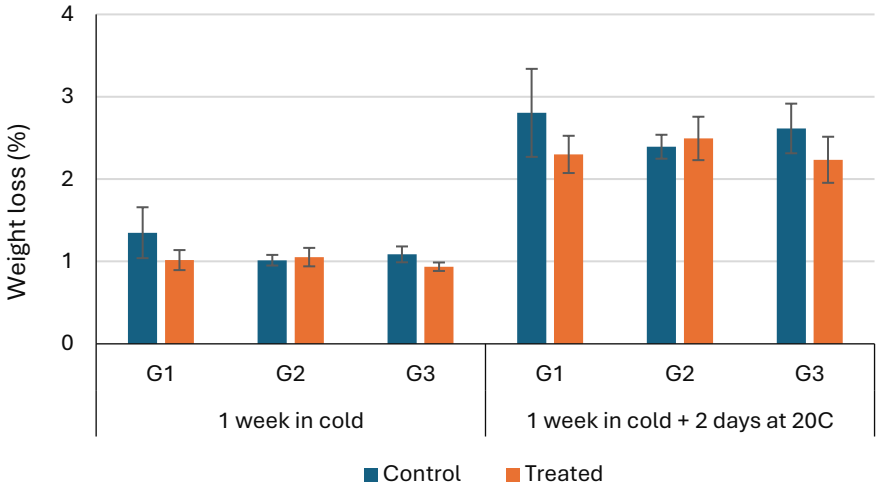


Figure 6. Percentage of weight loss (%) of the control and irradiated (treated) avocados of 3 growers/regions (G) after 1 week at 7 °C and 1 week at 7 °C + 2 days at 20 °C.
Bars are standard deviations around the means, *n* = 4.

Fruit skin colour. The objective colour of the Hass skin in the 3 grower batches as measured with the Minolta colour meter are presented in Figures 7-9 and show treated fruit had higher L*, chroma and hue angles. The results of the subjective skin colour score validated these measurements with treated fruit having delayed colour development after storage and shelf life (Figure 10).

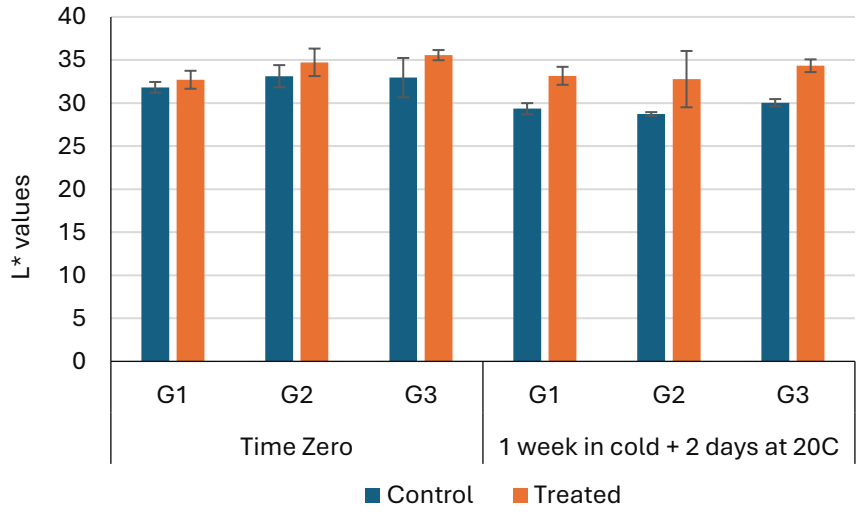


Figure 7. L* values of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

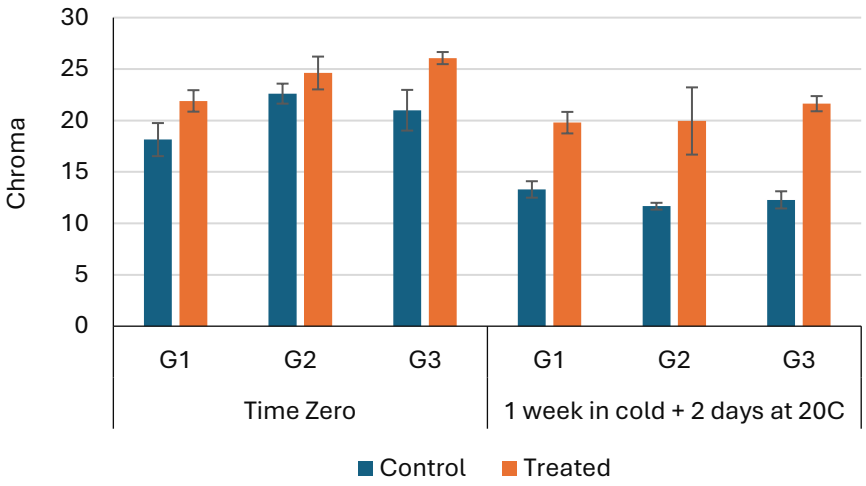


Figure 8. Chroma values of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

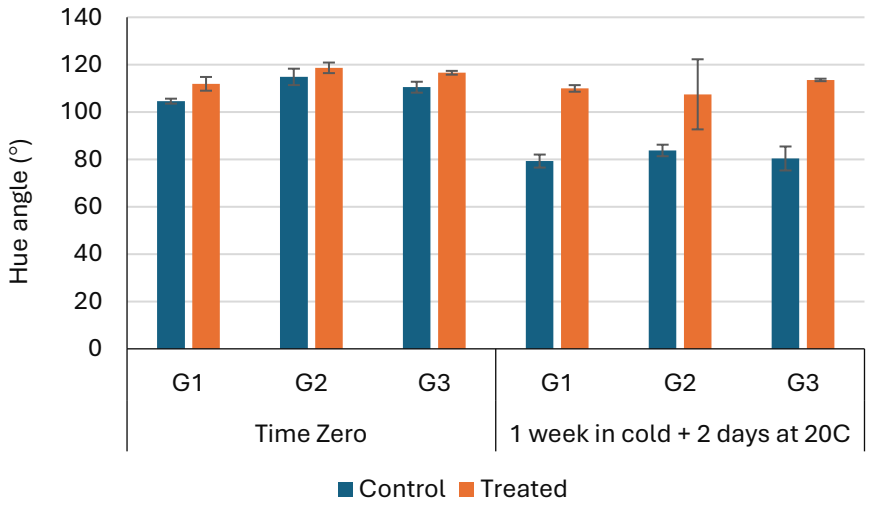


Figure 9. Hue angle (°) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

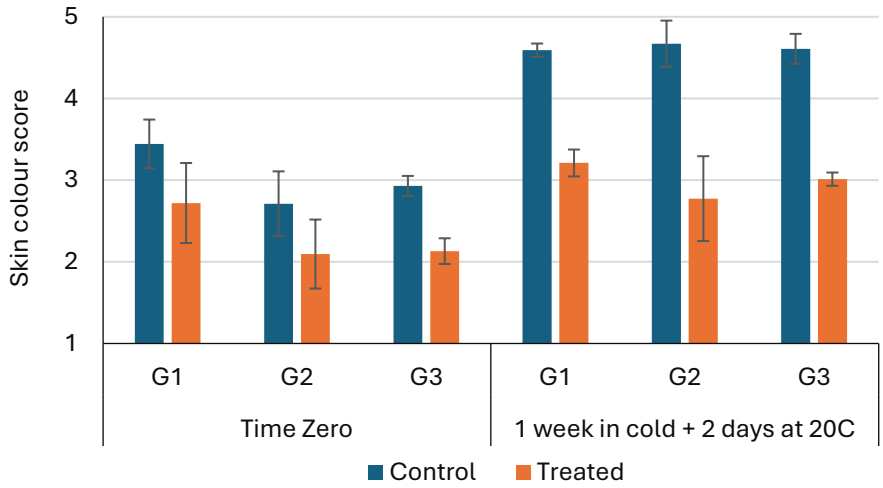


Figure 10. Subjective skin colour score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective skin colour score: 1 = unripe (emerald green), 2 = forest green, 3 = 1 – 25% coloured, 4 = 25 – 75% coloured and 5 = purple. Bars are standard deviations around the means, *n* = 4.

Skin spotting. The levels of skin spotting were moderate to high (10-25%) at the beginning of the trial (time zero) (Figure 11). Skin spotting was unable to be assessed after storage as the fruit had completely ripened (i.e. turned purple).

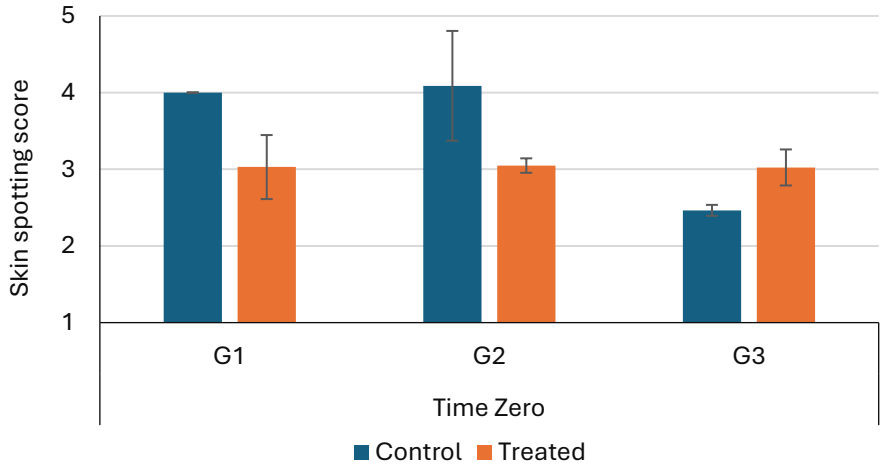


Figure 11. Subjective skin spotting score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero. Subjective skin spotting score: 1 = 0% of fruit surface, 2 = 1 – 5% of fruit surface, 3 = 5 – 10% of fruit surface, 4 = 10 – 25% of fruit surface and 5 = >25% of fruit surface.
Bars are standard deviations around the means, *n* = 4.

Flesh bruising. There was little / no flesh bruising in the fruit during the trial (Figures 12 - 14).

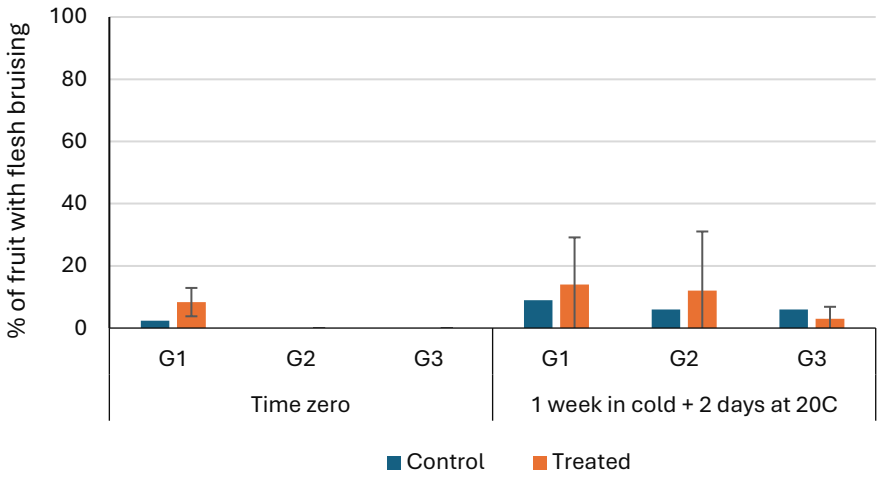


Figure 12. Percentage of fruit with flesh bruising (%) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

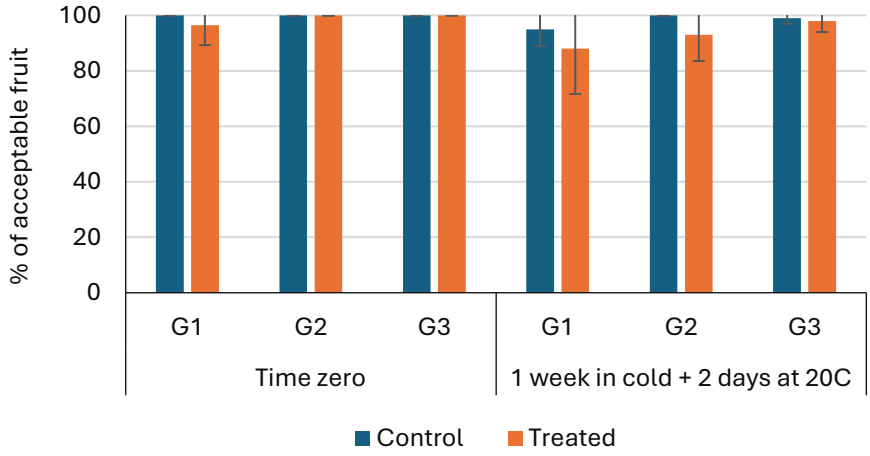


Figure 13. Percentage of acceptable fruit with flesh bruising (%) of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

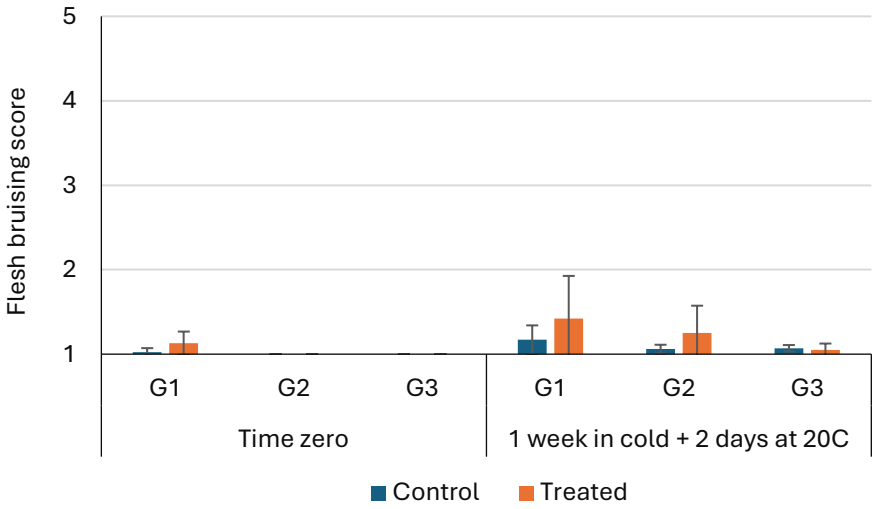


Figure 14. Subjective flesh bruising score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective flesh bruising score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Stem end rots. The levels of stem rots were relatively low in all fruit and treatments, except Grower 2 after 1 week at 7 °C and 2 days at 20 °C which had moderate levels of stem end rots (15-20%) (Figures 15-17).

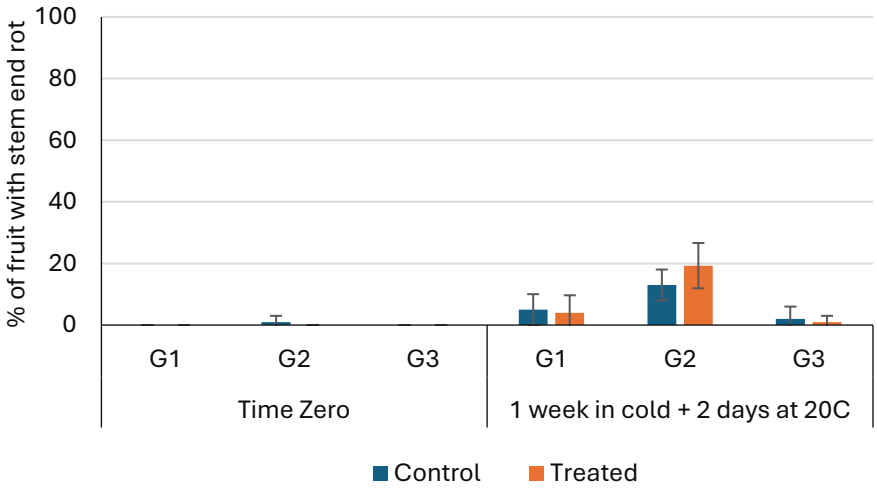


Figure 15. Percentage of fruit (%) with stem end rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

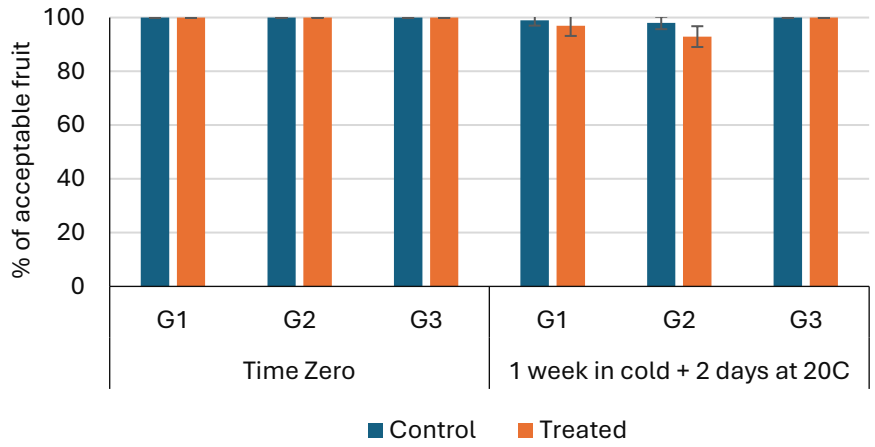


Figure 16. Percentage of acceptable fruit (%) with stem end rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

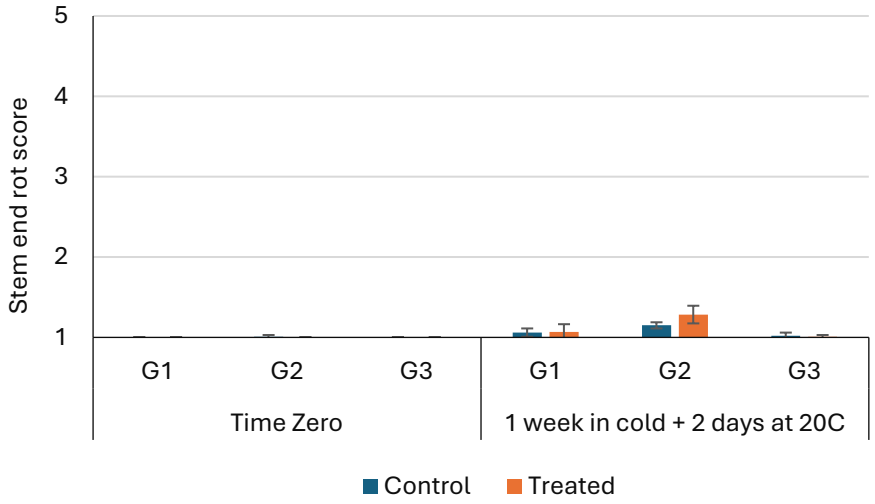


Figure 17. Subjective stem end rot score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective stem end rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Vascular browning. The levels of vascular browning in treated fruit were higher than in untreated fruit at both assessment times (Figures 18-20). There were very high levels of vascular browning in treated fruit from Growers 1 and 2 at the beginning of the trial, but untreated fruit had low levels of vascular browning at this assessment time. The numbers and severity of vascular browning increased with storage and shelf life (Figure 18), where most treated fruit were unacceptable (Figure 19).

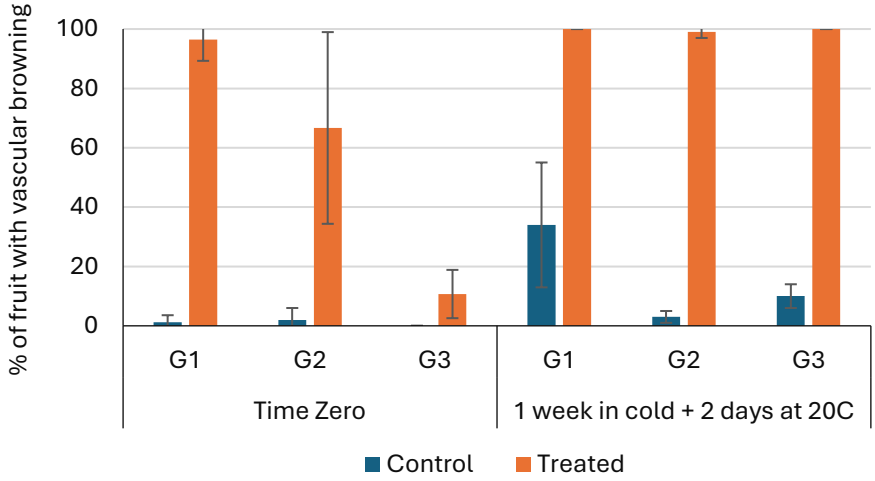


Figure 18. Percentage of fruit (%) with vascular browning of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

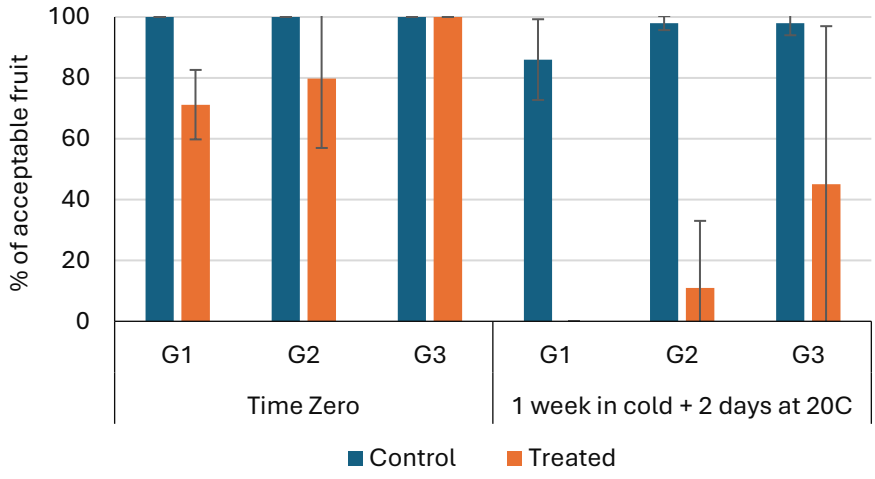


Figure 19. Percentage of acceptable fruit (%) with vascular browning of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

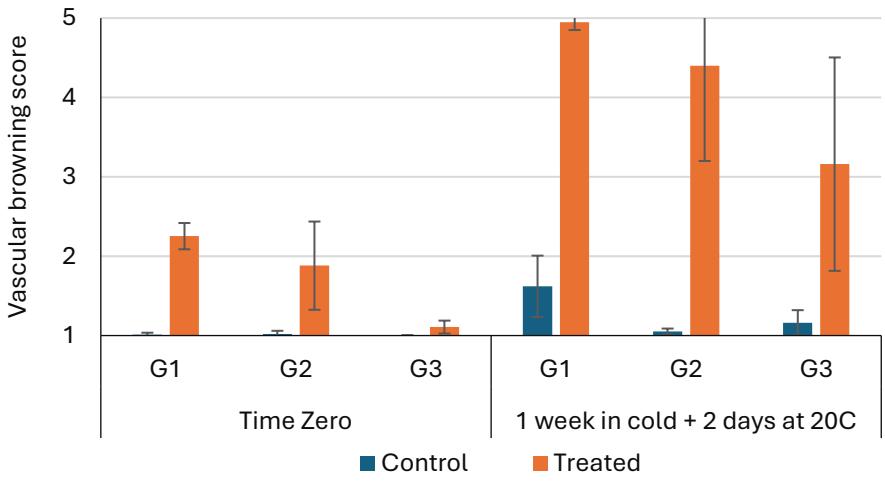


Figure 20. Subjective vascular browning score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective vascular browning score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 –25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Diffuse discolouration. There was no / little flesh diffuse discolouration in any fruit at the beginning of the trial (Figures 21 and 23), but with storage time and shelf life, the levels of diffuse discolouration increased, particularly in treated fruit from Growers 1 and 2 (Figures 21 and 23), resulting more unacceptable fruit in the treated samples (Figure 22).

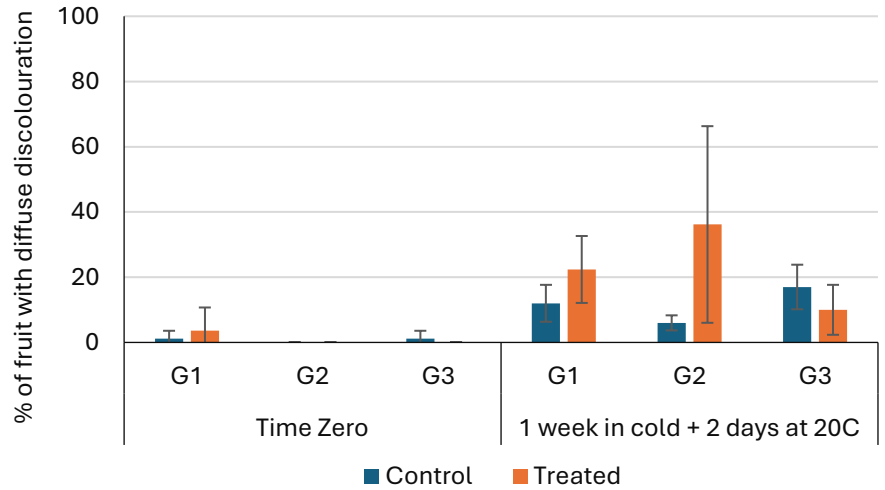


Figure 21. Percentage of fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

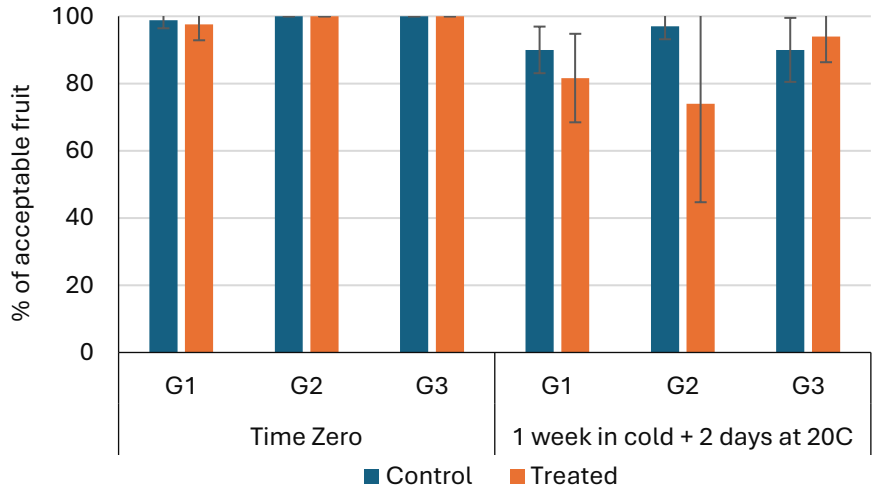


Figure 22. Percentage of acceptable fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

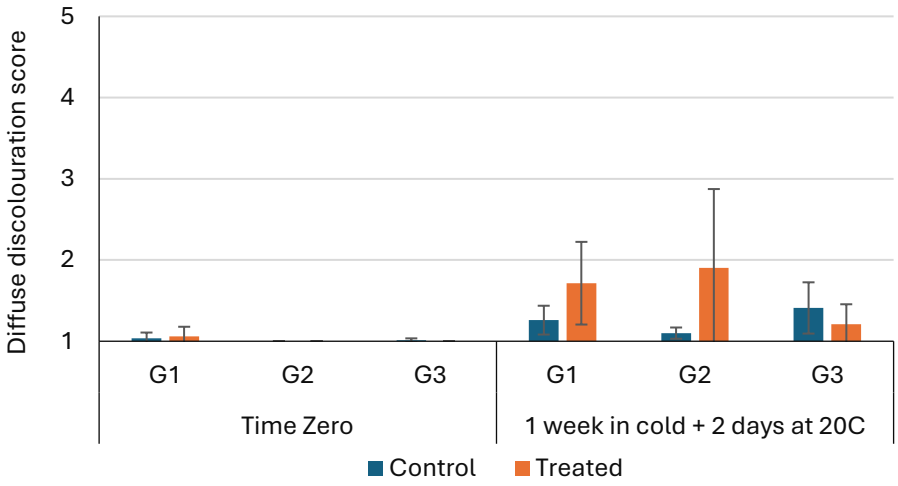


Figure 23. Subjective diffuse discolouration score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective diffuse discolouration score: 1 = 0% of flesh volume, 2 = 1 – 5 % of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Body rots. The levels of body rots in fruit at the beginning of the trial were low (Figures 24 and 26). These levels increased with storage and shelf life, with the treated fruit from Grower 2 possessing the highest levels of body rots following storage and shelf life.

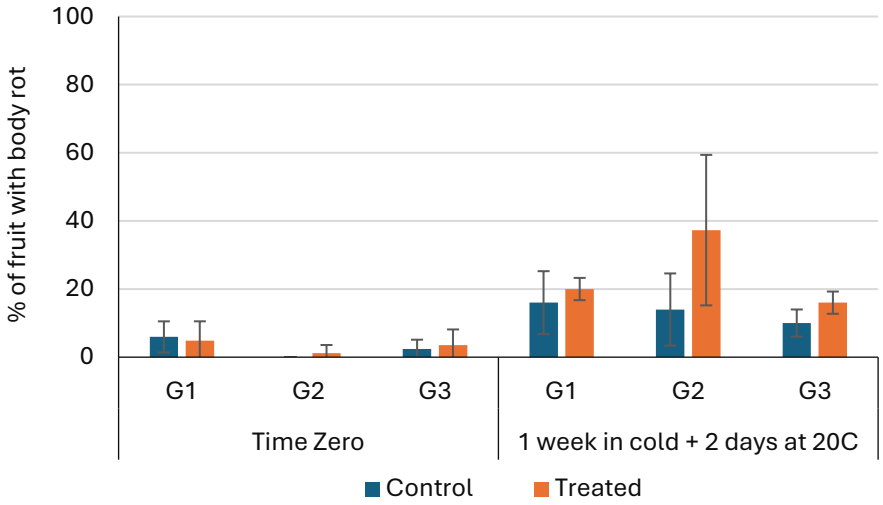


Figure 24. Percentage of fruit (%) with body rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

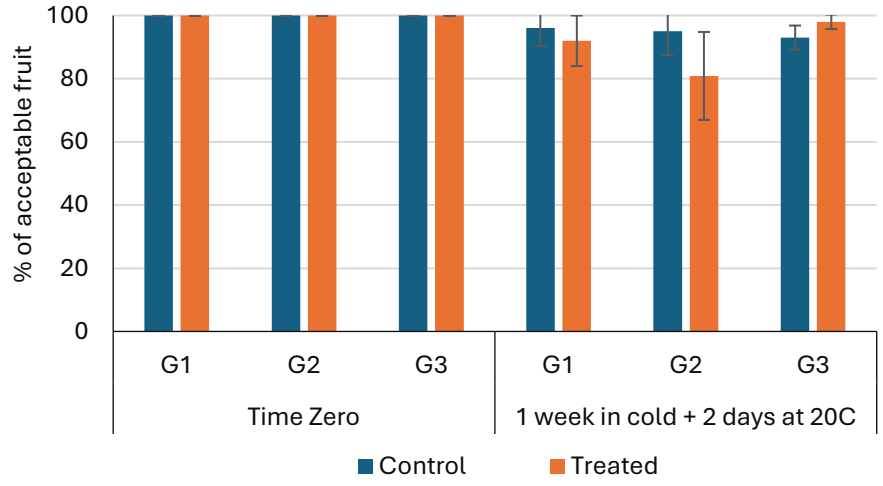


Figure 25. Percentage of acceptable fruit (%) with body rot of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

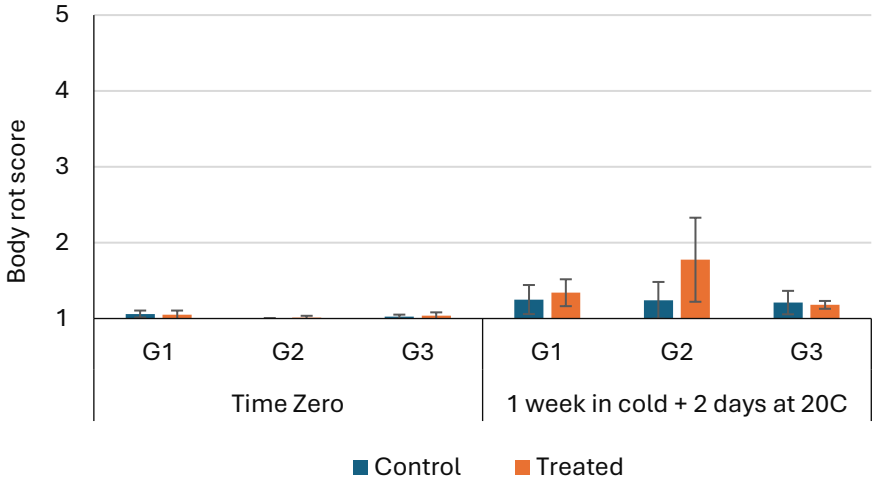


Figure 26. Subjective body rot score of the control and irradiated (treated) avocados of 3 growers/regions (G) at Time Zero and at the assessment 2 (1 week at 7 °C + 2 days at 20 °C). Subjective body rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Oil content quality. For this trial only (Experiment 5), the oil content quality was measured three days after phytosanitary treatment (12 September) on treated and untreated Hass fruit from the three growers. The oil quality parameters measured were edible oil free fatty acid content (%), edible oil peroxide value (mEq O_2/kg) and oil content (%, as received and at 50% moisture). This analysis was conducted the NATA approved oil testing laboratory at NSW Department of Primary Industries and Regional Development at Wagga Wagga. All methods were conducted according to standard certified standards.

The results presented in Table 1 show no differences between the treated and untreated oil quality in the Hass avocados.

Table 1. Effect of phytosanitary irradiation content on oil quality in Hass avocados 3 days after treatment from three different growers (G1, G2 and G3).

	Untreated				Treated			
	G1	G2	G3	average	G1	G2	G3	average
Edible Oil Free Fatty Acid Content (%)	0.07	0.07	0.08	0.07	0.07	0.07	0.08	0.07
Edible Oil Peroxide Value (mEq O_2/kg)	4	6	7	5.7	5	5	7	5.7
Oil content - as received (%)	8	7	9	8	5	10	4	6
Oil content - 50% moisture (%)	11	11	12	11.3	8	15	5	9.3

Photos

Time Zero

Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Time Zero

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Time Zero

Grower 1

Untreated (Top)

Treated (Lower)

Untreated Treated

Untreated Treated

Assessment 2. 1 week in cold + 2 days at 20 °C

Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2. 1 week in cold + 2 days at 20 °C

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2. 1 week in cold + 2 days at 20 °C

Grower 1

Untreated (Top)

Treated (Lower)

Untreated (Top)

Treated (Lower)

Untreated

Treated

Appendix 7. Experiment 6 – Shepard x4

Effects of phytosanitary irradiation on Shepard avocado from four North Queensland growers

Aim. Examine the effects of phytosanitary irradiation on quality of Shepard avocados from North Queensland.

Methods. Export-grade Shepard avocados were sourced from four commercial growers in North Queensland (Mareeba). Fruit were transported to Steritech in Melbourne and treated with 150 Gy X-ray treatment on 9 March 2025. The other half of the fruit were untreated (control) and handled the same way. After treatment, fruit were transported to NSW Department of Primary Industries at Ourimbah where fruit quality was assessed at two assessment times; upon receipt of fruit (2 days after treatment, time zero), and after 14 days storage at 7 °C and 4 days at 20 °C. Four replicates were allocated from each treatment and each treatment unit was a tray of fruit.

Results.

Fruit firmness. The levels of fruit firmness upon arrival at NSW DPIRD and after storage and shelf life are presented in Figure 1 and showed that all fruit were firm at the beginning of the trial with no difference between treated and non-treated. However, after the 2 weeks storage and 4 days shelf life, treated fruit were firmer than the control fruit in all growers. This was also reflected in the subjective hand score in Figure 2.

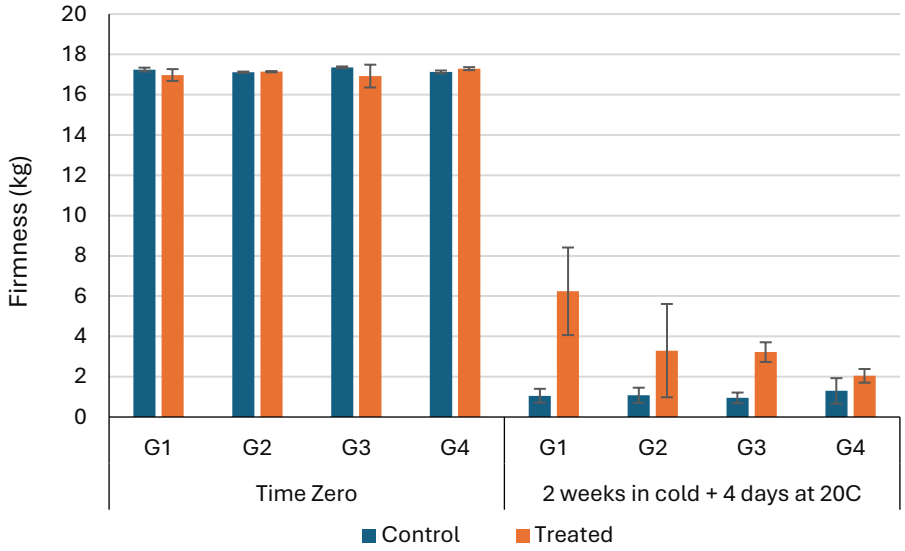


Figure 1. Objective firmness (kg) of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 week at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

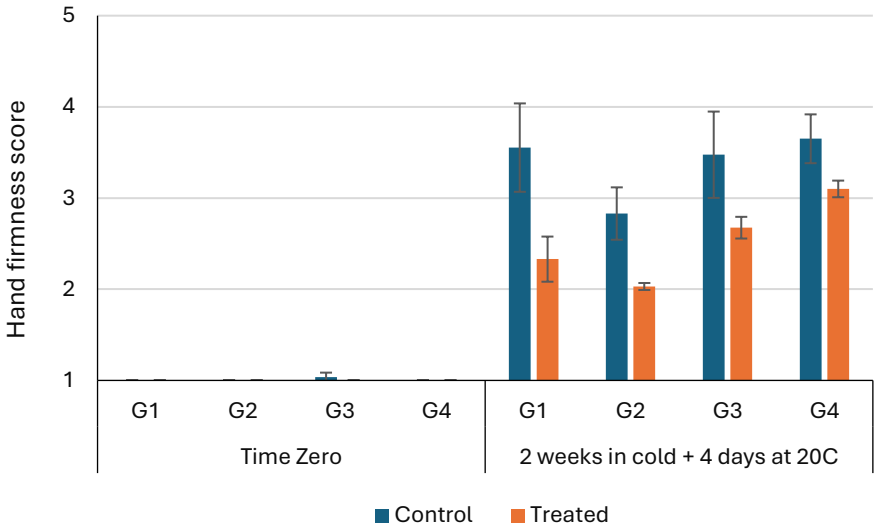


Figure 2. Subjective hand firmness score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 week at 7 °C + 4 days at 20 °C). Subjective hand firmness score: 1 = hard (no give with strong thump pressure), 2 = rubbery (slight give with strong thumb pressure), 3 = softening (deforms 2-3 mm with moderate thump pressure), 4 = firm ripe (deforms 2-3 mm with slight thumb pressure) and 5 = medium-soft ripe (deforms with moderate hand pressure).
Bars are standard deviations around the means, *n* = 4.

Ethylene production. The levels of ethylene production by the treated fruit from all growers was higher at all assessment times (Figure 3). As expected, ethylene production rates were higher after storage and shelf life.

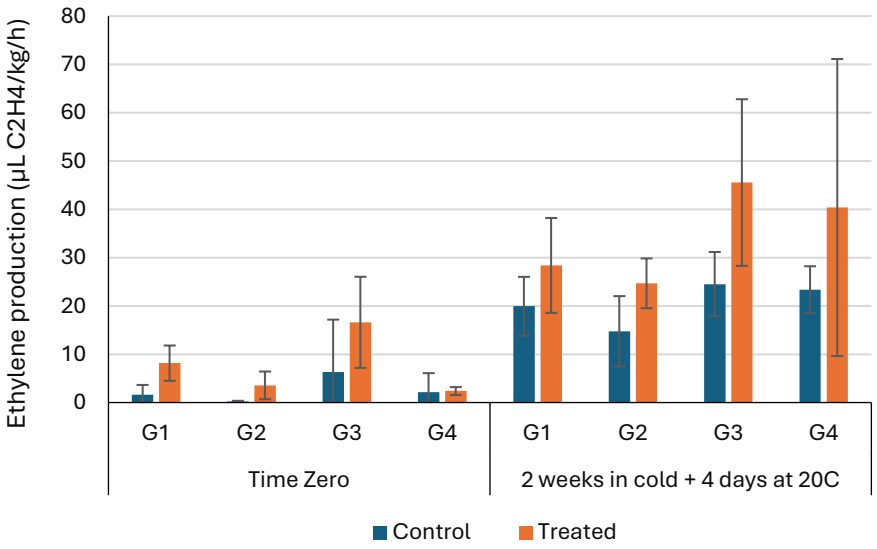


Figure 3. Ethylene production (µL C_2H_4/kg/h) of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Respiration rate. Fruit respiration rates were higher in treated fruit at the beginning of the trial, but there were no differences in respiration rates after storage and shelf life (Figure 4).

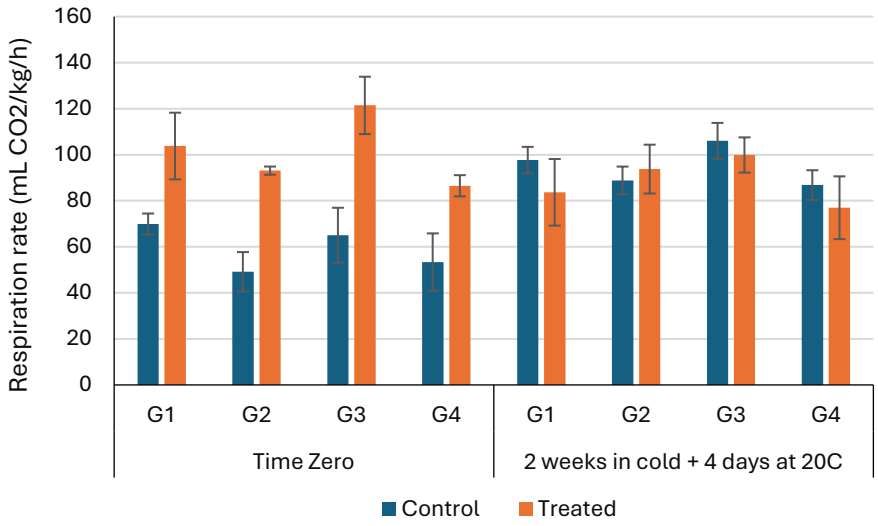


Figure 4. Respiration rate (mL CO_2/kg/h) of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Dry matter. The dry matter in Shepard fruit in all four growers were above the standard 21% dry matter (Figure 5).

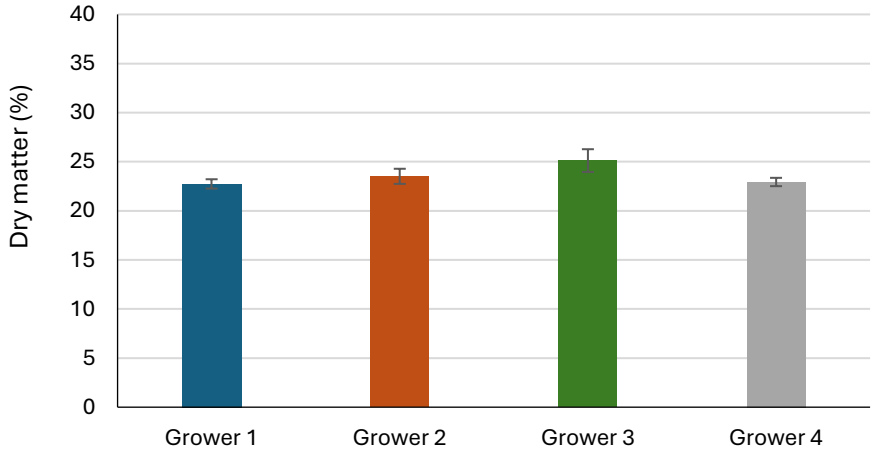


Figure 5. Dry matter (%) of avocados of 4 growers/regions (G) at Time Zero.
Bars are standard deviations around the means, n = 3.

Weight loss. Weight loss from all fruit increased after storage and shelf life with treated fruit having higher levels of weight loss than un-treated fruit (Figure 6).

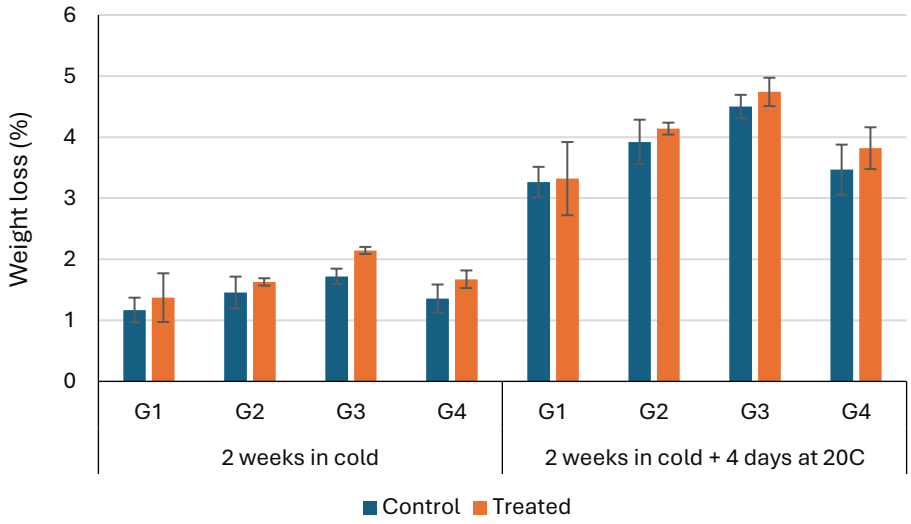


Figure 6. Percentage of weight loss (%) of the control and irradiated (treated) avocados of 4 growers/regions (G) after 2 weeks at 7 °C and 2 weeks at 7 °C + 4 days at 20 °C.
Bars are standard deviations around the means, *n* = 4.

Minolta. The skin colour as measured by the Minolta colour meter is presented in Figures 7-9. The treated fruit tended to have lower L* and chroma values indicating 'lighter' coloured fruit.

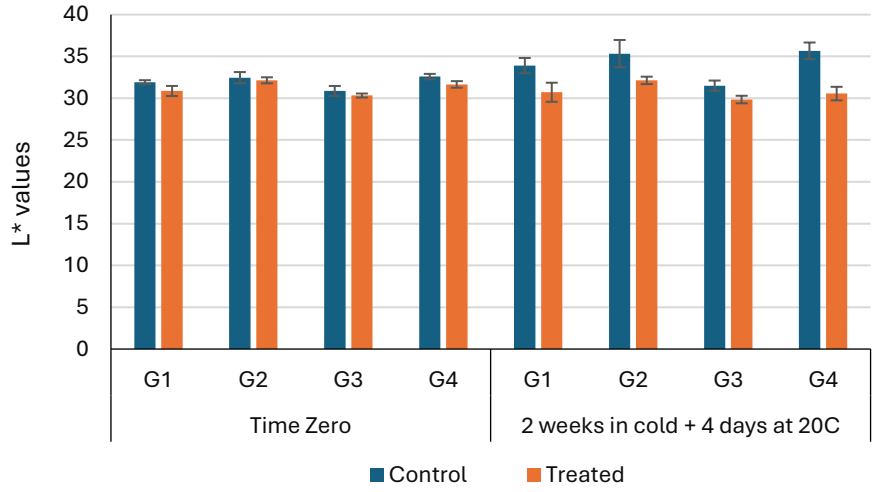


Figure 7. L* values of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, n = 4.

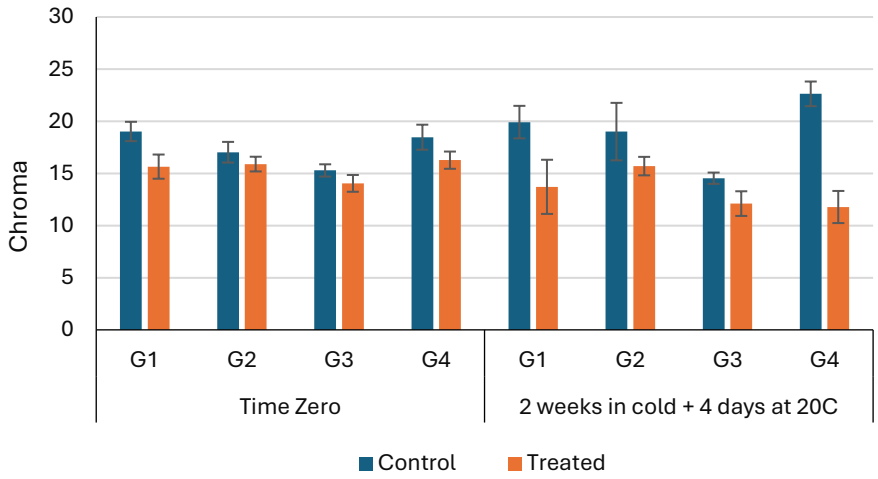


Figure 8. Chroma values of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

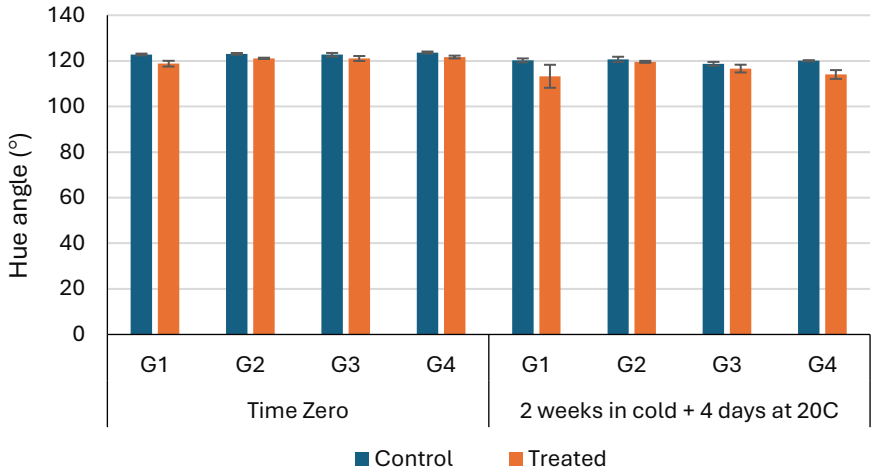


Figure 9. Hue angles (°) of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C).
Bars are standard deviations around the means, *n* = 4.

Skin colour. There were few differences between treated and untreated fruit across the four growers, although fruit from grower 1 tended to be darker (Figure 10).

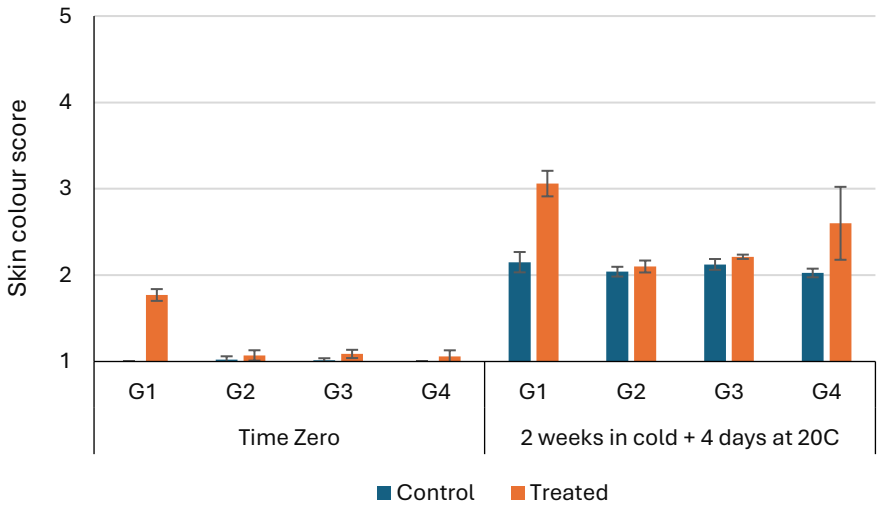


Figure 10. Subjective skin colour score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective skin colour score: 1 = unripe (emerald green and shiny), 2 = onset ripe (forest green and < 20% dark), 3 = ripe (black on green and 20 to 30% dark), 4 = eating ripe (green on black and 60 to 70% dark and 5 = over-ripe (mostly black and > 70% dark). Bars are standard deviations around the means, *n* = 4.

Skin spotting. Skin spotting is a natural attribute of Shepard avocado. Skin spotting was found in both untreated control and treated Shepard avocado, but the level of skin spotting in treated fruit was consistently higher than the untreated control fruit, except for the fruit from Grower 3 at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C) (Figure 11).

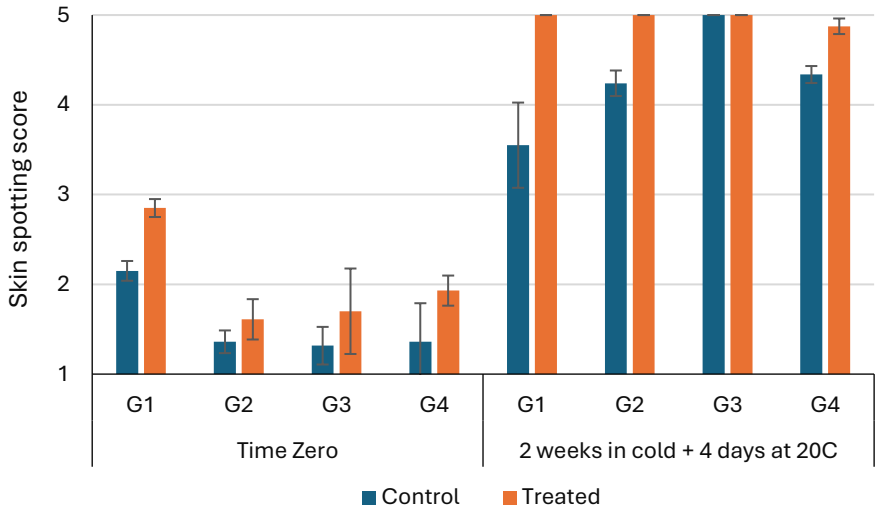


Figure 11. Subjective skin spotting score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective skin spotting score: 1 = 0% of fruit surface, 2 = 1 – 5% of fruit surface, 3 = 5 – 10% of fruit surface, 4 = 10 – 25% of fruit surface and 5 = >25% of fruit surface. Bars are standard deviations around the means, *n* = 4.

Flesh bruising. As the internal browning was found in both untreated control and treated fruit. The flesh became dark, especially in the treated fruit. Therefore, it was difficult to determine the flesh bruising, but internal browning assessment was conducted in this experiment.

Internal browning. There was no internal browning at the start of the experiment, but the percentage of fruit and severity of internal browning was higher in treated fruit (across all growers), resulting in lower levels of acceptable fruit (Figures 12-14).

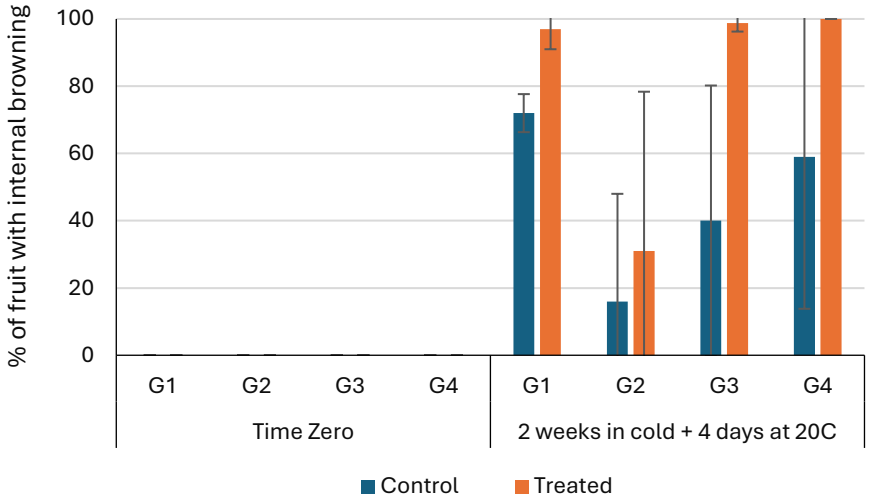


Figure 12. Percentage of fruit with internal browning (%) of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

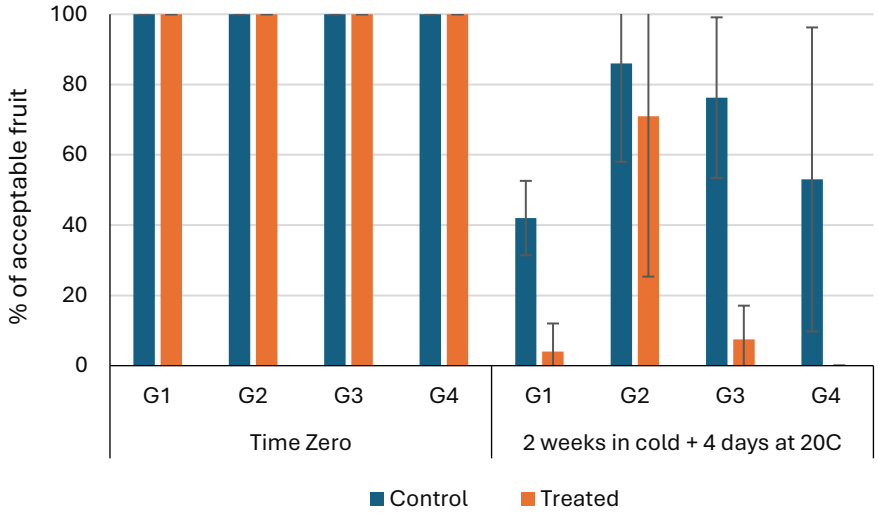


Figure 13. Percentage of acceptable fruit with internal browning (%) of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

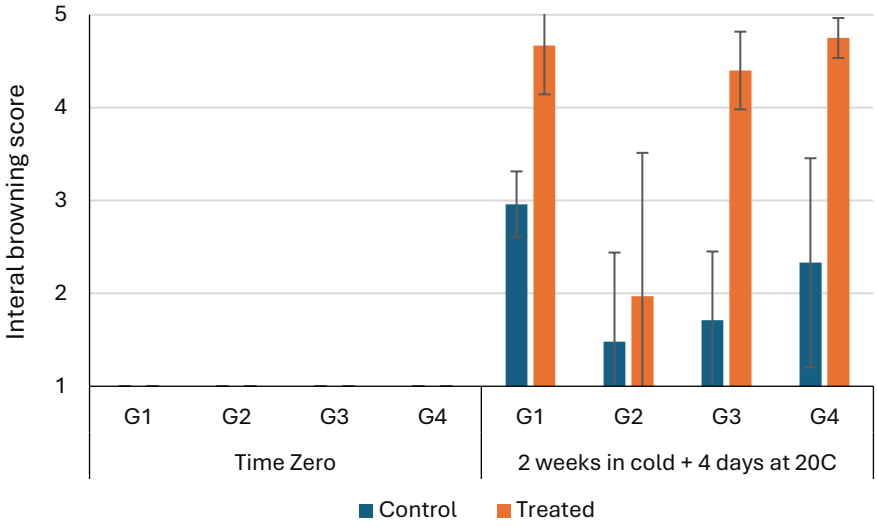


Figure 14. Subjective internal browning score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective flesh bruising score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Stem end rots. There were no stem end rots at the start of the experiment, but the percentage of fruit and severity of stem-end rots browning was higher in treated fruit (across all growers, particularly Growers 3 and 4), resulting in lower levels of acceptable fruit (Figures 15-17).

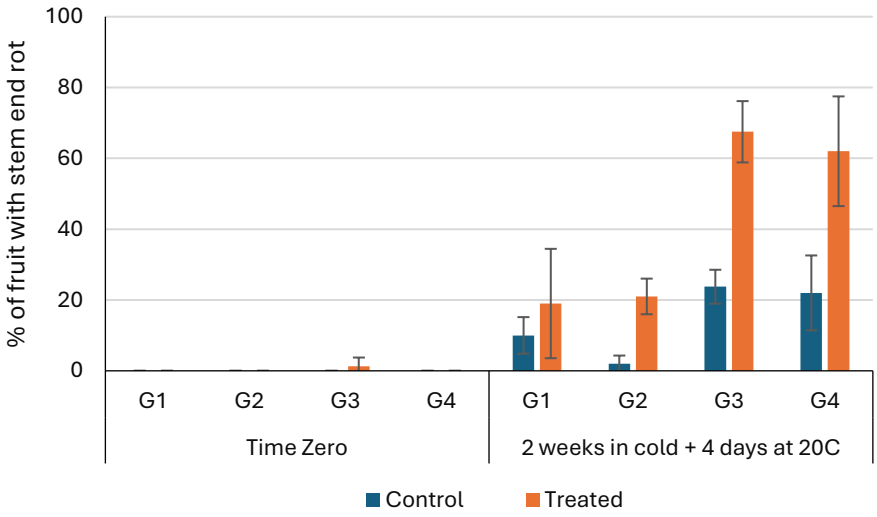


Figure 15. Percentage of fruit (%) with stem end rot of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

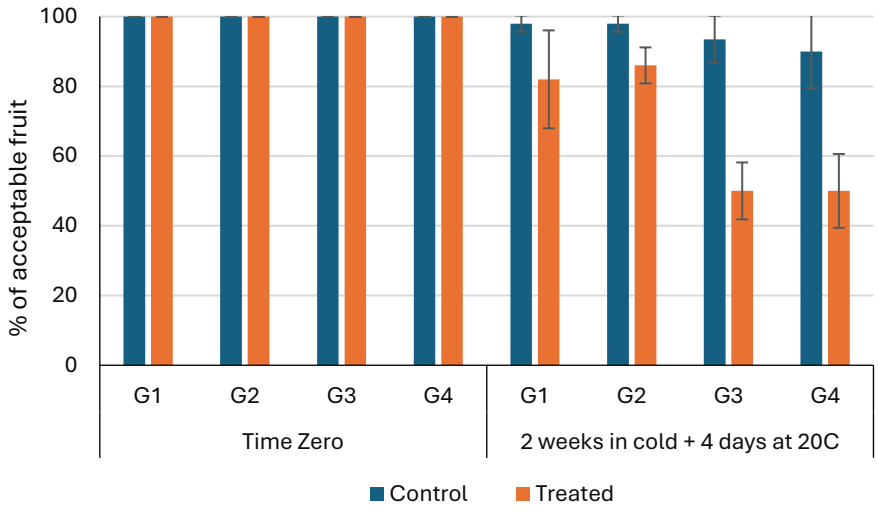


Figure 16. Percentage of acceptable fruit (%) with stem end rot of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

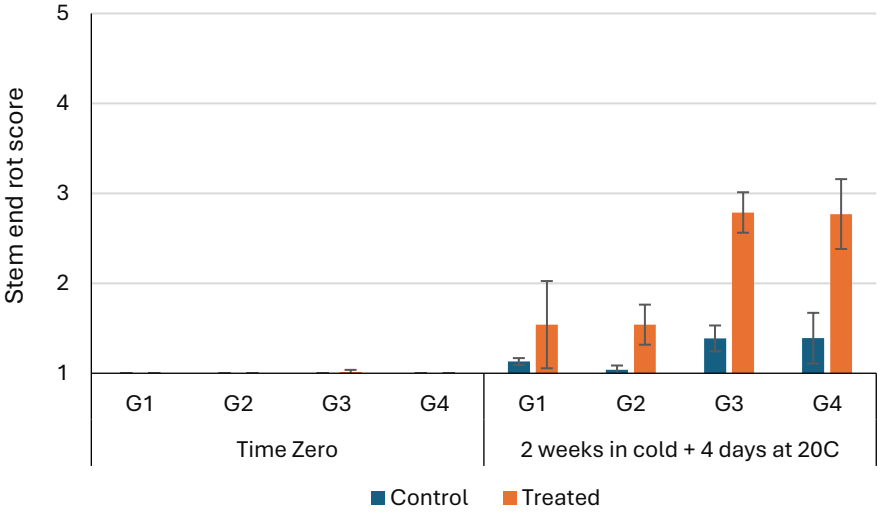


Figure 17. Subjective stem end rot score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective stem end rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Vascular browning. The levels of vascular browning in treated fruit were higher than in untreated fruit. This was observed in all fruit after storage and shelf life but was also observed at the beginning of the trial in fruit from Growers 3 and 4 (Figures 18 and 20). This increased level and severity of vascular browning resulted in lower levels of acceptable fruit after storage (Figure 19).

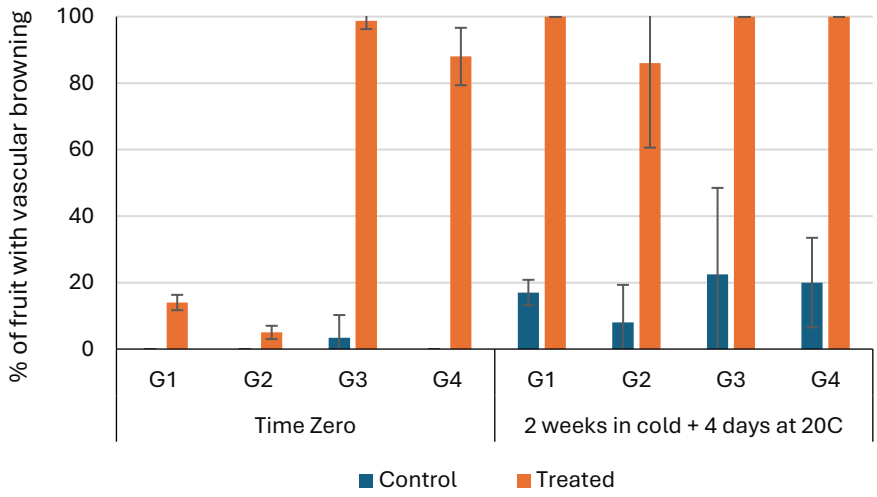


Figure 18. Percentage of fruit (%) with vascular browning of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

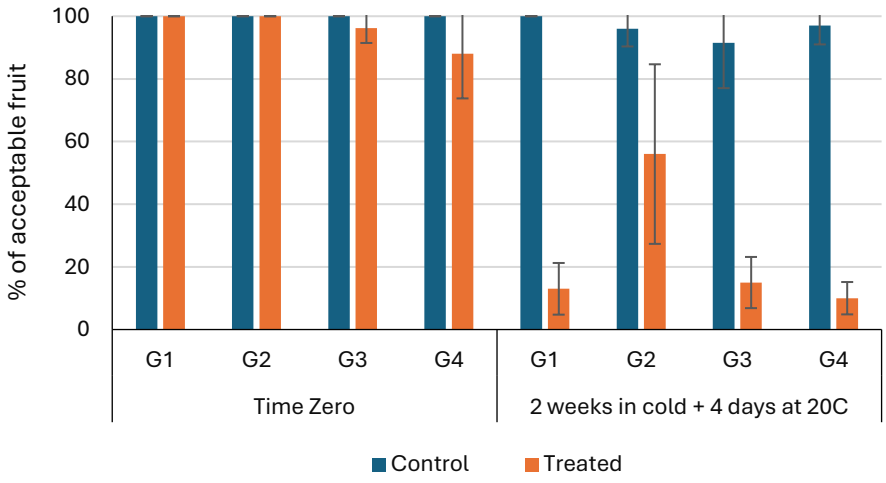


Figure 19. Percentage of acceptable fruit (%) with vascular browning of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

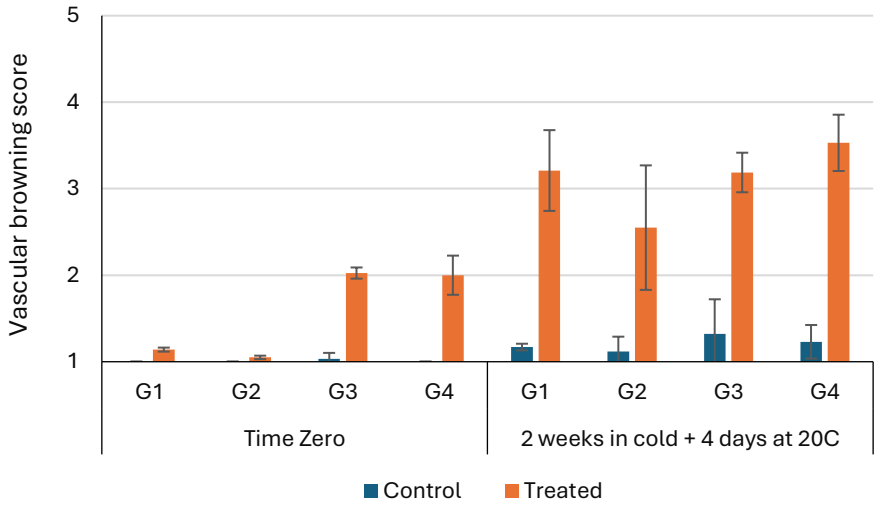


Figure 20. Subjective vascular browning score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective vascular browning score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 –25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Diffuse discolouration. Due to the similar physical symptoms in the same tissue, the levels of diffuse discolouration were confounded with internal browning. However given these potential issues, the levels and severity of diffuse discolouration were higher in treated fruit (Figures 21 – 23).

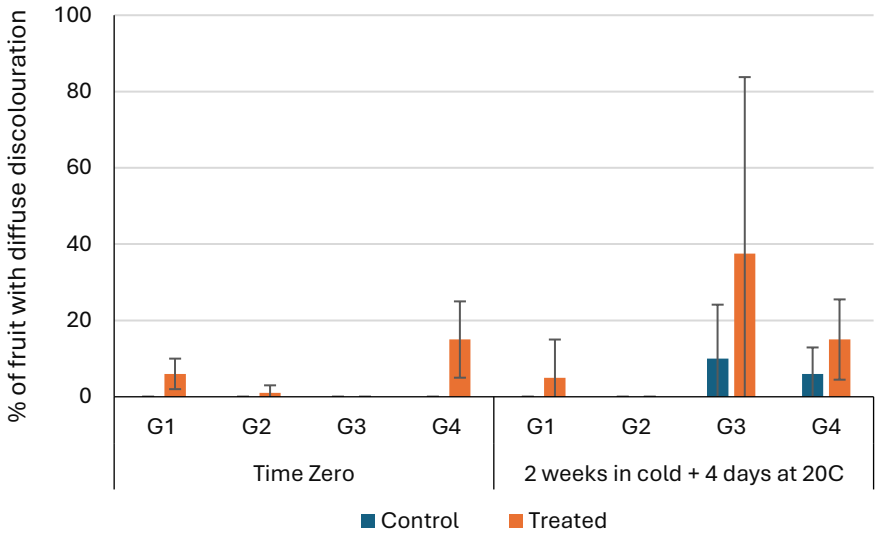


Figure 21. Percentage of fruit (%) with diffuse discolouration of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

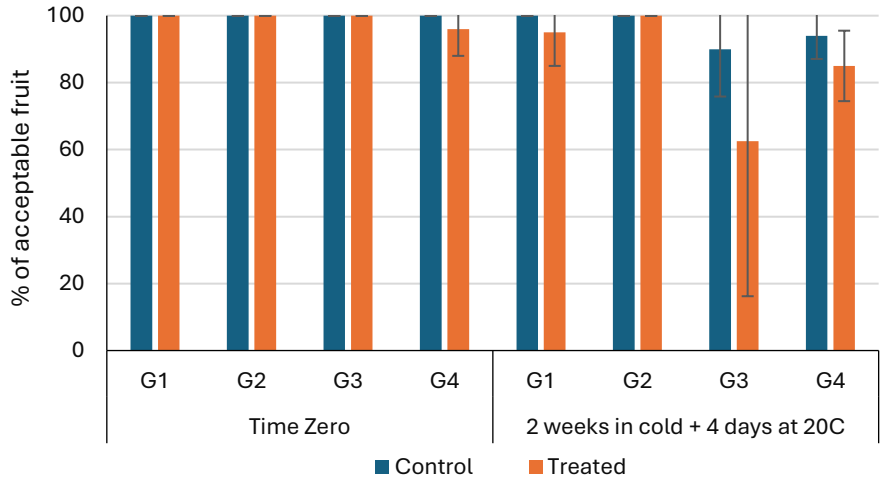


Figure 22. Percentage of acceptable fruits (%) with diffuse discolouration of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

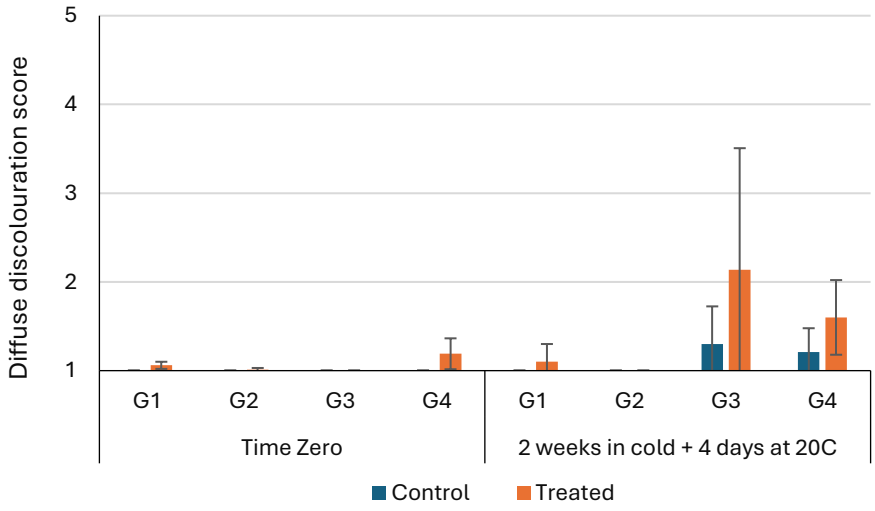


Figure 23. Subjective diffuse discolouration score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective diffuse discolouration score: 1 = 0% of flesh volume, 2 = 1 – 5 % of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume.
Bars are standard deviations around the means, *n* = 4.

Body rots. The levels of body rots were higher in treated fruit after storage and shelf life. There were high levels of body rots (>50%) with higher severity of rots in stored fruit from Growers 1, 3 and 4 (Figures 24-26).

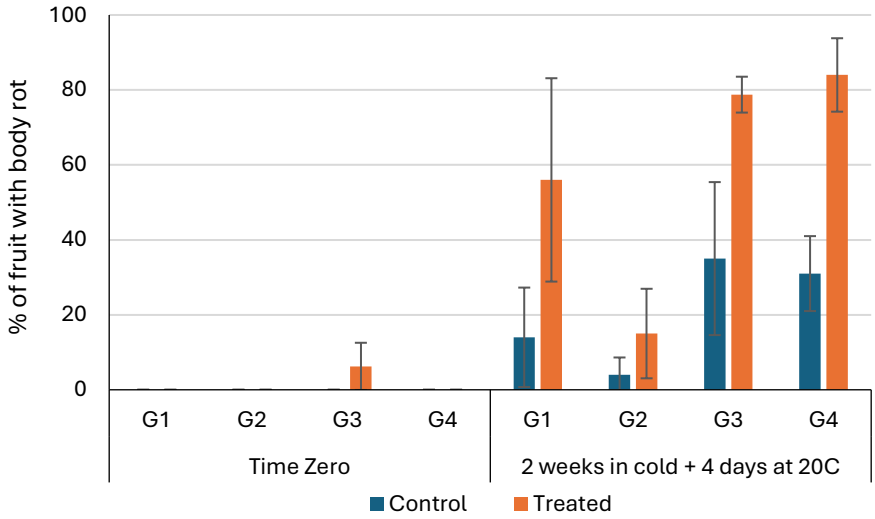


Figure 24. Percentage of fruit (%) with body rot of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

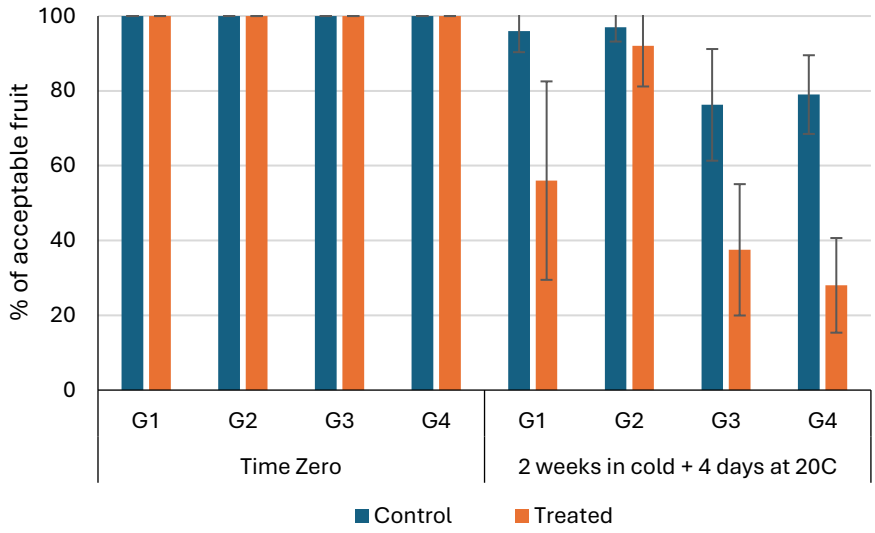


Figure 25. Percentage of acceptable fruit (%) with body rots of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Bars are standard deviations around the means, *n* = 4.

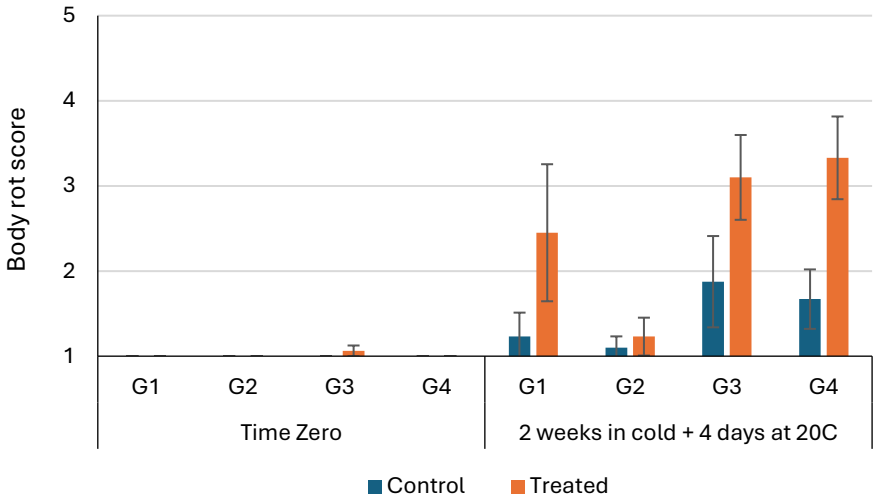


Figure 26. Subjective body rot score of the control and irradiated (treated) avocados of 4 growers/regions (G) at Time Zero and at the assessment 2 (2 weeks at 7 °C + 4 days at 20 °C). Subjective body rot score: 1 = 0% of flesh volume, 2 = 1 – 5% of flesh volume, 3 = 5 – 10% of flesh volume, 4 = 10 – 25% of flesh volume and 5 = >25% of flesh volume. Bars are standard deviations around the means, *n* = 4.

Photos from Grower 1 of treated and untreated Shepard avocados after treatment (Time Zero), upon removal from 2 weeks in cold storage and also after an additional 4 days at 20 ^{o}C.

Time Zero. Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Time Zero

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Time Zero

Grower 1

Untreated Rep 1 Rep 2

Rep 3 Rep 4

Time Zero

Grower 1

Treated Rep 1 Rep 2

Rep 3 Rep 4

Time Zero

Grower 1

Untreated (Top)

Treated (Lower)

Untreated (Top)

Treated (Lower)

Untreated

Treated

Assessment 2: Upon removal (2 weeks in cold)

Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2: Upon removal (2 weeks in cold)

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2: Upon removal (2 weeks in cold) + 4 days at 20 °C

Grower 1

Rep 1 Untreated Treated

Rep 2 Untreated Treated

Assessment 2: Upon removal (2 weeks in cold) + 4 days at 20 °C

Grower 1

Rep 3 Untreated Treated

Rep 4 Untreated Treated

Assessment 2: Upon removal (2 weeks in cold) + 4 days at 20 °C

Grower 1

Untreated Rep 1 Rep 2

Rep 3 Rep 4

Assessment 2: Upon removal (2 weeks in cold) + 4 days at 20 °C

Grower 1

Treated Rep 1 Rep 2

Rep 3 Rep 4

Assessment 2: Upon removal (2 weeks in cold) + 4 days at 20 °C

Grower 1

Untreated (Top)

Treated (Lower)

Untreated (Top)

Treated (Lower)

Untreated Treated

Appendix 8. Extension article

Summary article of the project outcomes submitted to '*Talking Avocados*' (March 2025)

Phytosanitary irradiation article for Talking Avocados magazine – due 14 March 2025

Sent 7 March 2025. 452 words

The effects of phytosanitary irradiation as a market access treatment on avocado fruit quality

John Golding and Thuy Pham

Centre for Australian Horticultural Market Access

NSW Department of Primary Industries and Regional Development

Ensuring access to current and new emerging markets is crucial for the long-term profitability of the Australian avocado industry. With an increasing supply of fruit, there is a need to increase the export opportunities for Australian avocados to improve grower returns and profitability. However, many of these new export opportunities are limited by phytosanitary quarantine barriers which require treatment of fruit to ensure control of pests (e.g. Queensland fruit fly).

Phytosanitary irradiation is a relatively new market access treatment that has grown in use for many horticultural crops. Over the past five years, Australian domestic and export trade volumes using phytosanitary irradiation have rapidly increased. A growing list of crops including table grapes, mangoes and cherries have all had export success using phytosanitary irradiation as a market access treatment.

Phytosanitary irradiation is a fast and chemical free treatment which can be applied without breaking the cold chain. While its use has many benefits, its effects on avocado quality have not been clearly documented. Previous studies of the effects of phytosanitary irradiation on fruit quality have shown inconsistent results. This Hort Innovation funded project examined the impacts of contemporary phytosanitary irradiation technology on avocado fruit quality.

Export grade Hass and Shepard avocados from different growers in different regions were treated with phytosanitary irradiation at the commercial treatment provider, Steritech in Melbourne. The quality of treated and non-treated fruit was compared after treatment and storage.

The overall results showed that fruit were unacceptable following treatment and storage. While treating fruit with phytosanitary irradiation generally slowed the rate of fruit softening and loss of green skin colour, there were high levels of vascular browning in treated fruit, particularly after storage. The negative effect of treatment was observed

in all trials, irrespective of region, grower or variety (Shepard and Hass). The increase in vascular browning will limit the use of irradiation as a market access treatment for avocados. Other market access options such as fumigation need to be explored to improve market access for Australian avocados.

For more information, please contact John Golding at NSW DPIRD - email john.golding@dpi.nsw.gov.au

Funding acknowledgement

This is a contribution from the project 'Evaluation of irradiation as a postharvest phytosanitary measure for Australian avocados' (AV 22008) funded by Horticulture Innovation and NSW Department of Primary Industries and Regional Development. Levies from Australian avocado growers are managed by Horticulture Innovation. NSW Department of Primary Industries and Regional Development also contributed to the funding this project. The Australian Government provides matched funding for all Horticulture Innovation's research and development activities.

Measuring fruit quality after treatment and after storage at NSW DPIRD at Ourimbah.

Internal appearance of Shepard (left) and Hass fruit (right) after 2 weeks at 7 °C and 4 days at 20 °C. Untreated fruit are on the top and treated fruit on the bottom.

High levels of vascular browning in Shepard (left) and Hass (right) fruit following treatment and storage. Also note high levels of additional stem end rot in treated Shepard fruit (left).

Appendix 9. Summary poster

Project poster presented at the Avocados Australia Regional Extension Forums (2025)

Department of Primary Industries and Regional Development

Hort Innovation AVOCADO FUND

NSW GOVERNMENT

Improving avocado market access

Testing the potential of phytosanitary irradiation as a market access treatment for Australian avocados

Phytosanitary irradiation is a new market access treatment that has grown in use for many horticultural crops. However previous work on its effects on avocado fruit quality have been inconsistent.

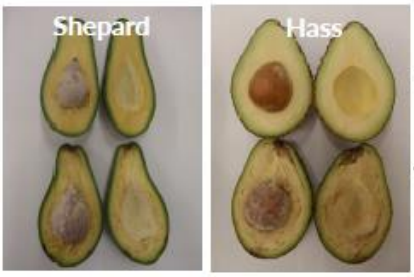
Phytosanitary irradiation treatment

Export grade Hass and Shepard avocados from different growers in different regions (north Queensland, Bundaberg, tri-state region) were treated with phytosanitary irradiation at the commercial treatment provider, Steritech in Melbourne. The quality of treated and non-treated fruit were then compared after treatment and storage.

Results

The overall results showed that treated fruit were unacceptable following treatment and storage. This was observed across different regions and varieties.

Internal appearance of Shepard (left) and Hass fruit (right) after 2 weeks at 7 °C and 4 days at 20 °C

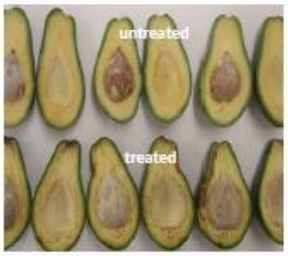


Untreated

Treated

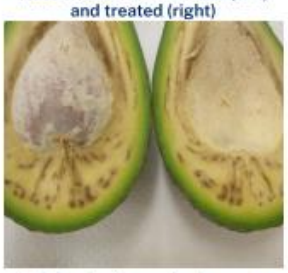
Note the severe vascular browning in the flesh of treated fruit

Treating fruit with phytosanitary irradiation generally slowed the rate of softening and loss of green skin colour. But treated Hass and Shepard fruit had higher than acceptable levels of vascular browning.



Shepard avocados - untreated (top) and treated (below)

Hass avocados - untreated (left) and treated (right)



High levels of vascular browning in Hass fruit following treatment

Acknowledgements
This project ('*Evaluation of irradiation as a postharvest phytosanitary measure for Australian avocados*', AV22008) has been funded by Hort Innovation, using the avocado research and development levies, contributions from the Australian Government and co-investment from NSW Department of Primary Industries and Regional Development. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.
We also acknowledge the assistance of Mark Bullot, Maddy Kavanagh, Ainhoa Redoute, Sarah Despaux and Julie Genebes who contributed to the outcomes of this research.
We also thank Avolution and Steritech for the supply of fruit, treatment and coordination of the trials.

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