Commercial-in confidence

# Effect of Seasol® fertigation on post-harvest quality of Hass avocado (Tolga & Bundaberg)

*FreshHort*

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*FreshHort is an independent R&D consulting company with over 25 years of experience in horticultural R&D encompassing trial design and statistical analysis, evaluation of postharvest supply chains, technologies, and treatments, and postharvest disease control. We also provide fresh produce handling and quality assessment training to the fruit and vegetable industry, and to fresh food retailers.*

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## Summary and commercial implications

### Background

Two postharvest cool storage and ripening trials were conducted in June-July 2020 to determine if Seasol fertigation reduced the rate of Hass avocado quality loss under simulated domestic storage and retailing conditions. The potential postharvest benefits of Seasol fertigation compared to untreated fruit may include:
-reduction in firmness loss during ripening and extended shelf life at retail and for the consumer;
-reduction in loss of skin green colour and extended marketability during retail;
-increased colour uniformity and consumer appeal among individual fruit during the early stages of ripening;
-extended overall marketability during retailing; and
-reduction in the risk of cool storage disorders such as diffuse and vascular flesh browning.

### Postharvest trials

Fruit for the postharvest trials were harvested from two large scale field trials on commercial farms (Tolga and Bundaberg) in North Queensland containing both Seasol-fertigated and untreated blocks. Fruit were commercially graded and packed, cartons randomly selected from among packed fruit, and cartons transported to Melbourne at 7°C. Fruit from Tolga were delivered 7 to 12 days after harvest (average of 11 days) due to multiple harvests among treatments whilst fruit from Bundaberg were delivered 7 days after harvest. Bundaberg fruit were harvested approximately two weeks after Tolga fruit. For the postharvest trial fruit were assigned to one of eight storage and ripening scenarios (without prior ethylene ripening) where Tolga fruit were stored for a total of 19 days at 7°C whilst Bundaberg fruit were stored for a total of 18 days:

A. Unripened fruit directly after delivery
B. Directly after delivery + Ripening at 18°C for 4 days
C. Directly after delivery + Ripening at 18°C for 6 days
D. Unripened fruit after further storage at 7°C
E. Extended storage + Ripening at 18°C for 2 days
F. Extended storage + Ripening at 18°C for 4 days
G. Extended storage + Ripening at 18°C for 6 days
H. Extended storage + Ripening at 18°C for 8 days

Tolga fruit were cool-stored for an additional 8 days at 7°C after delivery whilst Bundaberg fruit were stored for an additional 11 days. Fruit quality assessments at the end of each postharvest scenario included fruit weight, visual ripeness score, marketable quality score, fruit skin colour (hue angle), hand pressure firmness score, fruit skin and flesh hardness, flesh physiological disorders and flesh dry matter concentration. The postharvest trial using fruit from Tolga was compromised due to multiple harvest dates among both treatments with Seasol fertigated fruit assigned to extended storage and ripening harvested two days earlier than control fruit. The impact of different harvest dates on fruit quality were partially mitigated by allocating fruit to scenarios in such a way as to minimise differences in harvest dates between treatments.

## Key outcomes

On average Seasol fertigation significantly increased marketable quality (i.e., delayed quality loss) during ripening among fruit harvested from Bundaberg whilst also decreasing the rate of skin darkening as compared to untreated fruit (Table 4). No significant or consistent difference in fruit firmness among treatments was observed during ripening after delivery, and after extended cool storage. Postharvest results among fruit harvested from Tolga should be considered in the context of multiple harvest dates among treatments and scenarios that may have confounded Seasol fertigation effects.

Seasol fertigated fruit assigned to extended cool storage were harvested two days earlier than control fruit and thus were stored and ripened for up to 48 hours longer on average than control fruit. Unsurprisingly under these circumstances fruit firmness on average was greater among control fruit during postharvest ripening as measured by hand pressure firmness, and skin and flesh hardness. But surprisingly among Seasol fertigated fruit harvested two days earlier remained significantly greener on average during ripening, and skin colour among individual fruit was on average less variable than among control fruit.

## Estimate of shelf life extension

For Seasol-fertigated and untreated fruit from both sites the estimated postharvest degree hours >0°C at which point fruit reached their limit of retail marketability was determined and thus extension of shelf life (if any) due to Seasol fertigation relative to untreated fruit could be estimated. Among Tolga fruit harvest date of fruit assigned to each scenario was recorded and thus postharvest degree hours could be calculated for each treatment within and among scenarios, and thus shelf life estimates are valid. Shelf life estimation is presented visually in Figure 4 and 5, with analysis and calculations described in the Methods section, whilst when calculating postharvest degree hours it was assumed that all fruit were handled and stored at 7°C between harvest and fruit delivery.

Among fruit from both sites Seasol-fertigation was estimated to increase shelf life during ripening by 1 to 1.5 days based on marketable quality score. In other words untreated fruit reached the end of marketability at retail up to 1.5 days earlier than Seasol-fertigated fruit (Table 2 and 3). End of shelf life quality criteria used are summarised in Table 5. Seasol fertigation also extended shelf life by an estimated 1.5 to 3 days among fruit across both sites based on skin colour hue angle and the rate of loss of green colour among fruit. In other words untreated fruit darkened to the limit of marketability 1 to 3 days earlier than fertigated fruit.

Among Tolga fruit no measurable increase in fruit shelf life due to Seasol fertigation was observed based on the rate of firmness loss during ripening as measured by hand pressure firmness and flesh hardness score, that is, both fertigated and untreated fruit softened at the same rate during ripening. Among Bundaberg fruit Seasol fertigation reduced avocado softening compared to untreated fruit during ripening directly after delivery, and increased shelf life marginally by less than 0.5 days, whilst no difference in shelf life was observed among fertigated and control fruit after cool storage for 18 days and ripening.

### Commercial implications

Among commercially-graded fruit from both Tolga and Bundaberg postharvest storage and ripening trials simulating domestic marketing demonstrated that Seasol fertigation increased fruit marketability and shelf life over untreated fruit due to a reduction in loss of marketable quality, and loss of green skin colour, during ripening. After cool storage and during retailing shelf life estimates indicate that Seasol-fertigation is likely to increase shelf life, that is, delay the end of retail marketability, by approximately 1 to 3 days based on visual quality indicators. The actual improvement in retail shelf life due to Seasol fertigation will also depend on harvest timing, and pre-harvest agronomic factors, as well as fruit maturity as measured by flesh dry matter concentration (DM). In these postharvest trials average DM was comparable among field sites (33% in Tolga; 30% in Bundaberg), and the average difference in DM between treatments within each site was less than 0.5%.

Suppliers and retailers may be able to gain a commercial benefit via increased retail life and reduced wastage at retail among Hass avocados with field application of Seasol-fertigation whilst consumers will benefit via extended shelf life after purchase prior to consumption.

## Scientific recommendations

Two postharvest trials from two field sites simulating domestic supply chains have provided evidence that Seasol-fertigation reduces the rate of quality loss among Hass avocados during ripening, and future trials should be conducted to confirm the positive impact of Seasol-fertigation on avocado quality under various commercial supply chain scenarios. When conducting further trials the following recommendations should be implemented to strengthen experimental methodology and validity of results:

- Ideally sample fruit from large-scale replicated field trials to minimize or accommodate the impact of differences in field and agronomic factors among treatments;
- If possible sample treated and untreated fruit from adjacent blocks and locations among non-replicated trials ensuring that all fruit are harvested on the same day;
- Conduct ethylene ripening prior to cool storage to determine its interaction with Seasol-fertigation impacts on postharvest quality.

**Table 1.** Summary of estimated additional shelf life due to Seasol-fertigation based on fruit visual quality and firmness among two supply chain scenarios (Tolga).

| **Cool storage period** | **Quality indicator** | **Shelf-life extension at 18°C due to Seasol-fertigation** | **Correlation with postharvest degree hours ($r^2$)** | **End of marketability measure** |
|---|---|---|---|---|
| *11 days storage after harvest at 7°C and ripening at 18°C* | Marketable quality score | 1 to 1.5 days | 0.88 | Score = 2.5 |
| | Skin colour (hue) | 2 to 3 days | 0.96 | Hue = 85 |
| | Hand firmness score | | | |
| | Flesh hardness | | | |
| *19 days storage after harvest at 7°C and ripening at 18°C* | Marketable quality score | 1 to 1.5 days | 0.85 | Score = 2.5 |
| | Skin colour (hue) | 1.5 to 2.5 days | 0.94 | Hue = 85 |
| | Hand firmness score | | | |
| | Flesh hardness | | | |

**Shelf-life extension:** Estimated days of additional shelf life due to Seasol-fertigation during ripening at 18°C after the end of the transport/ cool storage stage; **Correlation with postharvest degree hours:** The degree of correlation between the quality indicator and storage period as measured by degree hours.

**Table 2.** Summary of estimated additional shelf life due to Seasol-fertigation based on fruit visual quality and firmness among two supply chain scenarios (Bundaberg).

| **Cool storage period** | **Quality indicator** | **Shelf-life extension at 18°C due to Seasol-fertigation** | **Correlation with postharvest degree hours ($r^2$)** | **End of marketability measure** |
|---|---|---|---|---|
| *7 days storage after harvest at 7°C and ripening at 18°C* | Marketable quality score | 0.5 to 1 day | 0.90 | Score = 2.5 |
| | Skin colour (hue) | <0.5 days | 0.97 | Hue = 85 |
| | Hand firmness score | <0.5 days | 0.94 | Hand firmness = 5 |
| | Flesh hardness | <0.5 days | 0.97 | Hardness = 35 |
| *18 days storage after harvest at 7°C and ripening at 18°C* | Marketable quality score | 0.5 to 1 day | 0.92 | Score = 2.5 |
| | Skin colour (hue) | 0.5 to 1 day | 0.91 | Hue = 85 |
| | Hand firmness score | | | |
| | Flesh hardness | | | |

**Shelf-life extension:** Estimated days of additional shelf life due to Seasol-fertigation during ripening at 18°C after the end of the transport/ cool storage stage; **Correlation with postharvest degree hours:** The degree of correlation between the quality indicator and storage period as measured by degree hours.

## Experimental objectives

1. Investigate the effect of Seasol® fertigation on visual quality, flesh firmness and storage disorders among Hass avocado after transport, and after further cool storage 7°C;

2. Determine the effect of Seasol® fertigation among Hass avocado during postharvest ripening that simulates marketing and consumer handling.

## Experimental methods

### Field trial and Seasol® fertigation

Two non-replicated field trials were conducted in 2020 on commercial farms (Tolga and Bundaberg) in North Queensland, Australia, that supply the Costa Group, to investigate the influence of Seasol® on yield of Hass avocados. Monthly applications of Seasol® were made from flowering until harvest, via under tree micro-sprinkler irrigation. Seasol® treatment was applied at 10 L/ha as a soil fertigation treatment to the treated block, with standard grower fertigation practices applied to the untreated control (ie., control block). All trees among field trials were grown in a typical, local agricultural soil type that was uniform across both treatments. Similar crop management (i.e., irrigation timing and amounts, nutrition and pest control) operations were applied across both treatments.

### Fruit preparation and storage

From each treatment block and control block used in two fertigation field experiments 160 fruit per treatment were randomly selected after all fruit were graded to commercial market standards. Fruit were then packed into trays and delivered to FreshHort in Melbourne within 7 to 11 days of harvest. It is assumed that average fruit temperature between harvest and delivery was approximately 7°C. <u>Note that fruit from Tolga were received 7 to 12 days after harvest (average of 11 days) due to multiple harvests whilst fruit from Bundaberg were received 7 days after harvest</u>. Bundaberg fruit were harvested approximately two weeks after Tolga fruit. Within 12 hours of delivery twenty fruit per treatment (grouped into four replicates of five fruit) were randomly allocated to one of the following eight postharvest scenarios (Tolga fruit storage days in parentheses):

A. Day 7 (or Day 11): unripened fruit directly after delivery
B. Day 7 (or Day 11) + Ripening at 18°C for 4 days
C. Day 7 (or Day 11) + Ripening at 18°C for 6 days

D. Day 18 (or Day 19): total days of storage at 7°C from harvest
E. Day 18 (or Day 19) + Ripening at 18°C for 2 days
F. Day 18 (or Day 19) + Ripening at 18°C for 4 days
G. Day 18 (or Day 19) + Ripening at 18°C for 6 days
H. Day 18 (or Day 19) + Ripening at 18°C for 8 days

Fruit selected for cool storage were stored for 11 days (Tolga), and 7 days (Bundaberg), at 7°C and 80% RH in trays within unsealed high humidity liners. After cool storage fruit were ripened at 18°C and 50% RH once cartons were removed from plastic liners.

## Postharvest experimental design

Each postharvest scenario was randomly assigned to an experimental unit of five fruit per field treatment that could be considered a storage replicate, with four storage replicates per field treatment and scenario. In randomly assigning scenarios to each experimental unit of five fruit within a field treatment we assume that orchard factors and agronomic practices affected all fruit equally so that any significant differences among assessments can be mainly attributed to field treatments (i.e., field blocks and trees used in fertigation trials are relatively homogeneous in terms of soil type, agronomic practices, tree age and size).

## Statistical analyses

Data were analysed as a factorial experiment with blocking using two-way ANOVA in GenStat 17 (VSN International Ltd., Oxford, UK) to determine the main and interaction effects of fertigation and scenario on fruit quality and physiological disorders. Violations of the ANOVA assumption of normality in the data, such as non-normality (Skewness, Kurtosis) or heterogeneity of treatment variance, were assessed using residual error plots, skewness and kurtosis tests of normality, and Bartlett's test of homogeneity of variance. Where necessary the appropriate data correction transformation was applied to data prior to ANOVA based on optimal values of lambda calculated from Box-Cox analysis in Genstat.

Multiple comparisons of treatment means were conducted at each scenario using Fisher's Least Significant Difference (LSD) test with statistical differences between means determined at a 5% significance level ($\alpha = 0.05$). Note that in the report the term 'significant' refers to statistical significance rather than to effects that may be commercially significant. Treatment means that were back-transformed from transformed data used for ANOVA are indicated in results tables.

## Multiple harvest dates (Tolga)

Fruit received from the Tolga field trial were harvested on different days both within and among field treatments (Seasol fruit - Harvested on 12/6, 14/6 and 15/6; Control fruit - Harvested on 11/6 and 16/6). Multiple harvest dates potentially confounded effects of treatment on fruit quality during postharvest storage and ripening. During allocation of replicates to each postharvest scenario fruit harvested earlier among both field treatments was assigned to ripening scenarios directly after delivery (Day 11), whilst later harvested fruit were assigned to extended cool storage and ripening scenarios. The majority of Seasol-fertigated fruit assigned to cool storage and ripening were harvested on the 14$^{th}$ June whilst most control fruit assigned to the same storage and ripening scenario were harvested on the 16$^{th}$ June (Table 5).

## Shelf life estimates

For Seasol-fertigated and untreated fruit from both field trials separate regression equations were determined for relationships between each quality indicator and postharvest degree hours >0°C for each scenario. Among Tolga fruit harvest date of replicates assigned to each scenario was recorded and thus postharvest degree hours could be calculated for each treatment within and among scenarios. For each quality indicator a minimum value indicating the end of avocado retail marketability (e.g., hand pressure firmness value of 5) was selected and postharvest degree hours calculated where this minimum value occurred for each treatment during ripening (Table 3).

The number of days during ripening required to reach the minimum marketable quality (i.e., shelf life) was calculated for each treatment from the estimated total degree hours required to reach this minimum quality. The difference in days required to reach minimum marketable quality between Seasol fertigated and untreated fruit for each quality indicator was thus deemed the additional shelf-life due to fertigation treatment.

### *Regression analyses*

Regression analysis was conducted in GenStat 17 (VSN International Ltd., Oxford, UK) to determine the degree of correlation between fruit quality indicators and postharvest degree hours, and associated regression equations, enabling an estimation of shelf life for both Seasol-fertigated and untreated fruit. Both linear and exponential curves were fitted to data with the later generally having a marginally higher correlation coefficient than linear relationships. All P-values were <0.001 (i.e., highly significant) among correlations for quality indicators used and postharvest degree hours.

*Total degree hour calculation*

Total postharvest degree hours > 0°C (Dh >0°C) were calculated by summing accumulated degree hours during the following stages:

<u>Harvest through to delivery for postharvest trials</u>

7 days at 7°C from harvest to beginning of postharvest trials

'Transport' Dh >0°C = 7 days x 24 hours x 7°C = 1176 Dh

<u>Cool storage at 7°C for 11 days</u>

Storage Dh >0°C (7°C storage) = 11 days x 24 hours x 7°C = 1848 Dh

<u>Ripening at 18°C for up to 8 days</u>

Example: 6 days at 18°C after storage

Ripening Dh >0°C = 6 days x 24 hours x 18°C = 2592 Dh

**Table 3.** Avocado quality indicators used to estimate additional shelf life at 18°C due to Seasol fertigation treatment.

| Quality indicator | Range of possible values for avocados | Value at harvest | Value after cool storage | Value at end of retail marketability |
|---|---|---|---|---|
| Marketable quality score | 5 (excellent) to 1 (unmarketable) | 4 to 5 | 3 to 4 | 2.5 |
| Skin colour (hue) | 125 (green) to 50 (black) | 120 | 110 to 115 | 85 to 90 |
| Hand firmness score | 0 (hard) to 7 (very soft) | 0 | 0 to 2 | 4.5 to 5 |
| Flesh hardness | 100 (hard) to 5 (very soft) | 100 | 90 to 95 | 30 to 40 |

### Fruit quality assessments

After each postharvest scenario the following quality attributes were measured among five fruit per storage replicate:

- Weight (using standard scales to one decimal place)
- Visual ripeness score
- Marketable quality score
- Fruit skin colour (hue angle)
- Hand pressure firmness score
- Fruit skin and flesh firmness
- Flesh physiological disorders
- Flesh dry matter concentration

The specific methods and scoring used to measure each fruit quality attribute are described below based on White et al., (2003) but methods modified to improve precision where necessary.

*Visual ripeness score*

A five-point rating scale was used to describe visual ripeness where 1= Unripe; 2 = onset ripe; 3 = ripe; 4 = eating ripe, and 5 = over-ripe (Fig. 1). Half ratings were used where necessary for a more precise ripeness score (e.g., 2.5).

**Figure 1.** Visual ripeness rating scale used during avocado assessments (5 = left; 1 = right).

*Marketable quality score*

A five-point rating scale was used to describe marketable quality (i.e., retail marketability) based on overall visual quality, ripeness, and skin disorders where 5= Excellent; 4 = Very good; 3 to 2.5 = Limit of marketability; 2 = Over-ripe; and 1 = End of shelf life. Half ratings were used where necessary for a more precise marketable quality score (e.g., 2.5).

**Figure 2.** Marketable quality rating scale where 5 = excellent (far left) through to 1 = very poor (far right).

*Fruit skin colour*

Skin surface colour was measured at four equidistant points at the widest diameter of each fruit with a hand-held tristimulus reflectance colorimeter (model CM-2600d, Minolta Corp.). Colour was recorded using the CIE L*a*b* uniform colour space (CIE Laboratories), where L* indicates lightness, a* indicates chromaticity on a green (-) to red (+) axis, and b* chromaticity on a blue (-) to yellow (+) axis. Numerical values of a* and b* for each fruit were averaged and then the average hue angle calculated using H° = arctan (b*/a*).

*Hand pressure firmness*

The deformation or 'give' of the whole fruit was determined by holding the fruit in the palm of the hand and gently squeezing with the whole hand if the fruit was soft, or with the fingers and thumb when fruit was hard. Each fruit was then given a firmness score based on the rating scale in Figure 3.

**The 'give' or deformation of the fruit is rated using the following scale**

| | |
|---|---|
| 0 = | Hard, no 'give' in the fruit |
| 1 = | Rubbery, slight 'give' in the fruit |
| 2 = | Sprung, can feel the flesh deform by 2-3 mm under extreme thumb force |
| 3 = | Softening, can feel 2-3 mm deformation with moderate thumb pressure |
| 4 = | Near-ripe, 2-3 mm deformation achieved with slight thumb pressure, whole fruit deforms with extreme hand pressure |
| 5 = | Ripe or eating soft, whole fruit deforms with moderate hand pressure |
| 6 = | Overripe, whole fruit deforms with slight hand pressure |
| 7 = | Very overripe, flesh feels almost liquid. |

**Figure 3.** Hand pressure firmness rating scale.

*Durometer fruit firmness*

At each assessment fruit firmness was measured on both cheeks of each fruit at its widest point with a hand-held Agrosta® Durofel DFT 100 digital firmness tester using the Shore A hardness 0 to 100 scale where 0 = extra soft, 20 = soft, 40 = medium soft, 70 = medium hard and >90 = hard. After removal of the skin on each cheek the same firmness measurement was conducted on the flesh of the fruit. During firmness measurements soft spots on fruit were avoided. The firmness tester was calibrated to zero prior to measurements at each assessment.

*Flesh dry matter (DM) concentration*

After flesh firmness measurements were completed the cheek of each side of a fruit within a replicate was sliced off, skin peeled off, and the flesh trimmed down to approximately 15 g. Flesh pieces within a replicate were then combined, weighed, placed in paper bags, and dried to constant weight at 65°C. Dried avocado cheeks were then weighed again and the average dry matter concentration calculated for each storage replicate.

## Discussion

### Summary of Seasol fertigation effects on postharvest fruit quality

The main effects of Seasol fertigation on fruit quality compared to untreated control fruit are summarized in Table 4, where the means for each treatment and quality indicator are averaged across all postharvest scenarios. P-values below 0.05 indicate a highly statistically significant effect whilst P-values between 0.05 and 0.200 are suggestive of a treatment effect but require further confirmation. Postharvest results among fruit harvested from Tolga should be viewed in the context of multiple harvest dates among treatments and scenarios that may have confounded treatment effects. Among postharvest scenarios Seasol fertigated fruit were harvested 1 to 2 days earlier than control fruit (Table 5), and thus were stored and ripened for 24 to 48 hours longer on average than control fruit. Unsurprisingly under these circumstances fruit firmness on average was greater among control fruit during postharvest ripening as measured by hand pressure firmness, and skin and flesh hardness. But surprisingly given the earlier harvest Seasol fertigated fruit remained significantly greener on average during ripening, and skin colour among individual fruit was on average less variable than among control fruit. Among fruit from Bundaberg harvested two weeks later Seasol fertigation significantly increased fruit marketability score when averaged among all postharvest scenarios with skin colour results also suggesting, as among Tolga fruit, that Seasol fertigation reduces the rate of skin darkening during ripening as compared to control fruit.

### Mean fruit weight and flesh dry matter

No significant differences between Seasol fertigated and control fruit weight were observed among both Tolga and Bundaberg avocados during postharvest storage and ripening, but among both trials similar and significant reductions in average fruit weight were observed with increasing cool storage duration and ripening (Table 6 and 7). Average fruit weight decreased similarly among Seasol fertigated and control fruit in both trials most likely due to water loss as fruit ripened. As fruit were commercially graded prior to packing it is unsurprising that little difference in fruit weight was observed among treatments. Flesh dry matter concentration (DM) was approximately 3% higher on average among Tolga fruit compared to Bundaberg fruit with considerable variation in DM among treatments and postharvest scenarios within both sites (Table 8 and 9). Main treatment effects averaged among postharvest scenarios were not significant in both trials with little impact of cool storage and ripening duration on final DM concentration.

### Effect of Seasol fertigation on fruit visual quality

Although control fruit from Tolga assigned to Day 19 storage were harvested two days earlier on average than Seasol fertigated fruit, no significant differences in marketable quality score or visual ripeness score were observed among treatments during ripening (Table 10). Similarly little difference in visual quality was observed among fruit during ripening at Day 11 although Seasol fertigated fruit were significantly less ripe than control fruit after ripening for 4 days. The limit of retail marketability was reached among both treatments after ripening for 6 days at Day 11, and ripening for 4 to 6 days at Day 19, based on both marketable quality and visual ripeness score.

Among avocados harvested from Bundaberg overall marketable quality score was significantly higher among Seasol fertigated fruit with significant differences among specific postharvest scenarios observed at both Day 18, and Day 7, after ripening for 6 days (Table 11). The rate of marketable quality loss during ripening was similar among Tolga and Bundaberg fruit both directly after transport, and after a total cool storage period of 19 and 18 days, respectively. No consistent or significant difference in visual ripeness score was observed among Bundaberg fruit during ripening after cool storage for 7 and 18 days.

**Effect of Seasol fertigation on fruit firmness**

Unsurprisingly among fruit harvested from Tolga, control fruit that were harvested two days later were generally firmer during ripening at Day 19 than Seasol fertigated fruit as measured by hand pressure firmness score, as well as skin and flesh shore hardness (Table 12). Control fruit were significantly firmer after ripening for 4 days at Day 19 based on hand pressure firmness, as well as skin and flesh hardness. During ripening at Day 11 where both treatments were harvested within one day of each other (on average), control fruit were significantly firmer after ripening for 6 days based on skin and flesh hardness, whilst Seasol fertigated fruit were significantly firmer after ripening for 4 days based on hand pressure firmness and skin hardness. At Day 19 little difference in fruit firmness was observed during the later stages of ripening where fruit had reached end of shelf life. Among fruit harvested from Bundaberg little difference in hand pressure firmness, and skin and flesh hardness, was observed among treatments during ripening at Day 7 and Day 19, with similar rates of firmness loss after both storage durations (Table 13). Fruit firmness was marginally higher among Seasol fertigated fruit at Day 7 after both ripening periods based on hand pressure firmness and flesh hardness whilst control fruit remained marginally firmer during the early stages of ripening at Day 18. Control fruit were also significantly firmer at Day 18 after ripening for 2 days but beyond this ripening duration no significant difference in fruit firmness was observed among treatments.

**Effect of Seasol fertigation on fruit skin colour**

Mean fruit skin colour measured objectively using a colourimeter was found to be significantly higher (i.e., significantly greener or less dark) during ripening among seven of sixteen assessments across both storage durations and sites. Seasol fertigated fruit from Tolga that were harvested at a similar time as control fruit were on average significantly greener at Day 11 after ripening for 4 and 6 days (Table 14). Surprisingly fertigated fruit that had been harvested two days earlier than control fruit were also significantly greener at Day 19 after ripening for 4, 6 and 8 days, noting that most fruit after ripening for 6 and 8 days among both treatments were dark green to black (See Appendix). The variation in skin colour among individual fruit was on average significantly lower among Seasol fertigated avocados at Day 11 after ripening for 4 and 6 days, and after ripening for 4 days at Day 19.

Seasol fertigated fruit from Bundaberg were on average significantly less dark during the later stages of ripening, specifically at Day 7 after ripening for 6 days, and at Day 18 after ripening for 8 days (Table 15). Seasol fertigated fruit were also marginally less dark than control fruit at Day 18 after ripening for 6 days but this difference was not statistically significant. Among Bundaberg fruit variation in skin colour among individual fruit was marginally lower among Seasol fertigated avocados at Day 7 after ripening for 4 days, and significantly lower after ripening for 6 days. No consistent pattern of skin colour variation was observed among treatments during ripening after cool storage at Day 18, whilst skin colour variation among all fruit and both sites tended to increase on average with ripening duration.

# Results

## Shelf life estimate examples

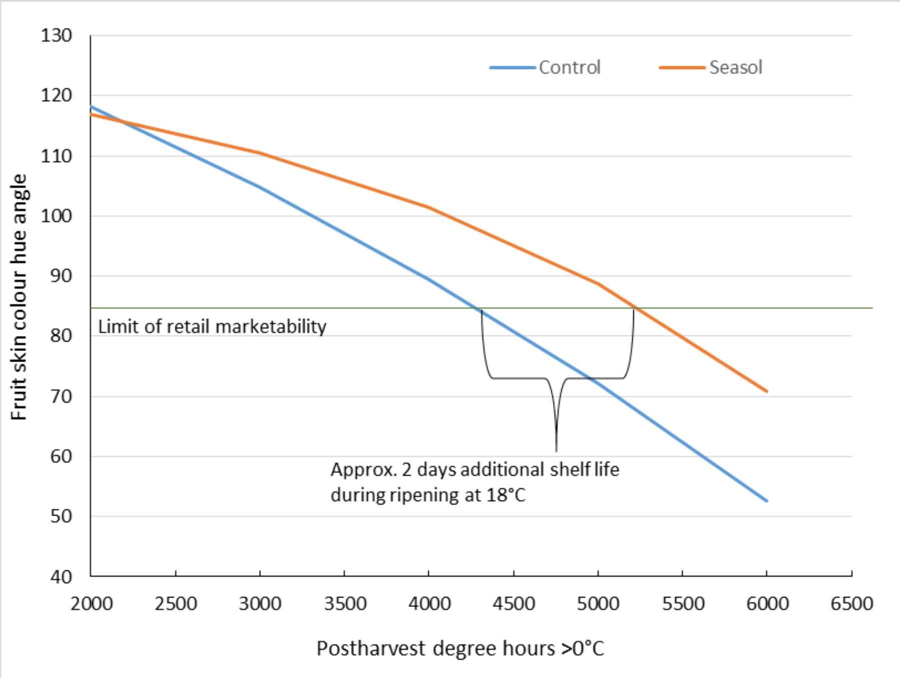



**Figure 4.** Visual example of shelf life calculation based on skin colour hue angle for Seasol-fertigated and untreated fruit from Tolga ripened at 18°C after cool storage at 7°C for 19 days; 430 Dh = 1 day of storage at 18°C (Tolga).

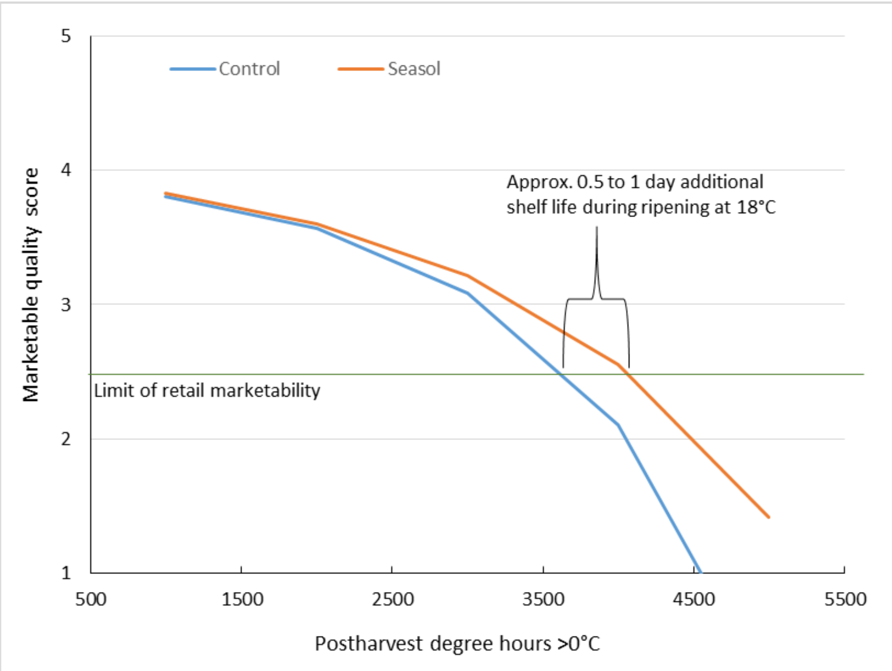



**Figure 5.** Visual example of shelf life calculation based on marketable quality score for Seasol-fertigated and untreated fruit from Bundaberg ripened at 18°C after cool storage at 7°C for 7 days; 430 Dh = 1 day of storage at 18°C (Bundaberg).

**Summary of Seasol fertigation effects on postharvest fruit quality**

**Table 4.** Summary of average quality and treatment effects among Seasol fertigated and control fruit during postharvest storage and ripening among avocados harvested from Tolga and Bundaberg.

| ***Tolga farms*** | | | | |
|---|---|---|---|---|
| **Quality factor** | **Score description** | **Seasol mean** | **Control mean** | **Overall treatment P-value** |
| **Ripeness score** | **Higher score = riper/ darker fruit** | 2.7 | 2.9 | 0.119 |
| **Marketable quality** | **Lower score = lower quality** | 2.9 | 2.9 | 0.972 |
| **Hand pressure score** | **Lower score = firmer fruit** | 2.9 | 3.1 | 0.152 |
| **Skin hardness (0-100)** | **Higher hardness = firmer fruit** | 92 | 93 | 0.082 |
| **Flesh hardness (0-100)** | | 44 | 46 | 0.067 |
| **Skin hue angle (°)** | **Higher angle = greener fruit** | 92 | 86 | <0.001 |
| **Variation in hue angle (%)** | **Higher variation = more uneven skin colour** | 6.9 | 8.5 | 0.004 |
| ***Bundaberg*** | | | | |
| **Quality factor** | **Score description** | **Seasol mean** | **Control mean** | **Overall treatment P-value** |
| **Ripeness score** | **Higher score = riper/ darker fruit** | 2.7 | 2.8 | 0.212 |
| **Marketable quality** | **Lower score = lower quality** | 2.9 | 2.8 | 0.013 |
| **Hand pressure score** | **Lower score = firmer fruit** | 3.2 | 3.2 | 0.629 |
| **Skin hardness (0-100)** | **Higher hardness = firmer fruit** | 94 | 94 | 0.885 |
| **Flesh hardness (0-100)** | | 52 | 53 | 0.444 |
| **Skin hue angle (°)** | **Higher angle = greener fruit** | 96 | 94 | 0.067 |
| **Variation in hue angle (%)** | **Higher variation = more uneven skin colour** | 6.8 | 7.2 | 0.527 |

**Table 5.** Harvest dates of Tolga fruit assigned to each postharvest scenario among Seasol fertigated and control avocados.

| | | **Harvest dates** | |
|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** |
| **Day 11** | **A** | 12-Jun | 11-Jun |
| | **B** | 12-Jun | 11-Jun |
| | **C** | 12 & 14 Jun | 11 & 16 Jun |
| **Day 19** | **D** | 14-Jun | 16-Jun |
| | **E** | | |
| | **F** | | |
| | **G** | | |
| | **H** | | |

## Mean fruit weight and flesh dry matter

**Table 6.** Effect of Seasol-fertigation on mean **fruit weight** compared to control fruit from Tolga assessed at each postharvest scenario; main effect of treatment not significant ($P$ = 0.596).

| | | ***Fruit weight (g)*** | | |
|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Difference** |
| **Day 11** | **A** | 199.7 | 205.2 | -5.5 |
| | **B** | 191.7 | 190.3 | 1.4 |
| | **C** | 184.5 | 196.0 | -11.5 |
| **Day 19** | **D** | 202.2 | 199.2 | 3.0 |
| | **E** | 195.5 | 193.5 | 2.0 |
| | **F** | 196.1 | 196.8 | -0.7 |
| | **G** | 188.6 | 185.9 | 2.7 |
| | **H** | 219.8 | 215.9 | 3.8 |
| ***Mean*** | | 197.3 | 197.9 | -0.6 |

**Table 7.** Effect of Seasol-fertigation on mean **fruit weight** compared to control fruit from Bundaberg assessed at each postharvest scenario; main effect of treatment not significant (*P* = 0.882).

| | | ***Fruit weight (g)*** | | |
|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Difference** |
| **Day 7** | **A** | 234.2 | 233.2 | 1.0 |
| | **B** | 227.0 | 228.6 | -1.6 |
| | **C** | 228.6 | 224.6 | 4.0 |
| **Day 18** | **D** | 228.1 | 226.0 | 2.1 |
| | **E** | 219.1 | 221.2 | -2.1 |
| | **F** | 216.9 | 220.7 | -3.8 |
| | **G** | 211.8 | 213.5 | -1.7 |
| | **H** | 219.8 | 215.9 | 3.8 |
| | ***Mean*** | 223.2 | 222.9 | 0.2 |

**Table 8.** Effect of Seasol-fertigation on mean **flesh dry matter concentration** compared to control fruit from Tolga assessed at each postharvest scenario; main effect of treatment not significant (*P* = 0.632).

| | | ***Dry matter (%)*** | | |
|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Difference** |
| **Day 11** | **A** | 32.6 | 34.5 | -1.8 |
| | **B** | 33.5 | 33.3 | 0.1 |
| | **C** | 34.9 | 34.6 | 0.3 |
| **Day 19** | **D** | 33.2 | 33.7 | -0.6 |
| | **E** | 31.6 | 31.8 | -0.2 |
| | **F** | 33.9 | 32.7 | 1.2 |
| | **G** | 34.2 | 34.0 | 0.2 |
| | **H** | 32.5 | 33.0 | -0.5 |
| | ***Mean*** | 33.3 | 33.5 | -0.2 |

**Table 9.** Effect of Seasol-fertigation on mean **flesh dry matter concentration** compared to control fruit from Bundaberg assessed at each postharvest scenario; main effect of treatment not significant (*P* = 0.404).

| | | ***Dry matter (%)*** | | |
|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Difference** |
| **Day 7** | **A** | 29.7 | 29.5 | 0.2 |
| | **B** | 29.7 | 28.8 | 0.9 |
| | **C** | 30.3 | 30.0 | 0.3 |
| **Day 18** | **D** | 31.7 | 29.9 | 1.8 |
| | **E** | 30.4 | 31.9 | -1.5 |
| | **F** | 30.0 | 30.2 | -0.2 |
| | **G** | 29.5 | 29.9 | -0.4 |
| | **H** | 30.9 | 29.5 | 1.4 |
| | ***Mean*** | 30.3 | 30.0 | 0.3 |

### Effect of Seasol fertigation on fruit visual quality

**Table 10.** Effect of Seasol-fertigation on mean **marketable quality score** and **visual ripeness score** as compared to control fruit from Tolga assessed at each postharvest scenario; grey cells indicate a significant difference among treatments within a scenario and quality indicator at *P* <0.05.

| | | ***Marketable quality score*** | | ***Visual ripeness score*** | |
|---|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Seasol** | **Control** |
| **Day 11** | **A** | 3.6 | 3.5 | 2.2 | 2.4 |
| | **B** | 2.9 | 2.7 | 2.6 | 3.4 |
| | **C** | 2.4 | 2.4 | 3.6 | 3.6 |
| **Day 19** | **D** | 3.0 | 3.3 | 1.3 | 1.2 |
| | **E** | 3.2 | 3.3 | 1.9 | 1.5 |
| | **F** | 2.8 | 2.7 | 3.6 | 3.7 |
| | **G** | 2.1 | 2.0 | 4.1 | 4.3 |
| | **H** | nm | nm | nm | nm |
| | ***Mean*** | 2.9 | 2.9 | 2.7 | 2.9 |
| nm = not measured | | | | | |

**Table 11.** Effect of Seasol-fertigation on mean **marketable quality score** and **visual ripeness score** as compared to control fruit from Bundaberg assessed at each postharvest scenario; grey cells indicate a significant difference among treatments within a scenario and quality indicator at *P* <0.05.

| | | ***Marketable quality score*** | | ***Visual ripeness score*** | |
|---|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Seasol** | **Control** |
| **Day 7** | **A** | 3.8 | 3.8 | 1.2 | 1.2 |
| | **B** | 3.3 | 3.2 | 2.3 | 2.4 |
| | **C** | 2.7 | 2.4 | 3.7 | 3.9 |
| **Day 18** | **D** | 3.7 | 3.6 | 1.1 | 1.3 |
| | **E** | 3.2 | 3.3 | 2.4 | 2.2 |
| | **F** | 2.8 | 2.9 | 3.0 | 2.9 |
| | **G** | 2.4 | 1.8 | 3.8 | 4.0 |
| | **H** | 1.5 | 1.5 | 4.4 | 4.5 |
| | ***Mean*** | 2.9 | 2.8 | 2.7 | 2.8 |

## Effect of Seasol fertigation on fruit firmness

**Table 12.** Effect of Seasol-fertigation on mean **hand pressure firmness score**, **skin shore hardness** and **flesh shore hardness** as compared to control fruit from Tolga assessed at each postharvest scenario; grey cells indicate a significant difference among treatments within a scenario and quality indicator at *P* <0.05.

| | | *Hand firmness score* | | *Skin hardness score* | | *Flesh hardness score* | |
|---|---|---|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Seasol** | **Control** | **Seasol** | **Control** |
| **Day 11** | **A** | 0.1 | 0.2 | 99 | 98 | 98 | 97 |
| | **B** | 3.4 | 4.2 | 93 | 90 | 31 | 22 |
| | **C** | 5.3 | 4.7 | 84 | 88 | 16 | 25 |
| **Day 19** | **D** | 0.4 | 0.3 | 98 | 98 | 96 | 97 |
| | **E** | 1.8 | 1.0 | 96 | 98 | 51 | 68 |
| | **F** | 5.0 | 4.2 | 86 | 91 | 16 | 28 |
| | **G** | 5.8 | 5.8 | 85 | 87 | 21 | 22 |
| | **H** | nm | nm | nm | nm | 18 | 14 |
| | ***Mean*** | 3.1 | 2.9 | 92 | 93 | 44 | 46 |
| nm = not measured | | | | | | | |

**Table 13.** Effect of Seasol-fertigation on mean **hand pressure firmness score**, **skin shore hardness** and **flesh shore hardness** as compared to control fruit from Bundaberg assessed at each postharvest scenario; grey cells indicate a significant difference among treatments within a scenario and quality indicator at *P* <0.05.

| | | *Hand firmness score* | | *Skin hardness score* | | *Flesh hardness score* | |
|---|---|---|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Seasol** | **Control** | **Seasol** | **Control** |
| **Day 7** | **A** | 0.3 | 0.4 | 99 | 99 | 98 | 98 |
| | **B** | 2.5 | 2.9 | 97 | 96 | 57 | 51 |
| | **C** | 4.9 | 5.3 | 89 | 88 | 21 | 19 |
| **Day 18** | **D** | 0.4 | 0.6 | 97 | 96 | 95 | 95 |
| | **E** | 2.2 | 2.1 | 97 | 98 | 58 | 74 |
| | **F** | 3.9 | 3.4 | 94 | 94 | 34 | 39 |
| | **G** | 5.2 | 5.3 | 84 | 85 | 26 | 26 |
| | **H** | 6.3 | 6.0 | nm | nm | 28 | 25 |
| | ***Mean*** | 3.2 | 3.2 | 94 | 94 | 52 | 53 |
| nm = not measured | | | | | | | |

**Effect of Seasol fertigation on fruit skin colour**

**Table 14.** Effect of Seasol-fertigation on mean **skin colour hue angle** and **variation in skin colour within individual fruit** as compared to control fruit from Tolga assessed at each postharvest scenario; grey cells indicate a significant difference among treatments within a scenario and quality indicator at *P* <0.05.

| | | ***Skin colour hue angle*** | | ***Variation in skin colour (%)*** | |
|---|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Seasol** | **Control** |
| **Day 11** | **A** | 118 | 117 | 1.2 | 1.8 |
| | **B** | 91 | 78 | 8.1 | 11.5 |
| | **C** | 81 | 72 | 10.4 | 13.7 |
| **Day 19** | **D** | 116 | 117 | 1.6 | 1.8 |
| | **E** | 109 | 111 | 3.6 | 4.1 |
| | **F** | 87 | 76 | 7.4 | 9.7 |
| | **G** | 81 | 69 | 7.8 | 11.3 |
| | **H** | 55 | 46 | 15.4 | 13.9 |
| | ***Mean*** | 92 | 86 | 6.9 | 8.5 |

**Table 15.** Effect of Seasol-fertigation on mean **skin colour hue angle** and **variation in skin colour within individual fruit** as compared to control fruit from Bundaberg assessed at each postharvest scenario; grey cells indicate a significant difference among treatments within a scenario and quality indicator at *P* <0.05.

| | | ***Skin colour hue angle*** | | ***Variation in skin colour (%)*** | |
|---|---|---|---|---|---|
| **Storage** | **Scenario** | **Seasol** | **Control** | **Seasol** | **Control** |
| **Day 7** | **A** | 121 | 120 | 1.1 | 1.4 |
| | **B** | 97 | 97 | 5.9 | 6.6 |
| | **C** | 69 | 59 | 12.6 | 16.5 |
| **Day 18** | **D** | 121 | 120 | 1.4 | 1.3 |
| | **E** | 105 | 106 | 3.9 | 3.7 |
| | **F** | 92 | 95 | 6.4 | 5.7 |
| | **G** | 83 | 78 | 11.5 | 11.0 |
| | **H** | 80 | 73 | 11.6 | 11.4 |
| | ***Mean*** | 96 | 94 | 6.8 | 7.2 |

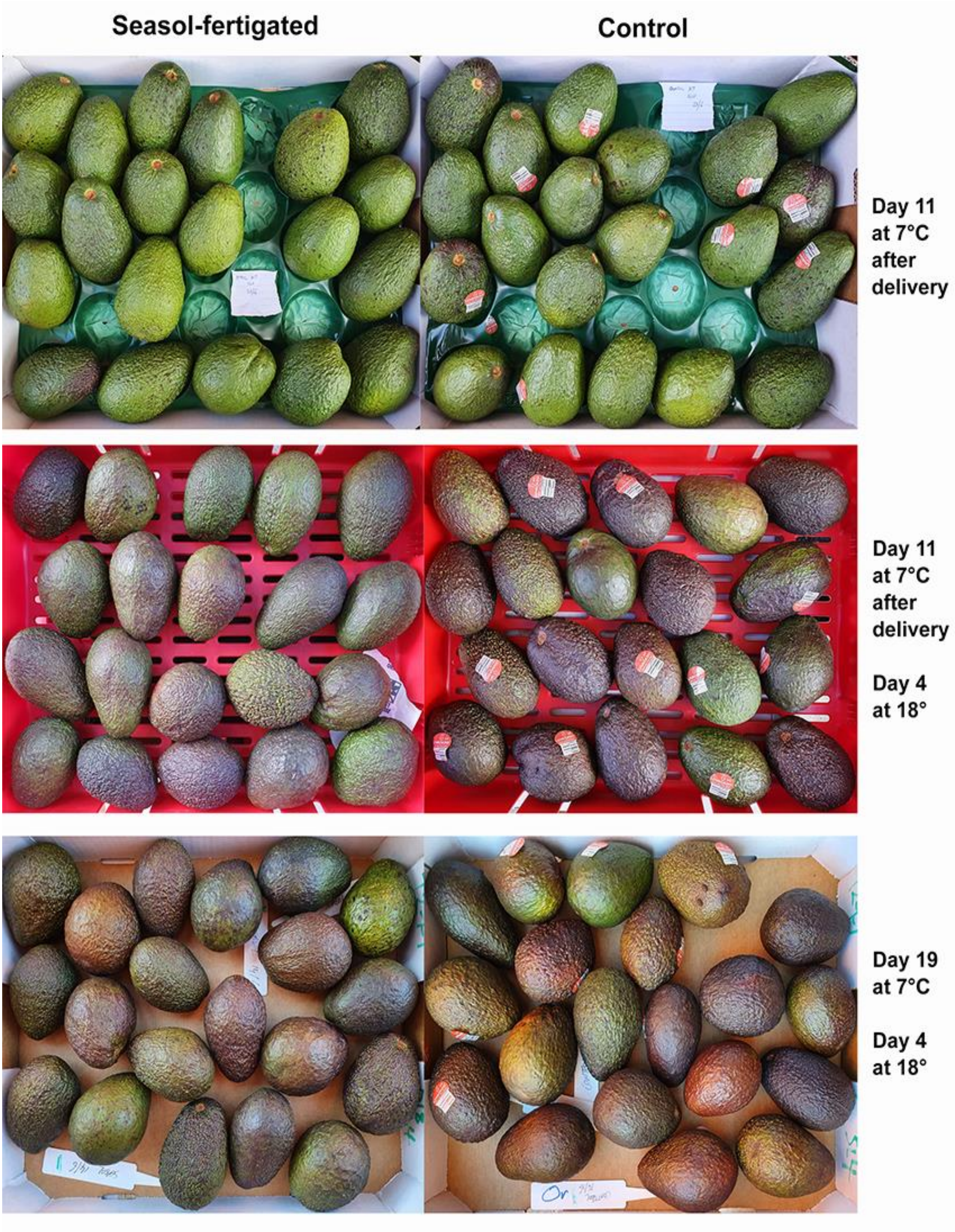
## References

-Hofman P, Jobin-Décor M (1999). Effect of fruit sampling and handling procedures on the percentage dry matter, fruit mass, ripening and skin colour of 'Hass' avocado. J. Hort. Sci and Biotechn., 74(3): 277-282.

-White A, Hofman P, Lu Arpaia M, Woolf A (2003). The international avocado quality manual, Ver. 1.3, HortResearch, New Zealand.

# Appendix

## Selected avocado scenario images – Tolga



**Selected avocado scenario images – Bundaberg**