Effect of Seasol® fertigation on harvest and post-harvest quality of citrus fruit

FreshHort

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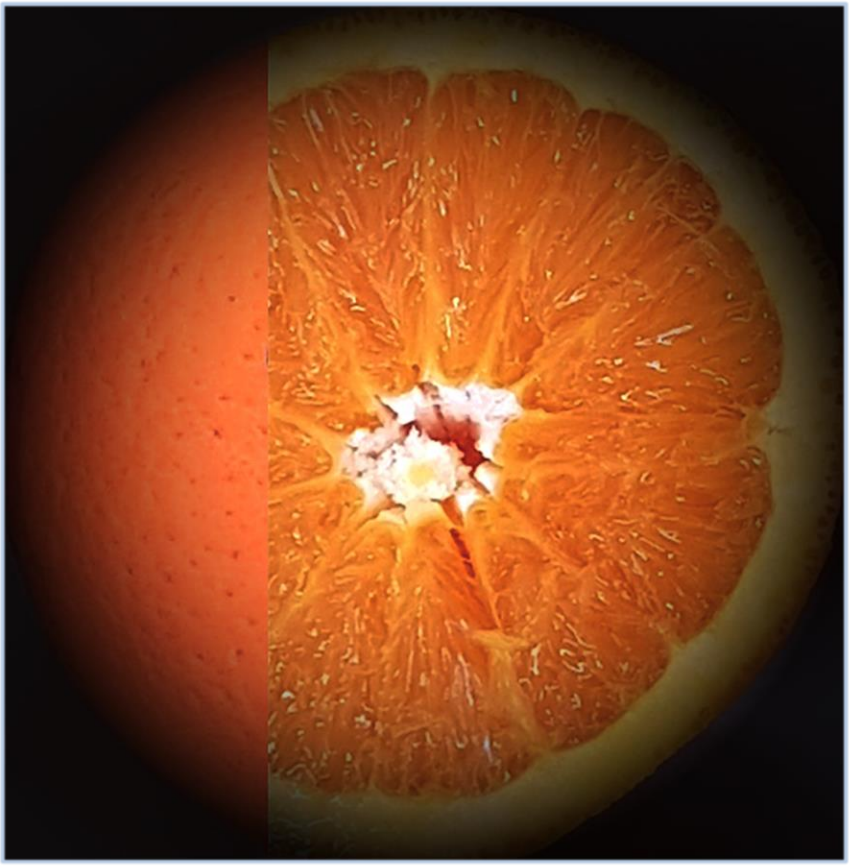

FreshHort is an independent R&D consulting company with over 50 years of experience in horticultural R&D encompassing trial design and statistical analysis, evaluation of postharvest supply chains, technologies, and treatments, and postharvest disease control. We also provide fresh produce handling and quality assessment training to the fruit and vegetable industry, and to fresh food retailers.

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Executive Summary

When purchasing oranges consumers are seeking a product that is visually appealing, firm to the touch, with no signs of fruit ageing, deterioration, water loss or skin disorders, and moist flesh with a balanced ratio of sweetness to acidity on consumption. Many factors during fruit production and after harvest can impact on fruit visual and eating quality particularly nutrition levels in the orchard, temperature management during postharvest handling and marketing, and length of storage and marketing period prior to purchase and consumption. There are three main market segments for Australian citrus including fresh market, supermarket and export market. Postharvest handling within each segment can vary greatly with fresh market consisting of a short distribution and marketing period, with little difference in fruit quality expected when compared to quality at harvest. Potential quality issues in this segment can include skin disorders due to orchard climate or insect damage, visually unappealing fruit due to poor colour uniformity, and low harvest maturity resulting in poor sweetness to acid balance and flavour.

The supermarket segment consists of domestic distribution and retail marketing and can include extended cool storage prior to marketing and consumption. Quality loss within this market segment usually occurs due to poor temperature management of fruit during storage and marketing, potentially resulting in firmness loss, fruit deterioration and skin, and flesh, disorders. The export market segment is characterised by the requirement for insect disinfestation of fruit consignments at low temperature during refrigerated shipping to export markets, and a marketing period where variable and sub-optimal handling temperatures are likely. The quality issues most likely to be encountered after export and marketing include fruit ageing, loss of visual quality, skin and flesh disorders such as flesh drying, due to extended storage at low temperature, and poor temperature management during marketing.

The effect of Seasol® fertigation treatment in the orchard on orange quality was scientifically determined for Australian-grown mid-season navel oranges during cool storage and marketing scenarios representative of the fresh market, supermarket and export market segments. The fresh market segment consisted of fruit quality assessment at harvest and after marketing for 10 days at 18°C, whilst the supermarket segment involved cool storage of fruit at 7°C for three weeks and a marketing period. The export market segment consisted of cool storage at 2°C for three weeks as an insect disinfestation treatment and a subsequent marketing period.

Trial results indicated that Seasol® fertigation treatment is likely to reduce commercially-important quality loss in oranges during cool storage and handling, and particularly after marketing, within supermarket and export market segments, whilst on average significantly improving skin colour uniformity, and fruit sweetness,across all market segments. The trial also indicated that there was a marginal reduction in flesh drying incidence after marketing in the supermarket and export market segments among Seasol®-treated fruit with further trials required to confirm this commercially-important effect.

Significant improvements in orange quality within a market segment due to Seasol® fertigation treatment compared to untreated fruit included:

Fresh market

- Increase in fruit firmness
- Improvement in skin colour uniformity (i.e., less green pigmentation) after marketing
- Higher juice sweetness
- Increase in sweetness to acid ratio after marketing resulting in better flavour

Supermarket

- Improvement in skin colour uniformity (i.e., less green pigmentation) after marketing
- Reduced variation in skin colour after marketing
- Reduced incidence of flesh drying after marketing

Export market

- Reduced variation in skin colour after marketing
- Increase in sweetness to acid ratio after export resulting in better flavour
- Reduced incidence of flesh drying after marketing

A commercial advantage and greater consumer acceptance are likely to result from marketing of oranges that better retain their visual quality and skin colour uniformity within supermarket and export market segments. Seasol® fertigation treatment is also likely to improve eating quality for the consumer due to greater sweetness, with the potential for better sweetness to acid balance and reduced flesh drying, resulting in fruit with better flavour and consumer appeal.

Technical Summary

A preliminary experiment was conducted to scientifically determine the effect of Seasol® fertigation treatment on mid-season navel orange quality at harvest, and after postharvest storage and marketing conditions used by industry in both domestic and export markets. Harvested fruit were treated with postharvest fungicide but were not waxed. Both treated and control fruit were allocated to one of six postharvest scenarios (A through to F) with fruit assessed for quality and physiological disorders at harvest (Scenario A), after harvest and marketing (B), after cool storage at 7°C for 21 days (C), after storage at 7°C and marketing (D), after cool storage at 2°C for 21 days (E), and after storage at 7°C and marketing (F). Scenario C and D simulated domestic handling and marketing whilst Scenario E and F simulated cold disinfestation of fruit for export. Industry standard quality assessments were performed on fruit after each scenario and included fruit weight loss; external visual quality; firmness; skin, flesh and juice colour; soluble solids concentration; titratable acidity; juice concentration; and physiological disorders associated with chilling injury.

Averaged over all postharvest scenarios Seasol® fertigation treatment was found to significantly improve average fruit visual quality score by 8 % (relative increase above control fruit), increase average skin colour uniformity by 16 %, increase average uniformity of skin red colour saturation by 18 %, and increase average soluble solids concentration by 2.5 % compared to control fruit. Significant increases in fruit visual quality score were observed among harvested fruit after a marketing period (Scenario B) and after marketing of fruit stored at 7°C for 21 days (Scenario D). Greater uniformity of skin colour within individual treated fruit was most apparent among fruit assessed after marketing (Scenario B, D and F).

The colour of juice from control fruit was significantly less yellow than juice from Seasol®-treated fruit but the relative difference in colour was <1 %. No significant difference in mean weight loss was found between Seasol®-treated and control fruit with relatively low weight loss observed during fruit storage and significantly higher rates of water loss during marketing. Although fruit were un-waxed the degree of weight loss under relatively high humidity storage conditions was comparable to that of commercially-waxed fruit based on previous research. In this experiment no significant difference in mean fruit weight at harvest was found among Seasol®-treated and control fruit.

Seasol® fertigation treatment did not significantly reduce the incidence and severity of skin darkening and pitting, and flesh drying due to chilling injury relative to control fruit. Skin pitting incidence was approximately 30% in both treated and control fruit when averaged over Scenario C, D, E and F, but pitting severity was very low. Both flesh drying incidence and severity were relatively low among all fruit. The effects of chilling injury tended to become more apparent after cool storage and marketing (Scenario D and F). At each postharvest scenario there was little difference in fruit firmness among treated and control fruit although Seasol®-treated fruit were significantly firmer at harvest by 11 % based on hand pressure firmness. Firmness among all fruit tended to decrease with cool storage and marketing period. Seasol® fertigation treatment did not significantly improve average fruit skin colour towards orange based on hue angle measurements, with no significant differences observed among treated and control fruit at each postharvest scenario.

Seasol® fertigation treatment did not significantly increase mean fruit juice concentration, a measure of eating quality, relative to control fruit, and no significant difference in flesh colour was observed among treated and control fruit. No overall significant effect of Seasol® treatment on mean SSC to TA ratio was observed relative to control fruit although Seasol®-treated fruit were on average 1.4 units higher than control fruit. Although results were inconsistent among scenarios, SSC to TA ratio was found to be significantly higher in Seasol®-treated fruit in Scenario B and E whilst a marketing period (Scenario D and F) tended to sharply and similarly decrease SSC to TA ratio among both treated and control fruit. A higher SSC to TA ratio usually indicates greater fruit maturity and improved eating quality and flavour due to a better balance between sweetness and acidity.

These preliminary results indicate that Seasol® fertigation treatment may potentially reduce commercially-important quality loss during domestic and export handling and marketing of citrus. It was shown that Seasol® treatment reduces the rate of visual quality loss relative to control fruit during postharvest handling and marketing, improves skin colour uniformity during marketing after storage, and on average increases fruit sweetness (i.e., soluble solids concentration). A commercial advantage and greater consumer acceptance are likely to result from citrus fruit that better retains its visual quality and skin colour uniformity during postharvest handling and marketing, and that is of higher eating quality due to greater sweetness (soluble solids concentration) and potentially has higher sweetness to acid ratio, resulting in fruit with better flavour and consumer appeal.

Recommendations

This experiment indicated that Seasol® fertigation treatment resulted in significant improvements in fruit visual quality, skin colour uniformity and soluble solids concentration and further scientific studies are recommended to confirm these findings including:

- Replication of this experiment over several more seasons to confirm the positive impact of Seasol® treatment on citrus quality, and to confirm its potential to improve fruit visual quality and sweetness;
- Clarify the effect of Seasol® treatment on soluble solids concentration to acid ratio, juice colour and fruit firmness;
- Further experiments conducted to determine the effect of Seasol® treatment on reducing chilling injury (i.e., flesh disorders, skin darkening) during cool storage and marketing whilst also comparing early and mid-season fruit to determine the interaction between Seasol® treatment and fruit maturity.

Experimental objectives

The aim of this experiment was to scientifically determine the effect of Seasol fertigation treatment on citrus quality at harvest and under similar postharvest storage and marketing conditions used by industry in both domestic and export markets. Specific experimental objectives were to:

1. Investigate the effect of Seasol® fertigation on visual quality, juice concentration, fruit firmness, soluble solids concentration (SSC), and titratable acidity (TA) at harvest and after postharvest handling;
2. Determine whether Seasol® fertigation reduces incidence and severity of chilling injury during cold disinfestation of fruit for export;
3. Determine whether Seasol® fertigation reduces fruit quality loss during cool storage that simulates handling, transit and fruit marketing in domestic markets.

Experimental methods

Fruit harvest, delivery and preparation

Mid-season navel oranges were hand harvested from a commercial orchard in the Sunraysia district in Victoria. Five fruit per sampled tree were placed in a small mesh bag and treated with postharvest fungicide in a commercial pack house prior to packing and transport. Fruit were not waxed prior to delivery. A total of 360 fruit were delivered to FreshHort in Melbourne within 72 hours of harvest. On arrival all fruit were placed in a cool room at 18 °C and 60 % RH for 24 hours. The following day all five fruit lots (representing the experimental unit) were weighed and randomly assigned to a postharvest scenario as outlined below.

Experimental design

Oranges were sampled from a field trial that included a block of trees fertigated with Seasol® during fruit development and an adjacent block irrigated as normal (i.e., Control block). At harvest six trees of similar age, size and health were randomly selected as sampling units in each of six tree rows within a field block. Both experimental field blocks had similar soil type and crop management inputs. Assuming that the two orchard blocks used were homogeneous the field experiment could be considered a completely randomised design (CRD) with tree rows as the unit of replication and individual trees as the sampling unit within each replicate. Upon delivery and warming to 18°C five fruit per replicate were allocated to one of the following postharvest storage scenarios to simulate common industry practice:

A. Assessment directly after harvest **(FRESH MARKET)**
B. Directly after harvest + marketing for 10 days at 18 °C
C. Cool storage for 21 days at 7 °C **(SUPERMARKET)**
D. Cool storage for 21 days at 7 °C + marketing for 10 days at 18 °C
E. Cool storage for 21 days at 2 °C **(EXPORT MARKET)**
F. Storage for 21 days at 2 °C + marketing for 10 days at 18 °C

The postharvest storage experiment was a completely randomised design with two factors, fertigation treatment and postharvest storage scenario, with the field replicate as the experimental unit (i.e., measurement unit) that was randomly assigned to one of six postharvest scenarios.

Postharvest storage and marketing

Within each postharvest scenario fruit were stored in their original mesh bags within cartons that were covered with plastic liners to minimise water loss from fruit. Seasol® treated and control fruit assigned to scenario C and D were stored at 6.5 ± 0.5°C and 85 ± 5% RH whilst fruit assigned to treatment E and F were stored at 2.0 ± 0.5 °C and 90 ± 5% RH. Simulated marketing of fruit was conducted at 18.0 ± 0.5 °C and 60 ± 5 % RH. Fruit from treatments A, C and E were warmed to 18 °C for 24 hours prior to quality assessments.

Statistical analyses

To determine the main effect of Seasol® fertigation on fruit quality and physiological disorders, and interaction with postharvest scenario, data were analysed as a CRD experiment using two-way ANOVA in GenStat 17 (VSN International Ltd., Oxford, UK). 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 using Fisher's unprotected Least Significant Difference (LSD) test with statistical differences between means determined a 5 % significance level ($\alpha = 0.05$). Multiple comparisons were conducted whether or not the overall *P*-value was significant (i.e., the comparison was unprotected). 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.

Fruit assessments

At each assessment the following quality attributes were measured on each of five fruit per replicate:

-fruit weight

-overall visual quality

-hand pressure firmness

-skin, flesh and juice colour (hue angle) and colour uniformity

-soluble solids concentration (SSC) and titratable acidity (TA), and SSC to acid ratio

-skin defects and disorders, and rot incidence and severity

-external and internal disorders associated with chilling injury e.g., flesh drying, skin pitting

-effegi penetrometer flesh firmness

-juice concentration (% w/w)

The specific methods and scoring used to measure each fruit quality attribute are described below and were adapted from Bassal and El-Hamahmy (2011), Cayuela and Wieland (2010) and Brown (1998).

Fruit quality

External visual quality

A five-point rating scale was used to score overall visual quality based on colour uniformity and loss of skin turgor where 5 = excellent, 4 = very good, 3 = good, 2 = poor, and 1 = very poor (Fig. 1). Fruit with a visual quality score of 1 or 2 would be considered unmarketable, with a score of 3 indicating limit of fruit marketability.

Figure 1. External visual quality rating scale (5 = far left; 2 = far right).

Fruit skin, flesh and juice colour

Skin surface colour was measured at four equidistant points along the equator 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 (i.e., colour saturation) on a green (-) to red (+) axis, and b* chromaticity on a blue (-) to yellow (+) axis (McGuire, 1992). Numerical values of a* and b* for each fruit were averaged and then the average hue angle calculated using H° = arctan (b*/a*) (Fig. 2). The variation in skin hue angle among individual fruit was determined by calculating the coefficient of variation (CV = standard deviation/mean x 100) based on four hue angle measurements per fruit. Flesh colour was measured at two points on the flesh of each fruit after fruit were cut in half before juicing.

Figure 2. Range of measured skin hue angle (Left = 80°; Middle = 73°; Right = 63°).

Prior to TA measurements the juice colour of each five fruit replicate was measured by placing the clear Eppendorf tube containing the juice sample length-wise over the colorimeter opening. Two colour measurements were taken per juice sample.

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. Each fruit was then given a firmness score by a single assessor based on the rating scale in Table 1. Fruit with a hand firmness score of 1 or 2 would be considered unmarketable at retail, with a score of 3 indicating the limit of fruit marketability.

Table 1. Hand pressure firmness rating scale for oranges.

Hand pressure firmness score	Description
5	Hard, no 'give' in the fruit
4	Slight 'give', fruit deforms 2-3 mm under extreme hand pressure
3	Moderate firmness, fruit deforms 5 mm under moderate hand pressure
2	Soft, fruit deforms 5 to 10 mm under moderate hand pressure
1	Very soft, whole fruit easily deforms under mild hand pressure

Penetrometer fruit firmness

Fruit firmness was measured on both cheeks of each fruit at its widest point after removal of the skin using an Effegi penetrometer with an 11 mm probe mounted on Firmtech FTA unit.

Soluble solids concentration (SSC)

SSC in °Brix was measured by cutting fruit in half along the equatorial plane and squeezing each fruit half to release approximately 0.5 ml of juice onto the lens of a temperature-compensated digital refractometer (ATAGO PAL-1) with a measurement accuracy of ± 0.2 °Brix. The refractometer was calibrated with distilled water prior to SSC measurements at each assessment. For each fruit mean SSC in °Brix was calculated from two SSC measurements.

Titratable acidity (TA)

After the juice of five fruit per replicate was collected and combined for juice concentration measurement, 10 ml of juice was collected in an Eppendorf tube, and juice frozen at -20°C until completion of all assessments. All juice samples were thawed at 20°C and 3 ml of juice from each sample diluted in 5 ml of distilled water once juice temperature in all samples was above 15°C. Titratable acidity of each sample was then measured via endpoint titration to pH 8.2 with 0.1 M NaOH using an automatic titrator (Steroglass Titre X) and AS23 Micro autosampler. Mean titratable acidity for each replicate was calculated as grams of citric acid equivalent per litre of juice using the

NaOH titre volume. Sugar to acid ratio for each replicate was calculated from mean SSC and titratable acidity measurements using the formula; SSC to acid ratio = SSC ÷ titratable acidity × 10.

Juice concentration

Five fruit per replicate were juiced using a commercial juicer and filtered juice collected and weighed to a single decimal place on a laboratory scale. Juice concentration per replicate was calculated in % w/w by dividing total juice weight by total fruit weight and multiplying by one hundred.

External disorders

Wind scarring damage

A five-point rating scale was used to describe external scarring severity likely due to thrip or wind damage in the orchard where 5 = none; 4 = slight; 3 = moderate; 2 = severe; and 1 = very severe (Fig. 3). This disorder was separately assessed from fruit visual quality.

Figure 3. Skin scarring severity rating scale (far left = 5; far right = 1).

Chilling injury

A five-point rating scale was used to describe severity of pitting and darkening on the skin of fruit due to chilling injury where 5 = none; 4 = < 10% of surface; 3 = 11 to 20% of surface; 4 = 21 to 50% of surface; and 5 = > 50% of surface (Fig. 4). During quality assessments no fruit were observed with a chilling injury severity score of 1.

Figure 4. Chilling injury severity rating scale (left = 4; middle = 3; right = 2 with 5 = none)

Flesh physiological disorders

Flesh drying

A five-point rating scale was used to describe severity of flesh drying associated with chilling injury where 5 = none; 4 = < 10% of flesh surface; 3 = 11 to 20% of flesh surface; 2 = 21 to 50% of flesh surface; and 1 = > 50% of flesh surface (Fig. 5). During quality assessments no fruit were observed with a flesh drying severity score of 1.

Figure 5. Flesh drying severity rating scale (left = 4; middle = 3; right = 2 with 5 = no flesh drying)

Both the incidence and severity of physiological disorders were calculated based on a five fruit replicate. For severity of fruit physiological disorders the severity score (SS) was calculated using the Townsend-Heuberger formula (Townsend and Heuberger, 1943):

$$SS\ (\%) = \sum(dn) \div DN \times 100$$; where

d = degree of infection or disorder according to severity scoring scale (i.e., 5, 4, etc.)

n = number of fruit per severity category

D = highest degree of infection or disorder possible

N = five fruit per replicate per assessment

Results and Discussion

Statistical comparisons are presented in tables with a focus on Seasol treatment effects relative to control fruit (main treatment effect), and treatment effects within each postharvest scenario (i.e., rows in tables), thus mean comparisons between postharvest scenarios among a treatment (i.e., columns in tables) have not been presented for ease of comprehension. The impact of different postharvest scenarios on Seasol treatment effects (i.e., interaction effects) will be discussed where relevant.

Harvest fruit weight & postharvest weight loss

All Seasol-treated and control replicates of five fruit were randomly assigned at harvest to a postharvest scenario with no significant difference in mean fruit size between treatments averaged among scenarios and within each scenario (Table 2). Mean fruit harvest weight ranged between 213 g and 260 g among Seasol-treated fruit whilst for control fruit mean weight varied between 220 g and 239 g and was marginally less variable among replicates.

Table 2. Treatment effect on mean fruit weight (g) at harvest on fruit assigned to different postharvest scenarios; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment within a postharvest scenario.

	Treatment			
Postharvest scenario	**Seasol**		**Control**	
Main treatment effect	230	a	231	a
A. No cool storage	232	a	220	a
B. No cool storage + marketing	213	a	231	a
C. Cool storage for 21 days at 7 °C	229	a	237	a
D. Cool storage for 21 days at 7 °C + marketing	228	a	227	a
E. Cool storage for 21 days at 2 °C	260	a	239	a
F. Storage for 21 days at 2 °C + marketing	216	a	235	a
Treatment P-value	0.820			
Scenario P-value	0.259			
Treatment x Scenario P-value	0.491			

No significant difference in mean weight loss was found between Seasol-treated and control fruit with relatively low weight loss observed during fruit storage and significantly higher rates of water loss during marketing (Table 3). Although fruit were un-waxed the degree of weight loss under relatively high humidity storage conditions was comparable to that of waxed fruit as found by Erkan and Pekmezci (2000). They found little difference in weight loss over various cool storage periods among waxed fruit and fruit only treated with postharvest fungicide.

Table 3. Effect of treatment and postharvest scenario on mean fruit weight loss (%); different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment within a postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	4.5 a	4.5 a
A. No cool storage		
B. No cool storage + marketing	4.6 a	4.4 a
C. Cool storage for 21 days at 7 °C	2.8 a	2.4 a
D. Cool storage for 21 days at 7 °C + marketing	5.7 a	6.8 b
E. Cool storage for 21 days at 2 °C	2.6 a	2.7 a
F. Storage for 21 days at 2 °C + marketing	6.6 a	6.1 a
Treatment P-value	0.862	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.191	

Fruit firmness

No significant main treatment effect on hand pressure firmness score was observed with both Seasol-treated and control fruit similarly and increasingly softening with storage and marketing period (Table 4). Seasol-treated fruit were found to be significantly firmer than control fruit at harvest (Scenario A) but this initial difference in firmness was not carried over into storage and marketing scenarios. No significant difference in Effegi penetrometer firmness was found among treated and control fruit at harvest (Table 5). This firmness measurement was not conducted for other postharvest scenarios as measurements were highly variable and inconsistent due to deformation of fruit during penetrometer measurement.

Table 4. Effect of treatment and postharvest scenario on mean hand pressure firmness score; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	3.3 a	3.2 a
A. No cool storage	4.4 a	3.9 b
B. No cool storage + marketing	3.0 a	2.7 a
C. Cool storage for 21 days at 7 °C	3.4 a	3.4 a
D. Cool storage for 21 days at 7 °C + marketing	3.0 a	2.8 a
E. Cool storage for 21 days at 2 °C	3.3 a	3.4 a
F. Storage for 21 days at 2 °C + marketing	2.8 a	2.9 a
Treatment P-value	0.198	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.444	

Table 5. Effect of treatment on mean Effegi penetrometer fruit firmness at harvest; different letters indicate a statistically significant difference at *P* < 0.05 when comparing treatment.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
A. No cool storage	4.3 a	4.1 a
Treatment P-value	0.709	

Fruit visual quality

Seasol treatment significantly improved overall fruit visual quality score relative to control fruit with significant differences in visual quality score observed among harvested fruit after a marketing period (Scenario B) and after marketing of fruit stored at 7°C for 21 days (Scenario D) (Table 6). The non-significant treatment x scenario interaction indicates that the effect of Seasol treatment was consistent among scenarios as can be observed by the equal or marginally higher mean visual quality score of treated fruit at each scenario.

Table 6. Effect of treatment and postharvest scenario on mean fruit visual quality score; different letters indicate a statistically significant difference at *P* < 0.05 when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	3.7 a	3.4 b
A. No cool storage	4.2 a	4.0 a
B. No cool storage + marketing	3.8 a	3.4 b
C. Cool storage for 21 days at 7 °C	3.5 a	3.5 a
D. Cool storage for 21 days at 7 °C + marketing	3.4 a	3.0 b
E. Cool storage for 21 days at 2 °C	3.7 a	3.4 a
F. Storage for 21 days at 2 °C + marketing	3.4 a	3.3 a
Treatment P-value	0.002	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.458	

Fruit skin colour

No significant effect of Seasol treatment on mean skin colour was observed relative to control fruit as measured by hue angle with little difference in mean hue angle among treated and control fruit at each postharvest scenario (Table 7). A lower hue angle indicates greater orange skin colour on fruit.

Seasol treatment significantly and consistently reduced the variation in skin colour within individual fruit based on four hue angle measurements per fruit (i.e., increased uniformity of skin colour) (Table 8). This effect was most apparent after fruit underwent a marketing period at harvest (Scenario B), after storage at 7°C for 21 days and marketing (Scenario D), and after storage at 2°C for 21 days and marketing (Scenario F). The non-significant treatment x scenario interaction indicates that the effect of Seasol treatment in lowering variation in skin hue angle within a fruit was consistent among scenarios.

Table 7. Effect of treatment and postharvest scenario on mean fruit skin hue angle; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	66.2 a	66.9 a
A. No cool storage	68.2 a	69.1 a
B. No cool storage + marketing	66.2 a	65.8 a
C. Cool storage for 21 days at 7 °C	66.7 a	65.3 a
D. Cool storage for 21 days at 7 °C + marketing	65.0 a	67.4 b
E. Cool storage for 21 days at 2 °C	65.0 a	66.7 a
F. Storage for 21 days at 2 °C + marketing	66.1 a	66.8 a
Treatment P-value	0.108	
Scenario P-value	0.001	
Treatment x Scenario P-value	0.084	

Table 8. Effect of treatment and postharvest scenario on mean coefficient of variation (%) for skin hue angle among individual fruit; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	2.6 a	3.1 b
A. No cool storage	2.7 a	2.9 a
B. No cool storage + marketing	2.7 a	3.5 a
C. Cool storage for 21 days at 7 °C	2.4 a	2.5 a
D. Cool storage for 21 days at 7 °C + marketing	2.4 a	3.3 b
E. Cool storage for 21 days at 2 °C	2.8 a	3.0 a
F. Storage for 21 days at 2 °C + marketing	2.3 a	3.2 b
Treatment P-value	0.004	
Scenario P-value	0.404	
Treatment x Scenario P-value	0.441	

Seasol treatment significantly increased the overall mean ‘redness’ or red saturation of fruit skin (i.e., reduced the greenness of skin) based on the a* chromaticity axis in the L*a*b* colour space (Table 9). This effect was not consistent among postharvest scenarios and was only statistically-significant in Scenario D.

Seasol treatment significantly reduced variation in skin red colour saturation within individual fruit (i.e., increased uniformity of skin ‘redness’) based on four a* chromaticity measurements per fruit (Table 10). Among scenarios treatment effect was significant after fruit underwent a marketing period at harvest (Scenario B), after storage at 7°C for 21 days and marketing (Scenario D), and after storage at 2°C for 21 days and marketing (Scenario F). The non-significant treatment x scenario interaction indicates that the effect of Seasol treatment was generally consistent among scenarios.

Table 9. Effect of treatment and postharvest scenario on mean fruit skin a* chromaticity on the green (-) to red (+) axis; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	29.7 a	28.8 b
A. No cool storage	27.1 a	26.1 a
B. No cool storage + marketing	29.5 a	29.4 a
C. Cool storage for 21 days at 7 °C	29.1 a	30.4 a
D. Cool storage for 21 days at 7 °C + marketing	31.9 a	29.2 b
E. Cool storage for 21 days at 2 °C	30.2 a	28.4 a
F. Storage for 21 days at 2 °C + marketing	30.4 a	29.5 a
Treatment P-value	0.039	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.099	

Table 10. Effect of treatment and postharvest scenario on mean coefficient of variation (%) for fruit skin a* chromaticity on the green (-) to red (+) axis among individual fruit; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	7.2 a	8.8 b
A. No cool storage	9.3 a	10.5 a
B. No cool storage + marketing	7.1 a	8.7 b
C. Cool storage for 21 days at 7 °C	7.4 a	6.4 a
D. Cool storage for 21 days at 7 °C + marketing	6.3 a	10.1 b
E. Cool storage for 21 days at 2 °C	7.5 a	8.1 a
F. Storage for 21 days at 2 °C + marketing	5.4 a	8.8 b
Treatment P-value	0.010	
Scenario P-value	0.127	
Treatment x Scenario P-value	0.120	

Fruit flesh and juice colour

No significant effect of Seasol treatment on overall mean flesh colour was observed relative to control fruit as measured by hue angle with little difference in mean hue angle among treated and control fruit at each postharvest scenario (Table 11).

The juice of fruit treated with Seasol was significantly more yellow in colour relative to control fruit based on mean hue angle (Table 12). This effect was not consistent among postharvest scenarios and was only statistically-significant in Scenario A, B and D. In both treated and control fruit, juice colour tended to become more yellow after the marketing period of 10 days at 18°C.

Table 11. Effect of treatment and postharvest scenario on mean fruit flesh hue angle; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	82.9 a	83.1 a
A. No cool storage	84.3 a	83.9 a
B. No cool storage + marketing	82.6 a	82.2 a
C. Cool storage for 21 days at 7 °C	82.5 a	82.0 a
D. Cool storage for 21 days at 7 °C + marketing	82.6 a	82.9 a
E. Cool storage for 21 days at 2 °C	82.8 a	83.6 a
F. Storage for 21 days at 2 °C + marketing	82.4 a	83.6 a
Treatment P-value	0.448	
Scenario P-value	0.001	
Treatment x Scenario P-value	0.241	

Table 12. Effect of treatment and postharvest scenario on mean juice hue angle; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	98.5 a	97.6 b
A. No cool storage	97.1 a	94.7 b
B. No cool storage + marketing	97.6 a	96.3 b
C. Cool storage for 21 days at 7 °C	95.1 a	94.6 a
D. Cool storage for 21 days at 7 °C + marketing	101.8 a	100.3 b
E. Cool storage for 21 days at 2 °C	97.5 a	97.7 a
F. Storage for 21 days at 2 °C + marketing	101.9 a	102.1 a
Treatment P-value	<0.001	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.031	

Soluble solids concentration (SSC) and SSC to titratable acidity ratio

Seasol treatment significantly increased overall mean soluble solids concentration (SSC) relative to control fruit but with significant differences in SSC only observed among harvested fruit after a marketing period (Scenario B) (Table 13). The non-significant treatment x scenario interaction indicates that SSC among treated fruit was consistently equal to or higher to SSC measured in control fruit among each scenario.

No overall significant effect of Seasol treatment on mean SSC to TA ratio was observed relative to control fruit although Seasol-treated fruit were on average 1.4 units higher than control fruit (Table 11). Although results were inconsistent among scenarios, SSC to TA ratio was found to be significantly higher in Seasol-treated fruit in Scenario B and E whilst a marketing period (Scenario D and F) tended to sharply and similarly decrease SSC to TA ratio among both treated and control fruit.

A higher SSC to TA ratio usually indicates greater fruit maturity and improved eating quality due to a more balanced sweetness to acid flavour.

Table 13. Effect of treatment and postharvest scenario on mean soluble solids concentration (°Brix); different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	12.0 a	11.7 b
A. No cool storage	12.3 a	11.9 a
B. No cool storage + marketing	12.4 a	11.5 b
C. Cool storage for 21 days at 7 °C	12.0 a	12.0 a
D. Cool storage for 21 days at 7 °C + marketing	11.5 a	11.6 a
E. Cool storage for 21 days at 2 °C	12.2 a	11.9 a
F. Storage for 21 days at 2 °C + marketing	11.7 a	11.4 a
Treatment P-value	0.015	
Scenario P-value	0.009	
Treatment x Scenario P-value	0.208	

Table 14. Effect of treatment and postharvest scenario on mean soluble solids concentration to titratable acid ratio; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	19.8 a	18.4 a
A. No cool storage	19.4 a	19.8 a
B. No cool storage + marketing	26.1 a	21.2 b
C. Cool storage for 21 days at 7 °C	20.6 a	22.1 a
D. Cool storage for 21 days at 7 °C + marketing	16.8 a	15.2 a
E. Cool storage for 21 days at 2 °C	22.2 a	16.9 b
F. Storage for 21 days at 2 °C + marketing	13.8 a	15.0 a
Treatment P-value	0.144	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.168	

Juice concentration

Seasol treatment did not significantly increase overall mean juice concentration in fruit relative to control fruit with little difference among treated and control fruit at each scenario and no consistent pattern among treatments at each scenario (Table 15).

Table 15. Effect of treatment and postharvest scenario on mean juice concentration (% w/w); different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	45.2 a	45.9 a
A. No cool storage	46.9 a	47.0 a
B. No cool storage + marketing	44.2 a	44.2 a
C. Cool storage for 21 days at 7 °C	44.0 a	45.2 a
D. Cool storage for 21 days at 7 °C + marketing	46.4 a	46.5 a
E. Cool storage for 21 days at 2 °C	45.4 a	46.2 a
F. Storage for 21 days at 2 °C + marketing	44.2 a	46.0 a
Treatment P-value	0.352	
Scenario P-value	0.215	
Treatment x Scenario P-value	0.976	

Skin disorders

No significant effect of Seasol treatment on mean wind scarring severity on fruit skin was observed as to be expected as skin scarring was apparent at harvest and caused whilst fruit were still on the tree (Table 16).

Table 16. Effect of treatment and postharvest scenario on wind skin scarring severity; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	4.1 a	4.2 a
A. No cool storage	4.0 a	4.4 a
B. No cool storage + marketing	4.2 a	4.1 a
C. Cool storage for 21 days at 7 °C	4.1 a	4.2 a
D. Cool storage for 21 days at 7 °C + marketing	3.9 a	3.7 a
E. Cool storage for 21 days at 2 °C	4.3 a	4.3 a
F. Storage for 21 days at 2 °C + marketing	4.1 a	4.3 a
Treatment P-value	0.553	
Scenario P-value	0.088	
Treatment x Scenario P-value	0.455	

No significant reduction in overall mean incidence of skin darkening and pitting due to chilling injury was found in Seasol-treated fruit compared to control fruit with no pitting observed at harvest (Scenario A) and at harvest after marketing (Scenario B) (Table 17). On average pitting incidence tended to be up to 10 % lower in Seasol-treated fruit within a scenario but this difference was not statistically-significant due to high variability among replicates within a treatment.

Mean severity of darkening and pitting on fruit skin was low in both treated and control fruit with severity increasing marginally in fruit from Scenario F (Table 18). Among treatments and scenarios very few fruit were assessed with a pitting severity score of 3 or less.

Table 17. Effect of treatment and postharvest scenario on mean incidence of darkening and pitting on skin; different letters indicate a statistically significant difference at *P* < 0.05 when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	28.3 a	33.3 a
A. No cool storage	0.0 a	0.0 a
B. No cool storage + marketing	0.0 a	0.0 a
C. Cool storage for 21 days at 7 °C	16.7 a	26.7 a
D. Cool storage for 21 days at 7 °C + marketing	53.3 a	53.3 a
E. Cool storage for 21 days at 2 °C	40.0 a	50.0 a
F. Storage for 21 days at 2 °C + marketing	60.0 a	70.0 a
Treatment P-value	0.212	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.900	

Table 18. Effect of treatment and postharvest scenario on mean darkening and pitting severity on skin; different letters indicate a statistically significant difference at *P* < 0.05 when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	4.7 a	4.7 a
A. No cool storage	5.0 a	5.0 a
B. No cool storage + marketing	5.0 a	5.0 a
C. Cool storage for 21 days at 7 °C	4.9 a	4.7 a
D. Cool storage for 21 days at 7 °C + marketing	4.6 a	4.6 a
E. Cool storage for 21 days at 2 °C	4.6 a	4.6 a
F. Storage for 21 days at 2 °C + marketing	4.3 a	4.4 a
Treatment P-value	0.932	
Scenario P-value	<0.001	
Treatment x Scenario P-value	0.938	

Internal physiological disorders

No significant reduction in overall mean incidence of flesh drying due to chilling injury was found in Seasol-treated fruit compared to control fruit with no flesh drying observed at harvest (Scenario A) and at harvest after marketing (Scenario B) (Table 19). Flesh drying incidence remained relatively low among scenarios but tended to increase after marketing (i.e., Scenario D and F) whilst the overall mean incidence of flesh drying was less than 7 % among both treated and control fruit.

Mean severity of flesh drying was very low in both treated and control fruit with little change in severity among scenarios (Table 20). Among treatments and scenarios very few fruit were assessed with a flesh drying severity score of 4 or less.

Table 19. Effect of treatment and postharvest scenario on mean incidence of flesh drying; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	5.6 a	6.7 a
A. No cool storage	0.0 a	0.0 a
B. No cool storage + marketing	0.0 a	0.0 a
C. Cool storage for 21 days at 7 °C	6.7 a	10.0 a
D. Cool storage for 21 days at 7 °C + marketing	10.0 a	13.3 a
E. Cool storage for 21 days at 2 °C	3.3 a	0.0 a
F. Storage for 21 days at 2 °C + marketing	13.3 a	16.7 a
Treatment P-value	0.669	
Scenario P-value	0.003	
Treatment x Scenario P-value	0.967	

Table 20. Effect of treatment and postharvest scenario on mean flesh drying severity; different letters indicate a statistically significant difference at $P < 0.05$ when comparing treatment at each postharvest scenario.

	Treatment	
Postharvest scenario	**Seasol**	**Control**
Main treatment effect	4.9 a	4.9 a
A. No cool storage	5.0 a	5.0 a
B. No cool storage + marketing	5.0 a	5.0 a
C. Cool storage for 21 days at 7 °C	4.9 a	4.9 a
D. Cool storage for 21 days at 7 °C + marketing	4.9 a	4.9 a
E. Cool storage for 21 days at 2 °C	5.0 a	5.0 a
F. Storage for 21 days at 2 °C + marketing	4.9 a	4.9 a
Treatment P-value	0.962	
Scenario P-value	0.028	
Treatment x Scenario P-value	1.000	

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Appendix – Orange visual quality among postharvest scenarios

Treated (left) and untreated (right) oranges assessed at harvest (Scenario A).

Treated (left) and untreated (right) oranges assessed after Scenario B.

Treated (left) and untreated (right) oranges assessed after Scenario C.

Treated (left) and untreated (right) oranges assessed after Scenario D.

Treated (left) and untreated (right) oranges assessed after Scenario E.

Treated (left) and untreated (right) oranges assessed after Scenario F.

Treated (left) and untreated (right) flesh of oranges assessed after Scenario D.

Treated (left) and untreated (right) flesh of oranges assessed after Scenario F.