Harvest temperature effects on postharvest avocado quality

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Project Number: AV03005

AV03005

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the avocado industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of Western Australian Avocado Growers Association.

ISBN 0 7341 1755 8

Published and distributed by:

Horticulture Australia Ltd

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HAL project AV 03005
(May 2008)

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This report summarises the information gathered during four years of investigation into whether high ambient temperatures during harvest have significant deleterious effects on the post-harvest quality of Hass avocados grown under Western Australian conditions. The report contains the science behind the final set of recommendations provided to Western Australian avocado growers.

This project was facilitated by Horticulture Australia Limited (HAL) in partnership with the Avocado Growers Association of WA and the Department of Agriculture and Food. It was part-funded by voluntary contributions from industry, collected through the 'Fee for Service' administered by the Agricultural Produce Commission - Avocado Growers Committee. The Australian Government provides matched funding for all HAL's R&D activities.

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Media summary

The Western Australian avocado industry has set high standards for production of Hass avocado and is keen to maintain these standards. Increased production over the last five years meant that current harvesting guidelines, based on production research from other production regions, were putting operational strains on growers. WA avocado growers needed more flexibility in the harvesting parameters under which they could confidently operate without impacting on the quality of the product they supply.

This project set out to determine the impact of high ambient temperatures during harvest and delays in removal of field heat of up to 24 hours after harvest on the quality of Hass avocados at a ready to eat stage. The subsequent research demonstrated that high ambient temperatures during harvest did not, on their own, cause deleterious impacts on the post-harvest quality of Hass avocados grown under Western Australian conditions. The research demonstrated that, provided sound industry practices are followed, fruit could be harvested even at ambient temperatures of 36°C, stored for up to four weeks and remain at a high saleable quality. Such industry practices include fruit to be protected from direct sunlight after harvest, removal of field heat as soon as possible (within 24 hours of harvest) and storage at the appropriate temperature for the intended period of storage.

A leaflet highlighting the suitable harvest conditions and important post-harvest practices has been developed for industry 'Temperature Guidelines for harvesting and storage of Hass avocados for the south-west of Western Australia'.

During the project, it was highlighted that the practices after harvest were critical to maintenance of high quality avocado. It is therefore essential that growers, distributors, wholesalers, transporters and retailers maintain the required practices. To this end, continuous monitoring and regular evaluation of the product is strongly encouraged.

Technical summary

In efforts to maintain a high post-harvest quality of avocados from Western Australia (WA), the industry had recommendations of not harvesting when ambient temperatures rise above 30ºC and to remove field heat within six hours of harvesting. This was found to be restrictive under Western Australian conditions and was based on growing conditions found in other production regions. This project set out to determine the impact of ambient harvest temperatures in excess of 30ºC and delayed removal of field heat by up to 24 hours on the quality of Hass avocados produced under Western Australian conditions.

In a series of experiments over three years, Hass avocados grown at a range of locations in the south-west of Western Australia were harvested at a range of increasing temperature from 28 to 37ºC, subjected to delays in removal of field heat up to 24 hours, stored for either 14 or 28 days cool storage and then ripened using ethylene in a ripening room. The fruit was assessed at approximately a 'ripe ready to eat' stage, using quality assessment parameters set out in the 'AvoCare Assessment Manual' (White *et al*. 2001).

The findings indicated that high ambient temperatures of up to 37ºC during harvesting did not have a detrimental effect on the quality of Hass avocado fruit when assessed at a ripe ready to eat stage. Further, delays in removal of field heat by up to 24 hours, provided fruit was protected from the elements, were also acceptable for producing quality fruit. It needs to be stressed that these findings are relevant to conditions in the south-west of Western Australia and that different conditions, particularly higher disease pressure levels, may impact significantly on these findings. It was found that conditions provided to the fruit after harvest had a much greater impact on the final quality condition of the fruit than the temperature at harvest.

As a result of the trials, a new set of guidelines has been produced for growers of Hass avocados in the south-west of Western Australia. They highlight that high ambient temperatures during harvest and delays in removal of field heat by up to 24 hours are acceptable provided that sound handling practices are observed after harvest. These new guidelines will provide much greater operating flexibility for Western Australian avocado producers. They will now be able to harvest all day instead of having to stop mid-morning. They will be able to harvest knowing that harvesting conditions are not impacting detrimentally on the quality of their produce.

The trial highlighted the need to observe recognised industry standards for storage requirement of Hass avocados and the benefits of cool chain monitoring. It is recommended that all shipments have some form of temperature monitoring during the entire storage period.

Further research should be considered into the most effective monitoring methods and what periods or levels of cool chain breakdown result in detrimental impacts on Hass avocado fruit quality.

Introduction

In efforts to maintain high post-harvest quality of avocados from Western Australia (WA), the industry had recommended not harvesting when ambient temperatures rise above 30ºC and to remove field heat within six hours of harvesting. Many growers find these recommendations to be too restrictive under WA conditions where fruit is regularly harvested during the hot, dry summer months with temperatures rising above 30ºC. Many growers currently do not have their own cooling facilities, relying on keeping the fruit under cover after harvest until transport to a packing operator, usually within 24 hours.

Several growers have indicated that they continue to harvest regardless of the temperature rising above 30ºC and have delayed cooling by up to 24 hours, yet have had few complaints that their fruit has suffered. However, this may be due to poor mechanisms for feedback on fruit quality or the fact that at this stage most fruit is held for less than 14 days cool storage before ripening. Increased production will see longer storage times and growers have expressed concern that harvesting during hot conditions could impact on fruit quality, yet consider stopping harvesting when temperatures rise above 30ºC as impractical.

There has been limited research worldwide to investigate the effect of hot conditions at harvest on the quality of avocado fruit. Research by Arpaia *et al.* (1992) suggests that allowing pulp temperature to rise above 30ºC post-harvest (fruit temperature at harvest was approximately 25ºC) will reduce the quality. Arpaia *et al.* (1992) also found that delays in reducing the field fruit pulp temperature after harvest beyond six hours reduced fruit quality. These results were all related to long-term storage (28 days) at 5ºC. Arpaia (pers comm.) and Florissen *et al.* (1996) have shown that there are few post-harvest issues with fruit stored for 7 or even 14 days, so long as the climacteric phase had not commenced before storage, even if fruit is subjected to higher temperatures or delays in cooling. Thus it would appear that fruit destined for short-term storage has a fair degree of flexibility with harvest temperatures and delay periods before cooling. Further, it is unclear in the Arpaia work whether it is the high temperatures and delays alone that caused the reduction in fruit quality or a combined effect of the increase in pulp temperature after harvest and the delay periods.

Research by Woolf *et al.* (1999, 2000) and Ferguson *et al.* (1999) has shown that fruit exposed to sun can be more than 15ºC higher than the ambient air temperature and that this rise in temperature is rapid and sustained while the air temperature remains high. Shaded fruit maintained a pulp temperature similar to the ambient temperature. Sun-exposed fruit's pulp temperature exceeded 30ºC when the ambient air temperature was only 22-25ºC. Under WA conditions, this could be achieved as early as 9.00 am, thus restricting harvesting to a few hours in the morning if pulp temperature below 30ºC was used as the harvest cut-off. However, Woolf *et al.* (2000) also showed that fruit exposed to sun and high temperatures while on the tree actually displayed greater tolerance to extreme cold storage (0ºC), slower softening and slower fungal development. Thus, the fruit appeared to benefit from exposure to high temperatures during the period immediately preceding harvest.

From the literature, it appears there are opportunities for modifying the current harvesting recommendations during high temperatures as it seems that fruit pulp temperature at harvest is not a critical factor affecting quality. The real issue would appear to be fruit pulp increasing in temperature during delays after harvest. The aim is to provide industry with as much flexibility at harvest as possible while minimising negative effects on quality of the fruit.

Observations were made over three seasons (2004, 2005 and 2007) on the Hass avocado variety and investigated in three progressive stages.

1. *Investigating the relationship between ambient temperature and fruit position on pulp fruit temperature*

Method

Both air temperature and pulp temperature were monitored continuously at 1 minute intervals during the chosen harvest day. Fruit was chosen that was either well leaf sheltered or exposed to the sun. Pulp and air temperatures were logged using Cox Tracer loggers, equipped with twin external temperature probes (80 x 4 mm stainless steel probes). The probes measuring the pulp temperature were inserted from the top at an angle that allowed them to go deep into the fruit just missing the seed and allowing the full length of the stainless steel probe to be inserted to minimise heating of the probe from any direct exposure to external conditions (Picture 1). To obtain ambient air temperature, a probe was hung within the tree canopy, with plenty of leaf cover to prevent direct sunlight contact.

***Picture 1**. Probe set in avocado fruit using Cox tracer loggers fitted with twin external probes, one probe inserted into the fruit for pulp temperature readings, the other to measure ambient shaded temperature*

Results and discussion

The pulp temperature of the avocado is influenced by prevailing ambient temperature and direct exposure to sunlight (Figures 1 and 2). Our results demonstrated that shaded fruit, while lagging slightly initially, follows closely the prevailing ambient temperature (air temperature recorded within the canopy of the tree). The sun-exposed fruit's pulp temperature increased at a faster rate than the ambient temperature to peak approximately 5°C higher than the ambient temperature when the daily maximum temperature was reached. As the ambient temperature slowly declined after reaching the maximum, so too did the pulp temperature of the sun-exposed fruit. The sun-exposed fruit's pulp temperature declined faster than the ambient temperature so that by late afternoon the pulp temperature of the sun-exposed fruit had dropped to a similar level to the ambient temperature.

One interesting finding as a result of incorrect fruit selection was that the increased pulp temperature of the sun-exposed fruit was only maintained with direct exposure. The fruit probed in the eastern block (site 2) received shading from a large tree in the neighbouring row during the middle of the day. As a result, the exposed fruit's pulp temperature declined to close to the ambient temperature and then rose again as the shade shifted (Figure 2). It is clear from this that if the fruit is exposed to direct sun contact, the pulp temperature will increase above the ambient temperature, but this increase will be lost if the fruit receives any shading.

These results, while not as excessive as those achieved by Woolf *et al.* (1999, 2000) and Ferguson *et al.* (1999) did concur with their findings that direct exposure to sunlight will result in higher pulp temperature than the ambient temperature, while fruit not exposed to direct sunlight will be similar to the ambient temperature or slightly lower.

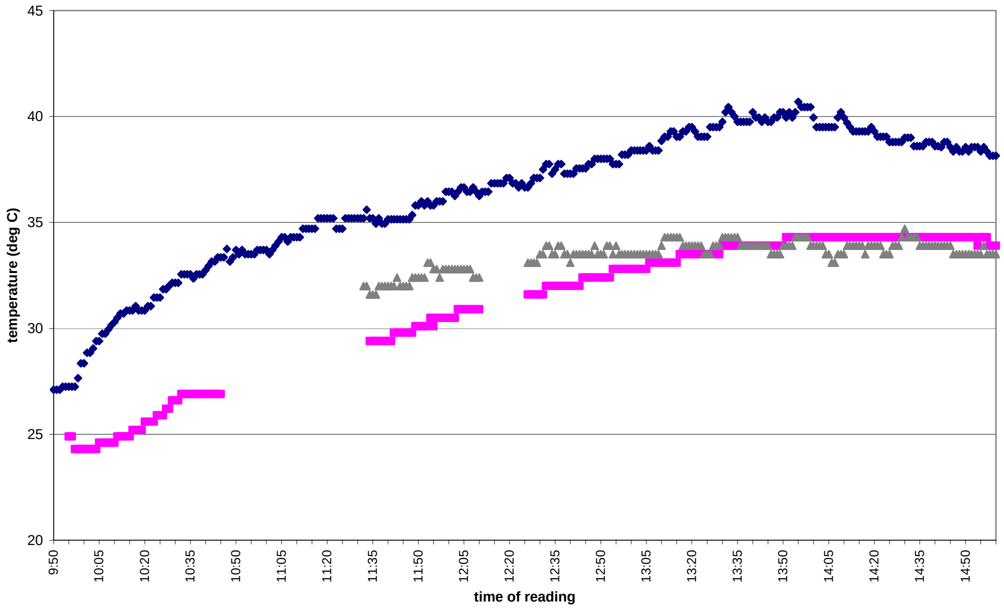

Figure 1. *Change in pulp temperature during a typical hot day at Kirup of Hass avocado hanging on the tree (northern block, site 1, 3 February 2004): fruit fully shaded by leaves (square symbols), fruit fully exposed to direct sunlight (diamond symbols) and ambient shaded air temperature (triangles)*

To ensure that any shading effects on the pulp temperature of the sun-exposed fruit was minimised, leaves were cleared away. This unfortunately resulted in extensive sunburn as a result of the extreme hot conditions on the recently exposed fruit. It does appear that fruit that is constantly exposed to the sun builds up some tolerance, but recently exposed fruit has very little. It was decided not to pursue assessing sun-exposed fruit any further and to recommend that exposed fruit be harvested earlier, before the more extreme weather conditions of January and February.

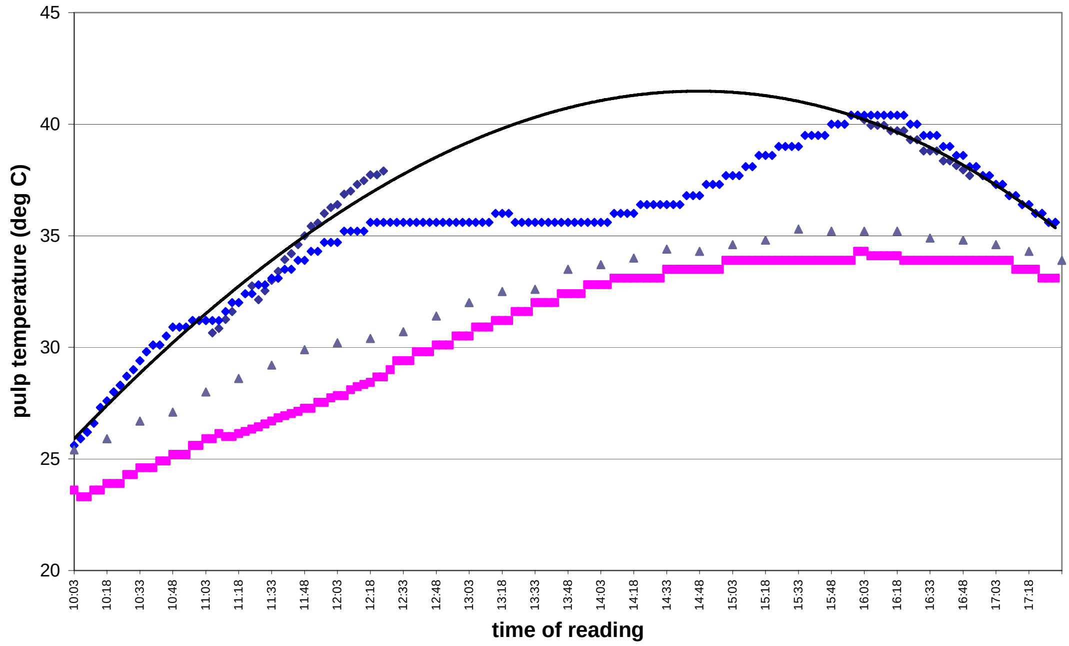

Figure 2. *Change in pulp temperature during a typical hot day in Kirup, Western Australia, of Hass avocado hanging on the tree (eastern block, site 2, 12 February 2004): fruit fully shaded by leaves (square symbols), fruit fully exposed to direct sunlight (diamond symbols), calculated course of temperature if shade not impacting on sun-exposed fruit (solid line) and ambient shaded air temperature (triangle symbols)*

2. *Investigating the potential for high harvest temperatures to affect fruit quality post-harvest*

Year 2004

Method

At an orchard near Kirup, in the south west of Western Australia, two sites of different aspect, an east facing slope and north facing slope, were chosen for monitoring. Predicted field conditions were monitored using weather forecasts from the Australian Bureau of Meteorology, for forecast hot and dry conditions. Pulp and air temperatures were logged on site using Cox Tracer loggers, as per investigation 1.

Fruit of approximately 200 g weight, with a mean dry matter of 36 per cent, was harvested from the two sites. Site 1 (northern block) was harvested on 3 February 2004 and site 2 (eastern block) was harvested on 12 February 2004. At each site, shaded fruit were harvested in a factorial of four temperatures (27-34°C), subjected to three pre-cooling delays (2, 6, 24 h; fruit held under shade at ambient temperature) and two cool-storage durations (14, 28 days; 6-8°C). Each treatment comprised 10 fruit plus two disposable fruit for pulp temperature logging. Fruit were ripened with ethylene in a temperature controlled room maintained at 18°C. Treatments were split among five sealed ripening chambers containing 100 ppm ethylene, which was vented and replaced each day for up to four days. The fruit was kept at 18°C until they reached an 'over-ripe' stage that allowed for full expression of post-harvest faults. Each treatment was assessed as a block when ripe. Fruit were considered ripe if greater than 50 per cent of fruit in the batch was of skin colour ≥4 and softening ≥5. Fruit quality was scored hedonically using parameters previously described (White *et al*. 2001). Assessments were made on skin colour (1-6), softening (0-7), external rot (0-3), stem end rot (0-3), body rot (0-3), vascular browning (0-3) and diffuse flesh discolouration (0-3). More details are in Appendix 1. Data were analysed using GenStat (Lawes Agricultural Trust, Hemel Hempstead, UK) using $P \leq 0.05$. Linear mixed models were fitted, with site as a block factor and chamber as a random effect. The models included fixed effects for harvest temperature (Temp), pre-cooling delay (Delay), cool-storage duration (Storage) and all interactions. Temp was subdivided into linear and quadratic effects of temperature. Plots of residuals were used to examine the statistical assumptions underlying the linear mixed model and where necessary the data was transformed prior to analysis.

Results and discussion

The results of significance testing of the effects are displayed in Appendix 2. Estimated means and five per cent least significant differences are displayed in Appendix 3.

There were indications, though not statistically significant, of an increasing linear effect of harvest temperature on softening, however a significant quadratic trend was shown ($Temp^2$ P=0.021, Figure 3A). Harvest temperature had a significant decreasing linear affect on vascular browning (Temp P=0.004, Figure 3B). A significant linear affect of harvest temperature could not be seen for body rot. However, as similar for softening, a significant quadratic trend was shown ($Temp^2$ P=0.017, Figure 3C). The increase in ambient harvest temperature did not have a significant effect on skin colour, external rots or diffuse flesh discolouration. The reductions in vascular browning and body rot for temperatures above 30ºC were significant. However, the apparent trends in reduction in skin colour and softening above 30ºC were not significant. Interestingly, the quadratic trend observed for softening and body rot was also evident for skin colour when fruit was delayed 24 hours before cooling (Figure 3D).

While significant effects from the increase in temperature above 30ºC could be determined for two important quality defects in body rots and vascular browning, they were both favourable declines. Further, the ranking means for each temperature did not, for any temperature, lift above a ranking of 1.5 or an equivalent of 15 per cent flesh affected. At this level, the fruit were still considered market-acceptable.

Cool storage duration also had significant effects on various post-harvest qualities. The ripening descriptors softening (P=0.027) and skin colour (P<0.001) were significantly greater after 28 days versus 14 days storage (data not shown). The increase in some disorders was in some cases high; diffuse flesh discolouration (P<0.001; increase >five-fold), vascular browning (P<0.001; increase >10-fold) and stem rot (P<0.001; increase >15-fold). This effect was attributed to the use of 8ºC as the storage temperature, which while commonly used by the industry, due to current short storage requirements, is not suitable for storage periods longer than 14 days. It has also highlighted the increase in expression of many post-harvest issues as a result of longer term storage which suggests the need for greater attention to detail when using longer term storage.

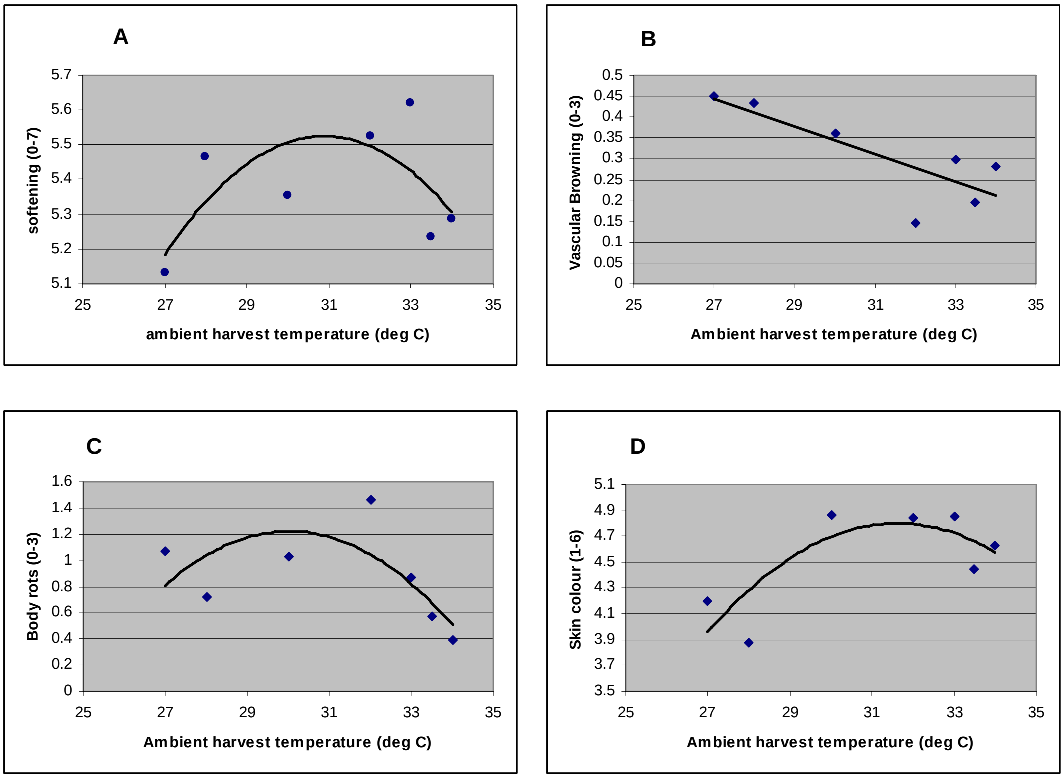

Figure 3. *Main effects of increasing ambient harvest temperature on the post-harvest quality of shaded Hass avocado fruits.* ***A-C,*** *Independent effects of temperature on softening, vascular browning and body rots;* ***D,*** *Effect of temperature on skin colour after a cooling delay of 24 hours. Estimated mean data and trend lines are displayed.*

While pre-cooling delay had significant independent effects on some qualities, the trend was not consistent or large enough to be of concern (data not shown). The delay in removal of field heat had a significant impact on the ripeness indicators of skin colour (P=0.026) and softening (P=0.007). Yet the delay had no significant impact on the other quality parameters including body rots, vascular browning and stem end rot.

In this trial, stem end rot incidence was very low and only significantly affected by the increase in storage period.

Although the present study requires further exploration before conclusion, we have highlighted the importance of separating pre- and post-harvest environmental variables on the quality of fruit. By separating harvest temperature, pre-cooling delay and cool-storage duration, we have shown significant but not deleterious effects of harvest at temperatures greater than 30ºC. The effect of high pre-harvest temperature on fruit quality, as distinct from sun-exposure, has been studied previously in oriental melon, tomato and grapes, showing that high temperature may also impart hardiness against post-harvest disorders (Sin *et al.* 1991; Kang and Park 1999; Spayd *et al.* 2002). The result of this initial investigation is encouraging and the results need to be tested for repeatability and increased robustness on other properties.

Year 2005

Method

To verify the results of 2004, fruit was collected from single sites at two orchards in the south-west of WA. The first orchard was near Bunbury on a deep sandy soil (site A). The second, at Pemberton, was on deep gravelly loam soils (site B). At harvest, fruit had a dry matter content of 31 and 35 per cent respectively from the two sites. Both sites were irrigated using small under-tree sprinklers and were mature stands of trees of greater than six years and touching down the intra-row space. The two sites were chosen to test the effect of location, different climate and soil type on the results and thus demonstrate repeatability and robustness.

As in 2004, weather forecasting was used to determine a suitable set of predicted conditions. For logistics, separate harvest dates were used for the two properties. As in 2004, fruit was harvested by hand at a range of increasing temperatures during the day (Table 1). This season, based on the results from 2004, only two cooling delays were used (2, 24 hr; ambient shade), one storage length (28 days; 5-6ºC) and only shaded fruit was harvested. Forty fruit (average size 200 g) were hand harvested for each temperature, 20 each for the two cooling delays. Pulp and ambient temperature were monitored as in 2004.

Table 1. Ambient air temperature (ºC) as logged at the time of the various harvests for the two properties

	Ambient air temperature in °C at the harvest times				
Site A	25.2	28.3	29.4	33.9	35.4
Site B		30.4	31.5	33.3	37.4

After 28 days storage, the fruit was transferred to a ripening room at 17-18ºC, treated with Ripegas® at an effective rate of 100 ppm. The room was purged daily and retreated with Ripegas® for four days. The fruit was then maintained at 17-18ºC until most had reached a slightly over-ripe state. Fruit was then assessed as in year 2004, for softness, skin colour, external rots, body rots and vascular browning.

Data were analysed using GenStat. A linear mixed model including fixed effects for temperature, delay, site and interactions, was fitted to the data for colour and softness. The random model allowed for different variance between fruit at each site. A similar model was fitted to the remaining measurements with the addition of colour and softness as covariates. This was so that treatment effects were compared at the same levels of colour and softness.

Since treatment effects interacted with site, a linear model (regression analysis) was used to test treatment effects at each site. In this analysis the linear effect of actual temperature, the effect of delay and their interaction were examined. No quadratic effect for temperature was included because of anomalous results at some temperatures which lead to unlikely temperature responses. In order to standardise to constant values of softness and colour (the indicators of ripeness) regression analyses of body rot and vascular browning were repeated including softness and colour as covariates.

Results

There were significant interactions between site and treatments for measurements of softness, colour and body rot, but not vascular browning. Regression analyses for individual sites are presented in Table 2.

Table 2: Significance of temperature and delay effects on post-harvest quality of Hass avocado at two separate sites in Western Australia

	Site A					**Site B**				
Accumulated analysis of variance										
Change	d.f.	Vascular browning	Body rot	Softness	Colour	d.f.	Vascular browning	Body rot	Softness	Colour
+ vT	1	0.620	0.001	<.001	0.675	1	0.425	<.001	0.197	0.435
+ Delay	1	0.046	0.016	<.001	<.001	1	<.001	<.001	0.094	0.044
+ vT.Delay	1	0.644	0.651	0.005	<.001	1	0.645	0.004	0.312	0.435
Residual	196					156				
Accumulated analysis of covariance										
+ Soft	1	0.173	0.008			1	0.337	<.001		
+ Colr	1	0.135	0.014			1	0.309	0.31		
+ vT	1	0.807	0.008			1	0.510	<.001		
+ Delay	1	0.317	0.017			1	<.001	<.001		
+ vT.Delay	1	0.428	0.981			1	0.638	0.008		
Residual	194					154				

At site A, the response (linear slope) to temperature varied significantly with delay for softness (P=0.005) and colour (P<0.001, Figures 4 and 5 respectively and Table 2). There was a significant response to temperature with a two hour delay (softness increased by 0.045 for every increase in temperature of 1°C) and no effect of temperature on softness with a 24 hour delay. Softness was consistently higher with a 24 hour delay compared to a two hour delay (5.06 ± 0.04 vs 4.80 ± 0.04). There was a small decrease in colour as temperature increased with a two hour delay (colour decrease of 0.036 for every increase in temperature of 1°C) and a small increase in colour as temperature increased with a 24 hour delay (colour increase of 0.028 for every increase of 1°C). At site B there was no response to temperature for softness (P=0.197) and colour (P=0.435) but the effect of delay was close to significant levels (P=0.094 and P=0.044, respectively).

Softness and colour did not affect vascular browning but did have a significant effect on body rot. However, the significance of treatment effects did not change markedly when body rot was standardised to common values of colour and softness. There was no effect of temperature on vascular browning (Figure 7) but there was a significant effect of delay at site B (Table 2). The level of vascular browning in this trial was very low and while a significant difference could be shown, it was a very small reduction in incidence after 24 hour delay compared to the two hour delay.

There were effects of temperature and delay on body rot at both sites (Figure 6). At site A, increases in temperature of 1°C caused increases in body rot of 0.03-0.04. Body rot with a two hour delay was slightly higher than with a 24 hour delay (0.72 ± 0.06 vs 0.52 ± 0.06). At site B, there was a significant response to temperate with a two hour delay (increase of 0.17 for every 1°C) but no response with a 24 hour delay. Body rot was generally higher with a 24 hour delay than a two hour delay (2.12 ± 0.10 vs 1.59 ± 0.10).

The level of stem end rot occurrence was so minor it did not warrant further analysis; data not shown.

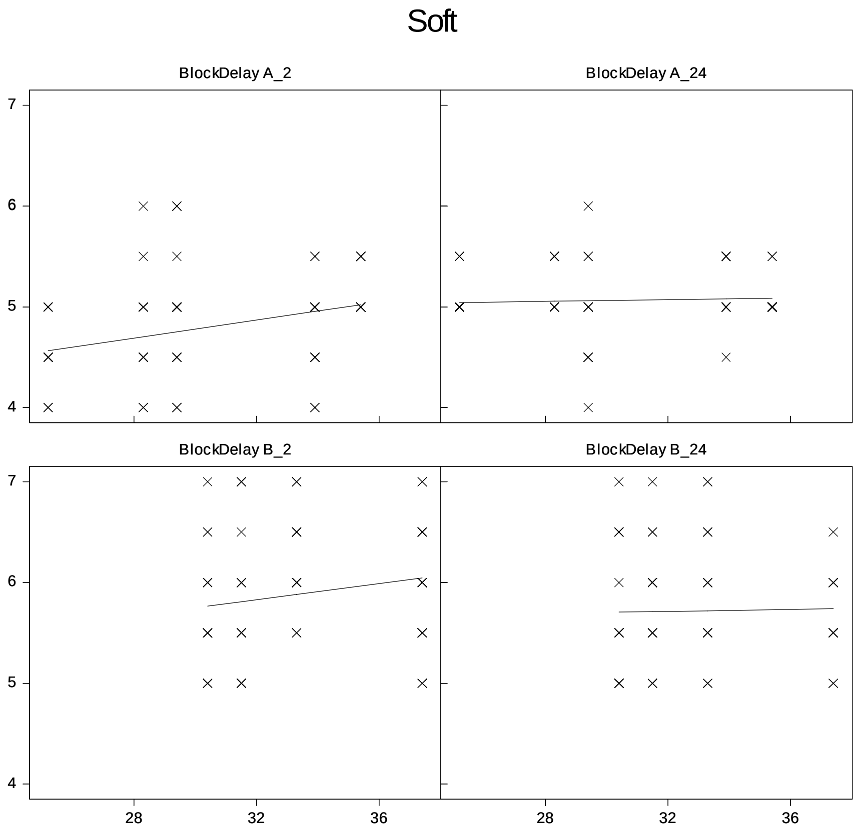

Figure 4. *Response of fruit softness to increases in ambient harvest temperature for each delay (2 and 24 hours) of removal of field heat for Hass avocado at two sites in Western Australia*

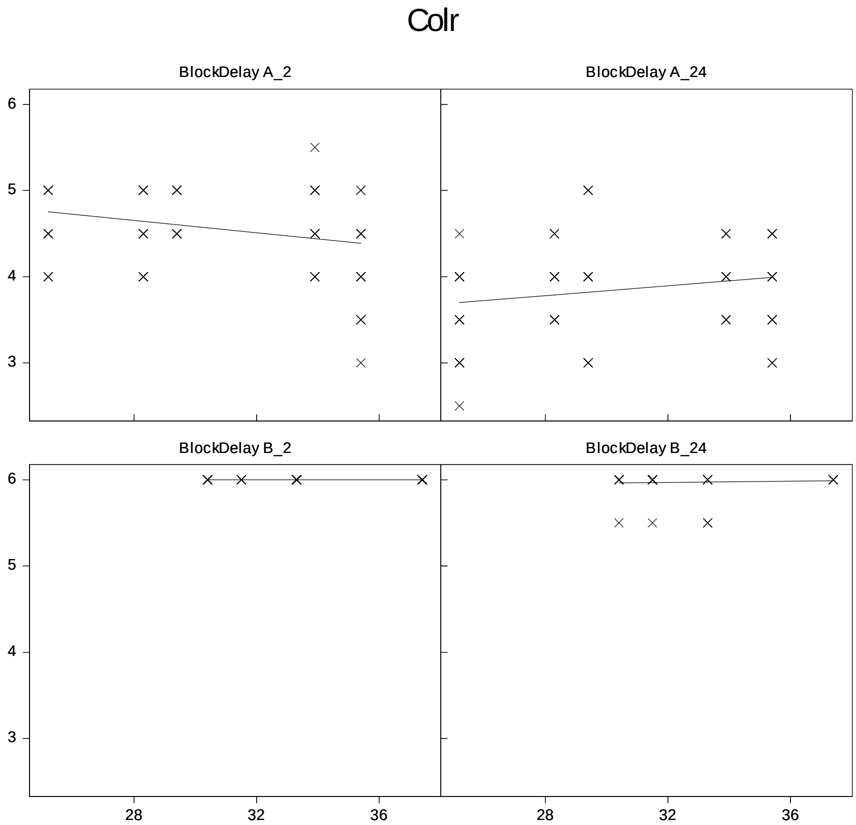

Figure 5. *Response of fruit skin colour to increases in ambient harvest temperature for each delay (2 and 24 hours) of removal of field heat for Hass avocado at two sites in Western Australia*

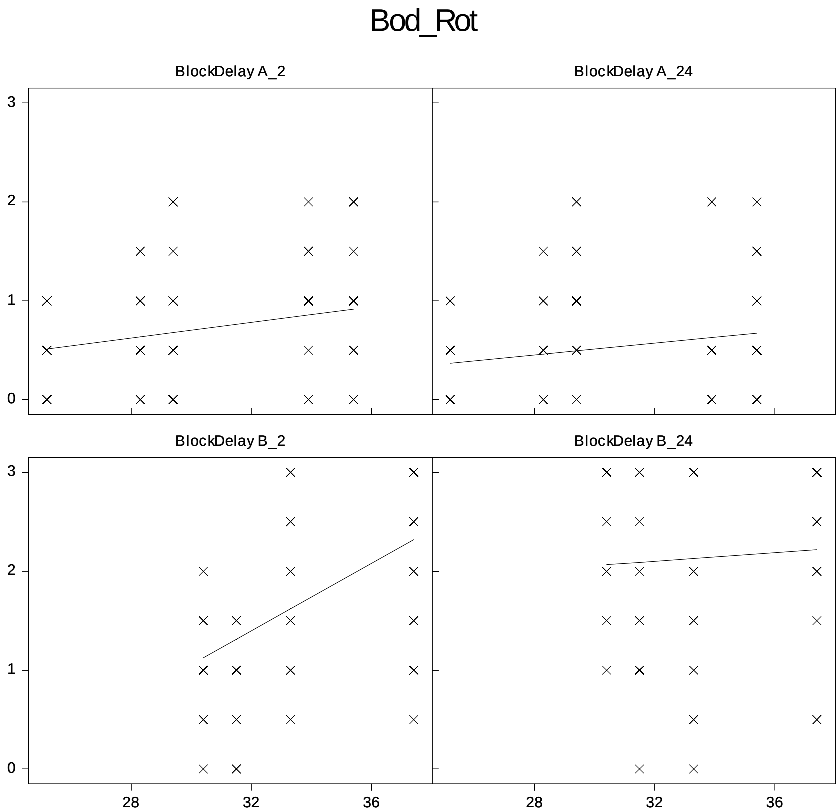

Figure 6. *Response of fruit body rots to increases in ambient harvest temperature for each delay (2 and 24 hours) of removal of field heat for Hass avocado at two sites in Western Australia*

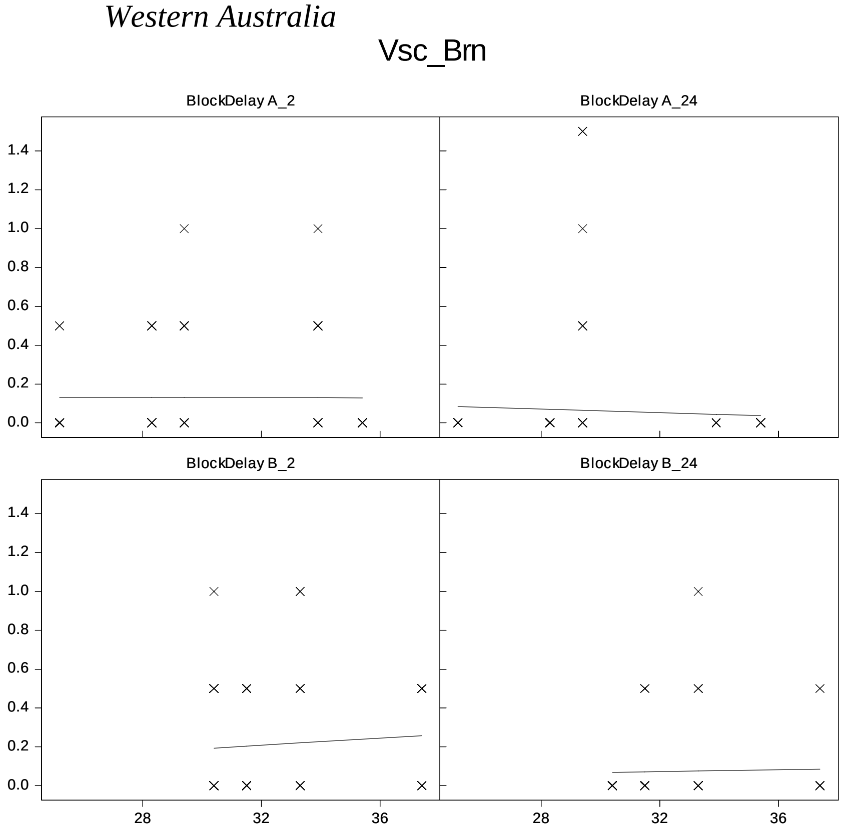

Figure 7. *Response of fruit vascular browning to increases in ambient harvest temperature for each delay (2 and 24 hours) of removal of field heat for Hass avocado at two sites in Western Australia*

Conclusions from 2004 and 2005 trials

The effect of delaying the removal of field heat from the fruit by up to 24 hours did impact on the post-harvest quality of the fruit. The impact of the delay was inconsistent between site and quality parameters. Only in one case did the delay indicate an impact of a scale that might shift the fruit from an acceptable to a non-acceptable state. In general, the impacts were inconsequential, but the variability highlights that other factors such as disease pressure or tree health may play important roles in these relationships as well. This is partially consistent with the findings of Arpaia *et al.* (1992) who demonstrated increased softening, discolouration and decay for increasing delays in removal of field heat.

In several cases, the impact of the delay produced similar results to the impact of the higher harvest temperature. This may indicate that the ambient temperature at which the fruit is held post-harvest is having the same effect on the fruit as the temperature at harvest. Arpaia *et al.* (1992) demonstrated the need to keep the harvested fruit protected from the elements as excessive heating or direct sunlight can increase disorders and weight loss. As a result, even though a delay of 24 hours may not have impacted greatly in most cases and appears to be acceptable practice, it is still advisable to remove the field heat as soon as possible.

Similar to delay, the rise in harvest temperature above 30ºC was only of minor consequence in all but one case (body rots, year 2005, site B, two hour delay). The fruit from this property (site B) had been allowed to ripen further than for site A, so it may be that the impact of higher ambient temperature at harvest begins to show up as a more rapid deterioration of fruit quality when ripe. It may also be that this property had a higher incidence of anthracnose (the main contributing factor to body rots) than other sites. Once again this highlights the potential impact of other issues on post-harvest quality. As a result, it is highly recommended that growers continue to monitor their fruit output (for example library trays) if they are going to stretch the harvesting parameters for both harvest temperature and delays to removing field heat.

In the final analysis of the data, there did not appear to be any compelling argument for continuing to recommend that growers stop harvesting when the ambient temperature rises above 30ºC under WA levels of disease pressure. However, controlled experiments do not always lend themselves exactly to field conditions. Therefore, to test these finding in a more robust manner, a commercial shipment evaluation was required.

3. Commercial shipment evaluation of recommendations

Method

In 2007, fruit was tested using full commercial practices.

A Pemberton orchard was chosen for this trial. As in previous seasons, weather forecasts were used to determine a suitable day for collection of the fruit that would provide hot dry conditions for harvest. Fruit was harvested commercially and packed into standard field bins. When filled, the bins were transferred to an undercover location until transported to the cooling and packing facility. Harvesting was carried out for the entire day on the chosen day. Bins harvested in the morning at the site were transferred to cool storage (6.5ºC) at midday. Bins harvested in the afternoon were transferred to cool storage at the end of the day. To compare low and high harvest temperature when packing, a bin was selected from the morning harvest for the low temperature and a bin from the afternoon harvest for the high temperature. The temperature range for the day of the harvest was 15.6ºC at mid-morning to 36.6ºC at mid-afternoon. Fruit had an average dry matter of 31 per cent.

The fruit was graded three days after harvest on a weight grader with a water dump, in-line washing, drying and fungicide application, as per industry standards. The fruit was split into two batches: one for transit to Sydney and one to Melbourne. Two trays (32 or 36 count) were then tagged, for both morning and afternoon harvested fruit for each destination, for tracking through the system and final evaluation. One fruit in each tagged tray was probed to allow the monitoring of the pulp temperature during transit and subsequent storage and ripening. The fruit was transported by road from Pemberton to Perth and then by rail to Melbourne or Sydney. After arrival at the respective markets, the fruit was held at 5ºC until ripening.

Melbourne fruit was held for 29 days in total after harvest and then removed to the market floor for six days for ripening. Due to an advanced stage of skin colouring, no ethylene gas was used. The fruit was then assessed as per year 2004.

Due to a technical breakdown, Sydney fruit was held for 37 days (nine days longer than programmed) in total after harvest, then removed for ripening at 24ºC for 36 hours without ethylene and then assessed as per year 2004.

Data were analysed separately by each consignment, using GenStat release 9.1. Due to the nature of the trial and the datasets, the data were evaluated using sample means which were compared for similarity via a probability derived from a ‘t-test’.

Results

The quality assessment of the avocados were carried out at an almost ready to eat stage of ripeness (Sydney) and at a ripe ready to eat stage (Melbourne). The afternoon harvested fruit sent to Melbourne was significantly ($P<0.001$) softer than the morning harvested fruit when assessed (Table 3). The morning harvested fruit sent to Sydney had a significantly ($P<0.001$) higher level of flesh adhesion than the afternoon harvested fruit. None of the other measured parameters displayed a significant difference between the morning and afternoon harvested fruit within each consignment.

Table 3. Results of quality assessment ratings for selected parameters of avocados at a ripe ready to eat state, harvested in the cool morning or hot afternoon (15.6/36.6ºC min/max day temperature), transported to Melbourne or Sydney and stored for a total of 29 or 37 days respectively before ripening

Destination	**Sydney**		**Melbourne**	
Harvesting time	*Morning*	*Afternoon*	*Morning*	*Afternoon*
Softness (1-7)	4.46	4.62	4.84*	5.14*
External rots (1-3)	0.12	0.25	0.06	0.08
Stem end rots (1-3)	0.23	0.25	0.48	0.57
Body rots (1-3)	0.18	0.17	0.34	0.23
Vascular browning (1-3)	0.67	0.87	0.53	0.43
Diffuse flesh discolouration (1-3)	1.61	1.76	0.21	0.19
Flesh adhesion (1-3)	0.86*	0.37*	0.37	0.24

* denotes significant difference at P<0.001

The Melbourne consignment turned out in acceptable eating condition, with all measured 'defects' averaging at less than five per cent affected area/volume for both the morning and afternoon-harvested fruit. Apart from the significant but small increase in softness for the afternoon-harvested fruit compared to morning-harvested fruit, there was no significant difference between the two harvest times. Therefore, the higher temperature of the harvest during the afternoon did not impact detrimentally on fruit quality.

The Sydney consignment generally did not turn out in acceptable condition with 'diffuse flesh discolouration' at a mean rating of 1.61 and 1.76 for the morning and afternoon-harvested fruit respectively, equivalent to 15 to 20 per cent of the flesh affected. Vascular browning in the Sydney fruit also rated at 0.69 and 0.87 for the morning and afternoon respectively (5 to 10 per cent of flesh affected). The external, stem end and body rots were all low and acceptable for the Sydney consignment. However, the fruit was at a slightly firmer state than ideal for expression of these rots. This level of diffuse flesh discolouration was not expected and had not been experienced in any previous trials.

Investigation of the Sydney consignment highlighted a breakdown in the cool chain during the rail leg of the transport from Perth, plus a failure to shift the fruit from cool storage to ripening at the programmed time. During the cool chain breakdown, the fruit pulp temperature rose from 7 to 20ºC over three days. One of the documented causes of diffuse flesh discolouration is storage in excess of 28 days at low temperatures such as 6ºC (White *et al.* 2001), and the Sydney fruit was held for some nine days longer than this. As a result, this is the likely cause of the high level of diffuse flesh discolouration.

A second documented cause of diffuse flesh discolouration is fruit being held at low temperatures while ripening (White *et al.* 2001). It is possible that the Sydney consignment commenced ripening during the period of raised temperature and the subsequent return to and holding at low temperature also contributed to the development of diffuse flesh discolouration. The level of diffuse flesh discolouration was not significantly different between the fruit harvested in the morning or afternoon. Therefore the ambient temperature at the time of harvest did not have an impact on this.

These two faults would have generally rendered the fruit unacceptable to the consumer. Unfortunately as they are internal disorders, the consumer wouldn't have seen these faults until after purchase. This highlights a need to monitor storage temperature and carry out quality checks if any discrepancies occur.

Research conclusions

The results have demonstrated that the ambient temperature at harvest, even up to 37ºC does not have significant impacts on fruit quality likely to render it unacceptable. Maintenance of the cool chain after harvest, including the storage temperature and length of storage is far more critical for maintaining acceptable fruit quality.

The results of this project have demonstrated that growers can confidently harvest fruit up to temperatures in the mid-30°s, provided that appropriate after-harvest care is maintained.

The delay in removing field heat by up to 24 hours did not result in deleterious impacts on the quality parameters likely to affect consumer satisfaction. However, the delays did impact on the main indicators for ripeness, in skin colour and fruit softness. As a result, this could be of concern to marketing as mixed batches of harvested fruit could result in varied ripeness after ripening treatments. Therefore, it is important that growers keep marketers informed of the status of the fruit they are sending so they can be aware of this.

Because of the 'hidden' nature of some avocado fruit quality disorders, it is important to continually monitor the storage temperatures and to maintain an accurate inventory of the fruit to ensure fruit does not remain held in storage for too long and is stored at the correct temperature. It would also be of value to carry out regular checks on the quality of the fruit throughout the entire supply chain, from harvest to retail sale.

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Acknowledgements

We would like to thank Paul and Maria Bidwell, Neil and Jenny Shenton, Phil and Wendy French, William, Debbie and Dean French, Wayne and Jennie Franceschi for their willingness to allow us to source fruit from their orchards, use their equipment and in the case of the Franceschis to also transport the fruit to Sydney and Melbourne for the verification trial.

Thanks also to Barkers Produce Merchants, Melbourne Markets and N & A Produce Merchants, Sydney Markets, for kindly storing our fruit in cool rooms for the verification trial.

Jane Speijers provided statistical analysis support.

Technology transfer

McCarthy A. Progress reports presented to Western Australian avocado industry at their twice-yearly industry meetings:

9 June 2004
14 September 2004
15 March 2005
26 July 2005
20 March 2007
31 August 2007

McCarthy A. Summary of trial progress presented to national industry R&D committee at their annual Research Workshop, Avocados Australia Limited:

25 August 2004
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Appendix 1 - Rating scales used

Ratings used were as per the *AvoCare Assessment Manual*, White *et al*. (2001). For more detailed descriptions of the ratings and comparative photographs, refer to the manual.

Skin Colour – scale 1, 2, 3, 4, 5, 6
- 1 equals emerald green
- 4 equals some green on black (greater than 50 per cent dark)
- 6 equals all black

Softness – scale 0, 1, 2, 3, 4, 5, 6, 7
- 0 equals hard
- 4 equals near ripe, whole fruit deforms with extreme hand pressure
- 7 equals very over-ripe, flesh feels almost liquid

External rot – scale 0, 0.5, 1, 1.5, 2, 2.5, 3
- 0 equals 0% of skin area affected
- 1.5 equals 15% of skin area affected
- 3 equals 50% of skin area affected

Stem end rot – scale 0, 0.5, 1, 1.5, 2, 2.5, 3
- 0 equals 0% of flesh volume affected
- 1.5 equals 15% of flesh volume affected
- 3 equals 50% of flesh volume affected

Body rots - scale 0, 0.5, 1, 1.5, 2, 2.5, 3
- 0 equals 0% of flesh volume affected
- 1.5 equals 15% of flesh volume affected
- 3 equals 50% of flesh volume affected

Vascular browning - scale 0, 0.5, 1, 1.5, 2, 2.5, 3
- 0 equals 0% of circumference of fruit with dark fibres
- 1.5 equals 15% of circumference of fruit with dark fibres
- 3 equals 50% of circumference of fruit with dark fibres

Diffuse flesh discolouration - scale 0, 0.5, 1, 1.5, 2, 2.5, 3
- 0 equals 0% of flesh volume affected
- 1.5 equals 15% of flesh volume affected
- 3 equals 50% of flesh volume affected

Appendix 2 – Statistical summary 2004 data

Significance of effects on a range of parameters of Hass avocado subjected to a range of harvest temperatures, delays to storage and storage length in 2004.

Measurement	***Effect***	***Significance***
Softness	Storage period	**0.027**
	Delay	**0.007**
	Harvest temperature *linear*	0.075
	Harvest temperature *quadratic*	**0.021**
Skin colour	Storage period	**<0.001**
	Delay	**0.026**
	Harvest temperature *linear*	0.259
	Harvest temperature *quadratic*	0.136
	Delay. temperature *linear*	**0.020**
	Delay. temperature *quadratic*	**0.011**
Log (External rot+1)	Storage period	0.544
	Delay	0.881
	Harvest temperature	0.672
Log (Stem end rot+1)	Storage period	**<0.001**
	Delay	0.438
	Harvest temperature	0.534
Body rot	Storage period	**0.048**
	Delay	0.774
	Harvest temperature *linear*	0.287
	Harvest temperature *quadratic*	**0.017**
Vascular browning	Storage period	**<0.001**
	Delay	0.056
	Harvest temperature *linear*	**0.004**
Log (Discolouration+1)	Storage period	**<0.001**
	Delay	0.344
	Harvest temperature	0.110

Appendix 3 – 2004 data means and 5% LSD

Estimated means for different storage periods, delays and harvest temperatures and their 5% least significant differences (5%LSD) for the 2004 trial.

Measurement	*Effect*	*Level*	*Mean*	*Average 5%LSD*	*Retransformed. mean*
Softness	Storage period	14	5.089	0.489	
		28	5.636		
	Delay	2	5.380	0.183	
		6	5.483		
		24	5.226		
	Harvest temperature	27.0	5.132	0.356	
		28.0	5.466		
		30.0	5.356		
		32.0	5.527		
		33.0	5.619		
		33.5	5.236		
		34.0	5.288		
Skin colour	Storage period	14	4.162	0.326	
		28	5.241		
	Delay/ Temperature	2/27.0	4.825	0.720	
		2/28.0	4.452		
		2/30.0	4.746		
		2/32.0	4.933		
		2/33.0	5.179		
		2/33.5	4.825		
		2/34.0	4.752		
		6/27.0	4.794		
		6/28.0	5.152		
		6/30.0	4.848		
		6/32.0	4.575		
		6/33.0	4.252		
		6/33.5	4.864		
		6/34.0	4.452		
		24/27.0	4.199		
		24/28.0	3.879		
		24/30.0	4.861		
		24/32.0	4.837		
		24/33.0	4.848		
		24/33.5	4.444		
		24/34.0	4.629		
Log (External rot+1)	Storage period	14	0.2498	0.1652	0.2838
		28	0.2983		0.3476
	Delay	2	0.2860	0.1233	0.3311
		6	0.2908		0.3375
		24	0.2454		0.2781
	Harvest temperature	27.0	0.2417	0.2456	0.2734
		28.0	0.3180		0.3744
		30.0	0.1794		0.1965
		32.0	0.3036		0.3547
		33.0	0.3036		0.3547
		33.5	0.2799		0.3230
		34.0	0.2922		0.3394
Log (Stem end rot+1)	Storage period	14	0.0161	0.1168	0.0162
		28	0.3035		0.3546

	Delay	2	0.1513	0.0961	0.1633
		6	0.1946		0.2148
		24	0.1335		0.1428
Log (Stem end rot+1)	Harvest temperature	27.0	0.1100	0.1931	0.1163
		28.0	0.2875		0.3331
		30.0	0.1374		0.1473
		32.0	0.0902		0.0944
		33.0	0.2646		0.3029
		33.5	0.0395		0.0403
		34.0	0.1892		0.2083
Body rot	Storage period	14	0.6700	0.4274	
		28	1.1036		
	Delay	2	0.8630	0.2876	
		6	0.9235		
		24	0.8740		
	Harvest temperature			0.5820	
		27.0	1.0677		
		28.0	0.7215		
		30.0	1.0328		
		32.0	1.4667		
		33.0	0.8673		
		33.5	0.5733		
		34.0	0.3881		
Vascular browning	Storage period*	14	0.1447	0.2302	
		28	1.9408		
	Delay	2	0.3991	0.1663	
		6	0.3612		
		24	0.2005		
	Harvest temperature	27.0	0.4493	0.3340	
		28.0	0.4324		
		30.0	0.3613		
		32.0	0.1472		
		33.0	0.2983		
		33.5	0.1942		
		34.0	0.2805		
Log (Discolouration+1)	Storage period*	14	0.1140	0.1376	0.1208
		28	0.9220		1.5143
	Delay	2	0.0670	0.0870	0.0693
		6	0.0307		0.0312
		24	0.0045		0.0045
	Harvest temperature*	27.0	0.4818	0.2044	0.6190
		28.0	0.5926		0.8087
		30.0	0.5605		0.7515
		32.0	0.3721		0.4508
		33.0	0.6101		0.8406
		33.5	0.4442		0.5592
		34.0	0.5648		0.7591

* Means calculated for the eastern block only as average across both blocks led to negative estimates due to removal of data for eastern block (14 day storage) and possible block-by-storage interaction.