

Development and commercial application of an avocado fruit robustness test

Danielle Le Lagades
Department of Employment, Economic Development
& Innovation

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FINAL REPORT

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Development and commercial application of an avocado fruit robustness test for 'Hass' avocados



Danielle Le Lagadec, Terry Campbell and Peter Hofman
Horticulture & Forestry Sciences
Agri-Science Queensland
Department of Employment, Economic Development and
Innovation (DEEDI)

HAL Project Number: AV07005

Project Leader: Danielle Le Lagadec
Senior Horticulturist
Agri-Science Queensland
Department of Employment, Economic
Development and Innovation
Bundaberg Research Station
49 Ashfield Road
Bundaberg, Qld 4670
Phone: (07) 4132 5524
Fax: (07) 4155 6129
Email: danielle.lelagadec@deedi.qld.gov.au

Key Personnel: Terry Campbell, Principal Extension Horticulturist
Peter Hofman, Senior Principal Horticulturist

Purpose:

The *Avocado Robustness project* was an initiative of Australian Avocado Ltd, Agri-Science Queensland and Horticulture Australia Ltd. The aim of this two year project was to develop a pre harvest test capable of predicting end-use fruit quality several weeks before the commercial harvest.

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MEDIA SUMMARY

In 2008, a project was launched to develop a test for Hass avocado quality. Two Avotests were developed—one for short-storage, domestic market fruit and one for long-storage or export fruit.

In an industry worth \$420 million, if only good quality fruit were marketed, the Avotest could increase the quality of the retail fruit by 10%. Avotest will allow growers to make informed marketing decisions and improve fruit quality before commercial harvest begins.

The short-storage Avotest can:

- identify fruit as marketable or unmarketable around 75–80% of the time,
- predict some insect damage, fruit rots and some physiological disorders.

The long-storage Avotest can:

- identify fruit as marketable or unmarketable around 86% of the time,
- predict cold damage, some insect damage, fruit rot and diseases.

Both consumers and industry would benefit from improved fruit quality.

Since the Avotest uses fruit samples from the orchard, it cannot predict damage from handling of the fruit. Therefore, it is recommended that the Avotest be further developed to include samples from the end of the packing line at the start of the avocado season.

If Avotest was widely used in central Queensland, there would be a reasonably high return for the industry. Potential commercial applications of Avotest include:

- identifying blocks that need to be improved,
- identifying the best blocks to supply markets that have strict quality requirements,
- giving feedback on individual growing practices.

TECHNICAL SUMMARY

Australia's avocado industry has 1200 growers, producing 46,500 tonnes of avocados each year worth \$120M at farm gate and \$420M at the retail level. Despite considerable research effort, the quality of ripe avocados often do not meet consumer expectations.

Quality issues usually only manifest during ripening and especially after storage, and are therefore rarely seen by the growers. With increased market supply and likely increases of on-tree and market storage, quality issues will become more important to the Australian industry. An accurate knowledge of fruit quality should become an important criterion on which stakeholders can base marketing decisions.

A project was launched in 2008 to develop a fruit robustness test called the Avotest. The test involved the rapid ripening of fruit under controlled conditions. This test, applied before the start of the commercial harvest, could be used as an indicator of expected retail fruit quality. Two Avotests were developed, one for short storage domestic market fruit and one for long storage or export fruit.

The Avotest results were verified by subjecting fruit from the same blocks to a commercial cold chain simulation test. After two seasons of experiments it was found that the domestic market Avotest can categorize fruit as either marketable or unmarketable with approximately 75-80% accuracy. On a block-to-block bases, the correlation between the Avotest and the commercial test was about 60% ($r=0.57$ for the 2008 experiment and $r=0.55$ for the 2009 experiment). The Avotest is a useful tool for ranking block performance. The test is best suited for indentifying outlying blocks i.e. those that produce poorer quality fruit. One of the major limiting factors of the Avotest is that the prediction model may need to be recalibrated each season.

The test effectively predicts levels of some insect damage, fruit rots and some physiological disorders. The domestic market Avotest has its limitation and can only predict defects which originate in the orchard. Fruit handling, which is a major cause of fruit rejection, and cold storage injuries cannot be predicted by the domestic market Avotest. Approximately 10% of 'Hass' fruit on the retail shelf are unacceptable due to rots. In an industry worth \$420M the correct use of the Avotest has the potential to increase the industry's fruit quality by 10% presuming only good fruit are offered to customers. The Avotest is able to give growers feedback regarding their fruit quality several weeks before the commercial harvest. This would enable growers to make informed marketing decisions and to take remedial action to improve their quality before the harvest begins.

The long storage Avotest closely mirrors the commercial test and therefore produced results which closely correlated with the commercial test ($r=0.74$). The long storage Avotest is able to reflect the fruits susceptibility to cold injury as well as some insect damage and rots. The test was able to categorize fruit into 'marketable' and 'unmarketable' with approximately 86% accurately. However, this is not a rapid test and requires two to three weeks of cold storage. Despite the long storage period, the test would still allow sufficient time for growers to make informed marketing decisions and take remedial action especially if they were planning on delaying the harvest.

A cost benefit analyses for the domestic Avotest was conducted at the end of the 2008 season. It is predicted that consumers and the whole of industry would be a major beneficiary of improved quality. If Avotest was widely used in central Queensland there would be a reasonably high benefit to cost ratio of 3:1 to 7:1.

Grower feedback for the 2008 and 2009 Avotest results was encouraging. Some growers made changes to their farm practices based on their 2008 quality and saw improvements in their 2009 quality.

Collaborator interviews showed that growers valued the ability to predict fruit quality and identified potential commercial applications for the test. These included the use of Avotest to identify blocks requiring remedial action; to identify elite blocks for markets with high fruit quality requirements; and to give feedback on farming practices. The negative influence of heavy pruning, high vegetative vigour and high nitrogen levels, and the positive influence of high crop load on fruit quality were evident.

Since fruit were sampled from orchards for the Avotest, the test could not reflect commercial handling injuries. To overcome this, it is recommended that the Avotest be developed into a structured library tray system with fruit being sampled from the packing line at the start of the avocado season. Although this would limit the growers' reaction time, end-use fruit quality results would still be available before the fruit reach the retail shelf. Growers and market agents would have sufficient time to make decisions regarding storage regimes and market selections. Furthermore, since blocks are often harvested repeatedly, growers may have sufficient time to take remedial action prior to the next harvest.

INTRODUCTION

Most avocado producing and importing countries recognize that a major factor limiting sales is variable fruit quality. The Australian industry produces approximately 47,000 tonnes of fruit each year worth \$120M at farm gate and \$420M at retail level (Avocados Australia Ltd Media Release, 12 May 2008). The industry is growing by 15% per year (Woolf *et al.* 2009). In order to maintain returns to growers consumption has to increase. A recent consumer survey found that repeat sales are closely linked to fruit quality (Harker *et al.* 2007). Consumers have a low tolerance for fruit with more than 10% internal defect. A recent survey of internal fruit quality problems on the retail shelf has shown that bruising is the major cause of fruit rejection affecting approximately 12% of fruit, followed by body rots (7.5%), vascular browning (6%), diffuse discolouration (5%), stem-end rots (3%) and other defects (0.5%) (Embry 2009a). Despite considerable research, quality remains a problem for the industry, slowing domestic and export expansion. The Australian industry has had a strong focus on quality for many years. This resulted in a number of surveys at retail outlets (Embry 2009a; Harker *et al.* 2007; Hofman and Ledger 2001; Ledger 1993), as well as targeted activities to improve the skills of ripeners/wholesalers, and retail staff (Improving Avocado Ripening Systems, AV08018). Despite these efforts, retail shelf quality has not improved much over the past decade (Embry 2007; 2009a; Hofman and Ledger 2001).

Considerable effort has been made to improve avocado fruit quality worldwide over the past thirty years. A lot of attention has been focused on postharvest storage, shipping temperatures and ripening regimes (Bezuidenhout *et al.* 1995; Blakey and Bower 2009; Burdon *et al.* 2008; Cutting and Wolstenholme 1992; Dixon *et al.* 2003a; Dixon *et al.* 2003b; Hofman *et al.* 2001; Mandemaker 2004; Roets *et al.* 2009; Van Rooyen 2009; White and Hopkirk 1995; Yearsley *et al.* 2002a; b). However, maximum fruit quality is determined before harvest. Postharvest treatments can only maintain quality or slow losses. Postharvest techniques cannot ameliorate an initial quality problem.

Quality varies from season to season and from region to region. Several studies have focused on identifying important preharvest factors affecting fruit quality. Water deficits can reduce fruit quality (Bower and Cutting 1987; Neuhaus *et al.* 2009), as can excess irrigation or rainfall (Kruger *et al.* 1999; Pak *et al.* 2003b). Quality has been strongly linked to fruit maturity (Dixon *et al.* 2003a; Dixon *et al.* 2003b; Dixon *et al.* 2004; Elmsly *et al.* 2007; Kruger *et al.* 2001; Kruger *et al.* 2000; Kruger *et al.* 2002; Kruger *et al.* 2004; Pak and Dawes 2001; Pak *et al.* 2003a) while environmental factors, cultural practices and rootstocks have also been implicated (Arpaia 2005a; Arpaia and Eaks 1990; Arpaia *et al.* 2004; Dixon *et al.* 2007; Elmsly *et al.* 2007; Everett and Pak 2001; Kruger *et al.* 2008; Kruger *et al.* 2004; Mandemaker *et al.* 2006; McCarthy 2008; Thorp *et al.* 1995; Whiley *et al.* 1997; Woolf *et al.* 1999).

Over the past two decades, researchers have attempted to identify parameters that can be used as indicators of avocado quality. Considerable attention was given to fruit nutrient content but despite years of research no consensus has been reached. While some correlations were found between fruit quality and calcium levels (Everett *et al.* 2007; Thorp *et al.* 1995; 1997) other studies have failed to verify this relationship (Kruger *et al.* 2004). Some studies have found that nitrogen levels in fruit were indicative of fruit quality (Kruger *et al.* 2001; Kruger *et al.* 2000; Kruger *et al.* 2008; Kruger *et al.* 2004), but others have failed to find similar correlations (Arpaia and Eaks 1990). Everett and Pak (2002) attempted to predict shelf life by calculating the growth rate of the stem-end rot causal pathogen and by quantifying the inoculum pressure in the orchards prior to harvest (Everett *et al.* 2003). The method has not

been commercially adopted. It has been suggested that the quality of late season fruit may be predicted by assessing the fruits' preharvest qualities (Lallu *et al.* 2005). Lallu *et al.* (2005) suggested that the pulp sugar content may serve as such an indicator. Bertling and Bower (2005) and Burdon *et al.* (2007) expanded on this theory and suggested that C7 sugars may be an indicator of fruit postharvest quality but their theory has yet to be tested. Modern technologies such as near-infrared (Blakey *et al.* 2008), magnetic resonance imaging (Lallu *et al.* 2005) and ultrasound (Mizrach 2000; Mizrach 2008; Mizrach *et al.* 1999; Mizrach *et al.* 1996) have been suggested as potential methods of gauging fruit quality. However, none of the above studies have resulted in a reliable, simple indicator of fruit quality. This may be partly because fruit quality is influenced by many biotic and abiotic factors.

Since no simple quality indicator has been identified, it was proposed that a test be developed to predict end-use fruit quality in a domestic market and a long cold storage situation. It was proposed that fruit be sampled before the commercial harvest, ripened and then quality assessed. It was hoped that those fruit could predict the quality of the crop. In order for this test, referred to as the 'Avotest', to be commercially viable it had to be an accurate reflection of end-use commercial fruit quality, the test had to be easily executed, requiring minimal technology and expertise, and cheap. The Avotest would involve ripening fruit at a controlled temperature, assessing the quality and verifying the resulting with that of fruit stored under simulated commercial conditions. The test would be conducted weeks before the start of the commercial harvest, giving growers sufficient time to take remedial action or make informed marketing decisions. Acceptable quality is difficult to define and is dependent on consumer preference, product availability and market price. A recent study conducted by Harker *et al.* (2007) identified that, depending of the price, consumers were willing to tolerate one fruit in ten with some internal damage as long as that damage did not exceed 10% of the fruits flesh. This was the quality benchmark used in Avotest. Avotest was developed and tested over two seasons. In the first season, the Avotest was developed for domestic market fruit. In the second, the domestic market Avotest was verified and a long cold storage Avotest developed.

First Season

MATERIALS AND METHODS

Fruit samples

'Hass' fruit were used for the experiment since this variety represents over 75% of the Australian industry (Australian-Avocados-Limited 2008). Fruit were sampled from two blocks per farm on 10 farms (total of 20 blocks) in Bundaberg and Childers, central Queensland. The blocks had a range in management practices, soil type, tree ages, crop load and tree health. The blocks varied in size from several uniform hectares to less than one hectare. The farms included both small and large operations and were a good representation of the industry in the area.

Seventy fruit were taken per sampling occasion per block. From each block, two fruit were taken from each of 35 trees for each harvest. Fruit of similar size from the same position and aspect of the tree were used in order to achieve a uniform sample. The same 35 trees per block were sampled throughout the season. For each block and sampling, 10 fruit were used for dry matter (DM) testing and the rest of the fruit were used in the Avotest or commercial test.

Dry matter testing

At the laboratory, 10 fruit per block were peeled and the flesh grated. Dry matter was determined for a composite sample of the 10 fruit. Twenty grams of grated flesh was weighed and placed in a drying oven at 65°C till they reached stable mass. The dry matter was then calculated as a percentage of the original wet mass.

Domestic market Avotest

Fruit were harvested/sampled from orchards at 19% and 21% dry matter (DM), i.e. approximately eight to nine weeks, and four to five weeks respectively, before the predicted start of the commercial harvest. It is recommended that growers only harvest fruit once they achieve 24% dry matter although 21% dry matter is the accepted minimum maturity level in Australia. An additional sample was taken at 24% dry matter and used for comparative purposes only. The fruit were not treated with a postharvest fungicide or put through any commercial packshed treatments. Fruit were packed into avocado boxes and were ripened using 10-20 parts per million (ppm) ethylene for three days at 22°C, then maintained at 22°C till ripe.

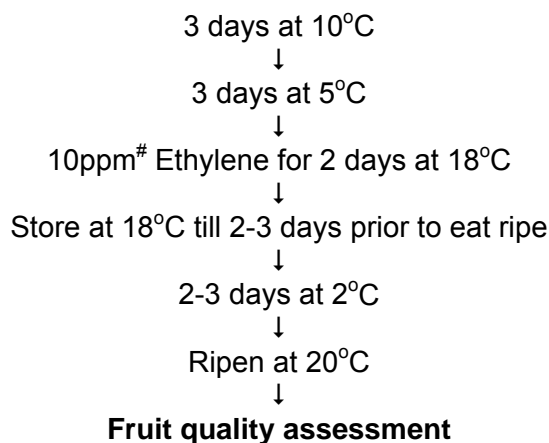
A third of the sample, 20 fruit, was assessed two days before eat ripe (firmometer reading of 6.9 ± 0.1), a third at eat ripe (firmometer reading of 8.7 ± 0.1), and the remaining third two days post-eat ripe (firmometer reading of 9.7 ± 0.1). According to experiments conducted in the Avocare Quality project (AV99007), 20 fruit is sufficient as a representative sample (Hofman *et al.* 2001). Both external and internal fruit quality was assessed. External fruit disorders such as skin spots, discrete patches and external rot were rated during the pre-eat ripe assessment. Thereafter the skin colour darkened and external fruit assessments were no longer meaningful. Internal fruit disorders assessed included stem-end rots, body rots, vascular browning, seed cavity browning, diffuse discolouration and stones in the flesh. Flesh bruising was monitored but was not included in the analyses since it is thought to be a handling injury.

The severity of defects was assessed using a rating system of zero to three in accordance with the AvoCare Assessment Manual (White *et al.* 2001). On this scale, 0=no flesh defects, 1=up to 10% of the flesh with defects, 2=up to 25% and 3=more than 25% of the flesh affected. Fruit with a cumulative severity rating equal to or less than one i.e. $\leq 10\%$ of the fruit pulp, was regarded as marketable. Internal flesh disorders and the incidence and severity of rots were the main parameters measured for fruit quality. Fruit were assessed individually.

Commercial simulation test

The quality of the fruit subjected to the Avotest at 19% and 21 % dry matter was compared with fruit from the same trees harvested at about 21% and 24% dry matter after simulated domestic handling. For the commercial test, fruit were harvested at 21% dry matter because this is the recommended minimum maturity for marketing avocado in Australia (Newett 2001) and at 24% dry matter since this closely reflects commercial reality.

The fruit were not placed over a commercial pack line but were immersed for 30 seconds in Prochloraz 450, 55ml/100L. The domestic commercial test, as developed in the Avocare Quality project (AV99007) (Hofman *et al.* 2001), comprised of:



#part per million

The fruit were assessed as in the Avotest.

Statistical analysis

Correlations were developed between fruit quality after the Avotest and the commercial test. All results were statistically analysed using GenStat 11th Edition using the following analyses: analysis of variance at 95% confidence level, linear regression analyses, and simple correlations.

Production practices

Grower management data was collected for the blocks sampled. This included spray records, irrigation and fertigation data, block yields and pruning practices. The data were collected through individual grower interviews during the feedback sessions. Comparisons were made between fruit quality and production practices in an attempt to identify possible factors affecting quality.

Potential commercial use and cost benefit analysis

The commercial applicability of the Avotest was discussed with industry collaborators using open questions. Growers currently using library tray assessments were asked to compare the Avotest results with their current library tray practices/results.

Responses concerning the potential use of the Avotest were developed into likely scenarios. These scenarios were discussed with a key fruit marketer, avocado researcher and industry representatives to identify likely uses of the Avotest. These were then used for the benefit cost analysis.

RESULTS AND DISCUSSION

Domestic market Avotest and the commercial test

External fruit quality

The fruit subjected to the Avotest and the commercial test ripened relatively evenly (Figure 1). The Avotest fruit ripened within seven days while the commercial test fruit ripened within 22 days. Very little, if any, shrivelling or mottled ripening was observed even for the fruit sampled at 19% dry matter.

The external fruit blemishes assessed included skin spots, discrete patches, and external rots. Physical damage to the skin, which can manifest as skin spots, is thought to be a potential entrance point for rots (Everett and Pak 2002; Pak *et al.* 2003b). In the pre-eat ripe fruit a positive relationship was found between the incidence of skin spots and the development of internal fruit rots ($P=0.0004$) and between the severity of skin spots and the severity of internal rots ($P=0.05$). Also, a highly significant relationship was found between external and internal fruit rots ($P<0.0001$).

Since 'Hass' fruit darken as they ripen, the external fruit defects were only assessed in the pre-eat ripe stage and were not emphasised. Also, much of the external fruit damage is believed to be caused by handling injuries. Since the fruit were not commercially handled, external fruit damage was not relevant. The focus of this study was on end-use internal quality.

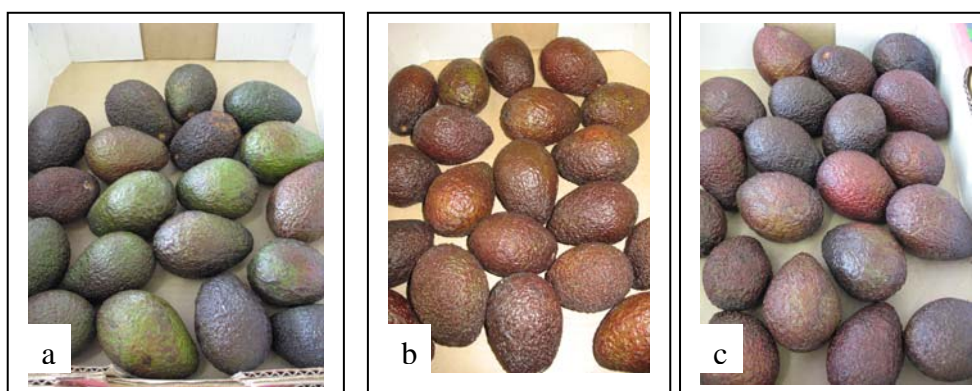


Figure 1. Typical external fruit appearance at assessment; (a) two days before eat ripe; (b) at eat ripe; (c) two days post-eat ripe.

Internal fruit quality

The average incidence of internal quality defects for the Avotest and commercial test fruit is shown in Tables 1 and 2.

Table 1. Average incidence (% affected fruit) of internal defects in Avotest fruit harvested at 19%, 21% and 24% dry matter and assessed at 2 days pre-eat ripe, at eat ripe and at 2 days post-eat ripe. Letters following the value indicates significant differences for individual defects. not statistically different.

Evaluation stage	19% DM			21% DM			24% DM		
	Pre	Eat	Post	Pre	Eat	Post	Pre	Eat	Post
Stem-end rot	6d	28c	46b	9d	34c	62a	9d	33c	71a
Body rots	3c	21b	57a	4c	25b	58a	4c	23b	64a
Vascular browning	2c	3c	3c	4c	9bc	14b	3c	16b	39a
Seed cavity browning	0c	0c	1c	2bc	3bc	5ab	3bc	3bc	7a
Stones in flesh	4*	2*	0*	6*	5*	3*	2*	3*	2*
Marketable fruit	99a	92ab	75c	99a	8 b	58c	99a	89b	51c

Table 2. Average incidence (% affected fruit) of internal defects in commercial test fruit harvested at 21% and 24% dry matter and assessed at 2 days pre-eat ripe, at eat ripe and at 2 days post-eat ripe. Letters following the value indicates significant differences for individual defects. not statistically different.

Evaluation stage	21% DM			24% DM		
	Pre	Eat	Post	Pre	Eat	Post
Stem-end rot	0c	5bc	12ab	0c	4c	1a7
Body rots	18c	34b	51a	19c	33bc	5a7
Vascular browning	1d	29b	6 a	2d	12cd	2bc0
Diffuse discolouration	0c	3c	10bc	4bc	13ab	22a
Seed cavity browning	17*	20*	22*	16*	10*	13*
Stones in flesh	5*	5*	4*	1*	3*	5*
Marketable fruit	99a	93a	73b	98a	93a	72b

Fruit rots and vascular browning were the major defects factors in the fruit. In both tests the incidence of these defects increased as the fruit ripened. Vascular browning is thought to be closely associated with disease incidence (Everett and Pak 2002). The increase in rots as fruit ripen is well documented and is thought to be related to the level of antifungal diene (Prusky *et al.* 1990; Prusky *et al.* 1991). Avocados contain antifungal agents in the skin called dienes which suppresses fungal spore germination and growth. As the fruit ripen, these antifungal agents break down, allowing quiescent spores to germinate or grow resulting in fruit rots (Prusky and Kaobiler 1992; Prusky *et al.* 1990; Prusky *et al.* 1991). Five days after harvesting avocados, the level of diene in the fruit drop rapidly allowing quiescent infections to manifest (Prusky *et al.* 1990; Prusky *et al.* 1991).

The incidence of rots increased slightly with fruit maturity, i.e. from 19% - 24% dry matter ($P < 0.05$, Tables 1 and 2). Previous studies have shown similar trends (Lallu *et al.* 2005; Pak 2001). This could be related to the antifungal diene levels and possibly to the increased inoculum pressure imposed on 'late' hanging fruit. In some studies, diene levels in early fruit were higher than those in late season fruit (Prusky *et al.* 1990; Prusky *et al.* 1991). This could explain why the Avotest fruit at 19% dry matter developed less rots than fruit at 24% dry matter.

Diffuse discolouration became more prominent in the commercial test fruit as they ripened. Diffuse discolouration is a symptom of chilling injury (Cutting and

Wolstenholme 1992) and was not observed in the Avotest fruit because the test did not involve cold storage. The incidence of seed cavity browning and stones in the fruit was high in some fruit lines but was not correlated to fruit ripeness or maturity ($P>0.05$). Stones in the flesh are due to preharvest insect damage (Joubert and Claasens 1994) and while this is valuable information for the grower the defect is not usually a major cause of fruit rejection.

Across all Avotest assessments:

- 33% of fruit had stem-end rots,
- 29% of fruit had body rots,
- 10% of fruit had vascular browning,
- 2.4% of fruit had seed cavity browning,
- 3% of fruit had stones.

Across all the commercial test tests:

- 35% of the fruit had body rots,
- 6.5% of the fruit had stem-end rots,
- 21% of the fruit had vascular browning,
- 17% of the fruit had seed cavity browning,
- 9% of the fruit had diffuse discolouration (grey pulp).

Some lines of fruit had more flesh bruising than others and appeared to be more susceptible to the defect. Eleven percent of the fruit in the commercial test had some bruising while very little bruising was observed in the Avotest fruit. This could be due to the higher fruit handling inputs in the commercial test.

The main cause of spoilage was stem-end rot in the Avotest fruit and body rots in the commercial test. Although the initial inoculum pressure at the time of harvest was not determined, it is apparent that the various fungi did not develop equally in the two tests. The various fungi have different optimum growth temperatures (Elmsly and Dixon 2008). Fifty percent of the spores of the main stem-end rot pathogen are killed after 14 days at temperatures below 5°C whereas the body rot spores are not affected (Everett and Pak 2001). That could account for the comparably high levels of body rots in both the Avotest and commercial test and the relatively low incidence of stem-end rot the commercial test fruit. Also, the fungicide used in the commercial test does not affect the stem-end rot and body rot organisms equally (Coates *et al.* 2008).

Marketable fruit

The Avotest was designed to be a rapid test to predict quality before the commercial harvest. Quality is difficult to define and is dependent on consumer tolerance, product supply and demand. Since Australian avocado consumers will not readily accept a fruit with more than 10% internal flesh defect (Harker *et al.* 2007), this was the benchmark used in the present study. Fruit rots and vascular browning were the major internal defects observed in the Avotest and were used to gauge quality.

The average percentage marketable fruit, unmarketable fruit and the percentage of fruit with no internal rots or vascular browning, as determined through the two tests are shown in Figures 2 to 4.

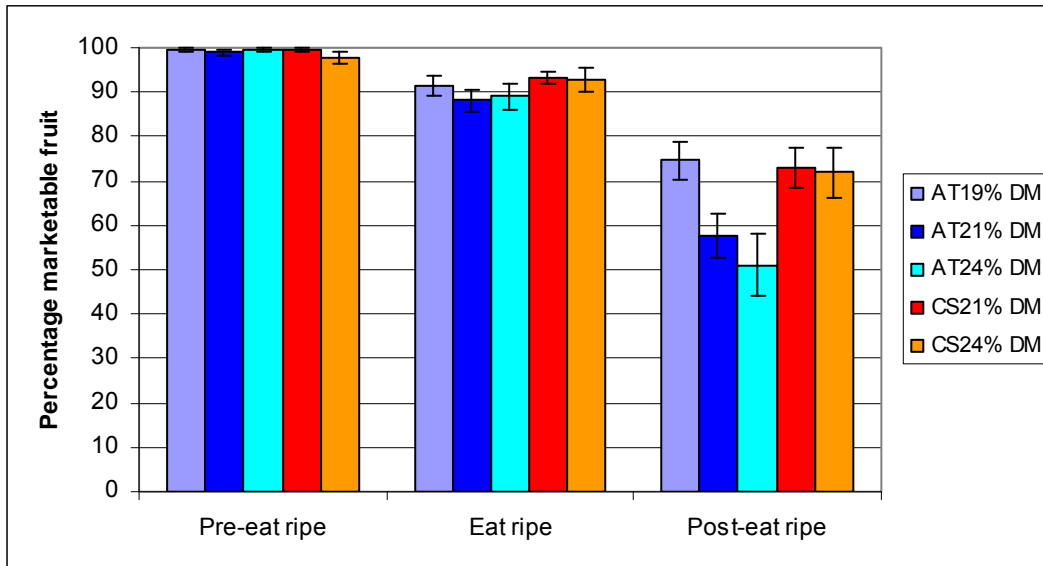


Figure 2. Average percentage of marketable fruit (fruit with an internal defect severity ≤ 1), as determined in the Avotest and commercial test, for fruit assessed at pre-eat ripe, at eat ripe and post-eat ripe. AT = Avotest; CS = commercial simulation test; DM = dry matter. The lines above the bars indicate the standard error of the mean.

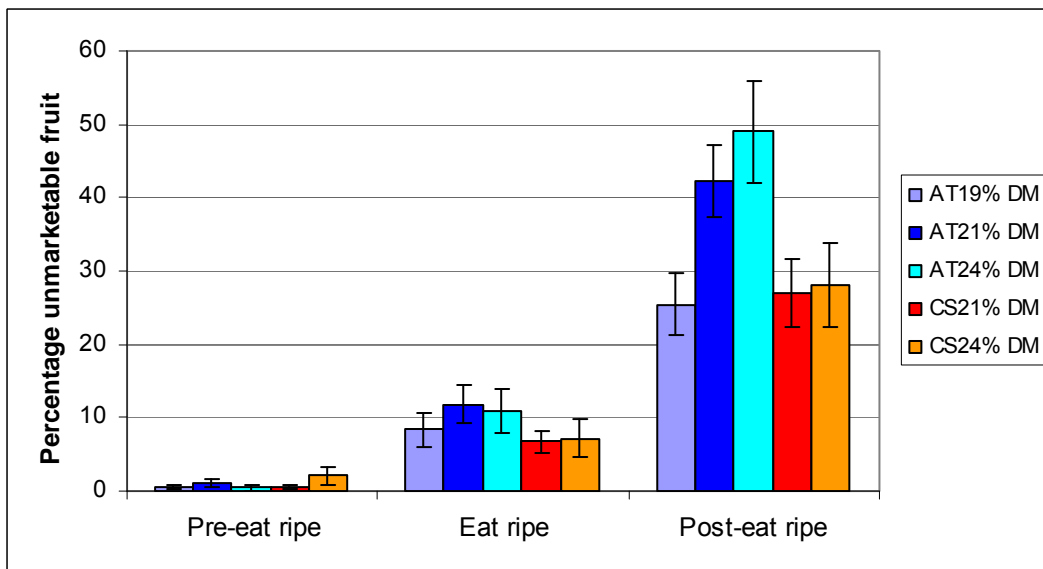


Figure 3. Average percentage of unmarketable fruit, (fruit with internal defect rating greater than 1), as determined in the Avotest and commercial test, for fruit assessed at pre-eat ripe, at eat ripe and post-eat ripe. AT = Avotest; CS = commercial simulation test; DM = dry matter. The lines above the bars indicate the standard error of the mean.

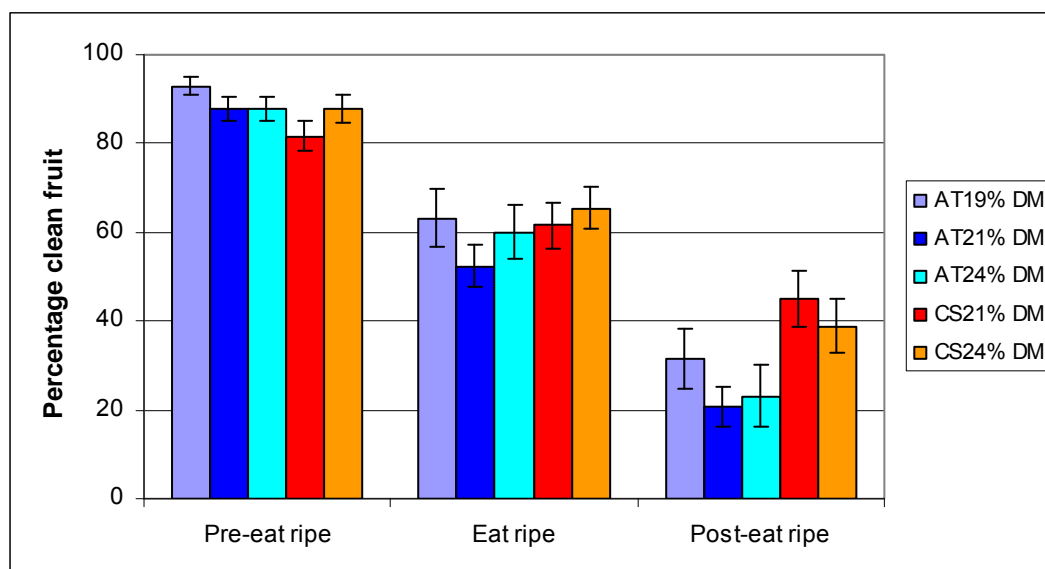


Figure 4. Average percentage of fruit with no internal defects, as determined in the Avotest and commercial test, for fruit assessed at pre-eat ripe, at eat ripe and post-eat ripe. AT = Avotest; CS = commercial simulation test; DM = dry matter. The lines above the bars indicate the standard error of the mean.

Figures 2 and 3 indicate that both tests produced similar fruit quality results especially in the pre- and eat ripe stages. At pre-eat ripe more than 95% of the fruit were marketable and at the ripe stage, marketability was about 90%. At the post ripe stage about 65% of the fruit were marketable. At this ripeness stage, the marketability of the 21% and 24% dry matter Avotest fruit was significantly less than those of the other treatments ($P=0.008$). It can be speculated that this reduction in quality could be related to fruit maturity and the associated lower diene levels (Prusky *et al.* 1990) reinforced by the absence of a postharvest fungicide treatment.

The variation in fruit quality between blocks sampled increased sharply as the fruit ripened (ref to standard error lines in Figures 2 to 4). This held true for fruit harvested at 19%, 21% and 24% dry matter for both tests. Some blocks produced fruit that maintained a high percentage of marketability as they ripened, while other blocks produced fruit that deteriorated rapidly. This was especially true for the fruit harvested at 21% and 24% dry matter after the Avotest. Marketability varied from 10-90% between blocks at the post ripe stage, indicating large variation in potential fruit quality on the retail shelf depending on where and how the fruit were grown.

For the more discerning markets, a lower tolerance of rots would be expected (Harker *et al.* 2007). Figure 4 shows that the percentage of fruit with no internal defects decreased as the fruit ripened, so that at the post ripe stage, about 25% of the fruit in the Avotest and 42% in the commercial test, had no defects. Once again, the variation between blocks was large and increased as the fruit ripened. Thus, some lines retained good fruit quality throughout the assessment period, while others deteriorated. This increasing divergence in defect incidence between blocks suggests that fruit from the 'good' blocks either retain their resistance to pathogens or had less inoculum to begin with. It would be interesting to determine if the antifungal agent concentrations remain higher in these resistant fruit at ripe and post-eat ripe, compared with the less resistant fruit.

The differences in fruit quality between the two tests, especially at post-eat ripe could be influenced by the fungicide used in the commercial test (Coates *et al.* 2008), and by the differences in fruit holding conditions (Everett 2001; Everett and Pak 2001).

Cold storage, as used in the commercial test, can reduce rots in ripe fruit, while higher temperatures, such as that used in the Avotest, can increase rots (Elmsly and Dixon 2008; Hopkirk *et al.* 1994). Furthermore, water loss in the early stages of fruit ripening has been linked to rots (Dixon *et al.* 2005; Lallum *et al.* 2004; Yearsley *et al.* 2002a; b). According to Lallum *et al.* (2004) water loss increases respiration and ethylene production which may contribute to the increased rots. Storage of fruit at higher temperatures, such as the Avotest fruit, will result in a higher respiration and water loss. This could further explain why the Avotest fruit had more disease than the commercial fruit. Ripening fruit at 20°C is a good predictor of both stem-end and body rots in commercial fruit (Everett 2001). In the present study, these rots affected 46% of the Avotest fruit and 39% of the commercial fruit. This indicates that Avotest may be a good predictor for rots in commercial consignments.

Correlation between Avotest and commercial test

The Avotest results were verified using the commercial test on a block-to-block bases. The analysis was carried out for two levels of severity; the percentage marketable fruit (rots rating ≤ 1) and fruit with no rots. Although the resulting fruit quality was similar for the two tests (especially in the pre-eat ripe and eat ripe assessment, Figures 2 to 4), the correlation between the two tests, as seen in a regression analysis (Table 3), was not consistently strong. This is partly due to the low incidence of rots in the pre- and eats ripe stages, and the natural variation in biological systems. The best correlation existed between the Avotest at 19% dry matter and the commercial test fruit at 24% dry matter (Figure 5; correlation values closer to 1 indicate a stronger relationship).

Table 3. Regression analyses between 'Hass' avocado fruit harvested at 19% and 21% dry matter and subjected to the Avotest (AT) and those harvested at 24% dry matter and subjected to the commercial test (CS). The quality of fruit from the Avotest at each stage of assessment was compared to that of the commercial test at post-eat ripe assessment. R values closest to 1 are most significant and P values smaller than 0.05 are statistically significant.

	AT 19% versus CS 24% post-eat ripe				AT 21% versus CS 24% post-eat ripe			
	Marketable fruit		Fruit with no rot		Marketable fruit		Fruit with no rot	
	R-value	P-value	R-value	P-value	R-value	P-value	R-value	P-value
Pre-eat ripe	0.09	0.7	0.28	0.25	0.5	0.036	0.43	0.07
Eat ripe	0.5	0.04	0.72	0.0007	0.47	0.05	0.26	0.3
Post-eat ripe	0.57	0.012	0.79	0.0001	0.09	0.7	0.16	0.5

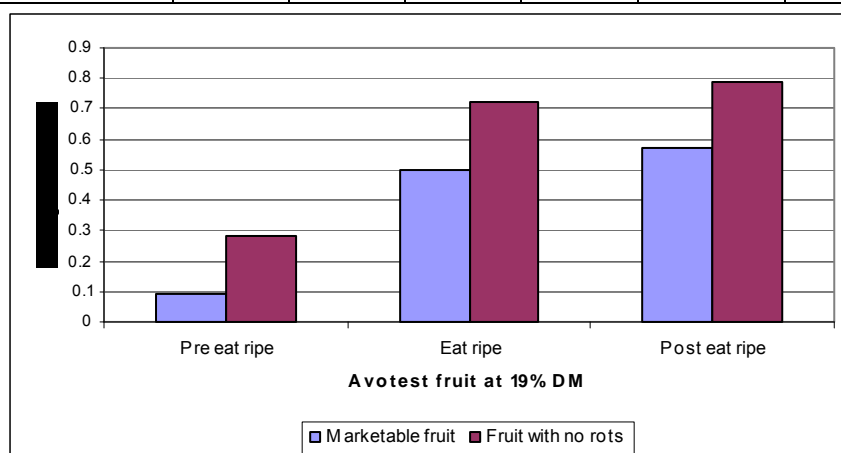


Figure 5. Regression analyses results used to indicate correlations. Correlation between Avotest at 19% DM and commercial test at 24% DM. The quality of fruit from the Avotest at each stage of assessment was compared to that of the commercial test at post-eat ripe assessment.

After extensive analyses, the Avotest was found to best predict the post-eat ripe quality of fruit in the commercial test, mainly because of the elevated level of rots at this ripeness. Table 3, and Figure 5 represent the post-eat ripe assessment stage of the commercial test fruit. At 19% dry matter the correlation between the Avotest fruit and the commercial test fruit strengthens as the fruit ripens. Therefore, the Avotest conducted at 19% dry matter is well correlated to the post-eat ripe quality of 24% dry matter commercial fruit ($r = 0.57$ for marketable fruit and $r = 0.79$ for 'clean' fruit).

Predictive model

Based on the first season's results a fruit quality model was developed using the 19% dry matter post-eat ripe Avotest fruit and the post-eat ripe 24% commercial test (Figure 6). The 'percentage marketable/unmarketable fruit' was used in the prediction model because this was thought to be a more commercially realistic quality target than fruit with no rots.

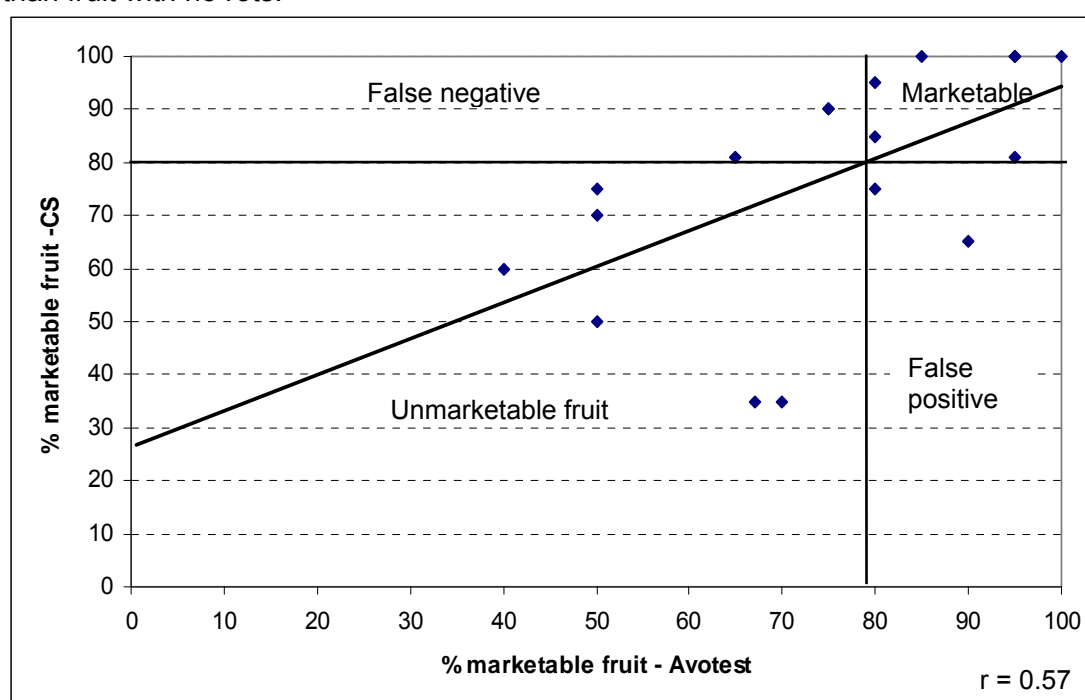


Figure 6. Percentage marketable fruit (rot level ≤ 1) for the Avotest fruit at 19% dry matter, post-eat ripe assessment and the commercial simulation (CS) fruit at 24% dry matter. Each point on the graph represents a block sampled. Both x- and y-axes = percentage fruit with rot level ≤ 1 .

Consumers' intent to purchase decrease if more than one in ten fruit had more than 10% of the flesh with defects (Harker *et al.* 2007). However for the purpose of this model two in ten fruit with more than 10% flesh defects was considered acceptable for the commercial test, i.e. 80% marketable fruit which correlated to approximately 78% marketable fruit in the Avotest. According to this model seven blocks produced fruit of marketable quality (top right sector of Figure 6) and eight blocks produced fruit of unmarketable quality (bottom left sector of Figure 6). The test produced three false negatives (top left sector of Figure 6), in that the Avotest suggested that the blocks were unacceptable, but the fruit were acceptable after commercial testing. The test also produced two false positives (bottom right sector of Figure 6), i.e. the Avotest incorrectly indicated that the blocks were acceptable. These results were verified using the block data as presented in Figure 7. Values above the horizontal line were regarded as unacceptable. The two false positive and three false negative values are indicated with the stars.

The model successfully predicted which blocks would provide fruit of acceptable quality after commercial distribution. Despite the relatively poor statistical correlation between the two tests ($r=0.57$), 75% of the blocks would have been correctly categorized.

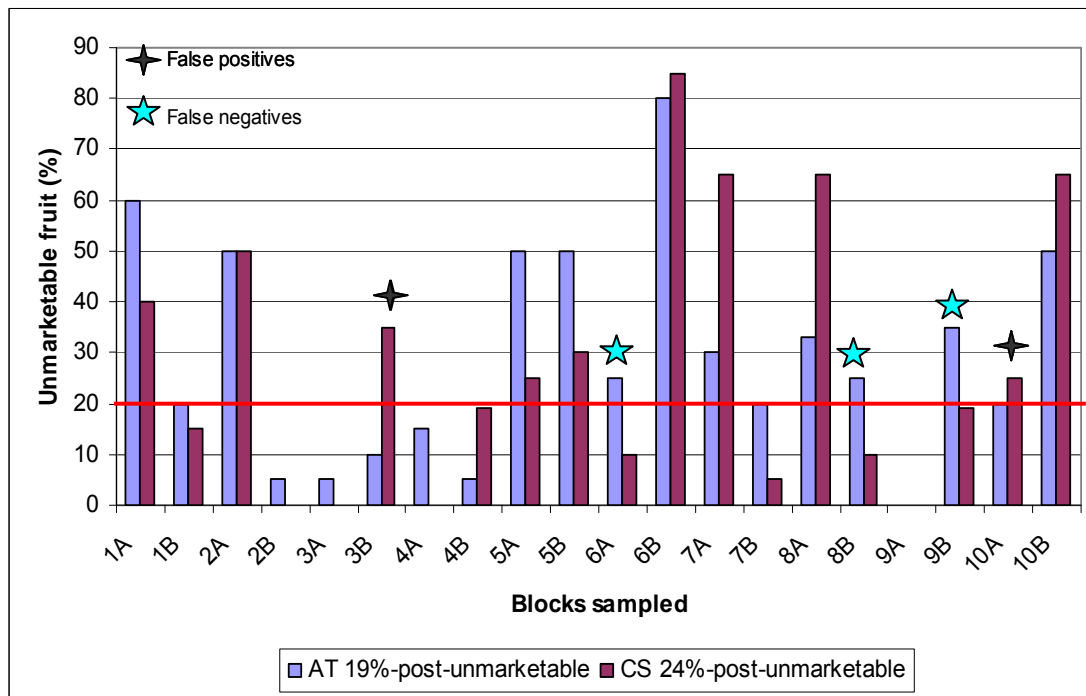


Figure 7. Average percentage unmarketable fruit for the Avotest (AT) at 19% dry matter and commercial simulation test (CS) at 24% dry matter assessed at 2 days post-eat ripe.

The standards used to determine market acceptability is fluid and will be determined by product demand, supply and consumer tolerance. In a season of under supply the poorer quality fruit may be acceptable to consumers while during periods of over supply consumer tolerance for poorer quality fruit could decrease.

Grower feedback

Growers were given feedback regarding their fruit quality and their position within the sample group. A typical collaborator feedback report is shown in Appendix 1. Collaborators were surveyed to determine attitudes to the Avotest, the test's possible uses in the industry and to determine cultural practices that may influence fruit quality. Responses were recorded on a questionnaire, (Appendix 2). Many of the collaborators responded with enthusiasm upon receiving evidence of their ripe fruit quality. They indicated that there was little or no feedback on internal quality from the markets for 'Hass' avocado. On the rare occasion where feedback was given, it concerned the external appearance at the pre-eat ripe stage. One of the strengths of the Avotest is its ability to provide growers with timely fruit quality feedback. The test provided growers with a new quantitative insight into commercial performance.

Influence of farm cultural practices on fruit quality

Possible reasons for differences in fruit quality between blocks from the same farm were discussed with collaborators, and cultural practices investigated. These are summarized in Table 4.

Table 4. The impact of certain farm practices on Avotest fruit quality as determined during the collaborator interviews.

Farm	Heavy pruning	High N nutrition/young trees	High crop load
1			Positive
2		Negative	
3			
4			Positive
5		Negative	
6	Negative		
7			Positive
8	Negative		Positive
9		Negative	Positive
10		Negative	

From the grower responses it appeared that crop load may have been one of the major influences on fruit internal quality. Although tree vigour was not physically measured for this study, it is likely to have also strongly influenced crop load. A strong relationship exists between high vegetative vigour and poor fruit quality (Cutting and Bower 1992; Hofman *et al.* 2005; Hofman *et al.* 2002; Voster *et al.* 1989; Witney *et al.* 1990a). Heavy pruning and high nitrogen nutrition application, particularly on young trees, are likely to have contributed to excessive vegetative vigour. Heavy pruning can increase vegetative vigour, competing with fruit for nutrients, and reducing fruit quality (Arpaia 2005a; Arpaia *et al.* 2004).

High soil nitrogen concentrations can reduce fruit quality probably through increased vegetative vigour (Hofman *et al.* 2006; Witney *et al.* 1990b). In the present study the negative impact of heavy pruning, high vegetative vigour and high nitrogen on fruit quality was confirmed. It became apparent during the interviews that growers are well aware of the research undertaken in pruning practices (Leonardi 2007; Leonardi 2008) and nutrition programs (Hofman *et al.* 2006) but they were unaware of the effects these practices had on fruit quality. This may be because there is little quantitative evidence on which to base decisions or that the yield effect and cost of pruning have a much stronger influence on profitability than fruit quality. Given the lack of feedback on fruit quality from avocado handlers and an apparent poor relationship to price, the latter explanation is very likely.

The potential practical applications of the Avotest

Producers were asked their views on the potential commercial application of the Avotest. Four applications were proposed:

1. Avotest may be used to identify blocks which need remedial action to improve fruit quality, for example applying a systemic fungicide, e.g. Amistar[®], to reduce fruit diseases. While this fungicide is commonly used on green skin cultivars, none of the co-operators interviewed had used Amistar[®] on 'Hass', despite a recent study supporting this practice (Coates *et al.* 2008). Since the Avotest is conducted several weeks prior to commercial harvest, should the fruit quality prove to be inadequate, growers would have sufficient time to apply the fungicide and abide by the mandatory withholding period.
2. Avotest may be used to identify blocks which meet the rigid and high fruit quality requirements needed for export markets, discerning local markets or for long

3. Avotest may be used to identify individual farm practices which influence quality. The survey of collaborators found that there is virtually no market feedback to indicate internal quality. Avotest could provide such feedback particularly where new farm practices are being trialled. Growers are keen to test new practices and products but often do not know how to evaluate the treatment benefits. Avotest may provide grower with an effective method of doing so.
4. Avotest may be used to distinguish between blocks with robust and poor fruit. The collaborators proposed that the blocks with robust fruit may be harvested when market prices are favourable, either early in the season or be allowed to hang fruit till later in the season, while the blocks with less robust fruit could be harvested when the dry matter is optimum. Numerous studies conducted in New Zealand have shown that as the fruit dry matter levels increase, so too does fruit quality (Dixon *et al.* 2003b; Pak and Dawes 2001; Pak *et al.* 2003a; Woolf *et al.* 1999). There is however an optimum dry matter beyond which the quality deteriorates (Dixon *et al.* 2003a; Lallu *et al.* 2005; Mandemaker 2004; Pak 2001). Optimum dry matter would probably vary from one region to the next and even from block to block. Thus, caution should be exercised if this option is to be considered.

Cost Benefit analysis of Avotest

The first three scenarios noted above were modelled to predict a cost benefit of the Avotest (Appendix 3). This was compiled by Joanna Embry, Agricultural Economist with Avocado Australia Limited. All benefit/cost calculations and the resulting benefit cost ratios are based on the assumptions provided by the project team, the Queensland Department of Primary Industries and Fisheries and on recent published results, particularly in regard to disease control measures and consumer perceptions (Anderson *et al.* 2003; Coates *et al.* 2008; Harker *et al.* 2007). For each scenario a benefit cost analysis was undertaken to determine likely benefit for consumers, industry and growers.

The assumptions and calculations used in these models are detailed in Appendix 3. In all three scenarios the benefit cost ratio ranged from 3.1:1 to 7.1:1. The benefit varies between growers, industry and consumers.

Benefits to consumers

In all scenarios, the avocado consumer benefits directly from the use of Avotest and subsequent action to improve quality, particularly when fruit purchase cost more than \$2.00 each. At average consumption, the consumer benefits by \$15 to \$30 per year. This benefit may flow to other participants in the handling chain since the consumer is expected to purchase more fruit when they perceive quality to be better.

Benefits to industry

If Avotest was widely used in the central Queensland production area there would be a high benefit to cost return. This is due to the harsh consumer backlash against poor fruit described by Harker *et al.* (2007). In this study, it was found that internal quality had a greater influence on consumers than price. Improvements to internal fruit

quality will result in benefits as consumers will purchase more fruit even at higher prices.

Where the Avotest is used to indicate the need for a remedial action such as the application of a partially curative fungicide (Scenario 1) the benefit to cost ratio is 5.9:1.

Where the Avotest is used to identify high quality blocks suitable for a higher return market such as the export market (Scenario 2) the ratio is 3.1:1.

Where Avotest is used to provide feedback to avoid practices which adversely effect quality or to improve existing quality (scenario 3) the ratio is 7.1:1

If these scenarios are correctly adopted in the central Queensland region, there is likely to be a positive benefit cost result to the whole industry.

Benefit to grower

Due to a current inability of the supply chain to identify and reward superior lines of fruit, it has not been possible in this study to apportion a cost benefit to growers who plan to use Avotest. More than one co-operator in this study expressed exasperation at the lack of price incentive to improve quality. However, most growers did recognise the need for the whole industry to improve fruit performance so as to achieve consumer satisfaction and repurchase. This inability to identify and reward superior fruit is largely because diseases and bruising in 'Hass' fruit are only detected at point of consumption.

In the long term it is likely that much of the benefit of meeting consumer expectations will be reflected in higher farm gate returns and brands delivering consumer value will be acknowledged with higher returns.

CONCLUSIONS

The Avotest carried out eight to nine weeks (at 19% dry matter) before commercial harvest can predict internal fruit quality after commercial distribution. The study found that co-operators valued the ability to predict end-use fruit quality and could indentify potential commercial applications for the Avotest. The test allows for remedial actions to ameliorate poor blocks and to make informed marketing decisions to take advantage of superior blocks. Use of the test will have a reasonable benefit to cost ratio with both consumers and the industry beneficiaries.

Second Season

Based on the results of the first season's experiments the method of fruit sampling and quality assessment were refined during the second season of testing. A long term cold storage Avotest was developed.

MATERIALS AND METHODS

Fruit samples

With the exception of two blocks, fruit were sampled from the same blocks in 2009 as in 2008 and an additional two blocks were sampled at a grower's request. Fruit were taken from 22 blocks representing 11 farms in Bundaberg and Childers, central Queensland. Four of the blocks were had been used for orchard management experiments by the grower. Two of the blocks were part of an irrigation experiment and two were used in a foliar fertilizer experiment. Fruit were also sampled from eight blocks representing two farms in Mareeba, northern Queensland. One hundred fruit were harvested per sampling occasion per block, of which 10 fruit were used for dry matter (DM) testing, 45 fruit were assessed at eat ripe, and 45 two days post-eat ripe.

Unlike the 2008 season, the fruit were picked at random while walking on the diagonal across the block. Fruit were picked from all sides of the tree, including internal and externally hanging fruit but only similar size fruit were used.

Dry matter testing

Dry matter was determined for individual fruit and not for composite samples as in the first season's experiment. Twenty grams of grated flesh was weighed out per fruit and placed in a drying oven at 65°C till they reached stable mass. The dry matter was then calculated as a percentage of the original wet mass. For each block the average dry matter and the dry matter range was noted.

Domestic market Avotest

Fruit were harvested from orchards about eight and four weeks before commercial harvest. Unlike the 2008 season, the fruit dry matter was not used to determine the harvest time. The same postharvest Avotest storage regime was used as in the first season.

Fruit quality was assessed at eat ripe and two days post-eat ripe. The same defect assessment procedure was used as in 2008 except that the severity of the internal defects was expressed as a percentage rather than a rating.

Domestic market commercial test

The quality of the fruit subjected to the Avotest at eight and four weeks pre-commercial harvest was compared with fruit from the same orchard at first commercial harvest. The same postharvest handling and cold storage regime was followed as that of the commercial test in the first season. The fruit were assessed as in the Avotest and diffuse flesh discolouration (chilling injury) was included as a defect factor.

Development of a long term storage (export) Avotest

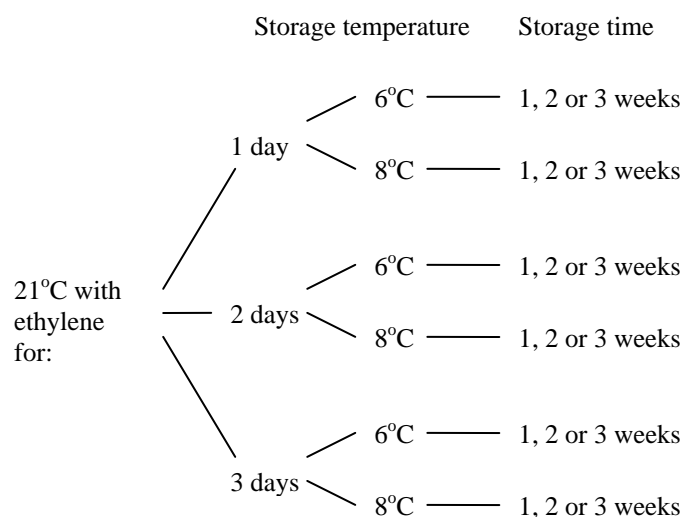
Since the domestic market Avotest did not involve cold storage, chilling injury could not be predicted. The aim of the long storage Avotest was to develop a test that could, in the shortest possible time, identify blocks that produced fruit with the potential to develop cold storage damage. In order to develop such a test two experiments were conducted.

Experiment 1

'Hass' fruit from an orchard in Northern Queensland were harvested about four weeks before commercial harvest. The fruit were treated with Prochloraz 450, packed in boxes and trucked to Bundaberg. The fruit were held at 6°C and treated with ethylene for one day (10-20ppm), and then held at 6°C for 1, 2 or 3 weeks. Thereafter, the fruit were moved to a ripening room at 22°C and treated with ethylene for two days and held at that temperature until assessment. Fruit were assessed as in the domestic market commercial test.

Experiment 2

'Hass' fruit from an orchard in Bundaberg were harvested in April about four weeks before the commercial harvest and treated Prochloraz 450. The following treatments were applied:



Following cold storage, the fruit were moved to a ripening room at 22°C, treated with ethylene for two days, then allowed to ripen at 22°C. Fruit were assessed at eat ripe and two days post-eat ripe.

Long term storage (export) Avotest

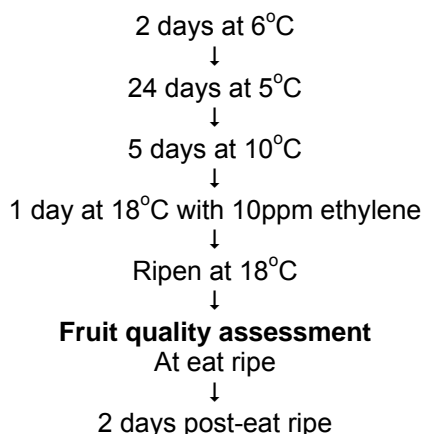
The regime used in this test was derived from the results of the two experiments noted above.

Fruit from the 11 collaborating farms in central Queensland were used for this Avotest. Fruit were harvested four weeks before the commercial harvest and treated with Prochloraz 450. Four weeks pre-commercial harvest was chosen since few growers would consider long storage of very early fruit. The fruit were placed at 6°C and treated with ethylene for one day (10-20ppm). The fruit were then held at 6°C for 21 days before being moved to a ripening room at 22°C and treated with ethylene for

two day. The fruit were allowed to ripen at 22°C and assessed as in the domestic commercial test.

Long term storage (export) commercial test

Fruit from the same orchards used in the long storage Avotest were sampled at first commercial harvest in May and subjected to a commercial test. The fruit were treated with Prochloraz 450 and stored under the following regime:



The fruit were assessed as in the Avotest.

Statistical analysis

The results of the 'long storage Avotest experiments 1 and 2' were analysed using GenStat 11th Edition using an analysis of variance at 95% confidence level.

Correlations were developed between fruit quality after the Avotest and the commercial test for both the domestic and long storage tests. All results were statistically analysed using GenStat 11th Edition using the following analyses: analysis of variance at 95% confidence level, linear regression analyses (r^2), and simple correlations (r).

Grower feedback and production practices

Individual grower interviews were held during the feedback sessions. Grower opinion regarding their fruit quality and possible related farm practices were collected. Grower opinion on the commercial benefits of the Avotest was discussed.

RESULTS AND DISCUSSION

Domestic market Avotest

Avotest and the commercial test

External fruit quality

Fruit ripened relatively evenly (Figure 8) with little shrivelling or variable ripening even eight weeks before the commercial harvest.

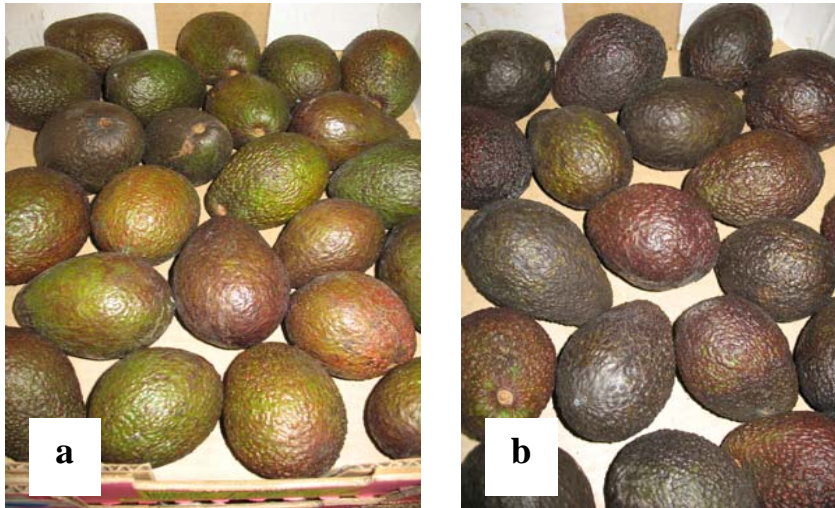


Figure 8. Typical external fruit appearance at assessment; (a) at eat ripe; (b) two days post-eat ripe, for fruit sampled 8 weeks pre-commercial harvest.

Internal fruit quality

The incidence of internal fruit defects in the four and eight week pre-commercial harvest Avotest and the commercial test are shown in Tables 5 and 6.

Table 5. The percentage of fruit (incidence) with defects at eat ripe, in the Avotest and commercial test. Letters behind the values indicate significant differences for individual defects.

	8 week preharvest Avotest	4 week preharvest Avotest	Commercial test
Stem-end rot	53a	34b	1c
Body rots	34a	8b	8b
Vascular browning	25a	16b	1c
Diffuse discolouration	0b	0b	37a
Seed cavity browning	18a	1b	21a
Stones in flesh	2b	6a	3b
Marketable fruit	72b	87a	96a

Table 6. The percentage of fruit (incidence) with defects at two days post-eat ripe, in the Avotest and commercial test. Letters behind the values indicate significant differences for individual defects.

	8 week preharvest Avotest	4 week preharvest Avotest	Commercial test
Stem-end rot	79 a	61 b	9 c
Body rots	66 s	34 b	6 c
Vascular browning	35 a	39 a	27 a
Diffuse discolouration	0 b	0 b	28 a
Seed cavity browning	11 a	1 b	4 b
Stones in flesh	1 b	5 a	3 b
Marketable fruit	49 c	63 b	89 a

The incidence of rots decreased as the fruit matured, i.e. from eight weeks before commercial harvest to the commercial harvest ($P < 0.001$). Also, rots were more common as the fruit ripen from eat ripe to two days post-eat ripe ($P < 0.001$). The lower levels of rots in the commercial test fruit may be indicative of the efficacy of the postharvest fungicide or of the different ripening conditions used for the two tests.

Stem-end rot was the dominant cause of spoilage in the Avotest, although body rots were also a problem. In the commercial test, physiological disorders were the most prevalent. Some of the fruit lines did not develop any defects even at two days post ripe, while other lines deteriorated rapidly. This information could be of commercial value to retailers and market agents.

Diffuse discolouration was only seen in the commercial test since this defect is associated with prolonged storage (Cutting and Wolstenholme 1992) and the Avotest fruit were not cold stored. However, it has been suggested that fruit susceptible to diffuse discolouration may also be susceptible to vascular browning (Arpaia 2005b) and to rots (Everett and Pak 2002). If this is so, it may be possible that the Avotest could be an indicator of cold injury susceptibility. There was a strong correlation between the incidence of diffuse discolouration at eat ripe and vascular browning ($r = 0.989$, $r^2 = 0.97$, $P < 0.001$) in the commercial test. The correlation between diffuse discolouration and rots was not as strong but significant ($r = 0.53$, $r^2 = 0.28$, $P < 0.001$).

The Avotest was designed to rapidly predict quality of specific fruit lines before commercial harvest. Avotest is effective in detecting lines which are susceptible to rots and vascular browning which is a physiological defect often associated with rots (Everett and Pak 2002). Rots and vascular browning account for approximately 25-35% of defects in avocado fruit in the commercial markets, but the greatest reject factor is flesh bruising (Hofman and Ledger 2001). Therefore, Avotest can only account for a portion of flesh defects, which may be a limiting factor of this test.

Marketable fruit

The average percentage marketable fruit for the 2009 experiment season, is shown in Figure 9. A fruit was judged marketable if it had no more than 10% of its flesh affected by rots, vascular browning or diffuse discolouration.

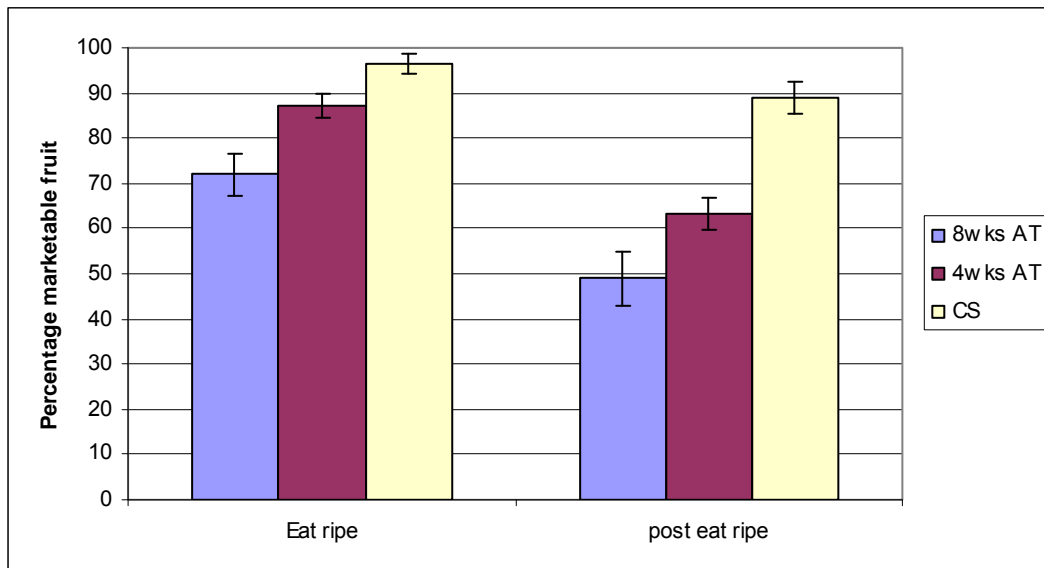


Figure 9. Average percentage of marketable fruit (fruit with an internal defect severity $\leq 10\%$), as determined in the Avotest and commercial test, for fruit assessed at eat ripe and post-eat ripe. AT = Avotest; CS = commercial simulation. The lines above the bars indicate the standard error of the mean.

Since the Avotest was designed to be an early warning system, growers should strive to produce fruit with as few rots as possible. Therefore, quality was also expressed as fruit with no internal defects, 'clean fruit' (Figure 10).

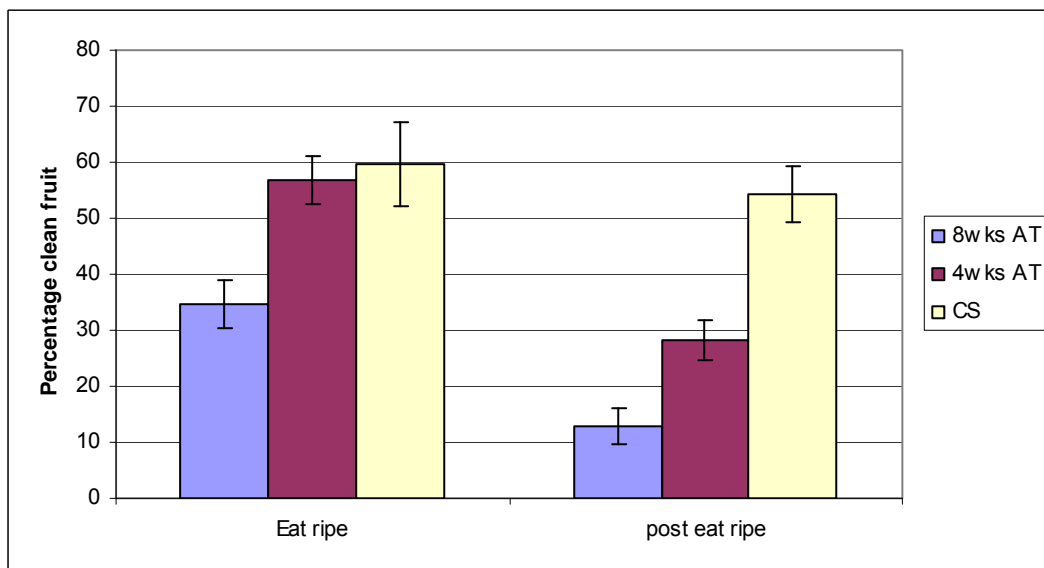


Figure 10 Average percentage of fruit with no internal defects as determined in the Avotest and commercial test, for fruit assessed at eat ripe and post-eat ripe. AT = Avotest; CS = commercial test. The lines above the bars indicate the standard error of the mean.

Fruit quality deteriorated rapidly as the fruit ripened ($P < 0.001$, Figures 9 and 10). Similar trends were observed in 2008. This could, once again, be related to the antifungal diene which break down as the fruit ripen and thus allowing the development of fungal pathogens (Prusky and Kaobiler 1992; Prusky *et al.* 1990; Prusky *et al.* 1991).

Unlike in 2008, the percentage of clean and marketable fruit increased with fruit maturity ($P < 0.001$, Figures 9 and 10). In some lines, the growers took heed of the

poor quality determined at 8 weeks preharvest and applied a curative fungicide. The resulting fruit quality seen at the 4 weeks preharvest Avotest was superior to all the other blocks tested. This is an example of the practical commercial value of the test.

Comparison of Domestic market Avotest fruit quality for 2008 and 2009

There was greater variability in fruit quality from one block to the next in 2009 than 2008 (Table 7). Quality in the 8 weeks preharvest Domestic Avotest was poorer in 2009 than in 2008. This could be an indication of higher inoculum pressure in the orchards in 2009, or fewer preharvest fungicide applications.

The fruit subjected to the 4 weeks preharvest domestic Avotest and the commercial test produced similar, if not slightly better fruit quality in 2009 than in 2008. As mentioned previously, some collaborators applied remedial treatments to their blocks after receiving the results of the 8 weeks preharvest Avotest in 2009. As a result, this may have contributed to the improvement in fruit quality in the 4 weeks preharvest Avotest and the commercial test. Therefore, the 8 weeks preharvest Avotest was used in 2009 by some collaborators as a warning system.

Table 7. A comparison of the 2008 and 2009 fruit quality results as found in the 8 and 4 weeks preharvest Avotest and the commercial test. Letters following values indicate significant differences for each ripeness stage.

	Marketable fruit (%)			
	Eat ripe		Post-eat ripe	
	2008	2009	2008	2009
Avotest - 8 wks	92y	72z	75bc	4e
Avotest – 4 wks	88y	87y	58de	63cd
Commercial test	93y	96y	72ab	89a
	'Clean' fruit (%)			
Avotest - 8 wks	63y	35z	32bc	13d
Avotest – 4 wks	52y	57y	21cd	28bc
Commercial test	66y	60y	39b	54a

Growers A and F (Figure 11a-d) produced higher quality fruit in the 2009 than in 2008. Both of these growers increased the frequency of their preharvest fungicide applications in 2009 which could have contributed to improved quality. Due to financial constraints, growers B, C, D and E reduced the frequency of their preharvest fungicide application in 2009 as is evident in the lower quality produced in 2009. The Avotest was able to identify these poorer blocks several weeks prior to the commercial harvest. This early warning system could be greatly beneficial to the growers, the industry and consumers.

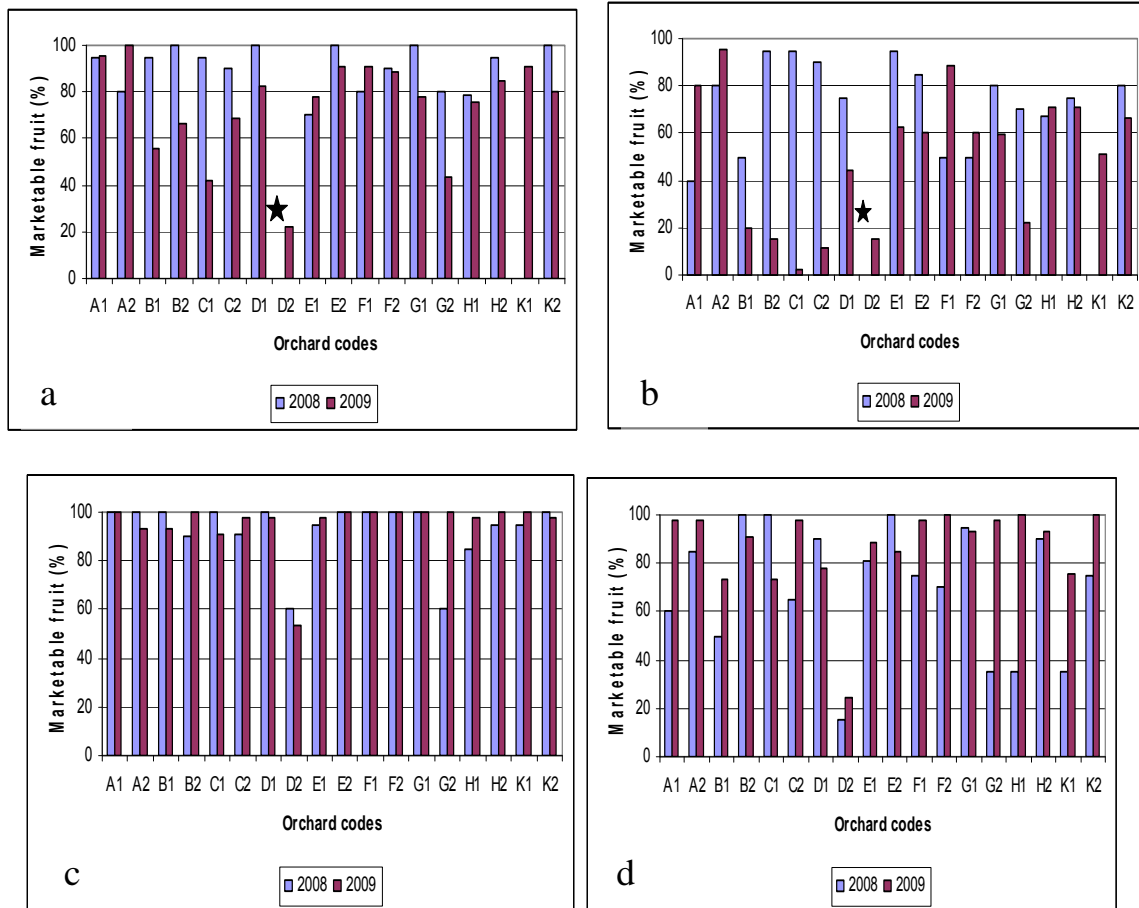


Figure 11. Comparison of the percentage marketable fruit for the various blocks for the 2008 and 2009 season for (a) Avotest at 8 weeks preharvest assessed at eat ripe; (b) Avotest at 8 weeks preharvest assessed at two days post-eat ripe; (c) commercial test assessed at eat ripe; (d) commercial test assessed at two days post-eat ripe. The star indicates a missing data point. The x-axis represents the various blocks sampled.

Comparison of the Avotest and commercial test

The accuracy of predicting end-use quality was assessed by comparing the results of the Avotest to that of the commercial test on individual blocks. The analysis was carried out for two levels of severity; the percentage marketable fruit and the percentage clean fruit, i.e. fruit with no rots or physiological disorders.

In 2008 the Avotest carried out at 19% dry matter (approximately 8 weeks before harvest) and the commercial test produced comparable fruit quality results (Tables 1 and 2). This did not occur in 2009 but may not be a failing, as long as blocks which performed poorly in the Avotest also performed poorly in the commercial test. Some of the variability between the seasons could be due to changes made in the sampling and assessment method and by changes to farm management practices.

During the 2008 season a 60% correlation was found between the Avotest conducted at 19% dry matter and the commercial test. As with the 2008 results, in the 2009 season the best correlation was found between Avotest conducted 8 weeks pre-commercial harvest and the commercial test. The 2009 correlation was statistically significant ($P=0.008$, $r = 0.54$) but the fit to the line was poor ($r^2 = 0.3$). This weaker correlation could partly be due to the remedial fungicide sprays applied by some of the growers prior to the commercial harvest.

Predictive model

A fruit quality model was developed using the Avotest conducted at 8 weeks pre-commercial harvest and the commercial test (Figures 12 and 13).

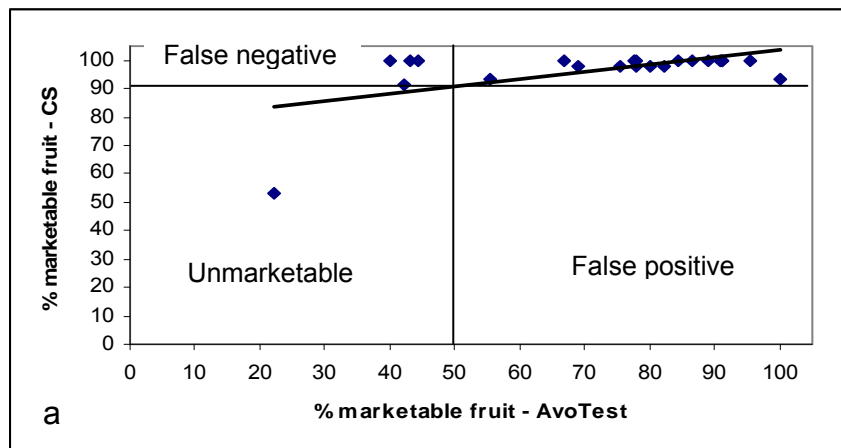


Figure 12a. Percentage marketable fruit for Avotest and the commercial test at eat ripe, $r = 0.55$; CS = commercial simulation.

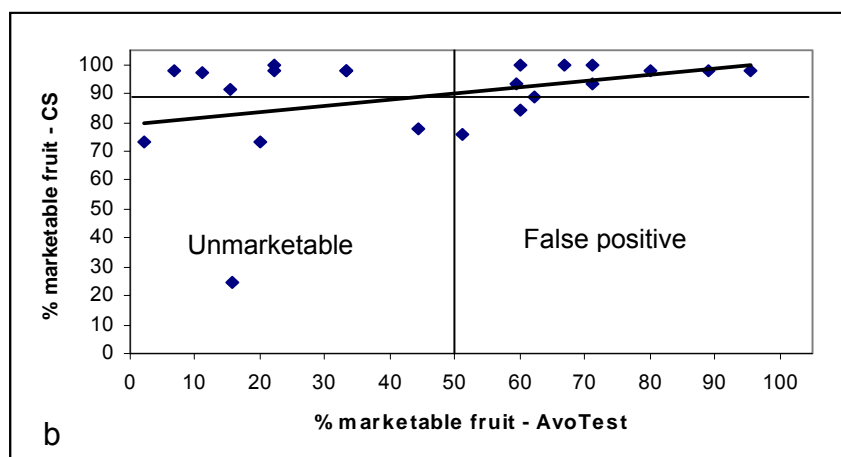


Figure 12b. Percentage marketable fruit for Avotest and the commercial test at two days post-eat ripe, $r = 0.35$; CS = commercial simulation.

Based on the consumer preference survey (Harker *et al.* 2007), 90% marketability on the commercial test was accepted as the norm and equated to 50% marketability in the Avotest (Figure 12). Seventeen of the 22 blocks sampled produced fruit that were marketable both in the Avotest and the commercial test (Figure 12a). Four of the 22 blocks produced fruit that were rated unmarketable in the Avotest, but were found to be acceptable in the commercial test. These four blocks would have been incorrectly rated as producing poorer quality fruit, 'false negatives'. False negatives are detrimental to the grower but not to the consumer. Thus at eat ripe, the Avotest would have correctly predicted quality for approximately 82% of the blocks sampled. At this ripeness the quality in the commercial test was acceptable for most blocks indicating that the Avotest can best identify outlying (poor) blocks.

Assessing the fruit two days post-eat ripe was a more stringent shelf life test but reflects consumer habits (Harker *et al.* 2007). The correlation between the two tests was relatively poor ($r = 0.35$) since the fruit deteriorated faster in the Avotest than in

the commercial test. However, the fruit quality of only six of the 22 blocks' would have been incorrectly predicted if this model was used. The prediction of marketable fruit at two days post-eat ripe would have been correct for 72% of the blocks sampled.

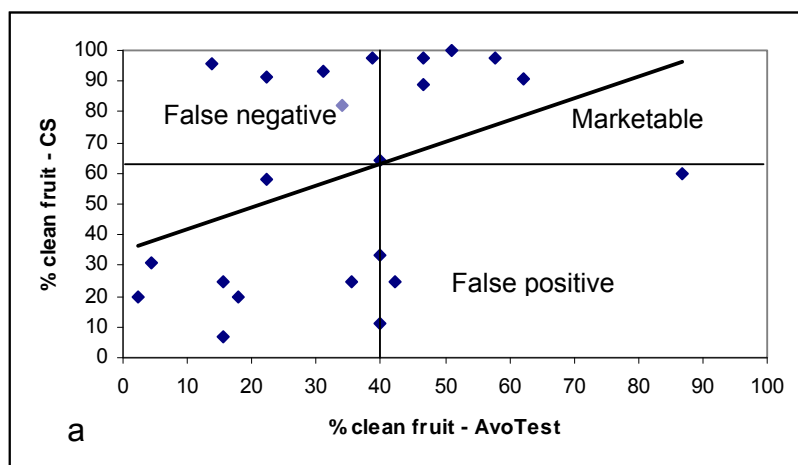


Figure 13a. Percentage clean fruit for Avotest and the commercial simulation test at eat ripe, $r = 0.397$; CS = commercial simulation.

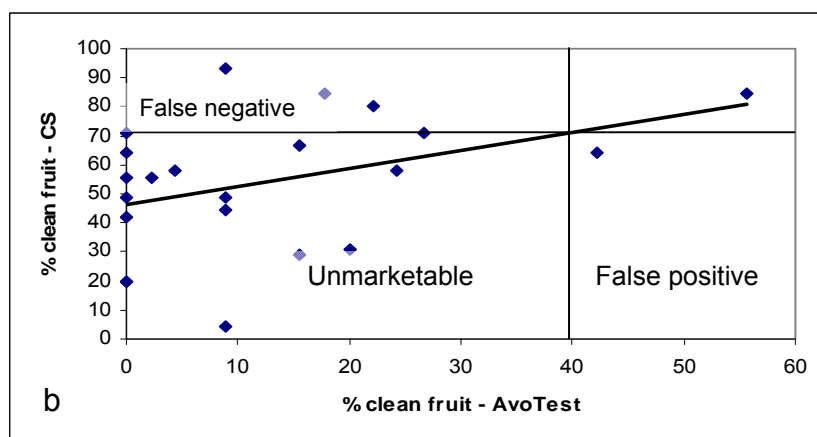


Figure 13b. Percentage clean fruit for Avotest and the commercial simulation test at two days post eat ripe, $r = 0.41$; CS = commercial simulation.

Comparing levels of clean fruit is a very stringent test. Since the Avotest's strength lies in its ability to detect rots and vascular browning before the commercial harvest begins, the clean fruit prediction model (Figure 13) could be used as a tool to gauge inoculum pressures in the field. The tolerance levels (intercept lines) can be determined by the industry based on consumer preference. Based on the 2008 and 2009 data a 40% intercept of the Avotest is equivalent to approximately 60 -70% intercept for the commercial test. Using these standards, only eight blocks would have had 'acceptable' levels of clean fruit at eat ripe (Figure 13a) and only one block at the post-eat ripe assessment stage (Figure 13b). The correlation between the two tests is not strong but the model would have correctly predicted fruit quality in 70-80% of the blocks.

Positive and negative aspects of the domestic market Avotest

Positives

1. Avotest allows growers to receive fruit quality feedback prior to commencing the commercial harvest. Growers receive virtually no quantitative feedback regarding their fruit quality and certainly none regarding end-use quality.
2. Avotest can be used as a means of measuring the effect of management practice changes on quality. By receiving fruit quality feedback growers are able to build up a record of their block performance and alter management practices if necessary.
3. Avotest can be used as an early warning system to identify blocks which have a high incidence of disease. Given that the test is conducted approximately 8 weeks before commercial harvest, it allows sufficient time for growers to apply remedial treatments to their blocks or to make informed marketing decisions.
4. This is a quick and simple test that can be carried out by growers or packshed operators. The results of the test can be obtained within approximately 10 days of collecting the fruit samples.
5. The test can effectively rank blocks based on fruit quality. The test is most effective in identifying poorer blocks with less robust fruit or high inoculum pressure.

Negatives

1. The criteria used to determine marketability of fruit in Avotest is based on the presence of rots and vascular browning. Only 25-35% of rejects on retail shelf are accounted for. Bruising, which is the biggest cause of rejects, is not measured. The Avotest cannot predict flesh bruising or diffuse discolouration, which accounts for approximately 50% of all avocado fruit rejects (Embry 2009b).
2. The test can sometimes wrongly categorize blocks as acceptable or unacceptable.
3. The predictive model's reliability may vary with the season.

Long storage Avotest

Developing a long storage Avotest

Experiment 1

In this experiment fruit were stored for one, two or three weeks at 6°C after being dipped in a fungicide. The incidence of body rots was relatively low and did not increase with storage time ($P=0.14$). Body rots affected 15-30% of the fruit and on average less than 2% of the fruit flesh was affected. This is not unexpected since prochloraz effectively controls the main body rot pathogens (Coates et al. 2008; Danderson 1986; Davas 1984; Everett and Pushparajah 2008). However, this chemical does not always effectively control stem-end rot (Coates *et al.* 2001) which increasing during storage ($P<0.001$, Figure 14). The main aim of developing a long storage Avotest was to predict susceptibility to cold injury. Unfortunately, none of the fruit developed chilling injury in this experiment.

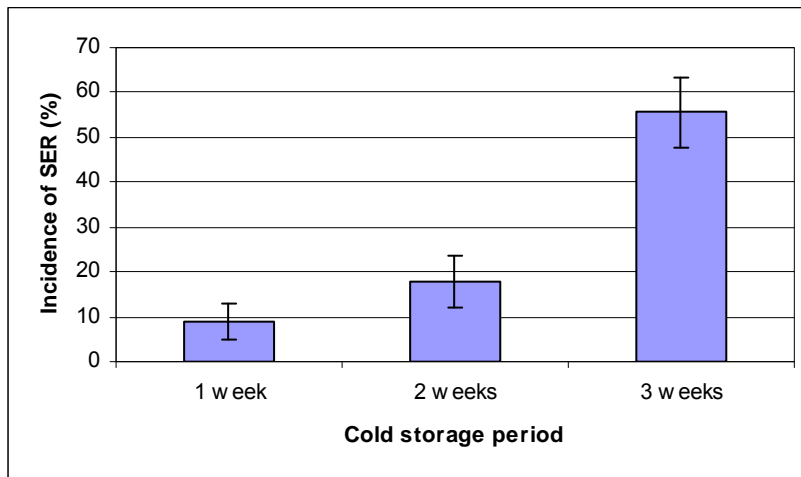


Figure 14. Incidence of stem-end rot (SER) in fruit cold stored for 1, 2 or 3 weeks. The lines above the bars indicate the standard error of the mean.

Experiment 2

The time in cold storage was the most influential factor affecting disease, diffuse discolouration and vascular browning (Table 8). The longer the exposure, the greater the loss in fruit quality. Three weeks at either 6°C or 8°C produced the greatest incidence of diffuse discolouration. However, even two week was sufficient to induce cold damage. It was also found that storing fruit for two or three weeks at 8°C resulted in a higher incidence and severity of rots than fruit stored at 6°C. Based on these results, it would appear that at least two weeks is necessary to induce cold damage. There is thus, no rapid Avotest for predicting cold damage susceptibility in the fruit.

Table 8. Statistical analyses of the results of experiment 2. Data fitted to a Generalised Linear Model (GLM) with a Binomial distribution and a logit link (i.e. logistic regression).

	Skin spotting	Stem-end rot	Seed cavity brown	Diffuse discol	Bruised flesh	Body rot	Vascular brown	Marketable fruit
Days_of_Ethylene	*	***	***	***	n.s.	**	P=0.09	***
Temp_stored	n.s.	**	n.s.	n.s.	**	**	***	*
Weeks_cold_store	***	***	**	***	**	***	***	***
Days_of_Ethylene.Temp_stored	n.s.	n.s.	**	***	n.s.	P=0.08	***	*
Days_of_Ethylene.Weeks_cold_store	***	***	***	n.s.	**	***	**	***
Temp_stored.Weeks_cold_store	**	P=0.09	P=0.07	n.s.	n.s.	**	**	n.s.
Days_of_Ethylene.Temp_stored.Weeks_cold_store	***	**	**	n.s.	n.s.	P=0.08	*	n.s.

note: n.s. - P<0.10; * - P<0.05; ** - P<0.01; *** - P<0.001

Long storage Avotest and commercial test

Fruit subjected to the long storage Avotest took about 28 days to reach eat ripe while the long storage commercial test took about 33 days.

Table 9. The incidence of internal fruit defects at eat ripe and post-eat ripe, expressed as a percentage of fruit assessed, for the long storage Avotest and commercial test. Letters following the values indicate significant differences for individual defects.

	4 week preharvest Avotest		Commercial test	
	Eat ripe	Post-eat ripe	Eat ripe	Post-eat ripe
Stem-end rot	6b	23a	1b	5b
Body rots	14b	44a	16b	37a
Vascular browning	13bc	40a	12c	22b
Diffuse discolouration	26c	38bc	40ab	53a
Seed cavity browning	24ab	33a	16b	13b
Stones in flesh	12a	6b	10a	11a
Marketable fruit	89a	66b	90a	76b

Diffuse flesh discolouration was the dominant internal defect in both tests especially at the eat-ripe stage (Table 9). The incidence of rots was relatively low at eat ripe but increased as the fruit ripened. Body rots were the dominant rots and the incidence of this disorder was similar in both tests ($P=0.7$). Both tests produced similar fruit quality as can be seen in Figures 15 and 16.

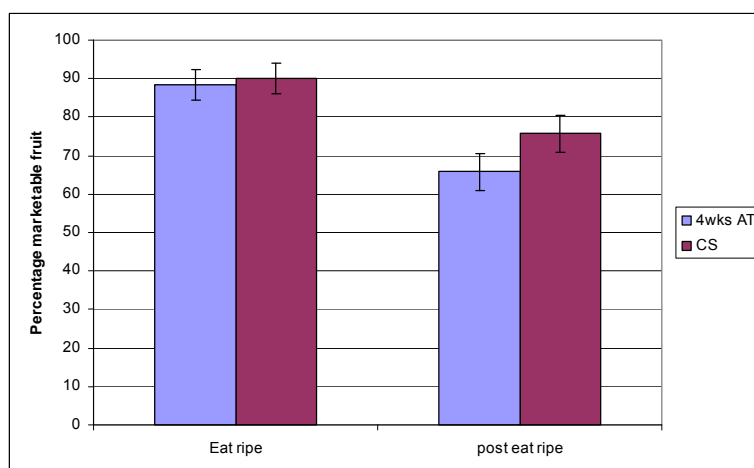


Figure 15. Average percentage of marketable fruit (fruit with an internal defect severity $\leq 10\%$), as determined in the long storage Avotest and commercial test, for fruit assessed at eat ripe and post eat ripe. AT = Avotest; CS = commercial simulation. The lines above the bars indicate the standard error of the mean.

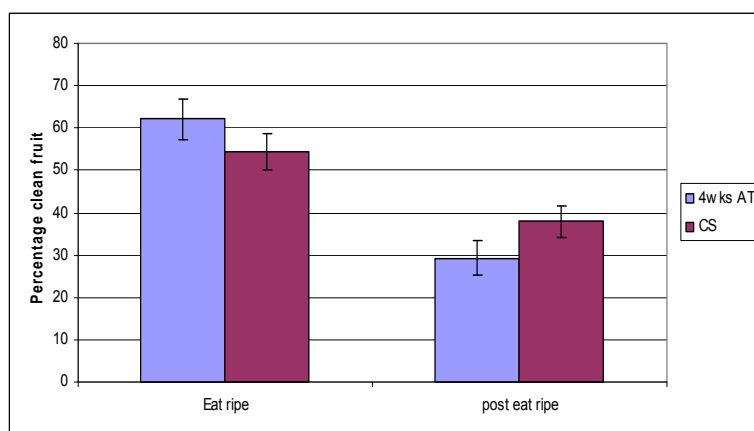


Figure 16. Average percentage of clean fruit (fruit with an internal defect severity = 0%), as determined in the long storage Avotest and commercial test, for fruit assessed at eat ripe and post eat ripe. AT = Avotest; CS = commercial simulation. The lines above the bars indicate the standard error of the mean.

The percentage marketable fruit was not statically different for the two tests at the various assessment stages ($P=0.222$) and neither was the percentage clean fruit ($P=0.948$). Thus, the Avotest conducted 4 weeks before harvest is a good predictor of quality of the main crop in long cold storage.

Comparison of the long storage Avotest and the commercial test

There were strong correlations for marketable fruit between the Avotest and commercial test at eat ripe ($r = 0.74$, $r^2 = 0.64$, $P<0.001$) and post-eat ripe ($r = 0.57$, $r^2 = 0.32$, $P<0.001$). The correlation for clean fruit was weaker, with a 50% correlation at eat ripe ($r = 0.52$, $r^2 = 0.27$, $P=0.013$) and a poor correlation of less than 10% for the post-eat ripe assessment ($r = 0.06$, $r^2 = 0.01$, $P=0.78$). The correlation between the two tests for some of the individual defects was good such as diffuse discolouration ($r=0.77$), stem-end rot ($r=0.82$) and body rots ($r=0.93$). Therefore, the fruit quality results obtained in the Avotest appeared to be a good predictor of the end-use quality following long storage. Although the long storage Avotest is not a rapid test, by subjecting fruit to the test four weeks before the harvest, growers can be made aware of their expected fruit quality before the harvest commences.

Predictive model

The predictive model used in the domestic Avotest was developed for the long storage Avotest (Figures 17 and 18).

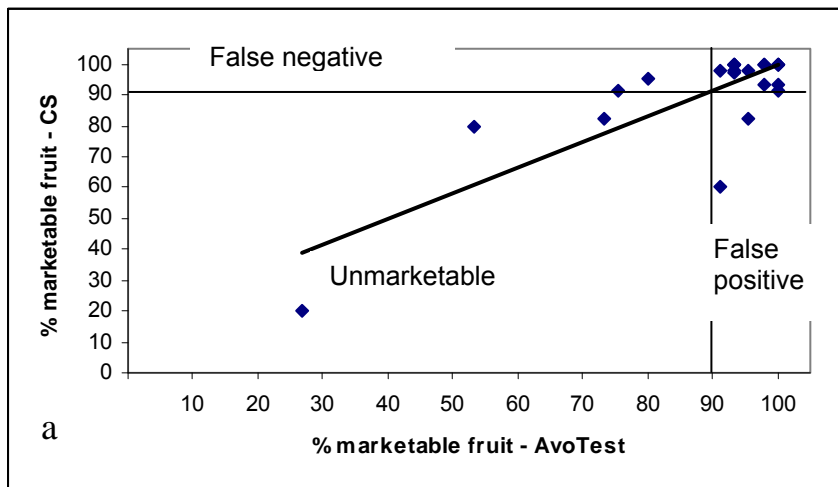


Figure 17a. Percentage marketable fruit for long storage Avotest and the commercial simulation test at eat ripe, $r = 0.74$; CS = commercial simulation.

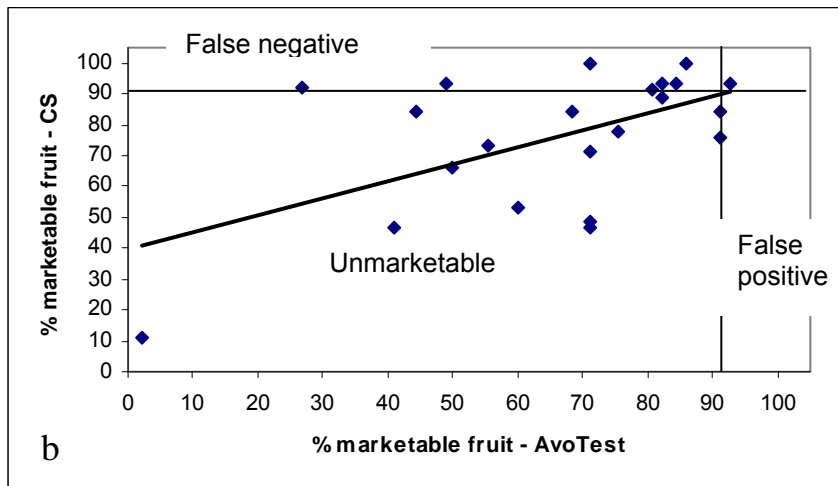


Figure 17b. Percentage marketable fruit for long storage Avotest and the commercial simulation test at two days post eat ripe, $r = 0.57$; CS = commercial simulation.

Ninety percent marketable fruit was regarded as the acceptable level for the commercial test. Since the tests were closely correlated they intercepted at 90% for both tests (Figure 17). Most of the avocado blocks sampled produced marketable fruit at eat ripe (Figure 17a). However, the fruit quickly deteriorated and two days post-eat ripe (Figure 17b) the fruit quality in the majority of blocks was no longer acceptable. At eat ripe (Figure 17a) the fruit quality for three of the blocks would have been incorrectly predicted, two false positives and one false negative. Prediction would have been correct for 86% of the blocks sampled. In the post-eat ripe model two blocks were incorrectly predicted and another seven were border line (data points fall on the intercept lines).

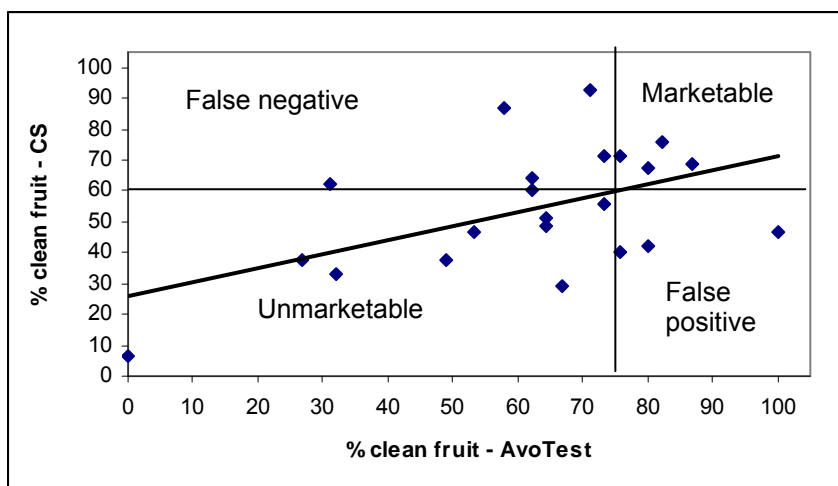


Figure 18. Percentage clean fruit for long storage Avotest and the commercial simulation test at eat ripe, $r = 0.52$; CS = commercial simulation.

For the 'clean' fruit prediction model (Figure 18), a 60% intercept for the commercial test was selected to make this model comparable with the domestic market model. A 60% intercept for the commercial test was equal to a 75% intercept for the Avotest. According to this model only four blocks produced satisfactory levels of clean fruit, four were incorrectly predicted and four were border line predictions. A prediction model for post-eat ripe was not developed given the poor correlation between the two tests.

Positive and negative aspects of the long term storage (export) Avotest

Positives

1. The test is a good indication of end-use fruit quality and can accurately predict quality for 85% of the samples.
2. The long storage Avotest is able to predict cold storage injury.
3. The Avotest allows growers to receive feedback regarding their end-use fruit quality.
4. Avotest can be used as a means of measuring the effect of management practice changes on quality. Growers are able to build up a record of their block performance and alter management practice if necessary.
5. Avotest can be used as an early warning system to identify blocks which will potentially produce fruit with a high disease incidence and fruit that are susceptible to cold injury. The test is conducted approximately four weeks before the commercial harvest and takes about 30 days to complete. This should allow sufficient time for growers to make informed marketing decisions or to apply remedial treatments to their blocks should they be willing to delay the harvest of the affected blocks.
6. The test can also effectively rank blocks based on fruit quality. The test is most effective in identifying poorer blocks with less robust fruit or high inoculum pressure.
7. The test is relatively simple and can be carried out by growers or packshed operators with suitable facilities.

Negatives

1. This is not a rapid test and using the existing method, takes about 30 days to obtain results.
2. The fruit are stored at two temperature regimes. Facilities have to be made available to allow for the temperature changes and for the pre and post storage ethylene treatments.
3. The test cannot predict the most significant reject factors – flesh bruising and handling injuries.

Grower Feedback

Collaborating growers were given one-on-one detailed feedback regarding their fruit quality and their position within the group. They were also given a comparative analyse of their 2008 and 2009 fruit quality. A typical collaborator feedback report is shown in Appendix 4. The collaborators were invited to comment on their rankings and to speculate about possible causes for their fruit quality issues.

As with the previous year, many of the collaborators enthusiastically received the evidence of their end-use quality. Two of the collaborators used the information provided in 2008 and made several changes to their farm practices. The grower who owns blocks A1 and A2 (Figures 11a-d) had some of the poorest quality fruit in 2008, altered nutrition and fungicide spray programs and produced some of the best fruit in 2009. The grower of blocks F1 and F2 (Figures 11a-d) made similar changes and his fruit quality improved.

There was a decline in fruit quality in eight of the blocks sampled in 2009 as compared to 2008. All four collaborators involved stated that they had reduced their fungicide application in 2009 due to financial and other constraints.

One of the growers saw the Avotest as an opportunity to test the effect of various management practices on quality. The grower trialed new foliar products on neighbouring blocks and offered these blocks for inclusion in the Avotest. He also offered two blocks on which he had been conducting an irrigation experiment for the past three years. The grower had collected yield data but was unable to assess the effect of these treatments on fruit quality. The resulting fruit quality was different for the various treatments and the grower was able to make an informed decision regarding the commercial use of these treatments.

It is well known that nitrogen and calcium affect quality (Hofman *et al.* 2006; Partridge *et al.* 2002; Witney *et al.* 1990b). Therefore, as an addition to this project leaf samples were taken before the 2009 flowering season from the blocks used in the Avotest. This was a non-replicated, small pilot exercise. Nutritional analyses were carried out on these leaf samples and the results are shown in Appendix 5. The nutritional content varied greatly. However, the block with the least robust fruit did have the lowest calcium to nitrogen ratio.

CONCLUSIONS

Despite not being able to improve on the correlation between the domestic market Avotest and the commercial test, the Avotest remains a good predictor of end-use fruit quality. The Avotest was able to correctly categorize fruit as either marketable or unmarketable in 80% of cases. The test is especially useful in identifying less robust or poor lines. The greatest strength of Avotest lies in its ability to predict fruit quality several weeks before the start of the commercial harvest giving the stakeholder sufficient time to make informed marketing decisions and, if necessary, to take remedial action. The weakness of Avotest is that it can only identify fruit defects which originate in the orchard and cannot predict handling or cold storage injuries. Also, the prediction model may require seasonal recalibration.

The long storage or export Avotest closely mimics the commercial test and therefore accurately predicts end-use quality. Unfortunately the Avotest is not a rapid test and requires approximately 30 days. Despite this, the quality results would be available before the commercial harvest begins.

Both the domestic market and long storage Avotest is a valuable decision making tool for industry stakeholders.

GENERAL DISCUSSION

Fruit quality is a major factor limiting the expansion of the avocado industry. However, unless growers and packshed operators are provided with the feedback regarding end-use fruit quality, they are unable to make the necessary changes to their operations which would lead to improved quality. The domestic market Avotest has the potential to provide industry stakeholders with the required feedback. The past two seasons' experiments have shown that although the Avotest has its limitations, it is an effective tool and several of the collaborators made use of the feedback to improve their management practices.

The Avotest is most effective at identifying blocks which produce less robust fruit. It is these less robust fruit that erodes consumer confidence and reduce sales. If growers and packshed operators were made aware of these 'problem' blocks, remedial action can be taken. The greatest strength of Avotest's lies in its ability to provide stakeholders with cost effective and timely information regarding end-use fruit quality. This would enable informed marketing decision to be made and problems to be addressed for future harvests.

One of the greatest limitation of the domestic market Avotest is its inability to predict handling and cold storage injuries. The test, in its present form, can only predict quality problems that originate in the orchard. These defects include rots and associated internal physiological problems, and insect damage. Rots and the associated physiological problems account for about 30% of all rejects on the retail shelf (Hofman *et al.* 2001). A recent survey has shown that up to 35% of 'Hass' on the retail shelf do not meet consumer expectation, i.e. they have more than 10% internal flesh defects (Embry 2007). Therefore, approximately 10% of all avocados have unacceptable levels of defects, namely rots that can be detected by Avotest, i.e. 30% of the 35% reject fruit.

The avocado industry is worth \$120M at farm gate (Avocados Australia Ltd Media Release, 12 May 2008). A 10% improvement in fruit quality would equate to millions of dollars and increased consumer confidence. Therefore, despite its limitation, the domestic market Avotest has the potential to improve the quality of avocado fruit by 10%.

The domestic market Avotest could be a valuable tool for growers to gauge quality, implement remedial actions, and to assess the impact of farm practices. The test would be useful to packshed operators to make informed decisions regarding fruit storage and marketing. The marketing agents and retailers could use the information to determine storage regimes and times. For example, if the fruit handlers are aware of an impending problem with a batch of fruit they could decide to move those fruit quickly and not store them.

To compensate for some of the limitation of the current Avotest, it may be possible to develop the test into a library tray system. By sampling fruit from the pack line, on-farm and packshed handling injuries would become apparent in the Avotest. The fruit would be collected at first commercial harvest rather than eight weeks earlier. While the Avotest would lose some of its early predictive ability, the fruit quality results would be available within about 10 days, certainly before the fruit reaches the retailer. Since most blocks are harvested multiple times, the grower and packshed operator should still be able to change practices or apply remedial fungicide sprays to improve the quality of subsequent harvests.

A rapid long storage Avotest which effectively predicted cold injury could not be developed. The fruit need to be stored for two to three weeks for symptoms to develop. However, given that the test would be run four weeks prior to the first commercial harvest and that most growers would only consider exporting or long storage of mid to late season fruit, the Avotest could still be useful. The long storage Avotest was found to be a good indicator of end-use quality and like the domestic market Avotest could effectively be used to identify poorer blocks.

CONCLUSIONS

The domestic market Avotest carried out approximately eight weeks before harvest can help predict internal fruit quality of the commercial crop. The test is especially efficient at identifying poorer blocks and can provide growers with much needed fruit quality feedback. It can be used by industry stakeholders to make informed marketing and fruit storage decisions and by growers to gauge the quality of their fruit. Efficient use of the Avotest has the potential to improve retail fruit quality by up to 10%. However, the test has limitations and cannot predict handling injuries. In order to accommodate some of the handling injuries which may occur on-farm and in the packshed, the development of the Avotest as a rapid and well structured library tray system is suggested.

TECHNOLOGY TRANSFER

The project was prematurely terminated by the IAC at the end of the 2009 season prior to the technology being transfer to the wider industry. Throughout the project collaborating growers were kept informed about their quality and were given a report at the end of each season (Appendices 1 and 4). Two presentations were given at grower meetings in Bundaberg and one to the AAL board in 2008. Two of the major role players in central Queensland who collaborated with the researchers have shown considerable interest in the implementation of the Avotest in their organizations.

RECOMMENDATION

It is recommended that the Avotest be developed into a well structured library tray system. Financial partners have been identified. A project entitled 'Development of an avocado rapid library tray system for Hass (AV09028) commenced in May 2010.

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Appendix 1

Grower report

2008

Collaborator: X

8-9 weeks pre-commercial harvest (19% dry matter)

Avotest

2 days pre-eat ripe



Eat ripe



2 days post-eat ripe



4-5 weeks pre-commercial harvest (21% dry matter)

Avotest

2 days pre-eat ripe



Eat ripe



2 days post-eat ripe



4-5 weeks pre-commercial harvest (21% dry matter)

Commercial test

2 days pre-eat ripe



Eat ripe



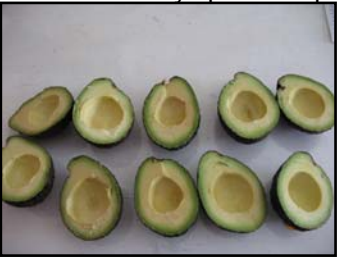
2 days post-eat ripe



At commercial harvest (24% dry matter)

Commercial test

2 days pre-eat ripe



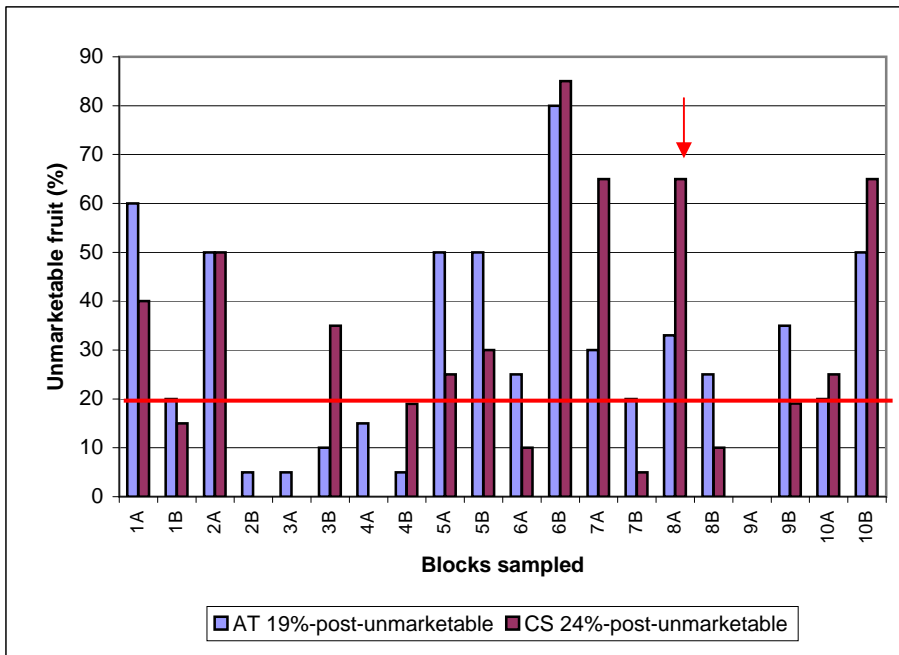
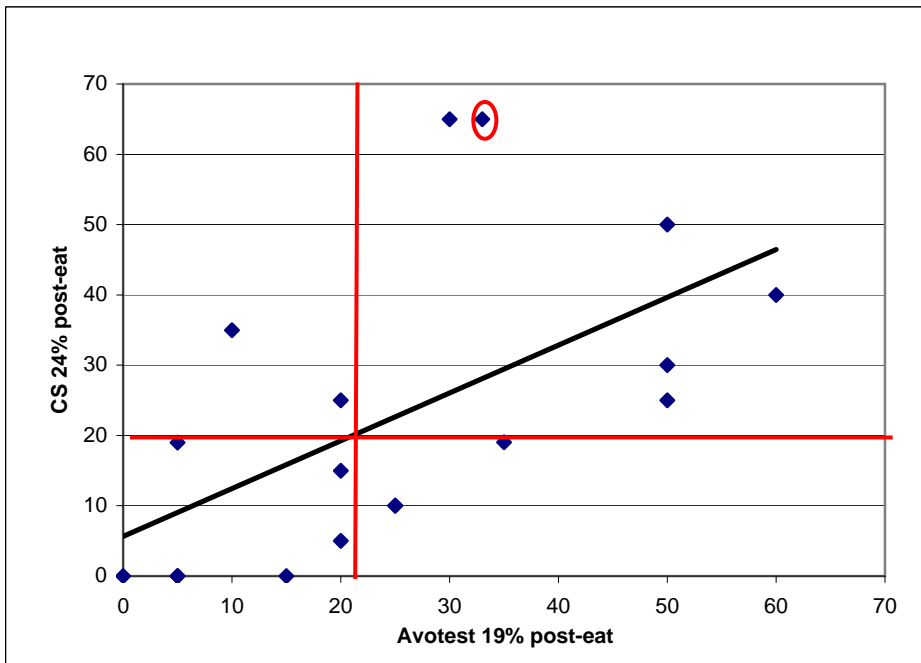
Eat ripe



2 days post-eat ripe



Relationship between Avotest and Commercial Simulation test



↓ ○ Block 8A

Avocado Fruit quality assessment

Avotest

DM	Eval time	Mass	Colour	Skin spots		Ext rot		Stem end rot		Body rot		Vasc Browning		Bruised flesh		Seed Cav Brown		Stones in flesh		Fruit with rot	Fruit with rot>1
				S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)		
Group Avg		209.49	3.86	0.1225	8.28	0.454	25.69	0.493	33.51	0.438	28.5	0.144	9.81	0.015	0.85	0.0354	2.38	0.0403	2.75	45.51	16.53
19%	Pre-eat	202.3	2.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	5.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eat ripe		3.53	0.74	47.37	0.74	31.58	0.63	42.11	0.42	36.84	0.05	5.26	0.00	0.00	0.00	0.00	0.00	0.00	57.89	21.05
	Post-eat		5.05	0.05	4.76	1.95	90.48	0.67	47.62	1.76	85.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	33.33
21%	Pre-eat	256.7	3.55	0.05	5.00	0.10	10.00	0.10	10.00	0.05	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.00	0.00
	Eat ripe		3.74	0.21	21.05	0.42	31.58	0.58	36.84	1.00	52.63	0.26	26.32	0.00	0.00	0.00	0.00	0.05	5.26	57.89	31.58
	Post-eat		5.16	0.00	0.00	1.20	50.00	1.30	70.00	1.70	100.00	0.15	10.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	70.00

Commercial simulation test

Grower	DM	Eval Tim	Mass	Colour	Skin spots		Discrete patches		Ext rot		Stem end rot		Body rot		Vasc Browning		Diffused discol		Bruised flesh	
					S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)	S	I (%)
Group Avg			216.96	4.15	0.05	4.48	0.02	1.23	0.07	5.68	0.08	6.19	0.49	36.40	0.30	20.80	0.12	8.25	0.13	8.81
21%	Pre-eat	228.90	2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	50.00	0.10	10.00	0.00	0.00	0.35	15.00	
	Eat-ripe		3.30	0.00	0.00	0.00	0.00	0.05	5.00	0.00	0.00	0.60	50.00	1.15	95.00	0.00	0.00	0.15	10.00	
	Post-eat		4.15	0.37	40.00	0.00	0.00	0.35	30.00	0.00	0.00	1.05	70.00	1.30	90.00	0.10	5.00	0.25	15.00	
24%	Pre-eat	221.00	3.90	0.05	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	25.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Eat-ripe		5.35	0.00	0.00	0.00	0.00	0.05	5.00	0.05	5.00	0.75	65.00	0.45	40.00	0.20	20.00	0.10	10.00	
	Post-eat		5.10	0.00	0.00	0.10	10.00	0.00	0.00	0.30	25.00	1.80	95.00	1.80	90.00	0.60	45.00	0.35	20.00	

Grower	DM	Eval Tim	Seed Cav Brown		Stones in flesh		Fruit with	Fruit with	Fruit with	Fruit with
			S	I (%)	S	I (%)	rot	rot>1	rot / diff	rot or diff>1
Group Avg			0.25	16.67	0.05	3.49	38.61	12.10	42.54	14.96
21%	Pre-eat		1.15	65.00	0.05	5.00	50.00	5.00	50.00	5.00
	Eat-ripe		0.45	25.00	0.05	5.00	50.00	10.00	50.00	10.00
	Post-eat		0.60	30.00	0.00	0.00	70.00	30.00	70.00	30.00
24%	Pre-eat		0.10	10.00	0.00	0.00	25.00	0.00	25.00	0.00
	Eat-ripe		0.40	35.00	0.00	0.00	65.00	15.00	75.00	20.00
	Post-eat		0.15	15.00	0.00	0.00	100.00	65.00	100.00	90.00

S = severity rating (0-3, with 0= absence, 3= pronounced)

I = Incidence expressed as %

Fruit with rot>1 = unmarketable

diff = diffused discolouration

Appendix 2

Avotest collaborator survey Questionnaire

Name

Position

Business type

Contact details

Email

Phone

Mobile

1 Your response to results

1.1 Are you surprised at these results and the performance of the blocks and your performance against the region?

1.2 What do you think is the reason for the differences between blocks and the performance against other farms?

2 Test Usefulness

2.1 On your farm how can these results be used?

Fruit destination

Harvest timing

Fungicide choice

Nutrient decision

Other

2.2 How could others/industry use the results?

Fruit destination

Harvest timing

Fungicide choice

Nutrient decision

Other

3 Inputs

We would like to get details of your management practices?

Practice					
N levels					
Ca Levels					
Nutrient schedule					
Fungicide Copper					
Fungicide Amistar					
Yield					
Tree Age					
Rootstock					
Sunny use					
Tree vigour					

Appendix 3

Cost benefit analysis

Scenario 1

In this scenario the use of Avotest was modelled where the test is used to identify blocks which need remedial action to improve fruit quality. In this case it is an application of a systemic fungicide, Amistar®, 7 days prior to harvest, to reduce disease incidence and improve fruit saleable quality.

The assumptions used in the benefit cost analysis were;

Block size 5 ha.
Yield 12,000 kg/ha

Proportion of blocks with high quality¹ 25%

Avotest cost \$150.00 (actual cost of test) + \$60 (grower cost to sample and deliver fruit to laboratory) = \$42/ha

Amistar® cost \$17.90 /100L X 1,000 L/ha = \$179/ha + \$45/ha (application cost; ¾ hour at \$60/hr) = \$224/ha

Effect of Amistar® ²	Likely disease incidence	Control	31.8 %
		Amistar®	12.7%
Likely disease severity	Control	25%	
	Amistar®	10%	

Effect of poor quality on consumer repurchase ³	Damage	Sales reduction
	0%	0%
	10%	6%
	25%	19%
	33%	24%
	50%	32%

Average consumption 50 fruit/year/person
Average retail price \$2.00/fruit

An analysis of the cost benefit of Avotest was undertaken by Joanna Embry (AAL Economist) using these assumptions which were provided by the project team. (See attached Excel file).

In the analysis it was identified that consumers are likely to benefit by around \$14/year.

Used in the central Queensland region the benefit would be \$1.3 M due to less reduction in sales due to lower fruit quality. The costs of Avotest and Amistar® and application are \$0.23M. The benefit cost ratio is 5.9:1.

¹ From results from this project sampling 20 blocks in the Bundaberg region. High quality blocks had less than 10% disease severity at eat ripe

² Values are based on work conducted by Anderson *et al* (2003) and Coates *et al* (2008) where severity measured as an average across all fruit of the a proportion of fruit surface area was converted to damage as a volume of flesh on affected fruit.

³ From work by (Harker *et al*. 2007)

Scenario 2

In this scenario the use of Avotest was modelled where the test is used to identify blocks which meet the rigid quality requirements or where high customer satisfaction is required. One such market is export, where volumes are low but does require fruit which can handle extended transport times and/or poor handling systems.

The assumptions used in the benefit cost analysis were;

Block size 5 ha.
Yield 12,000 kg/ha

Proportion of blocks with high quality¹ 25%

Avotest cost \$150.00 (actual cost of test) + \$60 (grower cost to sample and deliver fruit to laboratory) = \$42/ha

High quality market premium² \$1.00/tray

Proportion of fruit suitable for export 25%

Proportion of this fruit that could be exported 25%, assuming only 25% of production from elite blocks could be exported or attract a premium

Effect of poor quality on consumer repurchase ³	Damage	Sales reduction
	0%	0%
	10%	6%
	25%	19%
	33%	24%
	50%	32%

Average consumption 50 fruit/year
Average retail price \$2.00/fruit

An analysis of the cost benefit of Avotest was undertaken by Joanna Embry (AAL Economist) using these assumptions which were provided by the project team. (See attached Excel file).

Used in the central Queensland region the benefit would be \$147K resulting from a small premium for 25% of high quality fruit. The cost of Avotest is \$47K. The benefit cost ratio is 3.1:1

¹ From results from this project sampling 20 blocks in the Bundaberg region. High quality blocks had less than 10% disease severity at eat ripe.

² From discussions with a current exporter. Estimate for high quality fruit that meets specifications

³ From work by (Harker *et al.* 2007)

Scenario 3

In this scenario the use of Avotest was modelled where the test is used to identify individual farm practices which influence quality. Avotest could provide feedback particularly where potentially detrimental practices such as heavy pruning are being trialled.

The assumptions used in the benefit cost analysis were;

Block size 5 ha.
Yield 12,000 kg/ha

Proportion of blocks with high quality¹ 35%

Avotest cost \$150.00 (actual cost of test) + \$60 (grower cost to sample and deliver fruit to laboratory) = \$42/ha

Effect of Heavy pruning ²	Likely disease incidence	Control	30%
		Pruned	60%
	Likely disease severity	Control	10%
		Pruned	25%

Effect of poor quality on consumer repurchase ³	Damage	Sales reduction
	0%	0%
	10%	6%
	25%	19%
	33%	24%
	50%	32%

Average consumption 50 fruit/year
Average retail price \$2.00/fruit

Estimate of industry using heavy pruning 50%
Projection of Avo test uses who would heavy prune 40%

An analysis of the cost benefit of Avotest was undertaken by Joanna Embry (AAL Economist) using these assumptions which were provided by the project team. (See attached Excel file).

In the analysis it was identified that consumers are likely to benefit by around \$30/year.

Used in the central Queensland region the benefit would be 337K due to less reduction in sales due to lower fruit quality. The cost of Avotest is \$47K. The benefit cost ratio is 7.1:1

¹ From results from this project sampling 20 blocks in the Bundaberg region. High quality blocks had less than 10% disease severity at eat ripe.

² From results from this project where the fruit performance results from heavy pruning were compared to a control.

³From work by (Harker et al. 2007)

Avocado Fruit quality assessment

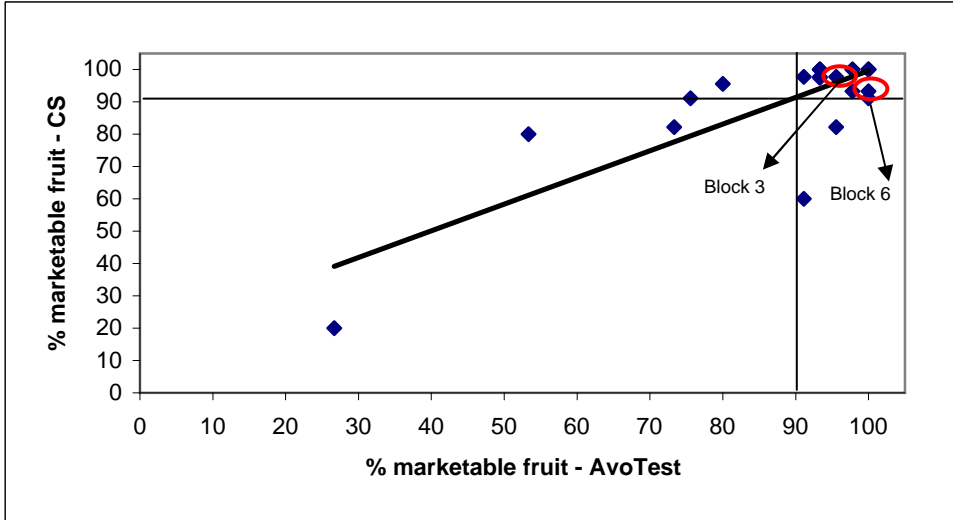
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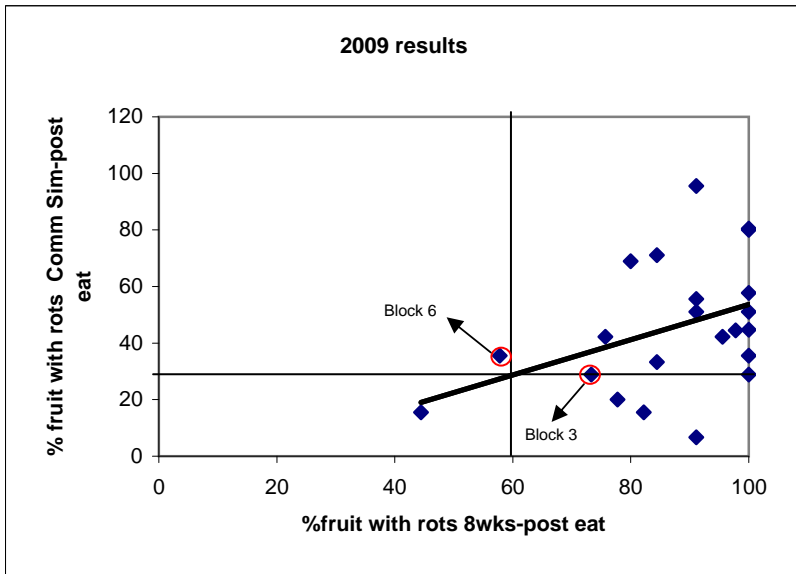
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Grower Collaborator: A

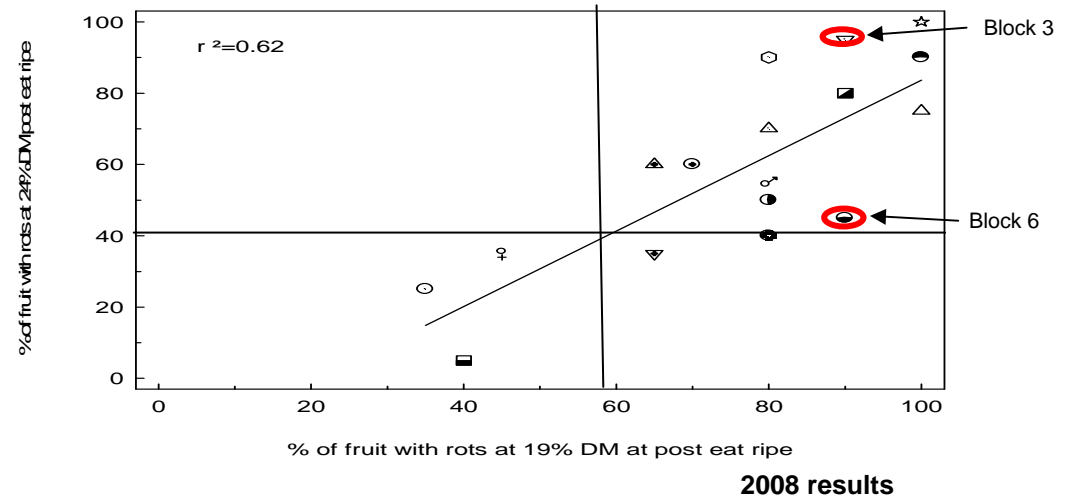
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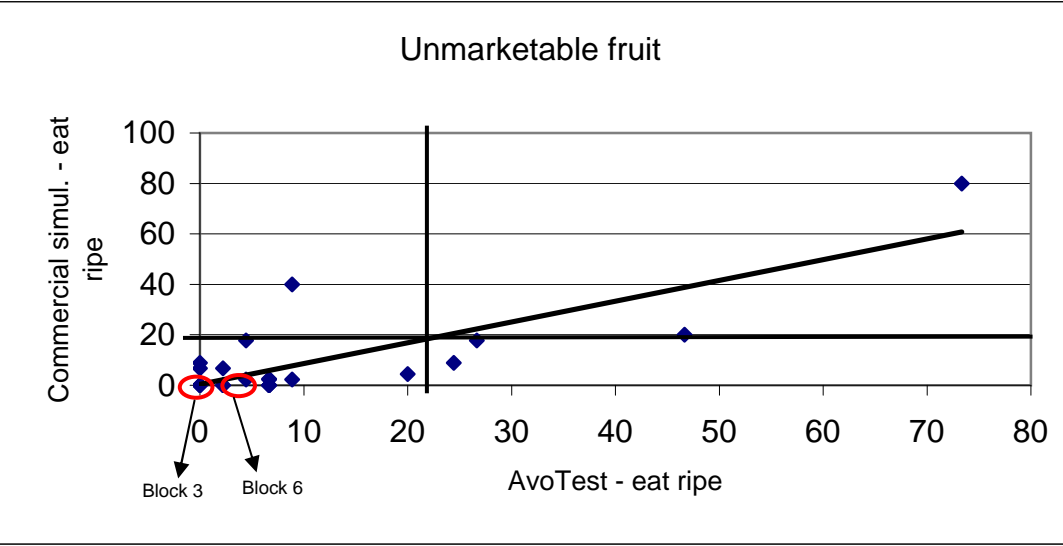


Domestic market Avotest v. commercial simulation test 2009



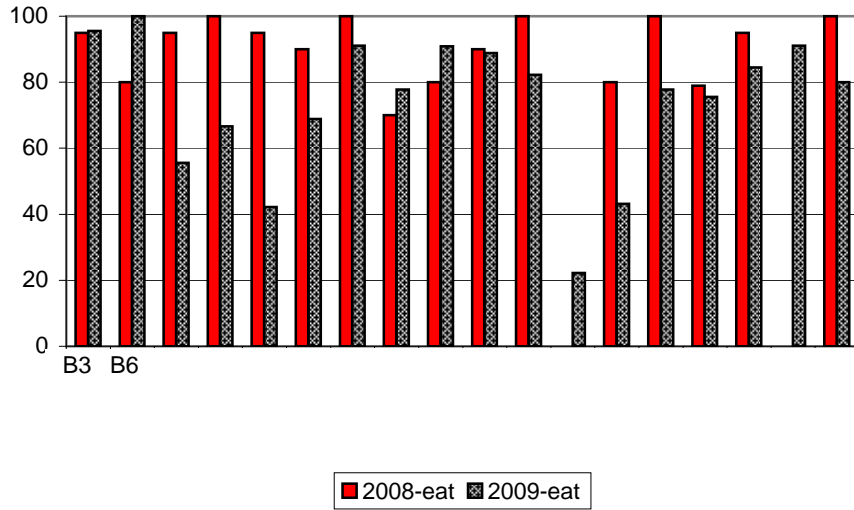
Relationship between Avotest and Commercial Simulation test



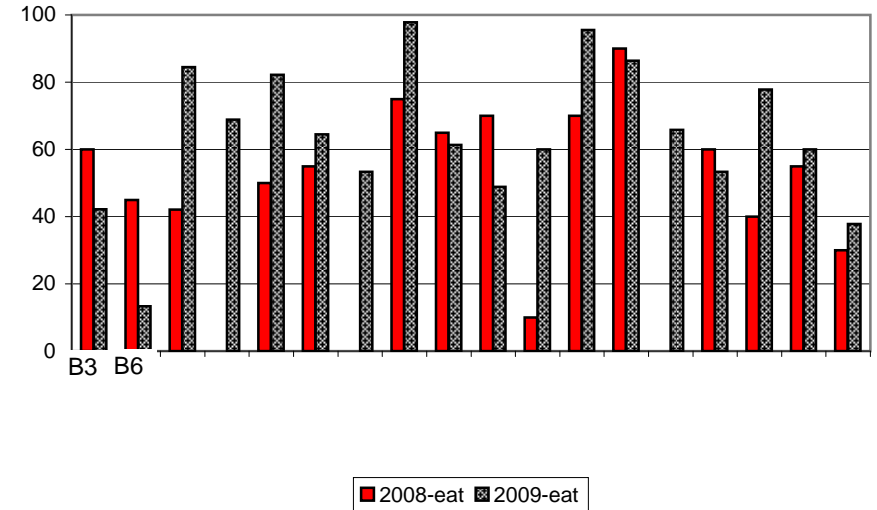


Long storage Avotest

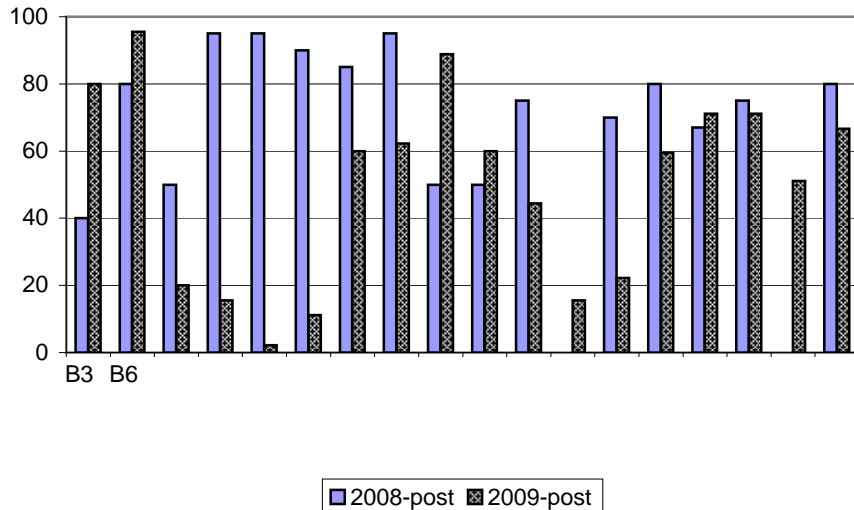
2008 & 2009 %marketable fruit -8wks - eat ripe



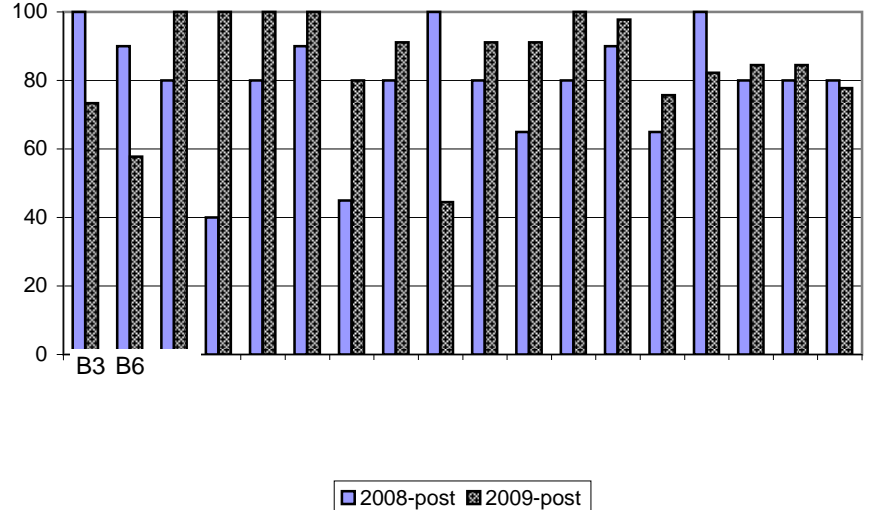
2008 & 2009 %fruit with rots-8wks - eat ripe



2008 & 2009 %marketable fruit -8wks - post eat ripe



2008 & 2009 %fruit with rots-8wks - post eat ripe



Domestic market AvoTest v. Commercial Simulation

Block 3		Firmness	Colour	Skin spots		Stem end rot		Body rot		Vasc Browning		Bruised flesh		Diffused discol		Seed Cav Brown		Stones	Marketable
				S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	I (%)	fruit (%)
8 wks before harvest	Eat ripe	45.54	2.13	1.49	97.78	0.93	15.56	0.81	35.56	1.00	6.67	0.38	6.67	n.a.	n.a.	2.01	22.22	2.22	95.56
	Post-eat	44.99	n.a	n.a	n.a	2.51	62.22	3.09	51.11	0.71	11.11	1.71	17.78	n.a.	n.a.	0.78	8.89	4.44	80.00
Group Avg Post-eat		45.28	n.a	n.a	n.a	16.13	78.87	13.04	66.03	8.54	35.30	2.03	32.02	n.a.	n.a.	2.04	11.01	0.93	48.97
4 wks before harvest	Eat ripe	47.98	2.11	1.11	68.89	1.39	26.67	0.10	11.11	2.56	6.67	0.04	4.44	0.00	0.00	0.00	0.00	0.00	93.33
	Post-eat	44.82	n.a	n.a	n.a	3.99	60.98	1.02	43.90	5.30	29.27	0.15	9.76	0.00	0.00	0.00	0.00	12.20	68.29
Group Avg Post-eat		46.16	n.a	n.a	n.a	8.00	61.31	2.39	34.19	8.88	38.86	0.34	6.68	0.01	0.10	0.08	1.29	5.02	63.27
Commercial Simul.	Eat ripe	47.39	3.04	0.00	0.00	0.00	0.00	0.04	2.22	0.00	0.00	3.16	33.33	0	0	0	0	0	100
	Post-eat	42.98	n.a	n.a	n.a	0.06	2.22	0.00	0.00	0.16	0.07	60.00	11.11	1.21	26.67	0.00	0.00	0.00	97.78
Group Avg Post-eat		48.87	n.a	n.a	n.a	0.24	8.80	0.41	5.51	1.60	0.27	36.42	6.71	2.18	27.77	0.11	3.60	2.49	88.96

Block 6		Firmness	Colour	Skin spots		Stem end rot		Body rot		Vasc Browning		Bruised flesh		Diffused discol		Seed Cav Brown		Stones	Marketable
				S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	I (%)	fruit (%)
8 wks before harvest	Eat ripe	41.40	3.11	0.69	64.44	0.09	6.67	0.07	6.67	0.00	0.00	0.02	2.22	n.a.	n.a.	0.83	13.33	2.22	100.00
	Post-eat	48.70	n.a	n.a	n.a	0.80	37.78	1.24	37.78	0.00	0.00	1.93	51.11	n.a.	n.a.	0.67	8.89	0.00	95.56
Group Avg Post-eat		45.28	n.a	n.a	n.a	16.13	78.87	13.04	66.03	8.54	35.30	2.03	32.02	n.a.	n.a.	2.04	11.01	0.93	48.97
4 wks before harvest	Eat ripe	53.38	2.13	1.44	84.44	0.28	4.44	0.08	8.89	0.11	2.22	0.00	0.00	0.00	0.00	0.00	0.00	2.22	97.78
	Post-eat	46.83	n.a	n.a	n.a	0.72	13.95	0.19	9.30	0.44	9.30	0.07	4.65	0.00	0.00	0.00	0.00	2.33	95.35
Group Avg Post-eat		46.16	n.a	n.a	n.a	8.00	61.31	2.39	34.19	8.88	38.86	0.34	6.68	0.01	0.10	0.08	1.29	5.02	63.27
commercial Simul.	Eat ripe	45.80	3.71	0.13	13.33	0.02	2.22	0.16	6.67	0.04	2.22	1.67	28.89	3.18	33.33	0.11	2.22	0.00	93.33
	Post-eat	43.58	n.a	n.a	n.a	0.00	0.00	0.00	0.00	1.27	0.20	73.33	15.56	1.44	26.67	0.00	0.00	0.00	97.78
Group Avg Post-eat		48.87	n.a	n.a	n.a	0.24	8.80	0.41	5.51	1.60	0.27	36.42	6.71	2.18	27.77	0.11	3.60	2.49	88.96

S = severity, % of fruit flesh affected

I = Incidence, % of fruit in the sample affected

Group Avg: for post-eat ripe evaluation

statistical differences between the two blocks

Long storage Avocado v. Commercial Simulation

Block 3		Firmness	Colour	Skin spots		Discrete Patches		Stem end rot		Body rot		Vasc Browning		Bruised flesh		Diffused discol		Seed Cav Brown		Stones I (%)	Marketable fruit (%)
				S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)		
4 wks before harvest	Eat ripe	52.02	2.67	1.09	95.56	1.02	77.78	0.03	2.22	0.09	6.67	0.16	15.56	0.13	4.44	0.53	17.78	2.30	28.89	15.56	100.00
	Post-eat	56.56	n.a	n.a	n.a	n.a	n.a	0.44	20.93	0.60	34.88	2.37	46.51	0.19	9.30	0.88	11.63	1.05	9.30	13.95	86.05
Group Avg Post-eat		51.41	n.a	n.a	n.a	n.a	n.a	1.16	23.32	2.99	44.27	6.09	39.90	0.26	9.25	6.63	38.11	4.68	32.82	5.84	65.79
commercial Simul.	Eat ripe		3.45	0.00	0.00	0.00	0.00	0.00	0.00	0.05	2.50	0.08	2.50	0.15	5.00	0.18	7.50	0.63	32.50	15.00	100.00
	Post-eat		n.a	n.a	n.a	n.a	n.a	0.09	4.44	0.16	13.33	0.00	0.00	0.07	6.67	0.56	22.22	0.42	13.33	17.78	100.00
Group Avg Post-eat			n.a	n.a	n.a	n.a	n.a	0.10	5.00	4.42	37.24	3.82	22.43	0.30	7.15	7.75	52.48	0.52	13.12	10.80	75.84

Block 6		Firmness	Colour	Skin spots		Discrete Patches		Stem end rot		Body rot		Vasc Browning		Bruised flesh		Diffused discol		Seed Cav Brown		Stones I (%)	Marketable fruit (%)
				S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)	S (%)	I (%)		
4 wks before harvest	Eat ripe	57.74	3.36	0.20	13.33	1.27	51.11	0.02	2.22	0.04	4.44	0.04	4.44	0.00	0.00	3.02	33.33	1.82	6.67	6.67	93.33
	Post-eat	45.83	n.a	n.a	n.a	n.a	n.a	1.72	31.11	1.31	55.56	8.80	71.11	0.36	15.56	9.38	40.00	8.78	44.44	11.11	48.89
Group Avg Post-eat		51.41	n.a	n.a	n.a	n.a	n.a	1.16	23.32	2.99	44.27	6.09	39.90	0.26	9.25	6.63	38.11	4.68	32.82	5.84	65.79
commercial Simul.	Eat ripe		3.38	0.49	42.22	0.00	0.00	0.00	0.00	0.04	4.44	0.00	0.00	0.00	0.00	0.11	8.89	0.16	15.56	4.44	100.00
	Post-eat		n.a	n.a	n.a	n.a	n.a	0.00	0.00	0.60	26.67	0.69	13.33	0.62	13.33	2.42	31.11	0.47	11.11	22.22	93.33
Group Avg Post-eat			n.a	n.a	n.a	n.a	n.a	0.10	5.00	4.42	37.24	3.82	22.43	0.30	7.15	7.75	52.48	0.52	13.12	10.80	75.84

S = severity, % of fruit flesh affected

I = Incidence, % of fruit in the sample affected

Group Avg: for post-eat ripe evaluation

Yellow cells: statistical differences between the two blocks

Development and commercial application of an avocado fruit robustness test

2009

Grower Collaborator: A

8 weeks pre-commercial harvest

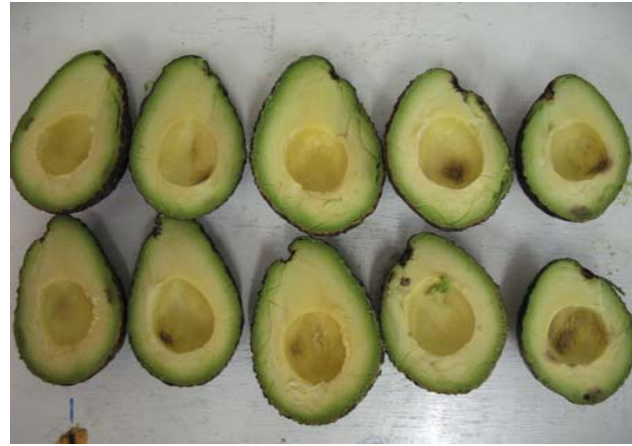
Domestic market Avotest

Block 3 (DM: 20%, 17.2 - 24.9 range: %)

Eat ripe



2 days post-eat ripe



Harvested: 17 March 09

Block 6 (DM: 20.1%, range: 18.3 - 23.4%)

Eat ripe



2 days post-eat ripe

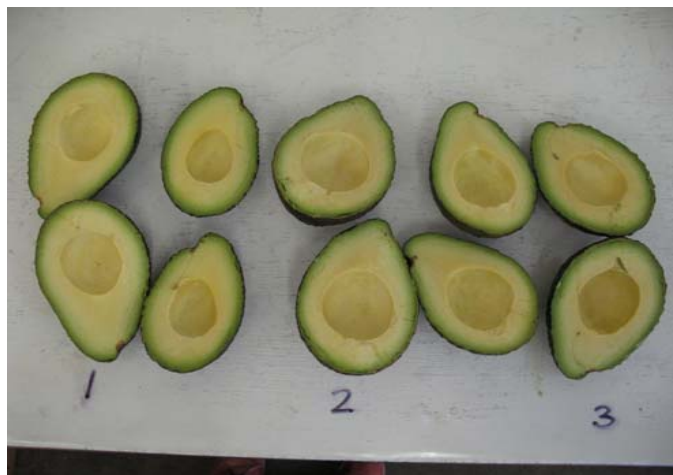


Harvested: 17 March 09

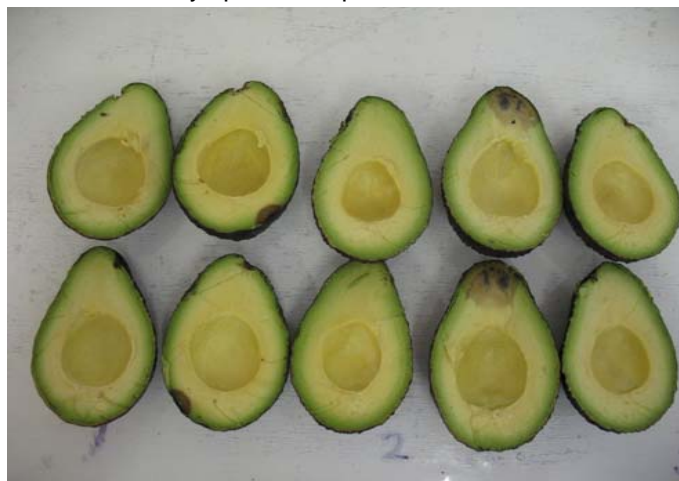
4 weeks pre-commercial harvest
Domestic market Avotest

Block 3 (DM: 20.7%, range: 17.3 - 23.4%)

Eat ripe



2 days post-eat ripe



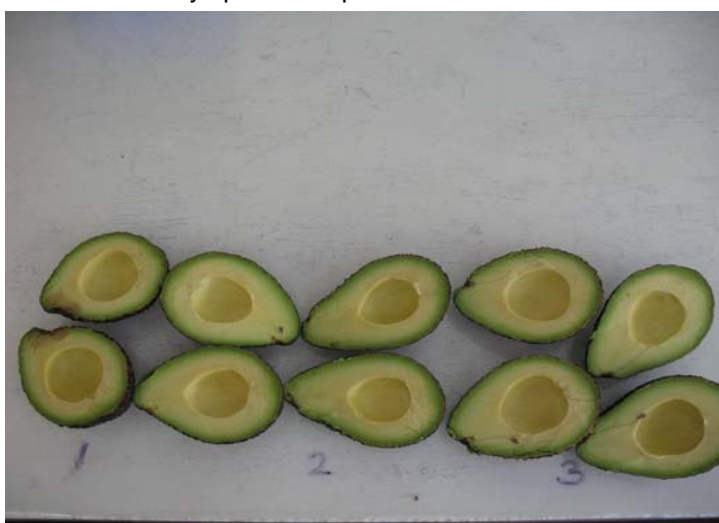
Harvested: 7 April 07

Block 6 (DM: 22.5%, range: 20.7 - 26.8%)

Eat ripe



2 days post-eat ripe



Harvested: 7 April 07

Commercial harvest

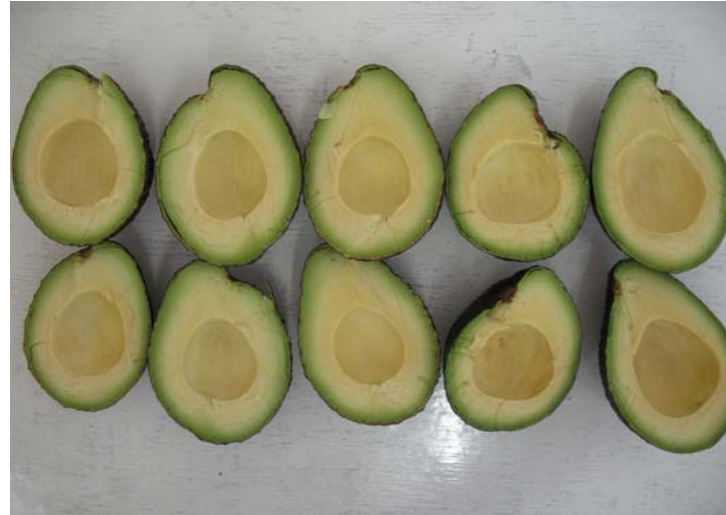
Domestic market commercial simulation test

Block 3 (DM: 23.4%, range: 21.9 - 25.6%)

Eat ripe



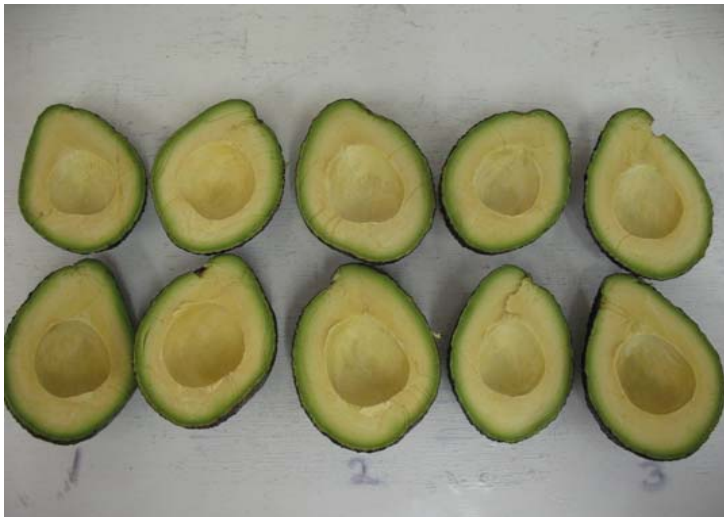
2 days post-eat ripe



Harvested: 5 May 09

Block 6 (DM: 24%, range: 22 - 27.2%)

Eat ripe



2 days post-eat ripe



Harvested: 11 May 09



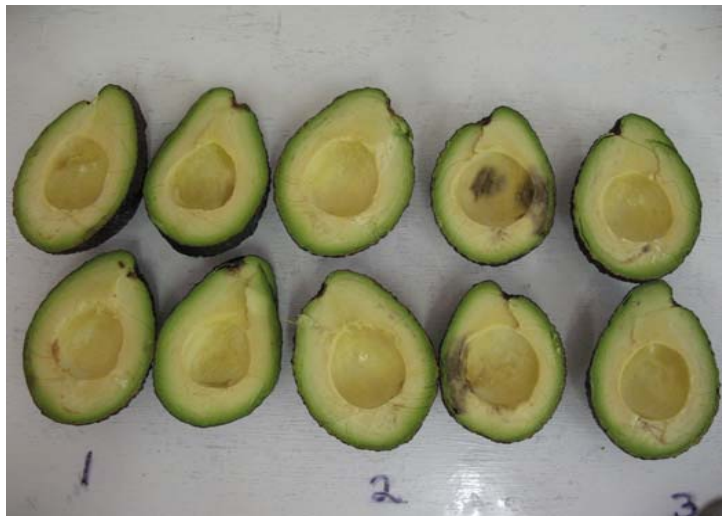
4 weeks pre-commercial harvest
Long storage Avotest

Block 3 (DM: 20.7%, range: 17.3 - 23.4%)

Eat ripe



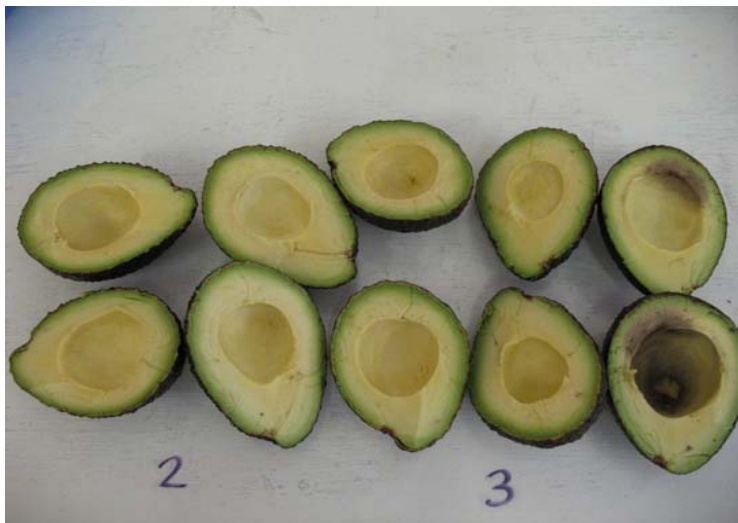
2 days post-eat ripe



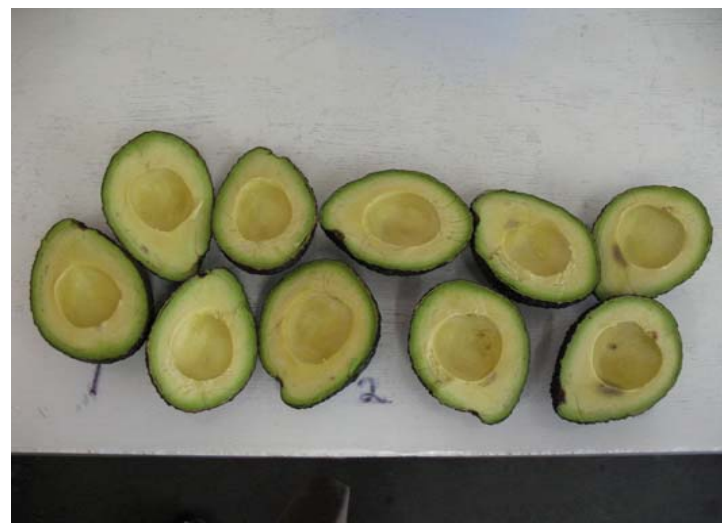
Harvested: 7 April 07

Block 6 (DM: 22.5%, range: 20.7 - 26.8%)

Eat ripe



2 days post-eat ripe



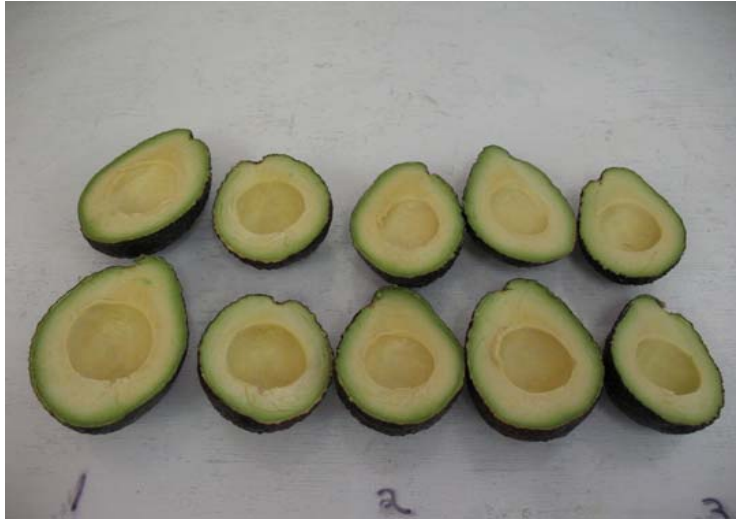
Harvested: 7 April 07

Commercial harvest

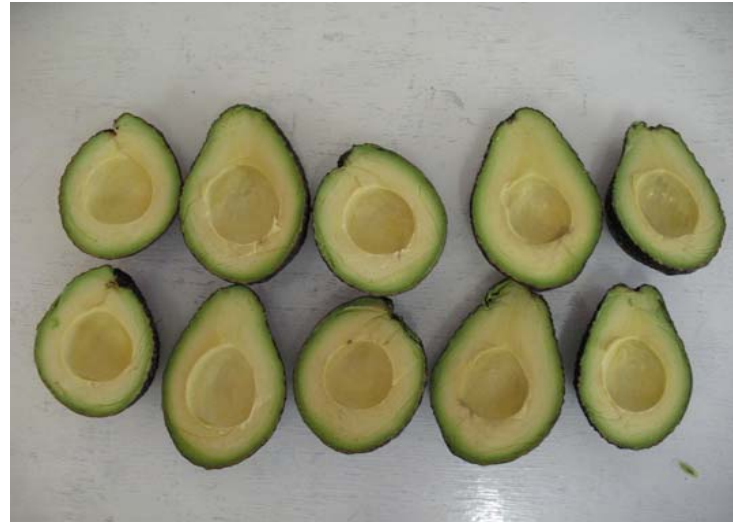
Long storage commercial simulation test

Block 3 (DM: 23.4%, range: 21.9 - 25.6%)

Eat ripe



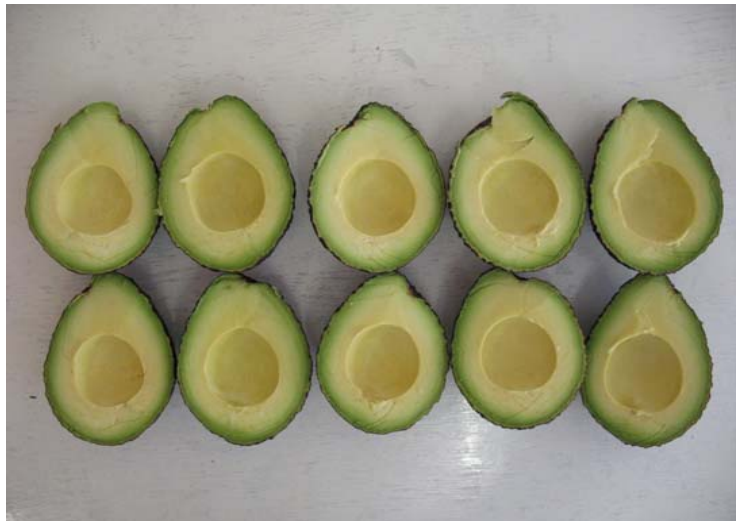
2 days post-eat ripe



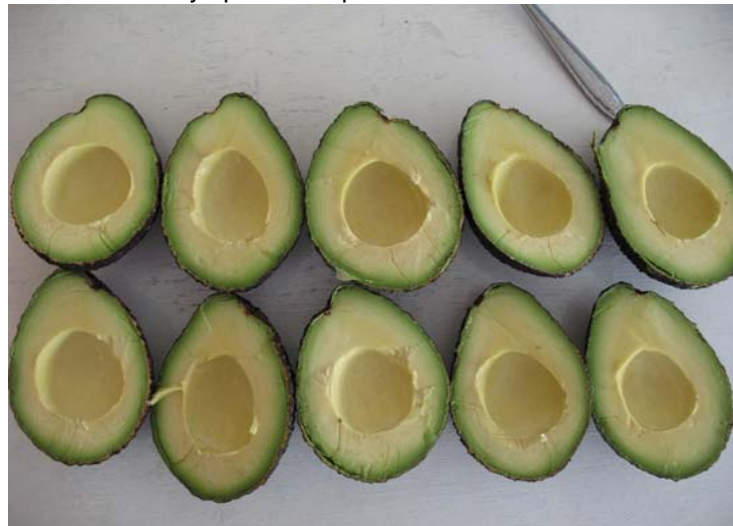
Harvested: 5 May 09

Block 6 (DM: 24%, range: 22 - 27.2%)

Eat ripe



2 days post-eat ripe



Harvested: 11 May 09



Appendix 5

Nitrogen and calcium analyses of leaf samples taken pre-flowering 2009.

Blocks	N	Ca	Ca/N
1a	2.24	1.403	0.626
1b	1.95	1.777	0.911
2a	1.81	2.214	1.223
2b	2.14	1.692	0.791
3a	2.15	1.405	0.653
3b	2.35	1.369	0.583
4a	1.95	1.946	0.998
4b	1.96	1.825	0.931
5a	1.98	1.752	0.885
5b	2.37	1.571	0.663
6a	1.68	2.189	1.303
6b	1.92	1.468	0.765
7a	2.41	1.859	0.771
7b	2.53	1.638	0.647
8a	1.88	1.741	0.926
8b	1.98	1.833	0.926
9a	1.96	2.114	1.079
9b	1.92	2.022	1.053
10a	2.32	1.828	0.788
10b	2.14	2.034	0.950
11a	2.11	1.960	0.929
11b	2.47	1.649	0.668