ADOPTION OF FIELD PRACTICES TO ASSIST IN EXPANDING AVOCADO MARKETS

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Introduction

The focus of this 2001 Australasian Avocado Conference is looking forward to identify changes that are required to ensure our industry remains competitive and able to meet the challenges of the future. To achieve this we need to make certain that all sectors of the industry, from production to retail are developed in an integrated and balanced manner. This might be seen as a tall order given the suspicion and distrust that has traditionally existed between the grower and wholesaler/retailer. Yet the prosperity of all parties is inseparably entwined due to their fundamental dependence on each other. Vital changes are occurring in the relationships between all parties comprising the supply chain, which are being driven by the increased marketing power of growers, either through larger individual suppliers or the formation of marketing groups as the industry matures. There are also changes occurring in the retail sector with the sale of Franklins to Woolworths and the Independants currently being negotiated, and the entry of the German supermarket chain Aldi into Australia. The latter is predicted to introduce new retail practices to our domestic market and our industry will need to monitor the situation to ensure that it can capitalise on changes that may occur.

To advance the professional standing between all supply chain parties, each should openly acknowledge their responsibilities with respect to production and handling of the fruit. Most importantly those involved in postharvest operations should not lose sight of the fact that an avocado fruit is a living product through to the point of consumption. Once harvested, respiration and transpiration continue and if not correctly managed can result in accelerated deterioration of the fruit (Milne, 1997). It should also go without saying that growers accept that they are answerable for the quality of their fruit through to the retail shelf and that they cannot and should not abdicate responsibility at the farm gate. Having control of your fruit through the supply chain is a natural extension of the capital and time invested in its production. Through production practices growers also hold the key to the quality of the fruit that is ultimately bought by consumers, as it is largely crop management procedures that determine size, shape, maturity, pest and disease status and susceptibility to internal disorders (Whiley *et al*., 1997).

There are no postharvest techniques that can improve fruit quality beyond that achieved at harvest. Thus, it is important that management strategies be used during production that will provide the quality of fruit that consumers require (Whiley *et al*. 1997). There are many procedures from flowering to harvest that will impact on quality. For example, timely use of pesticides will keep fruit free from insect damage and diseases; control of Phytophthora root rot will ensure that trees remain healthy with a full canopy that limits sunburn, and timely irrigation will result in greater numbers of fruit reaching required market sizes. The effect of production practices on fruit quality was reviewed at the 1997 Australasian Avocado Conference held at Rotorua, New Zealand and the topic is updated in this paper.

Expanding and Developing Markets

Traditionally avocado production in Australia has targeted the domestic market as quarantine issues have precluded entry into lucrative and developed export markets that can be reached within a reasonable time via commercial shipping routes. For example, the presence of Queensland and Mediterranean fruit fly has barred entry into Japan and the USA while fruit fly and avocado sunblotch viroid (ASV) has kept our fruit out of New Zealand. Recent technological advances with cold temperature disinfestation plus the production of fruit from certified ASV-free blocks has allowed entry into New Zealand however, the seasonal window and market size presents limited opportunities for Australian growers. The cold disinfestation process also places limitations on shelf-life once fruit is removed from the treatment and the technology for long sea voyages has not been tested. The latest data available shows that only 0.5% of the total Australian avocado production in 2000 found its way to export markets (Fig. 1).

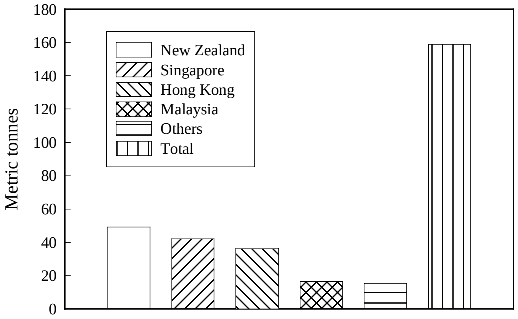

Fig. 1 Export destinations for Australian-grown avocados in 2000. Exports totalled 159 metric tonnes and were 0.5% of the total Australian production. Source: Horticulture Australia.

Asian countries without strict quarantine requirements are potential markets for Australia in the long-term but considerable effort and resources are required to capture palates conditioned to sweet or spicy flavours. Furthermore, it is only the top-end of the market able to give Australian growers the returns needed for sustained viability – although this may still be able to absorb a large volume of fruit. Competition from lower cost-of-production countries such as Chile and South Africa should not be ignored as these producers have an export focus and will certainly enter south-east Asian markets where opportunities develop. Thus, it is considered that at least for the short term, our domestic market remains the main opportunity to absorb the increased volume of fruit.

At the 1997 Australasian avocado conference, the rapid increase in the number of new avocado trees being planted in Australia and New Zealand was reported (Whiley *et al*., 1997). Increased production generated from greater tree numbers is beginning to appear showing as a 32% increase in fruit from 1999 to 2000 (Fig. 2). As there are still many young trees that have not reached bearing age it is predicted that avocado production will continue to increase for a number of years barring a significant exit of growers from the industry. The opportunity to increase domestic consumption of avocados from 1.6 kg/capita in 2000 appears good based on data from other producing

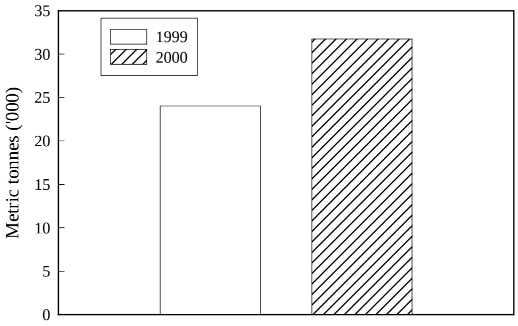

Fig. 2 Total Australian avocado production in 1999 and 2000. Production increased by 32% from 1999 to 2000. Source: Australian Horticulture.

countries. While the consumption in Mexico (10 kg/capita) is not seen as an achievable target in the foreseeable future, the consumption in Israel (4 kg/capita) and Chile (2.5 kg/capita) should be within reach of the Australian industry. However, to achieve this an improvement in the reliability of the product we offer to consumers is required. The development of fruit rots and the discolouration of flesh in ripe fruit remain the greatest challenge limiting market expansion. The problem is greatest with 'Hass', as externally this cultivar disguises defects and is often sold in an overripe condition (Ledger and Barker, 1995). Chilling injury is most prevalent during summer when West Australia and New Zealand 'Hass' dominate the market and it is suggested that these high-priced fruit are held too long by retailers.

Identification and monitoring supply chain procedures will assist in the delivery of better quality fruit to retail outlets. However, growing a product better able to withstand post farm gate stresses will improve the image of this nutritious fruit.

Growing Quality

Nutrition

Mineral nutrition of avocados is known to have a significant affect on the postharvest quality of fruit. In particular, fruit size and shape, shelf life and internal disorders, and susceptibility to anthracnose may be affected by the nutritional conditions that prevailed during growth and maturation of the fruit. Thus, through the judicious management of fertiliser applications, growers can directly affect many of the quality parameters of the fruit they produce.

1. Fruit size and shape

Fruit size is an important issue in today's markets, with retailers demanding specific counts to keep prices acceptable to consumers. Fruit size is of particular interest in the production of 'Hass', which is the most extensively grown variety in subtropical and Mediterranean climates. As 'Hass' trees get older they tend to carry an increasing number of small fruit that are downgraded. Production of this cultivar in the warm subtropics exacerbates this problem resulting in a significant percentage of fruit that fall outside market specifications (Cowan, 1997). Fruit size is largely determined in the first 7-8 weeks following fruit set and is dependent on the number of cells laid down in each fruit during this period (Cowan *et al.*, 1997). In fruit that develop normally, about 80% of the final number of cells are produced in the first eight weeks of growth, therefore it is important that adequate supplies of nutrients such as boron and zinc that are essential for cell division, are readily available. Smith *et al.* (1997a) reported that when 'Hass' trees growing on a red clay loam in Australia with leaf boron levels of 18-25 mg/kg were treated with soil-applied borax, mean fruit size at maturity was increased by about 15%. In similar studies in South Africa, Bard and Wolstenholme (1997) found that soil-applied borax increased fruit size by about 4%. Inadequate boron during fruit set and subsequent early development can also result in severe fruit distortion with retarded growth on one side of the fruit resulting in "sickle-shaped" fruit at maturity (Whiley *et al*., 1996).

Zinc deficiency during fruit set and early development can also affect final fruit size and shape. Although not quantified, Ruehle (1940), Gustafson (1973) and Crowley *et al*. (1996) reported that zinc deficiency reduced fruit size. In addition, 'Fuerte' and 'Hass' fruit become significantly rounder than the normal shape produced for these cultivars (Wallihan *et al*., 1958; Embleton and Wallihan, 1966; Crowley *et al*., 1996) and are generally not marketable. Once fruit become affected the condition is not reversible, but correction of the deficiency will result in normal fruit production the following season.

2. Shelf-life and internal disorders

Mineral content and balance have been related to storage potential and the development of internal physiological fruit disorders. Calcium is the most frequently implicated mineral, and there are numerous published reports of improved shelf-life and reductions in disorders in a range of fruit crops following improved calcium nutrition (Atkinson *et al*., 1980; Smith, 1984; Poovaiah *et al*., 1988).

In avocado, higher fruit calcium concentrations have been correlated with delayed ripening (Tingwa and Young, 1974; Eaks, 1985; Witney *et al*., 1990a; Cutting *et al*., 1992; Vuthapanich, 1998) which may significantly increase fruit shelf-life (Fig. 3).

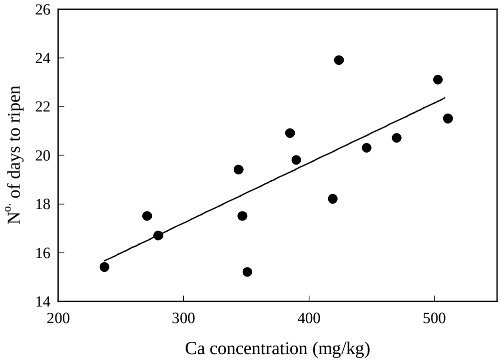

Fig. 3 The relationship between calcium concentration in the flesh of 'Hass' avocado fruit and the number of days from harvest to eating ripe. The regression line is represented by $y = 9.82 + 0.025x$; $r^2 = 0.61$. From Hofman *et al*. 2001.

These effects are partly through delayed respiration and ethylene climacterics (Eaks, 1985) and a general retardation of fruit senescence. Lower rates of nitrogen (Arpaia *et* *al*., 1995) and increased boron nutrition of trees has also been associated with increased shelf life of avocado fruit.

Calcium is also implicated in the development of physiological disorders with high fruit concentrations reducing chilling injury, flesh discolouration, pulp spot and vascular browning (Chaplin and Scott, 1980; Vorster and Bezuidenhout, 1988; Cutting *et al*., 1992; Thorp *et al.*, 1995, Penter and Stassen, 1999, 2000). Chaplin and Scott, (1980) found postharvest calcium infiltration reduced chilling injury when fruit were stored at low temperatures while Cutting *et al*. (1992) reported a decrease in fruit calcium as fruit maturity advanced with a concomitant increase in flesh discolouration following low temperature storage. Koen *et al*. (1990) reported an inverse relationship between soil and leaf calcium and grey pulp, Vorster and Bezuidenhout (1988) between calcium and pulp spot, Thorp *et al*. (1997) between fruit calcium and vascular browning, and Cutting and Bower (1991) between fruit calcium and polyphenol oxidase activity. More recently Hofman *et al*. (2001) established an indirect relationship between the calcium concentration in 'Hass' fruit and flesh discolouration when they had ripened. Hence, there is a substantial body of evidence directly linking fruit Ca concentrations with the physiological disorders that can develop in avocados during postharvest handling.

While management of calcium to optimise fruit concentrations would seem desirable, it is difficult to achieve. Calcium is absorbed through the roots and distributed to the rest of the tree mainly through the xylem (water conducting tissue). Leaves, which lose the largest amount of water, accumulate more calcium than other organs. Thus, factors affecting fruit calcium accumulation are soil calcium concentrations, concentrations of other cations (because they compete for calcium uptake by the roots), tree vegetative vigour (Witney *et al*., 1990b), water management, and probably rootstocks. Until recently, calcium foliar sprays during fruit growth have little effect on internal concentrations in most fruit due to poor fruit absorption, and lack of re-translocation within the tree. However, recent studies in South Africa provide renewed optimism that fruit calcium levels may be increased by simple management procedures. Penter and Stassen (1999) have reported that a 0.5% or 1.0% foliar application of a new organically chelated calcium product (Calcimax®) sprayed three weeks after fruit set increased fruit calcium levels and reduced the incidence of grey pulp and vascular browning in 'Edranol' avocado. Further research using Calcimax® foliar applications or postharvest dips to 'Pinkerton' resulted in a reduced incidence of grey pulp and anthracnose (Penter and Stassen, 2000). However, it should be noted that results have not always been consistent with this product. Nevertheless, there is sufficient evidence to warrant research with Calcimax® on 'Hass' growing under Australian conditions. To summarise, the management of all factors influencing fruit calcium accumulation is essential for best results. Too much soil calcium may reduce the uptake of other nutrients including potassium, magnesium and boron, which are also implicated in fruit quality. Excessive vegetative vigour will increase the amount of calcium going to the leaves at the expense of the fruit, and water stress will have the same effect. Thus, a holistic approach to calcium management is required.

In other research, attempts have been made to relate potassium and magnesium concentrations, and in particular various ratios of either soil or leaf (Koen *et al*., 1990; du Plessis and Koen, 1991), or fruit (Cutting and Bower, 1991) levels of calcium, magnesium and potassium to fruit quality with some success. This is not surprising as there is an interaction between these three minerals for uptake by roots (Ferguson, 1980) however, it is still likely that the calcium concentration is the dominant factor driving the relationship.

Apart from calcium and its relationship with potassium and magnesium, boron and zinc have also been reported to have a direct effect on the potential for development of postharvest internal disorders in avocado fruit. Smith *et al.* (1997b) found a higher incidence of internal discolouration in 'Hass' fruit that was harvested from trees with low boron status (leaf content of 22 mg/kg compared to 56 mg/kg) and stored at 7°C for four weeks then ripened at 20°C. Boron is closely linked to calcium in plant nutrition, being physiologically active at similar sites in the plant. South African research has found that high fruit (16.5 vs. 9 mg/kg) and leaf zinc is associated with lower pulp spot incidence in 'Fuerte' (Vorster and Bezuidenhout, 1988; Bezuidenhout and Vorster, 1991).

3. Susceptibility to anthracnose

In subtropical climates, anthracnose (*Colletotrichum gloeosporioides*) is one of the most important fruit diseases of avocado and may significantly reduce eating quality when fruit ripens. Anthracnose infects fruit during periods of extended rainfall, and due to high levels of diene, an antifungal compound found in the peel of unripe avocados (Prusky *et al.*, 1982), remains latent until the fruit begins to ripen. The susceptibility of fruit to disease is dependent on cultivar as diene concentrations are genetically dependant (Prusky *et al.*, 1988), and fruit calcium concentration (Vuthapanich, 1998). Hofman *et al.* (2001) reported an inverse relationship between fruit calcium concentration in 'Hass' and the severity of anthracnose following storage and ripening of the fruit (Fig. 4).

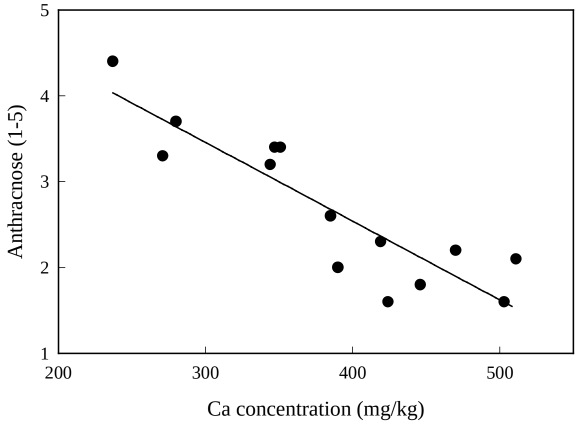

Fig. 4 Effect of calcium concentration in 'Hass' fruit on the severity of anthracnose (1 = no disease, 5 = severe disease). Each datum point is the average value of fruit from one tree (From Hofman *et al.* 2001.

Irrigation

Water can have an impact on fruit size. For example, in South Africa under good commercial irrigation practice, fruit produced during a season with high rainfall averaged 200-285 g, whereas those from the following dry year averaged 165-220 g

(Milne, 1994). Increasing irrigation can improve fruit size (Lahav and Kalmar, 1977; Van Eyk, 1994), but may also increase fruit number per tree at the expense of fruit size (Faber *et al.*, 1998; Vuthapanich 1998). Timing of irrigation in relation to tree phenology may also be important in influencing yield and fruit size responses.

Irrigation can potentially affect internal fruit disorders. Bower and van Lelyveld (1985) found that different irrigation schedules altered the activity of polyphenol oxidase (the enzyme often responsible for the browning reactions in damaged plant parts) in harvested fruit. However, Vuthapanich (1998) noted that irrigation regimes had little influence on fruit quality, but affected yield.

Plant growth regulators

Plant growth regulators are extensively used in horticultural and are increasingly playing an important role in avocado production. They are usually defined as synthetic compounds applied exogenously to modify plant growth and may be a related chemical that mimics hormone action or identical to the naturally occurring hormone. The triazoles are a group of chemically related plant growth regulators that inhibit gibberellin biosynthesis when exogenously applied to plants (Davis *et al.*, 1988), and give a predictable effect on vegetative growth and fruit size of avocados (Köhne and Kremer-Köhne, 1987; Köhne, 1988; Adato, 1990; Wolstenholme *et al.*, 1990; Penter *et al.*, 2000). Within this group, paclobutrazol (Cultar®) and uniconazole (Magic® or Sunny®) are commercially used on avocados in several countries.

Following extensive testing on avocados over two years, Sunny® (uniconazole) has been recently registered for use in Australia. The studies carried out showed that there was a general trend for cumulative yields of ‘Hass’ over two years to increase following the use of Sunny®, but the differences were not significant compared with untreated trees (Fig. 5) (J. Leonardi and A.W. Whiley, 2000 unpublished results).

There was also evidence suggesting that the management of fruit harvest also contributes to long-term tree performance when using this product. For example, Sunny®-treated trees at Walkamin were harvested as soon as fruit reached the legal maturity of 21% dry matter and all trees carried a heavier crop in the second year. The best Sunny® treatment produced 34% more fruit than untreated trees. However, at Glasshouse Mountains where fruit were not harvested until reaching about 27% dry matter, most of the Sunny® treatments had reduced yield in the second year of the experiment, which was greatest on the previously heaviest cropping trees (Fig. 5).

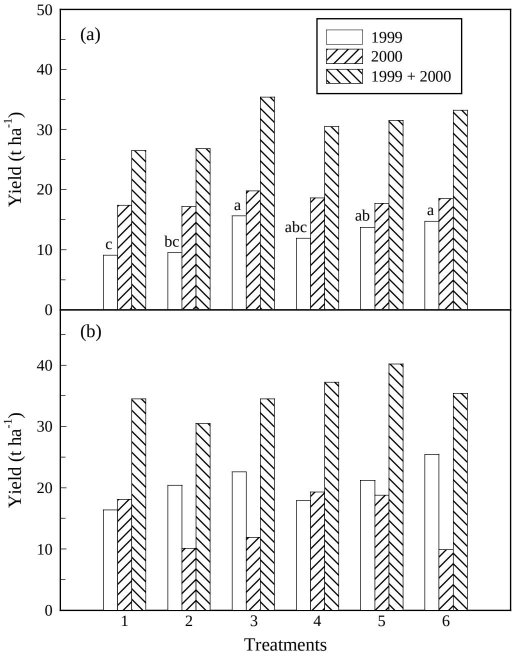

Fig. 5 Effect of foliar applications of Sunny® (uniconazole) on yield of 'Hass' avocados growing at (a) Walkamin and (b) Glasshouse Mountains in Queensland, Australia. The treatments used were 1) untreated; 2) 0.5% Sunny® + 1% UP50; 3) 0.5% Sunny® + N; 4) 1% Sunny® + 2% UP50; 5) 1% Sunny® + N; and 6) 1% Sunny® + 2% UP50 + N. Sunny® and the respective adjuvants were applied at mid-bloom. Where used N was soil-applied as urea. Columns represent means values of six trees. Columns of any one year marked with different letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

The greatest benefit from a mid-bloom foliar application of Sunny® was the consistent increase in mean fruit size (Table 1) that improved the pack-out (Figs 6-8) and returns to the grower (Table 2). Similar results with Sunny® have been reported for 'Hass' by Penter *et al*. (2000) in South Africa.

Table 1 Effect of mid-bloom foliar applications of Sunny® on ‘Hass’ (Walkamin and Glasshouse Mountains) and ‘Shepard’ (Childers) fruit size. Data are mean values of six trees. Fruit size values are adjusted means following a significant ($P < 0.05$) covariate analysis. Values in columns followed by different superscript letters are significantly different ($P < 0.05$) as tested by ANOVA.

Treatments	Mean fruit size (g)					
	Walkamin		Glasshouse Mts		Childers	
	1999	2000	1999	2000	1999	2000
Untreated control	242^{c}	204^{c}	257^{b}	217^{b}	238^{b}	225^{b}
Sunny 0.5% + buffer	267^{ab}	237^{b}	272^{a}	286^{a}	-	-
Sunny 0.5% + N	268^{ab}	249^{ab}	273^{a}	277^{a}	-	-
Sunny 1% + buffer	261^{b}	247^{ab}	281^{a}	267^{a}	237^{b}	2226 b
Sunny 1% + N	268^{ab}	255^{a}	285^{a}	274^{a}	247^{a}	265^{a}
Sunny 1% + buffer + N	274^{a}	251^{ab}	279^{a}	265^{a}	-	-

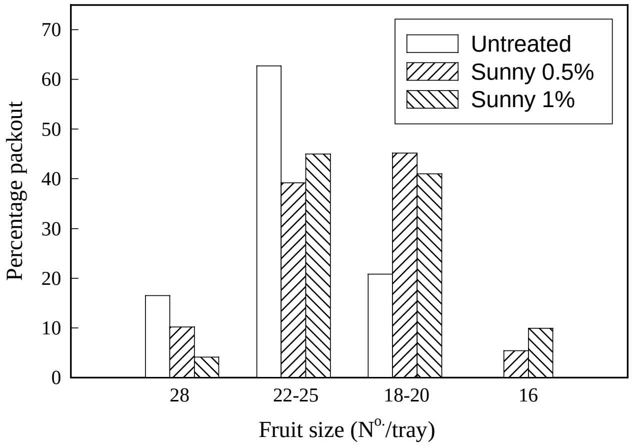

Fig. 6 Effect of a mid-bloom foliar spray of Sunny® on the percentage pack-out of ‘Hass’ fruit at Walkamin. Fruit were harvested on the 14th April 2000 and put over a commercial grading and packing line.

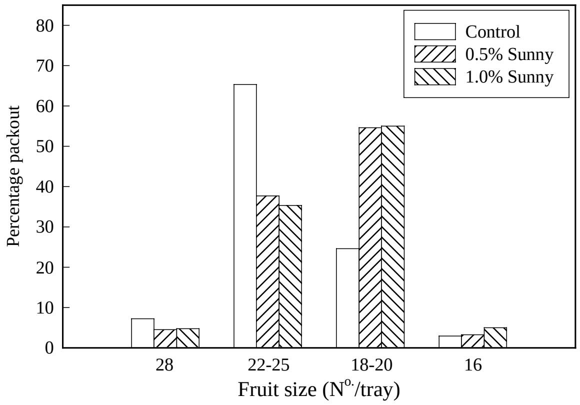

Fig. 7 Effect of a mid-bloom foliar spray of Sunny® on the percentage pack-out of ‘Hass’ fruit at Glasshouse Mountains. Fruit were harvested on the 12th July 1999 and put over a commercial grading and packing line.

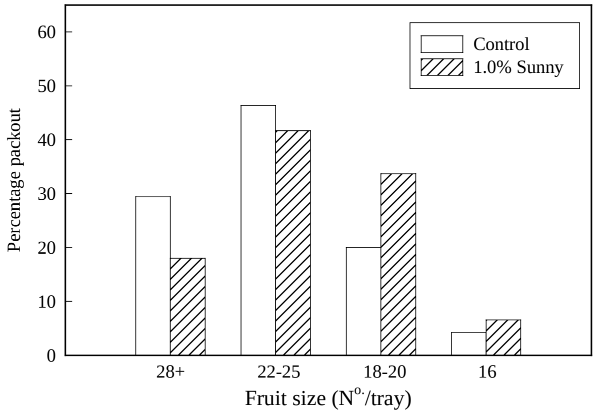

Fig. 8 Effect of a mid-bloom foliar spray of Sunny® on the percentage pack-out of ‘Shepard’ fruit at Childers. Fruit were harvested on the 2nd March 2000 and put over a commercial grading and packing line.

In each of the three studies reported, Sunny® increased the mean gross returns by $5000 to $8000 per hectare for each of the two years that trees were treated.

Table 2 Effect of Sunny® on the mean gross returns from 'Hass' (Walkamin and Glasshouse Mountains) and 'Shepard' (Childers) for 1999 and 2000. Net dollar values are minus the chemical cost of Sunny® but inclusive of all other costs.

Treatment	Mean gross returns for 1999 & 2000 ($/ha)*		
	Walkamin	Glasshouse Mts	Childers
Untreated control	35 041	28 399	34 474
Sunny® 0.5% + N	43 065	32 938	
Sunny® 1.0% + N	41 551	33 823	39 624

* Returns were calculated from the pack-out data for each treatment after passing fruit through a commercial grading and packing system and the dollar returns achieved for each line following marketing. The $/ha value was then estimated from the number of trees/ha where each of the experiments were carried out.

There was also a trend, in some cases significant ($P \leq 0.05$), for Sunny® applications to reduce flesh discolouration in 'Hass' following storage of fruit at 5°C for 4 weeks (Table 3). There was no significant effect from Sunny® on the development of body rots (anthracnose) as fruit ripened following storage at 5°C for 4 weeks, although there was a trend for less rot to develop in fruit from treated trees (Table 3). This is probably due to higher flesh calcium, which has been previously measured in avocado fruit following spring treatment with triazoles, and leads to less disease in ripening fruit (Fig. 4).

Table 3 Effect of mid-bloom applications of Sunny® on the development of fruit rots on 'Hass' during ripening after storage for 4 weeks at 5°C. Fruit were harvested from the Glasshouse Mountains experiment. Data has been transformed and back-transformed values are shown in parenthesis. Data are mean values of 40 fruit from each treatment. Values in columns followed by different letters are significantly different at $P < 0.05$ as tested by ANOVA.

Treatment*	% flesh discolouration	% Body rot (internal)
Untreated control	9.34^{b} (2.64)	0.44^{a} (0.01)
Sunny® 0.5% + N	7.66^{ab} (1.78)	0.10^{a} (0.00)
Sunny® 1% + buffer 2% + N	5.78^{a} (1.01)	0.19^{a} (0.00)

*Foliar treatments of Sunny® were applied with 0.05% Agral® at mid-bloom covering the trees to wetness. Nitrogen (N) was applied at the time of the Sunny® treatment (16 Sept 1998) as urea at 480 g N/tree. Sunny® was applied at the rate of 2 L of spray formulation per tree. Buffer as recommended by Sumitomo. Trees were harvested on the 12 Jul 1999.

Mid-bloom, foliar-applied Sunny® was also consistent in altering fruit shape of 'Hass' and 'Shepard'. In each case the length to breadth ratio of fruit was reduced giving an appearance of rounder fruit with a thickened neck (Fig. 9). In the case of 'Shepard', fruit with the changed shaped were easier to pack and ripened more uniformly without shrivelling around the neck region.

Fig. 9 Effect of Sunny® on Shepard fruit shape. Trees were sprayed with 1% Sunny® at mid-bloom with either 2% N/P buffer or soil-applied N.

Other management practices

Fruit size continues to be a problem with 'Hass', particularly when grown in the warmer regions of the subtropics. Wolstenholme and Whiley (1995) have reviewed factors which effect 'Hass' fruit size and suggest management strategies that may alleviate the problem. In summary these include:

- early summer scoring of limbs has increased fruit size of 'Hass' (Davie *et al*., 1995), but further studies investigating the long-term effects on tree health and productivity are required;
- selective harvesting of larger fruit with a corresponding delay in harvest of smaller fruit has been shown to increase the overall size of 'Fuerte' and 'Hass' fruit grown in a cool, subtropical climate (Kaiser and Wolstenholme, 1994; Whiley *et al*., 1996a);
- under-tree mulching can increase 'Hass' fruit size by about 12% in a cool subtropical climate in South Africa (Moore-Gordon *et al*., 1995; Moore-Gordon and Wolstenholme, 1996). Mulching prolonged root growth, especially during the summer/autumn, and improved root health and growth was considered a contributing factor to increased fruit size.
- cross pollination has been suggested to increase avocado fruit size. However, Robbertse *et al*. (1996) found that 'Hass' out-crossed to 'Ettinger' produced larger seed, but there was no increase in mean fruit size. This may have been due to the study being conducted on young trees (5-years-old) and fruit size benefits may occur as trees age and fruit size becomes a greater problem. Longer-term studies are required in this area.

Other management factors that influence fruit quality are:

- Arpaia *et al*. (1992) have reported that heating of fruit in the field following harvest increases the incidence of internal discolouration. Fruit left unprotected in bins for a number of hours after harvest were 22°C warmer than covered fruit and had a corresponding 25% increase in the incidence of flesh discolouration when ripe.
- Texture can occasionally be affected by hard lumps in the flesh or firm, rubbery-textured flesh around the seed. Information is scant on factors contributing to this uneven ripening. Sanewski (1984) and Whiley and Saranah (1988) have related high rainfall immediately prior to maturity to the development of firm flesh around the seed. Using only deep, well-drained soils for production in areas prone to high rainfall intensity periods, and maintaining a healthy root system, should reduce the incidence of uneven ripening from excessive rainfall.
- For the most part, flavour and texture is under the control of growers through the selection of cultivar, and harvest time. High-price opportunities on early and late markets often see eating quality compromised, and with decreasing intervention by government authorities in the market place, the industry will need to guard against practices which damage consumer confidence in this way.

The Role of Rootstocks in Fruit Quality

The performance of fruit tree crops is known to be intrinsically dependent on the choice of rootstock, whether it be either their ability to resist diseases or to impart greater productivity to the scion through the enhancement of physiological processes. The apple and citrus industries are clear examples where fruit production has been improved by the development of rootstocks that in many cases are specific to scion and soil type. With citrus, it has also been shown that rootstocks can influence fruit quality through the expression of rind thickness and pulp recovery.

At the 1997 Australasian Conference Whiley *et al*. (1997) reviewed a range of circumstantial evidence which suggested that at least in subtropical Australia, rootstocks were contributing to the yield and quality of avocado fruit. In summary these were:

- avocado rootstocks have a significant effect on tree growth and physiology which is often manifested in an appreciable rootstock over- or under-growth in relation to the scion (Whiley, 1994).
- there are large and consistent differences between the productivity of individual avocado trees grown on seedling rootstocks of unknown origin, with the best trees producing 400% more fruit than the worst trees over a 12 year period (Thomas, 1997).
- there are differences in the shape of fruit from trees grafted to different rootstocks. For example, Köhne (1992) found that fruit from ‘Hass’ trees grafted to ‘Duke 7’ were rounder than fruit from trees grafted to ‘G6’ and ‘G755C’.
- fruit from low yielding trees (‘Hass’ grafted to ‘Barr Duke’ or ‘D9’ rootstocks) developed more internal disorders in storage than fruit from high-yielding trees (‘Hass’ grafted to ‘Duke 7’, ‘G755’ and ‘Thomas’ (Smith, 1993).
- Mexican and Guatemalan rootstocks have different capacities with respect to mineral nutrient uptake. For example, trees grafted to Guatemalan rootstocks had higher leaf calcium and boron concentrations than those grafted to Mexican stocks

(Haas, 1950; Embleton *et al*., 1962; Ben-Ya'acov *et al*., 1992; Whiley *et al*., 1996b; Bard, 1997) while those grafted to Mexican rootstocks had higher leaf potassium concentrations (Haas, 1950).

- Coates *et al*. (1996) found considerable inter-tree variation with respect to anthracnose within single rows of 'Hass', even though all trees were exposed to the same spray program, and presumably the same inoculum pressure. For example, the average anthracnose rating for fruit harvested from a single tree varied from 7 to 57%.
- fruit calcium concentrations are variable between adjacent trees grafted to seedling rootstocks (Fig. 10).

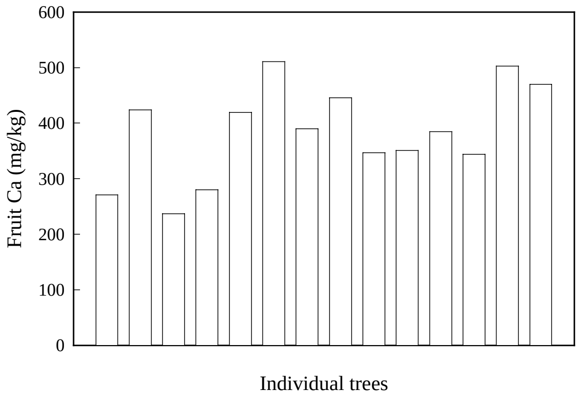

Fig. 10 Differences in calcium concentration in fruit from adjacent 'Hass' trees in the same orchard block (From S. Vuthapanich, P.J. Hofman and A.W. Whiley, 1998, unpublished results).

Recent information on rootstocks

Since the 1997 Australasian Avocado conference new information has been collected which further substantiates the influence of rootstocks on tree nutrition and associated fruit quality issues. In studies with 'Hass' trees grafted to either seedling 'Velvick', clonal 'Velvick' or clonal 'Duke 7' it was found that there were significantly higher calcium levels in the leaves and fruit of those trees grafted to clonal 'Velvick' (Table 4) (R. Marques, 2000, Nambour, unpublished results). Leaf boron was also significantly higher in the leaves of the two 'Velvick' rootstocks while there was a similar trend for fruit boron concentrations. There was no significant difference in the leaf and fruit potassium levels or fruit magnesium concentrations between rootstocks.

Table 4 Mineral concentrations of 'Hass' avocado leaves (g/kg_{dw}) and fruit flesh (mg/kg_{fw}) from trees grown on two different rootstocks. Data are mean values of eight trees per rootstock. Values with different letters within columns are significantly different at $P < 0.05$ as tested by ANOVA (from R. Marques, 2000, Nambour, unpublished results).

Treatment	Ca		B	
	Fruit	Leaf	Fruit	Leaf
Seedling Velvick	52.6^a	11.4^a	19.2^a	0.46^b
Clonal Velvick	58.6^b	13.3^b	19.0^a	0.43^b
Clonal Duke 7	51.5^a	10.8^a	16.4^a	0.34^a

When internal disorders were assessed, the incidence of flesh discolouration and vascular browning in stored then ripened 'Hass' fruit from trees grafted to clonal 'Velvick' was significantly less than fruit from trees grafted to clonal 'Duke 7' (Table 5). These results contribute to the body of information that associates fruit calcium and boron concentrations with internal fruit quality.

Table 5 Effect of rootstock on the severity (% of flesh affected) and incidence (% of fruit with defect) of flesh discolouration and vascular browning of 'Hass' avocado fruit ripened at 20°C following storage for four weeks at 5°C. Values are means of 20 fruit from 10 trees per rootstock. Means in columns followed by different superscript letters are significantly different at $P \leq 0.05$ (Source: Marques *et al*., 2001).

Rootstock	Flesh discolouration	Vascular browning
Seedling Velvick	48^{a}	57^{a}
Clonal Velvick	44^{a}	57^{a}
Clonal Duke 7	63^{b}	74^{b}

Of perhaps greatest industry significance has been the discovery that rootstocks can determine the potential for fruit to develop anthracnose when ripening. Recent studies by Willingham *et al*. (2001), Marques *et al*. (2001) and R. Marques and P.J. Hofman (unpublished data, 2000) have found that 'Hass' fruit from trees grafted to 'Velvick' rootstocks have a lower incidence of anthracnose when ripened than fruit from trees grafted to 'Duke 6' and 'Duke 7'. For example, Willingham *et al*. (2001) reported that fruit from 'Velvick' rootstocks had a 61-82% reduction in the severity and a 34-35% reduction in the incidence of anthracnose when compared with fruit from trees grafted to 'Duke 6' rootstock (Table 6). The reason for differences between rootstocks are potentially due to differences in either the level of antifungal activity (diene) and/or are nutritionally based and are further discussed by Willingham *et al*. (2001) in this publication.

Table 6 Effect of rootstock on postharvest development of anthracnose in 'Hass' avocado ripened at 22°C (65% RH). Mean values in columns with different superscript letters are significantly different ($P \leq 0.5$) as tested by ANOVA (Source: Willingham *et al*. 2001).

Rootstock	% anthracnose	
	Severity	Incidence
3½-year-old trees		
'Velvick'	7.7^b	61.9^b
'Duke 6'	41.8^a	93.2^a
8-year-old trees		
'Velvick'	15.6^b	50.0^b
'Duke 6'	39.5^a	77.0^a

In a separate study, Marques *et al*. (2001) found that fruit from trees on cloned 'Velvick' rootstock reduce the severity of anthracnose before and after storage by 67 and 44%, respectively compared with fruit from trees on cloned 'Duke 7' rootstock (Table 7).

Table 7 Severity (% of flesh volume affected) of body rots caused by anthracnose in 'Hass' avocado fruit grown at Maleny and ripened at 20°C without or following storage for 4 weeks at 5°C from trees grown on either seedling 'Velvick', cloned 'Velvick' or cloned 'Duke 7' rootstocks. Data are means of 20 fruit from each of 10 trees and have been angular transformed. Means followed by different superscript letters are significantly different at $P \leq 0.05$ (Source: Marques *et al*., 2001).

Rootstock	Severity (% of flesh volume) of anthracnose	
	Without cold storage	After cold storage
Seedling 'Velvick'	11^{b}	24^{a}
Clonal 'Velvick'	7^{a}	20^{a}
Clonal 'Duke 7'	21^{c}	36^{b}

In a separate study at another site, fruit from trees grafted to 'Duke 6' had significantly more fruit develop anthracnose during ripening than fruit from 'Duke 7' trees (Table 8) (P.J. Hofman and J.R. Marques, 2000, unpublished data).

Table 8 Effect of rootstocks on the percentage of 'Hass' fruit that had body rots caused by anthracnose when ripened at 20°C immediately after harvest. Values are means of 20 fruit from each of 10 trees per rootstock. Means with different superscript letters are significantly different at $P \leq 0.05$. (Source: P.J. Hofman and J.R. Marques, 2000, unpublished data).

Rootstocks	Percentage of fruit with anthracnose
Seedling Velvick	54^{ab}
Seedling Duke 6	67^{b}
Seedling Duke 7	50^{a}

Thus, the influence of rootstocks on mineral nutrition may be a factor in the observed variability in anthracnose susceptibility, ripening and disorders, because of the relationship between fruit calcium and boron, and quality.

Vision 2020

Whiley *et al*. (1997) wrote "We are of the opinion that to meet the marketing challenges of the future, a more robust product is required; a fruit that will better withstand the stresses imposed from the 'shed to the plate', and a fruit that consistently and reliably meets consumer quality and price requirements". This concept is still valid today with perhaps greater urgency for the wider implementation of known practices that will improve fruit quality. The industry is spending a considerable amount of money to promote avocados but unless a product that meets consumer expectations is delivered then this investment is wasted.

This review has shown that collectively we have substantial knowledge of production factors that impact on fruit quality yet in some cases we are still some way off understanding basic mechanisms that will allow us to change knowledge into successful management procedures. Effective control of anthracnose and stem-end rot still poses one of the greatest challenges to fruit quality. Protectant fungicides are effective when applied correctly but there are practical limitations in what they can achieve. For instance, prolonged wet weather can break the cover and prevent the application of new material, thus allowing a window for infection. This may occur several times throughout a season. Attention to spray application techniques to optimise coverage is likely to result in some gains, as is the acceptance that a regular field program is required for 'Hass' because of its lack of immunity to anthracnose and stem-end rot infections. However, perhaps the result of greatest significance in the last four years has been the discovery that the choice of rootstock can significantly reduce the incidence of anthracnose in ripening 'Hass' fruit.

"*A journey of a thousand miles must begin with a single step*". This quote has been attributed to Lao-Tzu, a Chinese philosopher of around 300 BC and is most appropriate in the context of rootstock improvement. There has now been sufficient data assembled to show that at least the subtropical component of the Australian avocado industry needs to pursue rootstock improvement vigorously as substantial gains in fruit quality are indicated where superior stock/scion combinations than currently used are planted. Success in this area has the potential to revolutionise our industry just as phosphorous acid did during the 1980's. I trust with the advantage of "2020 Vision" your industry will move forward in this direction.

Acknowledgments

The author thanks the Australian Avocado Growers' Federation, the Horticultural Research and Development Corporation and the Department of Primary Industries Queensland for support to progress the ideas developed in this paper.

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