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FROM SEED TO TRAY SOME FIELD PRACTICES TO IMPROVE AVOCADO FRUIT QUALITY

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Abstract

Improvement in consumer confidence is seen as a key factor for increasing avocado consumption in Australia. Anthracnose and other fruit rots, chilling injury and physiological disorders are the major contributors to the poor reputation this fruit has among Australian consumers. Maximum, potential fruit quality is determined between fruit-set to harvest, and there are a number of procedures that growers can follow to produce more robust fruit that will better withstand the stresses imposed by the market chain. These include sound nutrition with the enhancement of fruit calcium concentrations, irrigation to avoid imposing stress, effective field spray programs with protectant fungicides, postharvest treatment with prochloraz and the timely removal of field heat. Inter-tree variability within an orchard is also identified as a limiting factor with respect to fruit quality. This is likely due to the widespread use of seedling rootstocks throughout the Australian industry. Rootstocks are reported to influence fruit quality through tree nutrition, particularly calcium. Other disease control strategies such as the enhancement of antifungal diene activity in fruit are discussed.

Introduction

The avocado evolved in the highland subtropical to tropical areas of Mexico, Guatemala and Honduras, where it grows as a rainforest sub-story species (Kopp, 1966). Three ecological races of avocado are recognised: Mexican, Guatemalan and West Indian. These races freely hybridise, giving rise to genotypes with adaptation from cool semi-arid to hot, humid tropical lowland climates (Whiley and Schaffer, 1994). Commercialisation of this crop has resulted in production across a range of environments, where cultivars have been selected to suit specific conditions. Our interest is in cultivars developed from the Mexican and Guatemalan races which are commercially important in Australia, Chile, Israel, South Africa and the USA (California).

Production in these countries occurs in two major climatic zones: cool and semi-arid with winter-dominant rainfall, e.g. California, Chile, Israel and southern Australia, and subtropical with summer-dominant rainfall, e.g. eastern Australia, Mexico and South Africa (Whiley and Schaffer, 1994). Each of these climatic zones have both advantages and disadvantages for fruit production. For instance, fruit yields are generally lower and less reliable in the cool and semi-arid areas compared to subtropical regions (Wolstenholme, 1997), but pests and diseases are less prevalent and tree growth less vigorous. Possibly as a consequence, fruit from the cooler environments are generally of better quality at harvest and at the end of the marketing chain.

Most of Australia's avocado production is sold on the domestic market, but there is a growing realisation that export markets need to be developed to maintain profitability. The New Zealand industry also markets avocados in Australia, mainly in the summer months when local supplies are low. The total number of avocado plantings in Australia has increased by 60% over the last six years (Australian Bureau of Statistics, 1996). In addition there has been similar trend in New Zealand with a subsequent increase in fruit from this country being marketed in Australia (G. Thomas, Toowoomba, personal communication, 1997). Thus, increased production from a growing tree population in both countries will put greater pressure on the Australian market over the next five years.

In Australia, fruit quality has been identified as a major factor limiting market development. For example, Smith *et al.* (1990) found over 40% of consumers were dissatisfied with avocados they had purchased, while Dermody (1990) reported 53% of consumers said avocados were unsatisfactory when served. Black or brown flesh was the most common cause for dissatisfaction. Several extensive surveys on the quality of avocados presented for sale in major retail outlets in Sydney in 1993 found that 14-25% of ripe fruit were unacceptable, mainly due to anthracnose, stem-end rot, chilling injury, and flesh browning attributed to bruising (Ledger *et al.* 1993; Ledger and Barker, 1995). The problems were greatest with 'Hass', probably because this cultivar is often sold in an overripe condition, which allows greater expression of defects (Ledger and Barker, 1995). Chilling injury was most prevalent at the end of summer when New Zealand 'Hass' dominated the market. Ledger and Barker (1995) suggested that these high-priced fruit were held too long by retailers.

Ongoing programs have been implemented to educate wholesalers and retailers on handling procedures to reduce spoilage of avocados, however this is unlikely to eliminate the "abuse" that occurs to the fruit throughout the marketing chain. A more holistic approach is required, and we believe that, strategically, the industry should be investigating methods of producing more robust fruit which are better able to handle stress beyond the farm gate. This paper discusses how this might be achieved. We have mainly confined our comments to 'Hass' because of its dominance in the Australasian market.

In pursuit of quality

It is an accepted principle that fruit quality reaches its peak at the point of picking. There are no postharvest techniques which can improve the 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 demand. For avocado, the main quality criteria are shape, size, colour, flavour, flesh texture, internal disorders, rots and skin blemishes (rubs, insect stings, etc.). Each sector of the consumer market has specific requirements for these characteristics, and will increasingly demand that the quality be consistently at the level they require. Lower quality, and especially inconsistency in quality, will negatively affect repeat purchase. Orchard management strategies should be implemented/developed to achieve these market requirements of specific quality and consistency.

Fruit shape

Although fruit shape is not an important fruit quality parameter, nevertheless long-term exposure of consumers to a specific cultivar, especially one as dominant in the market as 'Hass', establishes a norm for fruit shape. Departures from this norm usually result in loss of recognition leading to buyer resistance. While fruit shape is highly interactive with the environment, and hence generally beyond grower control, there are management factors which directly contribute to shape at harvest. Deficiencies of boron (Whiley *et al,* 1996b) and zinc (Wallihan *etal.,* 1958; Kadman and Cohen, 1977), particularly during early fruit growth, cause fruit distortion which can result in a high rejection rate at harvest. Mature summer leaf concentrations of these micro-nutrients ideally should be 50-60 mg kg^{-1} for boron and 40-50 mg kg^{-1} for zinc.

Mid-bloom foliar sprays of paclobutrazol (Cuitar®) in Australia and paclobutrazol and uniconizole (Sunny®) in Israel and South Africa, are being used to increase fruit size and yield of 'Hass' avocado. These plant growth regulators inhibit the biosynthesis of gibberellins and reduce the length:width ratio of fruit, thereby giving it a rounder shape (Wolstenholme *et al.* 1990). However, it was suggested that these changes in fruit shape were no greater than the variability typical of different environments, and would be unlikely to have any market impact.

Fruit size

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

- Manipulation by plant growth regulators such as Cultar® and Sunny® (Adato, 1990; Whiley *et al.,* 1991). These treatments have been shown to increase mean 'Hass' fruit size at harvest by about 13%.

- 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.

• Correction of boron deficiency through soil application of Solubor® has given an increase of 11-15% in 'Hass' fruit size in Australia (Smith *et al,* 1995). In South Africa, Bard (1997) found a 10% increase in fruit size following soil applications of boron to 'Hass' trees. Mans (1996) also reported an increase in 'Hass' fruit size in trees grafted to 'Duke 7' when foliar nitrogen (4.5 g/tree) and boron (30 mg/tree) were applied when the first flowers opened. In these trees, leaf nitrogen (1.17%) and boron (23 mg kg^{-1}) were sub-optimal prior to treatment.

• 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.

Colour

'Hass' is most easily identified by consumers with its change in colour from green to black as the fruit ripens, and the consumer generally considers the fruit ready to eat when the skin is fully black. However, the black skin colour may be a negative feature of 'Hass', since it can mask fruit defects which remain undetected until the fruit is cut (Ledger and Barker, 1995). Large variations in the skin colour of ripe 'Hass' fruit have been reported, which have no apparent association with maturity at harvest (S. Vuthapanich, 1997, Gatton, unpublished results). Light and crop nutrition, particularly nitrogen and calcium, are most commonly associated with skin colour of fruit (Proctor and Creasey, 1971; Hofman and Smith, 1994). However, these factors generally influence the red, green and yellow colours, and there is no indication of their effect on ripe 'Hass' colour. Studies are required to investigate the causes of irregular skin colouration, followed by the development of strategies that promote more even colouring.

Eating quality

Eating quality in most fruits is determined by cultivar, growing conditions, and the stage of maturity at harvest. Similar influences on avocado oil content have been identified (Lee, 1981), and this is likely to have an impact on avocado flavour and texture because of the important effect of oil on these parameters.

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.

Internal disorders and ripening

Internal disorders develop after fruit begin ripening, and are generally more prevalent in fruit which has been cold-temperature stored for extended periods. Cultivar (Milne, 1994), maturity at harvest (Cutting and Wolstenholme, 1988; Cutting *et al,* 1992; Donkin *et al.,* 1995; Sippel *et al.,* 1995), locality (Rowell, 1988), irrigation practices (Bower, 1985; Bower and Lelyveld, 1986) and rootstock and tree yield (Köhne *et al.,* 1992) can all effect the susceptibility of fruit to internal disorders. While the relationship between these factors and physiological disorders are documented, little is known of the mechanism(s) which result in reduced internal fruit quality.

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.

Mineral content and balance have been related to the development of physiological fruit disorders. Calcium is the mineral most frequently implicated, and there are numerous published reports of reductions in disorders in a range of fruit following improved calcium nutrition (Poovaiah *et al.,* 1988). In avocado, higher fruit calcium concentrations have been correlated with reduced chilling injury, flesh browning, pulp spot and vascular browning (Chaplin and Scott, 1980; Vorster and Bezuidenhout, 1988; Cutting *et al.,* 1992; Thorp *et al.,* 1995). In addition, there have been reports that potassium and magnesium concentrations, and in particular various ratios of fruit calcium, magnesium and potassium, are correlated to fruit quality (Koen *et al.,* 1990; Cutting and Bower, 1992). This is not surprising, as there is an interaction between these three minerals for uptake by roots (Ferguson, 1980). Smith *et al.* (1997) reported a higher incidence of internal discolouration in 'Hass' fruit stored at low temperature for fours weeks when taken from trees with low boron status. Boron is closely linked to calcium in plant nutrition being physiologically active at similar sites in the plant.

It has also been shown that fruit with lower calcium concentrations ripen more quickly than those with higher concentrations (Witney *et al.,* 1990a). Vuthapanich (1996, Gatton, unpublished results) found similar effects, and also noted large variations in days to ripen between trees in the same block.

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 possibly rootstocks. Calcium foliar sprays during fruit growth have little effect on internal concentrations in most fruit due to poor absorption by fruit, and lack of re-translocation within the tree. 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.

<u>Fruit rots</u>

In subtropical climates, anthracnose and stem-end rot are the most important fruit diseases of avocado which reduce eating quality. The anthracnose pathogen infects fruit during periods of extended rainfall, and remains latent until the fruit begins to ripen. Stem-end rots may be systemic within the tree and grow down the pedicel into the fruit during growth (Johnson and Kotze, 1994). The susceptibility of fruit to disease is dependent on cultivar (Prusky *et al.,* 1988) and fruit calcium concentration (S. Vuthapanich, 1996, Gatton, unpublished results). At present, control of these diseases is through a comprehensive field spray program with protectant (copper) fungicides (Peterson and Inch, 1980) followed by postharvest treatment with the systemic fungicide Sportak® (prochloraz) (Muirhead *et al.,* 1982). Orchard hygiene and postharvest temperature management also play an important role in disease reduction.

The current field control of anthracnose is only as good as the protectant coverage given to the fruit. Peterson and Inch (1980) reported that a 14 or 28-day field spray program with copper oxychloride to selected trees in an unsprayed orchard provided a 70% reduction in fruit disease. When the whole orchard was on a 28-day interval copper field spray program, protection increased to 91%, the improvement possibly due to reduced inoculum levels. In separate experiments, postharvest treatment of fruit with prochloraz increased anthracnose and stem-end rot control to about 98% (Muirhead *et al,* 1982).

The continuing problem!

We have reviewed proven strategies which will improve fruit quality. Many of these have been successfully implemented by growers, with resultant reductions in fruit deformity and disease, and increases in fruit size and eating quality. Yet, the avocado industry still has major problems with lack of consumer confidence in its product. Is there more to the story than meets the eye?

Ledger *et al.,* (1993) and Ledger and Barker (1995) identified anthracnose, stem-end rot, chilling injury and flesh browning as the major factors reducing confidence in fruit quality. While research has reported high levels of disease control with fungicidal programs (98%), the implementation of these programs at the commercial level will not be as effective. Research procedures also make use of statistical analyses to reduce the background variability so that a true measure of the various treatments can be obtained. This luxury is not available to the commercial operator, who must work with the variation within the orchard. Is variation between blocks and individual trees in the orchard of commercial significance? We believe the answer to this is most likely "yes", and supporting data is now available.

With respect to anthracnose infection, Coates *et al.* (1996) found considerable inter-tree variation 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% within a single rows of trees. Vuthapanich (1996, Gatton, unpublished results) also found similar levels of inter-tree variation within the same block of 'Hass' trees. While micro-environment effects may be a contributing factor to this variability, we believe there are stronger forces responsible for the variation.

Is it in the genes?

"No factor of the avocado industry is more important than rootstocks, and there is no problem that we know less about, or which requires a longer time to solve". This statement was made by Webber (1926) in California when avocado commercialisation was in its infancy, but it could equally apply to Australia today. The power of tree manipulation through selective use of rootstocks or rootstock/scion combinations has long been recognised by other fruit industries, and substantial gains have been made in fruit quality and yield through this approach.

Avocados where first introduced into Australia around 1850, and shipping traffic from the Americas ensured the establishment of a diverse population of seedlings in subtropical east-coast regions. While representing all races, this pool of material was predominantly of Guatemalan and West Indian origin. Selections from this material were used to establish the first commercial orchards in Queensland (seedlings) and subsequently were used as rootstocks as the improved cultivars from California gained in popularity. Like any industry growing up in a hurry and without a sound knowledge base, rootstocks were obtained from many different sources with selection criteria based on availability and nursery performance. Unfortunately, little has changed with time and our knowledge of rootstock performance remains small. However, some research and diligent record-keeping has provided insights into potential problems through indiscriminate use of genetically diverse material in orchards.

Thomas (1997) has kept detailed yield records over six years from 'Hass' trees grown on mixed, seedling rootstocks of Guatemalan/West Indian origin. His data have revealed large and consistent differences between the productivity of individual trees, with the best trees producing 400% more fruit than the worst trees over the period studied. Whiley (1994) reported rootstock effects on tree growth and physiology with 'Hass' grafted to seedling or cloned 'Velvick' a Guatemalan selection. In these trees, an overgrowth of the scion (expressed by a scion/rootstock girth ratio of > 1.0) was detected when cloned 'Velvick' rootstocks were used. In contrast, the scion/rootstock interface in trees grafted to seedling 'Velvick' was near normal (Table 1).

Table 1 Scion/rootstock girth ratios of 'Hass' trees grafted to cloned and seedling 'Velvick' rootstocks. The ratios were calculated from girth measurements taken immediately above and below the graft union. Data are mean values of five trees ± standard errors. From Whiley (1994)

Rootstock	Scion/rootstock ratio			
	1991	1992	1993	1994
Cloned 'Velvick'	1.15 ± 0.04	1.21 ± 0.04	1.20 ± 0.05	1.17 ± 0.01
Seedling 'Velvick'	0.94 ± 0.02	0.97 ± 0.01	0.98 ± 0.01	1.00 ± 0.01

In *Pinus contorta,* scion overgrowth has been attributed to translocation incompatibility caused by phloem degeneration and necrosis (Copes, 1975). Similarly this has been confirmed in avocado, where trees with a scion overgrowth (grafted to clonal 'Velvick') had higher scion starch concentrations than trees with no scion overgrowth (grafted to seedling 'Velvick') (Figure 1). It was also reported that rootstocks changed the percentage of determinate inflorescences in 'Hass', with trees grafted to cloned 'Velvick' producing about 80% of determinate shoots and trees grafted to seedling 'Velvick' rootstocks producing about 60% determinate shoots (Whiley, 1994).

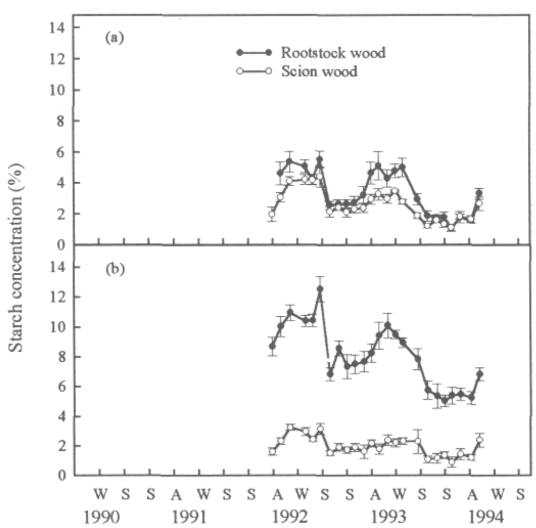

Figure 1 Effect of rootstock on seasonal changes in starch concentrations in scion and rootstock wood of 'Hass' avocado grafted to (a) cloned 'Velvick' and (b) seedling 'Velvick'. Data are mean values from 5 trees ± vertical SE bars

Rootstocks have been reported to influence aspects of fruit quality. Köhne (1992) found that fruit from 'Hass' trees grafted to 'Duke 7' were rounder than fruit from trees grafted to 'G6' and 'G755C'. Smith (1993) reported fruit from low-yielding 'Hass' trees (those grafted to 'Barr Duke' or 'D9' rootstocks) developed more internal disorders in storage (Figure 2). Fruit from high-yielding trees are known to be of better storage quality than fruit from low-yielding trees in Israel (Ben Ya'acov and Michelson, 1995).

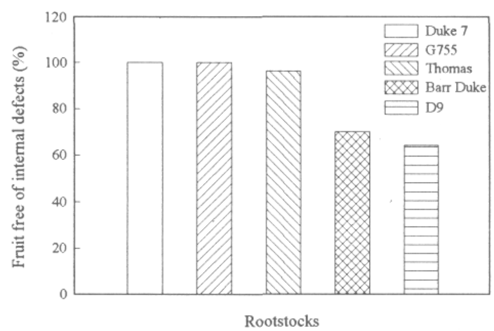

Figure 2 **Effect of rootstock on internal fruit quality (pulp spot, grey pulp and vascular discolouration) of 'Hass' following four weeks storage at 5°C. From Smith, 1993**

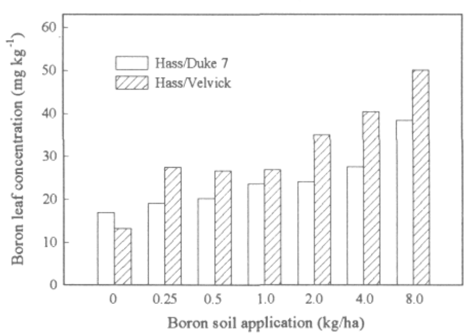

Figure 3 **The effect of soil boron application on leaf boron concentrations of 'Hass' grafted to 'Duke 7' or 'Velvick' rootstocks. From Whiley *et al.* (1996)**

The effect of rootstocks on mineral nutrition of fruit tree crops has been extensively reported, with selections in many crops being made to withstand adverse soil conditions. Studies with avocado have also demonstrated clear rootstock effects on tree nutrition. For instance, Haas (1950), Embleton *et al.* (1962) and Ben-Ya'acov *et al.* (1992) reported higher leaf calcium concentrations in trees grafted to Guatemalan compared to Mexican rootstocks. In contrast, trees on Mexican rootstocks had higher leaf potassium concentrations than trees on Guatemalan rootstocks (Haas, 1950). Whiley *et al.* (1996b) reported higher leaf boron concentrations in 'Hass' trees grafted to the Guatemalan rootstock 'Velvick' compared to those grafted on the Mexican rootstock 'Duke 7' (Figure 3). Field observations confirm that under marginal soil boron conditions, trees grafted to Mexican race rootstocks have stunted growth and low yield compared to trees on 'Velvick' rootstocks (Whiley, unpublished results). Bard (1997) has also reported higher leaf boron concentrations in 'Hass' trees grafted to 'Edranol' (a

Guatemalan race cultivar) than those grafted to 'Duke 7'.

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.

Growing more robust fruit

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. How is this likely to be achieved?

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.

The high level of variability in disease susceptibility and storage potential of fruit between trees urgently needs to be addressed. This is potentially the area of greatest gain for improvement in anthracnose and stem-end rot control, and storage performance and internal quality. Although genetic solutions are long-term in both delivering results and in implementation, it is highly likely that the solution lies with the development of rootstocks or rootstock/scion combinations which will enhance and improve the uniformity of tree nutrition. The calcium connection warrants further and more detailed investigation both on its effect on quality and its long term management in the orchard.

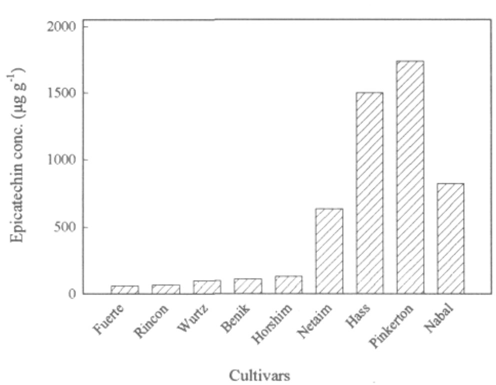

Figure 4 **Comparison of epicatechin concentration in ripe fruit of several avocado cultivars after storage at 20°C. Data are means of three determinations. From Prusky *et al*., 1988**

In relation to other disease control strategies, studies of the anti-fungal compounds in avocado fruit may lead to opportunities to manage these potentially powerful and natural fungicides, which are found in high concentrations in the skin and flesh of unripe avocado fruit. For example, it has been shown that the anti-fungal dienes at 790 ug ml^{-1} completely inhibit spore germination of anthracnose *(Colletotrichum gloeosporioides),* which is considerably less than the 1200 ug gfw^{-1} commonly found in the peel of unripe avocados (Prusky *et al.,* 1982). However, diene is metabolised during ripening, allowing latent infection structures of the anthracnose fungus to resume growth. Epicatechin is an inhibitor of the enzyme which breaks down diene. Prusky *et al.* (1988) reported a correlation between epicatechin concentration and the degree of anthracnose tolerance in avocado cultivars. In the anthracnose-susceptible cultivars Fuerte, Horshim, Wurtz, Rincon and Benik the epicatechin peel concentration in soft fruit decreased to 60-130 jag gfw^{-1}. However, in the more resistant cultivars Hass, Nabal, Netaim and Pinkerton it was 632-1740 ug gfw^{-1} in ripe fruit (Figure 4). Thus, the challenge is to maintain higher anti-fungal concentrations in fruit as they ripen, so that fruit are consumed before disease is excessive. A number of different approaches to maintaining high diene concentrations are currently being explored, including various chemical, physical and biological treatments. For example, US/Israeli research has shown that diene levels can be maintained to some extent through the application of non-pathogenic strains of the anthracnose fungus to detached avocado fruit (Prusky *et al.,* 1994). Development of anthracnose symptoms in fruit was delayed as a result of this treatment, presumably due to enhancement of diene levels. Thus non-pathogenic strains can be used to "cross-protect" against normal pathogenic strains of the anthracnose fungus. We intend to explore this option in more detail.

In conclusion, it is important to remember that there are no easy answers to these problems, and they will only be solved through a holistic approach involving integrated management strategies.

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