MANAGEMENT OF FRUIT SIZE IN ‘HASS’

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ABSTRACT

‘Hass’ trees produce a population of fruits, 5-25% in cooler, wetter and mesic conditions but up to 50% in warmer, more stressful conditions, that weigh less than ca 160-170g and fetch lower prices. The causes of the small fruit syndrome are discussed, and recent research on the metabolic control of fruit growth summarized. Remedial measures centre around stress reduction, maintenance of fruit cell division, and avoidance of premature seed coat senescence. Mulching is highly beneficial, and adjustments can be made to some cultural practices. Uniconazole sprays are effective in increasing average fruit size.

INTRODUCTION

The ‘Hass’ cultivar is the mainstay of the avocado industries in subtropical and Mediterranean countries and areas. These include California, Israel, Spain, Chile, South Africa, Australia and New Zealand. It has also come to dominate in commercial orchards in the highland tropics of Mexico. It has eclipsed ‘Fuerte’ due to more reliable bearing in relatively cool climates, and generally better fruit quality in respect of post-harvest disease and shelf-life. However, ‘Hass’ fruit is genetically smaller on average than most commercial cultivars.

Under any set of environmental conditions and management strategies, fruit size will follow a typical bell-shaped curve. The problem is that even under the best conditions, an unacceptably high proportion of fruit will be too small to reliably realize good prices. Hence strategies to reduce the extent of the ‘Hass’ small fruit problem have received the attention of researchers, especially in the 1990’s when more important problems such as Phytophthora root rot were largely brought under control.

This paper will briefly review the extent of the problem; the anatomy and physiology/ metabolic control of fruit growth; and the practical measures that growers can implement to alleviate the extent of the ‘Hass’ ‘small fruit phenotype’. It must be appreciated at the outset that the problem is essentially genetic. At best, all the grower can do is shift the bell-shaped fruit size distribution curve towards a higher proportion of medium to medium-large fruit. This will depend on the extent of the problem and on environment, but a grower who does the basics right can probably expect no more than a 15-20% increase in average fruit weight by fine-tuning management.

EXTENT AND CAUSES OF THE PROBLEM

Just what constitutes a 'small', fruit is a matter of local experience. Market acceptance at a good price, especially in 'on' seasons when supply may exceed demand, is the key issue. The export-oriented South African industry, with markets mainly in France, the U.K. and other European countries, has found that fruit counts of 20 or more per standard 4 kg export carton can fetch notably lower prices in over-supplied overseas markets. This equates to a fruit weight of ca 190g or less. Kremer-Köhne (1998) stated that fruits weighting >160g are exportable. Currently, in an attempt to reduce the impact of an over-supply, fruit weighing less than 171g, i.e. of counts 22 and higher, requires special dispensation for export from South Africa. Experience has shown a dramatic price decline of counts 24 (156-170g) and 26 (146-155g), to the extent that production and marketing costs may not be met. In 1994, the small fruit problem was estimated to have cost the industry R30 mill. in lost revenue (Moore-Gordon & Wolstenholme, 1996).

Köhne (1992) stated that up to 50% of the 'Hass' crop may be undersized, which he defined as count 20 or higher (191-210g fruit weight or less) per 4 kg carton. Even healthy trees produce 5-25% of small fruit in the warm, humid subtropics of Westfalia Estate, Tzaneen, South Africa. The problem is obviously worse in diseased, unhealthy or old trees, and certainly in stressed trees. In the latter regard, there is anecdotal evidence that high mean temperatures during fruit growth may reduce average 'Hass' fruit size by ca 30%, and this certainly reflects industry experience. An example is the difference between warm coastal subtropical Childers in Queensland, and cool sub-tropical and more elevated Maleny. Mean temperatures for the 4 months preceding fruit maturity were 28.6/19°C and 21.4/13.6°C respectively (Whiley & Schaffer, 1994). A later report noted mean fruit weights over 4 years of 195 ± 6.5g versus 227 ± 3.6g respectively, i.e. a 17% increase for the cooler site (Whiley *et al*., 1996). This assumes greater importance in view of expected significant global warming by 2020, with further temperature increases through to 2100.

Industry perceptions of larger mean fruit sizes in 'Hass' grown in cooler, moister, more mesic environments are also borne out by experience in South Africa (KwaZulu-Natal midlands vs Nelspruit or Levubu), as well as New Zealand. Furthermore, the cool tropical highlands of Michoacan State, Mexico, also characterised by well-aerated andosols, appear to produce larger 'Hass' fruit on average. Certainly, 'Hass' performs better in less stressful environments.

Other causes of the small fruit syndrome include poor tree condition. Healthy trees produced less than 20% small fruit, whereas moderately declined trees (Phytophthora root rot) produced more than 80% small fruit. At the other extreme, excessive vigour may reduce fruit size due to vegetative competition during the main cell division phase in fruits. A balanced crop load with a good leaf: fruit ratio is sought : a very large crop reduces average fruit size. Young trees typically have larger fruit than older or larger trees. Large trees have more fruiting sites, and expend more energy (carbohydrates) in transporting assimilates and water to the fruit sinks. There is also evidence from Israel that cross-pollinated fruits (especially 'Hass' pollinated by 'Ettinger') not only set better, but also end up larger (Guil & Gazit, 1992). In South Africa, Robbertse *et al.* (1996) reported that ‘Ettinger’ pollen had a positive influence on ‘Hass’ seed size, such fruits likely to be larger in size, but did not observe the yield decline with increasing distance from the pollinator which was found in Israel.

The avocado fruit is dependent on a viable seed and seed coat, the latter appearing to have critical importance, for longer than most fruits for normal fruit growth. An obvious manifestation of this is the size difference between seeded fruit and seedless “cukes” (Blumenfeld & Gazit, 1974). “Cukes” are effectively seedless due to early seed degeneration (stenospermocarpy). Small fruits in contrast have a viable seed, but the seed coat senesces and dries prematurely, thereby arresting further fruit growth by loss of vascular contact between seed and fruit flesh. This is accompanied by loss of effective cell-to-cell communication (Moore-Gordon *et al.*, 1998). The avocado seed coat is unusually thick and fleshy in developing, normal fruits, and it is permeated by vascular traces entering in a ring, from the flesh, at the distal end of the seed. Steyn *et al.* (1993) interpreted it as a pachychalaza, rather than the more usual seed coat derived from integuments of the ovule. A close correlation between seed size and fruit size is therefore found (Moore-Gordon *et al.*, 1997). Premature dieing of the seed coat is a common feature of ‘Hass’ small fruit. It is associated with environmental stress, one manifestation of which is a high incidence of fruitstalk ringneck (Whiley *et al.*, 1986; Whiley & Schaffer, 1994; Moore-Gordon *et al.*, 1997).

METABOLIC CONTROL OF AVOCADO FRUIT GROWTH

The ‘Hass’ small fruit problem gave rise to detailed studies of both the anatomy and the physiology and biochemistry of fruit growth at the University of Natal in South Africa. Moore-Gordon *et al*’s (1997) study of alleviation of environmental and tree stress by mulching, to promote root health, is well known, and I summarized the horticultural aspects of this study at your Rotorua Conference (Wolstenholme *et al.*, 1997). Since then Cowan and co-workers have looked in detail at the metabolic control of ‘Hass’ fruit growth. Their pioneering studies were recently summarized in an invited review (Cowan *et al.*, 2001), using the small fruit phenotype as a model for fruit growth in general. Prior ground-breaking papers in this series include Cowan *et al.* (1997); Moore-Gordon *et al.* (1998); Campbell *et al.* (2000); and Richings *et al.*, 2000).

Cowan *et al.* (2001) note that developing fruits are terminal sinks requiring a carbohydrate energy source, other metabolites, minerals, adequate water and plant hormones, which directly or indirectly alter gene expression, for sustained growth. ‘Hass’ trees produce both normal and phenotypically small fruit (Zilkah & Klein, 19987), but with no obvious pattern to fruit distribution on the tree. Anatomical studies (Moore-Gordon *et al.*, 1997) indicate that small fruit size is limited by cell number rather than cell size. The keys to normal fruit size are therefore to maximize cell division and maintain seed coat integrity until fruits are fully grown at horticultural maturity. Cowan *et al.*’s (2001) studies therefore focussed on metabolic events believed to be closely linked to fruit cell division. These are: plant hormone homeostasis; carbohydrate content and composition; and isoprenoid metabolism.

The current state of our knowledge is conceptualized in Fig. 1 (Cowan *et al*., 2001). The complex biochemistry underpinning the model is beyond the scope of this paper. However, distinct differences were found between normal and small fruits, and possible interactions and signalling cross talk between hormones and sugars are implicated. A host of important enzymes control the various steps.

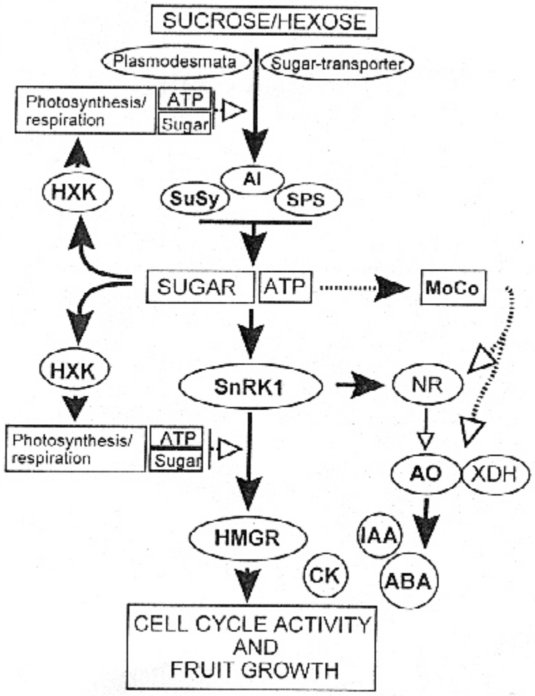

Fig . 1 Hypothetical scheme illustrating the temporal relationship between sugar sensing and signalling by SnRK1/HXK, activity of HMGR and plant hormones in sink cells of developing avocado fruit. Alternations in sugar content and composition coupled with changes in adenylate status impact on activity of HXK, SnRK1 and MoCo biosynthesis and allocation to maintain the supply isoprenoid compounds and optimise the sucrose/hexose ratio and plant hormone homeostasist for active cell proliferation, sustained sink strength and fruit growth. (Cowan *et al.*, 2001)

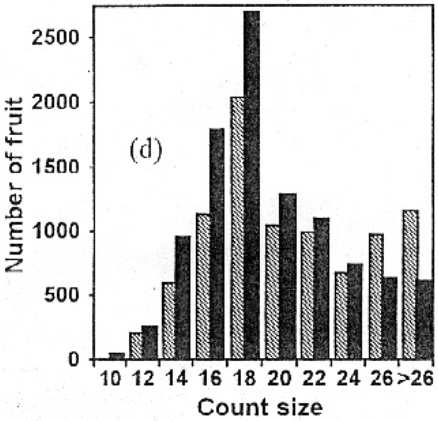

Fig. 2 Hass fruit size distribution by count per 4kg export carton, cumulative for three seasons. Solid bars represent mulched trees; striped bars unmulched trees (from Morre-Gordon *et al.* (1997).

Seeds of small as compared to normal fruits have aberrant plasmodesmatal structure-function, and loss of chemical communication from cell to cell. They also have ca 70% less activity of the key enzyme HMGR which regulates cell division dependent of the supply of isoprenoid compounds. Sucrose synthase (SuSy) enzyme activity is also reduced in the flesh, while that of insoluble acid invertase (AI) is increased in the seed. Seeds accordingly have a decreased sucrose concentration and an increase in the proportion of glucose. They are also higher in the hormone inhibitor ABA and its catabolites. Fruit flesh also has impaired plasmodesmata. In the flesh tissue, the Cytokinin (CK) to ABA ratio seems critical to post-phloem solute transport, growth rate and final fruit size. ABA metabolism is greater in small-fruit tissues. Applied ABA mimics the small fruit phenotype, while CK application negates the ABA effect. Clearly, hormone balance is important, probably allied to low flesh auxin content.

Summarising (see Fig. 1), Cowan *et al*. (2001) conclude that the enzymes HMGR and SnRKI are central to fruit growth and cell division. They suggest that fruit and seed sugar content and composition (sucrose: hexose ratio) of sink cells impact on SnRKI (and hexokinase, HXK) to modulate expression of sugar metabolizing enzymes, HMGR and molybdenum cofactor (MoCo) – containing enzymes. These changes affect hormone metabolism by affecting the allocation of purine-derived MoCo to aldehyde oxidase (AO), and thus the concentration of auxin, ABA and CK to alter hormone homeostasis. Essentially, seed coats senesce and cell growth is arrested by sucrose starvation, and fruits become horticulturally mature. AO may also increase reactive oxygen species and oxidative damage (browning) of seed coats in horticulturally mature fruit.

An interesting aspect of the avocado tree's translocation is the importance of the 7C sugar alcohol, perseitol, and its reduced form, manno-heptulose, in addition to the normal sucrose, recently studied by Liu *et al*. (1999). Their role in avocado fruit growth and the small fruit problem is unknown, but these authors have suggested that they may be inhibitors of fruit ripening.

PRACTICAL ASPECTS OF MANAGING 'HASS' FRUIT SIZE

If growers are confused by the above discussion of fruit growth biochemistry, they are in good company. We still have to sort out cause from effect, and recognise critical steps that are susceptible to manipulation. The processes are extremely complex, but again there appear to be two over-riding themes – maintenance of cell division, and delaying of seed coat abortion. Essentially this means maintaining the sink strength of the highest possible proportion of fruits, and their ability to compete against other sinks. The grower will intervene most successfully on the side of the fruits by reducing environmental and tree stress, and by eliminating or reducing the impact of limiting factors. These are nutrition, irrigation management, and orchard floor management, aided by timely plant protection and, hopefully, application of plant growth regulators.

Reducing Stress

Stress, if sufficiently severe and prolonged, slows down cell division and therefore organ growth. Stressed tissues increase in ABA concentration, altering the CK/ABA ratio. Net carbon assimilation in photosynthesis decreases; use of energy in respiration may increase. Stressed trees have impaired water relations, and canopy temperatures rise (Moore-Gordon *et al*., 1997). A cascade of events is set in motion, and mostly they do not benefit fruit size. Stress must be minimized, and even more so with anticipated global climate change.

Mulching

One of the simplest and most practical ways of reducing stress is to reinforce the natural leaf mulch under avocado canopies. Table 1 summarizes a three year trial, in which fruit weight was increased by an average of ca. 7% in spite of an average nearly 15% increase in fruit number and a 23% increase in yield per tree.

Table 1 Summary of effects of pinebark mulching on 'Hass' avocado productivity and fruit size. Means of three years, six trees per treatment (Moore-Gordon *et al*., 1997).

	Control	Mulch	% increase
Mean fruit mass (g)	203.1	216.5	6.6**
No. fruit/tree	509	540	14.7**
Yield kg/tree	100	122	22.6**

- Significant at P≤ 0.01

Fig. 2 summarizes the fruit count distribution for mulched and control trees. Moore-Gordon *et al*. (1997) concluded that mulched trees produced 45% more fruit in the "highly suitable for export" category, and reduced the "unsuitable" fruits by 29%. The initial high cost of the composted pine bark mulch was offset in the second season; the half-life of the mulch was estimated at 5 years. Root growth of this shallow-rooted, litter-feeding tree was strongly promoted. Mulched trees had ca 39% lower incidence of dead seed coats at harvest; and 7.1% fruits with ringneck as compared with 13.4% in control trees (the experiment was conducted in a cool, fairly mesic area).

Irrigation management

There is no doubt that irrigation plays a major role in relieving the stress associated with reduced cell division, and probably also premature seed coat abortion, associated with small fruits. Increasing irrigation has been shown to increase fruit size in Israel (Lahav & Kalmar, 1977) and South Africa (van Eyk, 1994). Milne (1994) noted that fruit size in a well cared for, irrigated orchard in a high rainfall area averaged 200-285g during a season of higher rainfall, as compared to 165-229g in the following drier year. There is however the danger of increasing fruit number at the expense of fruit size, as found in California by Faber *et al*. (1998) and in Queensland by Vuthapanich *et al*. (1998). Mulching reduces this danger (Moore-Gordon *et al*., 1997).

It is noteworthy that the subtropical type of avocado evolved in cool climates in which flowering occurs during a marked dry phase, and under these conditions the tree has reasonable drought tolerance (Wolstenholme & Whiley, 1999). Delayed onset of spring rains probably also reduces vegetative competition with setting fruits. However, such strategies also make for boom or bust cycles of fruiting, and a bumper "mast" crop every few years will certainly be at the expense of fruit size.

In commercial orchards, timing of irrigation according to tree phenology will influence both yield, and fruit size and quality (Whiley *et al.*, 1988). Depending of course on rainfall patterns, soil water storage capability, and salinity considerations where this is a factor, water needs are regarded as moderate to high during the critical fruit set period. They are highest at the start of the second shoot growth flush coinciding with the second fruit drops (usually January) when temperatures are highest. They then decline in autumn and winter, when a mild degree of tree stress is beneficial to a well synchronized and fairly heavy flowering in the humid subtropics. These are the principles – the actual practices are spelt out in the latest extension literature.

Gafni (1988) notes the adoption of new irrigation concepts in Israel, the main concept being reduction of stress year-round under their semi-arid winter rainfall conditions. To have a tree looking healthy (well-foliated) at flowering, optimal irrigation management is needed in the dry summer (April-October). Evaporation index coefficients used range from 0.35 in April to 0.65 in June, 0.80 in July, and 0.85 from August through October. Irrigation frequencies have also been increased, with recommended daily irrigation.

Nutrition

It is obvious that balanced nutrition, based on leaf and soil analysis, is vital to cropping, and furthermore every essential plant nutrient plays a role in fruit growth. In addition, soil ameliorants such as liming compounds indirectly benefit root growth and therefore nutrient uptake. It is also true that the comparative nutrient needs of the avocado tree are lower, per tonne of fruit, than for other subtropical tree crops (Lahav & Kadman, 1980; Wolstenholme, 1991), although this must not be misinterpreted as permitting low fertilization rates under all conditions – especially with heavy cropping and on nutrient-poor soils. Nevertheless, certain nutrient elements have been shown to directly affect fruit size, and should be emphasized where a small fruit problem occurs.

The work of Cowan *et al.* (1997; 2001) stresses the importance of maximizing cell division in fruit during the first 7-8 weeks after fruit set. Two key trace elements have been shown, if deficient, to reduce fruit size, viz boron (B) and zinc (Zn). Increases in 'Hass' mean fruit size with adequate soil B fertilization were 15% in Queensland (Smith *et al.*, 1997) and 4% in South Africa (Bard & Wolstenholme, 1997). In both cases, B-deficient, leached acid soils are involved. Insufficient B during fruit set and early development can result in distorted and smaller fruits (Whiley *et al.*, 1996; Whiley & Hofman, 2000). Similarly, Zn deficiency causes smaller and rounder fruit (Ruehle, 1940; Gustafson, 1973; Crowley *et al.*, 1996; Whiley & Hofman, 2000).

Nitrogen (N) is the key manipulator element, controlling vegetative vigour and the vegetative/reproductive balance. The phenological model for the humid subtropics (Whiley *et al*., 11988) emphasizes applying most of the annual N to the summer rather than the spring growth flush, to reduce vegetative/reproductive competition with setting fruits. This is undoubtedly a sound strategy for vigorous cultivars such as 'Fuerte' and 'Sharwil'. However, 'Hass' requires more N, especially in older trees, to maintain sufficient vigour for reasonable fruit size. Lovatt (1999) reported increased cropping and larger fruit size in California (winter rainfall climate) if extra N was applied during fruit set or at the end of the autumn growth flush (mid-November, = mid May S.H.). Clearly, N levels must be managed according to local conditions.

There is increasing interest in avocado fertilization programmes in both P and K, the latter especially in leached sandy soils (as in New Zealand; Cutting, 1999). Cutting is also experimenting with DRIS norms, based on nutrient balance and ratios. In view of the importance of molybdenum (Mo) in the cell division cycle (Cowan *et al*., 2001), it is perhaps time to investigate this neglected trace element in leached acid soils. Fertigation is an ideal method of delivering nutrients in small does when needed.

Orchard floor management

The programme adopted will depend on factors such as rainfall intensity, timing and amount; soil characteristics; planting density and canopy management; and topography. In high rainfall areas with steep slopes, some form of controlled vegetative cover is needed to reduce soil loss, whereas in hot, dry areas weeds and grass are highly competitive. Generally speaking, management adopts a compromise – a herbicided strip down the tree row, with a controlled vegetative soil cover between rows. Competition is ameliorated by extra irrigation and fertilization. Some soil cover is also more compatible with the concepts of sustainability and biodiversity in orchards, likely to be more emphasized towards 2020. In terms of maximizing 'Hass' fruit size, competition in spring and early summer would be most unwanted, as this is when cell division in fruits is at its maximum. However, the midsummer fruit drop is also aggravated by competition at a stressful and often dry time.

Plant Growth Regulators

The growth retardant Cultar® (paclobutrazol) has been used as a foliar spray to control excessive vigour at the fruit set period. Significant yield increases have been achieved for both 'Hass' and 'Fuerte' if measured over more than one growing season. Cultar® sprays at mid-anthesis, at 2.5 and 1.5g a.i. l^{-1}, increased 'Hass' fruit size by 16 and 11% respectively (Whiley *et al.*, 1991). Fruit size was also increased in Israel (Adato, 1990) and in South Africa (Kremer-Köhne, 1998). However, although obtaining registration, such sprays were not widely used, probably because of their expense, and the persistence of paclobutrazol in the tree.

Since the mid-1990's, Adato and co-workers in Israel obtained excellent results with a very similar but less persistent chemical, registered as Sunny ® and chemically known as uniconazole. This growth retardant is now widely used in pruned orchards in Israel as part of a package of manipulatory measures to control vigour in crowding orchards. Erasmus & Brooks (1998) found in South Africa that 1.0% sprays of Sunny 50SC at early flowering increased both yield and fruit size in ‘Hass’, with more fruits in the lower counts (12,14 and 16 per 4kg carton) that fetch up to 50% higher prices than smaller fruit. Fruit shape is altered (as for Cultar sprays) to a more oval or round shape.

Penter (2001) reported on further Sunny® trials in South Africa. He noted that the response to growth retardants depends on crop size and tree vigour. The effectiveness of Sunny® declines (in terms of yield) with increasing crop load, but it is necessary for improved fruit size. It is best used in “off” years and on high potential soils where vigour limits yield. Fruit size is increased regardless of yield. No residues were found in fruit with 0.5% and 1.0% sprays after 63 days. The withholding period registered in South Africa is 84 days. Sunny® is now quite extensively used, also on other cultivars and in pruned orchards. Gafni (1998) also notes recent changes in Israel, with commercial use of GA-synthesis growth inhibitors now widely used on most cultivars in vigorous orchards. This has significantly increased yield, and in ‘Hass’ , ‘Ettinger’ and ‘Pinkerton’ increases in fruit size. There is scope for new, improved growth retardants, perhaps arising from our better understanding of fruit growth.

NEW ‘HASS’-LIKE CULTIVARS

As the ‘Hass’ small fruit syndrome is basically a genetic problem, the ultimate solution lies in breeding – of both scion and rootstock. In the interim, the search in on for ‘Hass’ look-alikes with improved horticultural features if possible. Such research is underway in most subtropical avocado producing countries, with most of the promising selections coming from California and Israel.

Kremer-Köhne (1998) reported on an orchard at Westfalia Estate where 15 new avocado cultivars were topworked to trees on ‘Duke 7’ rootstock, with provision for expansion. With regard to ‘Hass’ look-alikes, Kremer-Kohne (2001a) gave initial results for 6 Californian selections (‘Harvest’, ‘Gem’, ‘Jewel’, ‘Sir Prize’, ‘BL-667’ and ‘99998-22-5’) and one Westfalia selection (‘Bonus’) compared with ‘Hass’. ‘Harvest’ was best after two crops. Kremer-Köhne (2001 b) also gave a final report on ‘Lamb Hass’, which matures later than ‘Hass’ at Westfalia (Aug-Oct as compared to May-Aug.). Suffice to say that it is a very precocious and productive cultivar, but with somewhat inferior fruit quality and different postharvest behaviour. It is in reality not so much an improved, larger '‘Hass'’ but a new cultivar requiring marketing as such. It needs to be handled with care; trees kept in good condition (more sensitive to stress), and marketing sorted out. Research continues, and there is a need for 2 or 3 new elite cultivars to supplement ‘Hass’.

CONCLUSIONS

The ‘Hass’ small fruit syndrome is a genetic fault of an otherwise good cultivar, affecting a varying proportion of the crop; more in warm, dry stressful areas and less in cooler, humid and more mesic environments. It is also worse in older trees, suggesting that rejuvenated, pruned trees with better leaf: fruit ratios and improved canopy light interception will produce larger fruit. New Zealand growing conditions, although on the cold side, seem to amongst the best for producing larger average fruit size.

Much has been learnt about the metabolic control of ‘Hass’ fruit growth, but at present the most obvious message for growers is still the need to alleviate environmental, root and tree stress. At best, growers doing the basics right can expect to increase average fruit size by 15-20% by adopting specific additional strategies. Growth retardant chemical sprays at mid-anthesis, especially with uniconazole, are effective, especially where vigour is problematical and cropping light. Mulching is highly beneficial in most situations. Fine-tuning of irrigation, nutrition and orchard floor management can be helpful. In the longer term, larger-fruited ‘Hass’-like selections, and probably also improved rootstocks, will be needed. Effective Phytophthora root rot control is considered to be non-negotiable.

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