Appendix B. Technical summary -

TECHNICAL GROWER SUMMARY OF THE REVIEW OF PREHARVEST MINERAL NUTRITION EFFECTS ON AVOCADO POSTHARVEST QUALITY IN AUSTRALIA

Project AV19004

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INTRODUCTION

A consistent supply of good quality avocado fruit is essential to grow and retain markets, however the quality of Australian avocados reaching consumers often fails to be of an acceptable standard. In 2017, an online survey of 1000 avocado buyers found that half of them often won't buy avocado because they are not satisfied with the quality available. Several strategies are being pursued to achieve better fruit quality but one that has not been closely examined until now is the effect of the mineral composition of the fruit. Many pre-harvest factors contribute to this including scion and rootstock genetics, soil properties, soil moisture, fertiliser practices, canopy management, climate and weather.

This study examines existing evidence of the relationship between mineral composition and fruit quality, outlines steps that can be taken to improve fruit robustness through better mineral content and provides recommendations for further research on the topic.

Table 1 summarises the associations between fruit mineral nutrient status and the development of postharvest rots and other quality defects in avocado as suggested by research.

Table 1. Fruit mineral nutrients in the peel or flesh associated with increased (+) or decreased (-) expression of postharvest quality defects in avocado fruit. Blank spaces indicate no association or no information available.

Defect name	Mineral nutrient										
	N	P	K	Ca	Mg	B	Mn	Si	Zn	N/Ca	(Ca+Mg)/K
Body rots	+	+	+/-	-	+/-	-		-		+	-
Stem end rot	+		+	-	+/-			-		+	-
Diffuse discolouration	+/-	+/-	+	-	-	-	-				+/-
Vascular browning	+			-		-					-
Vascular leaching	+		+/-	-	-					+	-
Pulp spot		+	-	-					-		
Discrete patches	+		+		+						-
Endocarp black spot						-					

MINERAL NUTRIENTS ASSOCIATED WITH POSTHARVEST QUALITY

1. Calcium

Calcium plays a dominant role in determining fruit quality. It combines with pectin in plant cell walls to give mechanical strength to fruit tissues and protection against degradation of the cell-wall. It also stabilises membranes and prevents leakage of cell contents. Fluctuations of calcium levels in cell sap act as a signal to trigger the plant's defence mechanisms against pathogen attack and environmental stresses (e.g. heat).

Elevated calcium levels in avocado fruit have been linked to delayed ripening, greater firmness after storage, reduction in quality defects (including rots associated with pathogens) and physiological disorders that include diffuse flesh discolouration and vascular browning. However total concentrations of calcium in 'Hass' avocado fruit have been found to vary greatly, ranging from 78 to 2500 mg kg^{-1} (dry weight) in the flesh and 230 to 1130 mg kg^{-1} (dry weight) in the peel. Within-tree variation is also marked, with flesh calcium levels ranging from ~800 to ~2500 mg kg^{-1} (dry weight) in a sample of 100 fruit harvested from the same tree.

A likely reason for the wide range of calcium levels in the plant is interaction between calcium and other mineral nutrients. The balance of fruit calcium to other nutrients, particularly nitrogen, potassium and magnesium, is more important for avocado quality than calcium concentration alone.

Calcium uptake by plants is a passive process driven largely by transpiration. The rate of calcium uptake is greatest at the root tip which is also the first point of attack of Phytophthora root rot, making it a particularly important factor to consider in Australia where this disease is rife. It should also be borne in mind that other cations such as sodium, potassium and magnesium compete with calcium for uptake.

Transport of dissolved calcium from the root occurs through the transpiration stream via the xylem (water conducting tissue) to leaves, flowers and fruits. Calcium uptake by plant organs is also driven by the plant hormone auxin which tends to be greater during periods of high metabolic activity. Hence, calcium mostly accumulates in plant organs that are actively growing and transpiring. Once deposited, calcium does not readily translocate to other organs. Lack of mobility, initial non-uniform distribution to plant organs (e.g. leaf vs. fruit) and the fact that leaves continue to transpire for their entire lifespan but fruit don't mean that leaf calcium concentrations are generally not a reliable indicator of fruit calcium levels.

Avocado fruit demand for calcium is greatest within the first eight weeks or so after fruit set whilst they are transpiring through their stomata, however after this period the stomata on the fruit become dysfunctional, form lenticels and cease to transpire. It is therefore critical to create conditions that favour calcium transport to the fruit during this early period. Providing adequate calcium supply in the soil is only part of the answer (Figure 1). Uptake by roots requires a correct balance of soil nutrients and sufficient soil moisture for calcium to enter the soil solution. How much calcium then reaches the fruit largely depends on xylem sap flow as influenced by transpiration and growth rates and competition from vegetative tissues. Factors that reduce transpiration (e.g. low vapour pressure deficit and stomatal closure), or increase the ratio of vegetative to reproductive material on the tree (e.g. over-supply of nitrogen fertiliser, low crop load, fruit thinning and insufficient or poorly-timed pruning) will limit fruit calcium uptake. Although interactions are complex, there is scope within a grower's control to manipulate factors to help maximise fruit calcium levels.

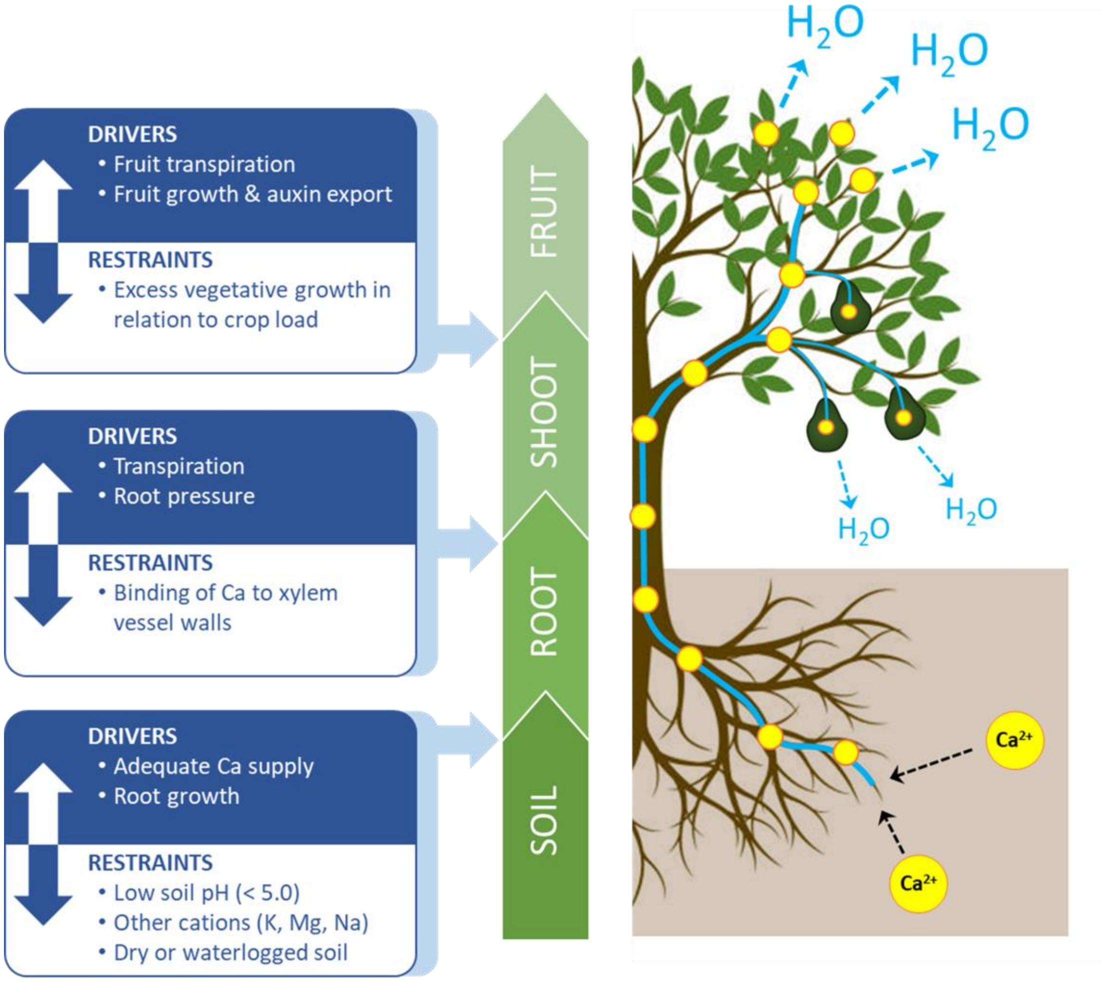

Figure 1. Processes of calcium accumulation in avocado fruit.

2. Nitrogen

Plant requirement for nitrogen is greater than any other mineral nutrient. An inadequate supply can result in lower yields, smaller fruit and less vegetative growth to support flowering and fruit set in subsequent seasons. On the other hand, an over-supply of nitrogen during fruit development can negatively impact fruit robustness because too much nitrogen promotes excessive vegetative growth and this diverts calcium away from developing fruit. Elevated levels of nitrogen in the peel makes the fruit more vulnerable to fungal pathogen attack such as anthracnose, whilst increasing levels of avocado fruit nitrogen have been linked to greater susceptibility to postharvest rots and vascular browning.

The timing and rate of nitrogen application needs to strike a balance between yield and fruit quality (Figure 2).

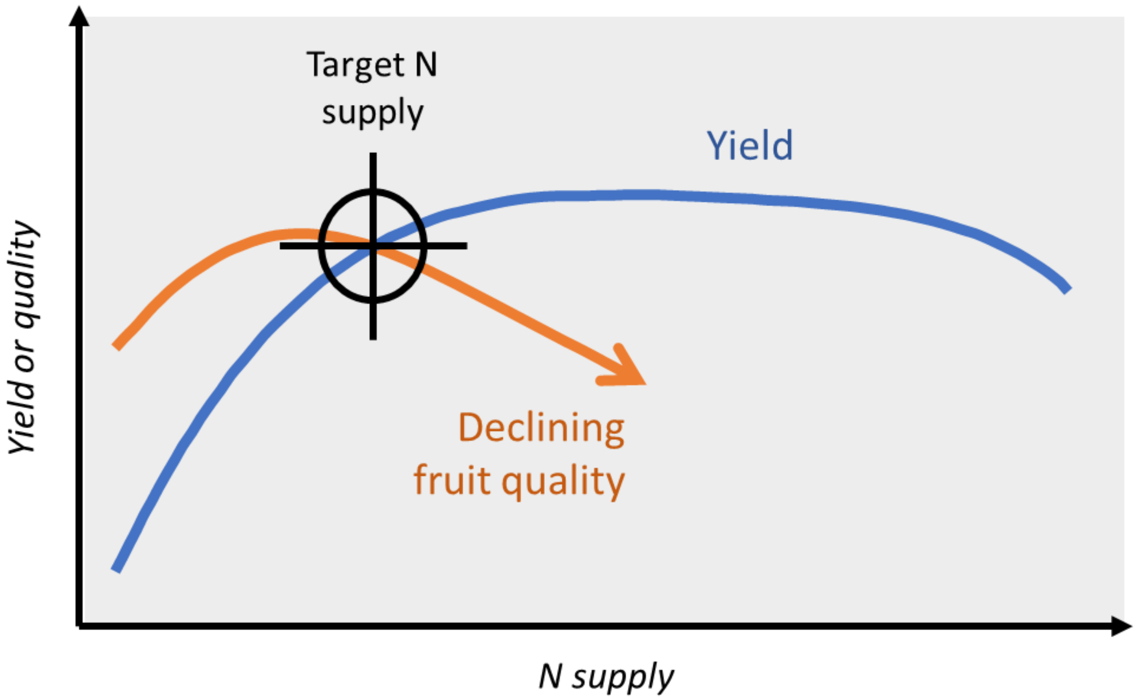

Figure 2. Nitrogen supply management for balance between avocado fruit yield and quality.

Reported concentrations of nitrogen in ‘Hass’ avocado fruit range from 0.5-1.7% dry weight in the flesh and 0.8-1.4% dry weight in the peel. Keeping flesh nitrogen levels below 1.7% in the mid-stages of fruit development and below 1% in the months leading up to harvest has been recommended for growing ‘Pinkerton’ in South Africa to minimise the risk of fruit developing diffuse flesh discoloration after cold storage.

Other recommendations pertain to leaf concentrations which are proportionate to levels in the fruit but are different for each variety. In Australia, recommended leaf nitrogen levels for fruit-bearing ‘Hass’ trees are 2.2-2.6% dry weight, with a slightly lower range of 2.0-2.4% dry weight recommended for more vigorous varieties such as ‘Fuerte’ and ‘Sharwil’.

3. Potassium

Potassium contributes to the regulation of fluids in cells, which is important for stomatal function and cell expansion (i.e. fruit growth). Also, potassium supply to deficient plants increases pest and disease resistance. However, increasing potassium supply beyond the minimum needs of the plant can result in ‘luxury consumption’ of this nutrient and possibly lead to potassium-induced deficiencies of calcium and magnesium.

In avocado, high fruit potassium concentration has been linked with increased diffuse discolouration, increased body rot severity and decreased ripening time of fruit. These influences on fruit quality are believed to primarily stem from the antagonistic effect that potassium has on uptake of other cations particularly calcium.

Potassium is highly mobile in the plant which means that leaf potassium levels are generally a good indicator of fruit potassium levels. In Australia, optimal leaf potassium for ‘Hass’ is considered to be 0.75-2.0% however, modelling of data from Californian ‘Hass’ orchards indicated that optimum leaf potassium for high-yielding trees is 0.8% and that yield potential is suppressed above 1% leaf potassium.

4. **Magnesium**

Correlations between fruit magnesium levels and avocado quality tend to be inconsistent and, in some cases, contradictory. More attention has been given to the cation balance between magnesium, calcium and potassium in the avocado fruit as this seems to be of greater importance to quality.

5. **Boron**

Increasing flesh boron levels in 'Hass' fruit have been linked with lower incidence and severity of diffuse flesh discolouration and vascular browning, as well as lower severity of body rots. Post-storage development of a localised flesh browning disorder referred to as 'endocarp black spot' was greatest in 'Hass' fruit from boron deficient trees and gradually declined as the rate of boron fertilisation increased. This defect occurred near the top of the seed cavity (the stem end), the region of the fruit which inherently contains the lowest boron concentration. However, growers need to be mindful of the narrow window between boron deficiency and toxicity. In this regard, it is advisable to seek expert advice.

Boron strengthens cells by cross-linking pectic substances in the cell wall and acting as a bridge between the cell wall and membrane.

Translocation of boron from mature leaves to flowers and young leaves has been demonstrated in avocado. Boron concentrations in 'Hass' avocado peel correlate well with leaf boron levels as would be expected for a phloem-mobile nutrient. A critical level of 46 mg kg-1 in summer flush leaves was found to be required to achieve 90% maximum fruit size.

6. **Silicon**

The presence of silicon has been shown to enhance the mechanical strength of fruit tissues as well as activate plant defences. Some research has shown a reduction in fruit body rots as a result of trunk injection of soluble silicon during fruit development but other attempts at trunk injection, foliar spray or soil drench have resulted in no reduction.

7. **Zinc**

'Fuerte' avocado fruit displaying pulp spot were found to contain lower calcium and zinc concentrations than unaffected fruit, however severity of body rots, stem end rot, diffuse flesh discolouration and vascular browning were found to have no correlation with flesh zinc levels in 'Hass' avocados.

Nutrient interactions

Calcium and nitrogen

In many instances, the nitrogen/calcium ratio in avocado fruit has proven to be a better indicator of postharvest quality than individual nutrient concentrations. For example, South African 'Pinkerton' fruit sourced from areas considered "high risk" in terms of diffuse flesh discoloration consistently had higher nitrogen/calcium ratios but did not necessarily have lower calcium levels than fruit from "low risk" areas. Additionally, the development of postharvest body rots in 'Hass' fruit has been more consistently correlated with nitrogen/calcium ratio than calcium concentration alone.

Studies on 'Hass' showed substantial development of postharvest body rots in fruit with flesh nitrogen/calcium ratios of 40-45 at harvest, but little or no body rot development when ratios were 33 or lower.

Figure 3. Body rot expression in 'Hass' avocado fruit at soft-ripe stage. Fruit were harvested on the same day from two orchards in Central Queensland and exposed to the same postharvest conditions. No fruit from the first orchard (left) developed body rots (flesh nitrogen/calcium ratio of 23), whereas all fruit from the second orchard (right) developed body rots (flesh nitrogen/calcium ratio of 43).

Calcium and other cations

The balance of cations in avocado fruit, particularly the ratio of (Ca+Mg)/K, has been found to be associated with better fruit quality. Fruit with higher values had fewer body rots, stem end rot, vascular browning and leaching, and discrete patches.

PRE-HARVEST FACTORS INFLUENCING FRUIT NUTRIENT STATUS

Genotype

Scion

Fruit quality is strongly influenced by choice of cultivar. In avocado, varietal differences have been reported for quality traits including browning potential and postharvest disease susceptibility but little is known of cultivar-related effects on fruit mineral nutrient status.

'Hass' fruit harvested from vigorous trees grown at a site in South Africa contained almost twice the calcium concentration of 'Fuerte' fruit from vigorous trees grown on the same site and rootstock. Competition from the vegetative flush was considered to be the main cause and since flowering and early fruit development in 'Fuerte' coincides with a vigorous vegetative spring flush this may have also contributed.

In another study, 'Shepard' fruit appeared to have higher calcium concentrations and lower nitrogen/calcium ratios than 'Hass' fruit harvested from the same site in North Queensland, irrespective of rootstock or season. Nitrogen/calcium ratios of 9-16 and 19-34 were reported in 'Shepard' and 'Hass' fruit, respectively. 'Shepard' is a smaller tree with a more compact growth habit and tends to flower when the spring vegetative flush is well advanced, hence the ability of this cultivar to readily accumulate fruit calcium may be a result of relatively low calcium demand from vegetative tissues during early fruit development.

Rootstock

In Australia, rootstock race has been found to influence the nutrient balance and quality of 'Hass' fruit. Fruit harvested from 'Hass' trees grafted to Mexican race rootstocks (e.g. 'Duke 6', 'Duke 7' and 'Thomas') generally had inferior quality and nutrient status compared with those grafted to Guatemalan (e.g. 'Anderson 10' and 'SHSR-03') or West Indian x Guatemalan (e.g. 'Velvick') race rootstocks. In 'Shepard', negative fruit quality issues and unfavourable nutrient balances were more often associated with Mexican race rootstocks than with Guatemalan or West Indian race rootstocks. It should be noted that in some of the studies, large seasonal effects and a high degree of site-to-site variability may have overshadowed rootstock effects on fruit mineral nutrients, indicating that other orchard factors may play a greater role in determining final fruit quality than rootstock.

ENVIRONMENT

Soil texture

In Australia avocados must be grown on free draining soils to help manage Phytophthora root rot, but this usually comes at the cost of cultivating them in soils with inherently low nutrient holding capacity (cation exchange capacity) and the potential for leaching of soil-applied nutrients.

Soil water

Avocado trees are sensitive to soils that are both too wet and too dry and respond by closing their stomata. Stomatal conductance can be slow to recover in drought-stressed trees and extended water deficit induces trees to produce permanent woody plugs (tyloses) in the xylem. These responses restrict water flow and thus reduce nutrient supply to the tree.

Waterlogging aids the spread of Phytophthora root rot and reduces soil aeration causing root hypoxia. The resultant root damage can further impede nutrient uptake. Although fruit calcium levels can be higher in trees with moderate root rot than in healthy trees, this is offset by other fruit quality issues such as sunburn, smaller fruit and a reduction in yield.

Maintaining soil moisture within an optimal range has well-documented benefits of improved yield and reduced alternate bearing. Effects on fruit nutrient status are less clear, with a number of irrigation studies producing inconsistent results. Since critical nutrients are often easily leached from the root zone, identification of critical periods of crop water and nutrient demand in relation to fruit robustness and quality could inform site specific irrigation management.

Soil organic matter

Improvements to soil health and fertility from the regular application of soil organic matter in agricultural production systems, including avocado, are well known. In avocado the addition of organic matter in the form of mulches can improve crop yields due to a reduction in crop stress. It is thought that the benefits from mulching relate to enhanced soil moisture availability and improvements in the soil's ability to hold nutrients (cation exchange capacity) which both lead to better retention and availability of nutrients. Also, the enhancement of a soil environment where soil biology can flourish has beneficial outcomes for the suppression of pest and diseases, most notably Phytophthora Root Rot. However, there are few definitive published studies linking soil organic matter and mulching to enhanced fruit quality.

Climate

Temperature and humidity

From a fruit mineral nutrient perspective, perhaps the most important climatic factors are those that influence transpiration rate and, hence, calcium accumulation, since this mineral is conveyed in the transpiration stream. High temperature and/or low humidity produces a strong evaporative demand, which is often characterised in terms of high vapour pressure deficit (VPD). Such conditions favour diffusion of water vapour from the leaf surface to the air. However, avocado trees respond to increasing VPD by closing their stomata and this may ultimately limit transpiration. Hence, there is likely to be an optimum VPD range for maximising transpiration rate and calcium accumulation.

Light

Avocado fruit exposed to direct sunlight, as opposed to those in shaded areas took longer to ripen and develop body rots. They also had greater tolerance to postharvest chilling and hot water treatments, and this was generally more pronounced on the sun-exposed side than the shaded side of the fruit. Maintenance of high antifungal diene levels in the flesh during ripening was considered responsible for the greater disease resistance of sun-exposed fruit. High skin and flesh temperatures during sun exposure were considered to enhance stress resistance. Another possibility, however, is that sun exposure promoted uptake and movement of calcium. One study found a 16% increase in fruit calcium between the sun-exposed and shaded sides of immature 'Hass' fruit.

MANAGEMENT PRACTICES

Nutrient application

Calcium

Increasing rates of soil-applied calcium in various forms typically provides little or no increase in avocado fruit calcium levels. This indicates a reliance on other factors for transport and distribution within the tree.

Traditionally lime, dolomite and gypsum are the main sources of calcium applied to the soil. Soil application of calcium nitrate and/or calcium thiosulphate after fruit set is being used by some growers in the belief that these more soluble sources of calcium will produce better results, but this has yet to be investigated.

Foliar calcium application has been investigated as an alternative means of getting calcium into the fruit, but results have been inconsistent. Calcium absorption by leaves is unlikely to have any bearing on fruit levels due to the poor mobility of calcium between plant tissues.

Attempts to increase fruit calcium concentration with postharvest vacuum infiltration of calcium chloride or calcium sulphate did show an increase in calcium content of skin and flesh, and in almost every study resulted in delayed fruit ripening. One study reported a reduction in diffuse flesh discolouration although also observed a reduction in external fruit quality.

Postharvest immersion of 'Pinkerton' fruit in organically complexed calcium products such as Calcimex®and Basifoliar Ca® generally reduced the incidence of grey pulp and increased fruit firmness, while some also reduced anthracnose incidence and lenticel damage. The advantage of these products compared to inorganic forms of calcium (calcium chloride and calcium sulphate) used in early studies is reportedly improved calcium uptake and translocation, thus removing the need to apply using vacuum infiltration.

Nitrogen

Timing of nitrogen application can have a large influence on the final nitrogen concentration in avocado fruit. When three different timings of nitrogen application were tested, namely (i) commenced during flowering, (ii) commenced after fruitlet formation, and (iii) supplied continuously, the nitrogen levels measured in the flesh just prior to harvest were about 2.0%, 1.4% and 1.9% (dry weight) respectively. Avoiding large applications of nitrogen before and during flowering is therefore recommended to produce more robust fruit.

The chosen fertiliser strategy needs to provide sufficient nitrogen to fuel flowering, fruit set and fruit retention without creating excessive vegetative vigour. Tree demand for nitrogen will depend on cultivar, climate and pruning practice. In warmer climates, flowering commences after the previous season's fruit have been harvested, however, trees grown in cooler climates often have overlapping crop cycles and managing the demands of both can be challenging. The differing nitrogen requirements of trees during 'on' and 'off' flowering years also needs to be considered.

Site aspects including soil texture, slope, rainfall and irrigation will determine how readily nitrogen is leached away from the root zone. Recent research conducted on a commercial avocado orchard in Queensland revealed that nitrate levels in soil solution in the upper 30cm zone of soil can vary considerably (by more than 500 mg/L) within the same block of trees.

Avocado trees are highly sensitive to chloride and application of nitrate nitrogen has been proven to alleviate chloride toxicity symptoms by reducing chloride uptake by the roots.

The dilemma of nitrogen nutrition in avocado has been recognised for many years and was neatly summarised by Professor Nigel Wolstenholme (University of Kwazulu Natal in South Africa):

"What is often not fully appreciated by growers and advisers is that nitrogen management strategies must be tailored to specific environmental and management conditions, to achieve the same desired effect of a balance between vegetative vigour and yield (and fruit quality)."

Potassium

Oversupply of potassium in the soil has been shown to limit calcium and magnesium uptake and reduce concentrations of these nutrients in the fruit flesh. This fruit subsequently developed more extensive diffuse flesh discolouration.

Australian avocado growers may be applying too much potassium. This possibility, along with the antagonistic effect of potassium on calcium uptake, has led to recommendations that potassium fertilisation of avocado trees be reduced especially during early fruit development when fruit calcium demand is highest. Most potassium accumulation in avocado fruit occurs during the later stages of development, so delaying potassium application until this time would seem to be logical.

Boron

Given the role of boron in pectin binding of the primary cell wall, boron is required for all the growing points of the tree, including shoots, roots and young fruit. Most studies on boron have focussed on improving fruit set and yield with little focus on fruit quality. Soil applied boron has been shown to increase boron levels in skin and seed but not flesh. However, higher flesh boron levels in 'Hass' fruit have been linked with lower incidence and severity of diffuse flesh discolouration and vascular browning, absence of a postharvest flesh browning disorder (endocarp black spot) near the stem end of the seed cavity and lower severity of body rots. Soil applications need to be carefully managed, as soil boron concentrations can easily build up to toxic levels and optimal soil boron concentrations vary greatly depending on soil texture.

Irrigation

Conflicting results on fruit quality from various treatments that investigated the effect of a range of wetter and drier irrigation regimes suggest involvement of other contributing factors. For example, periods of high environmental evaporative demand can induce stomatal closure even when soil moisture is adequate. Additionally, the extent to which irrigation alters the vegetative/reproductive balance will ultimately influence the amount of calcium distributed to the fruit.

Canopy management

A balanced ratio of vegetative/reproductive growth is credited for enhancing fruit quality. Avocado trees with low vegetative vigour and/or high crop load tend to bear fruit with high calcium levels and few postharvest diseases and disorders. Pruning that limits vegetative growth at the critical time of fruit set and early fruit development has been shown to produce larger fruit, higher fruit calcium levels and fewer postharvest body rots, whilst producing similar yields to unpruned trees. However, pruning that stimulates vegetative regrowth at this critical time can have a negative impact on fruit quality.

When vegetative regrowth after pruning coincided with reproductive growth, fruit from pruned as opposed to unpruned trees contained less calcium and were more prone to body rots, stem end rots, skin spotting, discrete patches, vascular browning and diffuse flesh discolouration.

The plant growth regulator paclobutrazol applied as a foliar spray suppresses vegetative growth and has been shown to increase fruit calcium levels and reduce body rot severity without sacrificing yield. Paclobutrazol foliar application also reduced the incidence of physiological disorders in 'Fuerte' fruit from treated as opposed to untreated trees, but only during an 'off' year. Paclobutrazol should only be used on vigorous, healthy trees, with well managed nitrogen levels.

Mulching

Few studies have investigated the effects of mulch on avocado fruit mineral nutrient status and postharvest quality. The use of pine woodchip or pine bark mulch at two Queensland orchards reduced the severity of diffuse flesh discolouration which may have been the result of nitrogen drawdown in the soil preventing excess nitrogen accumulation in the fruit.

A South African study found that mulching with composted Eucalyptus woodchips caused increased potassium and phosphorus in 'Hass' fruit, but no change in fruit calcium or magnesium, as compared with no mulching. This contribution to fruit potassium may have undesirable consequences for fruit quality.

Mulching may be of little benefit to fruit quality when applied to soils already rich in organic matter. A New Zealand study found that in such situations, postharvest development of body rots or stem end rot in 'Hass' fruit was unaffected by mulching.

MONITORING NUTRIENT STATUS IN AVOCADO

Leaf analysis

Sampling mature leaves from the summer flush in autumn is the recommended practice in Australia but fruit set, significant development and even harvest (in the warmest regions) have already occurred by this time. Leaf analysis is a good indicator of mobile nutrients such as nitrogen, potassium and boron, however calcium is a relatively immobile nutrient that may be apportioned non-uniformly between leaves and fruit, and since calcium continues to accumulate in the leaf as it ages, a high leaf calcium level is more a reflection of leaf age than it is of fruit calcium content. Sampling mature leaves from the spring flush in summer may provide a better opportunity to influence the nutrient content of fruit. For leaf sampling selecting the right leaf material at the right time is critical.

Soil analysis

Soil analysis is required less often than leaf analysis but is important for ensuring that nutrient supply, especially of cations, is adequate and balanced. Soil pH (which can influence nutrient availability) can also be measured, and emerging issues such as the build-up of salt, and potentially toxic levels of chloride, boron and manganese which can all adversely affect fruit quality can be detected.

Fruit analysis

Fruit nutrient analysis is less commonly used but is essential for determining fruit calcium levels and its ratios with other nutrients. Sampling at harvest will help predict whether fruit can handle the rigours of storage and/or long supply chains. Earlier sampling provides some scope for correcting nutrient imbalances.

A promising development in avocado fruit analysis is the use of relatively inexpensive meters to measure nutrient levels in 'juice' pressed from the flesh of hard, green mature fruit. The benefit of rapid, on-farm nutrient diagnosis potentially offered by this technique warrants further investigation.

Cauliflower stage inflorescence analysis

Research on 'Hass' trees showed that mineral nutrient levels in the cauliflower stage inflorescence were a better predictor of yield than leaf nutrient levels. Additionally, the cauliflower stage is easy to identify and collect so carries less risk of sampling the wrong tissue at the wrong time. The greatest advantage is that it allows sufficient time to correct nutrient imbalances before they can negatively impact yield, fruit size or quality. For these reasons the technique is considered high priority for further investigation.

PROPOSED MODEL FOR AVOCADO FRUIT ROBUSTNESS

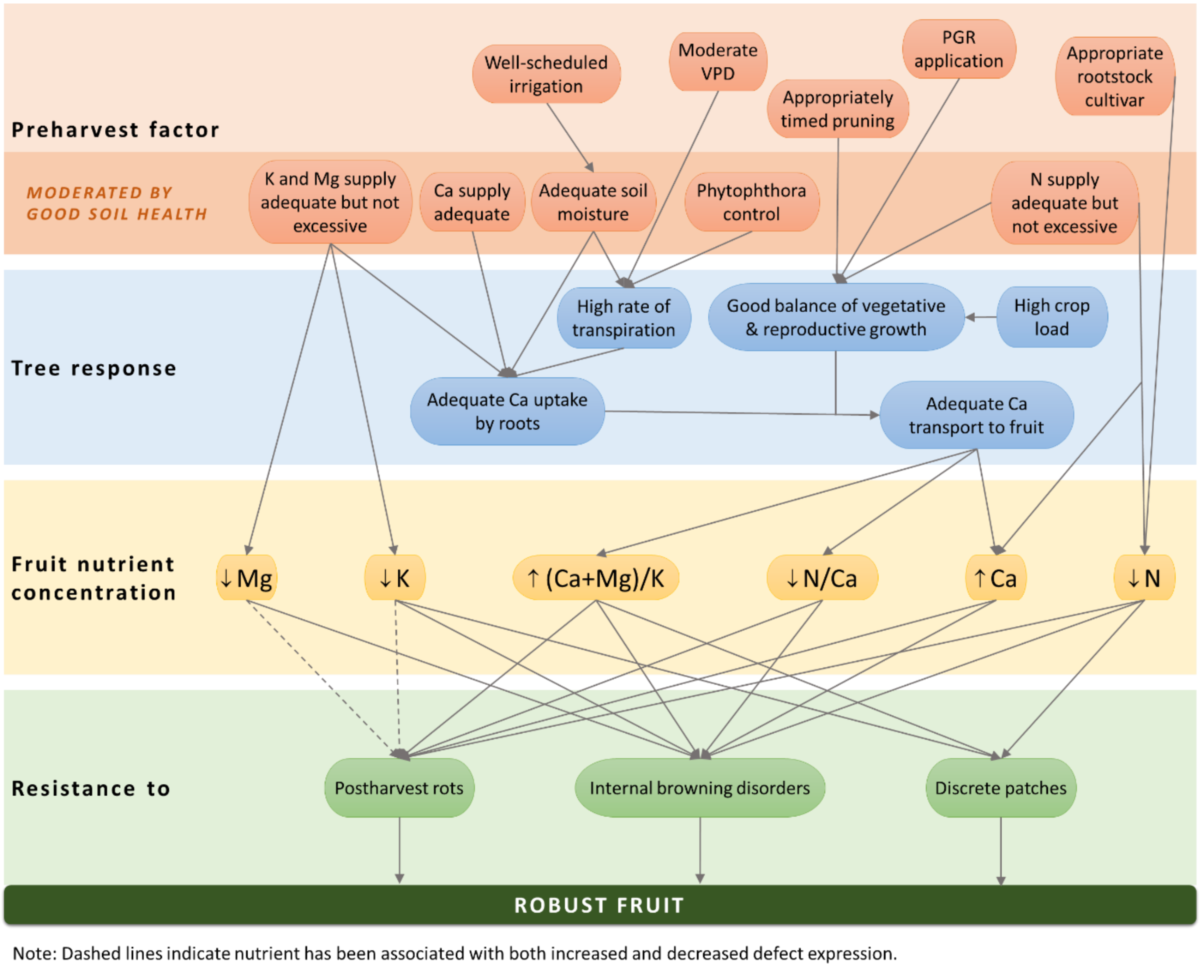

Figure 4. Robust avocado fruit are resistant to postharvest diseases/disorders and tend to have a fruit nutrient balance that is high in calcium and low in nitrogen, magnesium and potassium. This balance is influenced by several interacting pre-harvest factors and is underpinned by good soil health.

CONCLUSION

The robustness of avocado fruit in terms of resistance to postharvest diseases and browning disorders is linked to its mineral nutrient status. A high level of fruit calcium, coupled with low nitrogen, potassium and (possibly) magnesium levels in the fruit has consistently been linked with greater fruit quality. However, since fruit calcium levels are highly variable a more useful measure may be the nitrogen/calcium ratio in the fruit flesh and this could be useful for identifying fruit at risk of developing postharvest diseases and disorders. Rapid nutrient analysis tools to better inform this decision process are becoming available but require testing and development. Increasing fruit boron levels are also considered beneficial to avocado fruit quality, however caution must be exercised as there is a narrow window between deficiency and toxicity. Since nitrogen can have a major influence on fruit calcium content and is easier to manage than calcium, the manipulation of fruit nitrogen rather than fruit calcium may be easier to achieve.

RECOMMENDATIONS

Actionable now

Based on evidence presented from this review, the following recommendations to improve fruit quality through mineral nutrition are made:

1. **Provide adequate calcium to trees, especially during flowering, fruit set and early development.**
   Small relatively frequent doses applied to the soil can help to keep calcium in soil solution and the root zone. This may be more important on sandy soils and in areas of high rainfall. Figure 1 illustrates other factors affecting calcium uptake.

2. **Use fruit tissue analysis as a relatively reliable indicator of fruit calcium concentrations.**
   Calcium is not distributed evenly between leaves and fruit, and once deposited, it cannot move from one organ to another. Thus, leaf calcium concentrations are not closely related to fruit calcium concentrations. Analysis of fruit nitrogen at the same time will allow the nitrogen/calcium ratio to be calculated, this ratio tends to be a better indicator of fruit robustness than fruit calcium concentration alone. Fruit with nitrogen/calcium ratios in the high 30's or above are at risk of postharvest quality defects developing and should not be placed into extended storage or subjected to long supply chains.

3. **Ensure leaf nutrient concentrations for nitrogen and potassium do not exceed the optimum range.**
   Unlike calcium, leaf concentrations of nitrogen and potassium reflect concentrations in the fruit. For 'Hass', leaf concentrations should not exceed the optimum range of 2.2-2.6% nitrogen and 0.75-2.0% potassium. (N.B. Based on new research from California, possibly no more than 1% potassium). Monitoring of leaf nitrogen and potassium throughout the season can allow for more timely adjustment of nutrient application rates and lessen the likelihood of fruit with poor nutrient balance.

4. **Delay potassium application until latter stages of fruit development and only apply if needed.**
   Calcium and potassium compete for uptake by plant roots and so should not be applied at the same time. It is better to apply these nutrients when the fruit demand for each is highest. For calcium, peak demand is higher during the early fruit growth stages, whereas demand for potassium is higher in latter fruit growth stages. Some Australian orchards may be over-supplying potassium, so check leaf potassium concentrations before applying.

5. **Achieve a good balance between vegetative growth and crop load.**
   Excessive vegetative growth can divert calcium from developing fruit. Canopy management through careful and appropriately timed plant growth regulator application, pruning, irrigation, and nutritional management may all help to control vegetative vigour and improve nutrient balance in the fruit. An important goal is that re-growth does not coincide with early fruit development.

6. **Select appropriate rootstocks when establishing new plantings.**
   Improved fruit quality and nutrient balance in 'Hass' and 'Shepard' fruit may be achieved by selecting rootstocks of Guatemalan or West Indian heritage over Mexican race rootstocks. 'Velvick' is a West Indian x Guatemalan hybrid that has been shown to perform consistently well in this respect. Nonetheless although rootstock is a potentially important influencer, site

and season effects may have overriding influence on fruit mineral nutrient status and yield should not be unduly compromised.

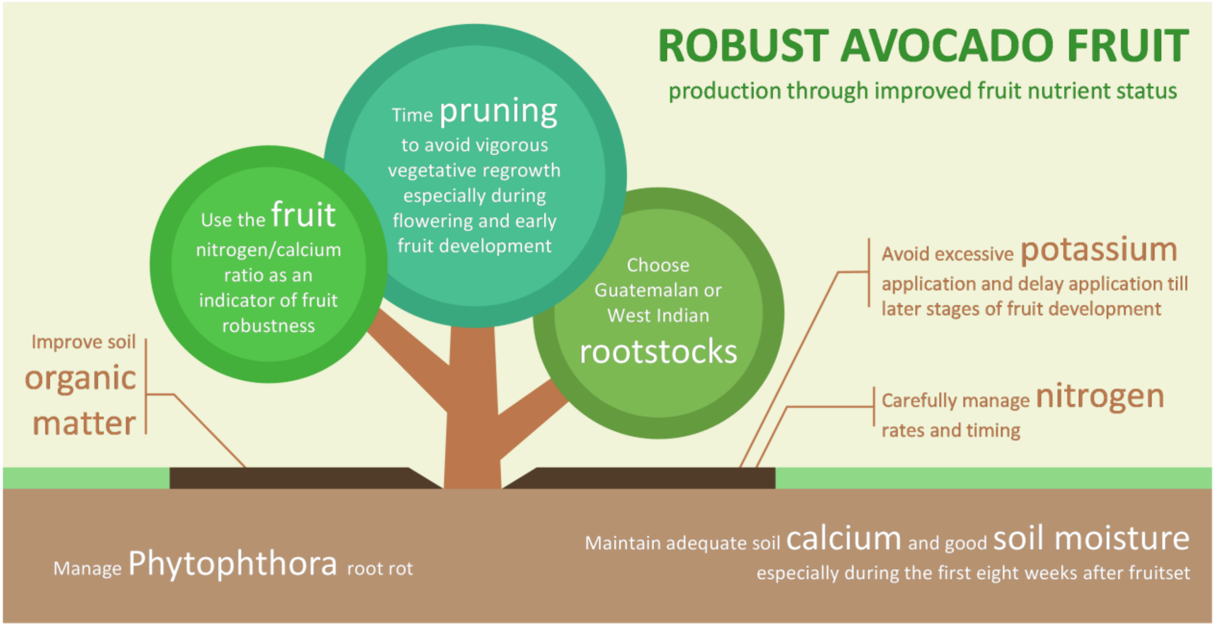

Figure 5. Orchard practices for improving avocado fruit quality through mineral nutrition.

Areas for future research aimed at improving fruit quality

In no particular order, research into the following areas is recommended.

1. **Mining big data sets to understand genetics, environment and management interactions**
   Re-appraisal of existing data sets in new and/or different ways could help to enable interpretation of and decision making from otherwise overwhelming complex interactions. Earlier Hort Innovation avocado projects may, for example, have generated rich data sets pertaining to fruit nutrient status and quality.

2. **Characterising production environments and practices governing 'good' vs 'bad' fruit nutrient status**
   Fruit nutrient data from orchards identified as producing fruit with superior or inferior postharvest quality could be related back to orchard activities and environment. Studies would cover multiple seasons and be informed by detailed production, management, and environmental records. Supporting leaf analysis data could be correlated to inform, for example, optimum leaf nitrogen and potassium guidelines. Acquiring data on fruit quality at retail level and subsequent trace-back to detailed orchard data could identify the key drivers for high quality fruit.

3. **Irrigation management**
   Maintaining soil moisture within an optimum range is important for nutrient availability, uptake and translocation. However, evidence for irrigation effects on fruit nutrient status is conflicting and merit deeper investigation. Studies would qualify and quantify relationships between different irrigation regimes and vegetative/reproductive balance.

4. **Wholistic approach to nitrogen management**
   Relatively comprehensive studies on nitrogen management in avocado have been conducted but not in the context of Australian conditions. It is recognised that nitrogen management is a complex issue requiring site-specific and season-specific adjustment. In this context, value is inherent in developing 'best bet' guidelines for Australian growers in climatically distinct sub-tropical to temperate regions. To optimise fruit mineral nutrient status without compromising yield, studies might consider (i) rates and timing of nitrogen application, as has been done for 'Hass' in California, (ii) dynamic contributions of compost and mulch to short, medium and long term nitrogen supply, (iii) sustained-release inorganic fertilisers and (v) nitrification inhibitors.

5. **Compost and mulch application**
   Benefits of compost and mulch on root health and Phytophthora root rot suppression are well documented and have engendered their widespread use in Australian avocado orchards. However, the nature and composition of these organic materials is highly variable. As such, the magnitude and dynamics of their contribution to fruit nutrient status under Australian conditions is poorly understood. Important insight could be gained by comparing and contrasting different materials under specific conditions. Also, mulch and compost options, including ratios, should be explored in conjunction with other orchard management practices towards an informed integrated approach to improving fruit nutrient status, as proposed above for nitrogen management.

6. **Soil application of additional calcium at fruit set**
   Applying relatively expensive highly soluble forms of calcium (e.g., calcium thiosulphate, calcium nitrate) at fruit set is sometimes practiced in Australia. Current understanding around calcium uptake and transport by avocado trees casts doubt on the efficacy of such treatments when soil calcium concentrations are often adequate. Whether and to what degree fruit calcium concentrations may be enhanced by this relatively high cost practice awaits determination.

7. **Timing and type of fruit tissue sampling for nutrient analysis**
   Fruit tissue analysis is typically conducted at harvest maturity and involves analysis of either the peel or flesh tissue. Good correlations exist between avocado peel and flesh calcium concentrations. However, this is not necessarily the case for other nutrients. Also, tissue type which provides the best indicator of fruit nutrient status and robustness remains to be thoroughly investigated. Sampling reproductive tissue at an early phenological stages (e.g. the cauliflower stage of flowers) provides scope for timely intervention to address nutrient imbalance. Optimum nutrient concentration ranges need to be established for specific phenological stages.

8. **Rapid diagnostic tools for monitoring fruit nutrient status**
   Fruit nutrient analysis pertaining to critical imbalances (e.g. high nitrogen/calcium ratio) is currently costly, involving destructive sampling and typical turnaround times of a week or more. With calcium being a relatively reliable base measure of fruit robustness, merit lies in developing and optimising its cost effective rapid on-farm measurement, ideally along with the key co-determining nutrient nitrogen; viz., nitrogen/calcium ratio. More, and more timely assessments could fine tune orchard management practices.

9. **Plant growth regulators for canopy management**
   Plant growth regulator use to control vegetative vigour is 'common practice' in Australia and has been shown to promote calcium accumulation in avocado fruit when applied mid-anthesis as a single foliar spray. Anecdotal reports suggest that growers are applying plant growth regulators in multiple, low doses during the 12 weeks following fruit set. At present, effects of such applications on fruit nutrient status and ultimately fruit quality are unknown and so warrant investigation.

10. **Susceptibility to flesh bruising**
   Flesh bruising is a prevalent defect in Australian avocados at retail. However, its suspected relationship to fruit nutrient status is largely undefined. Preliminary research suggested bruise susceptibility in avocado fruit increases with decreasing flesh calcium concentration. Further investigation is, however, needed to confirm the role of calcium and determine whether boron is also involved, given its co-involvement in cell wall strengthening.

11. **Influence of the graft union on nutrient translocation**
   Preliminary studies have identified effects of grafting on nutrient translocation in avocado nursery trees. Further investigation to determine effects on mature trees would be valuable, particularly in the context of the apparent negative influence of Mexican race rootstocks on fruit quality in 'Hass'. Recent studies of the characteristics of xylem tissue in different avocado cultivars belonging to the three botanical races of avocado have highlighted important structural differences between the different races.

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