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Between-tree variation in fruit quality and fruit mineral concentrations of Hass avocados

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Abstract. Inconsistent internal fruit quality in Hass avocados affects consumer confidence. To determine the influence of individual trees on fruit quality, Hass avocado fruit were harvested from adjacent trees of similar external appearance in 3 commercial orchards in 1998 and 1 orchard in 1999. The trees in each orchard were grown with similar commercial practices and in similar soil types. Within each location, there were significant (P<0.05) differences in the mean ripe fruit quality between trees with respect to fruit body rot severity (mainly anthracnose) with and without cold storage, internal disorders severity due to diffuse discolouration and vascular browning (after cold storage), days to ripen, percentage dry matter, and the percentage of the skin area with purple-black colour when ripe. These effects were also noted in the same orchard in 1999. There were significant (P<0.05) differences in fruit flesh calcium, magnesium, potassium, boron and zinc concentrations between trees. Significant (P<0.05) correlations were observed between average fruit mineral concentrations in each tree (particularly calcium, magnesium and potassium) and body rot severity, percentage dry matter and fruit mass. There was little conclusive evidence that characteristics such as the growth of the non-suberised roots or the degree of scion under- or overgrowth was involved in these tree effects; however, differences between trees with respect to other rootstock characteristics may be involved. The inconsistency of the correlations across sites and years suggested that other factors apart from tree influences could also affect the relationship between fruit minerals and fruit quality.

Additional keyword: rootstocks.

Introduction

Inconsistent fruit quality is an important commercial consideration for the Australian avocado industry. Surveys of the retail market from 1992 to 1998 indicated inconsistent internal quality in up to 44% of Hass avocado fruit on the display shelf, with rots and internal disorders being major problems (Hofman and Ledger 1999, 2001).

Appropriate postharvest practices are important to maintain fruit quality after harvest, but production practices can also have an important impact on the postharvest performance and quality of avocado fruit (Hofman and Smith 1994; Hofman *et al*. 2002). These effects can be partly mediated through fruit mineral concentrations, particularly calcium (Ca) (Penter and Stassen 2000; Thorp *et al*. 1997; Witney *et al*. 1990). Other minerals such as magnesium (Mg), potassium (K) (Koen *et al*. 1990; Witney *et al*. 1990), boron (B) (Smith *et al*. 1997), and zinc (Zn) (Vorster and Bezuidenhout 1988) have also been associated with avocado fruit quality.

In Australia, large differences in the productivity of individual Hass avocado trees have been reported over 6 consecutive seasons (Thomas 1997). Differences in fruit quality and fruit mineral concentrations have also been reported between adjacent Hass trees of the same age and grown under very similar management conditions (Hofman and Jobin-Decor 1999; Hofman *et al*. 2002). However, the nature and causes of between-tree variability in Hass avocado fruit quality have not been studied in detail, particularly under Australian conditions.

The purpose of this study was to test between-tree variability in Hass avocados to identify interactions between tree characteristics and fruit quality. Fruit mineral concentrations were also determined because of the demonstrated relationship with fruit quality. In addition, some characteristics of the rootstock and rootstock × scion interaction were quantified in order to explain how the rootstock could affect fruit mineral concentrations.

Materials and methods

Sites

Trials were conducted on 3 commercial avocado orchards in south-east Queensland. Two were at Beerwah (26.9°S, 152.8°E; 30 m a.s.l.), and the other was at Mt Tamborine (28.0°S, 153.2°E; 520 m a.s.l.). All 3 sites were used in 1998, but only 1 Beerwah site (called Beerwah 1) was used in 1999. The climate in these locations is subtropical, with the Mt Tamborine site being slightly cooler due to higher altitude.

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One plot of 22 visually uniform and healthy Hass avocado trees in adjacent rows from each orchard was chosen for each site. At Beerwah 1 and Beerwah 2 the trees were on random seedling rootstocks of unknown origin, while at Mt Tamborine the trees were on seedling 'Velvick' rootstock (an Australian selection). In 1998, trees were 5 years old at Beerwah 1, and 4 years old at Beerwah 2 and Mt Tamborine. Tree spacing was 4 by 12 m (Beerwah 1), 6 by 10 m (Beerwah 2), and 8 by 8 m (Mt Tamborine). All 3 sites were on sandy loam soil with no known considerable soil variations across each site, and on gentle slopes with good drainage. The trees were irrigated with under-tree sprinklers.

Fruit quality

At commercial harvest maturity, 30 fruit/tree were harvested from Beerwah 1 in June 1998 and from Beerwah 2 in July 1998. Thirty-two fruit/tree were harvested from Mt Tamborine in August 1998, and from Beerwah 1 in June 1999. The sampled fruit were of average size for each tree and free from insect, wind, and sunburn damage. They were harvested at random from each quadrant of the tree at 1–3 m above ground level and within 1 m of the outside of the canopy. The fruit were placed in single layer trays and immediately transported to the laboratory. No fungicide was applied to the fruit after harvest.

Fruit from all locations in 1998 were individually labelled and weighed, then fruit quality attributes assessed after ripening at 20°C (see following section). Half of the fruit from Beerwah 1 in 1999 (total of 16 fruit) were treated as in 1998 (referred to as 'non-stored' fruit). The remaining 16 fruit were stored at 5°C and 80–90% relative humidity for 4 weeks (referred to as 'stored' fruit), then ripened at 20°C.

Fruit firmness was determined daily by gently squeezing the fruit in the palm of the hand. Fruit was considered eating soft at a hand firmness corresponding to a reading of 75–85 using a 0.2 kg weight on the Anderson Firmometer (White *et al*. 2001). This corresponded to a firmness of about 5 Newtons when measured with an Instron Universal Testing Machine model 1122 (Instron, High Wycombe, UK), fitted with an 8-mm hemispherical probe (probe penetration 2 mm). The days to reach the ripe stage (DTR; based on firmness) was recorded, then the percentage of the skin surface area with purple-black colour visually rated.

Fruit were then longitudinally cut into quarters, the seed removed, and the skin peeled from the flesh. The quarters were visually rated for the severity of rots and internal disorders as a percentage of flesh volume affected. Body rots were characterised as those developing from the skin into the body of the fruit (caused mainly by *Colletotrichum gloeosporioides*), and stem end rots as those starting from the stem end of the fruit (caused by several pathogens, mainly *C. gloeosporioides* and *Dothiorella* spp.) (Coates *et al*. 1995). Indications of the main causal organisms were obtained by culturing samples from the advancing margin of representative lesions on potato-dextrose agar containing 0.5% streptomycin, and incubating at 25°C for 7–10 days under near-ultraviolet light with a photoperiod of 12 h.

Diffuse discolouration was characterised as areas of grey or grey-brown discolouration with poorly defined margins (White *et al*. 2001). Vascular browning (ignoring discolouration clearly associated with stem end rots) was rated as the percentage of the flesh rendered non-useable by the disorder.

Percentage dry matter and minerals analyses

Additional fruit were randomly taken from each quadrant for percentage dry matter (%DM) and minerals analyses from all locations in 1998 (6 fruit/tree), and from Beerwah 1 in 1999 (8 fruit/tree). Ten trees were selected from each site, with average fruit quality for each tree representing the full range from the lowest to the highest quality for each site based on the assessment of rots severity. Fruit were randomly taken from each quadrant of the tree from all locations in 1998 (6 fruit/tree), and from Beerwah 1 in 1999 (8 fruit/tree). Fruit flesh samples were taken from the equatorial section of each fruit quarter and transferred as soon as possible after collection to a dehydrating oven at 60°C and dried to constant mass to determine %DM.

Samples were then individually ground and each fruit analysed separately. All fruit and wood samples were re-dried at 60°C for at least 3 h immediately before analysis. A 0.5 g sub-sample was weighed and prepared using the wet digestion technique of Baker and Smith (1974). The concentrations of B, Ca, K, Mg, and Zn were determined with an inductively coupled plasma atomic emission spectrophotometer (ICPAES) model Spectroflame P (Spectro Analytical Instruments, Kleve, Germany). The results are presented as mg/kg or g/kg of each mineral on a fresh weight (FW) basis to account for the differences in %DM between trees at Beerwah 1 and Mt Tamborine. Fresh weight concentrations were calculated using the following formula:

$$\text{FW concentration} = \text{DW concentration} \times \%\text{DM} / 100$$

Fruit yield and tree characteristics

Total fruit yield/tree was recorded at all locations in 1998 and at Beerwah 1 in 1999. Canopy width/tree just after fruit harvest was estimated by averaging the down-row width and across-row width. Canopy height was also measured and then the canopy volume estimated by assuming the tree approximated the shape of 0.5 of a prolate spheroid as described by Arpaia *et al*. (1996). Fruit yield/canopy volume was calculated by dividing the fruit yield for each tree by its canopy volume.

An indication of the growth of the young, non-suberised roots of trees at the Beerwah 1 site during the 1999 season was obtained using the methods of Marques *et al*. (2003). Four clear perspex sheets (500 by 500 by 2 mm) were placed on the soil of each of the selected trees, after removal of mulch and about 1 cm of soil. This caused minimal root disturbance. The sheets were evenly spaced under the tree canopy in March 1999, midway between the trunk and the drip zone of the canopy. They were covered with black foam (500 by 500 by 5 mm) to prevent light penetration, then the foam covered with mulch. The length of the visible non-suberised 'feeder' roots (usually of white or light brown colour) were then measured in May, June, July, September, and November 1999 (Marques *et al*. 2003).

The rootstock and scion circumference about 3 cm below and above the graft union for each tree was measured in September 1998 and 1999 using a measuring tape.

Wood samples for minerals analysis were taken in May 1999 from 3 positions around the trunk at about 3 cm below the graft union (rootstock sample) and 3 sites above the graft union (scion sample) by first removing a plug of bark, then drilling 40 mm into the wood with a 9-mm diameter bit and collecting the drill shavings. The shavings were bulked to give 1 sample/tree for either rootstock or scion, and dried to constant mass at 60°C.

Statistical analyses

A completely randomised design was used. Each tree was considered a treatment unit within each location, with fruit as single replicates for each tree for fruit quality and fruit minerals concentration. Single tree observations such as fruit yield/tree could not be statistically analysed. The root length from the 4 sites/tree for each measurement date was used as replications for each tree. The results for each site/tree were averaged over the 5 measurement times as there was no statistical difference in measured root length between dates.

Analysis of variance was performed using Genstat 5 version 4.1 for Windows (Lawes Agricultural Trust, Harpenden, UK). All measurements had equal sample size (balanced data) and the l.s.d. procedure at $P = 0.05$ was used to test for differences among treatment means.

Residual analysis of the data was performed to check the need for transformation. Percentage data covering a wide range of values, such as severity of fruit rots and internal disorders, were angular (arcsin) transformed before analysis (Steel and Torrie 1980).

The relationships between tree characteristics, fruit quality attributes, and fruit mineral concentrations were established using correlation analysis on the means for each tree. The significance of the correlations was determined by linear regression analysis (P = 0.05) using Genstat.

Results

Fruit quality

The severity of body rot, DTR, fruit mass, and skin area with purple-black colouration when ripe at all sites in both years, and %DM in fruit from Beerwah 1 and Mt Tamborine in 1998, differed significantly (P<0.001) between trees (Table 1; Fig. 1 for body rots). Trees also had a significant (P≤0.05) effect on stem end rot severity at all locations in 1998. Across all sites in 1998, the mean for each tree ranged from 1–45% of the flesh affected for body rot severity, 0–2.8% for stem end rot severity, 5.7–11.8 days for DTR, 25–35% for percentage DM, 198–362 g for fruit mass, and 48–98% for skin colour.

Table 1. Characteristics pertaining to fruit quality of Hass avocados harvested from several sites in south-east Queensland in 1998 and ripened at 20°C

Location	P-value[A]	Mean[B]	Range[C]	Individual fruit range
		Days to ripen		
Beerwah 1	0.001	10.6	7.0–11.8	5–13
Beerwah 2	0.001	8.8	7.6–10.3	5–12
Mt Tamborine	0.001	7.5	5.7–8.4	4–11
		Body rot severity (% of flesh volume affected)		
Beerwah 1	0.001	6	2–39	0–90
Beerwah 2	0.001	6	1–16	0–80
Mt Tamborine	0.001	17	1–45	0–95
		Stem end rot severity (% of flesh volume affected)		
Beerwah 1	0.05	1.0	0.4–2.8	0–30
Beerwah 2	0.05	1.8	0–2.3	0–25
Mt Tamborine	0.05	1.0	0–2.8	0–35
		Dry matter (%)		
Beerwah 1	0.001	26.7	25–30	22–32
Beerwah 2	n.s.	29.3	28–30	25–35
Mt Tamborine	0.001	29.7	25–35	22–37
		Fruit mass (g)		
Beerwah 1	0.001	220	198–268	136–367
Beerwah 2	0.001	240	210–266	130–357
Mt Tamborine	0.001	312	291–362	179–474
		Skin area with purple-black colour when ripe (%)		
Beerwah 1	0.001	85	74–92	45–100
Beerwah 2	0.001	78	60–95	20–100
Mt Tamborine	0.001	93	86–98	50–100

[A]Variance ratio determined by analysis of variance; n.s., not significant (P>0.05). The severity results were angular transformed before the variance ratio was determined.

[B]Mean for all fruit on each site. Mean values are from 660 (Beerwah 1 and 2) or 704 (Mt Tamborine) fruit from 22 trees/location, except for percentage dry matter, where means are of 60 fruit from 10 trees/location.

[C]Range of the tree means for each site.

In addition, trees at Beerwah 1 in 1999 had a highly significant (P<0.001) effect on DTR and body rot severity in both non-stored and stored fruit, on diffuse discolouration and vascular browning severity in stored fruit, and on percentage DM, fruit mass and skin area with purple-black colour when ripe (Table 2). There was also a significant (P<0.01) tree effect on stem end rot severity in stored fruit. Diffuse discolouration and vascular browning was not observed in non-stored ripe fruit from all sites in 1998 or from Beerwah 1 in 1999.

Fruit mineral concentrations

Trees had a significant (P<0.05) effect on fruit flesh Mg, K, B, and Zn concentrations from all sites in both years, and on

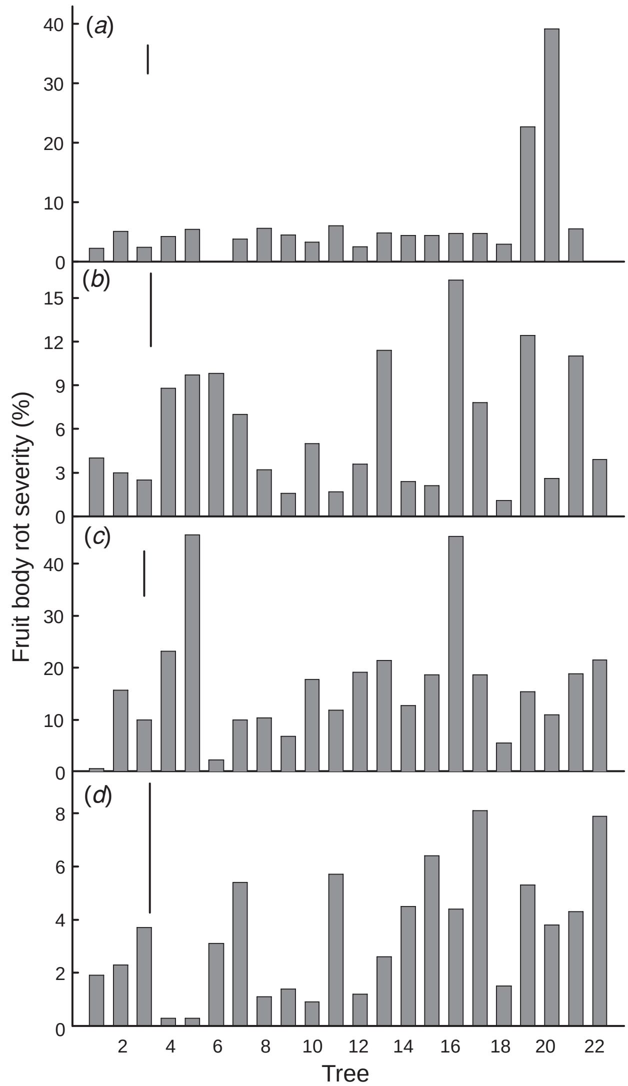

Fig. 1. Body rot severity (percentage of flesh volume affected) of Hass avocado fruit harvested from (*a*) Beerwah 1, (*b*) Beerwah 2, and (*c*) Mt Tamborine in 1998 and (*d*) Beerwah 1 in 1999 and ripened at 20°C. Data are angular transformed. The vertical bars for each location indicate the least significant differences (l.s.d.) at P = 0.05.

flesh Ca concentration from Beerwah 1 (in both years) and Mt Tamborine (Table 3). Generally, means for each tree had wider ranges for Zn, B, and Ca, and narrower ranges for Mg and K. Across all locations and years, means for each tree ranged from 31–92 mg/kg FW for Ca, 229–347 mg/kg FW for Mg, 5.1–6.8 g/kg FW for K, 6–27 mg/kg FW for B, and 6–15 mg/kg FW for Zn.

Tree characteristics

The mean fruit yield/tree for each site ranged from 46–64 kg/tree across sites and years with a range in individual tree yield of 1.5–126 kg/tree. The mean fruit yield/unit canopy volume was 1.2–2.8 kg/m^3 across sites and years with a range of 0.1–5.5 kg/m^3. The mean scion to rootstock circumference ratio was 1.04–1.06 for Beerwah 1 in 1998 and 1999, respectively, with a range between the trees of 0.93 (indicating scion undergrowth) to 1.15 (scion overgrowth). Trees had a highly significant (P<0.001) effect on the measured length of the visible white non-suberised roots at Beerwah 1 in 1999, with a mean total length of 5.7 m and a range between the trees of 2.2–12.6 m.

Table 2. Effect of holding condition on characteristics pertaining to fruit quality for Hass avocados from Beerwah 1 in 1999

Fruit were ripened at 20°C immediately after harvest (non-stored) or following storage at 5°C for 4 weeks (stored)

Holding condition	P-value[A]	Mean[B]	Range[C]	Individual fruit range
		Days to ripen		
Non-stored	0.001	9.4	7.7–10.4	6–11
Stored	0.001	3.5	3.0–4.4	3–5
		Body rot severity (% of flesh volume affected)		
Non-stored	0.001	3.0	0–8	0–50
Stored	0.001	53	31–72	4–95
		Stem end rot severity (% of flesh volume affected)		
Non-stored	n.s.	1.6	0–3.9	0–45
Stored	0.01	1.2	0–3.8	0–25
		Diffuse discolouration severity (% of flesh volume affected)		
Stored	0.001	47	2.3–73	0–95
		Vascular browning severity (% flesh volume affected)		
Stored	0.001	14	5–25	0–60
		Dry matter (%)		
Non-stored	0.001	22.8	21–24	19–28
		Fruit mass (g)		
Non-stored	0.001	253	235–295	194–385
		Skin area with purple-black colour when ripe (%)		
Non-stored	0.001	62	48–71	15–95

[A]Variance ratio determined by analysis of variance; n.s., not significant (P>0.05). The severity results were angular transformed before the variance ratio was determined.
[B]Mean for all fruit on each site. Mean values are from 352 fruit/holding condition from a total of 22 trees, except for percentage dry matter, where means are of 80 fruit from 10 trees.
[C]Range of the tree means for each site.

Correlations

Calcium was negatively correlated with body rot severity, fruit mass and %DM, and positively correlated with DTR and fruit yield, mainly at Beerwah 1 in 1998 (Table 4). Magnesium was negatively correlated to body rot severity at Beerwah 1 but positively correlated at Mt Tamborine in 1998. Potassium was negatively correlated to fruit body rot severity and percentage DM at some sites, and positively correlated to fruit yield at Beerwah 1 (1998) only. The correlations were generally not consistently strong across sites and years (for Beerwah 1). The correlations were stronger at the Beerwah 1 site in 1998 compared with the other sites in 1998, and compared with the same site in 1999.

Correlations between fruit quality and flesh B and Zn concentrations were not significant (P>0.05) in any of the sites over both years (data not shown).

There were positive correlations between fruit yield/tree and DTR in Beerwah 1 in 1998 (P<0.001, r = 0.89) and 1999 (P<0.05, r = 0.56), and in Mt Tamborine in 1998 (P<0.05,

Table 3. Flesh calcium (Ca), magnesium (Mg), potassium (K), boron (B), and zinc (Zn) concentrations of Hass avocado fruit harvested from several sites in south-east Queensland in 1998 and 1999

Location (year)	P-value[A]	Mean[B]	Range[C]	Individual fruit range
		Ca (mg/kg FW)		
Beerwah 1 (1998)	0.05	67	50–78	44–103
Beerwah 2 (1998)	n.s.	82	67–92	32–147
Mt Tamborine (1998)	0.001	42	31–60	25–77
Beerwah 1 (1999)	0.05	55	43–62	28–79
		Mg (mg/kg FW)		
Beerwah 1 (1998)	0.05	272	248–286	192–337
Beerwah 2 (1998)	0.001	252	229–275	210–321
Mt Tamborine (1998)	0.01	304	264–347	224–382
Beerwah 1 (1999)	0.01	312	282–331	254–375
		K (g/kg FW)		
Beerwah 1 (1998)	0.01	6.4	5.8–6.8	5.3–7.4
Beerwah 2 (1998)	0.001	6.2	5.6–6.6	4.8–7.1
Mt Tamborine (1998)	0.001	5.8	5.1–6.3	4.1–7.0
Beerwah 1 (1999)	0.001	5.9	5.4–6.3	4.3–7.0
		B (mg/kg FW)		
Beerwah 1 (1998)	0.001	19.0	17–22	10–31
Beerwah 2 (1998)	0.01	7.3	6–10	4–18
Mt Tamborine (1998)	0.001	18.1	13–27	10–45
Beerwah 1 (1999)	0.001	13.6	11–17	8–24
		Zn (mg/kg FW)		
Beerwah 1 (1998)	0.001	9.1	8–12	6–15
Beerwah 2 (1998)	0.01	9.5	6–15	4–28
Mt Tamborine (1998)	0.001	7.5	6–9	5–11
Beerwah 1 (1999)	0.05	7.8	7–9	5–11

[A]Variance ratio determined by analysis of variance; n.s., not significant (P>0.05).
[B]Mean across 10 trees/site. Values are means of 60 (1998) or 80 (1999) fruit from a total of 10 trees/location.
[C]Range of the tree means for each site.

$r = 0.59$). There were also positive correlations between tree yield and percentage DM in Beerwah 1 in 1998 ($P<0.05$, $r = 0.52$) and 1999 ($P<0.05$, $r = 0.48$), and in Mt Tamborine ($P<0.001$, $r = 0.71$).

There were no significant ($P>0.05$) correlations between the length of visible white non-suberised roots and fruit quality, flesh Ca, Mg, K, B, and Zn concentrations, tree yield, and yield/canopy volume at Beerwah 1 in 1999 (data not shown).

The correlations between the scion to rootstock circumference ratio and fruit quality, flesh Ca, Mg, K, B, and Zn concentrations at Beerwah 1 in either 1998 or 1999 were generally not significant ($P>0.05$; data not shown). However, there was a significant correlation between scion to rootstock circumference ratio and flesh Ca concentration in 1999 ($P<0.05$, $r = 0.73$).

The correlations between the scion to rootstock circumference ratio and rootstock wood and scion wood Ca, Mg, K, B, and Zn concentrations at Beerwah 1 in 1999 were not significant ($P>0.05$; data not shown).

Table 4. Correlations (*r*, linear correlation coefficient) between characteristics pertaining to fruit quality and mineral concentrations of the fruit flesh of Hass avocados

Fruit were harvested from several sites in south-east Queensland in 1998 and 1999 and ripened at 20°C. Correlations are based on means of 10 trees/location.year. For each tree, body rot severity and days to ripen were determined from 300 (1998) or 160 (1999) fruit. Flesh Ca, Mg, and K concentrations were determined from 60 fruit

Location (year)	Correlation coefficient (*r*) Ca	Mg	K
Body rot severity			
Beerwah 1 (1998)	–0.79**	–0.66*	–0.68*
Beerwah 2 (1998)	–0.32	0.36	0.06
Mt Tamborine (1998)	–0.44	0.72*	0.12
Beerwah 1 (1999)	–0.61	–0.28	0.43
Days to ripen			
Beerwah 1 (1998)	0.87**	0.42	0.51
Beerwah 2 (1998)	0.14	–0.11	0.04
Mt Tamborine (1998)	0.12	0.04	0.62
Beerwah 1 (1999)	0.58	0.47	0.56
Dry matter			
Beerwah 1 (1998)	–0.73*	–0.52	–0.69*
Beerwah 2 (1998)	0.34	0.09	0.56
Mt Tamborine (1998)	0.34	–0.32	–0.80**
Beerwah 1 (1999)	–0.72*	–0.52	–0.52
Fruit mass			
Beerwah 1 (1998)	–0.81**	–0.39	–0.48
Beerwah 2 (1998)	–0.70*	0.20	0.14
Mt Tamborine (1998)	–0.53	0.43	0.23
Beerwah 1 (1999)	–0.60	–0.09	0.18
Fruit yield			
Beerwah 1 (1998)	0.83**	0.49	0.63*
Beerwah 2 (1998)	–0.08	–0.32	–0.33
Mt Tamborine (1998)	0.07	–0.10	0.49
Beerwah 1 (1999)	0.62	0.02	0.18

*$P<0.05$, **$P<0.01$; values with no asterisk are not significant ($P>0.05$).

Discussion

The results of this study demonstrate that there is large variation between trees in fruit quality attributes such as the severity of body rot, diffuse discolouration and vascular browning. This tree effect could be an important contributing factor to the inconsistent avocado fruit quality offered to consumers in Australia (Hofman and Ledger 1999, 2001).

Likewise, there is variation between trees in the fruit flesh concentrations of minerals often associated with avocado quality, such as Ca, Mg, K, and B. These tree effects on fruit quality and mineral concentrations were consistently observed in the 3 commercial orchards, and over 2 seasons in 1 of the sites, even though there were no visible differences between trees at each site and there were no obvious differences noted in cultural practices or soil type among these trees.

The difference in rot severity between trees could result from differing tree inoculum loads. However, previous studies indicated little difference in inoculum load between trees on an avocado orchard close to the Beerwah sites (Marques 2003), and the tree differences in diffuse discolouration indicates a tree effect independent of inoculum load. Hofman *et al*. (2002) suggested that genetic variability between seedling rootstocks in commercial avocado orchards may contribute to this between-tree variability in fruit quality, as rootstock influences on fruit quality has been noted in other fruit trees (Castle 1995). The rootstock influence may be mediated through fruit mineral concentrations (Autio 1991), as suggested by the correlations between fruit mineral concentrations (particularly Ca, Mg, and K) and fruit quality attributes (particularly fruit susceptibility to body rots, percentage DM, and mass). Other avocado studies have found similar relationships between fruit mineral concentrations and quality (Eaks 1985; Hofman *et al*. 2002; Thorp *et al*. 1997; Witney *et al*. 1990).

Studies with avocado have demonstrated clear rootstock effects on tree nutrition (Lahav and Whiley 2002). For instance, trees grafted to Guatamalan race rootstocks have higher leaf Ca concentrations than those grafted to Mexican race rootstocks. Scion leaf concentrations of K, N and Mg can also be affected by rootstock race. Recent reports suggest that avocado rootstock can also affect fruit Ca concentration, the ratio of (Ca + Mg) : K in the fruit, and fruit quality (Willingham *et al*. 2001; Marques *et al*. 2003).

The present study suggested some rootstock-related factors which may influence fruit mineral concentrations or quality. A scion to rootstock circumference ratio of less than or greater than 1 can indicate physiological graft incompatibility (Whiley 1994). The correlation between this ratio and flesh Ca concentration in 1999 suggests that this factor may be involved, but further research is required to confirm this. In addition, the results from Beerwah 1 indicated that fruit from trees with a higher yield and producing smaller fruit, had higher Ca concentrations as also noted by Hofman *et al*. (2002). However, this was not consistent for all sites.

The measure of non-suberised root length in this study was not related to fruit quality or minerals, but root growth characteristics from flowering on may need to be considered. It is also possible that root efficiency in absorbing minerals from the soil, or the degree of lateral branching, may be more important than non-suberised root length.

Although the above factors may be involved in the difference in fruit quality between trees, the inconsistency in correlations across sites and years suggest that factors other than minerals influence fruit quality. Similar season or site effects on the correlations between Hass fruit quality attributes and flesh Ca, Mg, and K concentrations have been observed in New Zealand (Thorp *et al*. 1997) and Australia (Hofman *et al*. 2002; Vuthapanich 2001), with some sites showing strong correlations between fruit mineral concentrations and fruit quality in some years, but not in other years or in other sites. As the avocado industry in Australia is currently based on seedling rootstocks of unknown origin, it has been suggested that rootstocks may be a major contributing factor in the high between-tree variability in avocado quality and fruit minerals, and may present an important mechanism to improve avocado quality (Willingham *et al*. 2001).

This study confirmed large variation in fruit quality among Hass avocado trees, and that this variation could be partly attributed to fruit mineral concentrations. The most obvious variant among these trees was the unknown origin of the rootstocks on individual trees on 2 of the sites, and the use of seedling rootstocks on the third site. This justifies further investigation into the potential for selected rootstocks to improve avocado quality. For example, fruit quality and yield assessments over several years could identify high performing rootstock–scion combinations. These could be characterised for fruit minerals, and the root and growth characteristics that could influence minerals uptake and distribution to the fruit. Other factors related to fruit quality, for example, antifungal compounds influencing ripe fruit rots, could also be considered. Including genetic marker studies would help characterise these rootstocks and would be an important part of developing improved rootstocks for wider commercial use.

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