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Survey of fruit mineral concentrations and postharvest quality of New Zealand-grown 'Hass' avocado (*Persea americana* Mill.)

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Abstract New Zealand 'Hass' avocado (*Persea americana* Mill.) orchards were surveyed to determine if an imbalance in fruit mineral concentrations (Calcium (Ca), Magnesium (Mg), and Potassium (K)) was associated with poor fruit quality. Ranges for average fruit mineral concentrations on surveyed orchards were: Ca, 25–47 mg/100 g dry weight (DW); Mg, 91–113 mg/100 g DW; and K, 1126–1608 mg/100 g DW. Fruit with low Ca concentrations had more vascular browning and flesh browning than fruit with high Ca concentrations. Also, fruit Ca concentrations were lower and the incidence of vascular browning higher in fruit that were more mature at harvest. Fruit harvested below the minimum maturity standard (26% DW) had practically no postharvest rots. If harvested above this standard, 12–38% of ripe fruit had severe rots. A new disorder "anthocyanin staining" was observed in the flesh of several fruit. Results are discussed in relation to industry options for predicting and managing fruit quality.

Keywords *Persea americana*; avocado; fruit minerals; fruit maturity; fruit quality; anthocyanin

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INTRODUCTION

Preharvest factors affect fruit quality (Arpaia 1994; Hofman & Smith 1994). With avocados (*Persea americana* Mill.), these factors include fruit position within the tree canopy, crop yield, water stress, shoot vigour, and tree nutrition (Koen et al. 1990; Witney et al. 1990a,b; Cutting & Vorster 1991). Interactions between such factors determine inherent fruit quality. Growers and marketers require a good understanding of these interactions if they are to predict and manipulate fruit quality, and thus manage and maintain fruit quality after harvest. This is especially important for fruit held in cool-storage during transport to distant export markets.

In many fruit crops the interactions between calcium (Ca), magnesium (Mg), and potassium (K) within fruit determine fruit quality. For example, in apple (*Malus domestica* Borkh.) this mineral balance determines fruit susceptibility to bitter pit (Ferguson & Watkins 1989). In 'Fuerte' avocado, low fruit Ca concentrations have been associated with an increase in physiological disorders such as vascular and flesh browning (Chaplin & Scott 1980; Bower Cutting 1988). Both these disorders can be accentuated by cold storage. Ca has low mobility within the plant (Poovaiah et al. 1988). Competition for Ca between plant organs (leaves, shoots, fruit, roots, etc.) can be intense, especially in avocados early in the season when fruit are young and there is strong vegetative growth (Witney et al. 1990a). This may lead to reduced accumulation of Ca by the fruit in some situations. Mg and K have also been linked with fruit disorders. Koen et al. (1990) and du Plessis & Koen (1992) related high K-status (low (Ca+Mg)/K ratio) in the soil and plant to low levels of vascular browning and pulp spot in 'Fuerte', but they did not measure fruit mineral concentrations.

Here, we examine the influence of these minerals on avocado fruit quality. Our objective was to establish benchmark levels for Ca, Mg, and K in New Zealand-grown 'Hass' avocados, and to

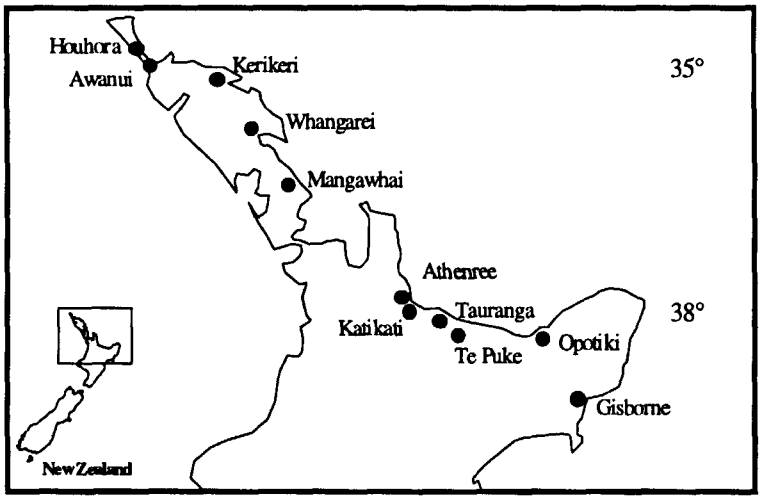

Fig. 1 Location of avocado (*Persea americana* Mill.) orchards used in fruit mineral survey, New Zealand.

establish if inadequate nutrition was related to a high incidence of physiological and pathological disorders. Fruit maturity will influence fruit quality and fruit mineral concentrations (Lee et al. 1983; Cutting et al. 1992). Thus, it was important in our study to harvest fruit at similar maturities. Future research would seek a physiological basis for the extreme variablility in fruit quality previously observed within trees (Hopkirk et al. 1994).

METHOD

In 1993, fruit were harvested from 'Hass' trees on 11 orchards in the major avocado growing districts of New Zealand (Fig. 1). In 1994, repeat samples were taken from three of these orchards. Harvest dates were staggered so that fruit maturity at harvest would be similar for each site and between years. Thus, Northland fruit were harvested before Bay of Plenty fruit.

Fruit were selected from trees of different ages and yield to obtain a range of samples for mineral analyses. Fruit were selected by randomly taking two fruit from each of 30 trees, using the method of Ferguson & Triggs (1990) for sampling apple fruit for Ca analyses. Harvested fruit were weighed, packed at random into single layer trays with 15 fruit/tray (4 trays/orchard) with fruit arranged in three groups of five fruit each. To emulate export conditions, fruit were stored for 3 weeks at 6°C, then transferred to 20°C until ripe.

Fruit ripening at 20°C were assessed every 2 days. Fruit were considered ripe when the fruit stem ("button") had completely blackened. At this stage of ripeness, fruit were considered to be "acceptably ripe" but not "fully ripe" (Hopkirk et al. 1994). We found this visual method of assessing fruit ripeness was faster and more reliable than other tests that require squeezing of fruit by hand to assess fruit softness. Such mechanical tests require frequent handling, which may influence fruit ripening.

When ripe, fruit were weighed, assessed for skin colour and external rots, then cut into quarters longitudinally. The skin was then peeled away and the flesh assessed for rots (stem end rot and body rot), vascular browning, and flesh browning—as described by Hopkirk et al. (1994). A severity rating scale from 0 (absent) to 2 (moderate or severe) was used. Several fruit had discolored flesh, mainly because of red anthocyanin staining. This staining was also observed in flesh adjacent to the vascular tissue (Fig. 2). Flesh colour at the neck of each fruit was measured using a Minolta Chroma Meter CR200 measuring in CIELAB with a D65 illuminant, to record this flesh discoloration. Data were converted to Chroma and hue angle (h°) to indicate colour intensity (McGuire 1992).

Individual fruit % dry weight (DW) and mineral concentrations were determined from 1 cm thick, longitudinal slices from each of the four fruit quarters. Flesh samples were taken from the ends and centre of each of these slices, using a 6 mm diameter cork borer. The combined sample (c. 5 g per fruit) was weighed, freeze-dried, and re-weighed to give % DW. This figure was converted

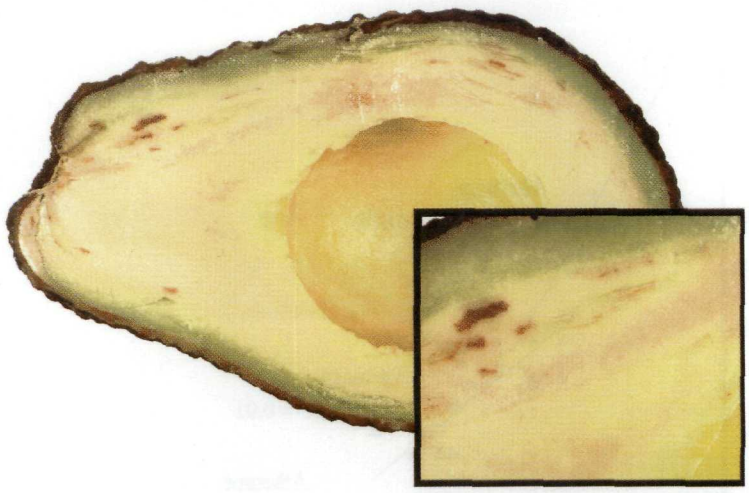

Fig. 2 Anthocyanin staining in the flesh of ripe 'Hass' avocados (*Persea americana* Mill.).

to % DW at harvest, by correcting for weight loss during storage and ripening. The dried tissue was then ground, and a 0.2 g subsample digested at 120°C for 120 min in 2 ml conc. HNO_3. After cooling to 60°C, a total of 2 ml 30% H_2O_2 was added in 0.5 ml aliquots, and the digestion continued for 60 min at 60°C, followed by 90 min at 120°C. Digested samples were then made up to 25 ml with distilled water containing 0.2% $LaCl_2$, and analysed for Ca, Mg, and K by atomic absorption spectroscopy (AA). Values were checked against blanks and fruit standards included with each digestion. Ca standards for AA analysis were made up with 1.5 ml HNO_3.

Soil and leaf samples for mineral analyses were collected from each orchard in March of 1994 and 1995. These samples were sent to a commercial laboratory (AgResearch Soil Fertility Service, Hamilton, New Zealand) for analysis.

Analysis of variance was performed on direct or transformed data to compare means between trays and between orchards. For fruit quality assessments, data were amalgamated into three groups of five fruit per tray and tray means determined from the group means. Standard errors were determined from the four tray means from each orchard. Percentage data from fruit quality assessments were analysed using transformed data based on arcsin angular transformations (arcsin $\sqrt{\%}$), and transformed back to the original units for presentation.

RESULTS

Fruit harvest and ripening

In 1993, fruit were harvested from orchards in the Far North (Houhora and Awanui) on 30 September, from Northland (Kerikeri, Whangarei, and Mangawhai) on 9 November; and from Bay of Plenty (Athenree, Katikati, Tauranga, Te Puke, and Opotiki) and Poverty Bay (Gisborne) during the third week of December (Table 1). Mean fruit weights at harvest ranged from 199 g at Gisborne to 254 g at Awanui. Fruit maturities at harvest ranged between 24% DW at Houhora and 35% DW at Athenree. Most fruit ripened within 7 days of being removed from cool-storage, with fruit that were less mature at harvest taking longer to ripen. Fruit from Houhora took the longest to ripen and had the lowest dry weights at harvest (10.2 days and 24% dry weight, respectively). This pattern also occurred for fruit within an orchard, especially on orchards with low average fruit maturities (Fig. 3). Most orchards had advanced fruit maturities with no relationship between fruit maturity and days-to-ripen. For clarity, data from just one of these orchards (Athenree) are included in Fig. 3. Water loss during storage and ripening ranged from 5.0% for Gisborne fruit to 8.2% for Kerikeri fruit.

In 1994, fruit were harvested from Houhora and Awanui on 9 November, and from Athenree on 25 November. Fruit maturities at harvest for these fruit were similar (Table 1).

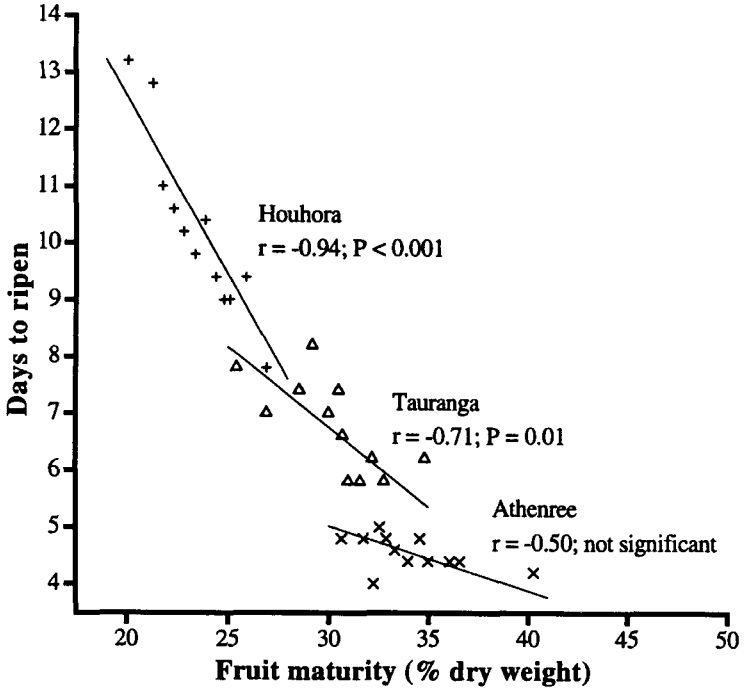

Fig. 3 Relationship between fruit maturity and days-to-ripen for 'Hass' avocados (*Persea americana* Mill.) harvested from New Zealand orchards in 1993. Fruit were stored for 3 weeks at 6°C, then ripened at 20°C. Each point is the average of five fruit. Fruit were sampled from 11 orchards (60 fruit/orchard). For clarity of presentation, data from three orchards with low, medium, and high average fruit maturities are presented here.

Table 1 Fruit weight and maturity at harvest, days-to-ripen, and water loss during ripening of 'Hass' avocado (*Persea americana* Mill.) fruit collected for mineral analysis from 11 New Zealand orchards. Fruit were stored for 3 weeks at 6°C, then ripened at 20°C. (Data are accompanied by ± 1 SE, derived from mean values per tray, from four trays with 15 fruit per tray.)

Region	Location	Harvest date	Fruit weight (g)	Fruit maturity (% dry weight)	Days to ripen	Water loss (%)
1993						
Far North	Houhora	30 Sep	250 ± 2	24 ± 0.2	10.2 ± 0.2	7.6 ± 0.2
Far North	Awanui	30 Sep	254 ± 5	31 ± 0.1	5.5 ± 0.8	6.8 ± 0.2
Northland	Kerikeri	9 Nov	217 ± 1	29 ± 0.2	6.0 ± 0	8.2 ± 0.1
Northland	Whangarei	9 Nov	209 ± 3	31 ± 0.6	7.8 ± 0.2	7.5 ± 0.2
Northland	Mangawhai	9 Nov	193 ± 5	28 ± 0.2	6.2 ± 0.1	8.0 ± 0.1
Bay of Plenty	Athenree	16 Dec	215 ± 4	35 ± 0.4	5.3 ± 0.1	5.7 ± 0.2
Bay of Plenty	Katikati	18 Dec	209 ± 2	34 ± 0.3	4.6 ± 0.1	6.4 ± 0.1
Bay of Plenty	Tauranga	21 Dec	201 ± 2	30 ± 0.4	6.8 ± 0.1	7.4 ± 0.2
Bay of Plenty	Te Puke	21 Dec	215 ± 2	32 ± 0.5	5.0 ± 0	7.1 ± 0.1
Bay of Plenty	Opotiki	17 Dec	209 ± 3	31 ± 0.3	5.1 ± 0.1	5.5 ± 0.1
Gisborne	Gisborne	17 Dec	199 ± 5	33 ± 0.2	4.3 ± 0.2	5.0 ± 0.2
1994						
Far North	Houhora	9 Nov	233 ± 2	28 ± 0.3	6.9 ± 0.3	5.7 ± 0.1
Far North	Awanui	9 Nov	241 ± 3	32 ± 0.5	6.0 ± 0	6.1 ± 0.3
Bay of Plenty	Athenree	25 Nov	261 ± 2	31 ± 0.5	5.5 ± 0.1	6.2 ± 0.1

Fruit mineral concentrations

Calcium

Mean fruit Ca concentrations varied by almost 2-fold between orchards (Table 2). In 1993, fruit from Awanui and Athenree had the lowest ($P < 0.05$) Ca concentrations with 25 mg/100 g DW and 28 mg/100 g DW, respectively. Fruit from the other orchards ranged from 37 mg/100 g DW at Katikati to 47 mg/100 g DW at Kerikeri. Concentrations at Awanui and Athenree were higher ($P < 0.01$) in 1994 than in 1993 with 33 mg/100 g DW at both orchards.

Magnesium

Mean fruit Mg concentrations in 1993 ranged from 91 mg/100 g DW at Athenree to 113 mg/100 g DW at Kerikeri (Table 2). Concentrations at Awanui in 1994 were lower ($P < 0.01$) than in 1993 (91 and

Table 2 Fruit mineral concentrations (mg/100g dry weight) in 'Hass' avocados (*Persea americana* Mill.) from 11 New Zealand orchards. (Data are accompanied by ± 1 SE, derived from mean values per tray, from four trays with 15 fruit per tray.)

Orchard	Calcium	Magnesium	Potassium	Ratio (Ca + Mg)/K
1993				
Houhora	42 ± 0.7	104 ± 0.8	1608 ± 22	0.093 ± 0.002
Awanui	25 ± 1.6	101 ± 0.9	1409 ± 29	0.091 ± 0.003
Kerikeri	47 ± 2.2	113 ± 3.3	1286 ± 23	0.127 ± 0.002
Whangarei	42 ± 2.1	95 ± 1.7	1126 ± 21	0.129 ± 0.004
Mangawhai	42 ± 2.0	104 ± 1.7	1378 ± 41	0.109 ± 0.004
Athenree	28 ± 1.2	91 ± 1.5	1398 ± 11	0.086 ± 0.001
Katikati	37 ± 1.7	92 ± 1.2	1319 ± 27	0.100 ± 0.003
Tauranga	37 ± 2.0	99 ± 1.9	1437 ± 19	0.097 ± 0.001
Te Puke	42 ± 3.7	101 ± 0.6	1441 ± 51	0.101 ± 0.006
Opotiki	41 ± 3.0	108 ± 0.3	1478 ± 20	0.102 ± 0.004
Gisborne	37 ± 2.3	97 ± 2.2	1486 ± 18	0.094 ± 0.004
1994				
Houhora	39 ± 1.5	102 ± 1.4	1387 ± 32	0.105 ± 0.002
Awanui	33 ± 1.4	91 ± 2.0	1292 ± 14	0.098 ± 0.003
Athenree	33 ± 0.6	94 ± 2.0	1305 ± 16	0.100 ± 0.001

Table 3 Soil and leaf mineral analyses from 11 New Zealand 'Hass' avocado (*Persea americana* Mill.) orchards. Samples were taken in late summer (March/April) 1994.

	Soil					Leaves				
					Ca+Mg					Ca+Mg
	pH	Ca	Mg	K	K	N	Ca	Mg	K	K
Location			(m.e./100g)					(% dry weight)		
Houhora	6.4	5.6	0.67	0.051	123	2.09	1.37	0.44	1.16	1.56
Awanui	6.2	4.4	0.80	0.103	50	2.44	1.16	0.40	0.94	1.66
Kerikeri	5.7	3.8	0.50	0.257	17	2.47	1.69	0.38	0.75	2.76
Whangarei	5.7	5.0	1.09	0.205	30	2.28	1.45	0.45	0.63	3.02
Mangawhai	5.6	6.3	1.05	0.770	10	2.55	1.38	0.38	0.92	1.91
Athenree	5.9	6.3	0.71	0.308	23	2.58	1.62	0.45	0.94	2.20
Katikati	5.4	1.9	0.46	0.257	9	2.80	1.40	0.36	1.07	1.64
Tauranga	5.7	3.1	0.67	0.359	11	2.40	1.21	0.36	0.99	1.56
Te Puke	6.6	6.9	1.60	0.718	12	2.40	1.13	0.36	1.10	1.35
Opotiki	6.1	5.0	0.97	0.154	39	2.31	1.57	0.47	0.81	2.52
Gisborne	6.0	11.9	1.47	0.667	20	2.10	2.26	0.36	1.19	2.20
Typical range for New Zealand (Barber et al. 1986)	5.4–6.3	2.5–6.3	0.6–1.2	0.4–0.6		2.0–2.4	1.0–3.0	0.3–0.8	0.8–2.0	

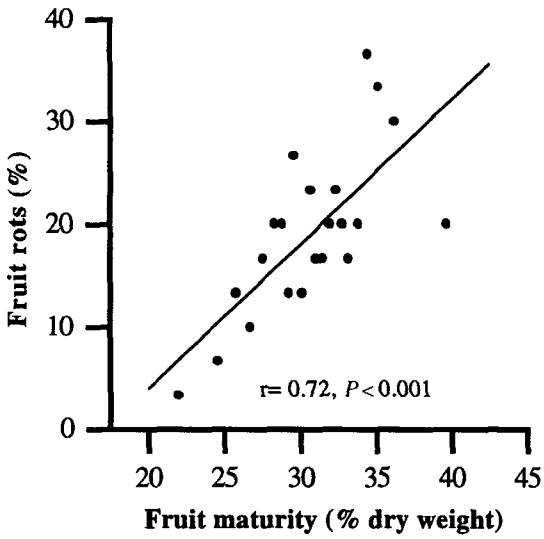

Fig. 4 Relationship between fruit maturity and incidence of fruit rots in New Zealand-grown 'Hass' avocados (*Persea americana* Mill.). Fruit were stored for 3 weeks at 6°C, then ripened at 20°C. Data are tray means for 11 orchards, with four trays of 15 fruit/orchard.

101 mg/100 g DW, respectively), whereas differences between years were not significant at Houhora or Athenree.

Potassium

In 1993, fruit from Whangarei had the lowest ($P < 0.05$) average K concentrations with 1126 mg/100 g DW (Table 2). Fruit from Houhora had the highest ($P < 0.05$) levels at 1608 mg/100 g DW. Otherwise values ranged from 1286 mg/100 g DW at Kerikeri to 1486 mg/100 g DW at Gisborne. The high reading for Houhora was not repeated in 1994, dropping to 1387 mg/100 g DW ($P < 0.01$).

Soil and leaf minerals

Soil and leaf mineral concentrations on the 11 orchards in our study were generally within the ranges reported as typical for New Zealand avocado orchards (Barber et al. 1986) (Table 3). The orchard at Katikati had unusually low levels of Ca and Mg in the soil, but not in the leaves or in the fruit (Table 2). There was no correlation between fruit concentrations, and soil or leaf concentrations for any mineral.

Table 4 Fruit quality of 'Hass' avocados (*Persea americana* Mill.) from 11 New Zealand orchards. Fruit were stored for 3 weeks at 6°C, then ripened at 20°C. (Data are percentages of fruit with severe symptoms, and are the mean values of four trays with 15 fruit per tray.) (Values with different letters show significant differences within columns by the Tukey-Kramer method.)

Orchard	Uneven skin colour	Fruit rots		Browning		Anthocyanin	
				Vascular tissue	Flesh	Vascular tissue	Flesh
1993							
Houhora	0	2	a	0 a	0	0	0
Awanui	5	13	ab	23 b	12	0	0
Kerikeri	0	22	bc	7 a	0	5	0
Whangarei	0	12	a	2 a	0	2	3
Mangawhai	0	22	bc	8 a	0	0	2
Athenree	0	38	c	2 a	0	7	6
Katikati	0	20	bc	2 a	0	3	3
Tauranga	0	15	abc	2 a	0	2	0
Te Puke	2	32	bc	2 a	0	0	2
Opotiki	0	13	ab	2 a	0	3	5
Gisborne	2	18	bc	0 a	0	5	0
1994							
Houhora	0	0		0	0	0	0
Awanui	0	12		0	0	0	2
Athenree	0	10		0	0	0	0

Fruit quality

Skin colour

Uneven skin colour is generally associated with fruit that have not ripened properly. Few ripe fruit in this trial had uneven skin colour (Table 4). Awanui fruit were most affected, but only 5% of these fruit had severe symptoms in 1993. These fruit also had the lowest Ca concentrations (Table 2). No fruit had uneven skin colour in 1994 (Table 4).

Postharvest rots

The most common fruit rots observed were the anthracnose fungi *Colleototrichum gloeosporioides* and *C. acutatum*, and the soft rot fungus *Botryosphaeria parva* (S. Forbes pers. comm.). In 1993, the proportion of fruit with severe rots ranged from 2% at Houhora to 38% at Athenree (Table 4). Fruit from Houhora and Whangarei had fewer ($P < 0.0001$) severe rots than fruit from Athenree, Kerikeri, Mangawhai, and Te Puke. Fruit from Houhora had the least rots ($P < 0.0001$), with only 2% of fruit severely affected. Incidence and severity of rots at each orchard increased with increasing fruit maturity at harvest (Fig. 4). There was no correlation between fruit mineral concentrations and incidence of fruit rots. In 1994, the incidence of fruit rots was either less than or unchanged compared with 1993 fruit (Table 4).

Physiological damage

Only fruit from Awanui had significant ($P<0.001$) levels of vascular browning and flesh browning in 1993 (Table 4). This orchard also had the lowest fruit Ca concentration. At Awanui, fruit with low Ca concentrations had more vascular browning than fruit with high Ca concentrations (Fig. 5A). Also, fruit Ca concentrations were lower in fruit that were more mature at harvest (Fig. 5B). Fruit Mg and K concentrations were not related to the incidence of physiological damage (data not shown). No fruit had visible symptoms of physiological damage in 1994 (Table 4).

Anthocyanin staining

Although anthocyanin staining was observed in fruit from most orchards, in 1993 the incidence of fruit with severe symptoms did not exceed 7% (Table 4). Such fruit would not be accepted by consumers. Flesh colour quantified by hue angle and chroma, however, were not different between orchards. The incidence of anthocyanin staining was not related to either fruit maturity or fruit mineral concentration.

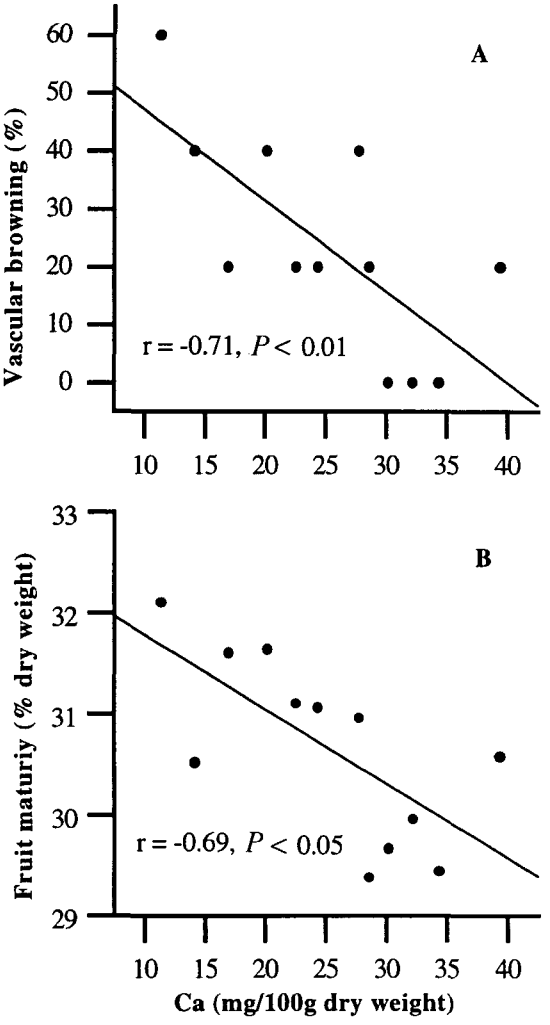

Fig. 5 Relationship between fruit Calcium (Ca) concentration and the incidence of: **A**, vascular browning; and **B**, fruit maturity of 'Hass' avocados (*Persea americana* Mill.) harvested from one orchard at Awanui, New Zealand. Fruit were stored for 3 weeks at 6°C, then ripened at 20°C. Vascular browning data is percentage of fruit with severe symptoms. Each point is the average of five fruit.

DISCUSSION

Benchmark concentrations for Ca, Mg, and K in New Zealand-grown 'Hass' avocados have been established in this research. Average fruit mineral concentrations on surveyed orchards were: 25–47 mg Ca/100 g DW; 91–113 mg Mg/100 g DW; and 1126–1608 mg K/100 g DW. The trial was not

designed to examine regional differences, and the results for each orchard are not considered to be representative of a particular region. Indeed the variation between the five Bay of Plenty orchards surveyed was just as great as the variation between the 11 orchards surveyed from Houhora to Gisborne.

Soil K at many orchards in this survey were below levels regarded as optimum in South African orchards (Koen et al. 1990). This may reflect a low K status of soils in our study or low levels of K fertiliser accessions. We observed no detrimental effects from low K in soils, but clearly growers will need to reconsider the amount of K they apply if they want to achieve leaf and soil levels within the range recommended by overseas workers.

We found most New Zealand fruit to have higher Ca and Mg concentrations, and lower K than fruit of the same cultivar grown in South Africa (Cutting & Bower 1992). Ratios of (Ca+Mg)/K, therefore, were consistently higher in New Zealand than in South African-grown fruit. Only one orchard (Awanui) had average fruit Ca concentrations less than those reported for South African fruit.

It is not clear what caused the low levels of Ca in the Awanui fruit. Low fruit Ca did not correlate with low Ca concentrations in the leaves or soil. This suggests that the amount of Ca in the tree does not limit Ca accumulation in the fruit, as also reported for apple (Ferguson & Watkins 1989).

Witney et al. (1990a) and Cutting & Bower (1992) suggested that tree vigour and the resulting competition between developing fruits and shoots, was the cause of low Ca concentrations in 'Fuerte' and 'Hass' fruit. This was unlikely to have been the cause in our study. Field observations at Awanui in 1993 and 1994 indicated heavy flowering with mostly determinate inflorescences. These inflorescences do not produce vigorous terminal shoot growth to compete with young fruitlets (Witney et al. 1990a). Water stress may have been the cause of poor fruit quality at Awanui. Avocado flowers have high transpiration rates and trees can suffer from excessive water loss during heavy flowering (Whiley et al. 1988). This may lead to low Ca concentrations in fruit, and to increased levels of physiological damage, although they may not be related (Bower & Cutting 1987).

Fruit Ca concentration alone was the better predictor of physiological damage (vascular browning) than the ratio between Ca, Mg, and K in fruit. This was also found when predicting bitter pit in apples in New Zealand (Ferguson & Watkins 1989).

Fruit at Awanui had an average of 25 mg Ca/100 g DW, and 23% of these fruit had severe vascular browning. At this orchard, fruit with low Ca concentrations had more vascular browning and flesh browning than fruit with high Ca concentrations. Apparently this was the only orchard with fruit Ca concentrations below a threshold for symptoms of Ca deficiency to appear. This threshold would appear to lie between 25 and 28 mg Ca /100 g DW. Fruit in New Zealand and South Africa with 28 mg Ca/100 g DW or above had practically no vascular or flesh browning (Cutting & Bower 1992). Also, in 1994 when we checked for low Ca concentrations at Awanui, we found higher levels than in the previous year and no vascular browning.

Fruit Ca concentrations at Awanui were lower and the incidence of vascular browning higher in fruit that were more mature at harvest. This relationship was observed over a range of fruit maturities above the minimum standard for New Zealand fruit of 26% DW (Anon.). Cutting & Wolstenholme (1992) reported that vascular browning was related to harvest date with high incidences of damage in early and late-harvested fruit. These workers did not record fruit maturity (% DW) so a direct comparison cannot be made with our results. However, we found no evidence of increased damage with fruit harvested at low fruit maturities. Cutting et al. (1992) also reported decreasing Ca concentrations with increasing fruit maturity in 'Fuerte'. If fruit Ca concentrations are known to be low, then it would be important to harvest these fruit earlier than fruit from orchards with sufficient Ca.

In contrast to our results, Cutting & Bower (1992) linked high Ca and Mg concentrations in 'Hass' fruit with high potential for physiological damage, as indicated by increased activity of the browning enzyme polyphenol oxidase (PPO). These fruit were harvested from trees treated with the plant growth inhibitor paclobutrazol and the fruit had no visual symptoms of physiological disorders. The plant growth inhibitor treatments may have led to increased PPO activity, independent of fruit mineral concentrations.

We did not find a direct link between fruit mineral concentrations and postharvest fruit rots. However, this relationship may have been masked by differences in fruit maturity. Incidence of rots increased as fruit maturity increased, and fruit Ca

concentrations decreased. We found no evidence that low Ca concentration caused fruit to ripen more quickly (Cutting et al. 1992). Thus, it would seem that if fruit are more mature at harvest and so ripen more quickly, they are more susceptible to rot development irrespective of fruit mineral concentrations.

In 1994, fruit from Houhora were harvested below the minimum maturity standard for New Zealand avocados (26% DW). These fruit had practically no postharvest rots. In 1993, fruit were harvested on 11 August from Houhora and Awanui at 21.3 and 22.4% DW, respectively. These fruit ripened evenly and had no postharvest rots (data not presented). The minimum maturity standard for New Zealand avocados is higher than the minimum standard of 21.6% DW, set for 'Hass' fruit in California (Ranney et al. 1992). Fruit exported from New Zealand in January and February would be well above these minimum maturities. Our results indicate these fruit would be over mature and hence highly susceptible to breakdown during storage. Clearly, maximum and minimum maturity standards need to be defined for New Zealand fruit.

Anthocyanin staining in the flesh occurred as a dark red speckle, or as distinctive red streaks adjacent to the vascular tissue (Fig. 2). Although this disorder has been seen before in New Zealand, South Africa, and Australia (A. White & B. Hartill pers. comm.; D. Roe & S. A. S. Vuthapanich pers. comm.), this is the first time the incidence of this disorder has been quantified and reported. Anthocyanin staining is likely to be a physiological rather than pathological disorder. It was not related to vascular or flesh browning and it was apparent in fruit that had not been cool-stored prior to ripening (data not presented). The disorder was most likely caused by conditions prevailing on the tree and may have been related to cold temperatures (D. Roe pers. comm). Its development during ripening at ambient temperature was not assessed.

In conclusion, Ca nutrition and harvest maturity were important determinates of postharvest fruit quality in these New Zealand-grown 'Hass' avocados. This information can be used to predict crop profiles prior to marketing, in terms of fruit storage potential and time to eating ripeness. Fruit harvested too early would be expected to have increased risk of uneven ripening although there could be benefits from an extended ripening period. In contrast, late harvested fruit would be expected to have reduced storage life and increased incidence of postharvest rots and physiological damage, especially if fruit Ca concentrations were low. Individual companies need to balance these risks against the price benefits from marketing fruit early and late in the season. Growers also need to consider the added risk of delayed harvesting on the formation of next year's crop (Whiley et al. 1996).

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