



ELSEVIER

Scientia Horticulturae 92 (2002) 113–123

SCIENTIA
HORTICULTURÆ

www.elsevier.com/locate/scihorti

Tree yield and fruit minerals concentrations influence 'Hass' avocado fruit quality

Peter J. Hofman^{a,*}, Surachat Vuthapanich^b, Anthony W. Whiley^a,
Andreas Klieber^c, David H. Simons^d

^aDepartment of Primary Industries, Maroochy Research Station, Queensland Horticulture Institute,
P.O. Box 5083 SMC, Nambour, Qld 4560, Australia

^bG.P. Technology Co. Ltd., 50/209 Moo 9 Suwintawong Rd., Sansab Minburi, Bangkok 10510, Thailand

^cDepartment of Horticulture, Viticulture and Oenology, The University of Adelaide,
Waite Campus, PMB 1, Glen Osmond, SA 5064, Australia

^dDepartment of Plant Production, University of Queensland, Gatton College, Lawes 4343, Australia

Accepted 21 May 2001

Abstract

To investigate the variation in quality of 'Hass' avocado fruit within an orchard, fruit were harvested at commercial maturity from 15 'Hass' trees of similar appearance, growing in three adjacent rows on the same soil type, and receiving similar management. Fruit were harvested at commercial maturity, and either ripened at 22 °C or stored at 2 or 7 °C for 3 or 5 weeks and then ripened. Significant positive correlations (based on the mean for each datum tree) were noted between fruit flesh calcium (Ca) and magnesium (Mg) concentrations and the (Ca + Mg)/potassium ratio, and the number of days for the fruit to reach the eating ripe stage (DTR). Negative correlations were also observed between these minerals and anthracnose and mesocarp discoloration (MD) severity. Negative correlations were observed between fruit potassium (K) and phosphorus (P) concentrations and DTR. Fruit from trees with high fruit yield were generally smaller, with lower anthracnose and MD severity, ripened more slowly, and had higher flesh Ca concentrations. It is likely that cultural practices that maintain moderate to high fruit yield and reduce variation in yield will improve avocado fruit quality and reduce variability in quality. Since the main differences between adjacent trees in this trial were the seedling rootstocks of unknown origin, it is suggested that rootstocks can have a significant impact on avocado yield and fruit quality. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Avocado; Calcium; Disease; Fruit; Minerals; Quality; Rootstocks

* Corresponding author. Tel.: +61-7-5444-9647; fax: +61-7-5441-2235.

E-mail address: hofmanp@dpi.qld.gov.au (P.J. Hofman).

0304-4238/02/\$ – see front matter © 2002 Elsevier Science B.V. All rights reserved.

PII: S0304-4238(01)00286-2

1. Introduction

Fruit mineral concentrations have been related to ripening, internal disorders and disease severity in a number of fruit (Hofman and Smith, 1994). In particular, calcium (Ca) has been implicated in fruit quality because of its role in cell wall and membrane function (Poovaiah et al., 1988). For example, pre-harvest Ca sprays and postharvest infiltration have reduced postharvest disease severity in a number of temperate fruit (Conway and Sams, 1987; Conway et al., 1994). In relation to avocado (*Persea americana* Mill.), Ca infiltration can delay softening (Eaks, 1985), and avocado shelf life has been positively correlated with fruit Ca concentrations (Witney et al., 1990).

Calcium is also implicated in avocado internal disorders. Sprays and postharvest dips with new Ca formulations have been reported to reduce internal disorders in 'Pinkerton' avocado fruit (Penter and Stassen, 2000), and Thorp et al. (1997) observed that fruit with high Ca had less vascular browning (VB) in the flesh. Potassium (K) and magnesium (Mg) have also been implicated in avocado fruit disorders (Witney et al., 1990), possibly through interactions with Ca during uptake by the roots (Ferguson, 1980). These interactions have also been identified in avocado (Koen et al., 1990).

Therefore, there is benefit in manipulating fruit Ca concentrations to improve fruit quality (Shear, 1975), and this is best achieved during fruit growth, rather than after harvest. However, improving fruit Ca concentrations is often difficult to achieve because Ca moves in the transpiration stream, so accumulation in low transpiring organs such as fruit is often unpredictable.

Fruit Ca concentrations can be influenced by several production factors other than Ca application, such as irrigation and vegetative/reproductive balance (Beverly et al., 1993; Hofman and Smith, 1994). Rootstocks can also affect fruit quality in temperate fruit crops (Drake et al., 1988). The Australian avocado industry is largely based on seedling rootstocks of unknown and variable origin, which could result in significant differences in fruit performance from adjacent trees receiving identical management. If so, it would suggest a potential to improve avocado fruit quality by using better rootstocks. We investigated this by comparing the quality and flesh minerals concentrations of 'Hass' fruit from trees on unknown seedling rootstocks in three adjacent orchard rows, to determine the potential for trees to influence fruit quality, and the role fruit minerals may play in this relationship.

2. Materials and methods

2.1. Experimental site and trees

The experiment was conducted in a commercial orchard at Childers (southeast Queensland; latitude 25°14'S) on 9-year-old 'Hass' avocado (*P. americana* Mill.) trees, from October 1993 to June 1995. The trees were grafted to seedling Guatemalan rootstocks of unknown origin, in rows at 6 m × 8 m spacing planted in a red clay loam (krasnozem) soil with high clay and organic matter content, and good water holding capacity.

The experimental site was on a gentle slope with good drainage that minimised root rot caused by *Phytophthora cinnamomi* (Rands). The climate was warm, humid subtropical with a mean annual rainfall of 1000 mm in a summer/wet, winter/dry pattern. All trees received normal commercial practices. Trees were fertilised with nitrogen (N), K, Ca and boron (B) following recommendations based on leaf analyses carried out by a commercial laboratory (Incitec, Brisbane, Australia). Most nutrient concentrations in mature leaves in May were within the optimum ranges recommended by Piccone and Whiley (1987). Avocado root rot (caused by *P. cinnamomi* Rands) was controlled through tree trunk injection of 20% mono-dipotassium phosphonate as recommended by Pegg et al. (1985). All trees maintained their health during the experiment with very little evidence of avocado root rot.

Three adjacent rows in the orchard were selected. Each row contained 19 trees but five trees of uniform canopy size and appearance from each row were selected as datum trees (total of 15 trees).

2.2. Fruit quality assessments

At commercial harvest (June; average of 23.4% DM of the fruit flesh in 1994, and 24.1% DM in 1995), all fruit on each datum tree were picked, counted and weighed. In 1994, 16 uniform fruit of 235–300 g fresh weight were harvested from each datum tree. Fruit were dipped in Sportak[®] (Prochloraz; 0.05%, v/v) for 1 min within 4 h of harvest. Half the number of fruit were ripened at 22 °C and the other half stored at 7 °C for 3 weeks then ripened at 22 °C. In 1995, 36 fruit were harvested from each datum tree and divided into three subsamples for either ripening at 22 °C, or storage at 2 or 7 °C for 5 weeks before ripening at 22 °C.

The days to eating ripe (DTR) was measured by the days for fruit to reach the eating soft stage as measured by gentle hand pressure. This corresponded to a firmness of 4–6 N 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). When ripe the fruit were halved longitudinally and the seed removed. The severity of mesocarp discolouration (MD) and VB (Cutting and Wolstenholme, 1992) was rated using the scale of 1: nil, 2: 1–10%, 3: 11–25%, 4: 26–50%, 5: 51–75% and 6: 76–100% of the cut surface area affected. Stem end rot (SER) severity was rated using the scale of 1: nil, 2: 1–5%, 3: 6–10%, 4: 11–25% and 5: 26–100% of the cut surface area of the fruit with lesions. The flesh was then scooped out from the skin and anthracnose severity rated using the same scale as for SER, but based on the percentage of the flesh adjacent to the skin with lesions. Disease lesions were occasionally isolated and cultured on potato dextrose agar to confirm pathogen identity.

2.3. Flesh minerals

Transverse equatorial sections of the ripe fruit flesh were oven-dried at 60 °C to constant mass. The dried flesh from each fruit was combined to provide a composite tree sample, ground with a Bamix blender (Bamix, Switzerland) and oven-dried again at 60 °C for 3 h. Sub-samples (0.5 g) were wet-digested using a modified method from Baker and

Smith (1974). The ground, dried flesh was digested in 18 ml concentrated nitric and perchloric acid (5:1 v/v) containing several drops of 6 μM ammonium metavanadate. The samples were pre-digested at ambient temperature for at least 2 h, heated on a hot plate to 120 °C for 30 min, and then cooled to 80 °C for a further 20 min. The cooled, digested sample was made to 25 ml with distilled water before analysis of Ca, Mg, K, B, sulphur (S), manganese (Mn), copper (Cu), iron (Fe), sodium (Na), zinc (Zn) and aluminium (Al) by inductively coupled plasma argon emission spectroscopy (Model M + P, SpectroInstrument). A certified sample of maize leaf was used as a reference. Results are expressed as dry weight of the ripe fruit flesh.

2.4. Statistical analysis

Individual fruit quality assessments and fruit minerals' concentrations were averaged to give a mean value for each datum tree. Then the relationships between major minerals and postharvest quality characteristics were established using individual tree results ($n = 15$) by linear regression analysis.

Table 1

Correlations (linear correlation coefficient, r) between fruit calcium (Ca), magnesium (Mg), potassium (K), $(\text{Ca} + \text{Mg})/\text{K}$ and phosphorus (P) concentrations and days to ripe, and anthracnose and MD severity of ripe 'Hass' avocado fruit, either ripened at 22 °C without storage, or after storage at 2 and 7 °C for 3 or 5 weeks^a

Year	Storage	Mineral				
		Ca	Mg	K	$(\text{Ca} + \text{Mg})/\text{K}$	P
<i>Days to ripe</i>						
1994	Non-stored	0.58*	0.23	-0.49	0.55*	-0.67**
	7 °C, 3 weeks	0.78**	0.73**	-0.38	0.82**	-0.46
1995	Non-stored	0.78**	0.51*	-0.85**	0.87**	-0.72**
	7 °C, 5 weeks	0.87**	0.67**	-0.56*	0.81**	-0.70**
	2 °C, 5 weeks	0.84**	0.43	-0.68**	0.77**	-0.82**
<i>Anthracnose</i>						
1994	Non-stored	-0.79**	-0.62*	0.35	-0.75**	0.54*
	7 °C, 3 weeks	-0.62*	-0.77**	-0.07	-0.57*	-0.11
1995	Non-stored	-0.88**	-0.59*	0.78**	-0.89**	0.78**
	7 °C, 5 weeks	-0.81**	-0.82**	0.60*	-0.87**	0.44
	2 °C, 5 weeks	-0.64*	-0.69**	0.46	-0.67**	0.40
<i>Mesocarp discoloration</i>						
1994	7 °C, 3 weeks	-0.07	-0.13	0.55*	-0.31	0.12
1995	7 °C, 5 weeks	0.30	0.31	0.06	0.19	0.00
	2 °C, 5 weeks	-0.83**	-0.75**	0.51*	-0.77**	0.63*

^a Correlations are based on individual tree means for the 15 datum trees. Correlations with no asterisk were not significant.

* Significance at $P \leq 0.05$ (not significant).

** Significance at $P \leq 0.01$ (not significant).

3. Results

Average fruit yield per tree, fruit mass and fruit number per datum tree in 1994 was 57 kg, 194 g and 321 fruit per tree, and in 1995, 130 kg, 216 g and 839 fruit per tree, respectively. In 1995, higher tree yield was primarily a result of higher fruit number per tree ($r = 0.97$; $P \leq 0.01$) with less fruit mass in the higher yielding trees ($r = -0.53$; $P \leq 0.05$). Similar relationships were obtained in 1994.

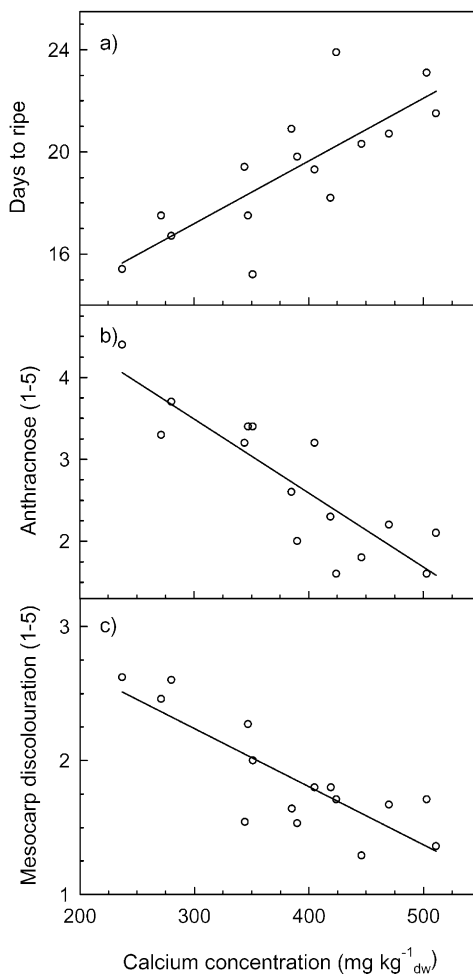


Fig. 1. Relationship between 'Hass' avocado ripe fruit flesh calcium concentration ($\text{mg kg}^{-1} \text{ dw}$), and (a) the number of days from harvest to the ripe (DTR) stage ($\text{DTR} = 0.025\text{Ca} + 9.83$; $r = 0.78^{**}$), (b) anthracnose (A) severity ($A = -9.03\text{Ca} + 6.20$; $r = -0.88^{**}$) and (c) MD severity ($\text{MD} = -4.34\text{Ca} + 3.54$; $r = -0.83^{**}$) for non-stored fruit in 1995. ** indicates significance for the correlation coefficient (r) at $P \leq 0.01$ (not significant).

The DTR following no storage in both years averaged 19 days (range of 16–24 days) and 6 days (range of 8–11 days) after 3 or 5 weeks at 7 °C. Anthracnose severity in non-stored fruit averaged 2.6 in both years, and 3.7 after storage for 5 weeks in 1995. MD severity was low in 1994, but in 1995 averaged 2.6 after storage for 5 weeks at 7 °C, and 1.9 after 5 weeks at 2 °C. Vascular browning and SER severity was negligible in both years.

Fruit flesh Ca concentrations averaged 302 and 385 mg kg_{dw}⁻¹ in 1994 and 1995, respectively, and Mg and K concentrations averaged 0.09 and 2.14%_{dw} over the 2 years.

There were strong positive linear relationships between fruit flesh Ca concentration and (Ca + Mg)/K, and DTR in both years, with less frequent correlations with Mg (Table 1). There was no evidence of the correlations being influenced by very high or very low values (Fig. 1). The average fruit Ca concentration per tree ranged from 220 to 510 mg kg_{dw}⁻¹, suggesting considerable tree to tree variation in Ca uptake and/or distribution to the fruit. In contrast, K and P concentrations were negatively correlated to DTR, particularly in 1995. The correlations between other elements (B, S, Mn, Cu, Fe, Na, Zn and Al) and DTR were generally not significant (data not shown).

There were strong negative correlations between Ca, Mg and (Ca + Mg)/K, and anthracnose severity (Table 1). Fruit K and P concentrations were mostly positively correlated with anthracnose severity, but with much weaker relationships. MD severity was occasionally negatively correlated with fruit Ca and Mg concentrations, and the (Ca + Mg)/K ratio, and positively correlated with fruit K and P concentrations after storage.

In both years, tree yield and fruit number per tree was positively correlated to fruit Ca and Mg and negatively to fruit K concentration, while the opposite correlations occurred for fruit mass (Table 2). Selected illustrations of these relations are presented in Figs. 2 and 3.

Table 2

Correlations (linear correlation coefficient, *r*) between fruit calcium (Ca), magnesium (Mg), potassium (K) and (Ca + Mg)/K concentrations and the fruit number per tree, average fruit mass (g) and tree yield (kg) of 'Hass' avocado fruit in two seasons^a

	Ca	Mg	K	(Ca + Mg)/K
1994				
Fruit number per tree	0.74**	0.80**	-0.33	0.80**
Fruit mass	-0.87**	-0.63**	0.36	-0.79**
Tree yield	0.65**	0.75**	-0.30	0.74**
1995				
Fruit number per tree	0.81**	0.68**	-0.74**	0.88**
Fruit mass	-0.82**	-0.57*	0.51*	-0.72**
Tree yield	0.70**	0.64**	-0.68**	0.80**

^a Correlations are based on individual tree means for the 15 datum trees. Correlations with no asterisk were not significant.

* Significance at $P \leq 0.05$ (not significant).

** Significance at $P \leq 0.01$ (not significant).

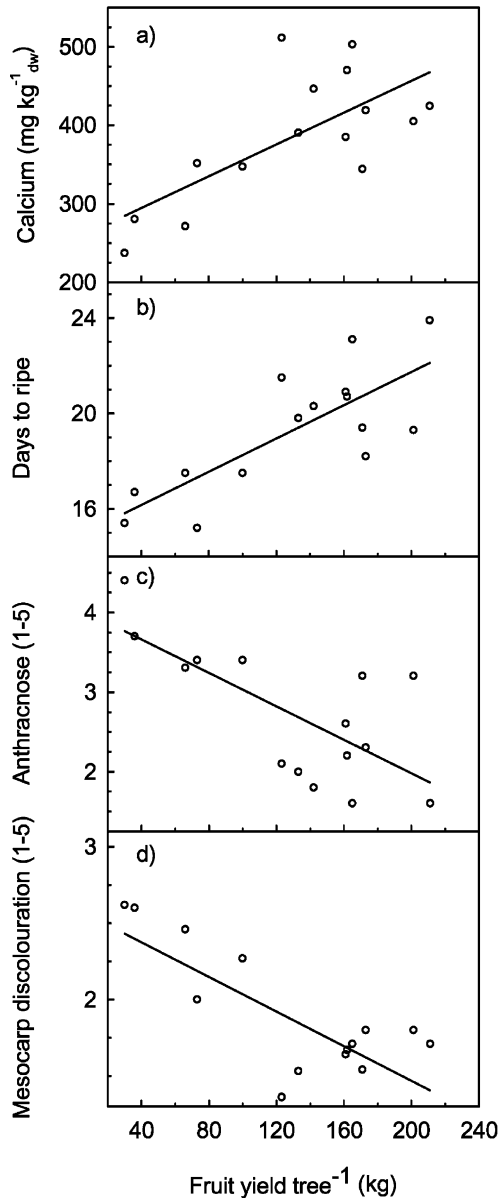


Fig. 2. Relationship between 'Hass' avocado fruit yield per tree (Y), and (a) ripe fruit flesh calcium concentration ($\text{mg kg}_{\text{dw}}^{-1}$) ($\text{Ca} = 1.01Y + 254.4; r = 0.72^{**}$), (b) the number of days from harvest to the ripe (DTR) stage ($\text{DTR} = 0.034Y + 14.77; r = 0.82^{**}$), (c) anthracnose (A) severity ($A = -0.011Y + 4.08; r = -0.81^{**}$) and (d) MD severity ($\text{MD} = -5.67Y + 2.60; r = -0.75^{**}$) for fruit stored for 5 weeks at 7 °C, before ripening at 22 °C in 1995. ** indicates significance for the correlation coefficient (r) at $P \leq 0.01$ (not significant).

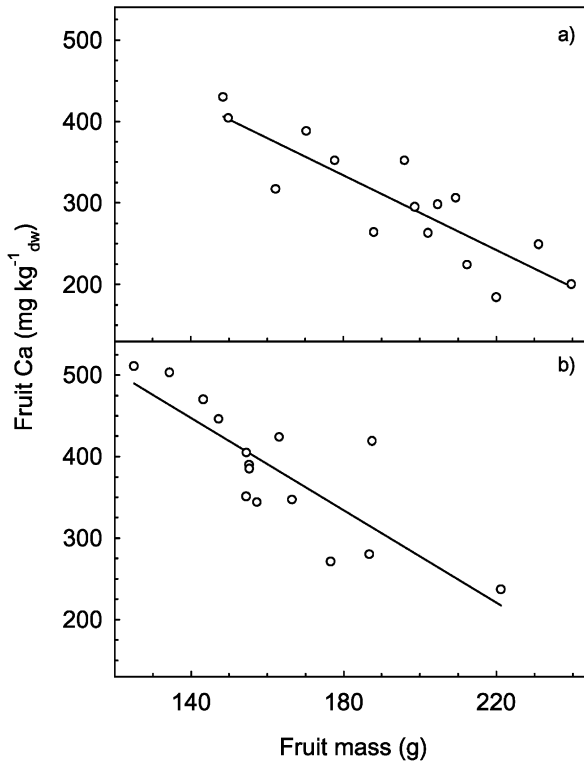


Fig. 3. Relationship between average 'Hass' fruit mass (g) per tree (M), and the average ripe fruit flesh calcium concentration ($\text{mg kg}_{\text{dw}}^{-1}$) for fruit stored for five weeks at 7°C , before ripening at 22°C in (a) 1994 ($M = -2.29\text{Ca} + 746.3; r = -0.87^{**}$) and (b) 1995 ($M = -2.83\text{Ca} + 843.9; r = -0.82$). ** Indicates significance for the correlation coefficient (r) at $P \leq 0.01$.

Tree yield was also positively correlated to DTR, and negatively correlated to anthracnose and MD severity in 1995 (Fig. 2). Similar results were obtained in 1994. Fruit mass was negatively correlated to DTR ($r = -0.66; P \leq 0.01$), and positively correlated to anthracnose ($r = 0.71; P \leq 0.01$) and MD severity ($r = 0.78; P \leq 0.01$) in 1995.

4. Discussion

The above results confirm the significant role fruit minerals can play in 'Hass' avocado fruit quality. Similar interactions have been observed in other studies. For example, postharvest Ca infiltration reduced chilling injury (brown or grey MD) (Chaplin and Scott, 1980). Koen et al. (1990) identified a positive relationship between avocado leaf and proximal fruit K concentration and grey pulp, and a negative relationship between distal fruit P and grey pulp incidence. In addition, pre-harvest Ca sprays and postharvest

infiltration have been shown to decrease postharvest disease severity in a number of temperate fruits (Conway and Sams, 1987).

Tree yield has also been related to fruit quality in other studies. Less internal disorders in 'Fuerte' (Cutting and Vorster, 1991) and in 'Pinkerton' (Kruger et al., 2000) avocado fruit were observed in fruit from higher yielding trees than from lower yielding trees, although this has not always been shown (Kremer-Köhne et al., 1991). Less bitter pit has also been found in apples from high yielding trees (Baugher et al., 1996). The improved fruit quality from higher yielding trees in this study may have been the result of lower leaf:fruit ratios, since all trees had similar canopy volume. In this situation proportionately more Ca may have accumulated in fruit as a result of relatively less transpiration from leaves compared to fruit. This is supported by Witney et al. (1990), who found that 'Hass' and 'Fuerte' avocado fruit from less vegetatively vigorous trees had higher flesh Ca concentrations than those from more vigorous trees. Similarly, Sharples (1980) found higher Ca concentrations in pear fruit from trees with lower leaf:fruit ratios. However, the smaller fruit size from the higher yielding trees may also have minimised the dilution of Ca due to fruit growth, thus increasing fruit Ca concentrations. Similar relationships between fruit size and fruit Ca concentration have been observed in pear and apple (Sugar et al., 1991; Ferguson et al., 1993).

The differences between trees in relation to fruit yield and fruit quality in this investigation suggests that genetic characteristics of the rootstock, or the rootstock/scion interaction play a significant role in quality, since there was no significant variation in soil characteristics of the experimental site, and the trees received similar management. Therefore, there appears to be considerable potential to improve both fruit yield and quality through genetic selection or greater knowledge of rootstock/scion interactions. For example, Whiley (1994) found considerable differences in total starch concentration and the areas of accumulation in 'Hass' avocado trees grafted to different rootstocks. Fruiting patterns were also significantly different between trees on different rootstocks with respect to determinate shoot cropping. In the study of Whiley (1994) the 'Hass' scion used on all trees was selected from the same mother tree source. Furthermore, the authors are unaware of any published data that supports an effect of 'Hass' scion source on tree performance, suggesting that the main factor in this study was the seedling rootstocks of unknown origin. In addition, rootstocks are known to affect leaf minerals concentrations in avocados (Whiley et al., 1996), and in fruit minerals concentrations and quality in other fruit (Drake et al., 1988; Castle, 1995).

In conclusion, avocado fruit quality can be improved by optimising tree yield and fruit minerals concentrations, and rootstocks may have an important role by contributing to consistent medium to high yields, and/or better fruit quality through improved Ca uptake. Other practices that reduce biennial bearing may also reduce the inconsistency in fruit quality between years and between trees.

Acknowledgements

We thank Mr. J. Dorrian for access to his orchard, Jack Saranah for technical assistance, Alan Lisle for assistance with statistical analyses and Kathy Raymond

for advice on mineral analysis. We also thank the Department of Primary Industries, Queensland, and the Australian Centre for International Agricultural Research for financial assistance.

References

- Baker, A.S., Smith, R.L., 1974. Preparation of solutions for atomic absorption analyses of Fe, Mn, Zn and Cu in plant tissue. *J. Agric. Food Chem.* 22, 103–107.
- Baughner, T.A., Hogmire, H.W., Biggs, A.R., Lightner, G.W., 1996. Packout audits of apples from five orchard management systems. *HortTechnology* 6, 34–41.
- Beverly, R.B., Latimer, J.G., Smittle, D.A., 1993. Preharvest physiological and cultural effects on postharvest quality. In: Shewfelt, R., Prussia, S. (Eds.), *Postharvest Handling: A Systems Approach*. Academic Press, San Diego, CA, pp. 74–93.
- Castle, W., 1995. Rootstock as a fruit quality factor in citrus and deciduous tree crops. *NZ J. Crop Hort. Sci.* 23, 383–394.
- Chaplin, G.R., Scott, K.J., 1980. Association of calcium in chilling injury susceptibility of stored avocados. *HortScience* 15, 514–515.
- Conway, W.S., Sams, C.F., 1987. The effects of postharvest infiltration of calcium, magnesium, or strontium on decay, firmness, respiration, and ethylene production in apples. *J. Am. Soc. Hort. Sci.* 112, 300–303.
- Conway, W.S., Sams, C.E., Kelman, A., 1994. Enhancing the natural resistance of plant tissues to postharvest diseases through calcium applications. *HortScience* 29, 751–754.
- Cutting, J.G.M., Vorster, L.L., 1991. Difference in fruit ripening and quality from trees with different yield—a progress report. *S. Afr. Avocado Growers' Assoc. Yrbk* 14, 56.
- Cutting, J.G.M., Wolstenholme, B.N., 1992. Maturity and water loss effects on avocado (*Persea americana* Mill.) postharvest physiology in cool environments. *J. Hort. Sci.* 67, 569–575.
- Drake, S.R., Larsen, F.E., Fellman, J.K., Higgins, S.S., 1988. Maturity, storage quality, carbohydrate and mineral content of 'Goldspur' apples as influenced by rootstock. *J. Am. Soc. Hort. Sci.* 113, 949–952.
- Eaks, I.L., 1985. Effect of calcium on ripening, respiratory rate, ethylene production, and quality of avocado fruit. *J. Am. Soc. Hort. Sci.* 110, 145–148.
- Ferguson, I.B., 1980. Mineral composition of fruit and vegetables in relation to storage life. *CSIRO Food Res. Quart.* 40, 94–100.
- Ferguson, I.B., Watkins, C.B., Volz, R.K., 1993. Assessment and reduction of bitter pit risk in apple fruit. *Acta Hort.* 326, 157–164.
- Hofman, P.J., Smith, L.G., 1994. Preharvest effects on postharvest quality of subtropical and tropical fruit. In: Champ, B.R., Highley, E., Johnson, G.I. (Eds.), *Postharvest Handling of Tropical Fruits*. ACIAR Proceedings No. 50. Australian Centre for International Agricultural Research, Canberra, pp. 261–268.
- Koen, T.J., Du Plessis, S.F., Terblanche, J.H., 1990. Nutritional factors involved in physiological postharvest fruit disorders of avocados (cv Fuerte). *Acta Hort.* 275, 543–550.
- Kremer-Köhne, S., Köhne, J.S., Kirkman, B., 1991. Yield and fruit quality of avocado cv Fuerte as influenced by paclobutrazol foliar applications. *S. Afr. Avocado Growers' Assoc. Yrbk* 14, 22–23.
- Kruger, F.J., Kritzing, M., Malumane, R., 2000. Recommendations for controlling the postharvest problems of the Pinkerton cultivar. *S. Afr. Avocado Growers' Assoc. Yrbk* 23, 8–14.
- Pegg, K.G., Whiley, A.W., Saranah, J.B., Glass, R.J., 1985. Control of *Phytophthora* root rot of avocado with phosphorous acid. *Aust. J. Plant Pathol.* 14, 25–29.
- Penter, M.G., Stassen, P.J.C., 2000. The effect of pre- and postharvest calcium applications on the postharvest quality of Pinkerton avocados. *S. Afr. Avocado Growers' Assoc. Yrbk* 23, 1–7.
- Piccone, M.F., Whiley, A.W., 1987. Nutrition. Avocado Fact Sheet, RQN 87039.
- Poovaliah, B.W., Glenn, G.M., Reddy, A.S.N., 1988. Calcium and fruit softening: physiology and biochemistry. *Hort. Rev.* 10, 107–152.
- Sharples, R.O., 1980. The influence of mineral nutrition on the storage quality of apples and pears grown in the United Kingdom. *Acta Hort.* 93, 17–28.
- Shear, C.B., 1975. Calcium-related disorders of fruits and vegetables. *HortScience* 10, 361–365.

- Sugar, D., Righetti, T.L., Sanchez, E.E., Khemira, H., 1991. Management of nitrogen and calcium in pear trees for enhancement of fruit resistance to postharvest decay. *HortTechnology* 2, 382–387.
- Thorp, T.G., Hutching, D., Lowe, T., Marsh, K.B., 1997. Survey of fruit mineral concentrations and postharvest quality of New Zealand-grown 'Hass' avocado (*Persea americana* Mill.). *NZ J. Crop Hort. Sci.* 25, 251–260.
- Wiley, A.W., 1994. Ecophysiological studies and tree manipulation for maximisation of yield potential in avocado (*Persea americana* Mill.). Ph.D. Thesis. University of Natal, Pietermaritzburg, South Africa.
- Wiley, A.W., Smith, T.E., Wolstenholme, B.N., Saranah, J.B., 1996. Boron nutrition of avocados. *S. Afr. Avocado Growers' Assoc. Yrbk* 19, 1–7.
- Witney, G.W., Hofman, P.J., Wolstenholme, B.N., 1990. Effect of cultivar, tree vigour and fruit position on calcium accumulation in avocado fruits. *Sci. Hort.* 44, 269–278.