IS THE POOR QUALITY OF LATE SEASON NEW ZEALAND 'HASS' AVOCADO FRUIT RELATED TO FRUIT CHARACTERISTICS AT HARVEST?

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ABSTRACT

New Zealand avocado fruit are harvested from August to March, although towards the end of the season fruit tend to develop increasing amounts of disorders when ripe. An increase in disorders can cause problems for exporters forcing an early exit from export markets. Identifying poor quality fruit at harvest would allow exporters to avoid placing such fruit on the market. A marker of advanced maturity that is related to increased disorder levels is required. Potential markers include the fruit's sugar content, either as the soluble solids content or levels of individual sugars, and the development of the seed. Changes in soluble solids, sugar composition and seed development of 'Hass' avocados were followed in fruit harvested from 2 orchards (designated Orchard 1 and Orchard 2, from the Eastern Bay of Plenty and Far North, respectively) about every two weeks from December through to February. A separate sample of fruit from the same harvests were stored for 4 weeks at 4°C and assessed for disorders immediately out of storage and also when ripe. The association between fruit composition and ripe fruit quality was then assessed. The soluble solids content of unripe fruit was about 7 to 9° Brix with a gradual decline over the first 3 harvests for fruit from Orchard 1, but no consistent change for Orchard 2. Total sugars were higher in fruit from Orchard 1 (9-16mg/mL) than Orchard 2 (7-9 mg/mL) with a discrete peak in Orchard 1 but a gradual decline in fruit from Orchard 2. The most abundant sugar was the 7-carbon mannoheptulose, which showed a discrete peak in fruit from Orchard 1 but not Orchard 2. Magnetic resonance images of the fruit showed the water content of individual seeds was between 20 to 50%. There was a general trend for the embryo water content to increase as the harvest season progressed. Ripe fruit disorders were mostly stem end rots with associated vascular browning and body rots. There was no consistent change in the incidence or severity of green and ripe fruit disorders with harvest. There was a tendency for a lower incidence of sound fruit to be associated with lower total sugars or mannoheptulose or higher seed water content, although no definitive marker of advanced fruit maturity was identified in this study.

Keywords: *soluble solids, sugars, embryo water content, ripe rots*

INTRODUCTION

The harvest season for 'Hass' avocados in New Zealand can extend from August to March. Over this time the fruit are retained on the trees and continue to grow in size and accumulate dry matter. Early season fruit harvested in September could therefore be expected to have different characteristics to late season fruit harvested in January or February. Fruit harvested in the months near the end of the harvest season are considered to have more advanced maturity than fruit harvested at the beginning of the harvest season. Typically fruit harvested towards the end of the season tend to develop increasing amounts of disorders such as stem end rots, body rots and diffuse flesh discolouration (Dixon *et al*., 2003). The increase in disorders presents a problem to exporters of New Zealand avocados in that they can be forced to exit a market prematurely due to poor quality fruit.

If the potentially poor quality fruit could be identified at harvest it should be possible to prevent it from being placed in the market, or it may be possible for exporters to choose how they would market and handle such high risk fruit. To do this, a marker of seasonal or advanced maturity that relates to when disorder levels are likely to be commercially unacceptable is needed. Such a marker could be used to set requirements for the export of late season fruit, and allow exporters to choose when to exit export markets. In doing so, it is expected exporters will be able to maximise returns back to New Zealand avocado growers.

Possible indicators of potential poor quality in late season fruit are most likely to be physiological or morphological in nature. While the dry matter content of the fruit is a useful practical guide to indicate the earliest point in time when the fruit can be harvested it is not considered to be useful for determining when fruit become over mature (Hofman *et al*., 2000). It is possible that the increased incidence of poor quality in late season fruit is due to compositional changes in the fruit that increase its susceptibility to post-harvest disorders and rots developing. One component of the fruit that may change with advancing maturity is soluble solids content. Soluble solids are used as a marker of maturity in other fruit crops (Kays and Paull, 2004) and are relatively straightforward to measure. The soluble solids level is usually regarded as an indication of sugars in the aqueous fraction of the flesh (Kays and Paull, 2004).

It is also possible that changes in the concentration of individual sugars may serve as markers of a change in the fruits' physiological state with advanced maturity. During growth and development on the tree the seed within an avocado fruit undergoes several morphological changes, the most obvious of which is a change in the seed coat from a thick fleshy organ to a dried papery covering on the seed (Scora *et al*., 2002). Further visual change occurs in the embryo of the seed where in very mature avocado fruit can have seed splitting and radical emergence into the flesh of the fruit. By using magnetic resonance imaging technology it may be possible to observe if there are any morphological changes in the seed occurring when the fruit are of advanced maturity.

To determine if soluble solids, sugar composition or seed development are suitable markers of potential advanced maturity in 'Hass' avocados, fruit were harvested approximately every two weeks from 2 orchards (one in the Far North and one in the Eastern Bay of Plenty) from December through to February. The composition of the fruit was then correlated with the quality of fruit from the same harvest.

MATERIALS AND METHODS

Fruit

Avocado fruit (cultivar 'Hass' on 'Zutano' seedling rootstocks) were harvested from one orchard located in the Eastern Bay of Plenty at Opotiki (Orchard 1) between 1/1/2/2004 and 3/2/2004 and one orchard located in the Far North region (Orchard 2) between 1/12/2004 and 11/3/2005. At each harvest 150 fruit were collected, 50 fruit were sent by courier on the day of harvest to HortResearch at the Mt Albert Research Centre in Auckland for determination of soluble solids content and individual sugar contents of an aqueous extract from the fruit and imaged for seed water and 100 fruit were sent to the Avocado Industry Council (AIC) offices in Tauranga for storage and quality assessment. Fruit were assessed or put into storage the day after harvest.

Soluble solids content (SSC)

Individual unripe fruit were cut into quarters and the peel, seed and seed coat removed. The pieces of fruit flesh were passed through a juice extractor (Breville JE95 Juice Fountain) and the separated solids discarded. The extracted liquid was centrifuged in 2 mL Eppendorf tubes (16000 g, 10 mins) and SSC measured on an aliquot of the aqueous layer using a digital refractometer (Atago, Japan).

Sugar analysis.

From the same aqueous extract that was used for SSC measurement, a 1 mL sample was added to 4 mL ethanol and stored at –20°C until analysed for individual sugar composition by gas chromatography (Burdon et al. 2007). The identity of mannoheptulose and perseitol were confirmed by gas chromatography-mass spectroscopy using authentic standards (Industrial Research Ltd, Wellington).

Magnetic resonance imaging.
Images of transverse and longitudinal slices (slice thickness of 3.3 mm) through individual fruit were collected using a GE 1.5T echospeed MR scanner (Mercy Radiology, Auckland). Fruit were imaged in batches of approximately 10 fruit using a torso phased array coil. Proton density images (for water content) and the spin-spin relaxation images (for interaction of water with other compounds) gave similar images and differences in images are discussed simply as water content. Within MR images the higher the water content (proton density) the lighter the image appears. In addition to seed water, other seed conditions such as embryo growth and stone splitting were recorded from the images.

Fruit storage and quality assessment
The fruit sent to the AIC were stored at 4ºC ± 0.5ºC, 85% relative humidity for 28 days before removal and inspection for the green fruit disorders discrete patches and fuzzy patches (Dixon, 2001). The fruit were then ripened at 20ºC ± 1ºC, 65% relative humidity. Once the fruit had reached at least a minimum eating softness determined by handfeel, equivalent to a firmometer measurement of 85 with a 300 g weight, the fruit were assessed for the ripe fruit disorders stem end rot, vascular browning, brown patches and diffuse flesh discolouration (Dixon, 2001). All disorders were quantified for severity according to the scales described in the AIC fruit assessment manual 2003 (Dixon, 2003). The incidence of sound fruit when ripe was determined as all fruit for which there was at least one individual disorder at greater than 5% severity.

Differences among harvests for each orchard were assessed statistically by One-way analysis of variance (ANOVA) using MINITAB version 13.31, with disorder data square root transformed prior to analysis.

RESULTS AND DISCUSSION

Soluble solids at harvest
The soluble solids content of unripe fruit from both orchards was in the range 7 to 9 °Brix, although the patterns of change in soluble solids content between harvests differed (Figure 1). The soluble

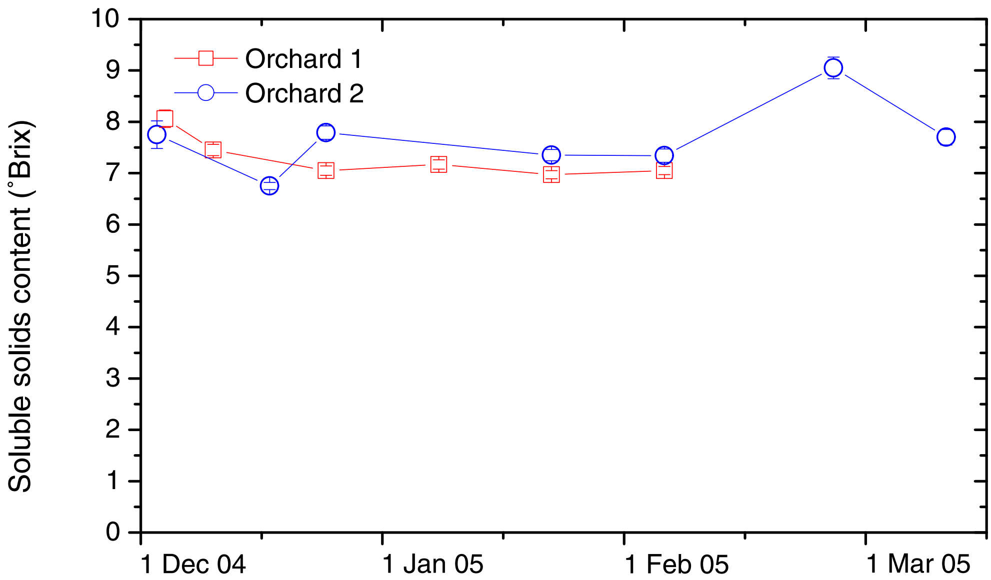


Figure 1. Soluble solids content at harvest of 'Hass' avocado fruit harvested between December 2004 and March 2005. Values are the mean of 20 fruit, ± the standard error of the mean.

solids content in fruit from Orchard 1 declined from 1/12/2004 until 22/12/2004 after which there was little further change with a soluble solids content of about 7 °Brix for the remaining harvests. The soluble solids content in fruit from Orchard 2 tended to be between 7.5 and 8 °Brix for most harvests, but with a lower soluble solids content (6.8 °Brix) in the fruit harvested on 16/12/2004 and higher soluble solids content (9.1 °Brix) on 24/2/2005. The sample of fruit from Orchard 2 on 11/3/2005 showed the increase in soluble solids content at 24/2/2005 to be specific to that harvest and not to be a consistent change in the fruit.

Composition of sugars

The pattern of change in sugars over the harvest period differed for the fruit from the 2 orchards (Figure 2). Overall, there was a greater total sugar content in fruit from Orchard 1 (9-16 mg/mL) than Orchard 2 (7-9 mg/mL) (Figure 3). While there was a trend for an overall decline in total sugars in fruit from Orchard 2, there was a peak in total sugars in fruit from Orchard 1. In fruit from both orchards, the main sugar was mannoheptulose and the peak in Orchard 1 sugars was largely the result of changes in mannoheptulose. The concentration of mannoheptulose in fruit from Orchard 2 was in the range 2 to 5 mg/mL whereas in fruit from Orchard 1 the concentration of mannoheptulose increased from about 4 mg/mL at the start of December to 10 mg/mL at the end of December and declined throughout January to about 7 to 8 mg/mL by February. The reason for this difference in the concentration of mannoheptulose between orchards is not known but it may provide a method of segregating orchards.

In comparison with mannoheptulose, the concentrations of glucose and fructose were low at about 2 mg/mL or less with only trace amounts of

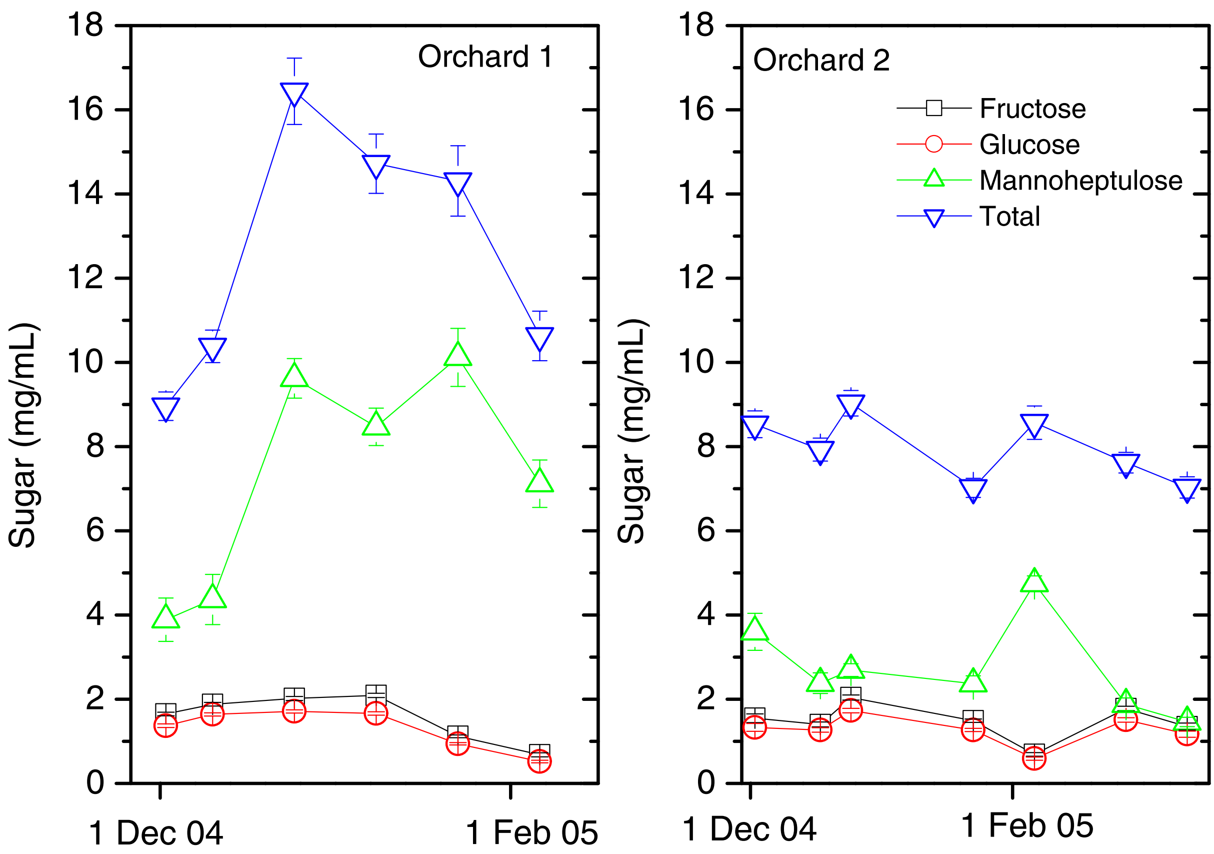
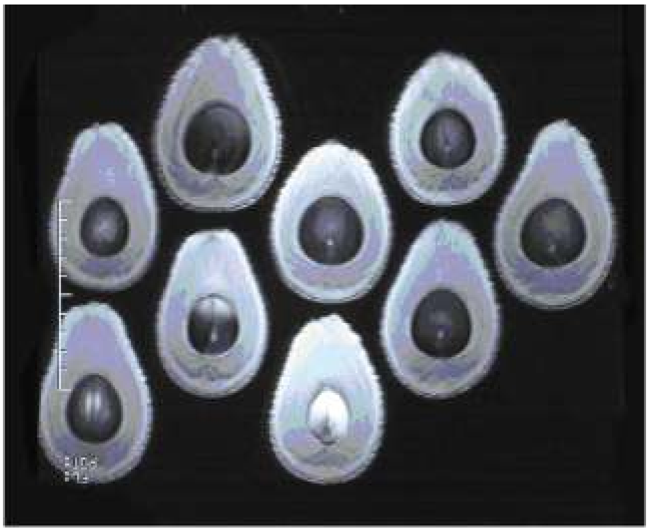


Figure 2. Total and individual sugars at-harvest in an aqueous fraction from 'Hass' avocado fruit. Fruit from 2 orchards harvested between December 2004 and March 2005. Values are the mean of 20 fruit, ± the standard error of the mean.

sucrose. In fruit from Orchard 1 there was a trend for the concentrations of fructose and glucose to be about the same for the first 4 harvests then be lower in the last 2 harvests. Fruit from Orchard 2 had concentrations of glucose and fructose that varied between harvests in the range 0.6 to 2 mg/mL. Perseitol, a 7-carbon sugar alcohol, was present at levels of 2 to 3 mg/mL, with no consistent trend with time. The data for perseitol and minor sugars is not presented.

A



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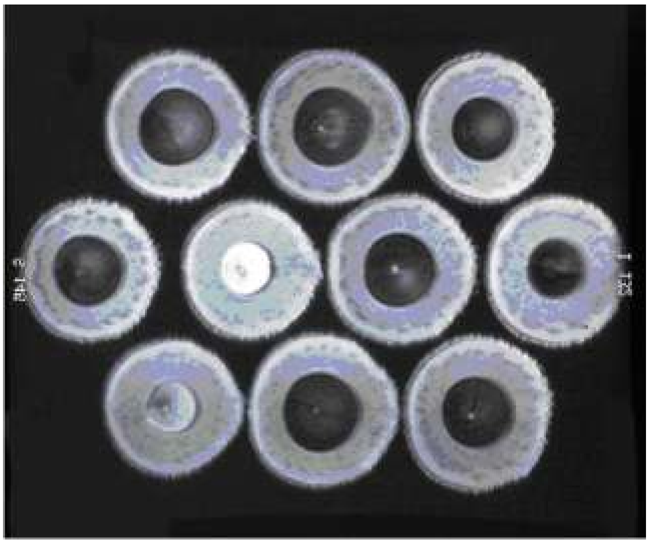

Figure 3. Longitudinal (A) and transverse (B) magnetic resonance images through 'Hass' avocado fruit at harvest.

Magnetic resonance images of intact fruit

Magnetic resonance images of whole avocado fruit provided clear images of the internal structure of the fruit, including the seed, embryo, flesh and skin. Among fruit from a single harvest there were differences in the overall seed water between fruit and also differences in water content within individual seeds allowing the embryo to be distinguished from the rest of the seed (Figures 3 and 4). The water content of individual seeds was in the range 20 to 50%, with up to one third of fruit in a single harvest having seeds containing water at the higher end of this range (Table 1). Seeds with 20% water appeared dark in the MR images whereas seeds with 50% water appeared white in the MR images. Embryo water content was variable and not related to seed water content. There was a general trend for embryo water content to increase as the harvest season progressed, seen by the increasing lightness of the embryo in the MR images. Seed splitting and radical emergence were easy to see in the MR images, but were only present in fruit from the final harvest from Orchard 2 on 24/2/2005 (Figure 4).

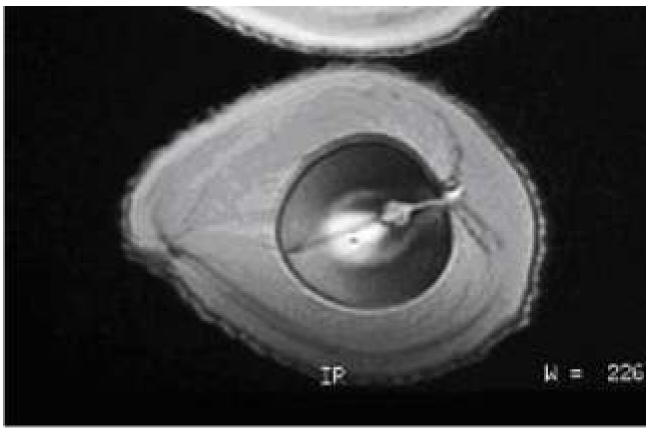

Figure 4. Longitudinal magnetic resonance image of a 'Hass' avocado fruit at harvest showing radicle emergence into the fruit flesh.

Table 1. Incidence (%) of 'Hass' avocado fruit with seeds with high water content (about 40% – 50%) at harvest.

Orchard 1		Orchard 2	
Harvest date	High water seeds (%)	Harvest date	High water seeds (%)
1/12/204	6	2/12/204	0
9/12/2004	10	16/12/2004	10
22/12/2004	5	22/12/2004	0
6/1/2005	24	19/1/2005	n.d.[1]
19/1/2005	n.d.[1]	3/2/2005	0
3/2/2005	30	24/2/2005	25

[1] *n.d. = not determined*

Disorders

In general, the incidence of sound fruit was high, often exceeding 90% (Table 2). Fruit from Orchard 1 had the highest incidence of sound fruit with a decrease in sound fruit occurring only at the last harvest in February. By contrast the incidence of sound fruit from Orchard 2 was between 65 and 94%, with no trend with harvest. While the incidence of disorders was high, the severity of disorders was very low, hence the high incidence of sound fruit when the sound/disordered threshold was at a severity of 5%. This suggests that

Table 2. Incidence (%) of disorders in green or ripe 'Hass' avocado fruit from 2 orchards harvested between December 2004 and February 2005. Fruit evaluated green after 28 days of storage at 4°C and again after holding at 20°C until ripe.

Orchard 1							
	Green fruit				Ripe fruit		
Harvest date	Discrete patches	Fuzzy patches	Stem end rot	Vascular browning	Brown patches	Diffuse flesh discolouration	Sound fruit[2]
1/12/2004	41.0a[1]	18.0ad	3.0a	1.0a	19.0a	0.0	98.0a
9/12/2004	7.1b	35.4b	4.0a	3.0a	44.4b	0.0	97.0a
22/12/2004	2.0b	0.0c	3.0a	5.0a	38.0bc	1.0	95.0a
6/1/2005	64.0c	12.0cd	4.0a	0.0a	32.0ab	0.0	99.0a
19/1/2005	55.0acd	16.0ad	2.0a	2.0a	25.0ac	0.0	98.0a
3/2/2005	40.4ad	30.3ab	17.2b	19.2b	68.7d	0.0	65.7b

Orchard 2							
	Green fruit				Ripe fruit		
Harvest date	Discrete patches	Fuzzy patches	Stem end rot	Vascular browning	Brown patches	Diffuse flesh discolouration	Sound fruit
2/12/2004	24.0a	6.0ac	3.0a	3.0a	23.0a	0.0	94.0a
16/12/2004	69.4b	29.6b	19.4b	20.4b	55.1b	3.1	65.3b
22/12/2004	21.0a	2.0c	9.0ab	12.0ab	47.0b	0.0	90.0ac
19/1/2005	20.0a	18.0ab	5.0a	6.0a	66.0b	0.0	69.0b
3/2/2005	12.0a	11.0ac	20.0b	10.0ab	52.0b	1.0	87.0ac
24/2/2005	14.3a	15.3ac	10.2ab	9.2ab	58.2b	0.0	76.5bc

[1] *Means in a column sharing a common letter do not differ at P=0.05.*

[2] *Incidence of fruit with no individual disorder > 5% severity*

Table 3. Severity of disorders (% of surface of skin or flesh affected) in green or ripe 'Hass' avocado fruit from 2 orchards harvested between December 2004 and February 2005. Fruit evaluated green after 28 days of storage at 4°C and again after holding at 20°C until ripe.

Orchard 1							
	Green fruit		**Ripe fruit**				
Harvest date	**Discrete patches**	**Fuzzy patches**	**Stem end rot**	**Vascular browning**	**Brown Patches**	**Diffuse flesh discolouration**	**Flesh adhesion**
1/12/2004	1.3	2.3	0.1	0.2	0.4	0.0	0.0
9/12/2004	0.3	2.2	0.1	0.0	1.1	0.0	0.0
22/12/2004	0.0	0.0	0.1	0.2	0.8	0.1	0.0
6/1/2005	1.6	0.2	0.1	0.0	0.8	0.0	0.0
19/1/2005	2.6	0.4	0.1	0.1	0.5	0.0	0.0
3/2/2005	1.3	0.9	0.9	3.0	7.5	0.0	0.0
Orchard 2							
	Green fruit		**Ripe fruit**				
Harvest date	**Discrete patches**	**Fuzzy patches**	**Stem end rot**	**Vascular browning**	**Brown Patches**	**Diffuse flesh discolouration**	**Flesh adhesion**
2/12/2004	0.4	0.1	0.0	0.1	1.0	0.0	0.0
16/12/2004	9.5	2.1	0.6	2.5	7.6	1.4	0.1
22/12/2004	0.5	0.0	0.4	0.8	3.0	0.0	0.0
19/1/2005	0.6	0.5	0.1	0.1	5.1	0.0	0.0
3/2/2005	0.2	0.3	0.8	0.9	2.1	0.5	0.0
24/2/2005	0.3	1.1	0.3	0.7	4.5	0.0	0.0

although the fruit ripened with low levels of disorders, if the fruit had been stored at a temperature higher than 4°C, or for longer than 4 weeks, there would have been a larger number of more severe disorders.

Green fruit

The incidence of discrete patches or fuzzy patches for fruit from Orchard 1 did not show a trend with harvest, but fluctuated between 0 and 64% (Table 2). The lowest incidence of discrete patches and fuzzy patches were in fruit from 22/12/2004. However, the severity of both disorders throughout the harvest period was low at = 2.6% (Table 3). There was a similar lack of overall trend for fruit from Orchard 2, with the incidence of discrete patches and fuzzy patches in the range 2 to 70%, but with severity predominantly < 1%. The highest incidence and severity of green fruit disorders from Orchard 2 was in fruit from 16/12/2004.

Ripe fruit

Stem end rot and vascular browning in fruit from Orchard 1 only increased markedly at the final harvest (from < 6% to about 18%), at which time the incidence of brown patches was also greatest at 69% (Table 2). In addition to a greater incidence of disorder, there was also a greater severity of disorder in fruit from the final harvest (Table 3). The greater incidence and severity resulted in an overall lower incidence of sound fruit at 3/2/2005 (66%) compared with the 95-99% sound fruit incidence for fruit from 1/12/2004 to 19/1/2005. For fruit from Orchard 2, there was no clear trend with harvest for any individual disorder incidence or severity, or overall incidence of sound fruit.

There was virtually no diffuse flesh discoloration in fruit from either orchard, irrespective of harvest.

Relationship between at harvest measurements and disorders after storage

Total sugars, mannoheptulose and the incidence of high water seeds of ripe fruit tended to show that a lower incidence of sound fruit was associated with lower total sugars and mannoheptulose and increased incidence of high water seeds (Figure 5). However, the associations are not strong, with one sample of fruit being a marked outlier in each instance. This outlier was not the same batch of fruit in each plot.

Probably the most marked association is between the high level of mannoheptulose and the high sound fruit incidence in fruit from Orchard 1 compared to the lower mannoheptulose and lower sound fruit incidence in fruit from Orchard 2.

While there was no overall association between soluble solids content and disorder incidence, the low incidence of sound fruit when ripe and a high incidence of disorder in fruit immediately out of storage for fruit harvested on 16/12/2004 from Orchard 2 corresponded with a low soluble solids content at harvest that did not fit the trend for other harvests.

Due to the restricted period over which the fruit were harvested it is possible that patterns of physiological or morphological changes indicative

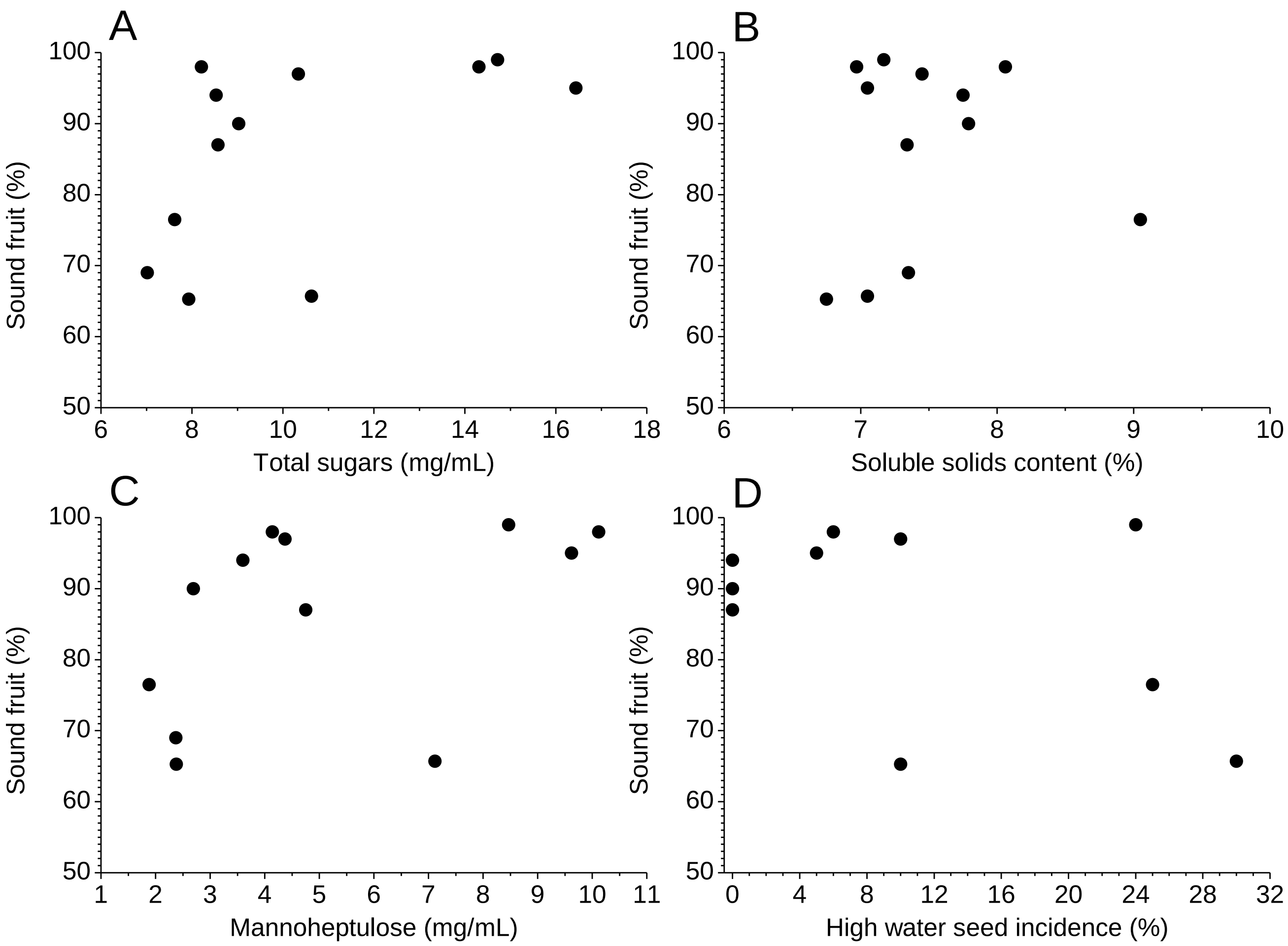

Figure 5. Relationship in 'Hass' avocado between the incidence of ripe fruit that were sound after 28 days storage at 4ºC and ripening at 20°C, and the content at harvest of A) total sugars, B) soluble solids, C) mannoheptulose and D) incidence of seeds with high water content. Fruit from 2 orchards and 6 harvests per orchard.

of increased disorder susceptibility may have been missed. For a clearer picture of how soluble solids content, individual sugars and seed water content change over the harvest season, fruit would need to be harvested from September to March and the data evaluated on a standardised unit tissue basis.

The observations described in this report suggest that changes in some fruit characteristics measured at harvest may provide an indication of an increase in development of disorders in the fruit after storage. The main disorders found in this trial were rots occurring in the skin or at the stem end of the fruit with comparatively few physiological disorders such as flesh greying or incomplete ripening. In future, it may be more appropriate to examine the skin and flesh just below it in more detail when trying to predict rots, and the seed or fruit flesh characteristics may be more appropriate for predicting physiological disorders of the fruit flesh. A prolonged storage period to induce physiological disorders would also assist in the determination of associations between fruit composition and the development of physiological disorders during storage.

CONCLUSIONS

While there was some indication of an association between total sugars or mannoheptulose and the incidence of sound fruit after storage, no definitive marker of advanced fruit maturity was identified in this study. Further research on changes in 7-carbon sugars in late season fruit may better define the relationship between disorders and sugars in the fruit. Magnetic resonance imaging confirmed that the longer the fruit remained on the tree, the greater the development of the seed to the point at which germination occurred. However, germination occurred very late and is unlikely to provide a marker for poor quality. In the future, identifying the risk of disorder will focus on fruit features more closely associated with the specific disorder, i.e. the skin and flesh just underneath it for rots.

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