CARBOHYDRATE STATUS OF LATE SEASON 'HASS' AVOCADO FRUIT

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ABSTRACT

In this study, changes in carbohydrate composition during the late season maturation phase of 'Hass' avocado fruit were determined for fruit harvested in the 2005-6 and 2006-7 seasons. Fruit were harvested fortnightly between December 2005 and April 2006 from three orchards and weekly between February and May 2007 from two orchards. Carbohydrate was quantified as the fruit dry matter, soluble solids content (SSC), starch content and the individual sugars mannoheptulose, perseitol, sucrose, fructose and glucose. Dry matter was in the range 32-38% during the 2005-6 season and 36-41% in the 2006-7 season. The levels of the individual carbohydrates (except mannoheptulose) and the change in their concentrations during the harvest period differed markedly for fruit from the two seasons. Perseitol was the predominant non-structural carbohydrate in the fruit mesocarp, with lesser amounts of mannoheptulose, sucrose, fructose and glucose. In both seasons, mannoheptulose levels were similar and declined in a consistent manner over the harvest period whereas the patterns and levels of the other sugars, starch and SSC varied considerably. It was concluded that mannoheptulose levels were similar and declined in a consistent manner between seasons but it remains to be established whether the decline in mannoheptulose reflects a decline in fruit quality.

***Keywords**: maturity, mannoheptulose, perseitol, sucrose, glucose, fructose, starch, soluble solids content*

INTRODUCTION

Maturity in avocado fruit is usually discussed in terms of the dry matter or water content of the fruit flesh. The dry matter content of the fruit flesh is correlated with the oil content (Lee *et al*., 1983) and is a useful measure of the minimum maturity required for harvest based on eating quality of the ripe fruit. Dry matter is less useful for determining fruit maturity for fruit that are more advanced or are over-mature (Hofman *et al*., 2000). Other compositional attributes including the carbohydrate status of the fruit flesh may be potential markers of fruit maturity. Carbohydrates have been researched recently as fruit attributes that change during fruit development and a question has been posed as to whether there is a link to fruit quality (Bertling and Bower, 2006). For carbohydrate status, the role of the 7-carbon sugar (C7) mannoheptulose and its sugar alcohol perseitol are of interest since they are the dominant sugars present in avocado (Liu *et al*., 2002). For fruit harvested late in the season, *i.e.* high dry matter fruit, there tends to be an increase in fruit disorders following storage (Dixon *et al*., 2003).

An initial study of the relationship in 'Hass' avocados between carbohydrates in the flesh at harvest with storage disorders was undertaken for fruit harvested in the period December 2004 to March 2005 (Lallu *et al*., 2005). A lower incidence of sound fruit was associated with lower total sugars or mannoheptulose, although from scatter plots the associations were not strong. It was concluded that while there was some indication of an association between total sugars or mannoheptulose at harvest and the incidence of disorders in fruit after storage and ripening, no definitive marker of advanced fruit maturity or susceptibility to disorder was identified. There were marked fluctuations in the levels of individual carbohydrates in the fruit during the late maturation period. How representative these changes in carbohydrate are for fruit from different orchards and seasons is not known. A better understanding of the changes in carbohydrate that occur during late maturation may assist in the identification of a late season maturity marker and in understanding the postharvest behaviour of the fruit.

In this study, changes in carbohydrate composition during late maturation were determined for fruit from the 2005-6 and 2006-7 harvest seasons. Fruit were harvested fortnightly between December 2005 and April 2006 from three orchards and weekly between February and May 2007 from two orchards. Carbohydrate status was quantified as the fruit dry matter, soluble solids content, starch content, and the individual sugars mannoheptulose, perseitol (a sugar alcohol), sucrose, fructose and glucose.

MATERIAL AND METHODS

Fruit

Avocado fruit (cultivar 'Hass' on 'Zutano' seedling rootstocks) were harvested from 2 orchards located near Te Puke (O1 and O3) and 1 orchard near Katikati (O2). In the 2005-6 harvest season, fruit were harvested from all 3 orchards at approximately fortnightly intervals between 20 December 2005 and 1 May 2006. In the 2006-7 harvest season, fruit were harvested from O1 and O3 at weekly intervals between 7 February 2007 and 11 April 2007. At each harvest, 20 fruit were analysed for individual sugar contents, soluble solids content (SSC), starch and dry matter the day after harvest. Carbohydrate analyses were undertaken at HortResearch, Mount Albert and Ruakura Research Centres.

Carbohydrate analysis

Dry matter

Two 20mm diameter cores of tissue were taken from the fruit equator, the skin, seed and seed coat were removed and the mesocarp sliced into approximately 2mm discs and dried to constant weight at 65°C.

Sugar and starch analysis

Approximately 1g of mesocarp taken from fruit at the widest point using a 10mm cork borer was diced into 4ml ethanol and stored at -20°C until analysed for individual sugar composition by gas chromatography. The identity of mannoheptulose and perseitol were confirmed by gas chromatography-mass spectroscopy using authentic standards (Industrial Research Ltd, Wellington). Starch was determined in the pellet remaining after ethanolic extraction of the sugars by reaction with amyloglucosidase. Individual sugars, total sugars and starch are expressed per gram of fruit mesocarp on a fresh weight (f.w.) basis.

Soluble solids content

After removal of the sample for dry matter and sugars, individual unripe fruit were cut into quarters and passed through a juice extractor (Breville JE95 Juice Fountain) and the separated solids discarded. The extracted liquid was centrifuged in 2ml Eppendorf tubes (16000g, 10min) and SSC measured on an aliquot of the aqueous layer using a digital refractometer (Atago, Japan).

RESULTS

Fruit dry matter increased from about 32 to 38% during the 2005-6 harvest season but fluctuated in the range 36 to 41% in 2006-7 (Figure 1). Starch concentration was in the range 2.1 to 4.0 mg/g f.w. in 2005-6 and 4.1 to 7.8 mg/g f.w. in 2006-7. In both seasons there were two peaks in starch content in the harvest period, although the timing of the peaks differed between seasons with no consistent trend through either season. There was no consistent trend in SSC over either season, with levels in the range 6.0 to 6.8% in 2005-6 and 6.5 to 8.1% in 2006-7 (Figure 1).

Total sugars did not change consistently during the 2005-6 season, with a concentration of 14 mg/g f.w. at the start of January, decreasing to 8 mg/g f.w. at the start of February and peaking at 12 mg/g f.w. towards the end of March (Figure 1). In the 2006-7 season there was a trend for total sugars to decline, from approximately 21 mg/g f.w. at the start of February to approximately 9 mg/g f.w. at mid-April (Figure 2). The pattern of change for total sugars was largely the result of changes in perseitol, which was the predominant sugar (Figure 2).

In both seasons, there was a consistent decline in mannoheptulose, from approximately 6 mg/g f.w. at the start of January to <1 mg/g f.w. by March in 2005-6 and from approximately 2.3 mg/g f.w. at the start of February to approximately 0.6 mg/g f.w. by the end of March in 2006-7 (Figure 2).

Compared with the 7-carbon sugars mannoheptulose and perseitol, the levels of fructose, glucose and sucrose were on average lower. In 2005-6, fructose and glucose levels were low, about 0.3-0.4 mg/g f.w. and 0.2 mg/g f.w. respectively, but increased in the final 2 harvests to about 0.6 and 0.4 mg/g f.w., respectively (Figure 3). In 2006-7, the levels of both fructose and glucose were similar, but more variable, than in 2005-6. There was between 1 and 2 mg/g f.w. sucrose in both seasons, with fluctuations between harvests, but no major trend through the season (Figure 3).

Comparing the 2 seasons, there were overall higher concentrations of carbohydrates in the fruit from 2006-7 than 2005-6, the main exception being mannoheptulose, for which there were very similar levels and trends in both seasons. While there were few consistent trends in carbohydrate concentrations through the harvest seasons, the fluctuations seen may simply be displaced in time and magnitude between the 2 seasons. This is perhaps most clearly illustrated by the starch data (Figure 1), in which the two peaks in each harvest season are displaced in time and magnitude.

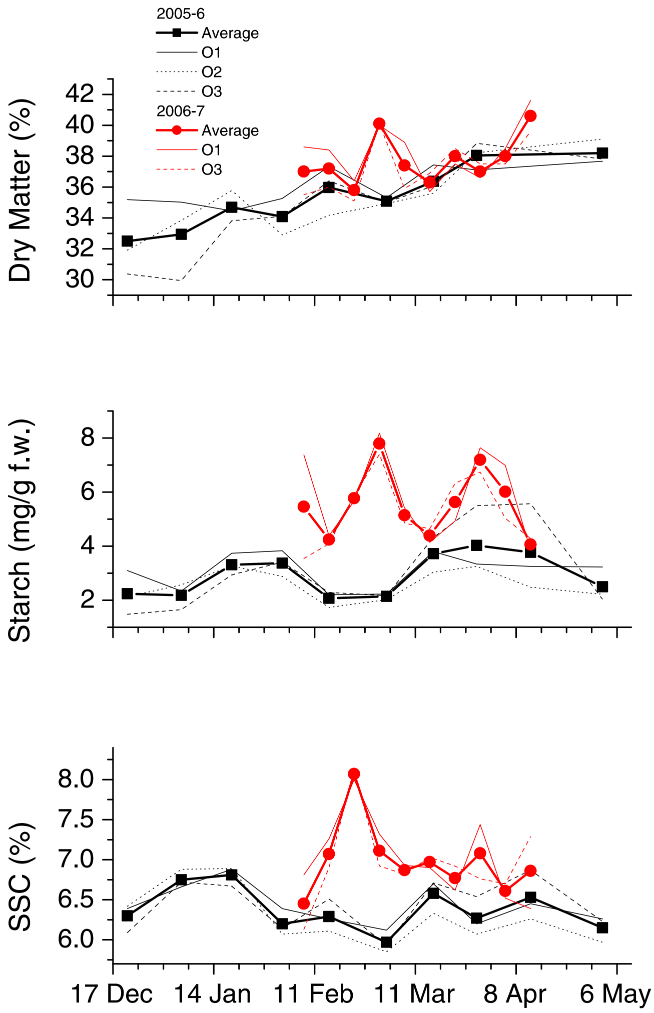
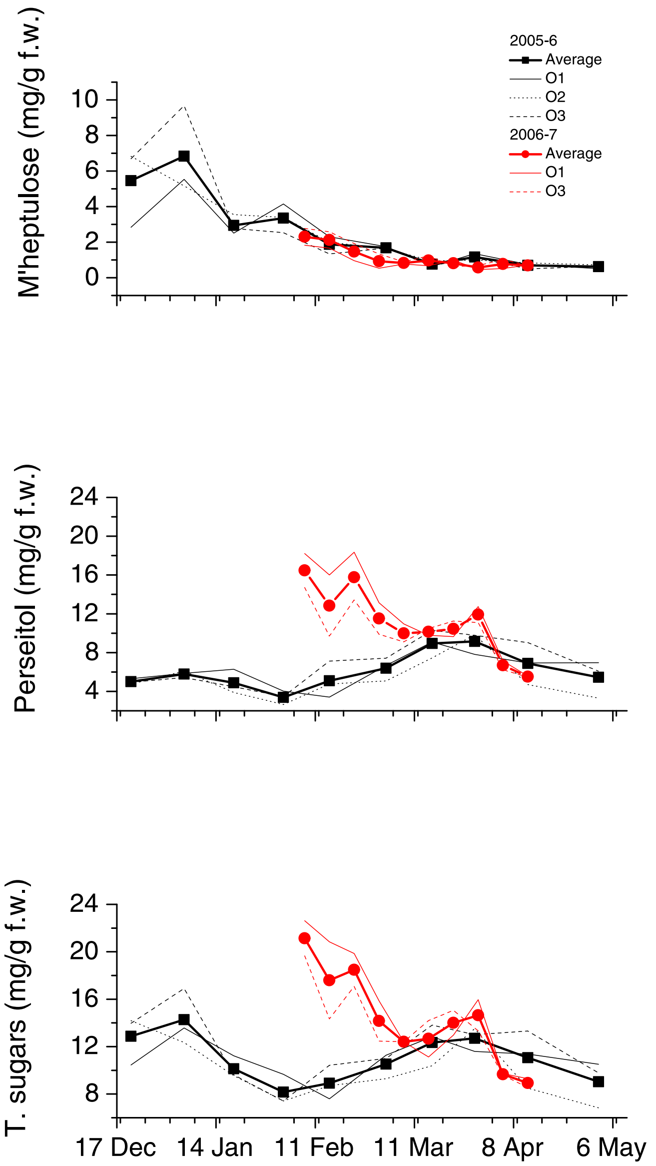


Figure 1. Dry matter, starch and soluble solids content (SSC) of 'Hass' avocado fruit at harvest in the 2005-6 (black lines) and 2006-7 (red lines) harvest seasons. Lines with symbols are the average for 3 orchards in 2005-6 (O1, O2 and O3) and 2 orchards in 2006-7 (O1 and O3). The lines without symbols are the individual orchard data with 20 fruit per orchard sample.



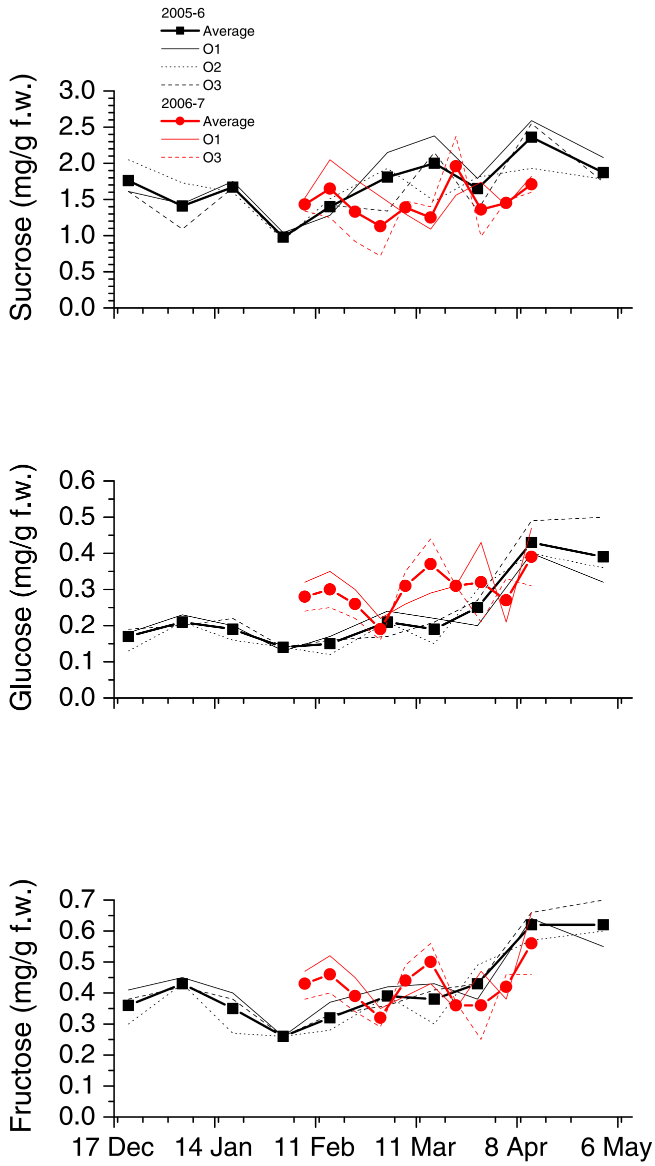


Figure 2. Mannoheptulose (M'heptulose), perseitol and total sugars (T. sugars) content of 'Hass' avocado fruit at harvest in the 2005-6 (black lines) and 2006-7 (red lines) harvest seasons. Lines with symbols are the average for 3 orchards in 2005-6 (O1, O2 and O3) and 2 orchards in 2006-7 (O1 and O3). The lines without symbols are the individual orchard data with 20 fruit per orchard sample.

Figure 3. Sucrose, glucose and fructose content of 'Hass' avocado fruit at harvest in the 2005-6 (black lines) and 2006-7 (red lines) harvest seasons. Lines with symbols are the average for 3 orchards in 2005-6 (O1, O2 and O3) and 2 orchards in 2006-7 (O1 and O3). The lines without symbols are the individual orchard data with 20 fruit per orchard sample.

DISCUSSION

There were marked differences in the fruit carbohydrate concentrations and their changes during the harvest period from the two seasons. Overall, there were higher levels of carbohydrates in fruit from the 2006-7 season than the 2005-6 season. The increasing DM content of the developing fruit is well known, and is associated with the increasing oil content of the fruit (Lee *et al*., 1983). However, other changes in carbohydrates have been less well defined, and it appears that the changes in concentration of carbohydrates other than mannoheptulose are not consistent over the harvest season.

Perseitol was the predominant sugar, but along with sucrose, fructose and glucose, the levels and changes with harvest date differed for the 2 seasons. In 2005-6, there was no consistent trend in perseitol level through the harvest season; instead there was a decline during January, an increase during February and a distinct peak towards the end of the harvest season. In contrast, in 2006-7, there was a trend for a decline in perseitol levels throughout the harvest season. Both perseitol and mannoheptulose have previously been reported to be primary products of photosynthetic CO_2 fixation in avocado, and also are both translocated in the phloem (Liu *et al*., 2002).

In contrast to the changes in other sugars, in both seasons mannoheptulose was present at similar concentrations, and the concentration decreased throughout the harvest season. The consistency of concentration and trends in mannoheptulose contrasts with the larger and less consistent changes in perseitol and sucrose. It has been suggested that a decline in the levels of C7 sugars is associated with the initiation of ripening in 'Hass' (Liu *et al*., 2002). The declining levels through the season support this in terms of a general association between both lower mannoheptulose levels in the fruit and a reduced preclimacteric period for later harvested fruit. A greater tendency to ripen can reduce storage potential and a higher occurrence of senescence related storage disorders could be expected. Since there are no external indications that ripening has been initiated, other than the reduced preclimacteric period in fruit harvested late in the season, the decline in mannoheptulose could be used as a destructive marker of late maturity if a strong and consistent relationship between mannoheptulose levels and storage quality exists. Such a relationship would need to be established using a wider range of orchards and seasons.

The differences in carbohydrates in the fruit within and between seasons may reflect differences in the competing growth aspects of the tree (*e.g.* flowering, fruit set, root activity, shoot growth). The discrete nature of periods of growth in roots, shoots and flowering have recently been documented for New Zealand grown 'Hass' avocado (Thorp *et al*., 1995; Dixon *et al*., 2005). With a prolonged period of fruit development that exceeds 12 months, there is considerable overlap of periods of fruit development and other phenological changes for New Zealand grown fruit that does not occur when fruit are removed from the tree less than 12 months after flowering. A major difference between seasons for 'Hass' avocado occurs because of alternate bearing resulting in high or low crop loads on the tree. In simple terms, the more fruit on the tree the less carbohydrate is available for each individual fruit. However, the difference between seasons appears to affect fruit irrespective of whether the orchard was in an 'on' or 'off' production season. In 2006-7 there was one 'on' orchard (O1) and one 'off' orchard (O3), yet the carbohydrate status of fruit from both orchards appeared to be more similar within the season, irrespective of an 'on' or 'off' crop load, than between seasons. There is an added complication in interpreting carbohydrate status of fruit on commercial trees where the crop load changes through the season as fruit are harvested.

An alternative explanation for the fluctuations in carbohydrate levels is that they may be the result of periods of environmental stress. If the stress were to occur at a regional level, *e.g.* temperature or rainfall, then affects would occur in all trees irrespective of whether they were in an 'on' or 'off' year, although the level of stress might vary depending on site specific factors.

CONCLUSIONS

Perseitol was the predominant non-structural carbohydrate in the fruit mesocarp, with lesser amounts of mannoheptulose, sucrose, fructose and glucose. With the exception of mannoheptulose, the levels of individual carbohydrates and the change in their concentration during the harvest period differed markedly for fruit from the 2 seasons. In both seasons, mannoheptulose levels were similar and declined in a consistent manner. It remains to be established whether the decline in mannoheptulose reflects a decline in fruit quality.

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