1999. Revista Chapingo Serie Horticultura 5: 353-358.

IMPACT OF SUN EXPOSURE ON HARVEST QUALITY OF 'HASS' AVOCADO FRUIT

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SUMMARY

Harvest quality of fruit exposed to the sun on the tree (sun fruit) was compared with that of completely shaded fruit (shade fruit). A range of attributes was examined on the exposed and unexposed sides of the sun fruit, and compared to shade fruit. Temperatures of 35 to 40°C were observed in the flesh of sun fruit, even in spring. At harvest, and during ripening, significant differences were found between the two fruit types, and between sides of the sun fruit. Sun fruit were found to have higher dry matter, and higher levels of potassium, calcium and magnesium. Sun fruit took longer to ripen than shade fruit, and the exposed side of sun fruit was firmer than the unexposed side. The exposed side of sun fruit was lighter in colour with a higher chroma and lower hue angle (more yellow) than the unexposed side of sun fruit and shade fruit. Sun fruit had higher oil content than shade fruit, with relatively little difference between exposed and shaded sides of sun fruit. The fatty acid composition of the total oil was determined. Sun exposure increased the proportion of the saturated fatty acid palmitic acid, and decreased the proportion of monounsaturated fatty acid oleic acid (which is the major fatty acid in avocado oil). Thus, sun exposure of 'Hass' avocados has a range of significant effects on fruit quality at harvest, and when ripe.

KEY WORDS: Oil content, minerals, maturity, *Persea americana* Mill.

INTRODUCTION

In New Zealand, flesh temperature of 'Hass' avocado fruit [*Persea americana* Mill.] has been measured in fruit from exposed and shaded parts of the tree during spring and summer. Fruit exposed to direct sunlight had diurnal patterns of flesh temperature which reached as high as 52°C with air temperatures of only 27°C (Woolf and Ferguson, unpublished data). The response of exposed and shaded fruit to postharvest temperature treatments differed significantly (Woolf *et al*., 1999a). External damage from 50°C hot water treatments was lower in exposed fruit, particularly on the exposed side of the fruit. Similarly, while shade fruit had high levels of external chilling injury when stored at 0.5°C for up to 28 days, the exposed side of the sun fruit was almost undamaged. Changes in heat shock protein (hsp) and hsp gene expression reflected the diurnal temperature cycle, with up-regulation of hsp mRNA and hsp synthesis, at flesh temperatures of > approx. 30°C. Time to ripen of sun fruit was significantly longer than shade fruit after storage at both 0.5 and 5.5°C.

Research has also been carried out in Israel to examine the postharvest behaviour of exposed versus shade fruit of five avocado cultivars: ‘Ettinger’, ‘Fuerte’, ‘Hass’, ‘Horshim’ and ‘Pinkerton’. With the exception of the cultivar ‘Ettinger’, the responses observed were similar to those in New Zealand (Woolf *et al*., 1999b). The exposed side of sun fruit was the most tolerant to high and low temperatures, and shade fruit the least tolerant. Ripening rate was also slower in sun fruit. The time to peak ethylene production was also delayed by 2 to 5 days in sun fruit over that of shade fruit. The exposed side of the sun fruit was generally firmer than the unexposed side, and the average firmness was greater than that of shade fruit. Following inoculation with *Colletotrichum gloeosporioides*, there was a delay of 2 to 3 days between the appearance of rots on shade fruit and their development on sun fruit.

Thus sun exposure of avocado fruit influences a wide range of postharvest responses including tolerance to high and low temperatures, rate of ripening, and resistance to pathogen invasion.

This work reports on a range of quality attributes at harvest (dry matter, oil and mineral content) and after ripening (firmness) of sun and shade fruit, and on associated differences between the sides of sun fruit.

MATERIALS AND METHODS

Experimentation

On two occasions, fruit were sampled from a commercial orchard in the Auckland region of New Zealand. Two fruit types were examined: fruit exposed to the sun, and shaded fruit (see details below). The first harvest was carried out in spring (October) and the second harvest in mid-summer (February). At each harvest a range of quality attributes were measured on the exposed and unexposed sides of sun fruit, and on a random position on shade fruit. These attributes were:

Harvest One;

- Fruit maturity (dry matter analysis)
- Skin colour (Minolta colour meter)
- Skin fluorescence (PAM fluorescence)
- Ripening rate (days to fully ripe)
- Flesh firmness (Effigi penetrometer) with and without ethylene treatment

Harvest Two;

- Dry matter
- Oil content
- Total oil content
- Fatty acid composition
- Mineral content (potassium, calcium and magnesium)

Fruit Types

Two avocado (*Persea americana* Mill.) fruit types were employed. “Shade fruit” were fruit selected from under the leaf canopy, and “sun fruit” were picked from the north-facing side of the tree which was in direct sunlight at noon. For the sun fruit, the side facing the sun was marked for future reference and this is referred to as the exposed side, while the opposite side is the unexposed side of sun fruit.

Temperature Monitoring

Fruit temperatures were monitored on shaded fruit and on the exposed and unexposed sides of sun fruit for at least one week prior to harvest. Air temperature was also monitored. Fruit temperature was monitored by inserting Squirrel thermister probes (CM-UU-V5-1; Grant Inc, Cambridge, UK) into the fruit at an angle such that the tip penetrated 10 mm into the flesh. Temperature was logged every 10 minutes using Squirrel Data Loggers (Model 1206; Grant Inc, Cambridge).

Dry Matter

A sample of 10 fruit was divided into three replicates, and a quarter of each (sliced vertically) was peeled, the seed coat removed and the flesh grated in a food processor. A subsample of ≅ 20 grams was dried in a petri dish for 36 hours at 60ºC (until constant weight) and then re-weighed.

Skin Colour

Skin colour was measured using a Minolta chromameter and expressed in LCh units (L = lightness changing from light to dark, C = colour intensity, and h° = actual colour). Three readings were averaged from around the equator of each fruit.

Skin Fluorescence

Fluorescence was measured using a MINIPAM fluorimeter in a darkened room as previously described (Woolf and Laing, 1996).

Ripening Rate

Ripeness was assessed daily by gentle hand-squeezing of each fruit by two trained assessors. Fruit were assessed at a fully-ripe stage of firmness (equivalent to an average Anderson firmometer value of > 100 using a 300 g weight, or 80 using a 200 g weight, White *et al*., 1998). When each fruit became fully-ripe the number of days taken to ripen (days to ripe; DTR) was recorded.

Flesh Firmness

For fruit that were fully ripe, the firmness of the flesh was measured by cutting a 2 cm^2 section of the skin from the fruit using a scalpel. The firmness of the flesh was then measured using a hand-held Effigi penetrometer with an 11.1 mm diameter head.

Oil Content and Fatty Acid Composition

Quantification of the total lipid content in the samples was by a modification of the Bligh and Dyer (1959) method for total lipid extraction. Lipids were extracted with a mixture of chloroform, methanol and water (1:1:0.9; v:v:v). Following thorough mixing and brief centrifugation, two clear layers were resolved. The lower, chloroform layer contained the lipids from the original tissue while the upper methanol/water layer contained water-soluble material from the original extract. Thus, when the chloroform layer was isolated, a purified lipid extract was obtained. This was dried at 35°C under flowing oxy-free nitrogen and weighed.

The extracted fatty acids were converted into their methyl esters (FAME) and dissolved in petroleum ether for injection into a gas chromatograph equipped with fused silica capillary column (30 m, 0.25mm ID, 0.20 μm film; SP™-2330) and flame ionisation detector. The FAME samples were identified by comparison to standards and the amount calculated as a percentage of the total lipids.

Mineral Content

The water/methanol fraction remaining after oil extraction was evaporated off and the resulting solid residue was weighed into100 ml digestion tubes (approximately 50 mg per tube). The samples were digested in nitric acid (2 ml) for 2 h at 120°C then heated to 170°C and held for 1 h during which time perchloric acid (0.75 ml) was added. The samples were then ramped to 200°C and held for 2 to 3 h until the nitric acid had boiled off. The samples were cooled and made up to 20 ml with distilled water containing lanthanum chloride (0.5% w:v) and analysed for calcium, magnesium and potassium using atomic absorption spectrophotometry.

RESULTS

During October when harvest 1 was carried out, fruit temperatures on the exposed side of sun fruit reached nearly 35°C even though maximum air temperatures were just over 20°C (Figure 1). During February (Harvest 2), air temperatures were higher (≅ 25°C) and the exposed side of sun fruit reached nearly 45°C, while the unexposed side of sun fruit were ≅ 30°C (Figure 2).

For both harvests, exposed fruit were significantly more mature (as measured by dry matter) than shade fruit (Tables 1 and 2). In addition, the exposed side of sun fruit had higher dry matter content than the unexposed side (Table 2).

The exposed side of sun fruit was lighter in colour with a higher chroma and lower hue angle (more yellow). The unexposed side of sun fruit was somewhat lighter in colour than shade fruit, but hue angle and chroma were not significantly different to that of the skin of shade fruit.

Exposed fruit took approximately 1.5 days longer to ripen than shade fruit (Table 1). When the firmness of the fruit was measured at eating ripeness (as determined by gentle hand squeezing), the side of the fruit exposed to the sun was found to be firmer than the unexposed side. Even when fruit were treated with ethylene (to synchronise ripening), the exposed side of the fruit ripened more slowly (was firmer) than the unexposed side of the fruit.

Fluorescence of the skin of shade fruit was clearly higher than that of sun fruit in F_o, F_m and F_v/F_m. However there were no differences in the fluorescence of exposed and unexposed sides of sun fruit.

Oil levels were significantly higher in sun fruit than shade fruit, and the exposed side of the fruit was slightly higher than the unexposed side (Table 2). There were some differences in fatty acid content. Palmitoleic acid (16:1) and linoleic acid (18:2) were not significantly different in the two fruit types or on different sides of the sun fruit. Although there were no major differences between the sides of the sun fruit, the sun fruit tended to have higher levels of palmitic (16:0) acid than shade fruit, and sun fruit had lower levels of oleic acid (18:1) than shade fruit. This resulted in a lower monounsaturated to saturated fatty acid ratio in sun fruit (≅ 3.0 vs 4.3). A high ratio of monounsaturated to saturated fatty acids is generally viewed as beneficial to human nutrition.

Table 1. Harvest 1, October (Spring). At-harvest and ripe fruit attributes of sun fruit (exposed to the sun on the tree) and shade fruit (inside the canopy). Two sides of the sun fruit were also examined (exposed and un-exposed). See Materials and Methods for details.

		Sun Fruit						Shade Fruit	
		Overall		Exposed		Un-exposed		Overall	
Attribute Measured		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Dry Wt	**(%)**	28.2	0.4					26.8	0.4
Colour	**L**			42.8	1.2	34.8	0.7	31.9	0.4
	Chroma			33.9	0.9	22.1	0.9	20.6	0.7
	Hue			94.3	3.4	121.0	1.8	123.4	0.3
Days to ripen		8.4	0.2					6.9	0.2
Firmness	**- C_2H_4**			7.2	0.4	4.3	0.2	6.4	0.4
(N)	**+ C_2H_4**			5.5	0.3	3.7	0.3	4.4	0.2
Flourescence	**F_0**			253	24	250	13	331	26
	F_m			1431	165	1415	82	2034	151
	F_v/F_m			0.796	0.010	0.794	0.001	0.835	0.001

Levels of calcium, magnesium and potassium in sun fruit were higher than those in shade fruit. There were also higher levels of all three minerals in the exposed side of sun fruit than in the unexposed side (Table 2).

DISCUSSION

Physiology

Our results have illustrated a wide range of differences between fruit which are exposed to the sun, and those that are shaded. In many cases the exposed side of sun fruit was also different to the shaded side. Although there are a range of possible mechanisms for this difference, such as exposure to UV light, the main factor is likely to be temperature. The exposed side of sun fruit repeatedly attained temperatures of 35 to 45°C when there was full sun. This diurnal high temperature exposure occurred repeatedly over as long as three or four months during fruit development.

The at-harvest and postharvest effects observed may be due to short-term heat exposure occurring immediately prior to harvest, and to repeated and long-term exposure to high temperatures. The latter is likely to be the case for differences such as dry matter. In apple fruit, soluble sugars, starch and acid levels are all higher on exposed sides of fruit (MacRae *et al.*, unpublished data), and firmness is also higher (Ferguson *et al.,* 1999). These differences have obviously developed over a reasonably long period during the growing season, and we would expect that the same would apply to the more rapid maturation (dry matter and oil accumulation) that we found in exposed avocado fruit.

Table 2. Harvest 2, February (Summer). At-harvest and ripe fruit attributes of sun fruit (exposed to the sun on the tree) and shade fruit (inside the canopy). Two sides of the sun fruit were also examined (exposed and un-exposed). See Materials and Methods for details.

		Sun Fruit				**Shade fruit**	
		Exposed		**Un-exposed**		**Overall**	
Attribute Measured		**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
Dry weight	**(%)**	49.2	0.6	44.6	0.5	40.8	0.4
Total oils	**(%)**	29.2	0.8	28.4	0.4	24.0	0.7
Fatty Acid content:							
Palmitic	**16:0**	21.8	2.2	21.6	1.2	16.5	1.3
Palmitoleic	**16:1**	6.7	0.7	7.5	0.3	5.7	0.5
Oleic	**18:1**	57.5	6.1	57.0	2.7	64.8	5.7
Linoleic	**18:2**	14.0	1.3	13.9	0.9	13.1	1.2
M:S ratio^{Y}		2.9		3.0		4.3	
Minerals:							
(mg·100 g^{-1} FWt)^{Z}	**Ca**	30.9	1.1	19.8	0.4	14.9	0.5
	Mg	94.0	3.9	65.1	0.4	61.0	2.2
	K	1605	1	1008	23	1092	61
(mg·100 g^{-1} Dry Wt)^{Z}	**Ca**	56.3	2.1	44.2	0.8	35.3	1.3
	Mg	171.5	7.1	145.3	1.0	144.9	5.2
	K	2928	1	2249	52	2593	145

Y Ratio of monounsaturated to saturated fatty acids
Z Weight of oil included

High temperatures are likely to affect a range of biochemical processes, such as reduced respiration rate (which can be reduced > 35°C; Eaks, 1978) and ethylene production (reduced at temperatures of > 30°C; Eaks, 1978). High temperatures are likely to reduce not only ethylene production, but also the ability to respond to ethylene (Lee and Young, 1984). High temperature leads to reduced protein synthesis generally, coupled with elevated transcription and translation of hsp RNA and protein (Lurie and Klein, 1991, Ferguson *et al*., 1994), and it is possible that repeated exposure has long-term effects on transcriptional activation and post-transcriptional modification of gene expression. This may be reflected in the overall metabolism of affected tissue.

Exposure of sun fruit to higher temperatures might also result in increased water flow to these fruit. Since many minerals move predominantly in the xylem, higher transpirational flow would lead to increased mineral accumulation in sun fruit, and possibly even higher accumulation in the exposed side of sun fruit. This is reflected in the analyses of the major cations as Ca, Mg and K are heavily affected by water flow. The marked “sidedness” in the mineral concentrations suggests that water flow into the fruit is compartmented. A recent study by Moore-Gordon *et al.* (1998) suggested that there is uneven distribution of vascular tissue in an avocado fruit, and further research may show that this is related to exposure/shade.

Light is also a major factor in sun and shade effects. It is likely that both light and temperature may be responsible for the reduced fluorescence measured from the fruit skin. The photosynthetic system is very sensitive to temperature and light (Greer *et al*., 1988).

Horticultural Implications

These results have a range of implications to the management and harvesting of ‘Hass’ avocados. The higher dry matter and oils observed in sun fruit suggests that this fruit can be harvested earlier as it is likely to be more acceptable in flavour.

Where fruit is exposed to the sun, and especially if left on the tree for long periods of time, such fruit will yield significantly higher levels of oils than shaded fruit. This may be of use for fruit which are already too coloured for sale to meet grade standards. These fruit could be left on the tree for longer periods to accumulate higher oil content, although they will be of slightly poorer quality from a nutritional viewpoint (higher M:S ratio).

Some of the observed differences have important implications in terms of sampling. For example, the fact that sun fruit have higher minerals, dry matter and oils should be considered during sampling as including or excluding sun fruit is likely to skew results.

The slower ripening of sun fruit means that they will take longer to ripen, even when ethylene treated. Under New Zealand conditions, there are periods in early summer where growers tend to harvest sun fruit to avoid excessive colouration (yellowing) and/or sunburn. The majority of fruit harvested at this time will respond significantly differently in terms of ripening rate, and tolerance to storage temperatures, particularly low/ chilling temperatures (Woolf *et al*., 1999a and b).

We conclude that ‘Hass’ avocados exposed to the sun have significant differences to those in shaded positions on the tree. This has significant implications to the culture and handling of these fruit.

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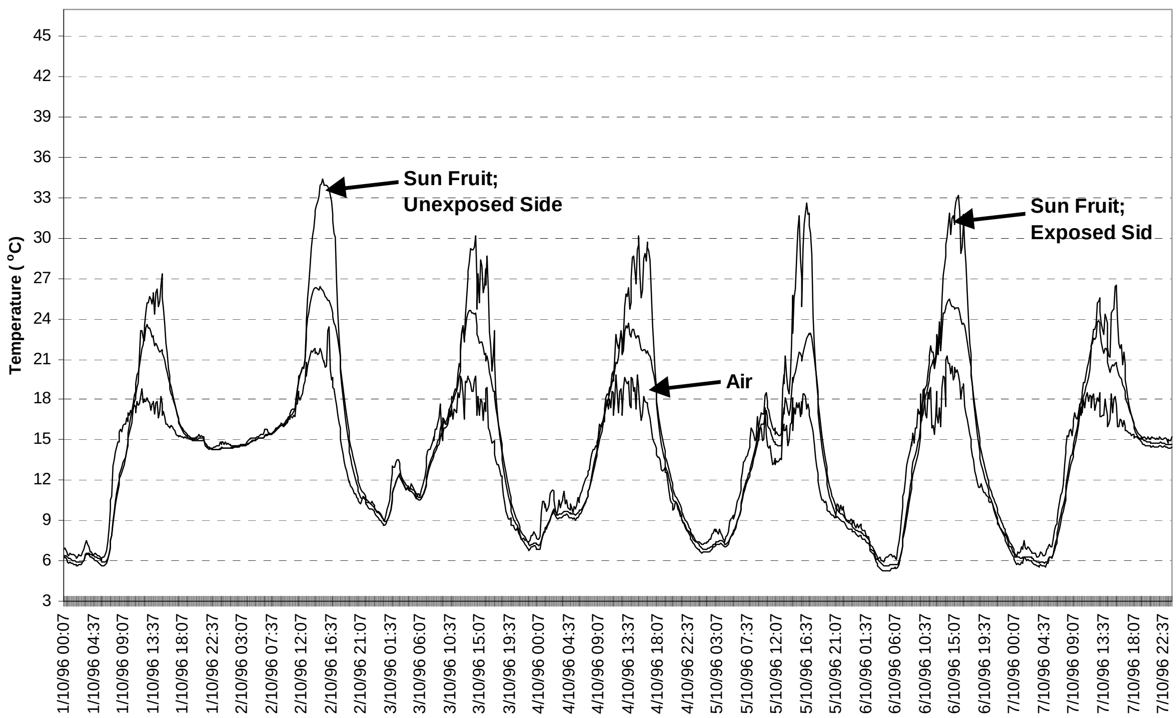
Figure 1. Temperatures during October (Harvest 1). Temperatures shown are for



air and for sun fruit on the exposed and unexposed sides of the fruit.

Figure 2. Temperatures during February (Harvest 2). Temperatures shown are for air, shade fruit, and for sun fruit on the exposed and unexposed sides of the fruit.