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ASPECTS OF LATE HUNG 'HASS' AVOCADO (*PERSEA AMERICANA* MILL.) FRUIT IN THE NATAL MIDLANDS I. FRUIT LIPID AND FATTY ACID ACCUMULATION

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SUMMARY

In the cool, mesic, subtropical Natal midlands, where delayed harvesting of 'Hass' avocado fruit was practised, fruit lipid levels on a dry mass basis peaked in September 1991 and August 1992 at Everdon (Howick) and October 1991 and September 1992 at Cooling (Wartburg). In subsequent months at Cooling(Wartburg) lipid levels decreased. These observations suggest that under the experimental conditions, late hanging was not strongly detrimental and may even be beneficial if fruit lipids are a partially mobile energy source, which maybe utilized during periods of peak demand such as flowering, fruit set and shoot flushing.

Fatty acid levels, which were dominated by the monounsaturated oleic acid, did not vary significantly with late hanging, and were very similar between the two sites in the cool Natal midlands. However, when compared to fruit harvested in late August in the north-eastern Transvaal, total monounsaturated fatty acid levels were some 10% higher, which may be advantageous in reducing serum cholesterol associated with human heart disease. Attempts at modelling monounsaturated fatty acid levels were unsuccessful as levels differed significantly in different months, making interpretation of the model almost impossible.

INTRODUCTION

Avocado trees, both seedlings and hybrids of the three 'horticultural races' viz. Mexican, Guatemalan and West Indian (Lowland) have all found their way into South Africa. In general, trees of the Mexican race are cold hardy and resistant to heat and low humidity, while trees of the West Indian race are most tolerant of heat and high humidity. Trees of the Guatemalan race are intermediate in their adaptation to climate and it is perhaps beneficial that most of the present commercial avocado cultivars are hybrids of the Mexican and Guatemalan races (Wolstenholme, 1977).

Characteristically the different cultivars mature at different times in a season in any particular area. Of the commercial cultivars grown in South Africa, 'Fuerte' fruit usually mature first, followed by 'Edranol', 'Pinkerton', 'Hass' and 'Ryan'. All of these cultivars are grown in South Africa in two distinctly different areas viz. the warm subtropical

north-eastern Transvaal and the cool subtropical Natal midlands. Because of the more southerly latitude, higher rainfall, the maritime effect and the moderating influence of the Drakensberg mountain range avocado trees grown in the Natal midlands flower and set fruit later and are thus harvested later than those grown in the Transvaal. In addition, harvesting may be delayed in cool environments until long after they are physiologically mature. This affords Natal farmers the opportunity of producing out of-season fruit up to December, some six months past the peak harvesting period in Natal.

When late hanging is practised, fruit may be present on the trees coincident with the critical flowering and fruit set periods of the following year's crop. The question thus arises as to how the energy reserves of the fruit and tree will be affected. In this first paper the accumulation of lipids and their fatty acid substituents in late-hung 'Hass' avocado fruit were examined. The health aspects of fatty acid concentrations in relation to late-hanging are discussed and in this light modelling to predicted monounsaturated fatty acid levels was attempted.

MATERIALS AND METHODS

On the basis of different climatic effects, two farms were selected. The first farm, Everdon Estate (30 ° 16'E and 29 ° 27'S), a Hans Merensky Holdings, is close to Howick, and falls under Bioclimatic Group 3 of subcoastal Natal (Phillips, 1973). The mean elevation is 1082 m above sea level, and the rainfall averaged 1007 mm for a 88 yr period (Anon., 1992a). The soil types with clay contents of ca. 45% range from Clovelly to Hutton. In addition, there is an impermeable layer of shale about 1 m below the surface in some places. Clearly, these soil types are not the best for avocados and it is not surprising that many of the trees are now infected with *Phytophthora cinnamomi,* which is controlled by phosphite injections. The second site, Cooling, belonging to Werner and Judy Seele, is situated in the Wartburg area, in Bioclimatic Group 2 of subcoastal Natal (Phillips, 1973), at 30 ° 40'E and 29 ° 27'S. The mean elevation is 950 m above sea level, and the rainfall averaged 934 mm, for a six year period (Anon., 1992b). The soil is Inanda form, Inanda series, with ca. 35% clay, derived from Table Mountain sandstone, with excellent physical properties (humic A on apedal B) and great depth.

In February 1989, at Everdon (Howick), 'Hass' trees on 'Duke 7' rootstock were selected for a randomised block design with five treatments and six replications (single tree plots) of monthly harvests from mid-July to mid-November. These trees were planted in November 1984 in a sloping orchard, with a gradient of 40° and a north-westerly aspect. A similar randomised block design was applied to trees selected at Cooling (Wartburg) in February 1991. These trees were planted in 1986 at a spacing of 7m x 7m in a sloping orchard with a gradient of 10° and a south-easterly aspect.

Based on 300 and 600 mm soil tensiometer readings, the trees on both farms were irrigated with microjet systems, when the soil moisture tension reached between -35 and -40 kPa. In addition, trees were also fertilized at critical periods during the season according to correlative leaf and soil analyses. Weed control was practised at Cooling (Wartburg) while winter oats were sown as a cover crop at Everdon (Howick). In general, management at both farms was intensive and of a high standard. Finally, mean

maximum and mean minimum temperatures from February 1991 to July 1992 show that Everdon (Howick) was the slightly cooler of the two sites (APPENDIX 1).

Eight fruits were taken from both farms, at monthly intervals from March to November in 1991 and 1992. The total fruit and seed masses were recorded for each fruit and two samples of 20 g each were taken from the fruit flesh as radial sections so as to include the meso-and endocarps. The first set of the freshly cut duplicate samples of 20g each was dried using a Scientific Equipment®freeze-drier and the percentage dry mass determined. Dried samples were then placed in labelled Whatman® cellulose extraction thimbles and extracted in petroleum ether (boiling point 40-60°C), using a Soxhlet apparatus. After 12 hr the extraction process was terminated and all excess ether in the receptacle flasks was removed using a Buchi® Flash Evaporator. The percentage total lipids was then determined gravimetrically.

The second set of freshly cut duplicate samples of 20 g each were blanched individually in boiling water, homogenized in methylene chloride:methanol (2:1 V\V) and then stabilized with butylated hydroxytoluene. The homogenate was then filtered through glass wool to remove excess pulp and again through anhydrous sodium sulphate, silica gel and glass wool to remove water and other impurities. Methyl esters of the fatty acids were obtained, using the organic base-catalysed technique of Metcalfe & Wang (1981), with the following modifications: A 10 ml aliquot was taken from the extract and dried down at 45 °C under gaseous nitrogen, to prevent any oxidation of the fatty acids in the sample. The dried sample was then resuspended in 2 ml diethyl ether and 0.5 ml of 1N tetramethylammonium hydroxide (in methanol). The sample was shaken for 1 min., after which 1 ml of distilled water was added. The phases were allowed to separate, with the lower phase consisting of water and other impurities and the upper phase of diethyl ether and the methyl esters of the fatty acids.

The upper phase was carefully pipetted and the methyl esters of the fatty acids analyzed using a Varian®Gas Liquid Chromatogram (Model 3700), fitted with a flame ionization detector, and compared against authentic fatty acid standards. A 2m x 3 mm I.D. glass column, packed with 10% Silar 5CP on 100/120 mesh Supelcuport 100G was operated isothermically at 180°C, with nitrogen as the carrier gas (flow rate of 30 ml min^{-1}). The injection and detector temperatures were 200°C and 360°C respectively.

RESULTS AND DISCUSSION

Lipids

In fruit flesh at Cooling (Wartburg), % lipids on a dry mass basis (Fig. 1) increased from about 37% in March 1991 and 1992 but peaked at slightly less than 75% in both August 1991 and September 1992 and then dropped to about 65% in subsequent months. The % fruit flesh lipids on a fresh mass basis (Fig. 2) at Cooling (Wartburg) only peaked at just less than 30% in October 1991 and at about 31% in September 1992 and then decreased to about 25% in subsequent months. The difference in time of peak lipid concentration between the fresh and dry mass basis is undoubtably due to confounding introduced by variability in the moisture content of the fruit, when working with lipid percentages on a fresh mass basis

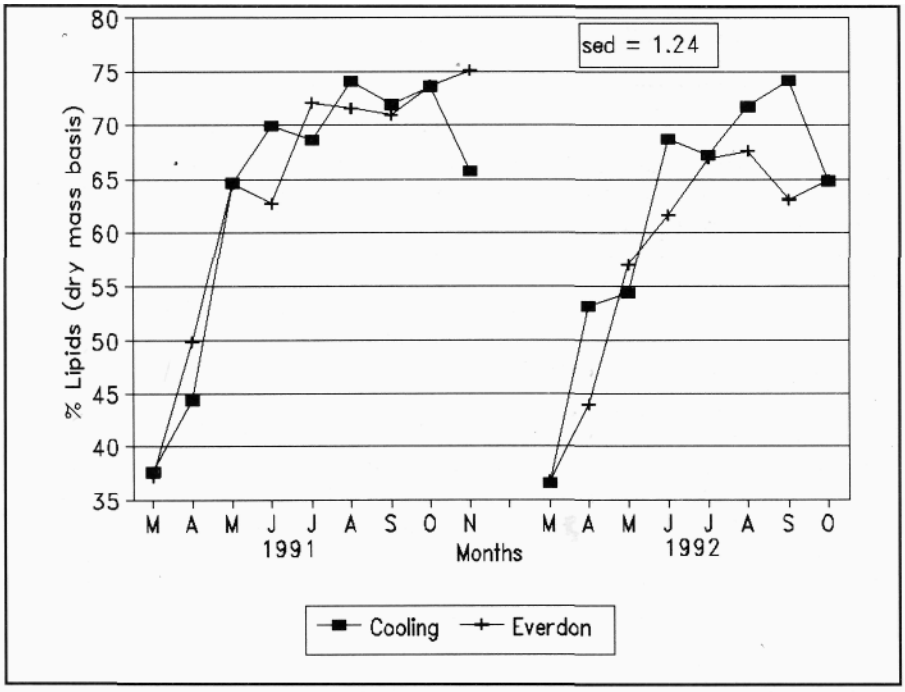

FIG. 1 'Hass' fruit flesh lipid percentages on a dry mass basis for Cooling (Wartburg) and Everdon (Howick) from March to November 1991 and March to October 1992.

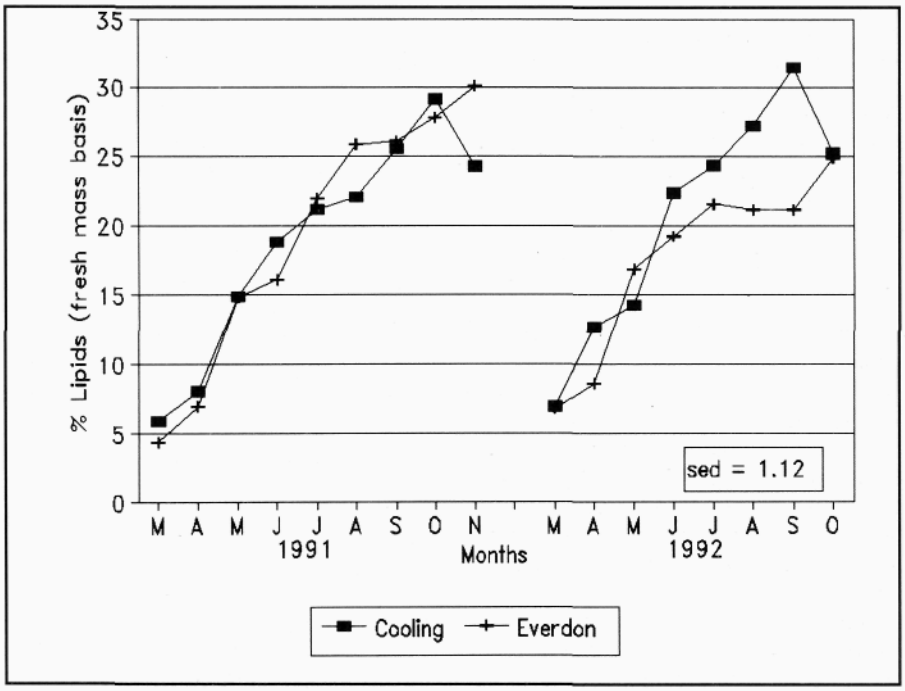

FIG. 2 'Hass' fruit flesh lipid percentages on a fresh mass basis for Cooling (Wartburg) and Everdon (Howick) from March to November 1991 and March to October 1992.

TABLE 1 F-test Probabilities (P) and standard errors of the difference of two means (SED) for farm and monthly effects and their interaction on % Moisture and % Lipids on both a fresh (f.m.b) and a dry mass basis (d.m.b.). Actual monthly means of % Lipids (dry mass basis dmb) and % Lipids (fresh mass basis fmb) on both farms are presented graphically in Figs. 1 and 2 respectively.

Source of Variation	% Moisture	% Lipids (dmb.)	% Lipids (fmb.)
Farm	$P < 0.01$	$P < 0.05$	$P < 0.01$
Months	$P < 0.01$	$P < 0.01$	$P < 0.01$
Farm x Months	$P < 0.01$	$P < 0.01$	$P < 0.01$
SED	1.24	2.28	1.12

In fruit flesh at Everdon (Howick) % lipids on a dry mass basis (Fig. 1) plateaued at about 71% in July 1991 and 68% in August 1992. These same lipid levels on a fresh mass basis (Fig. 2) in 1991 showed an increase, although markedly slower at the end of the season, but plateaued at about 31% in August 1992. These observations confirm the hypothesis that lipids on a fresh mass basis are confounded because of variability in the % dry matter. Indeed, the farm interaction for % lipids on a dry mass basis was only significant at the 5% confidence interval while the % lipids on a fresh mass basis showed strong farm effects, at the 1% confidence interval. This was undoubtedly due to the effects of % dry matter where farm effects were high (PO.01) (Table 1). It should be noted that % dry matter of fruit will differ because of many variables of which temperature and thus time of day, length of time since the last irrigation and relative humidity are but a few. Consequently, increments in % lipids on both a fresh and a dry mass basis, although related, will be different. Caution must thus be exercised when interpreting values obtained on a fresh mass basis and for accuracy, measurements of lipid concentrations should only be made on a dry mass basis.

The drop in lipid levels at Cooling (Wartburg) supports the work of Eaks (1990) who found a decline in 'Mass' lipid percentages on a fresh mass basis after a peak during April (October equivalent, Southern Hemisphere). It is possible that fruit flesh lipids may be acting as an energy source, which may be partially mobilized and utilized for flowering and fruit set of the following crop, which coincided with the observed decreases. Alternatively, this decrease may be temperature related, where some of the fruit lipid reserves may have been respired due to warmer temperatures in spring and early summer. A third possibility is that lipid synthesis may simply have been terminated. Meanwhile fruit size would continue to increase due to continued cell division and lipid concentrations would thus drop. Support for this last hypothesis can be seen for fruit from Everdon (Howick) where a plateau as opposed to a drop in lipid accumulation was observed. Alone or in conjunction, these hypotheses imply that lipid levels do not increase linearly with delayed harvesting of fruit. Late hanging of fruit may even have the positive effect of providing additional partial sources for the ensuing growth phases.

Incidental to the lipid analyses, it was observed that July harvested 'Hass' fruit from Cooling (Wartburg) in 1991 and 1992 did not ripen properly and had a bland flavour

while fruit harvested from August onwards did ripen properly. If the % lipids on a dry mass basis are traced for both farms in 1991 and 1992 then it is clear that lipid levels in July at Everdon (Howick) and August at Cooling (Wartburg) were both approximately 70%. This value of 70% lipids on a dry mass basis translated to about 25% lipids on a fresh mass basis for both farms. Leading on from these observations, this author is of the tentative opinion that fruit in the cool Natal midlands should not be harvested until lipid levels of about 70% on dry mass basis are reached if fruit are going to ripen to acceptable quality. From a local prospective, no maturity standard exists for 'Hass' fruit other than that % moisture should be below 80% (equivalent to approximately 10% lipids on a fresh mass basis) (Swarts, 1976). Studies relating actual lipid concentrations to fruit maturity are lacking and further investigations incorporating different climatic effects are implicated.

Fatty acids

The only fatty acids which occurred in significant concentrations were the saturated palmitic (16:0), monounsaturated palmitoleic (16:1) and oleic (18:1), and polyunsaturated linoleic (18:2) and linolenic (18:3) acids. These fatty acids were also the only ones identified by Davenport & Ellis (1959), Eaks (1990) and Luza *et al.* (1990). Gaydou *et al.* (1987) identified an unknown compound which in the authors' opinion may be a derivative of linoleic acid, arising as a result of oxidation, since extraction in that study was achieved using a Soxhlet apparatus. Extraction should rather have been done under anoxic conditions.

Fatty acids are extremely important for plant functioning as far as membranes are concerned, where they govern permeability, by forming the bilayer, together with proteins. For membranes to function correctly they must be in their liquid crystal state, which is related to the hydrocarbon tail viscosity. The moléculas in the bilayer can thus rotate, move in a lateral direction, and exchange places at a kinetic rate commensurate with the cellular temperature. Where the hydrocarbon tail is saturated, then below the true melting point the carbon-carbon bonds are in their trans arrangement, as this allows for better packing of the chains. If the temperature increases and the membrane enters the liquid crystal state then the molecules increase their kinetic movement and the carbon-carbon rotation results in cis arrangements. This in turn causes a kink in the chain and aids fluidity (Stryer, 1988).

Where the hydrocarbon tail is unsaturated, the unsaturated links are invariably of the cis type, which automatically induces a structure unsuitable for packing. This results in the liquid crystal state occurring at lower temperatures. Clearly, the more cis double bonds present, the lower the phase change between crystal and liquid crystal will be. It is thus not surprising that microorganisms grown at lower temperatures include higher and higher levels of unsaturated fatty acids in their membranes as the temperature drops, to allow the liquid crystal state to operate (Moretón, 1988; Stryer, 1988). Applying this to the avocado, it would seem that fruit developing under cooler temperatures eg. Natal midlands, as compared to warmer eastern or northern Transvaal, will have higher levels of unsaturated fatty acids. Furthermore, avocado export from South Africa is bedeviled by a range of 'Physiological' disorders which have been related, at least in part, to

membrane stability (Bower &Cutting, 1988).

As far as nutrition is concerned, there is irrefutable evidence that a diet, rich in monounsaturated fatty acids, is better than a low fat diet in terms of keeping cholesterol levels low in the human coronary system (Anon., 1985; Anon., 1991; McNamara, 1992). Serum cholesterol is positively related to increased coronary heart disease and if abundant, tends to build up and settle out along the artery walls, attracting blood and causing clotting, which in turn leads to heart attacks (Stamler *et al*., 1986; Anon., 1990). A reduced dietary intake of cholesterol is thus imperative.

High density lipoproteins (HDL), which are synthesized by the liver and intestine are secreted as disc-shaped particles, and contain unesterified cholesterol, phospholipid and apoproteins. The HDL obtain free cholesterol from cell membranes and in so doing, protect the cell walls of the cardio-vascular tracts from *a* build-up of cholesterol (Tall, 1990). Conversely, the low density lipoproteins (LDL), the major cholesterol-carrying lipoprotein in humans, have a lipid core containing mostly cholesteryl ester and one apoprotein (McNamara, 1992). LDL are very damaging as they bind to receptor surfaces of receptor cells along the artery walls. Cholesterol is then released from the LDL by lysosomal cholesterol esterase (Anon, 1990; Assman & Schriever, 1980). Assman & Schriever (1980) maintained that HDL either promote the transport of cholesterol out of smooth muscle cells or compete directly with LDL for binding and uptake receptor sites. In any event, *a* diet rich in saturated fatty acids has been shown to increase the amount of toxic LDL. The mono-and polyunsaturated fatty acids lower the levels of LDL, but after a relatively low saturation level, the latter tend to lower the protective HDL too (Anon., 1990; Bergh, 1991; McNamara, 1992). Monounsaturated fatty acids (eg. oleic acid) are therefore the most desirable from a health point of view.

Based on these facts, it is encouraging, from a marketing point of view, to know that avocado "oils" can be rated as cholesterol-free and even cholesterol-reducing, due to the exceptionally high levels of the mono-unsaturated oleic acid (Wolstenholme, 1990). In a study by Briggs & Galloway (1984), olive oil was shown to have 78% mono-unsaturated, 14% saturated and 8% poly-unsaturated fatty acids. In the same study the avocado (cultivar and source unspecified) had 69% mono-unsaturated, 19% saturated and 17% poly-unsaturated fatty acids. In this respect, the avocado can be seen as one of the healthiest lipid-rich food sources. There is even scope for promoting cultivars and localities with more favourable ratios of fatty acids, bearing in mind the current high profile of "health foods". In addition, the opportunity exists for marketing avocado oil as an edible oil. Indeed, in the light of economic returns for olive oil, this is strongly suggested.

At Cooling (Wartburg) (Fig. 3) the beneficial, monounsaturated cholesterol-reducing oleic acid was the most abundant fatty acid, increasing from 30% in March to about 62% of the total fatty acid component in August, after which concentrations plateaued. In 1992, the concentration rose from about 50% in March to about 62% in September where it plateaued. It is not clear why there was some 20% more oleic acid in March 1992 than March 1991 but it should be remembered that flowering and thus fruit set and subsequent fruit growth were not synchronous in 1991 and 1992. Concentrations of the other beneficial monounsaturate, palmitoleic acid, remained fairly constant in both 1991 and 1992, at just less than 10% of the total lipids. Concentrations of the cholesterol-

causing, saturated palmitic acid were the second most abundant fatty acid, remaining fairly constant at about 20% of the total lipids, during fruit growth in both 1991 and 1992. Concentrations of the polyunsaturates, linoleicand linolenic acid decreased from about 30% and 12% respectively to about 5% and 2% respectively.

At Everdon (Howick) (Fig. 4) oleic acid also increased to about 62% in November 1991 and October 1992. Again, the beneficial palmitoleic acid occurred in fairly constant concentrations of about 9% in both 1991 and 1992. The cholesterol-causing palmitic acid decreased slightly from about 20% in April 1991 to about 17% in November. In 1992 however, palmitic acid decreased from about 21% to about 16% in October. Concentrations of the polyunsaturates linoleic and linolenic acids remained fairly constant, but slight decreases were observed during fruit growth.

Changes in all the fatty acids at Cooling (Wartburg) and Everdon (Howick) showed relatively strong farm effects, but the monounsaturates palmitoleic and oleic acids had the highest correlation coefficients (r=0.69 and 0.19 respectively) where farm effects were concerned. The effect of months (ranging from r=0.69 to 0.86), however, was still responsible for most of the observed differences in all the fatty acids at both farms. The important thing was, however, that farm effects played a significant role. It was speculated that temperature was responsible for these differences and upon examination, levels of the cholesterol-reducing monounsaturated fatty acids viz. palmitoleic and oleic acids were higher by about 2% at Cooling (Wartburg) than Everdon (Howick) in 1991. In 1992 however, no obvious differences in monounsaturated fatty acid levels were seen between the two farms. This phenomenon may have been related to heat and stress factors caused by the prevailing drought in 1992. As far as late hanging was concerned, monounsaturated fatty acid levels peaked in September but dropped slightly until November in both 1991 and 1992 but still averaged about 70%.

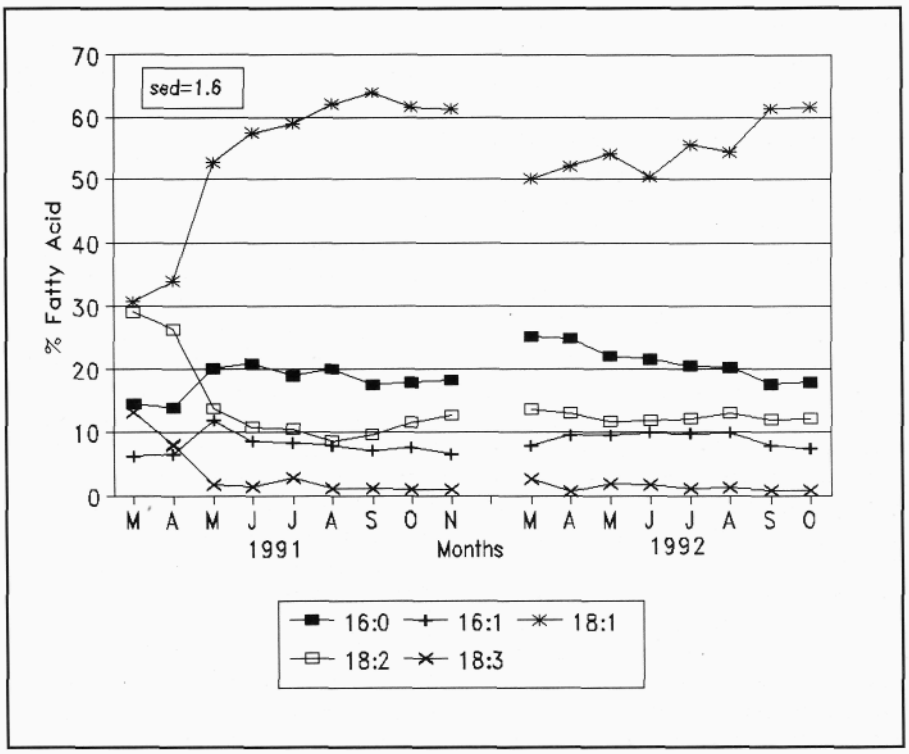

FIG.3 Fatty acid accumulation for fruit at Cooling (Wartburg) between March and November 1991 and March and October 1992 (16:0 = palmitic acid; 16:1 = palmitoleic acid; 18:1 = oleic acid; 18:2 = linoleic acid; 18:3 = linolenic acid).

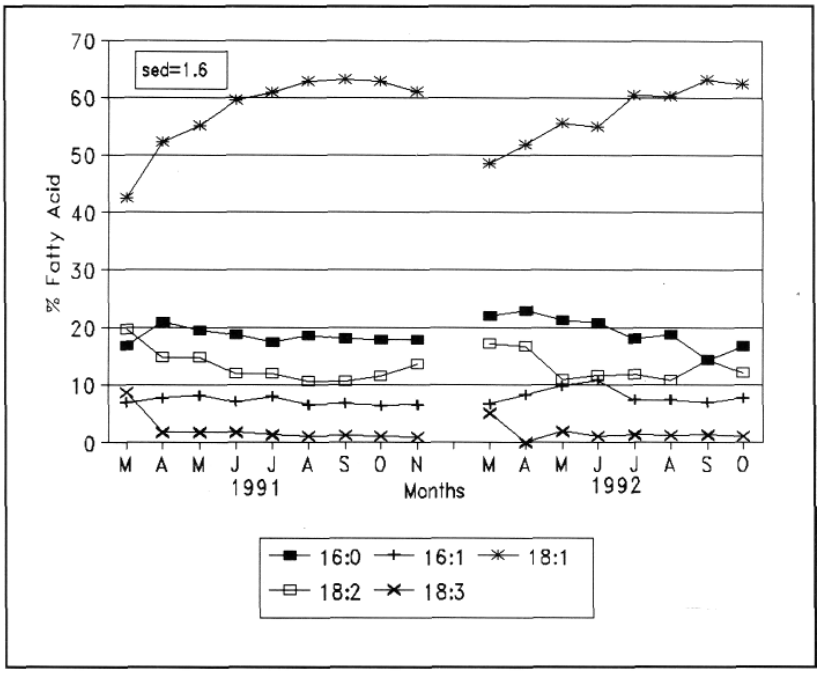

FIG. 4 Fatty acid accumulation for fruit at Everdon (Howick) between March and November 1991 and March and October 1992 (16:0 = palmitic acid; 16:1 = palmitoleic acid; 18:1 = oleic acid; 18:2 = linoleic acid; 18:3 = linolenic acid).

TABLE 2 F-test Probabilities (P) and standard errors of the difference of two means (SED) for farm and monthly effects and their interaction on individual fatty acids viz. palmitic acid (16:0); palmitoleic acid (16:1); oleic acid (18:1); linoleic acid (18:2); linolenic acid (18:3), in the avocado fruit. Actual monthly means of the individual fatty acids at Cooling (Wartburg) and Everdon (Howick) are presented graphically in Figs 3 and 4 respectively.

Source of Variation	Palmitic	Palmitoleic	Oleic	Linoleic	Linolenic
Farm	P<0.01	P<0.01	P<0.01	P<0.01	P<0.01
Months	P<0.01	P<0.01	P<0.01	P<0.01	P<0.01
Farm x Months	P<0.01	P<0.01	P<0.01	P<0.01	P<0.01
SED	0.737	0.485	1.63	0.955	0.819

TABLE 3 Average fatty acid percentages and standard errors of the difference of two means (SED) for a sample of eight fruit harvested in late August 1992 from Westfalia Estate (Tzaneen) and Everdon (Howick).

	Westfalia		Everdon	
Fatty Acid	Average (%)	SED (%)	Average (%)	SED (%)
Palmitic (16:0)	21.73	1.98	18.80	0.737
Palmitoleic (16:1)	11.07	1.18	7.27	0.485
Oleic (18:1)	50.44	3.29	60.30	1.630
Linoleic (18:2)	15.32	3.28	10.74	0.955
Linolenic (18:3)	1.094	0.30	1.16	0.800

Since the differences in total monounsaturated fatty acids between farms were so small, eight fruit from Westfalia Estate, Tzaneen, a much hotter site in north eastern Transvaal were sampled in late August 1992 and fatty acid levels were compared to similar samples taken from Everdon (Howick) (Table 3). Clearly, levels of oleic acid were some 10% lower in fruit from Tzaneen (±50%) than Natal (±60%). However palmitoleic acid the other monounsaturated fatty acid found in the avocado was slightly higher for Tzaneen fruit (11%) than Natal fruit (7%).

Overall the total sum of monounsaturates was higher in fruit from Natal than Tzaneen by about 7%. In addition, there was 3% more cholesterol-causing palmitic acid in the fruit from Tzaneen. Even though Tzaneen fruit had lower total levels of monounsaturates, it must be stressed that these levels are sufficiently high enough to be deemed healthy as far as reducing human cholesterol levels is concerned. The opportunity thus exists for stressing the cholesterol-reducing properties of avocados, especially those from cooler areas. There is a definite case for capitalizing on the higher level of monounsaturated fatty acid levels in fruit from the cooler Natal areas, should this be deemed in the interests of the avocado industry as a whole.

Since the monounsaturated fatty acids are of such importance from a health perspective, the fruit parameters of mass, seed mass, % dry matter and %lipids on both a fresh and a dry mass basis, were modelled to determine whether any of them could be used to predict monounsaturated fatty acid levels (Table 4). After adjusting for the

effects of farms, months and their interaction, by means of a regression analysis, only the effects of seed mass and % lipids on a dry mass basis had significant effects on the monounsaturate levels. All the other parameters examined had no obvious influence on monounsaturated fatty acid levels. The reason for seed mass affecting monounsaturate levels is unclear. However, as seeds are the major sink in fruit, they may be attracting assimilates and thus having an indirect influence on monounsaturates.

The % lipids on dry mass basis would be expected to have an influence, since monounsaturates are the major storage form of lipids in the fruit. The question however arises as to whether or not the effects of % lipids on a dry mass basis have the same effect on both farms, for all months? The % lipid on a dry mass basis x farm interaction was non-significant, which means that the relationship between monounsaturates and % lipids on a dry mass basis was constant across farms. Unfortunately, the % lipids on a dry mass basis, although only at the 5% confidence interval, differed significantly in different months. This makes modelling of predicted monounsaturated fatty acid levels very complex and practically meaningless. Consequently attempts at predicting monounsaturated fatty acid levels given % lipids on a dry mass basis were terminated.

TABLE 4 F-test probabilities (P) and correlation coefficients (r) for predicted monthly monounsaturated fatty acid levels for Cooling (Wartburg) and Everdon (Howick) for the period March to November 1991 and March to October 1992 (dmb = dry mass basis).

Source of Variation	r	P
farm	0.14	**
months	0.86	**
farm.months	0.32	**
seed	0.07	**
%lipids (dmb)	0.09	**
seed.months	0.11	**
%lipids (dmb).months	0.17	*
%lipids (dmb).farm	0.01	N.S.

Finally, from a maturity standpoint, to prevent uneven ripening, fruit should not be harvested until sufficient lipids have been accumulated. A tentative figure of about 70% lipids on a dry mass basis for 'Hass' in Natal is proposed. However more studies involving fruit ripening for various centres need to be undertaken to determine minimum legal lipid percentages so that fruit will ripen properly. From a marketing point of view and in particular the export market, fruit must not be picked prematurely as shrivelling, uneven ripening and associated physiological disorders will only have detrimental effects on subsequent prices.

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APPENDIX 1

Average temperatures from February 1991 to July 1992 for Cooling (Wartburg) (from 'Windy Hill' meteorological station at 30 ° 34'E and 29 ° 29') and Everdon (Howick) meteorological station (Anon., 1992a; 1992b).

	Cooling (Wartburg)		Everdon (Howick)	
Months	Maximum	Mean	Maximum	Mean
February 1991	26.9	22.2	24.6	20.3
March 1991	24.5	19.5	22.9	18.6
April 1991	25.9	18.3	24.2	17.8
May 1991	22.7	15.2	21.3	15.1
June 1991	18.6	13.2	17.0	11.2
July 1991	20.7	12.8	19.2	13.6
August 1991	21.8	14.5	20.7	15.2
September 1991	22.9	17.0	21.4	15.9
October 1991	22.5	17.8	20.6	16.4
November 1991	25.0	19.5	23.4	18.4
December 1991	26.4	20.8	25.0	19.5
January 1992	26.6	21.2	25.1	20.2
February 1992	27.7	22.0	26.6	21.3
March 1992	27.5	20.1	25.9	19.7
April 1992	27.1	19.9	25.3	19.3
May 1992	25.4	16.5	22.8	15.8
June 1992	22.1	13.7	20.7	13.7
July 1992	22.1	12.9	21.5	14.0