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Development of Simple Methods for the Determination of Optimum Stage of Maturity of Six Cultivars of Avocado (*Persea americana* Mill.) at Jimma, Southwest Ethiopia

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ABSTRACT

A study was conducted at Jimma (southwest Ethiopia) to develop simple method of estimating the optimum harvest time of fruits of six avocado cultivars. Fruit samples were collected six, seven, eight and nine months after flowering. At each harvest, physical measurements of the fruit samples were recorded and the fruit length-to-width ratio ($L\ w^{-1}$), fruit weight-to-length ratio ($m\ L^{-1}$) and equivalent diameter (d) were determined. The fruit samples were then allowed to ripe at ambient conditions. The dry matter and oil contents of the juice made from the ripe fruits were determined at each harvest date for respective cultivars. Oil content was highly significantly ($p<0.001$) influenced by the cultivars and harvesting dates compared. Dry matter content of fruits significantly differed among cultivars ($p<0.05$) and harvesting dates ($p<0.01$). Increased oil and dry matter contents were observed towards the later harvest dates. The cultivar Bacon recorded the highest mean oil content ($\bar{X}$ = 19.44±0.73%) while the lowest was obtained from the cultivar Pinkerton ($\bar{X}$ = 15.30±0.73%). The results revealed that harvest date could be a more reliable index of optimum maturity. No significant relationship was found between oil and dry matter contents; and the length-to-width ratio and the equivalent diameter. However, a significant correlation ($\alpha = 0.01$) was observed between the oil content and the fruit weight-to-length ratio ($m\ L^{-1}$) at various stages of maturity. This physical parameter could be used as a simple method (maturity index) for the determination of time of harvest for optimum oil content of avocado fruit.

Key words: *Persea americana*, harvesting date, dry matter, oil, cultivar, maturity index

INTRODUCTION

The avocado (*Persea americana* Mill.) is a tree native to the Caribbean, Mexico (Chen *et al.*, 2009) and is an important fruit crop in tropical and subtropical areas (Mickelbart and Arpaia, 2002). Adjei *et al.* (2011) estimated world avocado production to reach 4.7 million tonnes by 2012. Compared to other fruits, avocados are highly nutritious, healthy food (Ofosu *et al.*, 2011), a good source of potassium and a moderate source of Vitamin A (Crane *et al.*, 2008). Because of the high oil content, avocados have the highest energy value of any fruit (Azizi and Najafzadeh, 2008) and also are the highest in protein content (Kader and Arpaia, 2002). The maturity of harvested perishable commodities has an important bearing on their storage life and may affect the way they are handled, transported and marketed (Reid, 2002). Avocado belongs to a group of fruits known as climacteric that can be harvested at the mature (harder) stage and ripened off the plant. Identification of proper maturity (horticultural or commercial) is difficult in the case of avocado fruits, especially for cultivars that remain green upon ripening (McCarthy, 2001), as maturation is not accompanied by significant changes in external appearance. Reid (2002) defined horticultural or "commercial" maturity as the developmental stage where harvested fruit will undergo normal ripening and provide good eating quality. According to Kader and Arpaia (2002) a mature avocado is one that has reached a particular stage in development such that when harvested, it will ripen to an edible condition with acceptable flavor and texture identifiable with that particular cultivar. Hofman *et al.* (2002) stated that avocado fruit harvested before horticultural maturity may have unacceptable eating quality, or fail to soften without shriveling or may soften unevenly. Nutritional value of the fruit as an internal factor is one of the important considerations in the evaluation of quality. Since quality is highly linked with stage of maturity, the determination of right maturity stage for specific fruit cultivar would play an important role in improving the nutritional value (Kader and Arpaia, 2002).

In East African countries such as Kenya, avocado production (for local consumption and export) is increasing from time to time (Ouma, 2007). The crop is a relatively new to Ethiopia in general and Jimma area in particular (Garedew and Tsegaye, 2010; Shumeta, 2010). In recent years, because of its nutritional advantages, avocado is widely accepted by consumers compared to other fruits available in the local markets. Despite its importance, no work has so far been carried out on determination of fruit maturity at harvest of the major avocado cultivars grown in Jimma area. Proper stage of maturity (time of harvest) is important not only to achieve nutritional advantages but also to promote the marketing of avocados, therefore a study was conducted to determine the earliest picking dates for the most important avocado cultivars grown in Jimma area. Specific objectives of this investigation were to (1) investigate the relationships between internal factors (oil and dry matter) and the fruit physical characteristics at the time of harvest and (2) develop simple and rapid method for the determination of optimum harvesting date of common cultivars of avocado grown in Jimma area. The research was also aimed at assessing variations among the cultivars with regard to maturity indices.

MATERIALS AND METHODS

The experiment was conducted at Jimma Agricultural Research Center (southwest Ethiopia) in 2007/08 (October, 2007 to July, 2008). The center is located at 7° 46' N latitude and 36° E longitude at an altitude of 1,753 meters above sea level. The area receives an average annual rain fall of 1,532 mm with average maximum and minimum temperature of 26.8 and 11.8°C, respectively (JARC, 2008).

Materials: The avocado cultivars used in this study were: Bacon, Ettinger, Furete, Hass, Nabal and Pinkerton. The fruit trees were eight-year old and were selected according to canopy development and fruit load. Fruits from each of the six cultivars were harvested at four different times. To minimize variation, before the first picking, an adequate number of uniform fruits were labeled on four trees per each cultivar. Each sample consisted of 10 fruits of the initially labeled ones.

Methods: The first harvesting date was made to coincide with the currently practiced harvesting date in Jimma area that is, about six months after the flowering date of the tree. The next harvestings were done after every 30 days starting from the first date. For each harvest date, the fruits were allowed to ripen at ambient temperature in open air. The optimum ripe stages for all the samples were determined by subjective judgment when the fruit becomes softer and a gentle pressure between the thumb and the forefinger deforms the fruit skin inwards. At the ripe stage, the fruit samples were peeled by hand and the juice was extracted using a fruit blender. The dry matter and oil contents were determined according to AOAC (1980).

Statistical analysis: The Analysis of Variance (ANOVA) was completed using the Mixed procedure of SAS (2003). Model assumptions, namely constant variance and normal distribution assumptions on the error terms, were verified using methods described in Montgomery (2009). For significant effects, the least squares means were compared and letters generated. The correlation coefficients among the response variables (length- to-width ratio, dry matter content, oil content, weight-to-length ratio and equivalent diameter) were also calculated ($p<0.01$) to determine the type and strength of relationships.

RESULTS AND DISCUSSION

Oil content: The variations in oil content among the six cultivars were found to be highly significant ($p<0.01$). Significant differences in oil content were also observed between harvesting dates ($p<0.01$). The extent to which oil contents were influenced by harvest dates differed in the cultivars as evidenced by the existence of a highly significant ($p<0.01$) interaction between harvesting dates and cultivars. Highest oil values were observed for the cultivar Bacon ($\bar{X}$ = 19.44±0.73%) and lowest values of oil content were observed for the cultivar Pinkerton ($\bar{X}$ = 15.30±0.73%) (Table 1). The oil contents were found to be increasing as the fruit matures on the tree. The highest mean value of oil ($\bar{X}$ = 18.72±0.51%) was observed for the third harvesting date (8 months after flowering) and the lowest mean oil value (16.23±0.59%) was observed for the first harvest date.

These trends in oil content were found to be consistent with the works of other researchers (Hofman *et al.*, 2000; Chen *et al.*, 2009). To determine the mean rate of increase in oil content, regression analysis was made for oil against harvesting dates. Accordingly, the following regression equation for mean oil content (Y, %) against harvest dates (x, days after first harvest) was developed:

$$Y = 55.407 + 0.0852(x), \quad \bar{R}^2 = 0.68$$

Table 1: Average oil content (%) of six cultivars at 4 different harvesting dates

	Cultivars							
Days after flowering	1	2	3	4	5	6	Mean	Results of ANOVA
180	18.00	16.80	17.96	15.81	14.25	14.55	16.23	A***
210	18.33	19.49	17.70	19.98	15.92	12.99	17.40	B***
240	20.45	20.94	18.59	17.79	15.90	18.69	18.72	AB***
270	20.99	20.25	17.85	18.99	17.61	14.96	18.44	
Mean	19.44	19.37	18.02	18.14	15.92	15.30		

***Significant at 0.1% Cultivars: 1: Bacon, 2: Ettinger, 3: Furete, 4: Hass, 5: Nabal, 6: Pinkerton

Table 2: Mean values of oil and dry matter contents (%) for the six cultivars

Cultivar	Oil (%)	Dry matter (%)
Bacon	19.44[a]	27.35
Ettinger	19.37[a]	29.22
Furete	18.02[b]	27.05
Hass	18.14[b]	21.67
Nabal	15.92[cd]	17.10
Pinkerton	15.30[d]	20.73
G. Mean	17.70	23.85
LSD (0.05)	3.18	NS
CV	3.47	26.09

Means within a column followed by the same letter are not significantly different at $p<0.05$

Table 3: Mean values of oil and dry matter contents (%) at different harvesting dates

Harvest date(days)	Oil (%)	Dry matter (%)
180	16.23[b]	22.82[a]
210	17.40[b]	18.50[b]
240	18.72[a]	25.11[a]
270	18.44[a]	28.98[a]
G. Mean	17.70	23.85
LSD (0.05)	2.32	9.79

Means within a column followed by the same letter are not significantly different at $p<0.05$

The result showed a gradual daily increase in the oil content with the highest values towards the later days of harvest indicating the optimum time to harvest the fruit.

Dry matter content: Mean values for dry matter content of the six cultivars were found to be comparable with regard to their dry matter contents (Table 2). However, there was a significant ($p<0.01$) variation in dry matter content between harvesting dates with maximum dry matter observed towards the later days of harvest (Table 3). The later days of harvest (270 days after flowering) recorded significantly high dry matter content (28.98%). However, it was not statistically different from the one harvested at 240 days after flowering (25.11%). The lowest dry matter content (18.50%) was recorded at 210 days after flowering. A regression equation was generated between mean dry matter content (Y, %) and the number of days after the first harvest (x):

$$Y = 18.924 + 0.093(x) \quad R^2 = 0.412$$

Results of this study showed that starting from the first date of harvest the dry matter and oil contents tend to increase demonstrating advantages of later picking of the fruit to ensure better oil and dry matter contents.

The results of the present study agree with those reported by Ozdemir and Topuz (2004) and Yousef and Hassaneine, (2010) who reported an increase of dry matter and oil contents with advancement of fruit maturity of different avocado cultivars. Based on the experiences obtained in Mexico for export fruit, it was established that avocados should have an average of 22% of dry matter and the lowest value of a sample should not be under 20% (Dorantes *et al.*, 2004). In the present study also the mean dry matter content of the cultivars tested was within the range, except

Table 4: Mean effects of harvesting dates on weight to length ratio (m L^{-1}, g cm^{-1}) of six cultivars of avocado

	Cultivar						
Harvest date (days)	1	2	3	4	5	6	Results of ANOVA
180	31.98a	19.40^{a}	25.81^{a}	23.43^{a}	27.23^{b}	21.84^{b}	A***
210	23.61b	20.51^{a}	23.57^{b}	21.18^{b}	-	20.47^{bc}	B***
240	21.72b	19.85^{a}	23.49^{b}	23.99^{a}	29.86^{a}	23.08^{a}	AB***
270	23.53b	19.82^{a}	18.76^{c}	18.76^{c}	27.94^{b}	20.47^{bc}	
Mean	25.21	19.82	21.84	21.84	28.34	21.46	

***Significant at 0.1%. Means within a column followed by the same letter are not significantly different at $p<0.05$, Cultivars: 1: Bacon, 2: Ettinger,3: Furete, 4: Hass, 5: Nabal, 6: Pinkerton

Table 5: Mean values of weight to length ratio (m L^{-1}), Length to width ratio (L w^{-1}) and equivalent diameters (D_e) as influenced by calendar/harvest dates

Harvesting date (days)	m L^{-1} (g cm^{-1})	L w^{-1} (dimensionless)	De (mm)
180	54.09^{a}	1.49^{c}	80.44^{a}
210	21.87^{b}	1.57^{b}	77.53^{b}
240	23.67^{b}	1.60^{a}	80.85^{a}
270	21.55^{b}	1.61^{a}	78.10^{b}
G. Mean	23.01	1.56	79.23
LSD (0.05)	2.23	0.11	2.46
CV	8.75	5.10	2.76

Means within a column followed by the same letter are not significantly different at $p<0.05$

for Nabal which recorded very low (17.10%). On the other hand, Chen *et al.* (2009) reported very high dry matter content, ranging from 21.91 to 46.78% for 'Sharwil' Avocado. Similarly Clark *et al.* (2007) reported high mean dry matter content, ranging between 25.4 and 43.6%, for Hass cultivar. Such variations might have occurred due to growing location, crop management practices followed and cultivar. Gupta *et al.* (2011) reported variation in essential oil content as affected by altitude (growing location). Similarly Siddiquee *et al.* (2003) reported dry matter content increase of rice varieties with advancement of days after flowering. Ullah *et al.* (2004) also used days to maturity to determine stage of maturity of apple varieties.

Physical characteristics: As shown in Tables 4-6 the physical characteristics of the fruits were significantly affected by the harvest date ($p<0.01$). The length- to-width ratio (L w^{-1}) tended to increase slightly towards the later days of harvest for all the cultivars (Table 5). Significantly the maximum weight-to-length ratio (54.09 g cm^{-1}) was record from the fruits harvested at 180 days after flowering, followed by 240 days after flowering (23.67 g cm^{-1}). However, the latter was not significantly different from those recorded at 210 days (21.87 g cm^{-1}) and 270 days (21.55 g cm^{-1}).

Significantly the highest length to width ratio (1.61) was recorded at 270 days after flowering which was on par with that recorded at 240 days after flowering (1.60). The lowest length to width ratio (1.29) was obtained at 180 days after flowering. However, it was not significantly different from that recorded at 210 days after flowering (1.57). Significantly the maximum equivalent diameter (80.85 mm) was obtained from fruits harvested 240 days after flowering, followed by 270 days (78.10 mm) and 210 days (77.53 mm). However, there was no significant difference between values of the latter two. The results suggest that as the fruit matures on the tree, it elongates more along its length. The result is consistent with that reported by Ozdemir *et al.* (2009)

Table 6: Mean effects of harvest dates on length to width ratio (p/w, dimensionless) of six cultivars of avocado

	Cultivar						
Harvesting date (days)	1	2	3	4	5	6	Results of ANOVA
180	1.52^{c}	1.29^{c}	1.60^{c}	1.65^{b}	1.13^{b}	1.75^{a}	A***
210	1.65^{b}	1.39^{b}	1.66^{b}	1.42^{d}	-	1.72^{a}	B***
240	1.78^{a}	1.35^{b}	1.85^{a}	1.61^{bc}	1.24^{a}	1.77^{a}	AB***
270	1.69^{b}	1.40^{a}	1.69^{b}	1.86^{a}	1.29^{a}	1.75^{a}	
Mean	1.66	1.35	1.70	1.63	1.22	1.74^{a}	

***Significant at 0.1%. Values within a column followed by the same letter are not significantly different at $p<0.05$. Cultivars: 1: Bacon, 2: Ettinger, 3: Furete, 4: Hass, 5: Nabal, 6: Pinkerton

Table 7: Correlation matrix among the measured characteristics

Characteristics	1	2	3	4	5
1	1.00				
	(0.00)*				
2	0.269	1.00			
	(-0.210)	(0.00)			
3	0.071	0.700	1.00		
	-0.638	(-0.0001)	0.00		
4	-0.345	0.322	0.414	1.00	
	-0.01	-0.116	-0.003	(0.00)	
5	0.325	0.029	-0.174	0.432	1.00
	(-0.026)	(-0.890)	(-0.241)	(-0.002)	(0.00)

*Values within parenthesis indicate probability. 1: Length- to-width ratio, 2: Dry matter, 3: Oil, 4: Weight-to-length ratio, 5: Equivalent diameter

who worked on avocado cultivars, Bacon, Fuerte and Zutano. Simsek (2011) also reported existence of variation among fig fruits in terms of fruit shape index (width/length) and correlation of this index with Total Soluble Solids (TSS) content, serving to determine stage of maturity at harvest. All cultivars except Ettinger and Nabal reached their maximum oil and dry matter levels when the mean length-to-width ratio was 1.60 to 1.70 (Table 6). No significant relationship was found between the internal compositional factors (oil and dry matter) and the length-to-width ratio as well as the equivalent diameter. However, a significant ($p<0.01$) correlation was observed between the oil content and the weight-to-length ratio at the various stages of maturity (Table 7).

CONCLUSION

Results of present study have indicated that the oil and dry matter contents of avocado fruits tended to increase as the fruit maturity advances on the tree. Optimum fruit quality was observed towards the later days of harvest and advantages could be obtained by timing the picking. The best parameter to be used as a maturity index was found to be the calendar (harvest dates). As a supplement to calendar date (i.e., months from flowering to maturity), the weight-to length ratio could be used as simple and cheap method for the determination of optimum time of harvest. In addition, the length-to width ratio for all the cultivars has shown slight increase towards the later days of harvest. Further investigation is recommended to establish a significant relationship between the internal compositional factors and the physical characteristics of the fruit.

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