

The Relationship between Palm Oil Quality Index Development and Physical Properties of Fresh Fruit Bunches in the Ripening Process

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Abstract: Oil palm (*Elaeis guineensis*) is the most important tree crop in the rural economy of the humid rainforest of Malaysia. The oil is consumed as household food, used domestically for industrial purposes, and an important foreign exchange earning export. Normally, oil palm will be harvested after four years of planting. The oil palm yield will increase variously until the tenth year of planting. The yield will then remains at a stable stage until the twenty-fifth year. The maturity and palm oil development in the fruit ripening process is a good way to monitor harvest time and recommendation to evaluate the palm oil performance in food industries. This research is done on Tenera oil palm variety (A cross between Dura and Pisifera) on 8-year-old planted in 2003 at the Malaysian Palm Oil Board (MPOB) Research Station. Fresh fruit Bunches were carried and were divided to three regions (Top, Middle and Bottom) then were removed the fruits from outer and inner layers of them randomly, during the ripening process between 8, 12, 16 and 20 weeks after anthesis for these aims: The relationship between maturity and oil development in mesocarp and kernel also investigate to fatty acid compositions during the ripening process at each three regions of bunch by Gas Chromatography (GC) and Physical properties of oil palm fresh fruits such as length, width, thickness, weight, apparent volume, true density, bulk density, porosity, sphericity and surface area. Calculation of earned data related to ripening time, oil content and physical properties were done by MSTAT-C, SAS and Microsoft Excel computer programs.

Key words: Data analysis, palm oil, physical properties

INTRODUCTION

Physical properties are often required for designing post harvest handling/processing equipment for agricultural products. Physical properties of oil palm fruit are necessary for equipment used in activities such as transportation, storage, grading, oil extraction, and in food production processes like drying and so on. In this study some physical properties of oil palm fruit were determined. Physical properties, which were measured included fruit dimensions, mass, volume, surface area, true density, Bulk density, porosity and sphericity. Physical properties of food materials affect on handling/conveying characteristics and estimating the cooling and heating loads (Mohsenin, 1978). Furthermore, physical attributes such as size, shape, bulk density and porosity are major consideration in designing of hopper, drying and aeration systems, as these properties affect on the resistance to airflow of the stored mass. The importance of dimensions is in determining the aperture size of machines, particularly in separation of materials, as discussed by (Mohsenin, 1978). These dimensions may

be useful in estimating the size of machine components. For example, it may be useful in estimating the number of fruits to be engaged at a time, the spacing of slicing discs and number of slices expected from an average fruit for drying and jam production. The palm oil fruitlets, which are oval and pointed at the apex, vary in length (2-4 cm), diameter (0.5-2 cm) and weight (3-25 g) with the average weight of about 6-8 g. Matured color (yellow, orange, reddish brown, or nearly black) is also varied depending upon variety of the palm tree. (Razavi, 2007), in a study on Some Physical and Mechanical Properties of Kiwifruit reported that the length, of kiwifruit varied from 55.5 to 82.3 mm and the width from 46.8 to 54.8 mm.

MATERIALS AND METHODS

Fruit collection and preparations: Two 8-year oil palms (*Elaeis guineensis*), Tenera variety were obtained for each stage of ripening time 8, 12, 16 and 20 weeks after anthesis (total of 8 palms with almost same stage of bunch's anthesis) from MPOB Research Station (Plate 1 and 2). Two bunches were pulled down from two palms (one



Plate 1: Map location of oil palm fruit sampling at (MPOB) research station



Plate 2: Oil palm tree signed to each stage of ripening time at MPOB research station

bunch from each palm) from January till May 2010, and then bunches were divided to three regions (front, middle and bottom) (Plate 3).

Fruits were collected from outer and inner layers of each region, randomly. To easier statistical calculations, the number of samples for each region of two bunches were 9 fruits, (total of 27 samples) for Uniformity. The mean of 3 samples as a one replication. All the

measurements were carried out at room temperature. Also 20 fruits from each region of two bunches (total of 60 samples) during the Ripening process were selected to oil extraction and fatty acid analysis by soxhlet extraction tubes and Gas Chromatography (GC).

Physical properties determination and calculations: Linear dimensions, length (L), width (W) and thickness

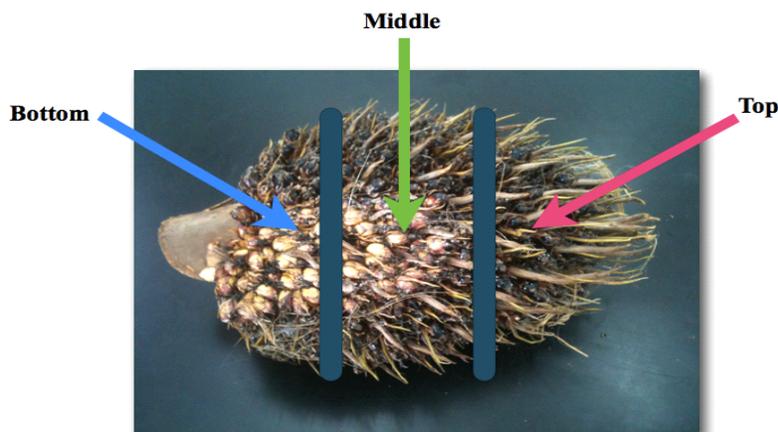


Plate 3: Oil palm fresh fruit bunches were divided to three regions

(T) were measured using a micrometer with an accuracy of 0.01 mm. (Mohsenin, 1978).

Also, all picked bunches (two bunches for each time of ripening time) and each fruit as a sample (total of 27 fruits) were weighted and recorded during the ripening stages. The oval shape used to describe the shape of oil palm fruit was sphericity. Thus: the sphericity (f) of samples was found according the relationship given by (Mohsenin, 1978) as:

$$\Phi = (\text{LWT})^{1/3} / L \quad (1)$$

Surface area is defined as the total area over the outside of the oil palm fruit. Surface area (S) was theoretically calculated as apparent surface area using two following equations that given by (Jain and Ball, 1997a, b), respectively:

$$S = \pi BL^2 / (2L-B) \quad (2)$$

where, $B = (\text{WT})^{0.5}$

$$S = \pi D_g^2 \quad (3)$$

Apparent volume (Va) calculated theoretically by the following equation used for volume of ellipsoid materials:

$$V_a = 4\pi/3 (\text{LWT}) \quad (4)$$

The true density of the palm fruit was determined by the water displacement technique (Dutta *et al.*, 1988; Owolarafe and Shotonde, 2004). Ten randomly selected palm fruits were weighed and lowered into a graduated-measuring cylinder containing 30 cm³ of water. Care was taken that each fruit did not float during immersion in water. The net volumetric water displacement by each fruit was recorded. The true density was then calculated

using Eq. (5) below where 'mass' is the mass of individual palm fruit (m_f) and 'volume' equals the volume water (V_w) displaced in each case:

$$\rho_t = m_f / v_w \quad (5)$$

For bulk density measurement, an empty cylindrical container of predetermined volume was filled with palm fruits and the bulk weight recorded. This was done in five replications. Using Eq. (6), the bulk density is then calculated for each of the replication:

$$\rho_b = m_f / v_f \quad (6)$$

The porosity of bulk fruits was computed from the values of true and bulk Density using the relationship as follow (Mohsenin, 1978):

$$\% \epsilon = (1 - \rho_t / \rho_s) \times 100 \quad (7)$$

Palm oil extraction and fatty acids analysis: The samples were weighed and chopped, then were dried in the oven under 70°C for a day to remove the water in the fruits. The dry kernels and mesocarp were weighed and were blended to get particle. The Oil was extracted in soxhlet extractor available in MPOB oil analyzing lab using chemical solvent namely hexane.

Preparation of fatty acid methyl esters (FAMES): This quick alkaline method carried out at ambient conditions, is suitable for neutral oils such as fresh RBD (Refined Bleached Deodorized) oils. It is not suitable for acidic lipids.

Apparatus: Micro tubes - 1.5 mL, Pipette 1000 mL, Pasteur pipette, Vortex mixer, Centrifuge, GC auto sampler vials.

Reagent:

Sodium methylate 0.5 M, hexane - AR grade

Methods: Transfer 1 mL hexane to the oil extract in the flask. Add 50 mL sodium methylate reagent. Vortexes mix several seconds and leave for about 5 min at least. Centrifuge at about 2000 rpm for 2 min. Transfer the clear upper layer into an auto sampler vial. Cap and inject 1 mL into the GC, (Agilent Technologies, USA).

The composition of the fatty acids is expressed as a percentage, which is calculated by integration of the peak area using GC (MPOB Test Method).

RESULTS AND DISCUSSION

Results of physical properties tests on oil palm fruits:

Fruit lengths: Among different parts of bunch there was no significant difference from aspect of fruit length. The slope of changes of mean length of fruit was varied from 33.8 mm at middle part to 34.15 mm at front part of fruit. However this difference was insignificant.

There was a completely significant difference among different sampling times from aspect of fruit length. By passing of time, from 8 weeks to ripening stage on 20 weeks, the mean length of fruit was increased. Index was increased: from 8 weeks (23.68 mm) to 12 weeks (33.71) equal to 42.3%; from 12 weeks to 16 weeks (36.51) equal to 8.3% and from 16-20 weeks (41.9 mm) equal to 14.76%. Also fruit length during growth, from 8 weeks to ripening stage (20 weeks) was increased equal to 76.9% (Fig. 1).

The interaction among different sampling times and three parts of bunch was not significant for fruit length and it was shown that changes of fruit length followed a similar process from 8 weeks to 20 weeks for front, middle and end parts of bunch.

Figure 2, shows the analysis of regression line of fruit length changes in different sampling times for different parts of fruit. For every part of bunch changes follow a linear function and high regression coefficients indicate the accuracy of equations' estimation. These equations showed that by increasing of time per week, mean length of fruit was increased for front, middle and end parts of bunch as 1.47, 1.44 and 1.41 mm, respectively (Table 1).

Fruit width: The results of variance analysis indicated that there was a significant difference among three different parts of bunch for mean fruit width ($\alpha = 0.05$). Maximum mean fruit width was related to front part of bunch equal to 23.94 mm and min. mean fruit width was related to end part of bunch equal to 22.01 mm (Fig. 3).

There was a significant difference among four sampling times for fruit width ($\alpha = 0.01$). By increasing of fruit growth, mean width was increased. Minimum mean fruit width was related to care in 8 weeks equal to

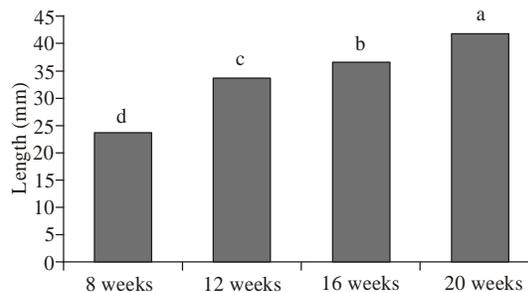


Fig. 1: Effect of sampling time on fruit length, alphabetic letters show significant or insignificant relation

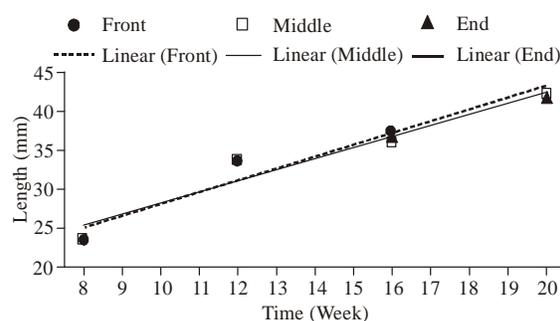


Fig. 2: Effect of sampling time and parts of bunch on fruit length

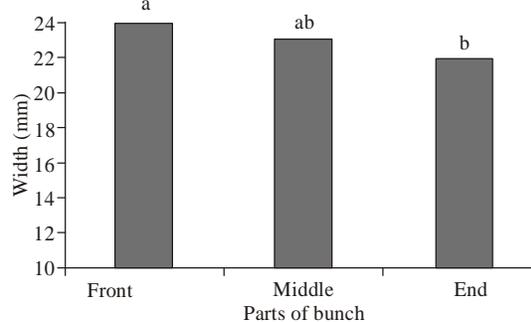


Fig. 3: Mean values of different parts of bunch for fruit width, alphabetic letters show significant or insignificant relation

Table 1: Regression analysis for fruit length

Parts of bunch	Regression equation	R ²	a	b
Front	y = 1.469x+23.862	0.9502	23.862	1.469
Middle	y = 1.4363x+23.749	0.9343	23.749	1.4363
End	y = 1.4045x+24.069	0.9369	24.069	1.4045

Table 2: Regression analysis for fruit width

Parts of bunch	Regression equation	R ²	a	b
Front	y = 1.329x+13.937	0.8944	13.937	1.329
Middle	y = 1.3938x+13.206	0.9606	13.206	1.393
End	y = 1.2608x+13.762	0.9062	13.762	1.260

15.12 mm. The value of this quality in 12 weeks was increased to 21.43 mm e.g., 41.7%, in 16 weeks increased to 22.79 mm e.g., 6.3% and in 20 weeks increased to

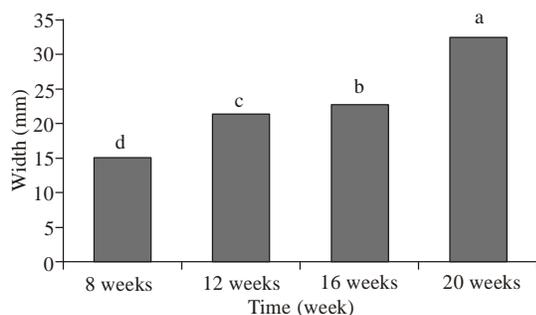


Fig. 4: Effect of sampling time on fruit width, alphabetic letters show significant or insignificant relation

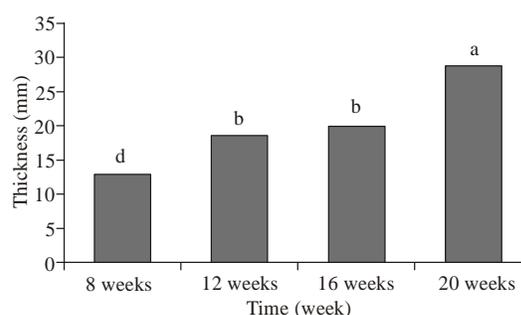


Fig. 6: Effect of sampling time on fruit thickness, alphabetic letters show significant or insignificant relation

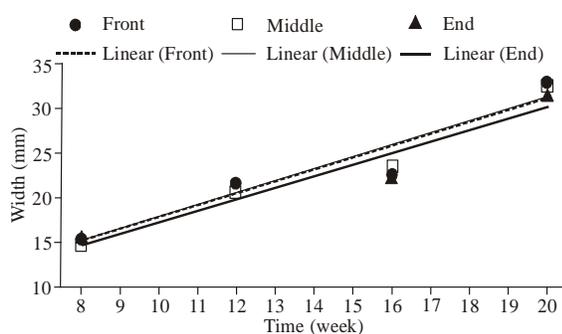


Fig. 5: Effects of sampling time and parts of bunch on fruit width

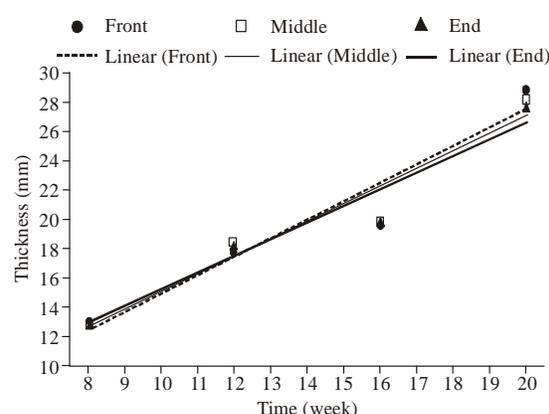


Fig. 7: Effects of sampling time and parts of bunch on fruit thickness

32.37 mm e.g., 42.37%. Maximum increase of mean fruit width was recorded during 8-12 and 16-20 weeks. The velocity of fruit width increasing was low at the beginning of growth (Fig. 4).

The interaction among different sampling times and three parts of bunch was insignificant for fruit width, and it showed that changes of fruit width like fruit length, during 8-20 weeks at front, middle and end parts of bunch followed a similar process.

Figure 5, shows the regression analysis of changes of fruit width on different sampling times for different parts of bunch. In each part of bunch, the changes followed a linear function and high regression coefficients indicate the accuracy of equations.

The equations in Table 2; shows that by increasing of time per week, the mean of fruit width was increased for front, middle and end parts of bunch as 1.329, 1.393 and 1.260 mm, respectively.

Fruit thickness:

The different parts of bunch had no significant difference for thickness (Table 3). But there was a significant difference among different sampling times. By increasing of growth of fruit until ripening stage, mean fruit thickness was increased. Minimum fruit thickness was recorded in care of 8 weeks with 12.92 mm. Thickness of fruit for cares of 12, 16, 20 weeks was increased to 42.26, 7.8 and 43.7%, respectively (Fig. 6).

Table 3: Regression analysis for fruit thickness

Parts of bunch	Regression equation	R ²	a	b
Front	$y = 1.2545x + 11.209$	0.9175	11.209	1.2545
Middle	$y = 1.2055x + 11.517$	0.9279	11.517	1.2055
End	$y = 1.1473x + 11.732$	0.9344	11.732	1.1473

Table 4: Analysis of variance for length, width and thickness

S.O.V	df	Length	Width	Thickness
Replication	2	1.312	0.088	0.093
Factor A (part)	2	0.373 ^{ns}	1.289**	0.179 ^{ns}
Error 4	0.171	0.056	0.358	
Factor B (time)	3	525.767**	457.196**	373.814**
RB	6	0.778*	1.457*	0.673
AB	6	0.443 ^{ns}	1.376*	0.784 ^{ns}
Error	12	0.209	0.375	0.31

*, **: Significant levels at 5 and 1%; ns: not significant; S.O.V: Source of variation; df: degree of freedom

Figure 7, shows the regression analysis of changes of fruit thickness on different sampling times for different parts of bunch. In each part of bunch, the changes followed a linear function and high regression coefficients indicate the accuracy of equations.

Based on estimations by regression equations, the fruit thickness at front, middle and end parts of bunch was increased to 1.25, 1.21 and 1.15 mm per week (Table 3).

Table 5: Mean comparisons length, width and thickness

Treat	MS		
	Length	Width	Thickness
Parts of bunch (A)			
1) Front	34.15 a	23.24 a	19.99 a
2) Middle	33.8 a	22.96 ab	19.96 a
3) End	33.9 a	22.59 b	19.76 a
Times of sampling (B)			
1) 8weeks	23.68 d	15.12 d	12.92 d
2) 12 weeks	33.71 c	21.43 c	18.38 c
3) 16 weeks	36.51 b	22.79 b	19.82 b
4) 20 weeks	41.9 a	32.37 a	28.48 a
A × B			
A1B1	23.71 e	15.59 f	13.15 e
A1B2	33.59 d	21.8 de	17.84 d
A1B3	37.18 b	22.49 d	19.72 c
A1B4	42.1 a	33.08 a	29.25 a
A2B1	23.57 e	14.96 f	12.76 e
A2B2	33.78 d	20.69 e	18.72 d
A2B3	35.82 c	23.64 c	19.9 c
A2B4	42.04 a	32.56 ab	28.44 ab
A3B1	23.76 e	14.82 f	12.87 e
A3B2	33.75 d	21.81 de	18.59 d
A3B3	36.53 bc	22.23 d	19.84 c
A3B4	41.56 a	31.49 b	27.75 b

alphabetic letters show significant or insignificant relation; MS: Mean of squares

Table 4, shows significant or insignificant relationship between parts of bunch and sampling times also interaction between replication and sampling times, parts of bunch and sampling times with length, width and thickness. Result has shown there was a high level significant between times of sampling with length, width and thickness. Also there was a high level significant relation between parts of bunch and width of fruits.

Table 5, shows significant or insignificant relationship between parts of bunch and sampling times with an interaction results between parts of bunch and sampling times with length, width and thickness. As a compare between numbers of Table 5, the numbers with even one common alphabetic letter show insignificant relations. For example a compare of A2B4 = 32.56 ab (the middle part of bunch and 20 weeks) with A1B4 = 33.08 a (the front part of bunch and 20 weeks), there was a no significant relation in width.

Fruit weight: There was a significant difference among different parts of bunch for fruit weight. The fruits on front part of bunch had max. Weight about 9.23 g, but difference between them and middle part was insignificant. The least mean fruit weight was recorded for fruits at the end parts of bunch equal to 8.33 g, but difference between this care and middle part was insignificant (Fig. 8). According to insignificant difference among fruits of three parts of bunch for length and thickness, and a significant difference for fruit width, it was cleared that the significant difference among fruits in these three parts of bunch for weight is resulted from their different width, so that maximum mean fruit weight

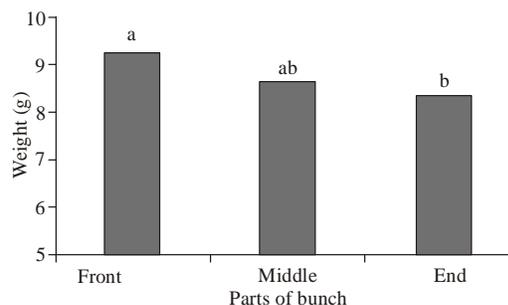


Fig. 8: Mean values of different parts of bunch for fruit weight, alphabetic letters show significant or insignificant relation

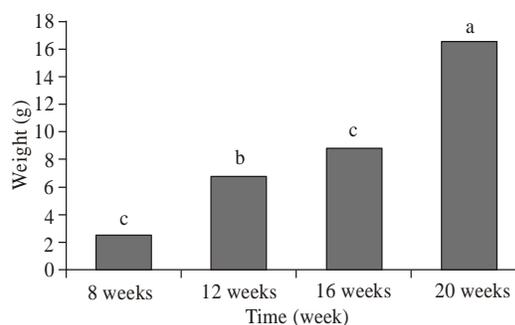


Fig. 9: Effect of sampling time on fruit weight, alphabetic letters show significant or insignificant relation

was related to front part of bunch that had maximum width, also minimum mean fruit weight was related to end part of bunch that had minimum width.

Among four different sampling times there was a significant difference for mean fruit weight. By passing of time from 8 weeks until end of ripen stage (20 weeks) the mean fruit weight was increased. Minimum mean fruit weight in 8 weeks was 2.516 g that was increased to 6.743 g in 12 weeks by increase of 168%. By passing of time and in 16 weeks, mean weight was 8.828 g by increase of 30.92% and in care of 20 weeks it was maximum 16.53 g by increase of 87.2%.

In general, fruit weight mean in 8 weeks was low because length, width and thickness of fruits were low. By passing of time, length, width and thickness indexes were increased that caused to increase the fruit weight during later stages (Fig. 9).

Analysis of regression model of changes of mean fruit weight in different parts of bunch is shown in (Table 6). In each part, changes of fruit weight followed a linear function and the regression equation was a linear function (Fig. 10).

For every three equations, high regression coefficient showed that more than 90% of these changes could be explained through above equations. Calculation of regression coefficients for front, middle and end parts of bunch indicated that mean fruit weight was increased to 1.13, 1.11 and 1.07 g per week (Table 6).

Table 6: Regression analysis for fruit weight

Parts of bunch	Regression equation	R ²	a	b
Front	$y = 1.1259x + 1.1173$	0.951	1.1173	1.1259
Middle	$y = 1.109x + 0.8694$	0.9474	0.8694	1.109
End	$y = 1.0754x + 0.8071$	0.9237	0.8071	1.0754

Table 7: Regression analysis for fruit surface area

Parts of bunch	Regression equation	R ²	a	b
Front	$y = 1.9434x + 4.4651$	0.8987	4.4651	1.9434
Middle	$y = 1.8944x + 4.5131$	0.9241	4.5131	1.8944
End	$y = 1.7434x + 5.1301$	0.9173	5.1301	1.7434

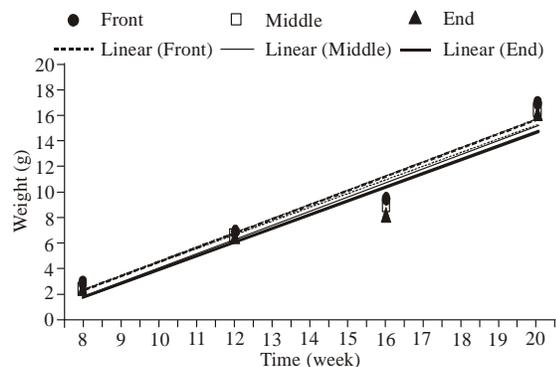


Fig. 10: Effects of sampling time and parts of bunch on fruit Weight

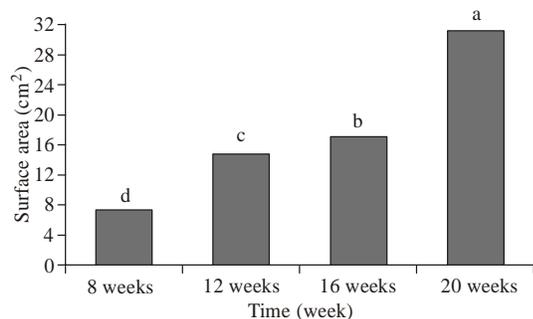


Fig. 11: Effect of sampling time on fruit surface area, alphabetic letters show significant or insignificant relation

Fruit surface area: There was a significant difference among three parts of bunch for fruit surface area. At front parts of bunch, maximum fruit surface area was recorded about 18.77 cm². Comparison of data mean showed that fruit surface area shall be decreased from front part of bunch to end part, so that the fruits have consist on contact place of bunch to stem had minimum fruit surface area equal to 17.03 cm². There was no significant difference between front and middle parts also between middle and end parts of bunch from aspect of fruit surface area. The different sampling times had a significant effect on fruit surface area. By increasing of time from growth of fruit to ripening stage, fruit surface area was increased significantly. Minimum fruit surface area in care of 8 weeks was recorded 7.39 cm². In care of 12 weeks, fruit

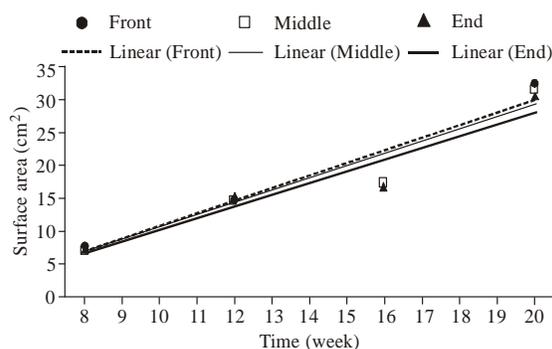


Fig. 12: Effects of sampling time and parts of bunch on fruit surface area

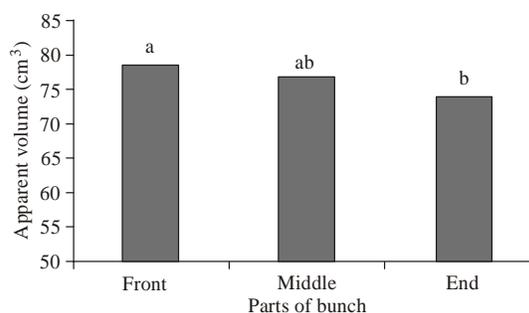


Fig. 13: Mean values of different parts of bunch for fruit apparent volume, alphabetic letters show significant or insignificant relation

surface area was increased to 101.6% equal to 14.9 cm² and in care of 16 weeks it was increased to 15.4% equal to 17.19 cm². Maximum fruit surface area in care of 20 weeks was 31.43 cm² that in comparison with 16 weeks it has increase of 82.8% (Fig. 11).

Maximum increase of fruit surface area was taken place in 16-20 weeks while in 12-16 weeks the growth process was low. Figure 12, shows the regression model of changes of fruit surface area in different parts of bunch by passing of 8 weeks after anthesis until end of ripening stage. For each three parts of bunch, the changes followed a linear function. Based on coefficients of equations, per week, mean fruit surface area at front, middle and end parts of bunch was increased to 1.94, 1.89, 1.74 cm² (Table 7).

The results showed that fruit surface area in each parts of bunch, during growth to ripening stage has a direct relation with width and length of fruits.

Fruit apparent volume: There was a significant difference among different parts of bunch from viewpoint of Fruit Apparent Volume. Maximum fruit apparent volume was related to front part of bunch with 78.87 cm³, but it has an insignificant difference with middle part of bunch. Minimum fruit apparent volume for end part of bunch was 74.08 cm³ that showed reduction of 6.5% in comparison with front part of bunch (Fig. 13).

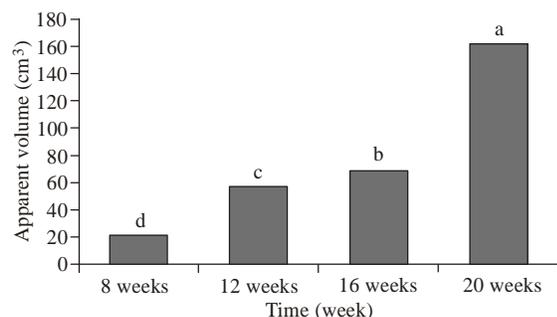


Fig. 14: Effect of sampling times on fruit apparent volume, alphabetic letters show significant or insignificant relation

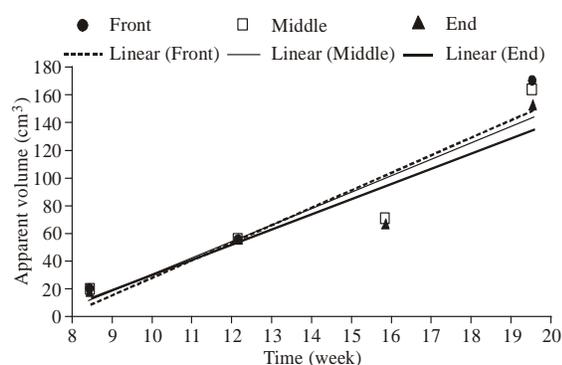


Fig. 15: Effects of sampling time and parts of bunch on fruit apparent volume

Table 8: Regression analysis for apparent volume

Parts of bunch	Regression equation	R ²	a	b
Front	y = 11.672x-2.8333	0.862	2.8333	11.672
Middle	y = 11.208x-1.3168	0.886	1.3168	11.208
End	y = 10.209x+2.6155	0.885	2.6155	10.209

Table 9: Analysis of variance for fruit Weight, Surface area and apparent volume

S.O.V	df	Weight	Surface area	Apparent volume
Replication	2	0.004	0.611	22.954
Factor A (part)	2	1.332**	1.649*	70.541
Error	4	0.005	0.278	12.861
Factor B (time)	3	310.356**	908.828**	33244.049**
RB	6	0.106**	1.355*	36.638
AB	6	0.143**	1.643*	73.121**
Error	12	0.018	0.406	14.742
CV		9.87	9.1	8.01

*, **: Significant levels at 5 and 1%, ns: not significant; S.O.V: Source of variation; df: degree of freedom

The sampling times had a significant effect on fruit apparent volume. By passing of growth time (8 weeks) until end of ripening stage (20 weeks) the mean fruit apparent volume was increased that was significant for all stages. In fruit apparent volume was recorded in care of 8 weeks about 19.74 cm³. Also for case of 12 weeks and 16 weeks an increase of 181.9 and 24.05% equal to 55.66

Table 10: Mean comparisons of weight, surface area and apparent volume

Treat	MS		
	Weight (g)	Surface area (cm ²)	Apparent volume (cm ³)
Parts of bunch (A)			
1) Front	9.230 a	18.77 a	78.87 a
2) Middle	8.632 ab	17.77 ab	77.14 ab
3) End	8.335 b	17.03 b	74.08 b
Times of sampling (B)			
1) 8 weeks	2.516 d	7.389 d	19.74 d
2) 12 weeks	6.743 c	14.90 c	55.66 c
3) 16 weeks	8.828 b	17.19 b	69.05 b
4) 20 weeks	16.53 a	31.43 a	162.3 a
A × B			
A1B1	2.745 h	7.645 f	20.38 f
A1B2	6.929 f	14.73 e	54.84 e
A1B3	9.381 c	17.15 d	68.97 d
A1B4	16.94 a	32.75 a	171.3 a
A2B1	2.357 i	7.245 f	19.33 f
A2B2	6.821 f	14.75 e	54.96 e
A2B3	8.901 d	17.52 d	70.76 d
A2B4	16.45 b	31.58 b	163.5 b
A3B1	2.446 i	7.275 f	19.5 f
A3B2	6.48 g	15.2 e	57.18 e
A3B3	8.203 e	16.91 d	67.42 d
A3B4	16.21 b	29.95 c	152.2 c

alphabetic letters show significant or insignificant relation; MS: Mean of squares

and 69.05 cm³ was recorded. Maximum fruit apparent volume was reported in 20 weeks with 162.3 cm³ that in comparison with 16 weeks, an increase of 135% was recorded (Fig. 14).

Figure 15, shows the regression model of changes of fruit apparent volume in different parts of bunch by passing of 8 weeks after anthesis until end of ripening stage. For each three parts of bunch, the changes followed a linear function.

In Table 8; analysis of regression equations of changes of fruit weight during periods, for front, middle and end parts of bunch indicated that by passing of every week (x) there was an increase of 11.67, 11.21 and 10.21 cm³ in fruit apparent volume.

Table 9 shows significant or insignificant relationship between parts of bunch and sampling times also interaction between replication and sampling times, parts of bunch and sampling times with weight, surface area and apparent volume. Result has shown there was a high level significant between times of sampling and weight, surface area and apparent volume. Also there was a high level significant relation between parts of bunch and weight of fruits.

Table 10 shows significant or insignificant relationship between parts of bunch and sampling times with an interaction results between parts of bunch and sampling times with weight, surface area and apparent volume. As a compare between numbers of Table 10, the numbers with even one common alphabetic letter are insignificant. For example a compare of A1B1= 7.645 f

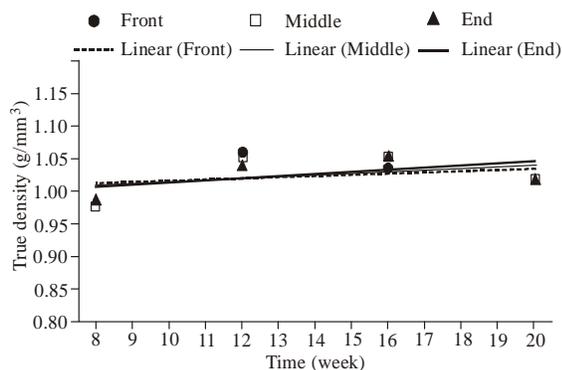


Fig. 16: Effects of sampling time and parts of bunch on true density

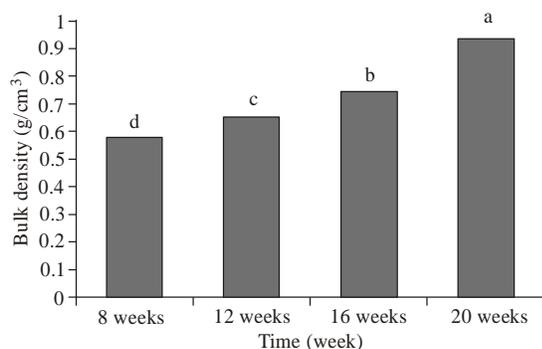


Fig. 17: Effect of sampling time on fruit bulk density, alphabetic letters show significant or insignificant relation

(the front part of bunch in 8 weeks) with $A3B2 = 15.2 e$ (the end part of bunch in 12 weeks) there was a significant relation in surface area.

Fruit true density: There was not a significant difference among the different parts of bunch for fruit true density. However, average of this index was varied from 1.023 g/mm³ at front part of bunch to 1.028 g/mm³ at middle part of bunch. Of course they weren't significant differences.

The difference among different times until ripening stage became significant for fruit true density. Minimum fruit true density was related to care of 8 weeks after anthesis equal to 0.981 g/mm³, which had a significant difference with three cares of 12, 16 and 20 weeks, so it placed on the lowest level of statistic (Fig. 16). However, there was not recorded any significant variation in oil palm fruit for aspect of fruit true density from 12 weeks until end of ripening stage. Interaction between different parts of bunch and sampling times was insignificant specially in aspect of fruit true density and showed that changes of mean fruit true density cannot be influenced by place of fruit in bunch.

Table 11: Regression analysis for true density

Parts of bunch	Regression equation	R ²	a	b
Front	$y = 0.0021x + 1.008$	0.1088	0.0021	1.008
Middle	$y = 0.0032x + 1.0021$	0.1982	0.0032	1.0021
End	$y = 0.0026x + 1.0059$	0.2327	0.0026	1.0059

Table 12: Regression analysis for bulk density

Parts of bunch	Regression equation	R ²	a	b
Front	$y = 0.0293x + 0.5453$	0.9338	0.0293	0.5453
Middle	$y = 0.0299x + 0.5376$	0.9428	0.0299	0.5376
End	$y = 0.0297x + 0.5377$	0.9443	0.0297	0.5377

Table 13: Analysis of variance for fruit True density and Bulk density

S.O.V	df	True density	Bulk density
Replication	2	0.026	0.008
Factor A (part)	2	0.001 ns	0.006 ns
Error	4	0.027	0.001
Factor B (time)	3	0.926 *	22.402 *
RB	6	0.013	0.004
AB	6	0.029	0.003
Error	12	0.011	0.003
CV		8.08	9.12

*, **: Significant levels at 5 and 1%; ns: not significant; S.O.V: Source of variation; df: degree of freedom

Figure 16, shows the regression model of changes of fruit true density in different parts of bunch by passing of 8 weeks after anthesis until end of ripening stage. For each three parts of bunch, the changes followed a linear function.

In Table 11, analysis of regression equations of changes of fruit true density during periods, for front, middle and end parts of bunch indicated that by passing of every week (x) there was an increase of 1.008, 1.0021 and 1.0059 g/mm³ in fruit true density.

Fruit bulk density: The results of analysis of data variances showed that there was no significant difference among the front, middle and end parts of bunch on aspect of fruit bulk density. However, slope of changes of this index was varied from 0.75 g/cm³ at front part of bunch to 0.746 g/cm³ at end part of bunch but this different was not significant. Among four sampling times there was a significant difference on aspect of fruit bulk density. Minimum fruit bulk density in 8 weeks was 0.597 g/cm³. In 12 weeks, the mean fruit bulk density was increased to 0.671 g/cm³ with an increase of 12.4% and in care of 16 weeks it was increased to 0.761 g/cm³ with an increase of 13.4%. Maximum fruit bulk density was recorded at end of ripening stage (20 weeks) equal to 0.962 g/cm³ that was increased about 26.4% in comparison with 16 weeks (Fig. 17).

Figure 18, shows the regression model of changes of fruit bulk density in different parts of bunch by passing of 8 weeks after anthesis until end of ripening stage. For each three parts of bunch, the changes followed a linear function.

In Table 12, analysis of regression equations of changes of fruit bulk density during periods, for front,

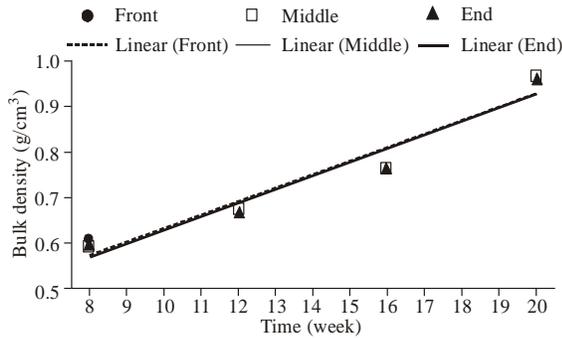


Fig. 18: Effects of sampling time and parts of bunch on bulk density

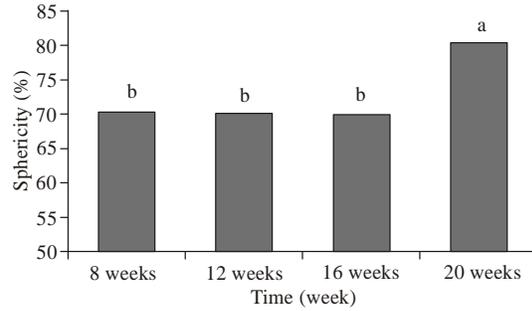


Fig. 19: Effect of sampling time on fruit sphericity, alphabetic letters show significant or insignificant relation

Table 14: Mean comparisons true and bulk density

Treat	MS	
	True density (g/mm ³)	Bulk density (g/cm ³)
Parts of bunch (A)		
1) Front	1.023 a	0.750 a
2) Middle	1.028 a	0.747 a
3) End	1.024 a	0.746 a
Times of sampling (B)		
1) 8weeks	0.981 b	0.597 d
2) 12 weeks	1.050 a	0.671 c
3) 16 weeks	1.047 a	0.761 b
4) 20 weeks	1.017 ab	0.962 a
A × B		
A1B1	0.980 b	0.602 c
A1B2	1.060 a	0.675 bc
A1B3	1.035 a	0.76 b
A1B4	1.017 ab	0.964 a
A2B1	0.975 b	0.593 c
A2B2	1.052 a	0.672 bc
A2B3	1.054 a	0.760 b
A2B4	1.017 ab	0.962 a
A3B1	0.988 b	0.595 c
A3B2	1.038 a	0.666 bc
A3B3	1.053 a	0.763 b
A3B4	1.018 ab	0.959 a

alphabetic letters show significant or insignificant relation; MS: Mean of squares

middle and end parts of bunch indicated that by passing of every week (x) there was an increase of 0.5453, 0.5376 and 0.5377 g/cm³ in fruit bulk density.

Table 13, shows there was a significant relation at level ($\alpha = 0.05$) between sampling times and true and bulk density. Table 14, shows significant or insignificant relationship between parts of bunch and sampling times with an interaction results between parts of bunch and sampling times with true and bulk density. As a compare between numbers of Table 14, the numbers with even one common alphabetic letter are insignificant.

Fruit sphericity: The results of variance analysis showed that the fruits at different parts of bunch have not any significant difference on aspect of fruit sphericity index. Slope of changes of fruit sphericity was varies from 72.3% at end parts of bunch (connection of bunch to

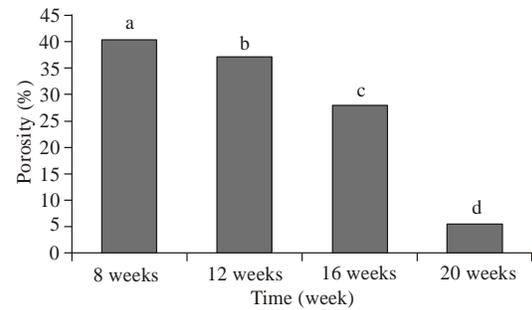


Fig. 20: Effect of sampling time on fruit porosity, alphabetic letters show significant or insignificant relation

stem) to 72.91% at front parts of bunch, but these differences were insignificant.

Difference among the different sampling times was significant on aspect of fruit sphericity. By passing of fruit growth (8 weeks after anthesis) until end of ripening stage, fruit sphericity was increased from 70.38 to 80.53% while difference among care of 8, 12 and 16 weeks was not significant. These results showed that final form of oil palm fruit tends to be spherical form at end of ripening stage (Fig. 19).

Fruit porosity: Among three types fruits at front, middle and end parts of bunch there was not a significant difference on aspect of fruit porosity. However, changes range of this index was varied from 26.67% at front part of bunch to 27.23% at end part of bunch. On the other hand, there was a significant difference ($\alpha = 0.01$) among different sampling times on aspect of fruit porosity percent.

By passing of fruit growth until ripening stage, fruit porosity percent was decreased. Maximum fruit porosity in 8 weeks was 39.18 that had a significant difference with other sampling times. In care of 12 weeks, fruit porosity was decreased to 36.09% by a decrease of 8.56% and in care of 16 weeks by a decrease of 32.1% equal to 27.32% was recorded. Minimum fruit porosity at end of ripening state was 5.46% (Fig. 20).

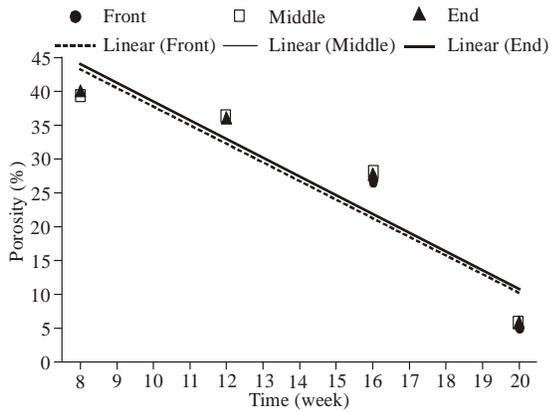


Fig. 21: Effects of sampling time and parts of bunch on fruit porosity

Table 15: Regression analysis for fruit porosity

Parts of bunch	Regression equation	R ²	a	b
Front	$y = -2.7523x + 45.933$	0.869	45.933	-2.7523
Middle	$y = -2.734x + 46.286$	0.858	46.286	-2.734
End	$y = -2.7593x + 46.541$	0.880	46.541	-2.7593

Table 16. Analysis of variance for sphericity and porosity

S.O.V	df	Sphericity	Porosity
Replication	2	1.684	2.822
Factor A (part)	2	1.592 ^{ns}	11.11**
Error	4	0.919	1.255
Factor B (time)	3	245.251**	2085.439**
RB	6	2.381	0.773
AB	6	4.485 ^{ns}	2.589*
Error	12	2.349	0.852
CV		7.27	9.02

*, **: Significant levels at 5 and 1%, ns: not significant; S.O.V: Source of variation; df: degree of freedom

Table 17: Mean comparisons of Sphericity and Porosity

Treat	MS	
	Sphericity (%)	Porosity (%)
Parts of bunch (A)		
1) Front	72.91 a	26.67 a
2) Middle	72.95 a	27.15 a
3) End	72.3 a	27.23 a
Times of sampling (B)		
1) 8 weeks	70.38 b	39.18 a
2) 12 weeks	70.27 b	36.09 b
3) 16 weeks	69.69 b	27.33 c
4) 20 weeks	80.53 a	5.458 d
A × B		
A1B1	71.51 b	38.63 a
A1B2	70.16 bc	36.3 b
A1B3	68.4 c	26.56 c
A1B4	81.56 a	5.18 d
A2B1	70.01 bc	39.13 a
A2B2	69.75 bc	36.15 b
A2B3	71.52 b	27.88 c
A2B4	80.51 a	5.433 d
A3B1	69.62 bc	39.79 a
A3B2	70.89 bc	35.82 b
A3B3	69.14 bc	27.53 c
A3B4	79.54 a	5.763 d

Alphabetic letters show significant or insignificant relation; MS: Mean of squares

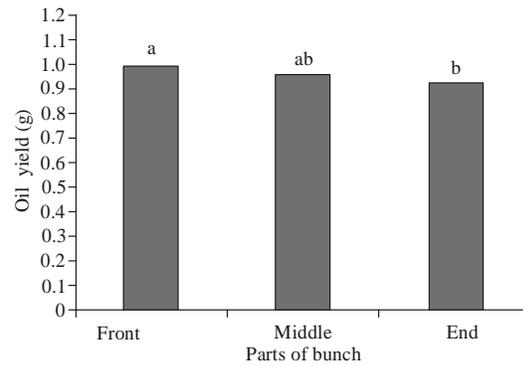


Fig. 22: Mean values of different parts of bunch for total fruit oil yield, alphabetic letters show significant or insignificant relation

Analysis of regression model of changes of fruit porosity for three parts of bunch, from growth to ripening stage (Fig. 21) showed that decrease process of fruit porosity followed a linear function. Regression coefficients of calculated equations showed that these equations could explain more than 85% of changes of fruit porosity by passing of time.

In Table 15 analysis of regression equations of changes of fruit porosity during periods, for front, middle and end parts of bunch indicated that by passing of every week (x) there was a negative values of -2.7523, -2.734 and -2.7593% in fruit porosity.

Table 16, shows significant or insignificant relationship between parts of bunch and sampling times also interaction between replication and sampling times, parts of bunch and sampling times with Sphericity and Porosity. Result has shown there was a high level significant between times of sampling and Sphericity and Porosity. Also there was a high level significant relation between parts of bunch and porosity of fruits.

Table 17, shows significant or insignificant relationship between parts of bunch and sampling times with an interaction results between parts of bunch and sampling times with Sphericity and Porosity. As a compare between numbers of Table 17, the numbers with even one common alphabetic letter show insignificant relations. For example a compare of A2B2 = 69.75 bc (the middle part of bunch in 12 weeks) with A2B3 = 71.52 b (the middle part of bunch in 16 weeks), there was a no significant relation in Sphericity.

Results of palm fruit oil yield analysis: The results of data variance showed that there was a significant difference among fruits at different parts of bunch in statistical level of 5% on aspect of total fruit oil yield. Maximum fruit oil yield was 0.985 g for fruits at front part of bunch but its difference in comparison with fruits at middle part of bunch was insignificant. Minimum one fruit oil yield was related to the fruits at end part of bunch



Plate 4: Palm oil samples (mesocarp and kernel oils) related to the ripening process (8, 12, 16 and 20 weeks after anthesis)

that was 0.921 g that it was 6.50% less than front part of bunch (Fig. 22, Plate 4).

$$\text{Fruit oil yield} = \text{oil (\%)} \times \text{Total weight}$$

For this reason, according to higher significance quality of total fruit oil yield at front part of bunch, oil yield was significant in this part in comparison with other parts.

Table 18, shows significant or insignificant relationship between parts of bunch and sampling times also interaction between replication and sampling times, parts of bunch and sampling times with total fruit oil yield, mesocarp oil yield and mesocarp oil yield to total fruit oil yield. Result has shown there was a high level significant relation between times of sampling with total fruit oil yield, mesocarp oil yield and mesocarp oil yield to total fruit oil yield. Also there was a high level significant relation between parts of bunch and sampling times with mesocarp oil yield.

Sampling time has a significant effect on fruit oil yield in statistical level ($\alpha = 0.01$). Minimum total fruit oil yield was recorded in care of 8 weeks after anthesis that was 0.005 g. At this time, because of non-formation of

Table 18: Analysis of variance for Total fruit oil yield, Mesocarp oil yield and portion of mesocarp oil yield to total fruit oil yield for 4 times sampling

S.O.V	df	MS		
		Total fruit Oil yield (g)	Mesocarp Oil yield (g)	MOY/ TFOY
Replication	2	0.006	0.001	8.978
Part of bunch (A)	2	0.012 *	0.03 **	17.707 ^{ns}
Error	4	0.009	0.001	5.049
Time of sampling (B)	3	25.641 **	14.281 *	1181.876 **
RB	6	0.007	0.001	7.608 *
AB	6	0.005	0.016 **	5.446 ^{ns}
Error	12	0.009	0.001	2.209
C.V		11.08	12.5	10.23

*, **: Significant levels at 5 and 1%; ns: not significant; S.O.V: Source of variation; df: degree of freedom; MOY: Mesocarp oil yield; TFOY: Total fruit oil yield

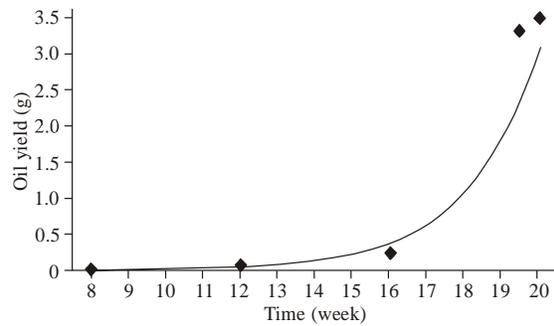


Fig. 23: Effect of sampling time on total fruit oil yield

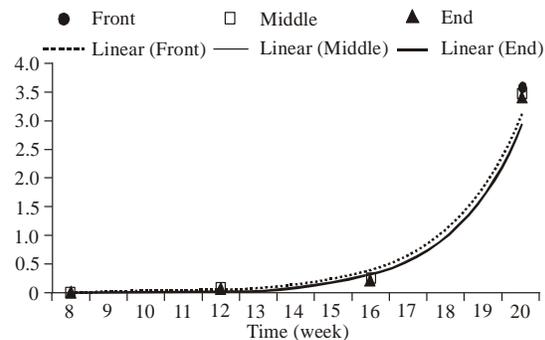


Fig. 24: Effect of sampling time and parts of bunch on total fruit oil yield

kernel into the fruit and the first growth stages, fruit oil yield was very low like as fruit weight. But by continuing the fruit growth, there was a significant increase on total fruit oil yield. So that in care of 12 weeks after anthesis the total fruit oil yields was reached to 0.083 g and in care of 16 weeks it was reached to 0.244 g and finally in care of 20 weeks after anthesis total fruit oil yields was increased to 3.480 g. Maximum total fruit oil yield at end part of ripening stage (20 weeks after anthesis) was 3.480 g. These changes followed an exponential function (Fig. 23).

Compare of mean interactions among different parts of bunch and sampling times, showed that total fruit oil

Table 19: Regression analysis for total fruit oil yield

R ²	Regression equation	Parts of bunch
Front	$y = 0.0045e^{0.5033x}$	0.9702
Middle	$y = 0.0037e^{0.5182x}$	0.9758
End	$y = 0.0027e^{0.537x}$	0.9808

Table 20: Mean comparisons of samples and dual effects for total fruit oil yield, mesocarp oil yield and portion of mesocarp oil yield to fruit oil yield for 4 times sampling

Treatment	Total fruit Oil yield (g)	Mesocarp Oil yield (g)	Kernel Oil yield (g)	MOY / TFOY
Bunch				
A1	0.985 a	0.771 a	0.331 a	90.52 a
A2	0.953 a	0.737 a	0.287 b	90.37 a
A3	0.921 b	0.672 b	0.286 b	88.34 a
Time				
B1	0.005 c	0.005 d	-	100 a
B2	0.083 c	0.081 c	0.002 b	97.64 b
B3	0.244 b	0.210 b	0.034 b	86.2 c
B4	3.480 a	2.612 a	0.868 a	75.12 d
Bunch × Time				
A1B1	0.006 e	0.006 f	-	100 a
A1B2	0.099 cde	0.098 e	0.820 a	98.3 a
A1B3	0.259 c	0.225 d	0.034 b	86.7 b
A1B4	3.576 a	2.755 a	0.002 b	77.07 d
A2B1	0.005 e	0.005 f	-	100 a
A2B2	0.084 cde	0.082 e	0.002 b	97.37 a
A2B3	0.253 c	0.222 d	0.031 b	87.97 b
A2B4	3.469 ab	2.641 b	0.828 a	76.13 d
A3B1	0.004 e	0.004 f	-	100 a
A3B2	0.063 de	0.062 ef	0.956 a	97.27 a
A3B3	0.219 cd	0.184 d	0.035 b	83.93 c
A3B4	3.396 b	2.44 c	0.002 b	72.17 e

B1 to B4: sampling times from 8 weeks to 20 weeks; Alphabetic letters show significant or insignificant relation; MOY: Mesocarp oil yield, TFOY: Total fruit oil yield

yield followed an exponential function at front, middle and end parts of bunch. However, this process was similar for these three bunches and had not any significant difference (Fig. 24).

In Table 19, analysis of regression equations of changes of total fruit oil yield during ripening stages, for front, middle and end parts of bunch indicated that by passing of every week (x) there was an exponential function.

Table 20, shows significant or insignificant relationship between parts of bunch and sampling times with an interaction results between parts of bunch and sampling times with total fruit oil yield, mesocarp oil yield, kernel oil yield and mesocarp oil yield to total fruit oil yield. As a compare between numbers of Table 20, the numbers with even one common alphabetic letter show insignificant relations. For example a compare of B1= 0.005 d (8 weeks after anthesis) with B4 = 2.612 a (20 weeks after anthesis), there was a significant relation in mesocarp oil yield.

Mesocarp oil yield: Difference among the different parts of bunch on aspect of mesocarp oil yield was significant. Maximum mean of mesocarp oil yield was 0.771 g related to fruits at front part of bunch but this difference was

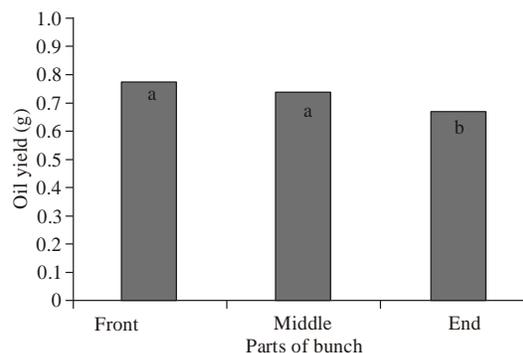


Fig. 25: Mean values of different parts of bunch for mesocarp oil yield, alphabetic letters show significant or insignificant relation

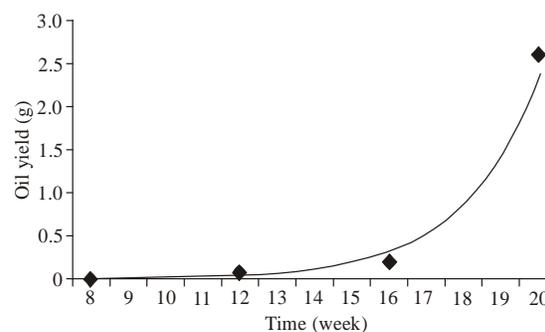


Fig. 26: Effect of sampling time on mesocarp oil yield

insignificant between these parts with fruits of middle part of bunch. Minimum mean of mesocarp oil yield was 0.672 g related to fruits at end part of bunch that in comparison with front part of bunch it was decreased about 12.8% (Fig. 25). Higher rate of mesocarp oil yield at front part of bunch in comparison with two other parts can be caused by two factors: higher mesocarp weight of fruits in this part and higher percent of mesocarp oil yield in this part. The results of comparison of data proved this point.

Effect of sampling time on mesocarp oil yield was significant. Changes of mesocarp oil yield mean had an upward movement and by passing of time it has increased significantly. Minimum mesocarp oil yield was 0.003 g related to care of 8 weeks after anthesis. Because of non-formation of kernel and initial growth stages, low weight of fruit and low weight of mesocarp, mesocarp oil yield like fruit weight was so low. But by growth continuing, there was recorded a significant increase in mesocarp oil yield so that in care of 12 weeks after anthesis, mesocarp oil yield reached to 0.081 g and in care of 16 weeks after anthesis it reached to 0.21 g. Maximum mesocarp oil yield for ripening stage (20 weeks after anthesis) was 2.612 g that was coinciding with time of maximum fruit weight and mesocarp. Regressive analysis of these

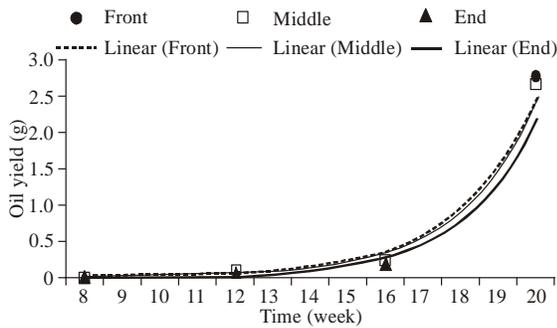


Fig. 27: Effects of sampling time and parts of bunch on mesocarp oil yield

Table 21: Regression analysis for fruit mesocarp oil yield

Parts of bunch	Regression equation	R ²
Front	$y = 0.0048 e^{0.4805 x}$	0.9644
Middle	$y = 0.0039 e^{0.4951 x}$	0.972
End	$y = 0.0029 e^{0.5082 x}$	0.976

changes, by passing of time, showed that this process followed an exponential function (Fig. 26).

Interaction among different parts of bunch and different sampling times was became insignificant on aspect of mesocarp oil yield and showed that changes of mesocarp oil yield was not influenced by place of fruit at parts of bunch from 8 weeks after anthesis until end of ripening stage and these changes were similar for these three parts (Fig. 27). Calculation of regression coefficients of mesocarp oil yield and analysis of regression line of these changes showed that in every three parts of bunch, the changes of mesocarp oil yield followed an exponential function with high regression coefficient (Table 21).

Kernel oil yield: Among the different parts of bunch there was a significant difference on aspect of kernel oil yield. As what we saw in mesocarp yield, kernel oil yield at end part of bunch was lower about 0.286 g that had no significant difference with middle part of bunch. Maximum rate of this quality was recorded about 0.331 g for fruits at front part of bunch in comparison with end part of bunch it was increased about 15.73%. According to higher kernel oil yield at front part of bunch and results of measuring of total fruit oil yield mean that showed preference of front part of bunch on aspect of oil yield and preference of fruits in this part on aspect of mesocarp and kernel oil yield the significance of fruits in this part was for the sake of determination of final fruit yield in comparison with middle and end parts. Sampling time influenced kernel oil yield.

In care of 8 weeks after anthesis, because of non-formation of kernel, total fruit yield was belonged to mesocarp. In care of 12 weeks after anthesis, mean kernel oil yield was least equal to 0.002 g, that by passing of time it was increased. This increase for both care of 16

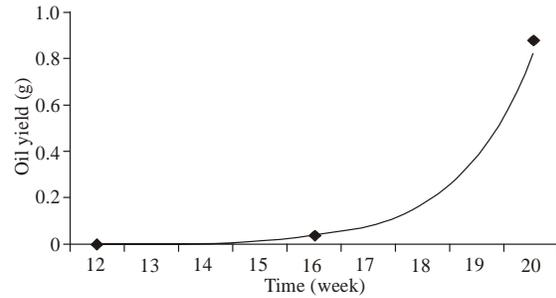


Fig. 28: Effect of sampling time on kernel oil yield

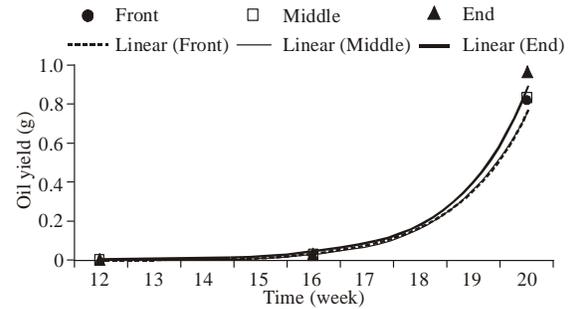


Fig. 29: Effects of sampling time and parts of bunch on kernel oil yield

Table 22: Regression analysis for fruit kernel oil yield

Parts of bunch	Regression equation	R ²
Front	$y = 0.0009e^{0.752x}$	0.9989
Middle	$y = 0.0009e^{0.7532x}$	0.9973
End	$y = 0.0009e^{0.7712x}$	0.9983

Table 23: Analysis of variance for kernel weight, kernel oil yield and Kernel Oil content for 3 times sampling

S.O.V	df	Kernel weight (g)	Kernel oil yield (g)	Kernel oil content (%)
Replication	2	0.014	0.011	0.022
Part of bunch (A)	2	0.050 **	0.006 *	0.024 ns
Error	4	0.002	0.008	0.039
Time of sampling (B)	2	8.835 **	2.171 **	27.91 **
RB	4	0.027 ns	0.010	0.031
AB	4	0.021 ns	0.006	0.020
Error	8	0.010	0.007	0.035
C.V		11.30	10.87	13.60

*, **: Significant levels at 5 and 1%; ns: not significant; S.O.V: Source of variation; df: degree of freedom

weeks (0.034 g) and 20 weeks (0.832 g) after anthesis was significant. In general, increase of fruit oil yield during growth period was arising of contemporary and significant increase of kernel oil yield and mesocarp (Fig. 28).

Interaction among different parts of bunch and different sampling times on kernel oil yield was became insignificant and showed that the changes of kernel oil yield on different times after anthesis was not influenced by different parts of bunch and these changes are similar for three parts (Fig. 29). Analysis of regression model of

kernel oil yield during different parts of bunch showed that this process followed an exponential function (Table 22).

Table 23, shows significant or insignificant relationship between parts of bunch and sampling times also interaction between replication and sampling times, parts of bunch and sampling times with kernel weight, kernel oil yield and kernel oil content. Result has shown there was a high level significant between kernel weight, kernel oil yield and kernel oil content. Also there was a high level significant relation between parts of bunch and kernel weight.

Mesocarp fatty acids percentage in three parts of bunch during the ripening process: The results of data variance analysis of calculation of mesocarp fatty acids percentage in three parts of bunch during four sampling times (8,12,16 and 20 weeks after anthesis) is shown in (Table 24). Among 12 Fatty Acids, except three fatty acids as Caproic acid, Caprylic acid, and Capric acid, other fatty acids (with different percents) were in mesocarp of fruits at every three parts of bunch. Difference among front, middle and end parts of bunch was insignificant on aspect of most fatty acids, but for two fatty acids e.g. Oleic acid and Linolenic α acid, this difference was significant in statistical levels of ($\alpha = 0.05$) and ($\alpha = 0.01$), respectively (Table 24).

Three fatty acids, e.g., palmitic acid (<39%), Oleic acid (<39%) and Linoleic acid (<10%) totally more than 90% of fatty acids in fruits are formed at three parts of bunch (Table 25). Minimum mesocarp fatty acids percentage in three parts of bunch during fruit growth was belonged to arachidic acid.

In Table 26; by passing of time, composition and mesocarp fatty acids percentage showed some changes and among four sampling times there was shown a significant difference in mesocarp fatty acids. Three fatty acids as palmitic acid, oleic acid and linoleic acid had most percent in four sampling times and composed the fatty acids in mesocarp. However, changes of palmitic acid were contrary to oleic acid and linoleic acid. Percent of palmitic acid at beginning of fruit growth (8 weeks after anthesis) maximum value was recorded 54.7%, but by passing of time, until 16 weeks after anthesis it was decreased and then it begun to increase again.

This process was reversed for two other acids. Oleic acid had min. value of 19.22% in 8 weeks after anthesis, while after that time, until 16 weeks, the percent of this acid was increased in mesocarp but then it was decreased again. For linoleic acid, minimum percent was recorded in care of 8 weeks (8.72%), but until 16 weeks this percent was increased in mesocarp, of course it was decreased again at end period (20 weeks).

Table 24: Analysis of variance for mesocarp fatty acids

SOV	df	Lauric Acid (12:0)	Myristic Acid (14:0)	Palmitic Acid (16:0)	Palmitoleic Acid (16:1)	Stearic Acid (18:0)	Oleic Acid (18:1)	Linoleic Acid (18:2)	α - Linolenic Acid (18:3)	Arachidic Acid (20:0)
Replication	2	0.130	0.447	2.057	0.007	0.237	0.548	0.494	0.305	0.159
Bunch (A)	2	0.187 ^{ns}	0.189 ^{ns}	20.681 ^{ns}	0.015 ^{ns}	0.353 ^{ns}	14.129 [*]	1.279 ^{ns}	1.457 ^{**}	0.048 ^{ns}
Error	4	0.154	0.033	4.166	0.014	0.064	1.577	0.506	0.055	0.029
time (B)	3	17.49 ^{**}	7.490 ^{**}	1037.79 ^{**}	2.080 ^{**}	34.80 ^{**}	1726.87 ^{**}	43.61 ^{**}	126.57 ^{**}	0.159 ^{**}
rb	6	0.150 ^{ns}	0.294 ^{**}	8.630 ^{**}	0.032 ^{ns}	0.107 ^{ns}	7.544 ^{**}	1.344 ^{ns}	0.423 ^{**}	0.190 ^{**}
ab	6	0.267	0.143	3.083	0.022	0.308	2.851	1.005	1.146	0.028
error	12	0.161	0.059	1.580	0.012	0.032	0.828	1.076	0.063	0.025
C.V		15.60	11.83	6.060	15.26	7.310	7.370	9.550	9.670	11.32

* , **: Significant levels at 5 and 1%; ns: not significant; S.O.V: Source of variation; df: degree of freedom

Table 25: Mesocarp fatty acids percentage at three parts of bunch

Parts of bunch	Fatty acids (%)									
	α - Linolenic acid	Linoleic acid	Oleic acid	Stearic acid	Palmitoleic acid	Palmitic acid	Myristic acid	Lauric acid	Arachidic acid	
Front	2.31 b	11.23 a	39.52 a	2.65 a	0.68 a	39.54 b	2.05 ab	1.62 a	0.51 a	
Middle	2.473 b	10.76 a	38.26 ab	2.33 b	0.75 a	41.52 ab	2.19 a	1.43 a	0.47 a	
End	2.98 a	10.60 a	37.36 b	2.39ab	0.71 a	42.02 a	1.94 b	1.66 a	0.38 a	

alphabetic letters show significant or insignificant relation

Table 26: Mesocarp fatty acids percentage at 4 times sampling

Week after anthesis	Fatty acids (%)									
	α - Linolenic acid	Linoleic acid	Oleic acid	Stearic acid	Palmitoleic acid	Palmitic acid	Myristic acid	Lauric acid	Arachidic acid	
8 weeks	8.15 a	8.72 c	19.22 d	4.06 b	0.35 c	54.70 a	2.72 a	1.36 b	0.59 a	
12 weeks	1.51 b	9.50 c	47.38 b	0.64 d	1.26 a	33.39 c	2.93 a	3.51 a	0.29 c	
16 weeks	0.31 c	13.60 a	49.62 a	0.88 c	0.97 b	31.59 d	1.55 b	1.21 b	0.52 ab	
20 weeks	0.38 c	11.64 b	37.32 c	4.25 a	0.27c	44.42 b	1.04 c	0.19 c	0.42 bc	

alphabetic letters show significant or insignificant relation

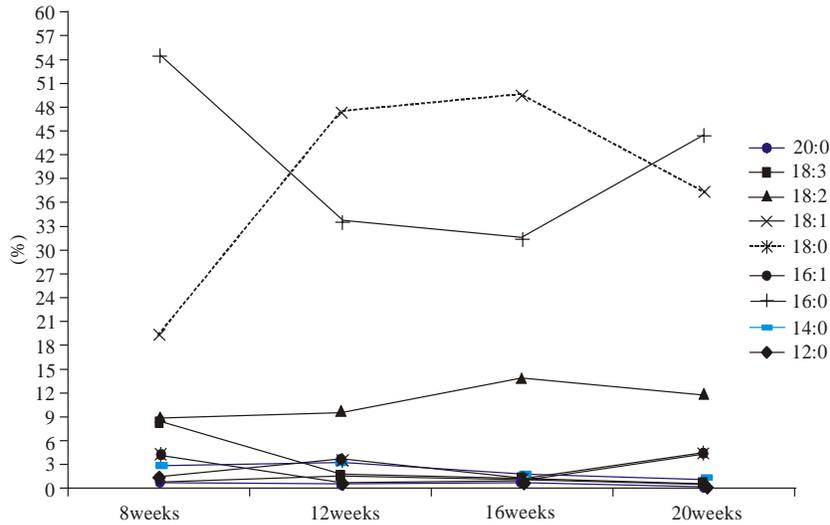


Fig. 30: Effect of sampling time on fatty acid composition of mesocarp oil

Table 27: Regression analysis for Oleic acid and Palmitic acid

Fatty acids	Regression equation	R ²	X max	Y max
Oleic acid	$y = -0.6322x^2 + 10.264x + 10.157$	0.9887	8.12	51.82
Palmitic acid	$y = 0.5334x^2 - 8.2841x + 62.207$	0.9966	7.76	30.05

Figure 30, shows changes of mesocarp fatty acids percentage in 8 weeks after anthesis until end of growth period (20 weeks after anthesis). As we seen, maximum percent and maximum changes of fatty acids in mesocarp is related to palmitic acid and oleic acid and also linoleic acid in four sampling times. Palmitic acid and oleic acid composed more than 73% of total mesocarp fatty acids on 8 weeks after anthesis and this value was increased more than 80% on 12, 16 and 20 weeks. By considering of linoleic acid in composition of mesocarp fatty acids we understand that these three fatty acids on 8, 12, 16 and 20 weeks include 82, 90, 94 and 93% of mesocarp fatty acids. α -linolenic acid was changed until ripening stage. Maximum value of acid was 8.15% on care of 8 weeks that had a significant reduction to 1.51, 0.31 and 0.38% on cares of 12, 16 and 20 weeks. α -linolenic acid was changed until ripening stage. Maximum value of acid was 8.15% on care of 8 weeks that had a significant reduction to 1.51, 0.31 and 0.38% on cares of 12, 16 and 20 weeks.

Analysis of regression model of changes of palmitic acid and oleic acid percent (that are dominant fatty acids in mesocarp) showed that changes of them followed a quadratic function $y = a+bx+cx^2$ (Table 27).

However, this function had a downstream for palmitic acid and upstream for oleic acid. Regression coefficient (R²) showed that the regressive models could explain more than 99% of changes of these two acids. Calculation of X maximum and Y maximum for change of palmitic acid percentage showed that maximum percent of this acid in mesocarp on 8/12 (15/12 weeks after

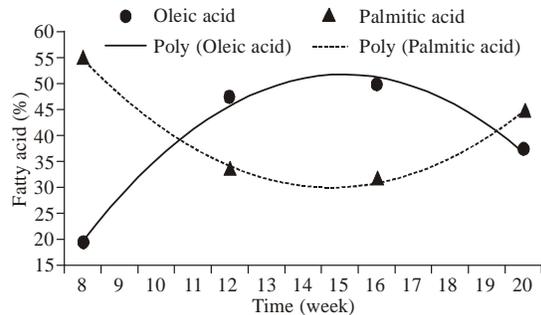


Fig. 31: Effect of sampling time on mesocarp oleic and palmitic acid percentage

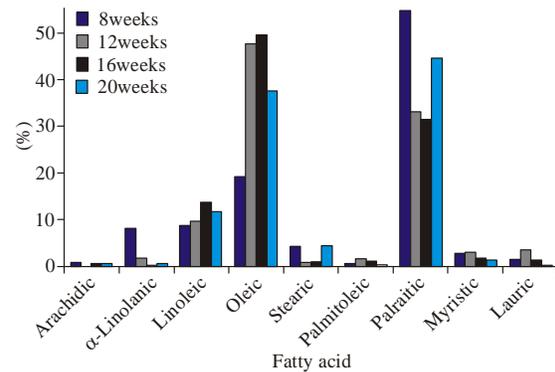


Fig. 32: Fatty acid changes during the ripening

anthesis) was 51.82%. Also Calculation of X maximum and Y maximum for change of oleic acid showed that minimum percent of this acid in mesocarp on 7/76 (14/76 weeks after anthesis) was 30.05% (Fig. 31).

Figure 32, shows by passing of time from kernel consist (12 weeks after anthesis) until end of ripening stage, the changes of fatty acids in fruits did not follow a similar process. By passing of time from fruit growth periods, percent of fatty acids of Caproic acid, Caprylic acid, Capric acid, Lauric acid, Myristic acid, Stearic acid increased significantly, while during this time the percent of fatty acids as Palmitic acid, Palmitoleic acid, Oleic acid, linoic acid, Alpha-linoleic acid and Arachidic acid was decreased.

The results of variance analysis for composition of fatty acids percentage in two parts of mesocarp and kernel during fruit growth (12 weeks after anthesis) until ripening stage (20 weeks after anthesis) showed that between two parts of mesocarp and kernel there was a significant difference on aspect of percent and composition of fatty acids. Also effects of time on percent of all fatty acids in fruit were significant (Table 28 and 29).

By passing of time from kernel consist (12 weeks after anthesis) until end of ripening stage, the changes of fatty acids in fruits didn't follow a similar process. By passing of time from fruit growth periods, percent of fatty acids of Caproic acid, Caprylic acid, Capric acid, Lauric acid, Myristic acid, Stearic acid was increased significantly, while during this time the percent of fatty acids as Palmitic acid, Palmitoleic acid, Oleic acid, linoic acid, Alpha-linoleic acid and Arachidic acid was decreased (Table 30 and 31).

Difference between kernel oil and mesocarp on aspect of fatty acids of Caproic acid, Stearic acid, Alpha-linolenic acid and Arachidic acid was insignificant, however for other fatty acids there was significant difference between oil in these two parts. Percent of fatty acids of Palmitic acid, Palmitoleic acid, Oleic acid and linoleic acid in mesocarp oil was significantly higher than kernel oil. While percent of Caprylic acid, Capric acid, Lauric acid and myristic acid, kernel oil was better than mesocarp oil. More than 91.8% of fatty acids of mesocarp oil are composed of oleic acid (44.3%), palmitic acid (36.01%) and linoic acid (11.52%). While for kernel oil, the dominant fatty acids include five acids as oleic

Table 28. Analysis of variance for palm oil fatty acids

S.O.V	df	Fatty acid (%)					
		6:00	8:00	10:00	12:00	14:00	16:00
Replication	2	0.001	0.004	0.005	0.024	0.017	0.029
Fruit parts (A)	1	0.028**	2.738**	2.516**	71.561**	11.777**	21.168**
Error	2	0.001	0.004	0.002	0.107	0.051	0.071
Time (B)	2	0.280 **	0.457**	0.529**	1.670**	0.407**	0.780**
RB	4	0.002	0.001	0.001	0.045	0.051	0.037
AB	2	0.028 ns	0.457**	0.269**	7.203**	1.848 *	3.026**
Error	4	0.012	0.001	0.002	0.139	0.016	0.016
C.V		6.370	3.370	4.800	11.14	5.330	5.540

*, **: Significant levels at 5 and 1%, ns: not significant; S.O.V: Source of variation; df: degree of freedom

Table 29. Analysis of variance for palm oil fatty acids

S.O.V	df	Fatty acid (%)					
		16:01	18:00	18:01	18:02	18:03	20:00
Replication	2	0.002	0.006	0.031	0.025	0.048	0
Fruit parts (A)	1	0.387*	0.049*	5.622**	1.537*	0.026 ns	0.115*
Error	2	0.005	0.002	0.057	0.080	0.002	0.002
Time (B)	2	0.219**	1.232**	5.507**	0.922*	1.095**	0.108**
RB	4	0.002	0.004	0.012	0.032	0.015	0.001
AB	2	0.060 ns	0.574 ns	2.512**	1.190**	0.195*	0.013 ns
Error	4	0.005	0.003	0.064	0.071	0.042	0.002
C.V		7.550	3.400	4.140	8.850	7.980	5.150

*, **: Significant levels at 5 and 1%, ns: not significant; S.O.V: Source of variation; df: degree of freedom

Table 30: Analysis of variance for palm oil fatty acids

Treatment	Fatty acids (%)					
	6:00	8:00	10:00	12:00	14:00	16:00
Time						
12 weeks	0.5 b	0.79 c	0.76 c	7.95 b	4.21 b	27.53 a
16 weeks	0.5 b	1.01 b	1.18 b	11.16 ab	6.01 a	20.54 c
20 weeks	0.69 a	1.99 a	2.13 a	15.02 a	6.45 a	24.72 b
Fruit parts						
Mesocarp	0.5 a	0.5 b	0.58 b	1.83 b	2.37 b	36.01 a
Kernel	0.62 a	2.22 a	2.29 a	28.5 a	9.98 a	14.69 b

alphabetic letters show significant or insignificant relation

Table 31: Analysis of variance for palm oil fatty acids

Treatment	Fatty acids (%)					
	16:01	18:00	18:01	18:02	18:03	20:00
Time						
12 weeks	1.34 a	1.1 c	46.99 a	9.73 ab	2.63 a	1.21 a
16 weeks	0.94 b	2.38 b	41.15 b	12.15 a	0.93 b	0.95 b
20 weeks	0.6 c	3.81 a	25.2 c	7.3 b	0.67 b	0.69 c
Fruit parts						
Mesocarp	1.24 a	2.13 a	44.3 a	11.52 a	1.21 a	1.1 a
Kernel	0.67 b	2.45 a	30.67 b	7.9 b	1.38 a	0.8 a

alphabetic letters show significant or insignificant relation

Table 32: Fatty acids percentage of kernel oil during the ripening process from 12 to 20 weeks after anthesis

Weeks after anthesis	Sample	6:0	8:0	10:0	12:0	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:0
12	P1BR1 (K)		0.7	0.6	15.0	7.4	23.6	0.7	0.7	48.2	10.1	2.5	0.6
12	P1BR2 (K)		0.5	0.5	11.3	5.8	18.6	0.3	0.5	51.6	9.9	2.1	0.5
12	P1BR3 (K)		0.3	0.2	12.9	2.5	28.2	1.2	0.6	47.9	9.5	3.8	0.7
12	P2BR1 (K)		0.8	0.8	13.7	4.5	24.3	0.3	0.8	49.3	9.1	2.7	0.8
12	P2BR2 (K)		0.7	0.7	10.8	5.1	20.4	0.4	0.6	47.6	9.7	2.7	0.5
12	P2BR3 (K)		0.4	0.4	15.1	3.1	27.6	0.7	0.5	45.7	9.8	4.2	0.6
16	P1BR1 (K)		1.1	1.5	26.5	10.6	12.1		3.8	32.6	11.2	0.5	0.4
16	P1BR2 (K)		1.0	1.6	28.5	10.5	10.7		3.0	32.3	11.4	0.5	0.3
16	P1BR3 (K)		1.3	1.6	28.2	11.0	10.4		3.0	32.9	10.9	0.3	0.3
16	P2BR1 (K)		1.3	2.1	34.9	11.1	9.3		3.3	29.7	7.9	0.3	0.1
16	P2BR2 (K)		1.6	1.8	31.0	11.5	10.2		2.8	30.6	9.9	0.3	0.3
16	P2BR3 (K)		0.8	1.2	23.1	10.1	11.9		3.4	36.7	12.0	0.5	0.3
20	P1BR1 (K)	0.4	4.0	3.7	47.8	14.2	10.1		2.4	14.3	3.2		
20	P1BR2 (K)	0.5	3.9	3.6	45.5	14.0	11.2		2.5	15.5	3.4		
20	P1BR3 (K)	0.5	4.0	3.7	47.1	14.3	10.0		2.5	14.6	3.4		
20	P2BR1 (K)	0.3	3.8	3.5	46.6	14.0	10.3		2.5	15.3	3.2		
20	P2BR2 (K)	0.3	4.2	3.9	50.5	15.2	7.8		2.4	13.1	2.6		
20	P2BR3 (K)	0.4	3.9	3.7	47.6	14.2	10.1		2.4	14.5	3.2		

P (Palm), B (Bunch), R (Region of the bunch) and K (Kernel)

acid (30.67%), lauric acid (28.5 %), palmitic acid (14.69%), myristic acid (9.98%) and linoleic acid (7.3%) that totally composed more than 91.1% of fatty acids in fruit oil.

Kernel fatty acids percentage in three parts of bunch during the ripening process: The result of fatty acids percentage of kernel oil during the ripening process from 12 to 20 weeks was shown in (Table 32). By passing of time from kernel consist (12 weeks after anthesis) until end of ripening stage, the changes of fatty acids in fruits did not follow a similar process. By passing of time from fruit growth periods, percent of fatty acids of Caproic acid, Caprylic acid, Capric acid, Lauric acid, Myristic acid, Stearic acid increased significantly, while during this time the percent of fatty acids as Palmitic acid, Palmitoleic acid, Oleic acid, linoleic acid, Alpha-linoleic acid and Arachidic acid was decreased.

CORRELATIONS AND CONCLUSION

By passing of time from fruit growth (8 weeks after anthesis), mesocarp oil content was increased significantly. Minimum mean mesocarp oil percent was 1.24 % in 8 weeks after anthesis, but after that time, in care of 12-16 weeks after anthesis, a significant increase

in mean of mesocarp oil percent was shown. Maximum mesocarp oil percent on ripening stage was 29.6%.

Fruits on three parts of bunch had a significant difference on aspect of mesocarp oil content. Maximum mesocarp oil content was 10.09% related to front part of bunch that had not significant difference with middle part of bunch and they were on highest statistical group. End part of bunch had minimum mesocarp oil content about 8.93%. Reduction of mesocarp oil percent was caused significant decrease of mesocarp oil yield and finally fruit oil yield. Kernel oil percent was varied between 1.14 and 1.24% for middle and end parts of bunch, but these changes were not significant. But there was a significant difference among different sampling times on aspect of Kernel oil percent from 12 weeks after anthesis until end of ripening stage. By passing of time and kernel growth (12 weeks after anthesis), Kernel oil percent was significant increase. Minimum kernel oil percent was 0.03% on 12 weeks after anthesis but after that time, on a 12-16 weeks distance, total kernel oil percent was increased significantly. Maximum kernel oil percent from care of 20 weeks (ripening stage) was 3.21%. As we can see, by passing of formation period until end of growth, the number of qualities influenced on fruit oil yield and value of their correlation with oil yield was increased.

There was seen a positive and significant correlation between percent of fruit porosity in care of 12 weeks after anthesis (0.989*) and oil yield (0.998**), in care of 16 weeks after anthesis (0.316*) and oil yield (0.955*). There was a negative and significant correlation between true density in care of 12 weeks after anthesis (-0.996**) and oil yield (0.998**), in care of 16 weeks after anthesis (-0.495*) and oil yield (0.955*). The correlation between bulk density in care of 12 weeks after anthesis (-0.997**) and oil yield (0.998**), in care of 16 weeks after anthesis (-0.999**) and oil yield (0.955*). So in care of 20 weeks after anthesis, between oil yield and fruit length (0.966*), fruit width (0.999**), fruit thickness (0.979*), fruit surface area (0.999**), porosity (0.997**) and oil content (0.933**) was seen. During this time, a negative and significant correlation was seen between oil yield and true density (-0.992*) and bulk density (-0.988*).

The results of variance analysis for composition of fatty acids percentage in two parts of mesocarp and kernel during fruit growth (12 weeks after anthesis) until ripening stage (20 weeks after anthesis) showed that between two parts of mesocarp and kernel there was a significant difference on aspect of percent and composition of fatty acids. Also effects of time on percent of all fatty acids in fruit were significant. Maximum percent and Maximum changes of fatty acids in mesocarp is related to palmitic acid and oleic acid and also linoleic acid in four sampling times. Palmitic acid and oleic acid composed more than 73% of total mesocarp fatty acids on 8 weeks after anthesis and this value was increased more than 80% on 12, 16 and 20 weeks.

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