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The Relationship Between Palm Oil Index Development and Mechanical Properties in the Ripening Process of Tenera Variety Fresh Fruit Bunches

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Abstract: This research has done to determine of the relationship between palm oil development in mesocarp and kernel and Mechanical properties of fresh fruit bunches during the ripening process. For this purpose, Tenera oil palm (*Elaeis guineensis*) variety (A cross between Dura and Pisifera) on 8 year- old palms planted in 2003 at the Malaysian Palm Oil Board (MPOB) research station were selected. Fresh fruit bunches were harvested and were divided into three regions (Top, Middle and Bottom) where the fruits from outer and inner layers of them were removed randomly during the ripening process between 8, 12, 16 and 20 weeks after anthesis. Fruit firmness test was done by using a Instron Universal Testing Machine to determine the mechanical responses of oil palm fruit under compressive loading of a cylindrical probe with a soft tip at 25ºC (Cylindrical probe diameter = 6 mm, tip thickness = 3.2 mm, and tip elasticity = 3.27 MPa). The soxhlet extraction tubes were used to the palm oil extraction.Calculation of earned data related to ripening time, oil content and mechanical properties has done by MSTAT-C and Microsoft Excel computer programs.

Key words: Mechanical properties, oil extraction, oil palm FFB

INTRODUCTION

Palm oil is basically from a tropical background. The unripe fruits contain very little oil but the mesocarp of ripe fruits has an oil content of 70-75% of its total weight. Palm oil production in Malaysia is one of the highest among the producing countries and this is attributed to the climate and good management arising from R&D (Basiron and Chan, 2004). The inner bunch bears fruit that is smaller with a smaller ratio of the mesocarp to the fruit as compared to the external fruit. Tan and Sharma (1995) stated that bigger bunches were responsible for producing a smaller ratio of the oil in terms of the bunch because of the nature of the inner fruit. Haniff and Roslan (2002) spoke about a maximum bunch weight of about 24 kg in collusion with mesocarp where the oil content of over 25% were acquired from a fruit set of 90 and 75%. The least fruit set required to maintain the mesocarp O/B ratio.20% is over 40%.

Currently, fruit growers, packers, inspectors, and retailers routinely use the destructive Magness-Taylor (MT) firmness tester to measure the firmness of fruit for determining their quality grade. The MT tester measures the maximum forces required to the force/deformation of the fruit under compression of a cylindrical steel probe, which renders the fruit unmarketable after testing. Different versions of MT testers are currently in use, including low-cost handheld mechanical testers based on a calibrated spring, portable testers equipped with an electronic gauge, and more expensive testers that are coupled to an universal testing machine (Lu and Abbott, 2004).

Rosnah and Wan (2009) reported the mechanical properties of pineapple fruit from the Josapine variety. The effect of fruit maturity on the firmness of each fruit at three different locations was measured using a cylindrical die of 6 mm in diameter with the Instron Universal Testing Machine. The results indicated that the average total weight of a single fruit is 886.86±49.67 g. The average pulp to peel ratio is 1.91. The average diameter (with and without peel) was 86.83±5.24 mm and 80.95±4.15 mm (top section), 100.77±3.84 mm and 90.19±3.73 mm (middle section) and 97.17±3.49 mm and 73.30±5.11 mm (bottom section), respectively.

Instrumental Texture Profile Analysis (TPA) of palm oil fruitlets were measured to observe the effects of thermal softening during the sterilization process. Different forces were applied to mesocarp, abscission layer, and kernel shell nut of the palm oil fruitlets and the effect of sterilization on the textural properties of the

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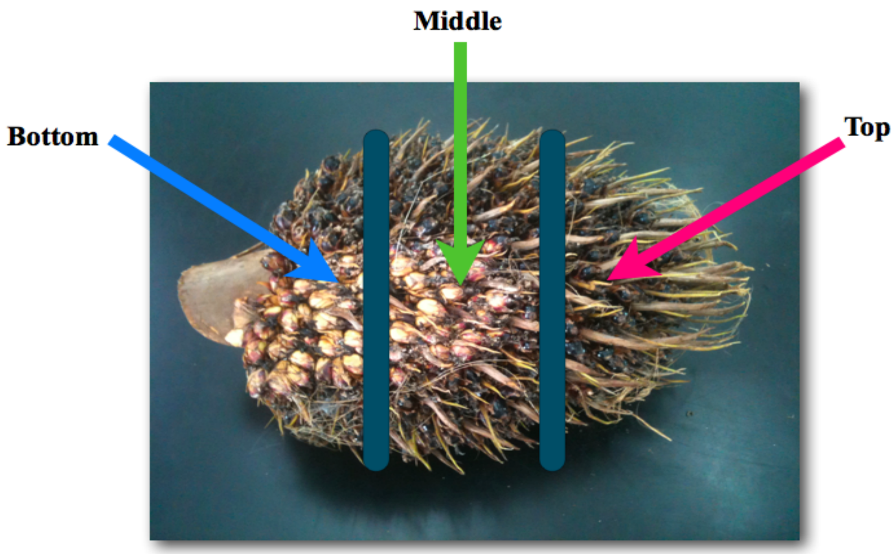

Plate 1: Sampling regions on oil palm bunches

Plate 2: Instron Universal Testing Machine to determine the mechanical responses of an oil palm fruit under compressive loading of a cylindrical probe with a soft tip

fruitlets were recorded. The textural parameters measured were fractura-bility, hardness, adhesiveness and cohesiveness (Abbas and Ali, 2009). In this study to investigate of the relationship between palm oil development in mesocarp and kernel and Mechanical properties of fresh fruit bunches during the ripening process

MATERIALS AND METHODS

Fruit collection and preparations: Two eight year-old oil palms (*Elaeis guineensis*), Tenera variety were obtained for each stage of ripening time 8,12,16 and 20 weeks after anthesis (total of eight palms with almost same stage of bunch's anthesis) from MPOB Research Station. Two bunches were pulled down from two palms (January till May, 2010), and then bunches were divided into three regions (Top, Middle and Bottom) (Plate 1). 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 nine fruits, (total of 27 samples) for Uniformity. The mean of three samples as a one replication (total of 9 replications). All the measurements were carried out at room temperature.

Mechanical responses of oil palm fruit: The firmness test was done to determine the mechanical responses of

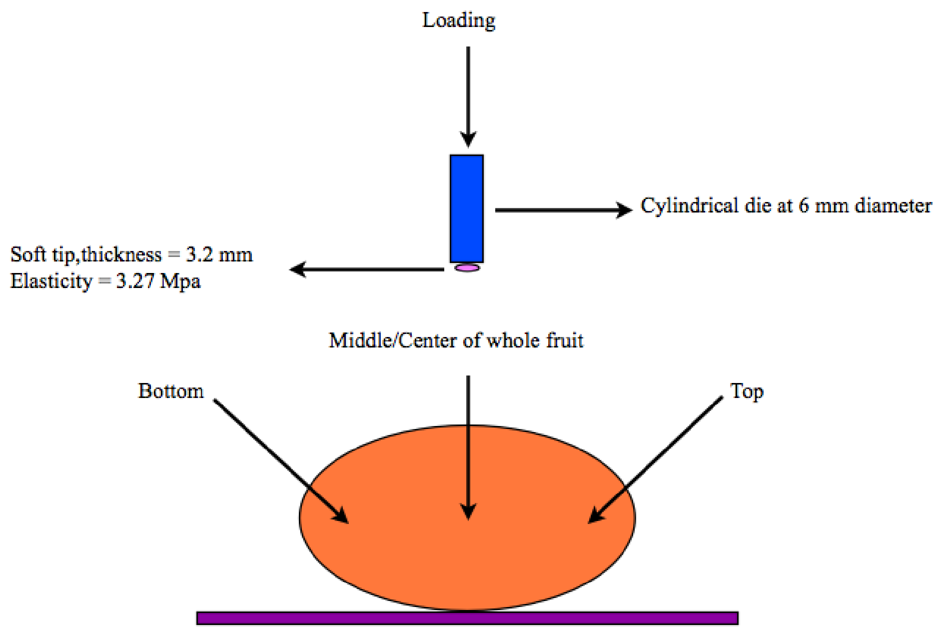

Fig. 1: Preparing kernels at final ripening stage to perform the hardness test

oil palm fruit under compressive loading of a cylindrical probe with a soft tip. (Diameter = 6 mm, tip thickness = 3.2 mm, and tip elasticity = 3.27 MPa). Rubber was selected for the probe tip because it has a high degree of elastic deformability and can achieve constant contact with the fruit at lower load. Fruit firmness was determined by using an Instron Universal Testing machine with a cylindrical probe of 6 mm in diameter at 25ºC (Plate 2). The oil palm fruit was loaded in a horizontal position. For analyzing the contact between the probe and the fruit, the oil palm fruit was assumed to be ax symmetric with respect to the contact center .The individual oil palm fruit was compressed at three locations of bunch (a) top section, (b) middle section and (c) bottom section as shown in (Fig. 1).

The oil palm fruits were taken from each stage of maturity (8, 12, 16 and 20 weeks after anthesis) for mechanical properties. The compression was started at the preset condition until rupture, occurred in the force-deformation curve. The rupture force was taken as the maximum peak force, which required rupturing the peel of the fruit. Also hardness test on kernel's shell was done by removing the kernels from oil palm fruit in final ripening stage (20 weeks after anthesis) to finding the kernel's resistance to break (Plate 3).

Palm fruit oil extraction: In doing this study, 20 fruits samples were pulled from each region of two bunches (total of 60 samples) on eight year- old of oil palm tree during the ripening stages. The samples were weighed, chopped and dried under 70ºC for a day to remove the water in the fruits. The dry nuts and mesocarp were weighed and blend to get particle. The Oil was extracted in soxhlet extractor available at MPOB oil analyzing lab using chemical solvent namely hexane.

RESULTS AND DISCUSSION

Results of mechanical properties tests on oil: Palm Fruits during the ripening process:

Crushing strength: The different parts of bunch showed a complete significant difference for Crushing Strength of fruits. Mean value of Crushing Strength at the bottom part of bunch (closest part to the stem) was more than middle and top parts, so they showed a significant difference for this quality. The least value of Crushing Strength was related to the samples of top part of bunch with 178.2 N. This index for middle part was 193.1 N and for bottom part was 223.4 N (Fig. 2).

Crushing Strength at the bottom part of bunch is more because of lower ripening rate in this part, so that fruit-ripening process in bunch proves this subject. During fruit growth until ripening stage in bunch, at first the fruits in top of bunch start to ripen and then the fruits closer to the stem or bottom part of bunch will be ripened. Different sampling times have significant influence on Crushing Strength. By passing of time from 8 weeks to 12 weeks and then 16 weeks, this value of index showed a significant increase, so that value of 96.2 N in 8 weeks increased to 258 N in 12 weeks and to 342.2 N in 16

Plate 3: Removing the kernels from oil palm fruit in final ripening stage (20 weeks after anthesis) to investigate of hardness test on kernels

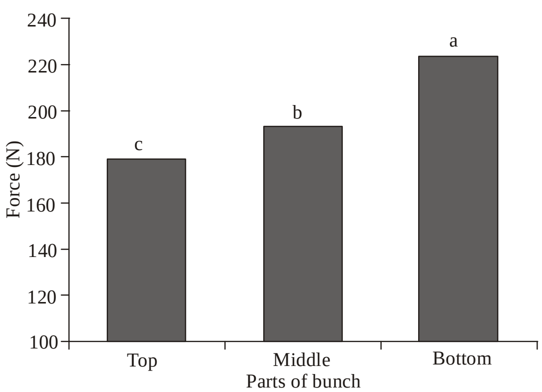

Fig. 2: Mean values of different parts of bunch for crushing strength, different letters indicate the values differ significantly ($p<0.05$), n = 27 for each region

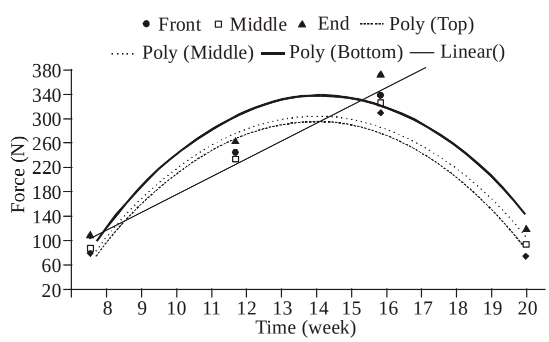

Fig. 3: Effects of sampling time and parts of bunch on crushing strength ($p<0.01$), n = 27 for each region

weeks; but it had downward movement, and in 20 weeks it was decreased again significantly (Fig. 3).

During four sampling times e.g. 8, 12, 16 and 20 weeks, value of this index for bottom part of bunch was more than top and middle parts. Maximum difference between these three parts was shown from 12 to 16 weeks. Maximum slope of force increase can be taken place from 8 to 12 weeks and maximum decrease of slope can be taken place from 16 to 20 weeks. Regression model for affects of ripening stage on value of Crushing Strength showed that changes of this index for top, middle and bottom parts of the bunch followed a quadratic function and showed a curved form; so the quadratic regression equation $y = a+bx+cx^2$ shall be used to explain the changes of Crushing Strength by passing of ripening stage. Maximum regression coefficient (R^2) for changes of Crushing Strength at top part of bunch was 94.9%, for middle and bottom parts it was 91 and 89%. These high coefficients showed that above equations have estimated the above changes accuracy. Calculation of regression coefficients showed that maximum time (X_{max}) for top, middle and bottom parts of bunch was 7.1, 7.16 and 7.24, respectively from starting of sampling coincide with 14.1 week, 14.16 week, 14.24 week from beginning of anthesis. So based on these findings, maximum value of Crushing Strength for these three parts was 302.1, 319.3 and 355.8 N, respectively.

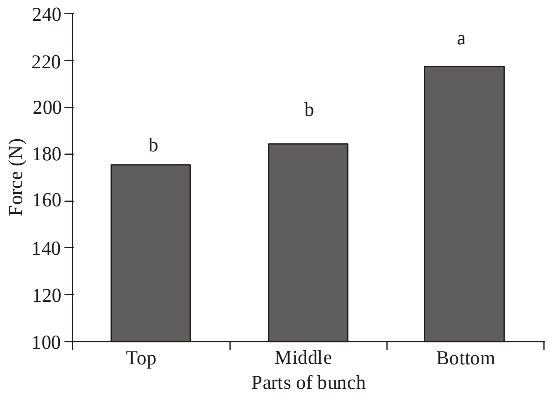

Fig. 4: Mean values of different parts of bunch for compressive load, different letters indicate the values differ significantly ($p<0.05$), n = 27 for each region

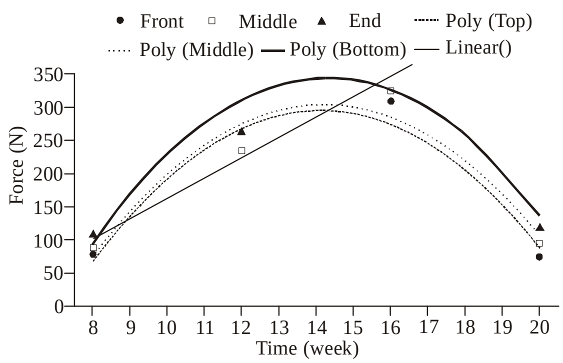

Fig. 5: Effects of sampling time and parts of bunch on compressive load ($p<0.01$), n = 27 for each region

On the other hand, from fruit growth (8 weeks after anthesis) to 16 weeks after anthesis there was a linear relation among Crushing Strength and Time as $y = 122.97x-13.784$ and it showed that intensity of increasing the Crushing Strength was 122.97 N per week. After 16 weeks, the changing process had downward movement.

Compressive load at break point: The results of Data Variance showed that there was a significant difference between different parts of bunch for compressive load required for fruit crushing. Maximum load for fruits at bottom part of bunch was 216.5 N that in comparison with least value of this load in top part of bunch (174.3 N), it showed increase of 24.2%. There was an insignificant difference among both top and middle parts of bunch for break load of fruit. Ripening process of fruits in bunch verifies this subject. During periods of growth until ripening of fruits in bunch, at first the fruits in top parts of bunch start to ripen and the fruits closer to stem or at bottom part of bunch will be ripened later (Fig. 4).

Different sampling times had a significant effect on compressive load required for crushing of fruits. Least mean value of this index was 91.32 N in 8 weeks that had not a significant difference with sampling care in 20 weeks. By passing of time from 8 weeks to 16 weeks the compressive load was increased significantly but from that time until bottom of ripening stage, this index showed an intense reduction (Fig. 5). Changes of compression load were similar for every three parts of bunch and followed a curve form.

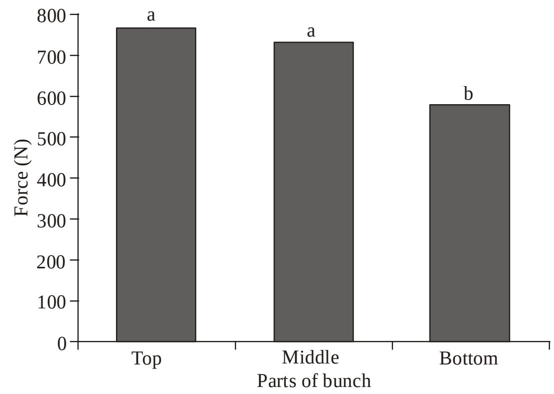

Fig. 6: Mean values of different parts of bunch for crushing strength at ripening stage, different letters indicate the values differ significantly ($p<0.05$), n = 27 for each region.

By passing of time from fruit growth, the value of compressive load was increased till 16 weeks significantly, but after that, it had a downward movement until bottom of the period.

Mechanical tests on ripened fruit: To review and compare of mechanical properties of kernel and mesocarp of fruits in the different parts of bunch at bottom of growth and ripening stage (20 weeks after anthesis), a Split Plot Plan in accidental Blocks Form by three frequencies was used. The main factor includes top, middle and bottom parts of bunch and secondary factor includes two parts of fruit (mesocarp and kernel).

Crushing strength: The results of data variance showed that in ripening stage there is a significant difference between different parts of bunch for Crushing Strength. Maximum mean load was 773.6 N for fruits of top part of bunch but there was no significant difference among this part and middle part of bunch. Minimum crushing Strength was 578.2 N at bottom part of bunch; but there was an insignificant difference among this part and middle part (Fig. 6).

Also there was shown a significant difference between two parts of fruit for Crushing Strength. Value of this load was 96.4 N for mesocarp and 1296 N for kernel (Fig. 7).

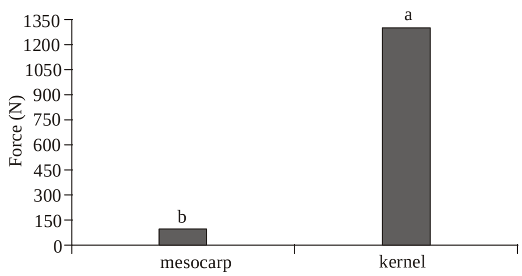

Fig. 7: Mean values of different parts of fruit for crushing strength in the ripening stage, different letters indicate the values differ significantly (p<0.05)

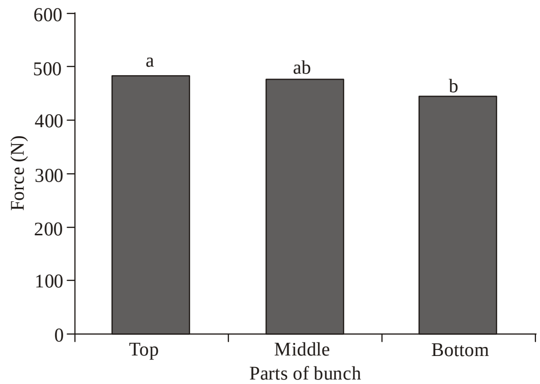

Fig. 8: Mean values of different parts of bunch for compressive load at break point in the ripening stage, different letters indicate the values differ significantly (p<0.05), n = 27 for each region

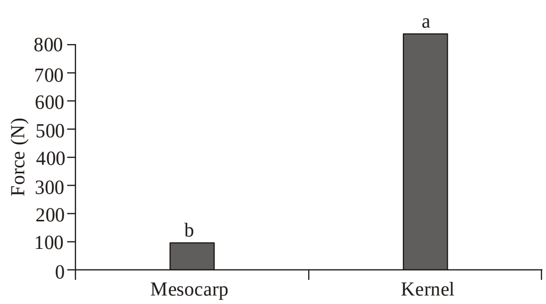

Fig. 9: Mean values of different parts of fruit for compressive load at break point in the ripening stage, different letters indicate the values differ significantly (p<0.05)

Compressive load at break point: The difference between different parts of fruit at ripening stage was significant for compressive load at break point. The top part of bunch had the maximum compressive load at break point equal to 487.5 N, although there was no significant difference with middle part of bunch. Minimum compressive load was 445.1 N at bottom part of bunch related to formed fruits (Fig. 8). Also, there was a significant difference among mesocarp and kernel for compressive load at break point. This load was 96.41 and 835.8 N, respectively (Fig. 9).

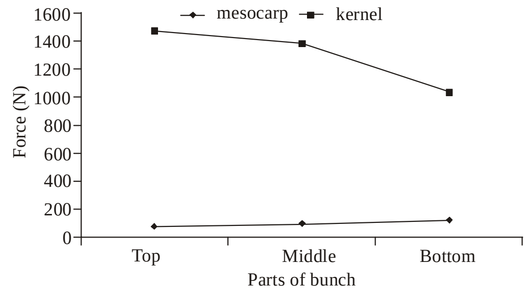

Fig. 10: Effect of different parts of bunch and different parts of fruit (mesocarp and kernel) on crushing strength

Interaction of two cares was insignificant and showed that the changes of required load at break point of kernel and mesocarp were not influenced by place of fruit in bunch. On ripening stage, there was a significant difference between different parts of bunch for mean time of break point. Mean time of break point was varied from 37.4 S at top part of bunch to 40.06 S at bottom part of bunch. However, there was no significant difference among top and middle parts of bunch or among middle and bottom parts of bunch. Also a significant difference between kernel and mesocarp was achieved for time of break point. This index was 37.2 S for mesocarp and 39.8 S for kernel. Interaction among different parts of bunch and sampling times was not significant of the point of this view and showed that time changes till crushing for fruits on different parts of bunch during the time passing are similar (Table 1).

So Minimum crushing strength related to mesocarp of fruits in top part of bunch (A1B1) was 74.9 N and Maximum crushing strength for fruits kernel in top part of bunch (A1B2) was 1472 N (Fig. 10).

Results of palm fruit oil yield analysis: The results of data variances 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 top 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 bottom part of bunch that was 0.921 g that it was 6.50% less than top part of bunch. A fruit oil yield is equal to: oil percent multiply by total weight. Therefore, according to higher significance quality of total fruit oil yield at top part of bunch, oil yield was significant in this part in comparison with other parts. Sampling time has a significant affect 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.

Currently, because of non-formation of kernel into the fruit and the first growth stages, fruit oil yields were very low like as fruit weight. But by continuing the fruit

Table 1: Mean of squares comparisons for crushing strength, compressive load at break point and time at break point

Treat	Mean of squares		
	Crushing strength(N)	Compressive load at break point (N)	Time at break point (sec)
Parts of bunch (A)			
1) Top	773.6 a	487.5 a	37.4 b
2) Middle	736.9 a	465.7 ab	38.1 ab
3) Bottom	578.2 b	445.1 b	40.06 a
Parts of fruit (B)			
1) Mesocarp	96.4 b	96.41 b	37.2 a
2) Kernel	1296.02 a	835.8 a	39.8 b
A×B			
A1B1	74.9 c	74.9 b	37.3 b
A1B2	1472 a	900 a	37.6 b
A2B1	94.03 c	94.03 b	36.5 b
A2B2	1380 ab	837.4 a	39.7 ab
A3B1	120.4 c	120.3 b	37.8 b
A3B2	1036 b	770 a	42.2 a

Different letters indicate the values differ significantly ($p<0.05$)

Table 2: 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	A1B1	0.006 e	0.006 f	-	100 a
× Time	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	0.005e	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

MOY: Mesocarp Oil Yield; TFOY: Total Fruit Oil Yield; Different letters indicate the values differ significantly ($p<0.05$)

growth, there was a significant increase on total fruit oil yield so that in care of 12 weeks after anthesis the total fruit oil yield was reached to 0.083 g and in care of 16 weeks after anthesis it was reached to 0.244 g. Maximum total fruit oil yield at bottom part of ripening stage (20 weeks after anthesis) was 3.48 g (Fig. 11).

These changes followed an exponential function. Compare of mean interactions between different parts of bunch and sampling times showed that total fruit oil yield followed an exponential function at top, middle and bottom parts of bunch. However, this process was similar for these three bunches and had not any significant difference (Table 2).

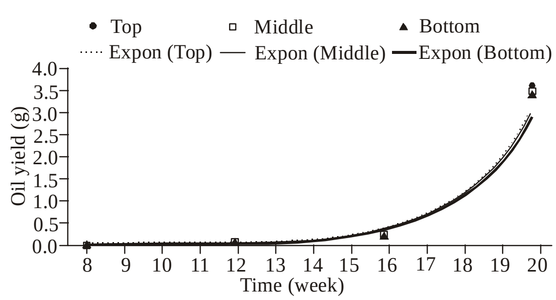

Fig. 11: Effect of sampling time and parts of bunch on total fruit oil yield ($p<0.01$), n = 27 for each region

Mesocarp oil yield: Difference between 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 top part of bunch but this difference was insignificant among these parts with fruits of middle part of bunch. Minimum mean of mesocarp oil yield was 0.672 g related to fruits at bottom part of bunch that in comparison with top part of bunch it was decreased about 12.8%. Higher rate of mesocarp oil yield at top 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 0.005 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 2.61 g that were coinciding with time of maximum fruit weight and mesocarp (Fig. 12).

Regressive analysis of these changes, by passing of time, showed that this process followed an exponential function. Interaction between 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 eight weeks after anthesis until bottom of ripening stage and these changes were similar for these three parts. 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.

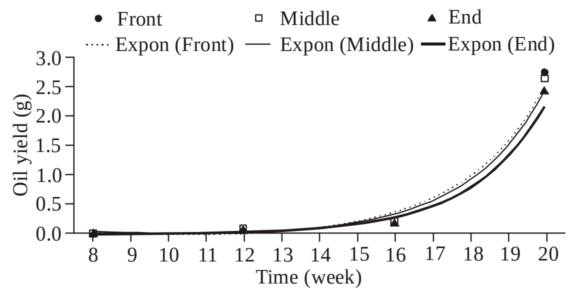

Fig. 12: Effect of sampling time and parts of bunch on mesocarp oil yield ($p<0.01$), n = 27 for each region

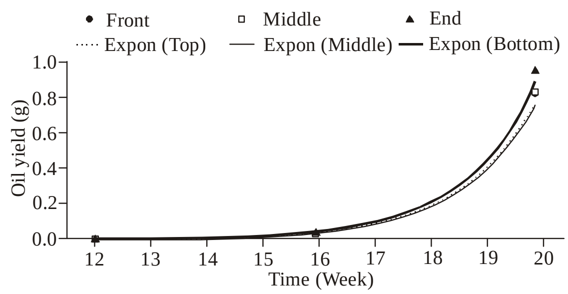

Fig. 13: Effect of sampling time and parts of bunch on kernei oil yield ($p<0.01$), n = 27 for each region

Kernel oil yield: Between the different parts of bunch there was a significant difference on aspect of kernel oil yields. As what we saw in mesocarp yield, kernel oil yield at bottom 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 0.331g for fruits at top part of bunch in comparison with bottom part of bunch it was increased about 15.73%. According to higher kernel oil yields at top part of bunch and results of measuring of total fruit oil yield mean that showed preference of top part of bunch on aspect of oil yield and preference of fruits in this part on aspect of mesocarp and kernel oil yields the significance of fruits in this part was for the sake of determination of final fruit yield in comparison with middle and bottom parts. Sampling time influenced kernel oil yield. In care of 8 weeks after anthesis, because of non-formation of kernel, total fruit yields were belong with 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 weeks (0.034 g) and 20 weeks (0.832 g) after anthesis was significant (Fig. 13). In general, increase of fruit oil yield during growth period was arising of contemporary and significant increase of kernel oil yield and mesocarp. Interaction between different parts of bunch and different sampling times on kernel oil yields was became insignificant and showed that the changes of kernel oil yields on different times after anthesis was not influenced by different parts of bunch and these changes are similar for three parts. Analysis of regression model of kernel oil yield during different parts of bunch showed that this process followed an exponential function.

CORRELATION AND CONCLUSION

As we can see, by passing of formation period until bottom of growth, the number of qualities influenced on fruit oil yield and value of their correlation with oil yield was increased. During 8 weeks after fruit formation the number of qualities showed a negative and significant correlation with Crushing Strength (-0.979*) and Compressive load (-0.987*). The lack of significant relations among qualities with oil yield is because of placing fruit at the first formation stages and non-formation of oil. Liquid form of oil into fruits verified this subject. By passing of time and consistency of oil into the fruit during 12 and 16 weeks after anthesis despite of correlation increasing, there was a negative correlation among Crushing Strength (-0.995* and -0.986*) and Compressive Load (-0.897*and -0.982*) with oil yield.

So in care of 20 weeks after anthesis, a negative and significant correlation was seen among oil yield with crushing strength (-0.998**) and Compressive load (-0.998**). (Abbas and Ali, 2009) reported textural analysis on oil palm fruit by food texture analyzer with a single bite P2 plunger probe 25 kg maximum force load cell gave the best results for the textural properties of the abscission and mesocarp layers where fracturability, hardness and adhesiveness were measured. On the other hand, double sub sequential compression bites of a 75 mm platen, again using a 25 kg maximum applied force, was best for the textural properties of the kernel shell nut where hardness and cohesiveness were measured.

Currently, this research experimentally still conducting with mechanical characteristic response of FFB from oil palm tree to finding the best relationship between firmness and oil development with difficult to recognize the fruit maturity process. Theoretically the FFB will take 22 weeks to ripe from pollination process (Haniff and Roslan, 2002). God willing later the robust equation will develop between relationships of mechanical properties of FFB and oil content to realize the development of real time maturity prediction device.

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