International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 1
ISSN: 2088-5334

Effects of Ripening Level and Processing Delay on the Characteristics of Oil Palm Fruit Bunches

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***Abstract*—Palm fresh fruit bunches (FFBs) are raw materials used in CPO mills and produced by palm oil plants. The nature and quality of these raw materials considerably affect the characteristics of the crude palm oil (CPO). The characteristic of crude palm oil (CPO) can be affected by freshness level, ripening of palm fruit bunches, growing sites, poor transportation and harvest and postharvest systems. Amongst the aforementioned factors, the major problems that occur frequently are the ripening level and processing delay of palm fresh fruit bunches (FFBs) and also brondolan (loose fruits from bunches). Harvested FFBs must be optimally ripened to achieve high oil content and must be immediately taken to the factory for processing. Accordingly, the present study aims to evaluate the characteristics of palm oil produced at different ripening levels and processing delay times of palm fruit bunches from oil palm plantations in Ungaran, Central Java, Indonesia. The objects of this research are ripening level (underripe, ripe, overripe and brondolan) and processing delay time (12, 36 and 60 h). Results show that the ripening level and length of processing delay of palm fruit bunches can affect the deterioration of bleachability index (DOBI) value, free fatty acid (FFA) content, oil content, peroxide value (α = 0.05) and profile of fatty acid composition. A long processing delay increases FFA content and peroxide value, but decreases DOBI value and oil content. From the observed parameters, the best results are found on ripe FFBs with a processing delay time of 12 h. The results are still good at 36 h but deteriorated after 60 h.**

***Keywords*— processing delays; ripening level; fresh fruit bunches; brondolan**

I. INTRODUCTION

Palm fresh fruit bunches (FFBs) are raw materials used in CPO mills and produced by palm oil plants. The nature and quality of these raw materials considerably affect the characteristics of the palm oil they contained and their products (e.g. CPO) [1]. Although the quality of FFBs which will be processed into CPO can be influenced by on-farm, harvest and postharvest activities, including storage time and processing delay time [2,3], the nature of raw materials and palm oil is closely related to quality components, such as free fatty acid (FFA) content, oil content, deterioration of bleachability index (DOBI), peroxide value and fatty acid composition. After being harvested, fruit bunches still undergo respiration and physiological activities that can cause changes in the chemical content of palm oil in the mesocarp. In addition, the condition of underripe, ripe and overripe FFBs and loose fruit bunches can affect components that are related to the quality of palm oil. The components of CPO include FFA content, oil content, DOBI, peroxide value and fatty acid composition, which are parameters for determining the quality of the contained oil. A poor transportation system can delay processing in a palm oil mill for up to 3 days [4-7]. The nature of palm oil is influenced by the age of a plant, the place where it grows and the fruit ripening level.

Harvested FFBs must be optimally ripened to achieve high oil content and must be immediately taken to the factory for processing. In accordance with a 2018 Ministry of Agriculture decree, FFBs must be processed after harvesting for a maximum of 24 h [8]. In reality, however, some companies harvest FFBs that are still underripe and processed them by cooking and brewing. Moreover, processing delays after being harvested for more than 24 h or even 2–3 days are due to various factors, including transportation, waiting to meet the capacity and damage to palm oil mill machinery. These factors affect the characteristics and quality of the produced palm oil , such as changes in fatty acid composition due to oil damage caused by oxidation and hydrolysis [9-11].

Palm oil is composed of saturated and unsaturated fatty acids [12] [6]. Palmitic fatty acid ($C_{16}H_{32}O_2$) comprises the highest amount of fatty acids in CPO, followed by oleic fatty acid ($C_{18}H_{34}O_2$), and small amounts of stearic (C18H36O2), myristic ($C_{14}H_{28}O_2$) and linoleic ($C_{18}H_{32}O_2$) fatty acids [2]. Unsaturated fatty acids are easily oxidised by oxygen to produce hydroperoxide compounds as the primary result; when damage, they will continue to form FFAs [2,3,13]. Transportation delay and FFB bruising will accelerate oil damage, decreasing its quality. Accordingly, the current research aims to assess the effects of the ripening level of FFBs, i.e. underripe, ripe, overripe and brondolan (i.e. loose fruits from bunches) and processing delay times, i.e. 12, 36 and 60 h, on characteristics of crude palm oil.

II. Materials and Methods

Palm FFBs harvested from oil palm plants (age: 12 years old) in Ungaran Plantation, Central Java, Indonesia, at different ripening levels (underripe, ripe, overripe and brondolan) were used as research materials. The following criteria were adopted for ripening levels: underripe (no brondolan), ripe (brondolan 1–2 fruits/kg FFB), overripe (brondolan 3–4 fruits/kg FFB) and brondolan (loose fruits from bunches) [9][2]. A completely randomised design with two factors was used in this study. The first factor was the ripening level of FFBs, namely, underripe, ripe, overripe and brondolan. The second factor was the processing delay time of FFBs, namely, 12, 36 and 60 h. FFBs and brondolan were placed in open space for processing delays. Subsequently, oil extraction was conducted to analyse oil content [14], DOBI, analysed from palm oil samples dissolved in n-hexane in a 25 ml measuring flask and diluted to the mark. Furthermore absorbance was tested using a UV spectrophotometer at 446 nm with 269 nm. DOBI is the ratio of absorbance values at 446 nm to 269 nm [15], fatty acid profile in the analysis using modified AOCS,2003 method, by preparing 2 mL of sample methylated with BF3-methanol complex as much as 400 µL in a closed tube. The mixture is heated for 2 hours at 90OC. The methyl ester from the fatty acid residue was extracted with 500 µL hexane and divortex for 1 minute to extract FAME. Furthermore, FAME of 0.3 ul is injected into GCMS. Fatty acid composition (relative percentage) was identified based on molecular weight using GCMS-QP2010S Shimadzu with an Rtx 5 MS column which was set at 50^{o}C and held for 5 minutes, then raised to 260^{o}C at 5OC/min and held for 30 minutes. carrier gas: Helium [14], FFA ontent with the titration method [14] and peroxide value with the titration method[14]. The oil extraction method presented in [14] was modified; fruit bunches were extracted, crushed with a digester and continued crushing with a hydraulic press until oil was obtained. Then, 1:1 hot water (water dilution) was added to the pressed oil. Thereafter, the pressed oil was filtered and precipitated. The oil at the top was collected for analysis. The data obtained were statistically analysed using SPSS version 25. In particular, analysis of variance (ANOVA) was performed, followed by a post hoc test (Duncan's test at 5%).

III. Results and Discussion

The research and data analysis results of each observation parameter are presented in Table 1. These results indicated that ripening level and processing delay time significantly affected DOBI, FFA content, oil content and peroxide value based on ANOVA.

TABLE I

Effect Of Ripening Level And Processing Delay To Dobi, Ffa Content, Oil Content And Peroxide Value Of Crude Palm Oil

Treatment Level of Ripening	DOBI	Free Fatty Acid (%)	Peroxide Value (meq/kg)	Oil Content (%)
Under-ripe	2.31 ± 0.36^a	2.00 ± 0.21^a	1.57 ± 0.32^a	35.36 ± 2.33^a
Ripe	3.44 ± 0.71^b	3.01 ± 0.63^b	1.88 ± 0.46^b	52.14 ± 2.93^b
Over-ripe	2.98 ± 0.88^b	3.72 ± 0.60^c	2.19 ± 0.40^c	50.49 ± 2.62^c
Brondolan	2.21 ± 0.32^a	6.25 ± 1.05^d	2.59 ± 0.35^d	49.48 ± 3.17^d
Processing Delay (hours)				
12	3.03 ± 0.80^a	3.17 ± 1.34^a	1.71 ± 0.40^a	49.81 ± 7.31^a
36	2.76 ± 0.81^{ab}	3.60 ± 1.64^b	1.92 ± 0.40^b	47.07 ± 7.10^b
60	2.42 ± 0.64^{bc}	4.47 ± 2.00^c	2.53 ± 0.42^c	43.72 ± 6.76^c

As shown in Table 1, the highest DOBI values were found in ripe FFBs and a significant effect was observed after processing was delayed for 60 h. The highest FFA levels were found in brondolan and a significant effect was observed after processing was delayed for 12, 36 and 60 h. The highest oil levels were recorded in ripe FFBs, and delays at 12, 36 and 60 h exerted a significant effect. Peroxide presented the highest values in brondolan, and a significant effect (α = 0.05) was observed at delay times of 12, 36 and 60 h. The discussion for each observed parameter is presented as follows.

A. Deterioration of bleachability index (DOBI)

DOBI is an indicator of damage to oil or fat, and it illustrates the power of bleaching oil or fat. When the value is high, oil quality is good. The highest DOBI value (Table 1) for the ripening level of FFB factor was obtained in ripe FFBs, followed by in overripe FFBs, underripe FFBs and brondolan. Meanwhile, when the processing delay was long, the DOBI value was small. This finding showed that oil damage in ripe FFBs can be controlled by the presence of natural antioxidants found in oil in the form of tocopherol and vitamin A components, which come from carotene.

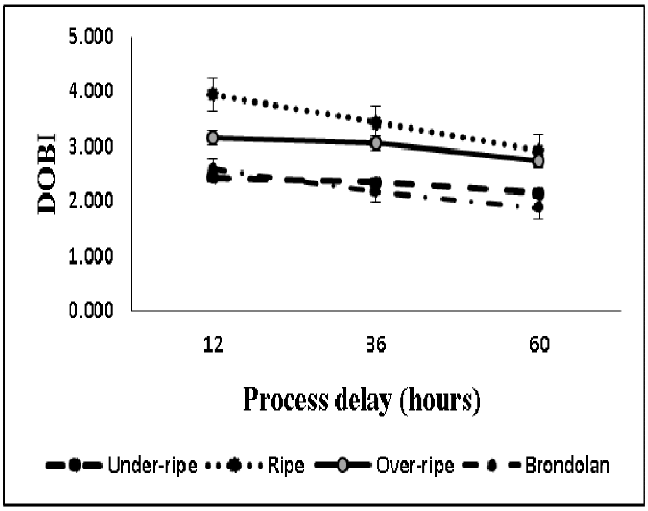

Fig. 1. Relationship of DOBI values with the processing delay and ripening level of FFBs.

The DOBI values of palm oil are as follows: bad (1.68–2.30), sufficient (2.31–2.92), good (2.93–3.24) and very good (>3.2) [16]. In ripe FFBs, the DOBI values were very good (3.435), the damage level was low, and the bleaching process was easy. A long processing delay corresponds to a small DOBI value (Table 1). This result indicated that oil damage due to oxidation or hydrolysis is greater. The processing delay times of 12 h (3.03) and 36 h (2.76) had no significant effect on the DOBI value; however, a significant effect was noted after 60 h (2.42), as shown in Table 1. From the DOBI value for the interaction between ripening level and processing delay length, ripe FFBs clearly had the highest DOBI value during processing delay. Moreover, all ripening levels decreased during processing delay. The decline in the DOBI value of palm oil occurred due to oil damage, which could be caused by oxidation and hydrolysis [17]. Processing delays decrease the quality of palm oil [11] [18]. Figure 1 shows that the highest DOBI value was observed in ripe FFBs, but it also exhibited the fastest decline rate.

B. Free Fatty Acid (FFA)

One of the indicators of palm oil quality is FFA content. As shown in Table 1, the effect of the ripening level factor was the highest on the FFA content of brondolan (6.248), followed by those of overripe, ripe and underripe FFBs (in that order). A significant influence was found based on Duncan test's (α = 0.05). Similarly, the processing delay factor exerted a significant effect on Duncan's test (α = 0.05).

Brondolan had the highest FFA content, and a long processing delay increased FFA content. The high FFA content of the ingredients was due to the considerable amount of oil damage primarily caused by the hydrolysis of lipase enzyme activity. For the ripening level factor, the highest oil damage was found in brondolan; therefore, the FFA content was also higher than those in overripe, ripe and underripe FFBs. Meanwhile, the accelerated oil hydrolysis process with the lipase enzyme activity was also higher to produce high FFA content due to a long processing delay (60 h) [19][20][21]. High FFA content indicated considerable damage to palm oil.

The minor components of palm oil can also experience certain changes [22]. The presence of Ohmic influences can also cause changes in the quality and quantity of palm oil [23][5]. The riper the palm fruit, the higher the lipase activity. The hydrolysis process will also increase, which is marked by an increase in FFA content. A palm fruit that has been separated from its bunch and came in contact with air can cause damage to oil either by hydrolysis or oxidation, increasing FFA content. Table 1 clearly shows that during processing delay, all treatment levels increased fatty acid content, with brondolan achieving the highest. This result showed that damage to oil is due to the rapid hydrolysis process [24][25]. High FFA content indicated the damage degree to the hydrolysis of palm oil in the material. Fig. 2 presents the highest FFA content in brondolan, and processing delay became longer due to hydrolysis damage. Free fatty acid quality standards in Indonesia and Malaysia a maximum of 5% special grade maximum of 2.00-2.50%. Based on the results of the best research TBS is ripe (3.01%) and the process delay is 12 hours the best results but the process delay is up to 60 hours the results of FFA levels are still standard (4.47%) Fig.2 also clearly shows FFA content at the ripening level and process delay, and the highest FFA content was observed in brondolan This happens because the longer the processing delay the hydrolysis reaction the longer the contact between water, oil and lipase enzymes so that the free fatty acids produced are higher Likewise for brondolan because it has already begun the hydrolysis process and is faster which produces the highest free fatty acids.

C. Peroxide value (PV).

Oil damage due to the oxidation process, including those on oil palm commodities, is known as peroxide value. A high value leads to considerable damage. For the ripening level factor (Table 1), the highest peroxide value was found in brondolan (2.59 meq/kg) The maximum PV standard is 2 meq/kg. This factor also exerted a significant effect (α = 0.05) on overripe, ripe and underripe FFBs. Similarly, the length of processing delay (12, 36 and 60 h) had a significant effect, and the highest peroxide value recorded at 60 h was 2.53 meq/kg. In the formation of peroxide and hydroperoxide in palm oil, as evidence of the oxidation and degradation of palm oil, a high peroxide value indicates high oil oxidation, which is the beginning of the rancid process [26][10].

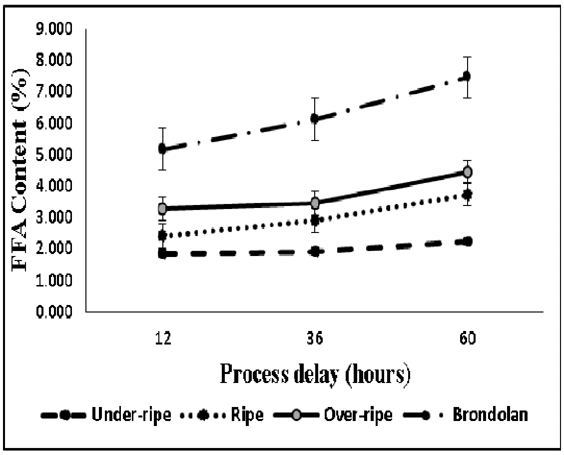

Fig. 2. Relationship of FFA content with the processing delay and ripening level of FFBs.

Damage to palm oil by oxidative degradation results in ever-increasing peroxide and hydroperoxide in stored palm fruit [27], a poor management system also increases oxidative damage to palm oil [33]. An increase in peroxide number indicates oxidation damage to the oil is getting higher [20] [22].

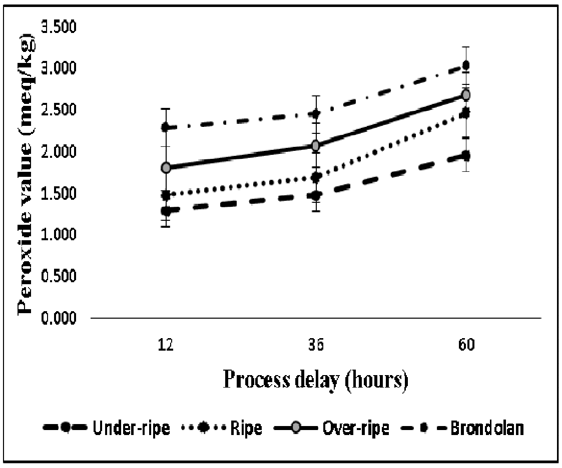

Fig.3. Relationship of peroxide value with the processing delay and ripening level of FFBs.

As shown in Fig. 3, the longer the processing delay at all ripening levels, the higher the increase in peroxide value. However, the highest peroxide value is infeasible

D. Oil content

The ripening level (Table 1), i.e. underripe, ripe, overripe and brondolan, and the time processing delay times of 12, 36 and 60 h exerted a significant effect (α = 0.05) on palm oil content. The difference in oil content can be due to various factors, including oil formation in the mesocarp not being maximised and oil loss during postharvest. After being harvested, FFBs still experience physiological processes, namely, the respiration process and the occurrence of microbial activities and lipase enzymes that utilise oil. Consequently, oil content decreases.

As shown in Table 1, processing delay reduced oil content and the highest oil content was found in ripe FFBs [8]. The oil content of the mesocarp reaches the maximum under optimal chemistry. The highest oil content is generally found in palm fruits that have ripen optimally physiologically, i.e. 5–6 months after pollination [29][17]. After harvesting, palm fruit bunches will still undergo chemical and biochemical processes, resulting in a decrease in quality and quantity, including oil content.

The ripening level of palm fruits can be related to colour; the more mature the oil content, the higher the ripening level [30][31][32]. Figure 4 shows the highest oil content in ripe fruits; the oil content decreases as processing delay is prolonged.

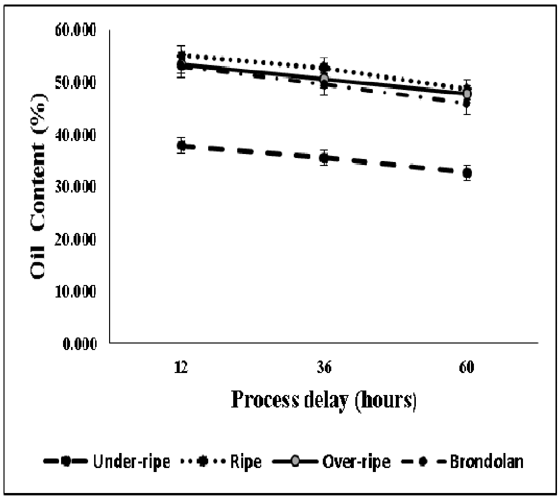

Fig. 4. Relationship of oil content with the processing delay and ripening level of FFBs.

E. Fatty acid profile

The ripening level of FFBs and the different processing delay times changed the profile of fatty acids, as seen from the percentages in Table 2.

As indicated in Table 2, the highest composition was noted in the percentage of palmitic acid, followed by oleic acid; ripe FFBs had the highest percentage. A change in fatty acid indicates that a decrease in the percentage of certain fatty acids will be followed by an increase in the percentages of other types of fatty acids. Such decrease occurs more quickly in fatty acids with double bonds (e.g. oleic and linoleic).

The percentage of fatty acid composition in palm oil can be affected by ripening level and oil damage. The primary component of fatty acids in palm oil is palmitic acid, followed by oleic, linoleic, myristic and stearic acids [12][6][21]. The amount of palmitic acid is the highest amongst the components of palm oil, but it can change in percentage due to maturity, ripening and processing. Therefore, changes in the percentage of fatty acid composition in palm oil can occur on-farm and off-farm.

Changes in fatty acid profile can occur due to chemical and biochemical processes in the formation and damage of fatty acids [33].

Damage to unsaturated fatty acids due to oxidation likely causes changes in the relative percentage of fatty acids in palm oil. During hydrolysis, oils or fats are converted into FFAs and glycerol due to the role of water and lipase enzymes.

The results of such reaction can cause rancid hydrolysis, which produces a rancid flavour and odour. In oxidation damage, if contact occurs between oil and oxygen with the formation of peroxide and hydroperoxide, then the subsequent release of fatty acids is accompanied by the conversion of hydroperoxide to aldehyde, ketones and FFAs. Rancidity is formed by aldehyde and not by peroxide [10][34]. Consequently, oil damage can also affect other components of palm oil [21].

Figs. 5a, 5b, 5c. shows the relative percentage change in the composition of five types of palm oil fatty acids (myritic, palmitic, linoleic, oleic and stearic acids) at various ripening levels and processing delay times. These changes are due to oil damage caused by hydrolysis and oxidation in saturated or unsaturated fatty acids.

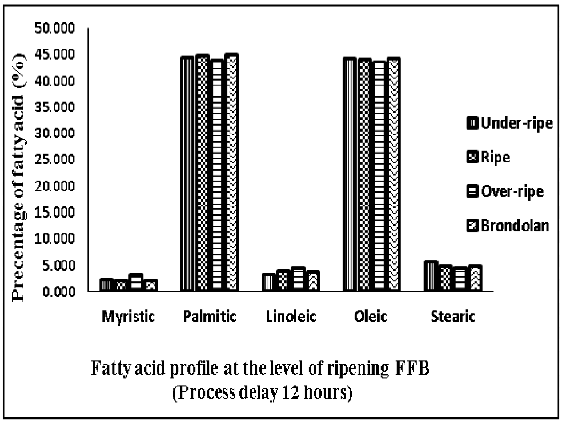

Fig. 5a. Relationship of the ripening levels of FFBs and processing delay times of 12 h with the profile of palm oil fatty acids.

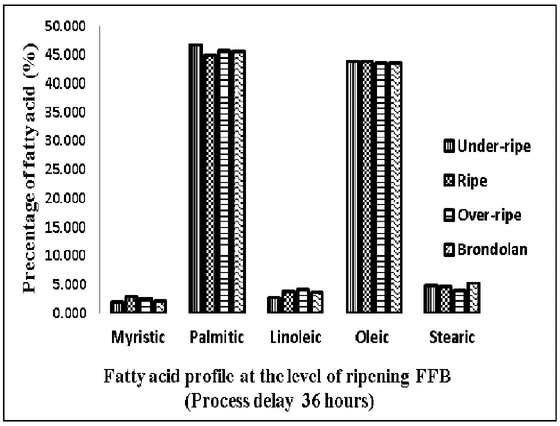

Fig. 5b. Relationship of the ripening levels of FFBs and processing delay times of 36 h with the profile of palm oil fatty acids.

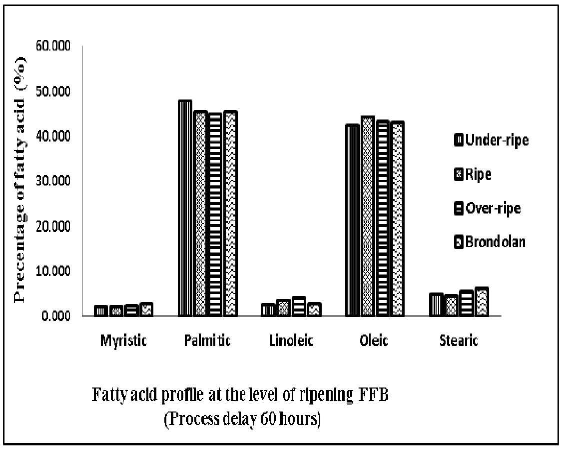

Fig. 5c. Relationship of the ripening levels of FFBs and processing delay times of 60 h with the profile of palm oil fatty acids.

Changes in the level of fatty acids presentation (relative percentage) both in the ripening levels of FFBs and processing delay times of the oil palm fruit bunches and brondolan, because the oxidation process in unsaturated fatty acids (Linoleic and oleic) and continues with the auto-oxidation reaction, while the saturated fatty acids (myristate, palmitate, stearate) mainly begin with hydrolytic damage involving water and lipase enzymes, resulting in a decrease in the amount of fatty acids, but because the composition of fatty acids is calculated based on relative percentages so the results seem fluctuating.

IV. CONCLUSION

The ripening level and processing delay time of FFBs affect the characteristics of existing palm oil. The results of the present study shows that the maturity level of oil palm fruit bunches affects DOBI, FFA content, oil content, peroxide value ($\alpha = 0.05$) and the relative percentage of fatty acid composition. A long processing delay decreases DOBI value and oil content, increases FFA content and peroxide value and causes a change in the relative percentage of fatty acids. Ripe FFBs exhibit the best maturity level, and the produced palm oil remain in good condition after a processing delay of 36 days based on the observed parameters.

ACKNOWLEDGMENT

The authors would like to express their gratitude to DRPM DIKTI for providing funding for this research under the scheme of Penelitian Disertasi Doktor (Number: 719/UN27.21/PN/ 2019).

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