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Oil Extraction and Quality Stability of Crude Palm Oil Derived from Ripeness Variations of Palm Fruits

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ABSTRACT

Oil content increases during the ripening (maturity) process of fresh fruit bunches (FFB) which is characterized by color change and fruit detachment from the bunch. Based on ripeness level, oil palm FFB are classified into three, namely unripe, ripe, and over ripe. One problems at the palm oil mill (POM) is that selection of FFB is conducted manually. This research aimed to evaluate the effect of variations in palm fruit maturity level milled in POM on the crude palm oil (CPO) yield and quality as well as its oxidative stability and color. Four treatments based on maturity The research results showed that the variation in palm fruit maturity used resulted in the highest yield, namely 17% in P2. The quality of crude palm oil obtained from variations in fruit maturity shows different results, where the highest free fatty acid content of 2.57% is located in P2, namely a mixture of ripe and overripe fruit, while the highest water content is found in P2, namely 0.65 %. P3 has the highest impurity content of 0.68%. The oxidative stability and color obtained from using variations in fruit maturity that were heated for 24 h decreased in value to red and yellow.

1. INTRODUCTION

Oil palm is an attractive plant. Oil palm plantations are growing and spreading throughout Indonesia, both owned by companies and individuals. Oil palm plants produce fresh fruit bunch (FFB) as their main product. Processing FFB produces vegetable oil extracts consisting of crude palm oil (CPO) which comes from the mesocarp, and palm kernel oil (PKO) which comes from the endocarp of the palm fruit. The level of CPO continues to increase during the fruit ripening process (Sujadi *et al*., 2019). The level of fruit maturity is a very important factor in determining the quality of the fruit. Maturity and ripeness are different terms. Fruits consumed by the public, such as tropical fruit, are often mature when picked but not yet ripe. The fruit will ripen after undergoing the ripening process and then become damaged or rotten. Ripeness indices can include hardness, color, and size (Sari *et al*., 2019).

The quality of the FFB received from oil palm plantations influences how well palm oil mills (POM) can extract the oil. Even though POMs cannot create yields, they help the extraction process to obtain good yield. The FFB processing produces a lot of CPO. The quality of FFB affects the amount of CPO produced (Rangkuti & Wahyuni, 2019). Enzymatic processes can increase FFA levels in FFB. FFA levels will increase if the oil palm fruits are harvested overripe or if the fruits are handled improperly. These factors affect CPO productivity and directly reduce the quality of CPO with a high FFA content (Nainggolan, 2021).

High FFA (>3%) occur due to hydrolysis by lipase enzymes and oxidation in oil palm fruit. This process results in high levels of free fatty acids and water, which can damage the quality of CPO produced from FFB processing

(Harahap *et al*., 2020). High free fatty acids are precursors in oil damage and accelerate the oxidation process which results in color damage and causes rancidity. The physico-chemical properties of palm oil include color, odor, flavor, solubility, melting point, polymorphism, boiling point, flash point and fire point, iodine number, and saponification number. These properties can vary depending on the purity and quality of palm oil (Sitompul, 2014).

Based on the explanation above, this study aims to evaluate variations in the ripeness level of oil palm fruit to be processed in a palm oil mill (POM) in relation to CPO yield and quality. The results are expected to provide an appropriate FFB blend formulation based on fruit condition and ripeness level.

2. MATERIALS AND METHODS

2.1. Materials and Tools

This research was carried out in the quality laboratory at the Indonesian Palm Oil Institute (ITSI). Analytical test for free fatty acid (FFA) content, peroxide value, oxidative stability and color stability of crude palm oil were performed in the yield and quality processing laboratory of Indonesian Oil Palm Research Institute (PPKS). Raw materials in form of fresh fruit bunches (FFB) were harvested from ITSI oil palm plantation. The oil palm trees used as research samples ranged in age from 5 years to 10 years (mature plants). The harvested FFB was classified as unripe, ripe, over ripe fruit, and bruised fruit as depicted in Figure 1. Unripe oil palm fruit is described as FFB whose outer fruit has not yet loose off, while ripe fruits have the outer palm fruit bunch 2-10 loose beans. The mature fruit is a palm fruit bunch whose outer part has already formed more than 20 fruit stalks. Meanwhile, injured fruit is a palm fruit bunch that has bruises and wounds on the outside of the fruit. The equipment used in this research included analytical balance and glassware.

2.2. Design of Experiment

This research was carried out using FFB composition simulated to represent the use of variations in fruit maturity levels in palm oil mills (POMs) which often occur. Fruit composition described the level of maturity and condition of the fruit, namely unripe, ripe, over ripe, and bruised fruits (Figure 1). All treatments were carried out with three replications and using 10 kg fruits for each experimental unit. Four treatments of FFB compositions based on maturity level and condition included P1 (5 kg unripe + 5 kg ripe fruits); P2 (5 kg ripe + 5 kg over ripe fruits); P3 (5 kg ripe + 5 kg bruised fruits); and P4 (2.5 kg unripe + 2.5 kg ripe + 2.5 kg over ripe + 2.5 kg bruised fruits).

Figure 1. Oil palm fresh fruit bunches: (a) Unripe, (b) ripe, (c) overripe, and (d) wounded fruit

2.3. Research Procedures

Oil palm FFB was harvested from experimental plantation of ITSI, Medan. The FFB. Four fruit compositions (P1, P2, P3 and P4) were prepared for experiment. The process of boiling the palm fruit bunches was done by steaming them using a steamer until the inside of the fruit buds. The extraction process was carried out using a hydraulic press so that the crude palm oil can be extracted optimally. Where the loose skin has been peeled, it is put into a white cloth, after entering it, it is tied and the extraction process is carried out. When the cloth is placed under and pressed using hydraulics, oil will come out of the cloth and then it will be collected using a bottle. Purification of the extracted oil was carried out using a centrifuge to separate the liquid phase and the solid phase in the extracted oil. Testing the quality of crude palm oil included analyzing free fatty acid content, peroxide value, oxidative stability, color stability.

2.4. Measurement

2.4.1. CPO Yield

Crude palm oil yield was analyzed using the SNI 2901-2021 method. Fresh fruit bunches (FFB) or loose palm fruits were weighed (kg) before processing. After the extraction process, the resulting CPO was weighed (kg). The yield value was calculated using the following formula:

$$Yield = \frac{CPO\ (kg)}{FFB\ (kg)} \times 100\% \quad (1)$$

2.4.2. Fatty Acid Analysis of Crude Palm Oil

Free fatty acid (FFA) levels were analyzed using the method (SNI 2901-2021). The resulted CPO sample was weighed (*W*) using a digital analytical balance. It was then placed in a 250-ml Erlenmeyer flask and 15 ml of hexane (C_6H_{14}), 10 ml of 96% alcohol (C_2H_6O), and 5 drops of phenolphthalein (pp indicator) were added. The solution was then titrated using a burette containing 0.1 N potassium hydroxide (KOH) solution until the solution changed color. The volume of KOH solution used was recorded (*V*). The *FFA* content was then calculated using the following formula:

$$FFA = \frac{25.6 \times V \times 0.1}{W} \quad (2)$$

2.4.3. Impurity Analysis

Impurity levels were analyzed using the SNI 2901-2021 method. Approximately 5 grams of the sample was weighed (*Z*) and the results recorded. Then, weigh the filter paper (Z_1) and cup before use and record the results. Afterward, dissolve the sample in 100 ml of n-hexane until boiling and then filtered it using filter paper. Then, place it in an oven for 1 hour at 105°C. Next, cool it in a desiccator and weigh the cup and sample after oven-drying (Z_2). Record the results after oven-drying. Impurity levels are calculated using the following formula:

$$Impurity = \frac{(Z2-Z1)}{Z} x\ 100\% \quad (3)$$

2.4.4. CPO Oxidative Stability Analysis

The oxidative stability of CPO was determined using peroxide value analyzed by heating the CPO for 0, 6, 12, 18, and 24 h at 100°C. Peroxide value analysis was based on the AOCS Cd-8b-90 method that detects all oxidizing agents of potassium iodide (KI) under acidic conditions. Around 5 g CPO sample was weighed (*W*) and placed in a 250 ml Erlenmeyer flask. As much as 30 ml of acetic acid and chloroform solution was added in a ratio 3:2. Then 0.5 ml of saturated KI solution was added and let stand for 1 min, then mixed thoroughly. The formed iodine was titrated using a standard sodium thiosulfate solution ($Na_2S_2O_3$) with starch as indicator till the blue color disappeared. The volume (*S*) and normality (*N*) of $Na_2S_2O_3$ was recorded and the peroxide number was calculated as follows:

$$Peroxide\ Number = \frac{S \times N \times 1000)}{W} \quad (4)$$

2.4.5. CPO Color Stability

Color stability analysis was performed using a Lovibond Tintometer according to the AOCS Official Method CC 13e-92. The crude palm oil was heated for 0, 6, 12, 18, and 24 h at 100°C. The crude palm oil sample was placed in a measuring glass cell and the readings were taken according to the limits specified in the instrument instructions. The glass cell containing the crude palm oil sample was placed in a light cabinet near the observation tube. The color of the crude palm oil was measured using a color rack with a yellow to red ratio of 10.

3. RESULTS AND DISCUSSION

3.1. Yield of CPO

The variations in fruit maturity and condition used in the research were unripe, ripe, overripe, and bruised fruits. The effect of fruit composition on the yield for CPO is presented in Figure 1a. It shows that treatments affected the CPO yield. The CPO yield ranges from 9.5% with fruit composition P1 (unripe + ripe), to 17% with composition P2 (ripe + overripe). The ideal yield for CPO is around 20-23% of the processed FFB. The results of the ANOVA show that the

F-count value is 10,092, higher than F-table values of 4.07 at a significance level α = 5% and F-table of 7.59 at α = 1%. Therefore, the fruit composition resulted in a very significant difference on the CPO yield. In this case, fruit composition consisted of ripe and overripe (P2) produced the highest yield of 17%. Meanwhile, fruit composition P1 (unripe + ripe) resulted in the lowest CPO yield. The oil content in fruit depends on the ripeness, where the maximum will be gained if the fruit is completely ripe, and the lowest will be resulted from unripe fruit (Islamiah *et al*., 2021).

The yield of CPO and kernels are greatly influenced by the percentage of mesocarp and oil per fruit as well as the percentage of seeds and kernels per bunch. Thick mesocarp tends to contain high oil content. However, the oil content of a bunch is influenced by the weight of the bunch and the loose fruit beans. Ripe fruit tends to produce higher CPO yields than unripe and overripe fruit. The increase in CPO yield from unripe to ripe fruits is caused by process including fruit ripening, fruit enlargement, increase in mesocarp thickness, formation of seeds and kernels, as well as a decrease in water content (Sujadi *et al*., 2019). Uncollected loose fruits will cause oil and kernel loss in the plantation, thus decreasing the CPO and kernel yields from the bunches (Makky & Soni, 2014). High oil yields can be achieved through superior varieties, productive plant age (juvenile and mature), good technical culture, a suitable climate conditions that supports the oil palm growth, and harvesting the fruit at the right time of maturity and ripening (Hasibuan & Nuryanto, 2015).

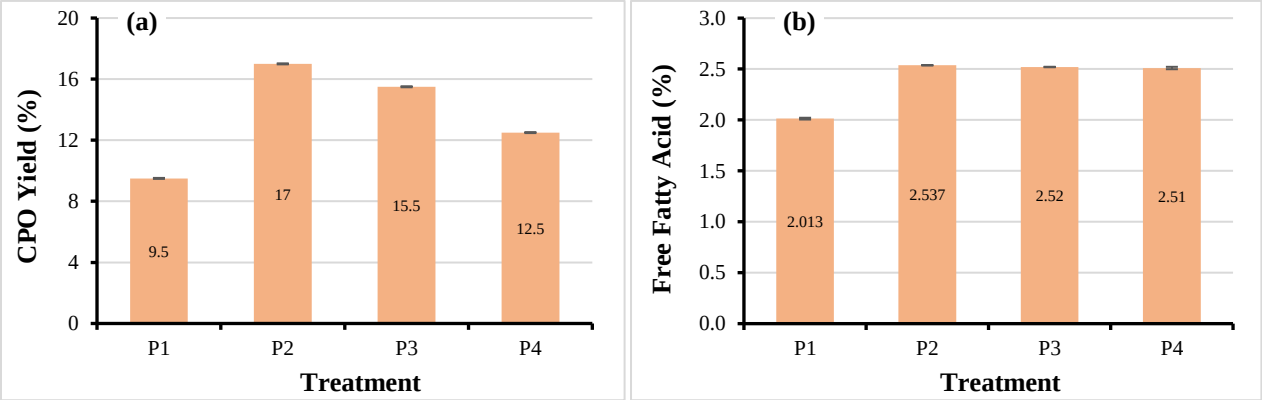

Figure 1. Effect of fruit mixture treatment on: (a) CPO yield, and (b) Free fatty acid content

3.2. FFA Content of the CPO

Figure 1b shows the FFA content in the CPO resulted from different fruit composition. The FFA content resulted from all fruit compositions are still below the SNI 2901: 2021 norm where the FFA value must be maximum 5%. Treatment P1 consisted of unripe and ripe fruits resulted the lowest FFA content with 2.013%, while P2 (ripe + overripe) produced the highest FFA value of 2.537%. Treatments consisting of overripe and bruised fruits (P2, P3, and P4) resulted in CPO with higher FFA content. This is in line with (Sirait *et al*., 2023) stating the higher the fruit ripeness fraction, the higher the FFA levels produced. The results of the ANOVA analysis show that the F-count value is 1144.71, higher than F-table which is 4.07 at α = 5% and F-table of 7.59 at α =1%. Therefore, there is a very significant difference in the FFA values due to variations in fruit ripeness.

Free fatty acid is one of the determinants quality of CPO, as dictated in the SNI 290: 2021, where the FFA content is maximum of 5%. Even so, the process of extracting oil from FFB should be performed to produce CPO with FFA content as minimal as possible. High levels of FFA indicate that CPO has a poor quality (Winardi & Prasetyo, 2022). According to Harahap *et al*. (2020), the high level of FFA occur due to hydrolysis enhanced by lipase enzyme. Lipase is a hydrolase enzyme that catalyzes the breakdown of fats. The hydrolysis process breaks down triglyceride (fat) molecules into smaller fatty acids and glycerol. Other factors that increase FFA content in the CPO include oxidation processes and water content. Therefore, FFA in CPO increase by the long storage of CPO. Harvesting time, fruit maturity, and the way to handle the fruit greatly influence the FFA level of the fruit. The FFA content will be higher in fruits that have been waiting for a long time for processing, overripe fruits, and bruised fruits.

3.3. Water Content of CPO

Figure 2a shows water content of the resulted CPO due to different fruit composition. It can be seen that water content of the CPO ranges 0.209% to 0.652%. The results of the ANOVA revealed F-count value of 7.417, which is higher than F-table value of 4.07 at α = 5%, but lower than F-table 7.59 at α = 1%. Therefore, the treatment of fruit composition influence significantly on the water content of the CPO. Treatment P1 constituting of unripe and ripe resulted in the highest water content in the CPO (0.652%), while P3 (ripe + overripe + bruised fruits) produced CPO with the lowest moisture content (0.209%). The standard SNI 2901: 2021 requests that CPO should contain moisture no higher than value of 0.5%. Therefore, only fruits composed of unripe and ripe (P1) produced CPO with moisture content surpass the standard norm.

Water content is one of the parameters used to determine the purity of an oil or fat and is related to its shelf life, odor, and taste. Water content significantly determines the quality of the oil or fat. Water content also plays a role in the oxidation and hydrolysis processes of the oil, which can ultimately lead to rancidity. The higher the water content, the more quickly the oil will go rancid (Nurfiqih *et al*., 2021). The ripeness level of the palm fruit and the fruit fractions with different levels of ripeness can affect the water content of the resulting oil because each level of fruit ripeness has a different percentage of water content in the fruit flesh (mesocarp).

The high water content in CPO can be caused by the level of fruit ripeness, as shown in Figure 2a, where the P1 fruit composition (unripe + ripe) yielded the highest water content compared to other treatments. The increase in water content can be influenced by the length of the sedimentation process and also the condition of the fruit, such as unripe, rotten, or damaged fruit (Yuniva, 2010). Damaged or rotten fruit during harvesting, as well as uncontrolled post-harvest processing, can increase the water content in palm oil fruit, which in turn can affect the quality of CPO (Harahap *et al*., 2020).

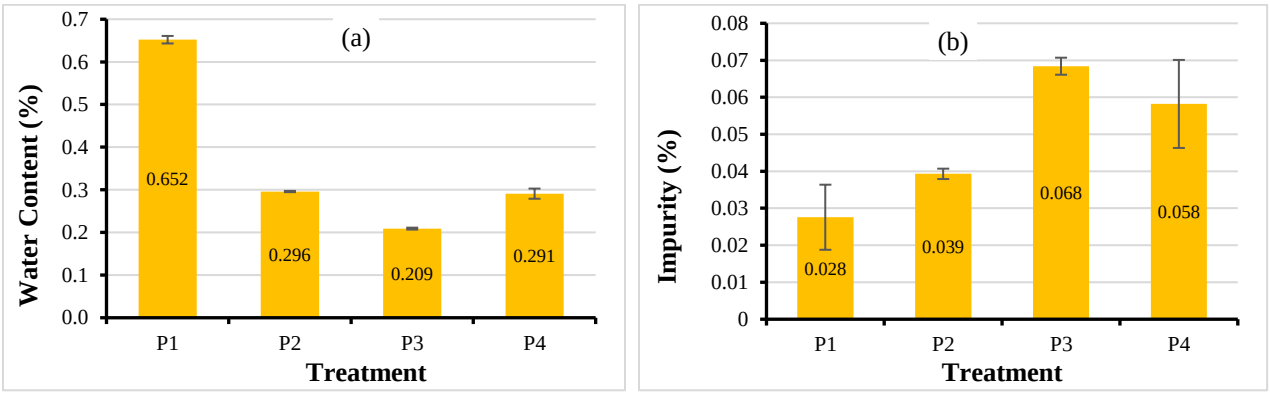

Figure 2. Effect of fruit mixture treatment on: (a) Water content of the CPO, and (b) Impurity of the CPO

3.4. Impurity Level of CPO

The levels of dirt and dissolved substances are all foreign materials that are not dissolved in the oil. Insoluble dirt is expressed as a percentage of dirt substances to oil or fat. The levels of impurities contained in CPO can come from shells, kernels, fibers, sand and other objects included in the oil (Maulana & Susanto, 2015). The impurity levels of the CPO obtained from variations in fruit composition are shown in Figure 2b. It shows the lowest impurity content, namely 0.0276% was resulted from P1 fruit composition (unripe + ripe), and the highest impurity content of 0.0684% was found in P3 (ripe + bruised fruits). The SNI 2901: 2021 standard limits the CPO impurity content of maximum 0.5%. When compared with the SNI standard, the level of impurities in the CPO produced in this research is very low. This was caused by the centrifugation process that was carried out so that dissolved and insoluble impurities were separated. The results of the ANOVA analysis show that the calculated F value is 7.417 with a 5% F Table value of 4.07 and a 1% F Table value of 7.59, so there is a significant difference between the impurity content due to variations in fruit composition. P3 and P4 resulted in the highest impurity content value due to the use of bruised fruit, which

causes the impurity content to be high. The higher the maturity level of the oil palm fruit, the higher the impurity content produced. This can be caused by greater fruit damage at higher maturity levels (Tambunan, 2022).

3.5. Oxidative Stability of CPO

The oxidative stability of the CPO resulted from variations of fruit composition was evaluated through peroxide number with heating at a temperature of 100 °C for 0 (zero) to 24 h (increment of 6 h). The peroxide value indicates the level of damage caused by oxidation. Therefore, the peroxide value and the oxidation stability of an oil have an inverse relationship: the higher the peroxide value, the lower the quality and oxidation stability of the oil. Good quality oil has a peroxide value close to zero. As shown in Figure 3, at 0 h of heating, all CPO resulted from different fruit composition showed a peroxide number of 0 (zero) meq/kg. The peroxide number of the CPO in general increase with the increase of heating duration. The Indonesia's standard SNI-3741–2012 (BSN, 2012) regarding the quality of CPO set at a maximum limit for the peroxide value of 1.6 meq/kg. Fruit compositions consisting of unripe fruits produce CPO with better oxidation stability. Meanwhile, overripe and bruised fruits tend to produce CPO with lower oxidation stability. Fruit composition P1 (unripe + ripe fruit) produces CPO with the lowest peroxide value, meaning it has the best oxidation stability. Even after heating for 24 h, the peroxide value is still below the SNI standard. Fruit composition P4 (containing 25% unripe fruit) also produces CPO with fairly good stability. After heating for up to 12 h, the peroxide value is still below the SNI standard. Conversely, fruit compositions containing overripe fruits P2 (ripe + overripe fruits) and damaged fruit P3 (ripe + bruised fruits) produce CPO with low oxidation stability. The CPO from P2 fruits has a peroxide value exceeding the SNI standard after heating for 12 h. Meanwhile, CPO from P3 fruit has a peroxide value exceeding the SNI standard even after heating for only 6 h. Overripe fruits stimulate the development of peroxide levels. Overripe and bruised fruits show an increase in enzymatic activity and lipid oxidation which causes an increase in peroxide values.

The results of the ANOVA show that the calculated F value for fruit composition factor is 2086.46, much higher than those of F-table value 2.84 (at 5%) and 4.31 (at 1%), so there is a very significant difference of the oxidation stability of the CPO due to the variation in fruit composition. The calculated F value for factor heating duration is 8744.42, higher than F-table value of 2.61 (at 5%) and 3.83 (at 1%), meaning that fruit heating duration very significantly influenced the peroxide number of the CPO.

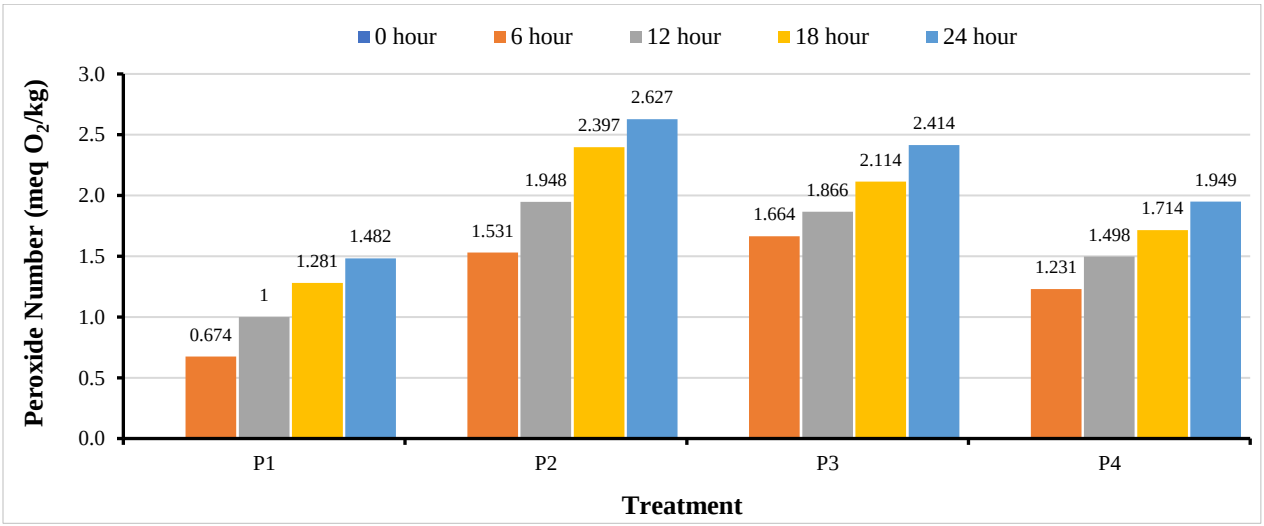

Figure 3. Effect of fruit mixture treatment on the oxidation stability of the CPO

The peroxide number is a quantitative measure of the peroxide of an oil or fat which indicates the level of oxidation that has occurred. The peroxide value increases with increasing fruit maturity. Unripe fruit to ripe fruit with 1-3 grains has a relatively low peroxide value (Sumarna, 2014) stating that oil containing unsaturated fatty acids can

be oxidized by oxygen to produce a peroxide compound. Measuring the peroxide value is basically measuring the levels of peroxide and hydroperoxide formed in the early stages of the fat oxidation reaction. A high peroxide number indicates that the fat or oil has undergone oxidation, but a lower number does not always mean that the oxidation state is still early. Considering that peroxide levels quickly degrade and react with other substances, fat oxidation by oxygen occurs spontaneously if fatty materials are left in contact with air, while the speed of the oxidation process depends on the type of fat and storage conditions (Rangkuti & Purwanto, 2020).

3.5. Color Stability of CPO

Color stability can be an indication of CPO quality. The red and yellow colors of CPO are assessed using the Lovibond Tintometer. The red and yellow colors of the CPO are natural pigments derived from carotenoids, and the measured R (red) and Y (yellow) values determine its quality. The higher the carotene content (especially β-carotene), the stronger the red and yellow colors in the CPO (Dewi *et al*., 2023). Figure 4 and 5 shows color stability for red and yellow, respectively, of the CPO obtained from different fruit composition heated at temperature of 100 °C for 0 to 24 h with 6 h increment. The red color of the CPO was initially in the range of 20 to 25. After heating at 100 °C the red color value decrease, and more with longer heating duration. This indicates a decrease in β-carotene content due to prolonged heating. Heating can cause color degradation, especially in reds. The percentage reduction in red color can reach 23.5 – 36.4% (Rangkuti *et al*., 2018).

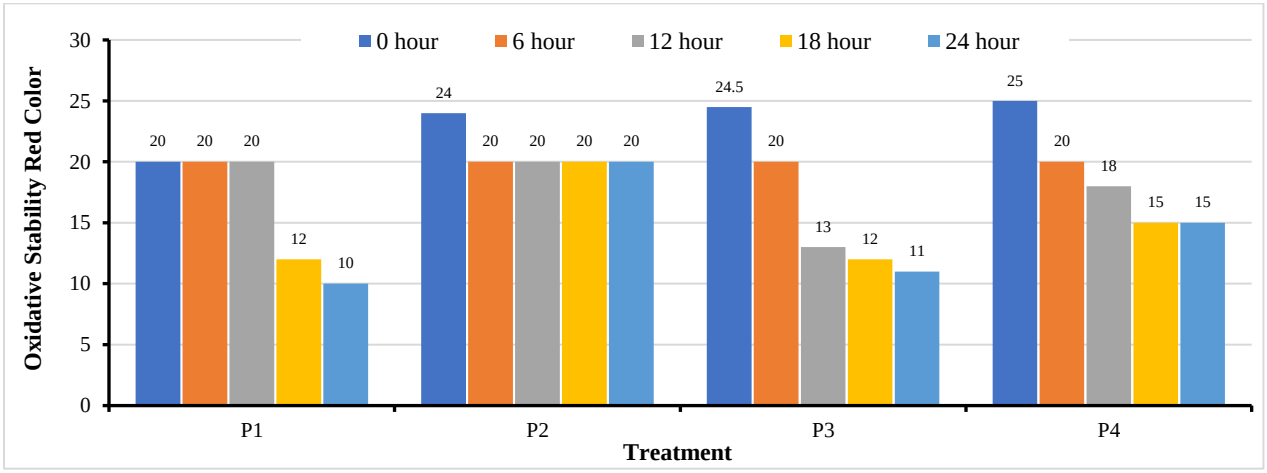

Figure 4. Stability of red color of the CPO from 100 °C heating duration for each treatment

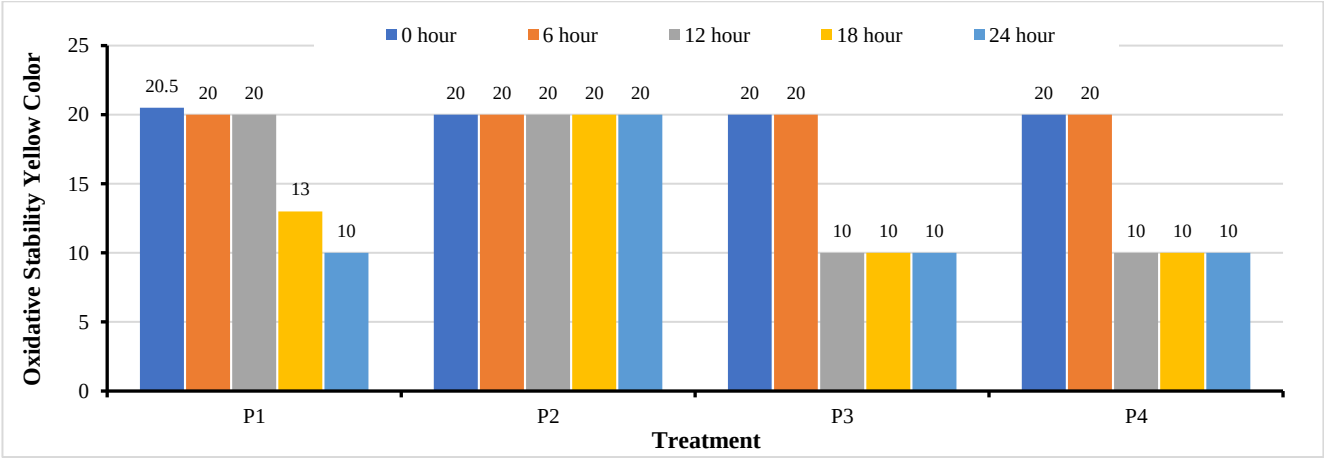

Figure 5. Stability of yellow color of the CPO with heating time of 100 °C for each treatment

The color quality of the CPO decreases due to the long heating time. The red color (Figure 4) of CPO from P1 was in the range of 20 (Red) at 0 -12 hours of heating, at 18 and 24 hours the color decreased to 10 (red). In the P2, the CPO was red with a value 24 and decreased to 10 after heating. The CPO from P3 decreased gradually the red value from 24.5 to 11 within 24 h heating. Similarly, the CPO from P4 fruits also decreased progressively from 25 (red) to 15 within 18 h. The longer the heating on CPO will cause the quality of the color to decrease due to the tocopherol being degraded by heat. Oxidation of tocopherol causes the red color to become pale. The higher the temperature and the longer the heating, the faster the tocopherol is degraded and the greater the color change. Low tocopherol levels will cause the red color to become less stable and change more easily. The higher the tocopherol content, the more stable the red color will be.

Palm fruit changes color during the ripening phase. Unripe palm fruit has a blackish purple color, turns to orange, and when ripe the fruit generally turns reddish orange, which is usually directly proportional to the carotene content (Rangkuti & Syahputra, 2019). The color of CPO analyzed using a tintometer has a yellow value of 20.5 and a red value of 25. Figures 5 show the yellow color of CPO resulted from variations of fruit composition. The yellow color in the P1 treatment was initially in the range of 20 (yellow) and decreased to 13 for 18 h of heating and then 10 for 24 h of heating. The second treatment was in the range of 20 (yellow). In the third and fourth treatments it was in the range of 20 (yellow) and decreased to 10 for 12 to 24 h of heating.

Crude palm oil or CPO has a red-yellow color indicating a high carotenoid content (Dewi *et al*., 2023). Apart from containing provitamin A, namely α-carotene, β-carotene and vitamin E (tocopherol and tocotrienol), palm oil also contains various other types of bioactive substances such as riboflavin, niacin, lycopene, minerals consisting of phosphorus, potassium, calcium, and magnesium (Sumarna, 2014).

4. CONCLUSION

Based on the results and discussions, conclusions can be drawn as follows:

1. Variations in palm fruit composition determine different CPO yields, where P2 (ripe + over ripe) has the highest yield value (17%) as compared to other treatments.
2. The quality of CPO obtained from variations in fruit composition shows different results, where the lowest free fatty acid content (2.014%) is resulted in P1 (unripe + ripe fruits), while the lowest water content of 0.209% is found in P3 (ripe + bruised fruits). The P1 fruit mix also resulted in the highest impurity content of 0.02970%.
3. Oxidative and color stability of the CPO obtained from variations of fruit maturity and condition that were heated for 24 h decreased. Unripe fruits tend to produce CPO with higher oxidative stability, while overripe and bruised fruits tend to produce CPO with lower oxidative stability.

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