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THE IMPACT OF CPO QUALITY BASED ON THE RIPENESS CRITERIA OF OIL PALM FRESH FRUIT BUNCH

Widya putriani[1], Muhammad Fuad Asrofillah[2]
[1,2]*Business Administration Department, State Polytechnic of Bengkalis, Indonesia*
widyaputriani996@gmail.com[1], fuadasrofillah@polbeng.ac.id[2]

Abstract

Crude Palm Oil (CPO) quality is primarily determined by the maturity level of the harvested Fresh Fruit Bunches (FFB). The ripeness level affects oil content, free fatty acid (FFA) concentration, moisture, impurity, and oxidative stability of the extracted oil. This study aims to analyze the influence of oil palm fruit maturity on CPO quality based on physicochemical parameters and to identify the optimal maturity stage that produces the best oil characteristics. The research was conducted on the Tenera variety using three ripeness categories: unripe, ripe, and overripe. Optical and fluorescence sensors were used to identify fruit ripeness non-destructively, followed by laboratory extraction and analysis of CPO. The results revealed that fruit maturity significantly influenced CPO quality. Ripe fruits yielded the highest oil content (24.5%) with FFA 1.5%, moisture 0.25%, DOBI 4.2, and carotene 720 ppm, whereas overripe fruits increased FFA levels (>3%) and reduced oxidative stability. These findings confirm that optimal ripeness produces superior CPO quality, while delayed harvesting or overripe fruits lead to degradation of oil properties. The study contributes novelty by integrating empirical and optical-based approaches to determine ripeness criteria that enhance both the yield and quality of CPO, supporting sustainable palm oil production.

Keywords: *Crude Palm Oil, Ripeness, Quality, FFA, Carotene*

1. INTRODUCTION

Oil palm (Elaeis guineensis Jacq.) is a strategic commodity in Indonesia that contributes significantly to the national economy through the production of Crude Palm Oil (CPO). The quality of CPO is greatly influenced by the condition of Fresh Fruit Bunches (FFB) at harvest, particularly their level of ripeness. According to research by Rangkuti et al. (2025) and (Akbar et al., 2023) variations in the ripeness of palm fruit—ranging from unripe, ripe, to overripe—cause significant differences in the Free Fatty Acid (FFA) content, moisture content, impurities, and oxidative stability of the oil produced. Proper fruit ripeness results in higher oil yields and better quality compared to unripe or overripe fruit.

Theoretically, the maturity level of palm fruit determines the physiological processes in the mesocarp, where there is an increase in oil content and a decrease in water content. Makky & Soni (2014) explain that during the ripening process, there is a conversion of triglycerides and carotenoids, which directly affects quality parameters such as color, Deterioration of Bleachability Index (DOBI), and oxidative stability. Research by Basyuni et al. (2017) reinforces this theory by showing that storage or delayed processing of fruit accelerates carotenoid degradation and increases the level of ALB (Free Fatty Acids), reducing the quality of CPO.

In recent years, non-destructive approaches such as optical properties (Rahmi et al., 2024), fluorescence spectroscopy (Phimpisan & Chungchoo, 2023), and computer vision and LiDAR (Goh et al., 2025) have been developed to detect fruit ripeness levels in real time. This technology utilizes color characteristics, reflectance, and texture to predict oil and carotene content in TBS without damaging the sample. The use of this method has the potential to overcome the subjectivity constraints in manual selection, which often reduces the consistency of raw material quality in factories.

However, most previous studies have only focused on measuring optical parameters or chemical content, with few directly linking maturity classification to the quality of CPO produced in the actual extraction process at palm oil mills (PKS). In fact, the empirical relationship between TBS classification and CPO chemical characteristics such as FFA,

moisture content, carotene, and DOBI is an important basis for controlling raw material quality and production efficiency (Sitorus et al., 2023).

This study is novel in that it integrates the criteria for palm oil fruit maturity with CPO quality parameters empirically and theoretically. This approach combines the results of previous optical and sensory-based studies with chemical quality data on CPO at the mill. The objective is to analyze the effect of fresh fruit bunch (FFB) maturity on CPO quality, including FFA, moisture content, impurities, DOBI, and carotene parameters, so that optimal harvesting and processing criteria can be formulated to produce the best CPO quality.

2. REVIEW OF LITERATURE

As a basis for our research, we summarized key findings from previous literature related to increasing the added value of local products in BUMDes, as described in the following subsections :

a. (Basyuni et al., 2017) found that optimally ripe fruit had the highest carotenoid and DOBI levels with the lowest FFA (≤1.5%), while overripe fruit increased FFA to >3%. Rangkuti et al. (2025) reported that a mixture of ripe and overripe fruit produced the highest yield (17%) but reduced color and oxidative stability.
b. (Akbar et al., 2023) used Partial Least Square (PLS) to predict oil and carotene content based on RGB and Lab* color values, resulting in an R^2 correlation of up to 0.93, indicating a strong relationship between ripeness and oil content. Phimpisan and Chungchoo (2023) used UV fluorescence technology (395–400 nm) to detect the maturity level of the Tenera variety with 100% accuracy, proving the reliability of non-destructive optical methods.
c. (Guspa et al., 2024) in a systematic review confirmed that the combination of LiDAR and computer vision is the most promising approach for real-time classification in field conditions. (Akbar et al., 2023) also emphasized the importance of optimal harvest time—up to 6 days after the first fruit falls—to maintain yield and reduce FFA formation. Research at PT Agricinal Bengkulu (Sitorus et al., 2023)shows that CPO quality is directly influenced by raw materials (FFB) and factory process variables.

3. METHOD

This study uses a descriptive-experimental quantitative approach, which aims to empirically analyze the effect of Fresh Fruit Bunch (FFB) maturity on the quality of Crude Palm Oil (CPO) produced. This approach was chosen because it is able to explain the relationship between physiological variables of the fruit (maturity) and the chemical and physical characteristics of the palm oil produced in a measurable manner. The research was conducted from May to August 2025 at two locations, namely the quality laboratory of the Palm Oil Research Center (PPKS) in Medan for CPO physicochemical testing and the Palm Oil Mill (PKS) in the Bengkalis region for the extraction process and fresh fruit sampling.

The samples used were from 8–12-year-old Tenera palm oil trees with uniform planting conditions. The fruit used was classified into three categories of ripeness: unripe, characterized by a dark purple exocarp color without loose fruit; ripe, characterized by a reddish-orange color and 10–50% loose fruit; and overripe, with more than 50% loose fruit from the bunch. Ten bunches were taken from each category as replicates, resulting in a total of 30 bunch samples tested.

To detect the level of ripeness non-destructively, an optical imaging system based on an RGB camera and Lab* color sensor is used, as well as a fluorescence spectroscopy device that utilizes eight UV LED lamps with wavelengths of 395–400 nm. Each bunch is scanned in a dark room to record the intensity of light reflected from the fruit surface. The data obtained is then analyzed using image analysis software to obtain color histogram values and brightness levels that describe the carotene and oil content in the fruit.

Next, each bunch was extracted to obtain crude palm oil using the solvent extraction method with n-hexane at a temperature of 60°C for 2 hours. The extracted oil was filtered and the solvent was evaporated before laboratory analysis. The CPO quality parameters tested included free fatty acid (FFA) content using the alkali titration method, moisture and impurity content using the gravimetric method, DOBI (Deterioration of Bleachability Index) using a UV-Vis spectrophotometer at wavelengths of 446 and 269 nm, and total carotene content measured with a spectrophotometer at 446 nm.

Data analysis was performed quantitatively by calculating the mean and standard deviation of each parameter at the three maturity levels. To determine the significant effect of maturity level on CPO quality, analysis of variance (one-way ANOVA) was used, followed by Duncan's Multiple Range Test (DMRT) at a significance level of 5%. This approach was used to ensure that the differences between maturity groups were actually caused by physiological factors of the fruit and not by random variability.

In addition, the relationship between fruit optical parameters (RGB and Lab* values) and oil quality parameters (FFA, DOBI, and carotene) was analyzed using linear regression analysis and Partial Least Square (PLS) models to determine how well the optical data could predict CPO quality. The results of data processing were presented in tables, graphs, and analytical descriptions. With a combination of optical observation, chemical extraction, and statistical analysis, this research method is expected to provide a comprehensive picture of how the maturity criteria of fresh palm oil fruit affect the quality of the CPO produced.

4. RESULT & DISCUSSION

The research results indicate that the maturity level significantly affects the quality of the resulting CPO. Ripe fruit yields the best results with an average yield of 24.5%, FFA of 1.5%, DOBI of 4.2, and carotene content of 720 ppm. Meanwhile, unripe fruit produces oil with low free fatty acid (FFA) content (0.9%) but a yield of only 18%. Conversely, overripe fruit increases FFA to 3.1% and lowers DOBI to 2.8, indicating high oxidative degradation.

These findings are consistent with the results of Rangkuti et al. (2025) and Basyuni et al. (2017), who stated that oil degradation occurs due to the activity of the lipase enzyme when the fruit is overripe or stored for a long time before processing. From an optical perspective, the Lab* value is directly proportional to the carotenoid content – the deep orange color of ripe fruit indicates higher carotenoid stability (Rahmi et al., 2024).

The UV fluorescence results show a clear difference in signal intensity between unripe and ripe fruit, proving the effectiveness of the non-destructive method (Phimpisan, 2023). This supports the idea of Goh et al. (2025) that computer vision-based combinatorial technology can replace manual field assessment.

Overall, this study proves that optimal maturity is the most critical factor in maintaining the quality of CPO, and the integration of non-destructive measurement methods can be a practical innovation in modern TBS assessment systems for the sustainable palm oil industry.

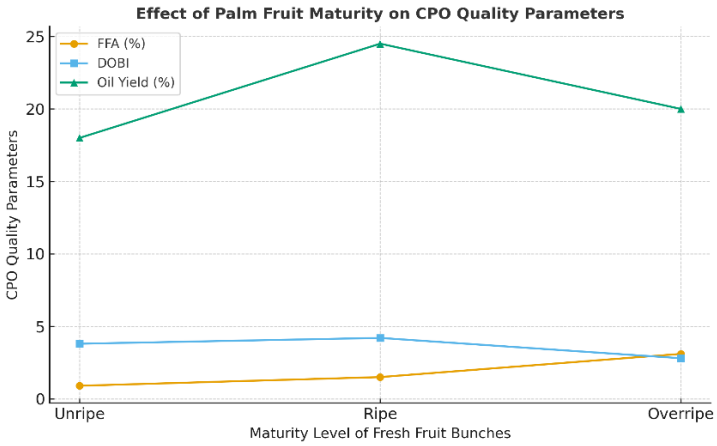


Fig. 1. The Effect Of Palm Oil Fruit Maturity On CPO Quality Parameters.

5. CONCLUSION

The results of this study demonstrate that the maturity level of oil palm fresh fruit bunches (FFB) has a significant impact on the physicochemical quality of crude palm oil (CPO). The research findings revealed that ripe fruits produced the most optimal oil characteristics, with the highest yield and carotene content, a low free fatty acid (FFA) level, and a high *Deterioration of Bleachability Index* (DOBI). In contrast, overripe fruits led to a notable increase in FFA and a decline in oxidative stability, while unripe fruits yielded low oil content despite having minimal FFA levels.

This study confirms that harvesting at the correct maturity stage is a critical factor in maintaining oil quality and processing efficiency. The integration of optical and fluorescence-based non-destructive technologies also provides a reliable approach to objectively classify FFB ripeness, reducing human error in manual grading systems.

In conclusion, optimal ripeness classification not only enhances the yield and quality of CPO but also supports sustainable palm oil production through improved raw material management and processing consistency. Further research is recommended to refine the integration of optical sensing and machine learning models for large-scale, real-time implementation in palm oil mills.

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