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Optical properties of oil palm Fresh Fruits Bunch (FFB) for optimum harvest-window prediction

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Abstract. Oil palm is among the strategic commodity of Indonesian agroindustry. The oil produced from the fresh fruits bunch through several steps of extraction process. The oil palm industry contributes to the advancement of country's economy, development and human resource. It provides job for more than 50 million Indonesian, directly or through secondary activities. Today, the industry needs to improved its efficiency, to address market competition and global demand. In the upstream region, oil palm plantation still practices outdated method, particularly harvest. Improper harvest decision contributes to national production loss of 15%. This study aimed to identify the optimum time for harvesting the oil palm FFB. When harvested on prime and optimum ripe, the FFB can yield 25-28% of oil extraction rate (OER), much higher than the current 18-20% nation-wide OER. While the FFB is commonly harvest according to its physical properties (fruits' colour and the number of loose fruits), the visual based observation is subjective and prone to influence by the mental state of the labour. Here, device which can identify the FFB true ripeness is needed to perform proper harvest when the FFB truly obtained its optimum ripe. Our previous studies suggest that, upon grading, the FFB quality can be identified by its optical properties. The same approach opens the possibility to be used when evaluating the FFB for harvest. In this study, the FFB colour model was established to identify the optimum harvest window of FFB under observation.

1. Introduction

The increase of Indonesia's palm oil production in 2017 by 11% is a consistent-achievement within the last 20 years [1-3]. With this increment-rate in the production output, Indonesia is estimated to be able to produce 40 million tons of CPO by 2020, and expected to meet more than 55 percent of world demand, which estimated at 180 million tons by the end of this decade [4-6]. Indonesia, as the lead producer in world palm-oil market-share, supported by various factors, among other are climate suitability, labour availability, and immediate reserve of 17 million hectares of arable land [3].

Currently, the area of oil palm plantations in Indonesia reached more than 12 million hectares [2]. Most of this land are owned by private companies and small-holder farmers. However, there are still some challenges that need to be addressed. The main focus of the problems in the national level is the weakness in sustainability aspect for the Indonesian oil palm industry. The main caused is identified as the chain of improper actions upon harvesting the fruits.

When determining the ripeness of oil palm fresh fruit bunches (FFB) for harvest, the observation commonly done manually, and, based on the observer knowledge and experience, the harvest then be determined. As a result, more than 15% of the FFB harvested at incorrect ripeness, and this potentially caused losses [7-9].

The FFB normally develop, after anthesis, for 110 days before the oil in the fruits' mesocarp start to form [10-13]. It required another 50 to 70 days until the oil in the fruits' mesocarp fully accumulated and the bunch ready to be harvested [10-13]. When the FFB cropped before it reached its full maturation, the oil in the mesocarp is not fully accumulate, yet. This will cause the oil extraction-rate of the FFB to be short, and the actual value of the FFB is less than expected. When combine with the total production at the national level, this improper harvest reduced the overall oil-palm productivity in Indonesia, and approximately cost the oil-palm industry USD 2.5 billion per annum [14-21].

Determining the optimum window-time for harvesting the FFB, based on its ideal oil content in the mesocarp had never been done before. In current practice, the FFB will be harvested if 2 – 20 of its fruitlets had been loosed or detached [22-25]. Based on our previous studies [26-53], this approach did not necessarily able to identify the correct window time for harvesting the FFB. In reality, this un-based standard more than often fails to harvest the FFB at the ideal state. Therefore, a new approach for identification of optimum window-time for harvesting the FFB need to be explored.

Based on the previous studies and findings [1-54], the optimum ripeness of the FFB can be determined correctly using devices such as digital camera [1-11], machine vision [12-37], spectrophotometry [38], photogrammetry [39-54], and thermography [55]. Furthermore, the oil content inside the mesocarp of the FFB can be determined correctly as well [14-22]. Yet, these studies examined the FFB after it had been harvested [28-54]. On the contrary, study report on FFB prior to harvest is still limited.

In this study, the optimum window time for harvesting the FFB was investigate. The observation done, using a machine vision system [14-22], by monitoring the FFB development, in particular its appearance, from the antheses, until the oil accumulates and saturate in the fruits' mesocarp. The output of this research will support the development of harvesting technology, including the determination of the optimum FFB harvesting time, FFB harvesting techniques, as well as technological innovation and mechanization in FFB harvesting. The outcomes of this study are expected to be a solution for the development of Indonesian oil-palm industry.

2. Materials and methods

The study was conducted in oil palm plantation in the West Sumatra province, Indonesia (0°19'57.8"N 99°22'57.1"E). The sample consist of 225 oil palm trees aged between 7 to 14 years, of the Tenera variety. The plants are from Marihat clone and cultivated in a controlled mono-culture condition. Fertilizer, pesticides, and herbicides were applied regularly according to the recommended dosages. Pruning, weeding, and harvesting were performed on regular basis to maintain the plants health.

For observation, the mantled pistillate flower in each plant was recorded daily using a machine vision [28-29], from the anthesis until the fertilized female flower turn into a cluster of fruit. The fruits cluster or fruits bunch then continually recorded, daily, using the same device, until harvest. An image processing software was developed to extract optical features of the fruits from the recorded image, and present the features in the value of red (R), green (G), blue (B), hue (H), saturation (S) and intensity (I) value with 0-255 scale [36-39]. Each value then plotted into a graph to show the change of appearance of the observed fruits bunch during development, ripening progress and until harvest.

In order to determine whether the oil content in the fruits already reached its peak, from the 100th day after anthesis was observed, three fruitlets from each observed fruit bunch, were sampled weekly. Its weight was recorded. The fruitlets then steamed according to the palm-oil sterilization process [51]. Then, the nut was separated from fleshly mesocarp, and the later part was weighed to determine the mass-ratio between fruit and the mesocarp. The mesocarp then dried in the oven (105°C) for 24 hours and re-weighed to determine its moisture content.

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A Soxhlet extraction method was performed to take the oil from the mesocarp. The extraction method follows [9, 18-22]. The obtained oil then weighed, and mass ratio between oil and fruitlets determined. The data then plotted into graph to profile the oil development in the fruit bunch from the formation of the fruit cluster until the bunch was harvested.

The optimum window time for harvesting the oil palm fresh fruits bunch (FFB) determined according to the oil content profile and the observation time.

Statistical engineering software was used to process the data. A regression line was used for each plotted feature value to explain the trend line between FFB development time and its optical features. A second regression line was set for each plotted feature's value to correlate optical features of the observed bunch with oil content. Coefficient of determination was used in each plot to measure how close the data were to the fitted regression line.

3. Results and discussion

The current practice for harvesting oil palm fresh fruit bunches (FFB) in Indonesia has caused a yield-gap between the ideal and the actual results. The oil palm productivity in Indonesia is still sub-optimum. The main caused was identified due to the method for determining the harvesting time of the FFB. It is a common practice to count the number of detached fruitlets for harvest decision of an observed FFB.

The number of detached fruitlets, though influenced by fruits metabolism and as an indicator of ripeness, may be accelerated due to external factors, such as wind, rain, animal disturbances, disease, and pests. As a result, most FFB harvested prior to reach its optimum ripeness. Thus, the yield of oil extracted from these FFB will be smaller than its potential. This research tries to understand how to identify FFB when it is reached its ideal ripening time.

Since human visual observation cannot correctly differentiate small change in appearance, a machine vision was used to record the FFB and extract its' optical features. The difference in features will explain if there was a change in appearance on the observed FFB. The aims were to correctly identify if the FFB under consideration has reached its optimum maturity, so when harvested, the oil can be obtained maximally.

Oil synthesis in a bunch continues for certain period even after the first fruits detached. The increase of oil in bunch cannot be explained simply by loss of moisture. Previous study has shown that maximum oil content in the bunch may not be reached until several hundred fruit have detached. Therefore, the optimum window time for harvesting the FFB will be a compromise between maximizing oil yield and minimizing loss of detached fruitlets.

Most normally-detached fruitlets content high oil concentration in its mesocarp. If this fruit is not collected, the total oil yielded from processing the FFB in the mills will be dropped.

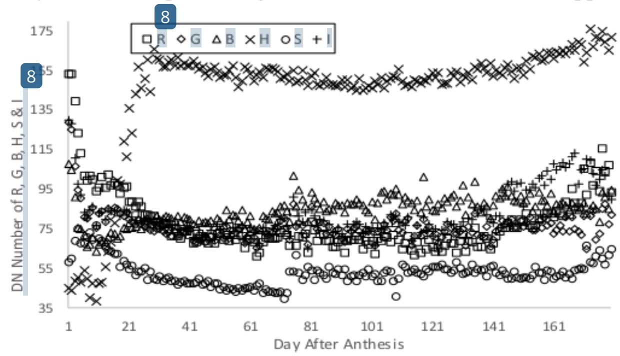

Figure 1. The Average Optical Features from 225 Observed FFB, from Anthesis to Harvest, observed for 180 days using a Machine Vision. The features expressed in the value of R, G, B, H, S, and I.

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In this study, a machine vision used to record the image of FFB, since the anthesis was observed on mantled pistillate flower, until the fertilized female flower turns into a cluster of fruit, and become fully ripe just before harvest. The recorded image then processed using an image processing software. The FFB appearance as recorded by the device is expressed into six measurable features in the value of red (R), green (G), blue (B), hue (H), saturation (S) and intensity (I). Each value has 0 to 255 scale. The data from 255 sample plants were plotted as shown in Figure 1.

While the data in Figure 1 do not immediately indicated a linear trend from each feature to the FFB development stage, it shown that for the first 25 days of observation, the value of R, G, B, S, and I constantly decrease, in opposite to the value of H. Afterwards, until day 73 all features value have small variation and all tend to decrease. A shift in value of R, G, B, S, and I were observed between day 73 to 77. In this stage, the size of fruits in the observed bunch significantly enlarge and the exterior colour of the fruits change toward purplish.

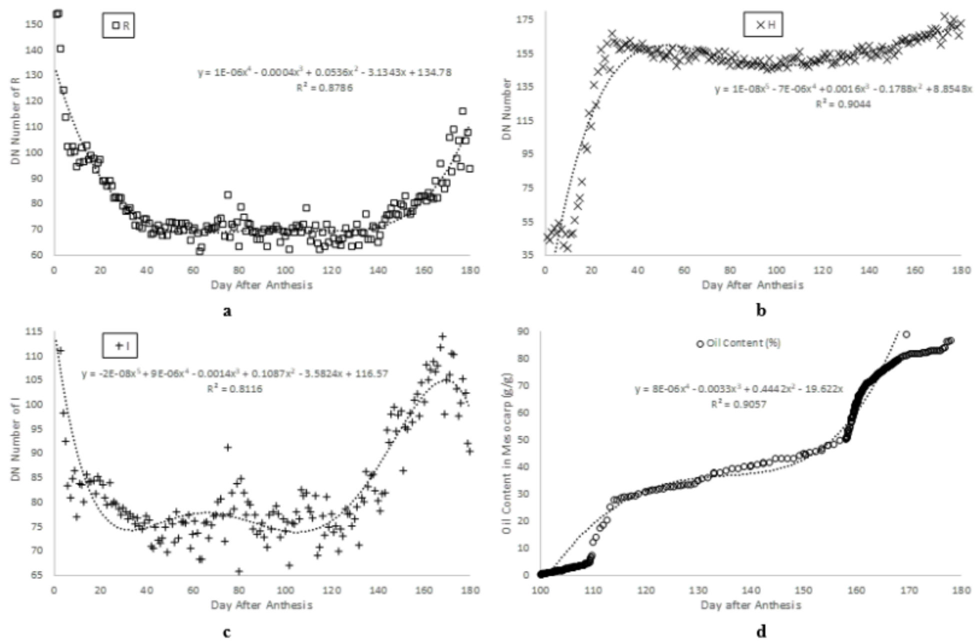

Figure 2. Three Optical Features from all Observed FFB, namely R (a), H (b), and I (c) correlate with the oil formation in the fruits mesocarp (d) along with the fruits development and maturing.

The oil formation inside the fruits mesocarp start from the day 100, indicated by the increase in variation of most optical features. By the day 140, fruits start to lose and detached. In most oil palm plantation, it indicates that the fruits are ready to harvest. At the same time, the change in fruits' appearance also observed by the machine vision, shown by the increase of most optical features' values (Fig. 1). Toward the end of the fruits' development and ripening stage, most optical features' values rise steadily until the end of observation day and harvest performed.

From the Figure 1. It is understood that the optical features of FFB as observed by a machine vision can be used as an immediate indicator for fruits development and ripening stage, in particular after 140 day of anthesis. Further evaluation, by means of step-wise analysis, offered three optical features, which have strong coefficient of determination. These features were selected according to how well its regression line represents the data (R^2). Most of the data point in these three-feature passed by its regression line.

The three chosen optical features are R, H, and I (Fig. 2). The R value of observed FFB has R2 of 0.8786 thus indicated a strong coefficient of determination (Fig. 2a). The R regression line showed that 87.86% of the total variation in R value can be explained by the linear relationship between fruits age after anthesis and its optical feature. Here, only 12.14% of the total variation in R remains unexplained.

Similarly, the second optical value, H (Fig. 2b), showed that its regression line explained 90.44% of H in relation to the fruits age after anthesis. The third selected optical value, I (Fig. 2c), while has lower coefficient of determination (R2 = 0.8116) among the three, still able to explained more than 81% of total variation of linear relationship between its value and the fruits age after anthesis.

Development of oil in the lipid-rich fleshy mesocarp tissue of the oil palm (*Elaeis guineensis*) fruits is the main source of edible oil for the world, and the richest dietary source of provitamin A. Fruit development, maturation, and ripening are complex biological processes unique to plants. The monocotyledonous oil palm fruit is a drupe whose thick fleshy mesocarp is exceptionally rich in oil (80% dry mass), making this species the highest oil-yielding crop in the world. The mesocarp is also especially abundant in carotenoids. During the maturation and ripening, oil-accumulation in fruits tissues of the oil palm mesocarp regulate by mechanism which is not fully understand. However, during the maturation and ripening in the oil-rich mesocarp, change in colour commonly observed in fruits skin due to accumulation of carotenoid pigments which present in the oil.

In this study, the oil present in the fruits mesocarp samples were observed. Starting the from 100 day after anthesis, the presence of oil was identified although the amount is still in minuscule. The acceleration of oil formation in the mesocarp observed from the 110 day after anthesis (Fig. 2d) until day 117, and start to slow down from day 120. The second hike of oil formation in the mesocarp was observed on day 160 onward, the same time that the fruit normally harvested. Then, by day 170 the oil formation started to slow down.

From this study, the optimum harvesting window-time for FFB lies around 170 day after anthesis. Although oil synthesis and accumulation in the bunch continues until day 180, yet the number of fruits detached increased exponentially. Therefore, the optimum window time for harvesting the FFB at more than 170 day after anthesis will not be ideal, since the number of detached fruitlets become too great, and the resources required to collect it will not be justified.

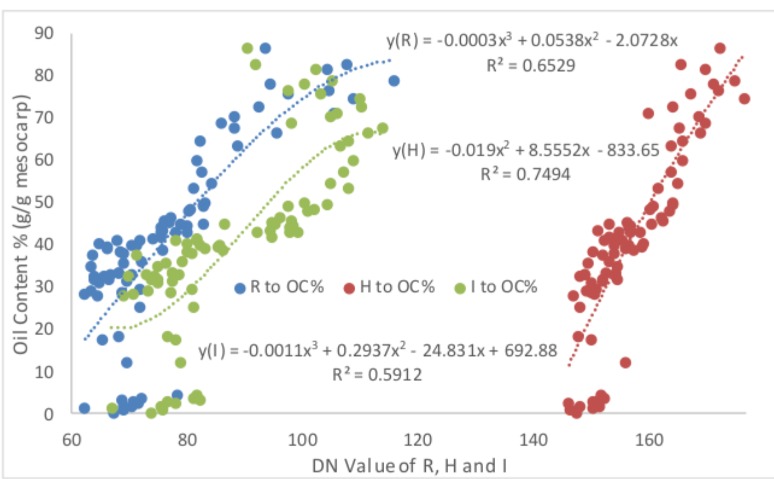

Figure 3. Correlation between fruits oil content in its mesocarp with three optical features (R, H, and I). H produce higher coefficient of determination among the three optical features.

Based on this finding, correlation between the amount of oil in the fruits mesocarp with its optical properties can be determined. Of the three selected optical properties, H produce the best correlation with mesocarp oil content with R2 of 0.7494 (Fig. 3). Therefore, determination of optimum harvest-window for oil palm FFB can be determined according to its H value. When the H value reached 172, the amount of oil in the mesocarp had exceed 80%.

From this result, the study proposed that the best window-time for harvesting the FFB will be around day 170 after anthesis. In the case the anthesis time cannot be determined, the FFB can be observed using a machine vision and whenever its optical value of H already reached 172, then the optimum harvest-window can safely assume had been achieved, and the FFB can be collected.

The study opens a breakthrough-option for harvest practice improvement in Indonesian oil palm industry. This ideal method would deliver an optimum harvesting interval, and a minimum number of loose fruits. If this new way of harvesting the FFB can be achieved in practice, the cost for collecting the loose fruits can be minimized. Thus, the total cost for harvesting the FFB subsequently become smaller, while at the same time, the revenue for oil palm cultivation can be improved.

It is expected that by practicing this new approach for harvesting the FFB, the oil yield will increase considerably. In that case, harvesting the FFB assisted with a machine vision device may be economically justified. In the long term, it may open the possibility for the upward trend in oil palm productivity in Indonesia. Determining the optimum harvest-window for oil palm fresh fruit bunches can be done non-destructively using the machine-vision detection device. The outcomes of this study support the development of oil palm mechanization and technology in Indonesia. The results are expected to be the solution for the development of Indonesian oil palm industry.

4. Conclusion

In this study, optimum harvest-window for collecting the oil palm FFB can be determined based on its Optical Properties and by using a machine vision. The FFB colour model was established for identification of its optimum harvest window. The optimum harvest window for FFB can be identified, first, by its mantled-pistillate-flower anthesis-time, where harvest can be done 170 days later. The second option is by evaluating the bunch optical properties using a machine vision. The properties in discussed is the H value, and the optimum harvest window for FFB determined when the H value reached 172. The same feature can also be used to determine the amount of oil in the fruits mesocarp, based on the strong correlation between H and mesocarp's oil content. The study opens the opportunity to improve the efficiency of oil palm industry in Indonesia.

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