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Identification of tenera and dura variety of oil palm fresh fruit bunches based on RGB color and fruit firmness

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ABSTRACT

Sorting and grading oil palm fresh fruit bunches (FFBs) by variety in oil palm mills is destructive and inefficient, necessitating a more accurate, rapid, non-destructive approach. This preliminary study aims to develop a computer vision system to identify oil palm FFBs varieties (dura and tenera) using RGB intensities and fruit firmness levels. The study used 20 dura FFBs and 20 tenera FFBs, each with 10 ripe and 10 unripe FFBs, while fruit firmness was measured with a GY-3 needle-type penetrometer. Analysis of RGB intensities showed that ripe tenera had the highest values, while unripe dura had the lowest. In addition to RGB intensity analysis, this study also used principal component analysis (PCA) to visualize the separation patterns of varieties and ripeness levels based on RGB values. The PCA results showed that RGB intensity values clearly distinguished the dura and tenera groups in both ripe and unripe conditions. In terms of firmness, unripe fruits of both varieties had significantly higher firmness values than ripe fruits, with unripe dura showing the highest value of 12.5 kg/cm^2 and ripe tenera showing the lowest value of 7.23 kg/cm^2, indicating an inverse relationship between ripeness and fruit firmness. This study demonstrates that RGB intensities and fruit firmness levels can serve as potential parameters for distinguishing between the dura and tenera varieties in a computer-vision-based oil palm FFBs sorting system.

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1. INTRODUCTION

Indonesia is the largest producer of Crude Palm oil (CPO) in the world, a major source of
Indonesia is the largest producer of Crude Palm oil (CPO) in the world, a major source of vegetable oil for many purposes, such as biofuel, cooking oil, and raw materials for cosmetic products. Maintaining the sustainability of productivity and quality is a major task that requires the efforts of all stakeholders. Many issues hinder the sustainability efforts of CPO industries, including environmental issues, labor shortages, aging palm oil trees requiring replanting, and the quality of fresh fruit bunches (FFBs) [1]. The quality of oil palm FFBs determines the quality of CPO; therefore, sorting and grading are key factors in obtaining high-quality FFBs. However, sorting FFB at palm oil mill reception areas is usually done manually and traditionally, relying on experienced workers. The sorting process aims to identify and separate unwanted FFBs in accordance with sorting regulations imposed by the Indonesian Government, including ripeness stages, defects, and varieties. However, due to various circumstances during transportation, oil palm FFBs are sorted out upon arrival at the reception area. The regulations are imposed strictly on FFBs of small holder plantations to obtain good quality CPO, besides the sorting criteria, to overcome various factors, such as anti-palm oil sentiment, new quality standard, by certifying the palm oil industries, such as using Roundtable on Sustainable Palm Oil (RSPO) and Indonesian Sustainable Palm Oil (ISPO) certification systems [2].

The variety of oil palm FFB is one of the sorting criteria at a palm oil mill. Based on mesocarp and shell thickness, oil palm fruit varieties are dura, pisifera, and tenera. The dura variety has a thinner mesocarp and a thicker shell, while the tenera variety has a thicker mesocarp and a thinner shell, and the pisifera variety has no shell. There is also a significant difference between the dura and tenera varieties in bunch weight and fruit-to-bunch ratio, with dura excelling in both parameters [3]. Most palm oil producers prefer tenera FFBs due to their higher oil content [4]. However, there is a significant unintentional planting of dura and tenera trees, at about 10.9%, which could have an economic impact [5], especially for smallholder plantations. Despite that, some plantations have cultivated both tenera and dura plants due to demand for palm kernel oil (PKO) and for oil palm kernel shell as a biomass fuel. Traditional sorting methods identify tenera and dura FFBs by cutting some FFB fruits to measure the mesocarp and shell thicknesses. However, this approach is destructive and inefficient. Therefore, non-destructive sorting and grading of FFBs by variety are challenging.

Computer vision (CV) has extensive applications in sorting and grading fruits and vegetables, including oil palm fruits and FFBs. CV systems are widely used in postharvest activities, such as quality control and evaluation, damage detection, and the classification of fruits and vegetables. The advantages of using CV for evaluating fruits and vegetables include non-destructive evaluation, the ability to collect large amounts of data, and fast analysis. When combined with machine learning or deep learning, the CV system becomes powerful for classifying and evaluating fruits and vegetables [6]. CV systems have been developed to evaluate oil palm FFBs, primarily for assessing FFB ripeness based on surface color changes. CV and machine learning based on surface color have been used, including principal component analysis (PCA) and artificial neural networks (ANN) [7], as well as deep learning with the You Only Look Once (YOLO) v5 series [8]. Computer vision was also used with ImageJ to measure physical properties of Dura and Tenera varieties [9], and with deep learning using ResNet-50 [10].

Computer vision and color models enable the classification of fruits and vegetables. Fruit surface color is an indicator of ripeness stages and other fruit physical properties. There are many color models used for fruit and vegetable classification and regression, including RGB (Red, Green, Blue), HSI (Hue, Saturation, Intensity), and HSV (Hue, Saturation, Value). Color models serve as feature-based image representations. Color spaces provide the frameworks for the color models [11]. In other words, color models are the mathematical formulas or coordinate systems for color representation, while color spaces are the spaces where the color model is applied. An automatic classification of palm oil Fresh Fruit Bunch (FFB) ripeness has applied eight color models and a multi-class Support Vector Machine (SVM). The eight color models were HSV, I1I2I3, LAB, XYZ, YCbCr, YIQ, YUV, and RGB, which classify FFB ripeness into four stages: unripe, under-ripe, ripe, and over-ripe [12].

Fruit firmness, or fruit hardness, is one of the physical parameters for determining fruit quality and ripeness. As fruits ripen, the firmness of the fruit tissue decreases. Traditional firmness measurements use portable commercial firmness tools, such as a penetrometer. A penetrometer works by pushing a standardized plunger into the fruit tissue; the penetrometer scale records the force required to break the fruit skin. Different ripeness stages result in different force values. Common force units for fruit firmness are kg/cm^2 (pressure) and kgf (kilogram force). A penetrometer can be analog or digital. One should choose a different plunger tip size based on the fruit's hardness and size. An analog penetrometer uses a dial indicator, while a digital penetrometer has an LCD screen. Firmness measurement with a penetrometer is widely used because it is simple and provides immediate results. However, penetrometer measurements are destructive because they damage the fruit tissue. Researchers have developed many methods to measure the firmness of fruits and vegetables, including sensors based on mechanical, sonic, or optical properties [13]. Other methods are nondestructive, such as using vision-based tactile sensing [14], hyperspectral imaging [15].

This study used a computer vision system to identify the oil palm fresh fruit bunch (FFB) varieties, Dura and Tenera, based on RGB values. Fruit firmness measurements were also performed to support the differentiation of Dura and Tenera FFB varieties and ripeness stages. The RGB intensity values were measured using ImageJ, while firmness was measured with a manual fruit penetrometer. Most methods for identifying Dura and Tenera FFB are destructive. This research is a preliminary study on using computer vision to identify Dura and Tenera FFBs in real time during the sorting and grading process, with the eventual aim of replacing traditional practices.

2. RESEARCH METHODS

This section describes the research steps for measuring RGB values and fruit firmness. The steps include sample preparation of fresh fruit bunches (FFB) from a private palm oil plantation in the vicinity of University Riau, image acquisition, fruit firmness measurements, image processing, and image analysis. RGB intensity values were extracted from images of the fruit's outer surface using ImageJ software to identify differences in color characteristics between varieties and ripeness levels. Meanwhile, fruit firmness was measured with a penetrometer to assess differences in the physical properties of the FFB samples.

2.1. Sample Preparation

This study used 40 oil palm fresh fruit bunches (FFBs), comprising 20 Dura and 20 Tenera varieties, with each variety comprising two ripeness levels: ripe and unripe. There were 10 unripe FFBs and 10 ripe FFBs for the Dura variety, and 10 unripe FFBs and 10 ripe FFBs for the Tenera variety. Validation of the FFB varieties assesses shell thickness and ripeness based on color changes and the number of fruitlets that have loosened, conducted by the plantation's experienced workers. Figure 1 left shows (a) ripe dura and (b) ripe tenera, while (c) and (d) are unripe dura and unripe tenera respectively. Conventional practice for validating tenera and dura varieties and ripeness involves making incisions in 1 – 2 FFB fruitlets, with dura showing a thick shell and tenera a thin shell. A glossy blackish-purple color characterizes unripe oil palm FFBs, while ripe oil palm FFBs have a reddish-orange color. Each FFB sample was marked at the FFB stalk cut. Oil palm FFB masses were measured in order to have insight of Dura and Tenera physical properties [9]. The FFB masses of 40 samples were measured using a calibrated digital scale. Figure 1 right shows the mass variation of the samples based on the variety and ripeness.

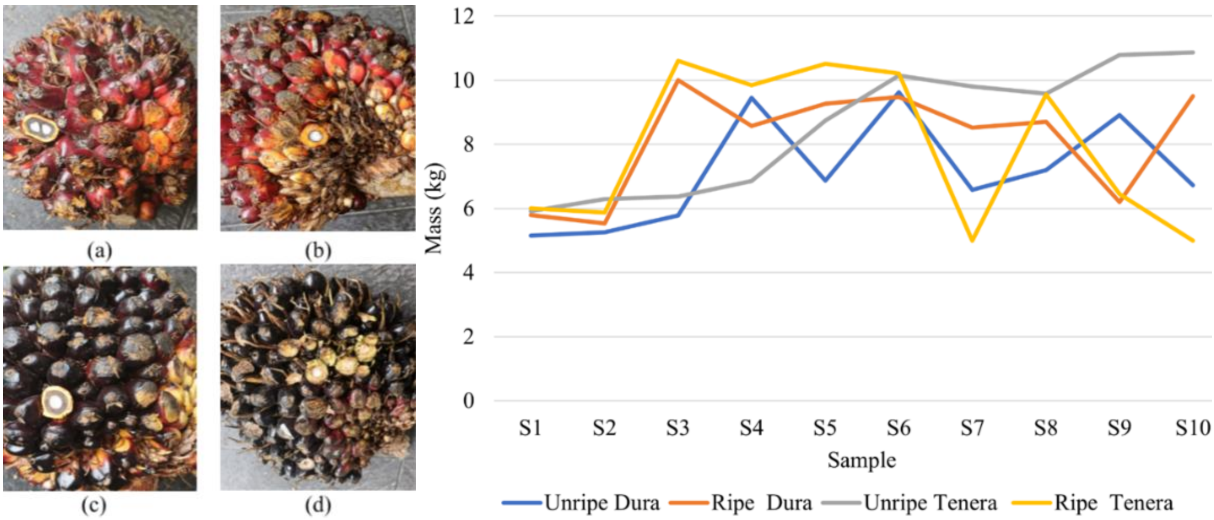

Figure 1. Samples of fresh fruit bunches (FFB) of oil palm (left) and FFB masses (right).

2.2. Image Acquisition System

Figure 2 shows the experimental setup used to acquire FFB images. A digital camera was positioned at a fixed distance of 60 cm from the FFB on a conveyor with a white belt, which enhances image contrast. The camera was a 2.3 MP (megapixel) color digital camera with a CMOS sensor and a frame rate of 76 FPS, and connected to a laptop using a USB 3.0 cable. The camera has a camera lens of 4 – 12 mm focal length. The image acquisitions used the camera and the IC Capture software to record and save FFB images in BMP format, and then converted them to JPG format. The camera is positioned above the FFB. The camera stand keeps the camera stationary to minimize image noise. Each FFB had two images: the front and back sides. The front side is the FFB part that faces the sunlight during growth.

Figure 2. Image acquisition system [9].

2.3. Analysis of RGB Intensity Values for Oil Palm Varieties

In this study, the RGB value of each FFB image was extracted using ImageJ software. ImageJ is one of open source image processing software. It have been used widely for biology and medical image data. Is a powerful image processing software because it contains huge collections of plugins, ready to use for many purposes, such as, feature extraction and fruit or cell counting. The advantages of using ImageJ areits public domain and can operate in any operating systems (Linux, Windows, Mac), and easy to use [16].

The procedure for obtaining the RGB intensity of an FFB image involved several steps. The first step is to obtain a segmented FFB image, then set the region of interest (ROI) using the ImageJ menu (Measure-Tools-ROI Manager). This step aimed to set the same area of pixels evaluated for each FFB image. The second step is to split the image's color channels (Image-Color-Split Channels). This step produced three separate images with distinct color channels: R, G, and B. The next step is to measure the Mean Intensity for each color channel (Analyze-Measure). Finally, to represent the RGB intensity of each FFB image, the average of the three channel values is computed using Equation (1). The intensity of each FFB image will be used to compare and identify the varieties of Dura and Tenera, as well as their ripeness levels.

$$RGB\ intensity\ (I) = \frac{R+G+B}{3} \quad (1)$$

This study uses Principal Component Analysis (PCA) to visualize the RGB values for each variety and ripeness level. PCA is one of the unsupervised learning algorithms that contains continuous output. PCA aims to reduce high-dimensional data to only some dominant or principal features in a new coordinate system, such as R, G, and B color intensities, thereby enabling easy classification without losing important information. The PCA method also aims to find the hidden pattern in high-dimensional data. The PCA results are presented in a 2-dimensional graph showing the scores for the two principal components, PC1 and PC2 [17].

2.4. Firmness Measurement of Fresh Fruit Bunches (FFB) of Oil Palm

The fruit firmness measurement was conducted to aid in identifying the FFB varieties. The measurement was taken using a Model GY-3 needle-type penetrometer with a pressure scale in kg/cm^2. Each FFB was pressed vertically at the center of the fruit flesh with a constant force until the penetrometer needle penetrated the fruit. When measuring the firmness of oil palm FFB, the needle is inserted directly into the exocarp or mesocarp of the peeled fruit to obtain the actual firmness value. The maximum pressure value indicated by the instrument is recorded as an indicator of fruit firmness. Measurements are taken three times for each fruit, which are from three parts of the fruit, and averaged. For each FFB, measurement is done using fruits detached from each part of a FFB bunch: the top, middle, and bottom bunches. Each FFB has a single average firmness value to enhance data validity.

3. RESULTS AND DISCUSSIONS

This study aimed to identify oil palm FFBs by variety and fruit ripeness. The study was performed by acquiring fresh fruit bunch (FFB) images, processing them in ImageJ, measuring RGB intensity values, and then measuring fruit firmness with a needle-type penetrometer. The image data obtained were the average RGB intensity for each FFB image and the firmness (kg/cm^2) for each FFB. The average RGB intensity values were used as indicators of brightness and surface color changes to distinguish between the Dura and Tenera varieties non-destructively. Fruit firmness was used to indicate FFB ripeness.

3.1. The Relationship Between RGB Intensities and Varieties

The RGB intensity data for this study comprised 40 back-side FFB images and 40 front-side FFB images. However, in this article, only the RGB intensities of the front-side FFB image were used because of its homogeneous fruit density. Both sides have comparable RGB intensities, with the back side slightly lower. The 40 images were divided into four categories: unripe dura, ripe dura, unripe tenera, and ripe tenera. Figure 3 shows the RGB intensities for each category, which has 10 FFBs labeled S1 to S10. Figure 3 shows that S1 means the first sample of each category.

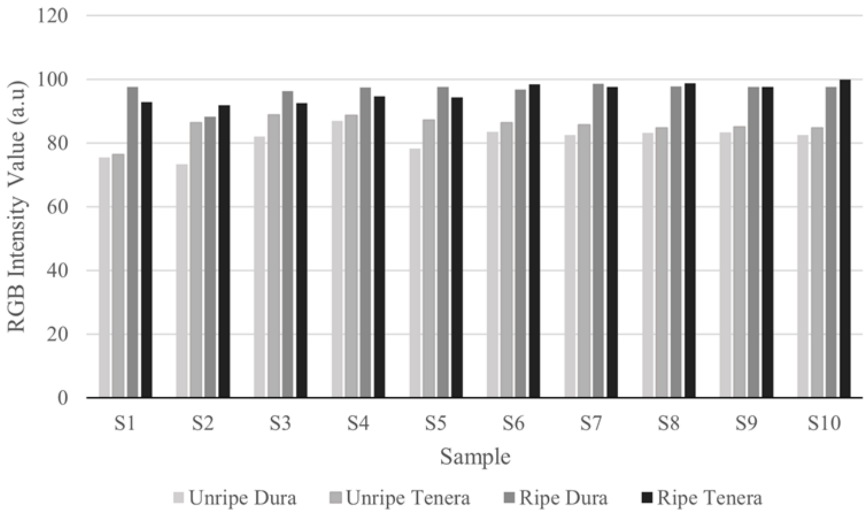

Figure 3. RGB intensity values for the dura and tenera varieties in ripe and unripe conditions.

Figure 3 shows the RGB intensity measurements for 4 categories of oil palm fresh fruit bunches. Ripe tenera RGB intensities are slightly higher than ripe dura intensities. Ripe RGB intensities are higher than unripe RGB intensities for both varieties. The difference in RGB intensities of unripe and ripe FFBs correlates with chlorophyll and anthocyanin contents of unripe and ripe FFBs [18]. Variation across all categories could be due to variations in ripeness. Ripeness levels can be further categorized as unripe, underripe, ripe, and overripe, but in this study, they were classified only as unripe and ripe.

The difference in RGB intensity between dura and tenera intensities indicates that these two varieties have different surface fruit densities. Figure 1 (left) shows the mass variation of oil palm FFBs, with dura varieties having smaller masses and bunches. A smaller bunch of dura FFBs could affect the surface area of segmented FFB images when measuring RGB intensities [9]. According to [19], the mean size of the fresh dura fruit, i.e., fruit length, width, and thickness, is bigger than that of the tenera. The average fruit mass of the tenera variety was 8.50 g, while the average fruit mass of the dura was 7.65 g. Other factors could include varying shell and mesocarp thicknesses, which influence the amount of incoming light reflected from their surfaces.

3.2. Analysis of RGB Intensity using PCA

The PCA technique was performed on the RGB intensities of the four sample categories to identify separation patterns among varieties and ripeness levels. Figure 4 shows the PCA results for the RGB intensity values of the four categories of fresh fruit bunches (FFB) of Dura and Tenera varieties under both ripe and unripe conditions. Based on the graph, the four sample categories exhibit a fairly clear separation along PC1 values. Unripe Dura data occupies the lowest PC1 position, ranging from -2.2 to -0.3, indicating the lowest RGB intensity values among all categories. Unripe Tenera falls within the range of -1.9 to -0.1, slightly higher than unripe Dura but still within the low-intensity zone. Meanwhile, ripe Dura falls within the range of -0.3 to 1.2, and ripe Tenera (orange) falls within the range of 0.3 to 1.4, with the highest PC1 value. The order of PC1 values from low to high unripe Dura, unripe Tenera, ripe Dura, and ripe Tenera shows that PCA successfully separated the four categories based on RGB intensities.

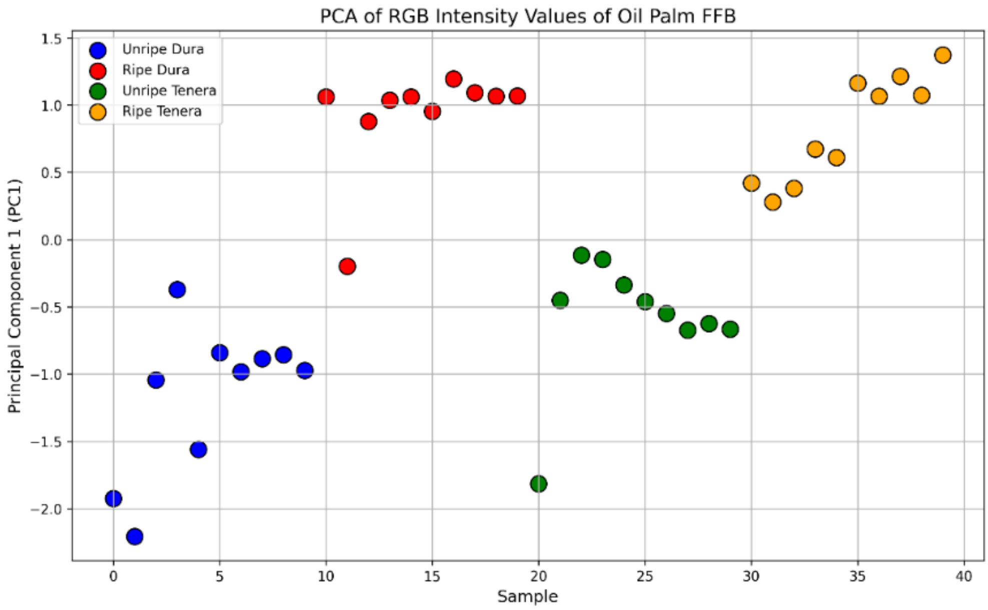

Figure 4. PCA results for RGB intensity values across varieties.

3.2. The Relationship Between Oil Palm Fruit Bunch Varieties and Fruit Firmness

The variety and ripeness levels greatly influence the firmness of fresh fruit bunches (FFB). The firmness of oil palm fruit bunches was measured using a GY-3 model penetrometer with units of kg/cm². Firmness values for four FFB categories were obtained from the fruits of the three sections of an FFB bunch: the top, middle, and bottom. Each fruit had three measurements at different parts of the fruit, then averaged. The firmness values from each section of the oil palm fruit bunch were then averaged to obtain the final result. Figure 5 shows the variations in fruit firmness across all categories.

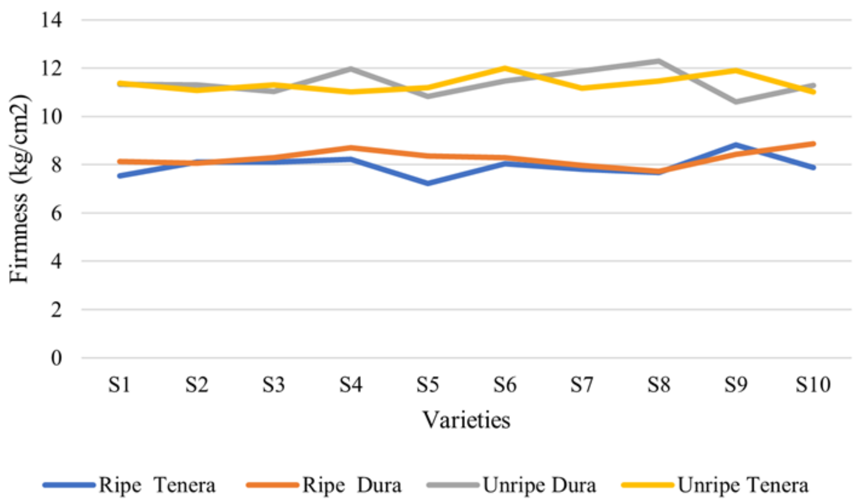

Figure 5. Firmness values of dura and tenera fruit varieties and ripeness.

Figure 5 shows the fruit firmness values of oil palm FFBs, with the x-axis representing the sample numbers (S1 to S10) for each category, and the y-axis representing the firmness values in kg/cm². Figure 5 shows that the firmness of unripe FFBs is much higher than that of ripe FFBs. The results indicate an inverse relationship between ripeness and firmness. They are true because ripe oil palm fruits have more oil content, which softer the FFB mesocarp [20]. Ripe tenera has a firmness value between 7 – 9 kg/cm^2, indicating low firmness. Ripe dura has higher firmness values, ranging from 8 – 9.5 kg/cm^2. Unripe tenera ranges from 10.5 – 11.5 kg/cm^2, while unripe dura has similarly stable values, ranging from 10 – 12.5 kg/cm^2. When comparing varieties under the same conditions, ripe dura tends to have a slightly higher firmness value than unripe Tenera; similarly, in the unripe state.

Figure 5 shows that when unripe, the fruit has a high level of firmness, whereas when ripe, its firmness is low. The high firmness of unripe dura, compared to other varieties, is associated with the thicker shell and denser mesocarp structure of dura, making the fruit tissue more resistant to penetration when unripe. Fruit firmness influences the fruit's resistance to mechanical damage [4]. According to [19], the mean pressures applied on the fresh dura are higher than those on the tenera varieties, the same as the cracking force due to the thicker shell of dura varieties. The observed differences in firmness values between the Dura and Tenera varieties, both in ripe and unripe conditions, indicate that fruit firmness has the potential to be used as an identification parameter between the two varieties in an FFB identification system.

4. CONCLUSION

This study has shown that the variety of dura and tenera, as well as their ripeness, can be identified using RGB intensities and fruit firmness. The RGB intensity values of two varieties of oil palm FFBs were measured and analyzed using ImageJ software. The results of the study show that ripe tenera has higher RGB intensity values than ripe dura; both ripe FFB varieties have higher intensity than the unripe. Additionally, PCA results showed a fairly clear separation between sample groups based on RGB intensity values. In terms of fruit firmness, the unripe fruits of both varieties have significantly higher firmness values compared to ripe fruits, with unripe Dura recording the highest value of 12.5 kg/cm^2 and ripe Tenera showing the lowest value of 7.23 kg/cm^2, indicating an inverse relationship between ripeness level and fruit firmness. RGB intensity values and fruit firmness levels can distinguish the Dura and Tenera varieties. This study is a preliminary study toward building a computer vision system to identify dura and tenera oil palm FFBs during the real-time sorting and grading process.

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