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Physical properties of oil palm fresh fruit bunch varieties

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ABSTRACT

Identification of oil palm fresh fruit bunches (FFB) based on variety is a crucial step in sorting and grading FFBs to produce good-quality crude palm oil (CPO). Most palm oil mills receive two varieties of FFBs at the reception stations, Tenera and Dura, and only a certain percentage of the Dura variety is allowed in a transporting truck. The conventional identification is destructive, cutting several fruits off an FFB bunch and checking for fruit Mesocarp and shell thickness. The method suffers a high increase in free fatty acid (FFA) content. This study is a preliminary study using computer vision and image processing to differentiate the two varieties based on their physical properties. The samples consisted of 20 Dura and 20 Tenera FFBs, 10 unripe and 10 ripe FFBs. The FFB images were acquired for both front and back sides using a color CMOS camera. ImageJ software was used to obtain the number of outer fruits and bunch surface area, used to calculate fruitlet density. Both varieties are also compared based on mass and by red, green, and blue (RGB) intensities. The results were compared to the results measured manually. The results showed that the Tenera variety exhibited higher fruit density, fruitlet count, RGB intensity compared to the Dura variety. Both varieties have higher correlations between fruit density and their masses. These results show the potential of computer vision and image processing methods to differentiate Tenera and Dura varieties, used for sorting and grading oil palm FFBs.

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1. INTRODUCTION

Nowadays, imaging methods have various applications in agriculture due to their nondestructive and fast way to identify and classify agricultural objects, such as fruits and vegetables. Many imaging techniques have been developed for various purposes, for instance, hyperspectral and multispectral imaging, traditional computer vision, and Raman imaging. The identifications and classifications are based on the physical and biological characteristics of fruits and vegetables. The physical properties comprise size, shape, and color, while the biological properties include variety and ripeness level [1]. A traditional computer vision system is one of the simplest imaging techniques, which consists of a camera sensor, a lighting unit, image processing software, and objects. Computer vision and image processing are a combination method to support automation in agriculture, especially for sorting and grading fruits and vegetables. The automation aims to substitute the manual sorting and grading, which are subject to time and labor inefficiency, consuming, and also inconsistent [2]. Computer vision and image processing have enabled color, size, and weight measurement, hence can be used for sorting fruits such as tomatoes [3].

ImageJ is an open-source imaging processing program to quantify images. It has various applications in many fields, including agriculture, to measure the physical properties of fruits and vegetables. The software is unique because it has user-centric plugins with many functionalities for image analysis. Some of the functions can measure size, shape, color, and even count the number of particles in an image [4]. One of the functionalities of ImageJ is counting objects in an image, such as counting cells. Cell counting is very crucial in Biology, especially when using an optical microscope accompanied by a digital camera [5]. ImageJ can obtain RGB or grey values, enabling the characterization of fruits or leaves of plants to differentiate spinach plants due to the variety of sunlight. In this study, ImageJ has been used to process fluorescence spectroscopic images of spinach leaves treated with three variations of sunlight [6].

Crude Palm Oil (CPO) is one of the key export commodities for countries such as Indonesia and Malaysia. The productivity and quality of CPO highly depend on the quality of fresh fruit bunches (FFBs). Sorting and grading FFBs are the crucial processes at a CPO mill reception station, before the FFBs enter the production stages. Variety is one of the FFB quality attributes, in addition to ripeness levels. There are three varieties of oil palm FFBs: Dura, Pisifera, and Tenera. However, only Dura and Tenera varieties are cultivated and sent to palm oil mills. Tenera variety has a thicker mesocarp, hence has higher oil content, while Dura has a thicker shell but a thin mesocarp. Dura variety is still important due to its kernel for palm kernel oil (PKO) [7]. According to palm oil mill regulations, only a certain percentage of Dura is permitted in a transporting truck entering the reception area, such as 25%. Currently, the identification of FFB varieties is often performed destructively, for instance, by cutting the FFB fruitlets to observe shell thickness. Although this method is accurate, it is inefficient, damaging the samples, and is difficult to apply to large quantities. Accurate identification between Dura and Tenera is crucial as it directly affects the oil extraction rate.

Computer vision and image processing methods have been developed extensively over the last two decades for evaluating oil palm FFBs, for harvesting, and post-harvest activities. The techniques enable automation and reduce the labor shortage problem, such as in the harvesting stage. Maturity or ripeness level is the FFB quality attribute often evaluated for harvesting and for post-harvest purposes. Computer vision and deep learning offer a nondestructive technique, which is economical, fast, real-time, and accurate [8]. The traditional ripeness identification is by visual inspection based on fruit color and the number of fruits that are loose. Thick technique is subjective, less efficient, and time-consuming [9]. Computer vision and neural networks allow for the classification of the FFB ripeness based on color and texture features [10].

There are other physical properties of oil palm FFBs also used to identify and classify FFB qualities. The physical properties of two FFB varieties, Tenera and Dura, including size, sphericity index, aspect ratio, true density, bulk density, and porosity, have been investigated. The mean size of the fresh dura fruit is slightly smaller than that of the Tenera fruits, while the sphericity and aspect ratio of the fresh dura variety were found to be higher than those of the Tenera variety. Dura variety fruits have slightly higher true densities, bulk densities, density ratios, and porosities [11]. The physical and mechanical properties of fresh and sterilized oil palm fruitlets were also investigated. The physical properties studied were size, sphericity index, aspect ratio, true density, bulk density, and porosity. Most of the physical properties of the sterilized fruitlets obtained lower values compared to fresh fruitlets, except that the porosity is higher [12]. Computer vision and image processing methods have been used to obtain the fruit's physical properties, such as volume and mass, including oil palm FFBs. Volume measurement using images can be used to estimate fruit mass [13]. Volume of oil palm Tenera FFBs has been estimated and compared to the water displacement method (WDM). It showed the linearity with an R2 of 0.9336. The measurement used a segmentation and an ellipsoid equation to estimate the FFB volume with a cross-line laser beam to contour the oil palm bunch dimensions [14].

In this study, the physical properties of Dura and Tenera FFBs were measured using ImageJ software. The physical properties measured were the number of outer fruits, bunch area, and fruitlet density. The results were compared to the results obtained by manual measurement using a measuring tape and human vision. The FFB fruit densities were measured in two ways: by segmenting the whole surface, and by a constant surface in the middle of a bunch. The fruit density is the ratio of fruit number to the bunch area. The fruit densities were correlated with the FFB masses. This study contributes to the classification method based on images, and can be beneficial in sorting and grading FFB varieties.

2. MATERIAL AND METHOD

This section describes the preparation of oil palm Fresh Fruit Bunch (FFB) samples, the image acquisition system, and the steps for extracting and analyzing FFB physical parameters based on variety using ImageJ software. The physical parameters include the number of fruitlets, the surface area, RGB color intensity, and mass. The fruitlet density value is calculated as the ratio of the number of fruitlets to the bunch surface area. The correlation between fruitlet density and FFB mass is analyzed.

2.1. Sample Preparation

This study used 40 oil palm Fresh Fruit Bunch (FFB) samples collected from a smallholder plantation near Universitas Riau. The samples consisted of 20 bunches of the Dura variety and 20 bunches of the Tenera variety. Both varieties have 10 unripe and ripe FFBs. Each bunch image was recorded for two sides, namely the front and the back, resulting in a total of 80 images. The samples have different masses and size as shown in Figure 1. Figure 1 displays oil palm FFBs from two varieties and two sides of view. The Dura variety is known for having a thicker shell and a lower mesocarp-to-kernel ratio [7]. Image (c) shows the front view of the Tenera variety, and image (d) displays its back view. Tenera, a hybrid between Dura and Pisifera, typically has a thinner shell and a higher mesocarp content, making it superior in terms of oil yield. Taking images for both the front and back sides helps to highlight morphological differences between the varieties, supporting more accurate identification using digital image analysis.

(a) (b) (c) (d)

Figure 1. Samples of oil palm Fresh Fruit Bunches (FFB) from Dura and Tenera varieties: (a) front view of Dura, (b) back view of Dura, (c) front view of Tenera, and (d) back view of Tenera.

The mass of the oil palm FFB was measured using a digital weighing scale. Before weighing, each bunch was cleaned of debris to avoid interference with the measurement results. Each bunch was also marked according to variety type and ripeness level on its basal part. The bunch was then placed on the scale, and the mass value was recorded once the reading on the display had stabilized [13]. The recorded mass values were used as an additional physical parameter to differentiate the samples, and will be correlated to other physical parameters.

Figure 2. Image acquisition system for oil palm fresh fruit bunches.

2.2. Image Acquisition System

The image acquisition system is shown in Figure 2. The system has a color camera (DFK33UX174, Imaging Source) with a CMOS sensor of 1024 × 768 resolution. The camera is equipped with a manual zoom lens with a focal length range of 4 – 12 mm. The camera was connected to a laptop via a USB cable to control image acquisition and store the captured images. A belt conveyor moves the samples to the center of the camera. The camera was mounted vertically above the conveyor using a stainless steel stand, 60 cm from the conveyor surface. The working distance was adjusted to ensure that each FFB image was captured with a wide field of view, regardless of size, and was constant throughout the acquisition process. Image acquisition was conducted with outdoor lighting. Each FFB sample was placed on the white conveyor belt, which was covered with a white sticker to provide a uniform background, as in Figure 2. The acquisition step records images of each bunch from two sides, front and back, and stores them in JPEG format for image processing.

2.3. Image Processing and Feature Extraction

The first step after image acquisition is to calibrate pixels to cm. Image processing for this study was performed using ImageJ software version 1.54. The scale calibration was carried out by placing a ruler as a reference object aligned with the sample and taking the calibration image. The number of pixels was converted to cm. The calibration stage resulted in a conversion factor of 27.018 pixels per centimeter. This conversion factor is used throughout the measurement. The next stage is to find the oil bunch area seen by the camera using the segmentation plugin of ImageJ [4]. The segmentation process has two approaches. The first approach used ROI (Region of Interest), involving manual selection of the bunch area by tracing the contour of the bunch image. The second approach employed automatic segmentation using thresholding, which separates the bunch from the background using pixel intensity distribution. The next stage is to find the oil bunch area seen by the camera by segmentation plugin of ImageJ. The segmentation process has two approaches. The first approach used ROI (Region of Interest), involving manual selection of the bunch area by tracing the contour of the bunch image. The second approach employed automatic segmentation based on thresholding, which separates the bunch from the background based on pixel intensity distribution.

After segmentation, image feature extraction was conducted to obtain the physical parameters. Extracted features included the number of fruits using Particle Analyze after converting the image to grayscale, the area of the bunch, both from the ROI and the automatic segmentation, as well as the RGB color intensity values obtained from separate channel analyses and then calculated as the average RGB intensity using a simple formula (R+G+B)/3 [14]. For validation, the fruit count was also performed manually through visual observation. This dual approach ensures that the digital image analysis results can be compared with manual counts, thus improving the reliability of the developed system [5].

2.4. Fruit Density Calculation

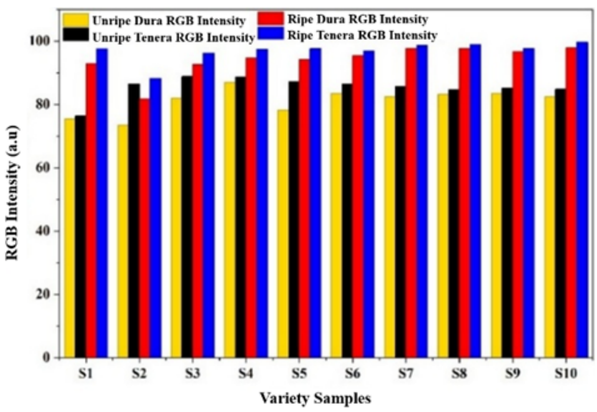
The key physical parameter in this study is fruit density, to differentiate the Dura and Tenera varieties. It is calculated as the number of fruits per unit area of the bunch. Density calculation was performed using two approaches: manually selected areas (ROIs) and the area obtained from automatic segmentation, both measured using ImageJ software. The manual approach involved directly selecting the bunch area, constant for each bunch, while the automatic approach used segmentation results to calculate the density automatically using ImageJ for the bunch. The obtained fruit density data were then used to classify oil palm varieties, specifically the Dura and Tenera varieties, in a non-destructive manner.

3. RESULTS AND DISCUSSIONS

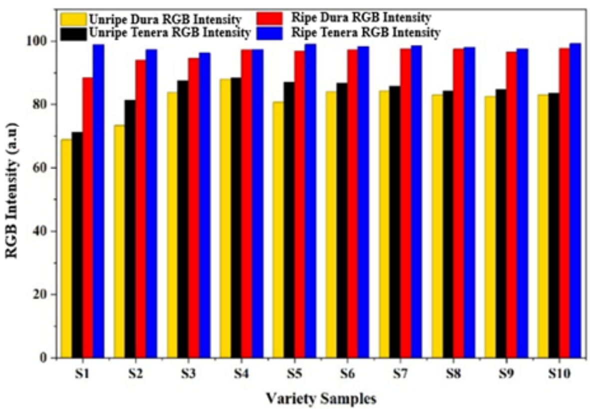
The research was done by acquiring FFB images, processing them using ImageJ software, measuring physical parameters digitally, and comparing them to those obtained manually. The manual data includes the number of fruits on the front and back sides, as well as the bunch mass. The image data comprises the ROI area, segmented area, number of fruits, fruit density, and average RGB intensity. Each FFB image was recorded from both the front and back sides. Fruit density was calculated as the ratio of the number of fruits to the area and used as a key parameter for variety identification. Moreover, the average RGB intensity was extracted as an indicator of brightness level and changes in fruit surface color, which are essential for non destructively distinguishing between the Dura and Tenera varieties. The bunch mass was also measured to correlate with FFB fruit densities.

3.1. RGB Intensity of Dura and Tenera Varieties

Figure 3 shows the average RGB intensities for each FFB sample at the varieties, unripe, and ripe levels. The graphs of RGB intensities were shown for the front (a) and back view (b). The front side is the FFB side, which is exposed to sunlight, while the back side is the side between oil palm fronds. The RGB intensity values were obtained using the ImageJ program. Figure 3 (a) and (b) show that ripe fruits consistently exhibit higher RGB intensity values than unripe fruits for both varieties. The Tenera variety displays RGB intensity values ranging from 97 to 100 a.u. (ripe) and 87 to 90 a.u. (unripe) for the front view, and from 94 to 98 a.u. (ripe) and 83 to 87 a.u. (unripe) for the back view, which is slightly higher than the front bunch. In contrast, the Dura variety exhibited lower intensity values, with 91 to 95 a.u. (ripe) and 81 to 85 a.u. (unripe) in the front view, and 88 to 93 a.u. (ripe) and 78 to 82 a.u. (unripe) in the back view. These results show that the Tenera variety has higher RGB intensity compared to Dura, particularly in the ripe condition. The results could be due to the bigger size of Tenera fruits compared to Dura, hence more light gets reflected [11]. Most Indonesian oil palm FFBs are the Nigrescens variety, which has a blackish purple color when unripe, and yellowish-orange to red when ripe. Unripe FFBs show lower RGB intensities [14].



(a)



(b)

Figure 3. Comparison of average RGB intensity of Dura and Tenera varieties in ripe and unripe conditions: (a) front view and (b) back view.

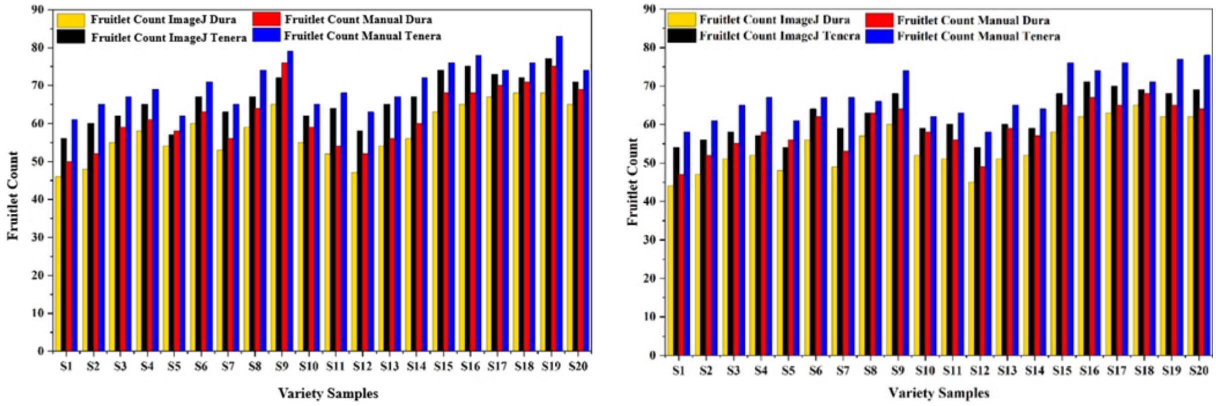
3.2. Fruit Count using Thresholding Method

The thresholding process was conducted to extract fruit count information from the FFB images of Dura and Tenera varieties. This step aims to separate the fruit areas from the background by converting the colored image into a binary image, allowing the fruit objects to be more clearly identified as seen in Figure 4. Through this method, fruit counting can be performed more accurately and non-destructively, while minimizing the effects of lighting variation and surface texture [5]. Figure 4 show the thresholding results of FFB Dura and Tenera varieties, which associated with Figure 1. As shown in Figure 4, the thresholding results display binary images of the fruit bunches both the front and back views of each variety. Images (a) and (b) represent the Dura variety from the front and back views, while images (c) and (d) show the Tenera variety from the front and back views.

The number of outer fruits using fruit count analysis on the images of Dura and Tenera FFBs varieties is shown in Figure 5. Figure 5 shows that the front side of the Tenera variety has a higher number of fruits compared to the Dura variety. A similar pattern is observed for the back side, where the fruit number of the Tenera variety is larger than that of Dura. These results are consistent with the findings of [7], who reported that although Dura has a slightly higher average bunch weight, the Tenera variety exhibits a higher fruit-to-bunch ratio. Figure 5 also shows that the number of outer fruits counted by ImageJ is much smaller than those counted manually. The findings show that the thresholding method using ImageJ has some error because the adjustment is done manually. The overlapping fruits, such as those of oil palm FFBs, need another plugin, such as a watershed algorithm [5].

(a) (b) (c) (d)

Figure 4. Thresholding of Dura and Tenera varieties for fruit count: (a) Dura front view, (b) Dura back view, (c) Tenera front view, and (d) Tenera back view.

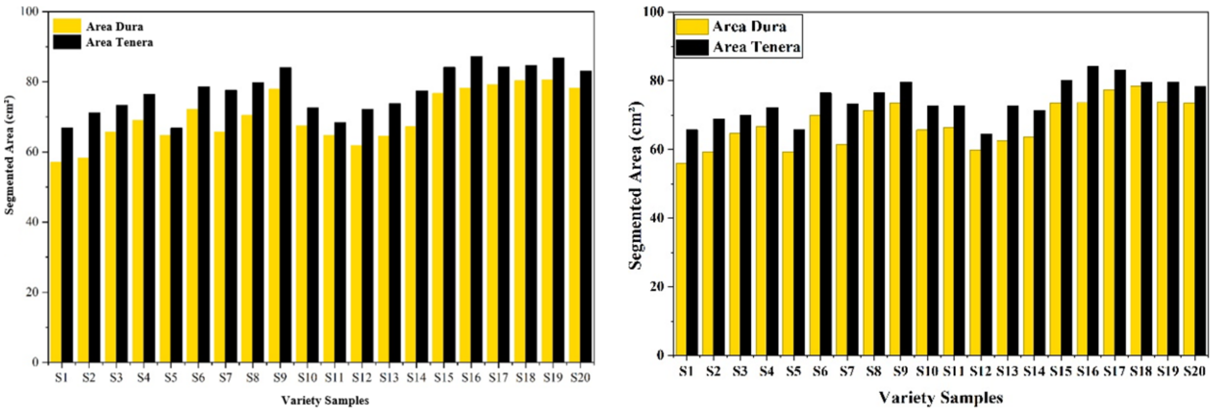


(a) (b)

Figure 5. Comparison of fruit count between Dura and Tenera varieties: (a) front view and (b) back view.

3.3. FFB Bunch Area

The bunch area analysis was conducted by setting a constant ROI size of 139 cm² for each bunch and measuring the segmented area representing the fruit portion. Figure 6 shows that the segmented bunch area of the Tenera variety is generally larger than that of the Dura variety, both from the front view (a) and the back view (b). The results could be due to the Tenera fruit size being slightly larger than Dura [11]. The size of fruitlets affects the weight and the size of oil palm FFB [14].

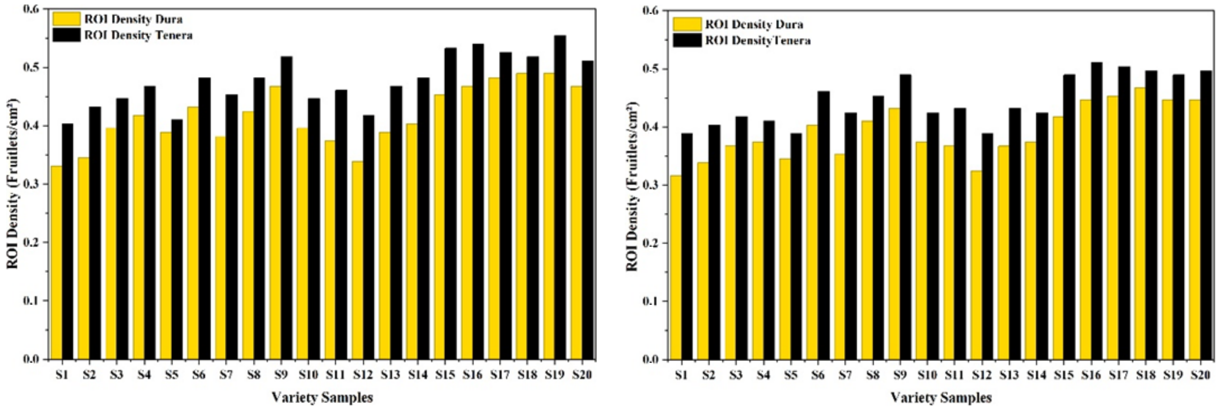


(a) (b)

Figure 6. Comparison of segmented area size between Dura and Tenera varieties: (a) front view and (b) back view.

3.4. Bunch Fruitlet Density

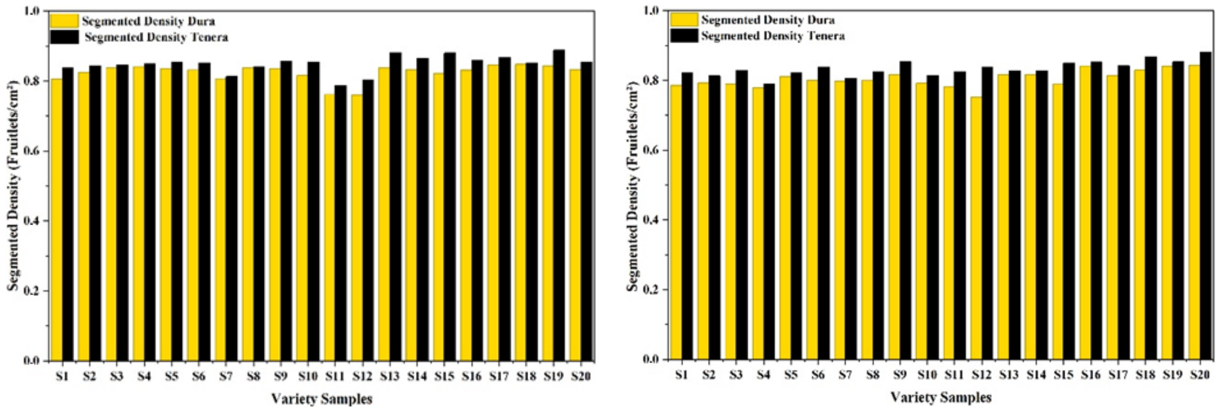
The fruitlet density analysis aims to evaluate the distribution of oil palm fruits in the FBB bunch area. The assessment was conducted using a Region of Interest (ROI) with a constant area across all bunch images. Figure 7 presents a comparison of fruitlet density within the ROI area between Dura and Tenera varieties, from both the front view (a) and the back view (b). Although the ROI area is consistent across all images, the number of fruits within each ROI varies. Observations indicate that the Tenera variety has a greater number of fruits and exhibits a more uniform distribution compared to the Dura variety. The results could be due to larger size and mass of Tenera variety [14].



(a) (b)

Figure 7. Comparison of ROI area density between Dura and Tenera varieties: (a) front view and (b) back view.

Another approach was using the bunch area, calculated from the segmentation process. Each FFB has a different bunch area. Fruitlet numbers were counted accordingly on the bunch area seen by the program. Figure 8 presents a comparison of the segmented fruitlet density areas for Dura and Tenera varieties, from the front view (a) and the back view (b). The results indicate that the Tenera variety consistently exhibits slightly higher fruitlet density values, suggesting a greater number of fruits within the segmented areas. However, compared to bunch areas obtained using the ROI method, the segmentation approach resulted in uniform fruit density for both varieties. The results are due to the variation of the sample sizes and masses. Smaller FFBs have a small bunch area but higher density, while large FFBs have a large bunch area and then smaller density. It shows that the ROI method has better results.



(a) (b)

Figure 8. Comparison of segmented fruitlet density between Dura and Tenera varieties: (a) front view and (b) back view.

3.5. Correlation Between Fruitlet Density and Bunch Mass

The correlation analysis between fruitlet density and bunch mass was conducted to evaluate the effect of bunch mass on fruit density of oil palm FFBs within bunch areas, using ROI and segmentation approaches. This evaluation was carried out for the oil palm Dura and Tenera varieties using the front side. Figure 9 shows the relationship of fruit densities of Dura and Tenera FFBs versus the FBB masses using the ROI approach. Figure 9 shows that Dura FFB samples have less mass variation compared to the Tenera. These results cause fruit density variations. The analysis of the relationship between bunch mass and fruitlet density based on the ROI area reveals a clear difference between the Dura and Tenera varieties. The Dura variety shows a relatively strong relationship with the linear regression equation of $y = 0.0189x + 0.2716$ and $R^2 = 0.4038$. Equally, the Tenera variety shows less correlation with $y = 0.0040x + 0.4441$ and $R^2 = 0.0384$.

The analysis for the segmentation approach is shown in Figure 10. Thee Dura variety also shows a fairly significant correlation between bunch mass and fruitlet density with $y = 0.0077x + 0.7656$ and $R^2 = 0.2803$. Meanwhile, the Tenera variety has lower correlation with $y = 0.0034x + 0.8214$ and $R^2 = 0.0888$.

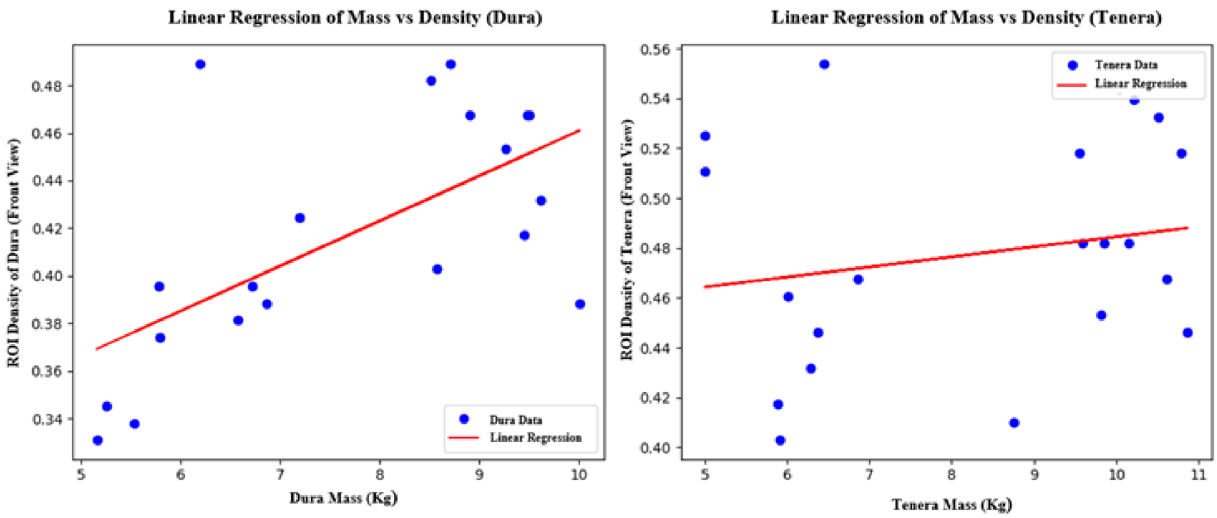


Figure 9. Regression relationship between bunch mass and fruitlet density in the ROI area of Dura and Tenera varieties: front view.

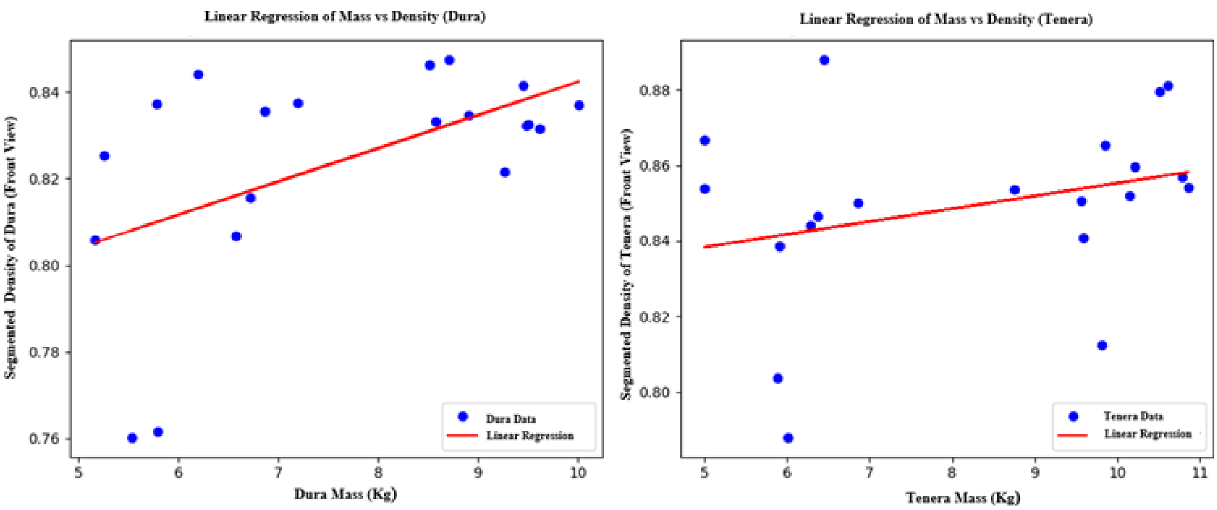


Figure 10. Relationship between bunch mass and fruitlet density from segmented images in Dura and Tenera varieties: front view.

Figures 9 and 10 show that the ROI and segmentation approaches have different results. The results indicate that the Dura variety tends to have a more consistent and moderately strong correlation between bunch mass and fruitlet density, unlike the Tenera variety, which exhibits a low correlation. The identification of oil palm varieties based on the physical properties has successfully shown the differences. More samples, image processing, and machine learning are needed to differentiate between the two varieties. Hence, the computer vision methods can be adopted for sorting and grading oil palm FFBs based on variety. The results showed that the Tenera variety consistently exhibited higher fruitlet density compared to the Dura variety, as observed in both the ROI-based data and segmentation approach. This distinct difference could enable the systematic separation of the two varieties.

4. CONCLUSION

The physical properties of two varieties of oil palm fresh fruit bunches (FFBs) have been calculated and analyzed using computer vision and image processing based on ImageJ software. The physical properties are mass, RGB intensities, outer fruit number, bunch area, and fruit density. The bunch mass and fruit density relations were also analyzed. The results demonstrated that the Tenera variety shows denser fruits and higher density values, while Dura showed a stronger correlation between bunch mass and fruit density. Fruit density has shown a quite effective parameter in distinguishing between varieties while also supporting bunch mass estimation. Although ImageJ proved effective for image-based analysis, its limitations in automation and advanced features remain a challenge. Therefore, the integration of soft computing methods and automatic classification algorithms is recommended to enhance accuracy, improve efficiency, and expand the potential application of digital image–based classification systems for oil palm varieties.

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