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Relationship Between Oil Content and Fruit Surface Color in Oil Palm (*Elaeis guineensis* Jacq.)

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Abstract: This study was aimed at investigating the relationship between oil content in oil palm fruit and its surface color distribution. A total of 80 fruit samples were randomly collected from the field; each sample consisted of two individual fruits. Fruit samples were photographed digitally under room temperature and controlled lighting and then subjected to total oil analysis using soxhlet extraction techniques. The digital images were first rectified using Adobe Photoshop®. Rectified images were clustered and subjected to unsupervised classification using MultiSpec Application®. Quantification of surface color distribution was performed in Arc View®. Relationship between oil content and color distribution was determined using multiple linear regression. Results showed that total oil content ranged between 35.2 and 86.4%. Significant correlation was found between total oil and all color components, with black yielding the strongest correlation (r = -0.85), followed by red (r = 0.81), orange (r = 0.62) and yellow (r = 0.48). The relationship between total oil content and color components was best explained with the following regression models: (1) %Total oil = 88.08-0.52 (%Black)+1.30 log (%Yellow), and (2) %Total oil = 36.84+0.63 (%Red)+1.52 log (%Yellow). Both these models explained 80-81% of the variation in fruit color with 76-78% accuracy. When validated on a separate data set, these models showed 55-56% accuracy. The benefit of harvesting oil palm fruits based on the relationship between surface color distribution and total oil was estimated as USD 0.15 per tree per year.

Key words: Oil palm, fruit ripeness, FFB harvesting, image processing, surface color

Introduction

The harvested part of the oil palm is known as Fresh Fruit Bunch (FFB). Typically, the FFB harvest cycle begins 36 months after planting and stretches for a period of 18-22 years at 10-14 day intervals. Oil palm cropping is a very labor-intensive system in which labor consumes 37% of the total production costs, while the harvesting operations account for 76-85% of the total labor costs despite constant efforts toward mechanization.

At present, FFB ripeness is ascertained based on the number or percentage of fruits detached from the bunch and visible on the ground. Theoretically, it would take several hundred detached fruits to indicate that a bunch has reached maximum oil content (Corley and Law, 2001). Ground collection

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of detached fruits is costly when carried out manually but is necessary because they influence oil extraction rates. For this reason, commercial plantations carry out FFB harvesting based on the Minimum Ripeness Criterion (MRC), which usually ranges from 1-5 detached fruit per FFB (Ariffin *et al*., 1991; Teo and Yeang, 1992). However, the use of MRC can be questioned due to physical problems such as entrapment of fruits within the tree trunk and feeding of detached fruits by pests. Harvesting of FFB is essentially a compromise between consideration of oil quantity, oil quality and operating costs.

To ensure quality, the harvested FFB is physically graded just before it passes through the oil extraction process. The current method of grading FFB is an extremely tedious and time-consuming process that is prone to errors and inconsistencies. Further, it has a strong bias towards the FFB crushing facility (mill). More often than not, the ripeness standard used in the field and the grading standard employed in the mill appear to be dissimilar as a result of FFB handling, transportation and storage between the field and the mill.

It is therefore desirable to develop a better system of assessing FFB ripeness and grade that combines reporting accuracy, consistency and speed at reasonable cost. A system that implicitly quantifies FFB oil content based on measurable physical attributes, such as color or shape, of the oil palm fruit is one plausible option to consider.

Color is widely used as an inspection criterion for food quality, in that surface color of a fruit/vegetable indicates maturity or defects. Neuman *et al*. (1987) discriminated wheat classes and varieties by identifying color differences between wheat varieties. Wigger *et al*. (1988) used ratios of primary colors (red-green, blue-green and red-blue) to determine color differences in soybeans. These ratios were assigned a binary value depending on a predetermined threshold for analysis. Casady *et al*. (1992) used color information to develop an algorithm which was able to discriminate asymptomatic soybean seeds, immature seeds and seeds discolored by fungal damage. Similar color-based investigations have been performed on other food crops including potatoes (McClure, 1988; Tao *et al*., 1995), sweetpotato (Wooten *et al*., 2000), apples (Rehkugler and Throop, 1986; Tao *et al*., 1995) and peaches (Miller and Delwiche, 1989; Delwiche *et al*., 1987) to quantify external qualities such as size, shape and surface damage/bruises. Color information also has been used to estimate internal qualities such as chemical composition. Fadel *et al*. (2001) estimated sugar content of date palm for several varieties using the principal color (RGB) scheme. The intensities of RGB components of date fruits were calculated via an image-processing algorithm. It was found that date sugar content correlated significantly with the blue and red bands.

The objective of this study was to investigate the relationship between oil content of the oil palm fruit and the fruit surface color.

Materials and Methods

Study Location

This study was carried out in a commercial oil palm plantation located at Sungai Lilin, South Sumatra, Indonesia. The plantation is divided into four distinct management entities (estates) with estate size ranging between 900 and 3000 ha. The site selected for this study was Sungai Pelepah Estate, which comprised 2689 ha of single-variety (ASD, Costa Rica) plantings aged between 3 and 5 years. The FFB yield average varied from 3.9 to 5.7 mt ha^{-1} based on planting year.

Fruit Sampling

A total of 80 fruit samples were collected from random blocks bearing 5 year-old palms. These blocks were managed uniformly and were not subjected to any ongoing agronomic trial. Unbruised fruits were obtained consistently from the central periphery of healthy harvested FFBs. Each sample consisted of two individual fruits, which were similar in color composition and shape.

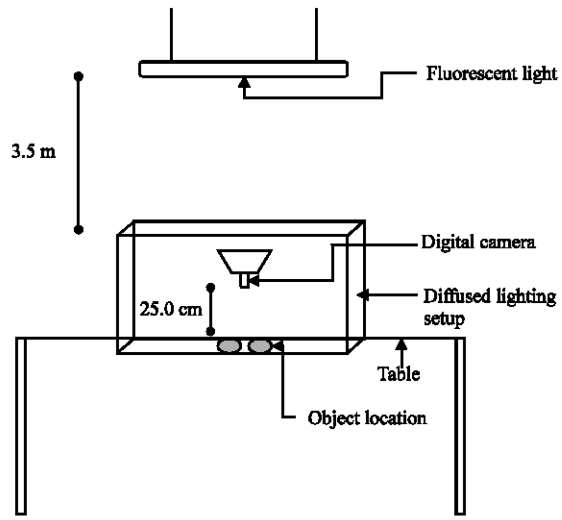

Fig. 1: Image acquisition setting

Data Acquisition

Fruit samples were photographed using a Canon Powershot 600 digital camera (0.5 million effective pixels, 7 mm lens). The photography was performed at room temperature (27°C) with illumination from a white 34-watt fluorescent tube (length: 1.22 m, diameter: 0.46 m). To overcome the glaring effect on the fruit image as a result of direct exposure to light, a diffused lighting setup was created using a cardboard box laced with white paper sheets in the interior and positioned 3.5 m below the fluorescent tube. Each sample was photographed against a white background to obtain both front and rear surface views at a constant distance of 25 cm between lens and object. The image acquisition setting is shown in Fig. 1.

After photography, each fruit was measured for length and width to derive a shape index, which was taken as the ratio of length to width. The shape index is reported as average values for each sample. Subsequently, the fruit samples were analyzed for total oil content using soxhlet extraction techniques. The formula used for determination of percent total oil is as follows:

$$\%\text{Total oil (wet basis)} = [(W6-W5) * (W3-W1)/(W2-W1) * W4] * 100$$

$$\%\text{ Total oil (dry basis)} = [(W6-W5)/W4] * 100$$

where:

W1 = Weight of beaker+cotton wool
W2 = Weight of beaker+cotton wool+sample
W3 = Weight of beaker+cotton wool+sample after drying
W4 = Weight of samples to be extracted
W5 = Weight of flask
W6 = Weight of flask + oil

Image Processing

Fruit images were processed using a suite of computer programs. Images captured in Joint Photographic Experts Group (JPEG) format were first viewed in Adobe Photoshop® Version 6.0 to separate each fruit within a sample and to establish the zone of interest. The ‘lasso’ function was used to eliminate shading effects at the fruit periphery. Rectified images were individually saved in Tag Image File (TIF) format. This amounted to four TIF images per sample (two individual fruits with front and rear views). The images were next loaded into MultiSpec Application®, an image-processing tool. Each TIF image was clustered using the isodata algorithm and then processed through unsupervised classification using the maximum likelihood procedure to create 40 classes. Histograms explaining the color intensity based on an RGB scheme was extracted for each image. Classified images were output as Geographic Information Systems (GIS) files. These files were re-saved in TIF format. The classified TIF images were retrieved as shape files in Arc View® Version 3.1. To facilitate further analysis, the shape files were converted to grid files. The images, each bearing 40 class segments, were manually re-colored using Arc View's color palette based on the eyeball-fit technique against the rectified image to produce visible colors, viz. black, red, orange and yellow. This was followed with a re-classification operation to aggregate each true color into single attribute values. Finally, attribute table analysis was performed to calculate the percentage of color distribution for each image. The color information was exported into a spreadsheet for data analysis.

Data Analysis

The true color distribution of fruits per sample was averaged two ways: between individual fruits and between surface views. For each of the 80 observations, data were expressed as %black, %red, %orange, %yellow, shape and %total oil. The full data set was partitioned into two sub data sets to facilitate model calibration and model validation. For model calibration, 50% of the total observations were selected randomly, amounting to 40 data points. The remaining data points were used for model validation.

Descriptive statistics were computed for all the variables. Supplementary to the descriptive statistics, normal quantile plots were constructed to describe data distributions. Detection of significant outliers was done using the Extreme Studentized Deviate (ESD) method (Rosner, 1983). Data transformation was performed for variables that deviated from normality.

Linear relationships between total oil content and color components/shape were investigated using correlation analysis. The predictive ability of color components and shape on total oil content was determined by regression analysis. Multiple Linear Regression (MLR) was performed using Arc® Version 1.04. Diagnostic tools employed to detect MLR violations were residual plots and non-constant variance plot. Model selection was based on a stepwise backward elimination approach. Validation of the final model(s) was evaluated using a linear fit between observed and predicted values. Regression models relating color components/shape and total oil content were used to estimate the economic benefit of harvesting at optimum ripeness based on current market price of FFB and plantation standards with regard to FFB weight, fruit to bunch ratio and planting density.

Results and Discussion

Data Distribution

Total oil content ranged between 35.2 and 86.4% with a 23.1% Coefficient of Variation (CV). Among fruit color components, red had the widest range in values, followed by black, orange and yellow (Table 1). However, the CV was highest for yellow, followed by orange, red and black. Fruit shape had the narrowest range and lowest CV. The high variability for yellow is due to 31% of the data set that had an almost negligible percentage of yellow.

All variables exhibited a fairly straight curve on the normal quantile plot indicating a normal distribution and hence did not require data transformation before proceeding to the next stage of data analysis. However, the distribution of yellow color indicated a cluster of low data values, which could affect final estimates during regression modeling. To overcome this potential effect, the variable yellow was transformed using a base-10 logarithm function.

Table 1: Descriptive statistics of the model calibration data set

	(%)					
Parameter (n = 38*)	Black	Red	Orange	Yellow	Total oil	Shape
Mean	51.11	39.83	8.20	0.95	58.55	1.26
Standard deviation	20.20	16.29	5.54	1.19	13.50	0.14
Standard error	3.28	2.64	0.9	0.19	2.19	0.02
Minimum	16.40	3.38	0.001	0.001	35.16	1.06
Maximum	96.75	66.00	25.00	4.48	86.35	1.61
Coefficient of variation (%)	39.52	40.89	67.58	125.48	23.07	11.13

* Based on the outlier test, two observation points were discarded from the data set

Table 2: Pearson correlation (r) between variables

Variable	Black	Red	Orange	§Yellow	R-band	G-band	B-band	Shape
Black	1							
Red	-0.97**	1						
Orange	-0.77**	-0.57**	1					
§Yellow	-0.21	-0.14	0.18	1				
R-band	-0.96**	0.93**	0.73**	0.21	1			
G-bande	-0.70**	0.63**	0.65**	0.07	0.79**	1		
B-band	-0.27	0.22	0.31	-0.18	0.37*	0.83**	1	
Shape	-0.13	0.07	0.23	-0.11	0.09	0.18	0.17	1
Total oil	-0.85**	0.81**	0.62**	0.48**	0.82**	0.55**	0.15	0.17

§Transformed into $\log_{10}$, ** Significant at p = 0.05 and p = 0.01, respectivily

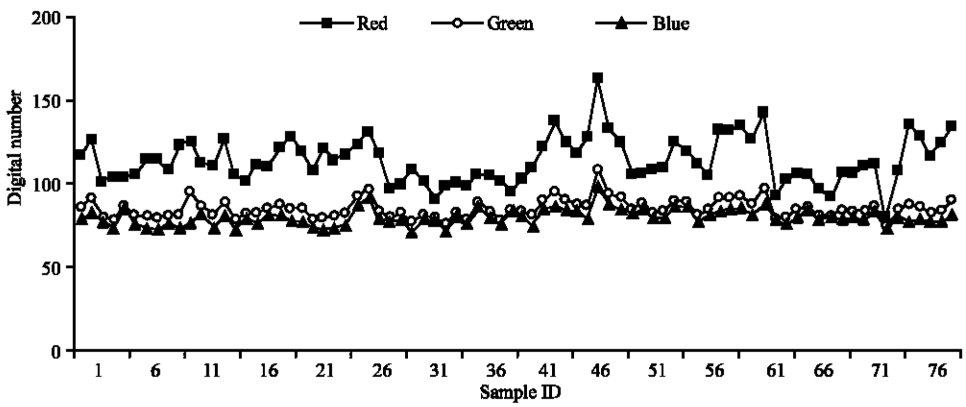

Fig. 2: RGB color intensity values for fruit samples (n = 80)

Captured images were each stored based on a 24-bit RGB scheme. Each color band in the RGB scheme produces different color intensity as measured by a Digital Number (DN). Figure 2 shows the mean color intensity values for the 80 observations. The red band showed a color intensity range of 79-137, while the green and blue bands recorded a range of 73-95 and 71-86, respectively. Fluctuations in color intensity, particularly for red, may be attributed to variability in fruit surface texture, luminance and photography angle.

Relationship Between Variables

The linear association between variables, including the RGB bands, is shown in Table 2. Results of the correlation analysis are interpreted based on Pearson values.

Visible color components (i.e., black, red and orange) were each significantly correlated with the red and green bands. Comparatively, these visible colors registered higher correlation values with the red band in the following order: black (r = -0.96), red (r = 0.93) and orange (r = 0.73). Significant correlation was found between total oil and all color components, as well as with the red and green bands. Among the color components, black yielded the strongest correlation (r = -0.85), followed by red (r = 0.81), orange (r = 0.62) and yellow (r = 0.48). This infers that fruits with a high percent total oil are associated with surface color that comprises a low proportion of black and high proportions of red, orange or yellow. Correlation between total oil and the red band registered an r-value of 0.82, which is comparable to that recorded for red color. As such, it seems justifiable to use visible colors instead of color intensity bands to predict the total oil content. The visible colors showed significant correlation between one another, such as black and red (r = -0.97), black and orange (r = -0.77) and red and orange (r = 0.59). Therefore, these colors would exhibit co-linearity in the model when used together as predictors.

Model Calibration

Fitted models to predict total oil content using fruit color and shape as predictors are shown in Table 3. Based on model fit assessment parameters such as R^2, sigma hat and lack of fit, sub-models 8 and 10 were found to be the most appropriate in predicting total oil content. As such, the relationship between total oil and surface color is best explained by the following regression functions:

- %Total oil = 88.08-0.52*Black+1.30*log (Yellow)
- %Total oil = 36.84+0.63*Red+1.52*log (Yellow)

Table 3: Linear regression models and their diagnostic attributes

Model (description)	Equation[Φ]	R^2	Sigma hat	Regression p-value	Lack of fit[Ψ] p-value
1 (full)	TO = 62.80-0.42*B+0.15*R-0.17*O+ 1.43*log(Y)+12.77*S	0.83	5.96	**	-
2 (sub)	TO = 87.43-0.57*B	0.71	7.31	**	0.668
3 (sub)	TO = 31.71-0.63*R	0.66	7.98	**	0.137
4 (sub)	TO = 46.17-1.51*O	0.38	10.75	**	0.750
5 (sub)	TO = 62.91-1.95*log(Y)	0.23	12.01	**	0.694
6 (sub)	TO = 37.60-16.65*S	0.03	13.49	ns	-
7 (sub)	TO = 91.07-0.61*B-0.19*O	0.72	7.38	**	-
8 (sub)	TO = 88.08-0.52*B+1.30*log(Y)	0.81	6.02	**	0.718
9 (sub)	TO = 31.63-0.57*R-0.51*O	0.69	7.74	**	-
10 (sub)	TO = 36.84+0.63*R+1.52*log(Y)	0.80	6.25	**	0.823

[Φ] Where: TO = %Total oil, B = %Black, R = %Red, O = %Orange, Y = %Yellow and S = Sahpe
[Ψ]computed only when all terms in the model show statistical significance, ** Significant at p = 0.01, ns = not significant

Essentially, total oil is inversely related to black but proportional to red and yellow. The selected final models explain 80-81% of the variation in fruit color. The relationship between measured and predicted total oil content from both selected models is given in Fig. 3. The R^2 values obtained for both model fits were 0.78 and 0.76, respectively, indicating that both models seem to predict total oil content with fair accuracy.

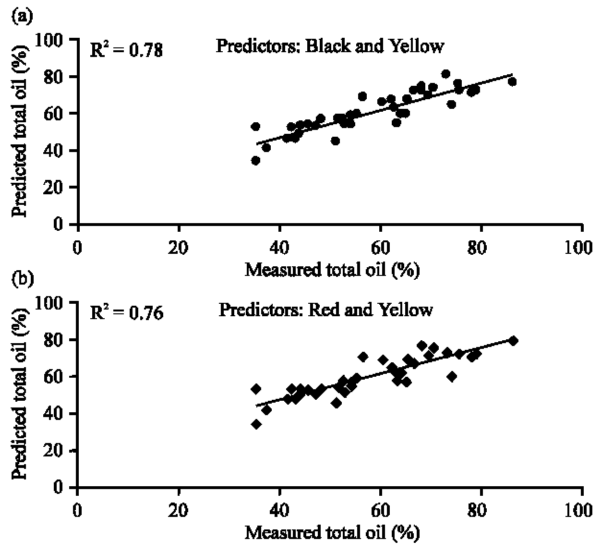

Fig. 3: Relationship between observed and predicted total oil content from (a) submodel 8 [% Total oil = 88.08-0.52 (% Black)+1.30 log (% Yellow)] and (b) submodel 10 [% Total oil = 36.84+0.63 (% Red)+1.52 log (% Yellow)]

Model Validation

The calibrated models were tested using the remaining 50% of the outlier-free full data set, which amounted to 37 data points. Descriptive statistics for this data set are given in Table 4.

In comparison to the calibration data set, the validation data set exhibited smaller variations in all of the variables except for yellow. Particularly, the CV for red was 13% lower, while the CV for yellow was 17% higher. For total oil, a narrower range of 38.7% was recorded as compared to the calibration data set.

Table 4: Descriptive statistics of the model validation data set

	%					
Parameter (n = 37*)	Black	Red	Orange	Yellow	Total oil	Shape
Mean	44.10	46.28	8.76	0.90	63.36	1.25
Standard deviation	15.72	12.88	5.53	1.28	10.65	0.16
Standard error	2.58	2.12	0.91	0.21	1.75	0.02
Minimum	17.93	19.00	0.50	0.001	40.93	1.05
Maximum	75.50	66.75	26.25	6.50	79.59	1.52
Coefficient of variation (%)	35.65	27.83	63.09	142.63	16.81	10.83

Based on the outier test, three observation points were discarded from the data set

Validation of both calibrated models, expressed as the relationship between measured and predicted total oil is given in Fig. 4. The fit between observed and predicted percent total oil from both models produced R^2 values of 0.56 and 0.55, respectively. This indicates that both models give reasonably accurate estimates of total oil content based on surface color composition.

Economic Inference

Results obtained thus far indicate that fruits with high total oil content are dominated by red color, while those with low total oil content are dominated by black color. Based on current understanding, high total oil content is a measure of true ripeness (Rajanaidu *et al*., 1988). Therefore, it is reasonable to infer that a dominant proportion of red color signals the optimum phase of fruit ripeness.

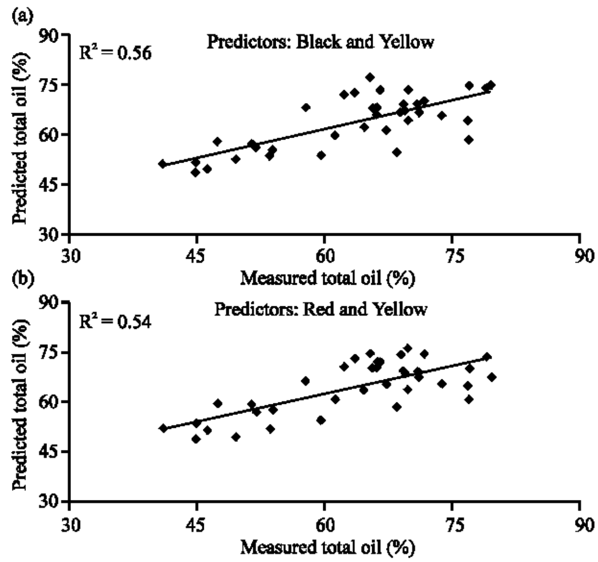

Fig. 4: Validation of (a) submodel 8 [% Total oil = 88.08-0.52 (% Black)+(1.30 log(%Yellow) and (b) submodel 10 [% Total oil = 36.84+0.63 (% Red)+1.52 log (% Yellow)]

The established empirical models were used to estimate the monetary benefit of harvesting at optimum ripeness. This was pursued using two contrasting scenarios, viz. ,1) fruit surface dominated by black color and 2) fruit surface dominated by red color. In both scenarios, percent black or red was taken as the mean±standard deviation, while percent yellow was fixed to reflect its mean. Mean and standard deviation values were averaged between the calibration and validation data sets. The model inputs for both scenarios are as follows:

	Scenario 1		Scenario 2	
Parameter	Black (%)	Yellow (%)	Red (%)	Yellow (%)
Mean	47.6	0.93	43.1	0.93
Standard deviation	8.0	-	14.6	-
Values used in model:	30, 48, 66	0.9	29, 43, 58	0.9

The economic assessment featured an extrapolative approach based on the following assumptions:

- A Fresh Fruit Bunch (FFB) contains 1500 fruits and the fruit loss per bunch due to injury, rotting and/or abnormality is 25% and
- The value of 1 unit of FFB (taken to consist of 1125 fruits) at a typical weight of 5 kg with 100% total oil is USD 0.47, which amounts to USD 9.40 per tree per year based on a standard bunch production rate of 20 FFB per tree per year and a planting density of 136 palms per ha.

The estimated monetary benefit of harvesting at optimum ripeness is given in Table 5. Based on the economic assessment, it is clear that monetary benefits increase when harvesting fruits that show

Table 5: Economic implication of this study

	Senario 1			Senario 2		
[1]Model	TO = 880.08-(0.52*B)+(1.30*logY)			TO = 36.84+(0.63*R)+(1.52*logY)		
Input	B = 30, Y = 0.9	B = 48, Y = 0.9	B = 66, Y = 0.9	R = 29, Y = 0.9	R = 43, Y = 0.9	B = 58, Y = 0.9
Predcted total oil (%)	72.42	63.06	53.70	55.04	63.86	73.31
[2]Value (USD):						
pertree per year	13.62	11.86	10.10	10.358	12.01	13.78
Per ha per year	1851.65	1612.33	1373.01	1407.27	1632.78	1874.40
Benefit (value per tree per year) comparison matrix:						
	Model input	B_{30} $Y_{0.9}$	B_{48} $Y_{0.9}$	B_{66} $Y_{0.9}$		
	R_{29} $Y_{0.9}$	-3.27				
	R_{43} $Y_{0.9}$		0.15			
	R_{47} $Y_{0.9}$			3.69		

[1]Where: TO = %Total oil, B = %Black, R = %Red, Y = %Yellow, [2]Extrapolated to represent an FFB based on a sample mean of two fruits

a higher percent red and/or lower percent black. When comparing both scenarios based on the mean values for red and black, the Estimated Monetary Return (EMR) was US $0.15 per tree per year for scenario 2 relative to scenario 1. This benefit translates to US $204,000 when extrapolated to a plantation scale of 10,000 ha. At one standard deviation below the mean, the EMR showed a loss of US $3.27 per tree per year relative to scenario 2. However, at one standard deviation above the mean, the EMR showed a profit of US $3.69 per tree per year relative to scenario 2. It appears that the distribution of percent red on the fruit surface, especially at values above the mean, results in a higher EMR. The reverse is true at values below the mean. Therefore, it seems reasonable to assume that the economic and optimum amount of red color, in terms of percent distribution, lies somewhere between the mean and one standard deviation above the mean.

Study Implication

This study outlines an empirical method to estimate total palm oil content based on external (surface) fruit color. It lays the foundation for the development of a sensor-based system that can capture the distribution of fruit color to enable accurate and rapid oil yield estimation across the field/plantation. Such a system should be equipped with complementary hardware and software components to ensure effective image acquisition, analysis and quantification of color distribution. The following discussion delineates the possible application of this method with regard to quality determination, ripeness and grading assessment and yield mapping for site-specific management.

Oil analysis is routinely performed, often in a destructive manner, to derive the Oil Extraction Ratio (OER). Southworth (1976) defines OER as the amount of extractable oil per weight of FFB. The OER serves as a quality index for FFB production and ranges from 18-28% depending on stand age. When deriving the OER, the weight of the extracted product is obtained via direct measurement while the product content of the input material (i.e., FFB) can only be determined by sampling methods. Unfortunately, the sampling procedure is often complicated by high fruit variability. Another limitation to routine oil analysis is the high analytical cost involved. Estimating oil content based on surface color distribution offers a non-destructive option at potentially cheaper cost.

A common cutoff range for fruit ripeness as measured by total oil content is 65-70%. This means that fruits testing lower than 65% are classified as unready for harvest. However, this assessment is often not in harmony with the Minimum Ripeness Criterion (MRC) that is used to decide whether an FFB is ripe and ready for harvest. Also, the MRC seldom conforms directly to the grading standards employed at the crushing facility. Using the models developed in this study, fruit ripeness level can be conveniently ascertained in advance, thus facilitating a more coordinated harvest operation. In addition, these models when incorporated with the proposed sensor-based system can offer an alternative to the MRC and possibly automate the grading procedure.

A major factor that impedes site-specific management in oil palm plantations is the unavailability of a practical yield mapping system. It is challenging for plantations to record and map yields at the precise scale required for site-specific management due to pressing labor and logistical issues. Regression models developed in this study can be exploited to perform actual or projected yield mapping at the desired scale.

Conclusions

The surface color distribution of oil palm fruits was found to correlate significantly with total oil content. Total oil was negatively correlated with black but positively correlated with red, orange and yellow. However, there was no relationship established for total oil and fruit shape. Regression models were developed to predict total oil based on color distribution. In the first model, black and yellow were used to predict total oil based on the following equation:

$$\%\text{Total oil} = 88.08 - 0.52\ (\%\text{Black}) + 1.30\ \log\ (\%\text{Yellow})$$

In the second model, red and yellow were used as predictors based on the following equation:

$$\%\text{Total oil} = 36.84 + 0.63\ (\%\text{Red}) + 1.52\ \log\ (\%\text{Yellow})$$

Both models explained 80-81% of the variation in fruit color with 76-78% accuracy. These models were validated with 55-56% accuracy.

From an economic perspective, the estimated monetary return of harvesting fruits based on relationship between surface color distribution and total oil was USD 0.15 per tree per year.

The findings of this study suggest that it would be beneficial to develop a sensor-based system that can estimate oil yield accurately and rapidly to facilitate FFB quality determination, ripeness and grading assessment and yield mapping for site-specific management of oil palm.

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