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Full Length Research Paper

Surface color based prediction of oil content in oil palm (*Elaeis guineensis* Jacq.) fresh fruit bunch

K. Sunilkumar* and D. S. Sparjan Babu

Indian Council of Agricultural Research, Pedavegi–534 450 West Godavari District, Andhra Pradesh, India.

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The oil palm, a perennial oil yielding crop, is the richest source of vegetable oils which can produce 4 to 6 MT of palm oil (mesocarp oil) and 0.4 to 0.6 t of palm kernel oil per hectare per annum. The extent of oil available/extractable depends on the ripeness stage of the fruits. The present study was undertaken to evaluate different maturity stages of oil palm fruits in terms of color and oil content, establish their inter relationship and to develop prediction models based on color values so that non destructive ripeness evaluation could be achieved. Models developed with Red, Green and Blue (RGB) values showed that the oil content on fresh fruit bunch (FFB) could be predicted with 57 to 66% efficiency. Models developed using L*a*b* values could predict oil content in fresh fruit bunches up to 79% accuracy. Validations of the models were done with different data sets. The RGB based model showed 64% accuracy in prediction. The L*a*b* model upon validation could predict oil percent up to 89% accuracy. The L*a*b* based model would be ideal for incorporating in gadgets like colorimeters for the purpose of color based grading of FFB and prediction of oil content. Further, it will be useful in automation of harvesting through a machine vision system. This will finally help in harvesting at correct stage of ripeness and objective grading as well as price fixation of oil palm FFB.

Key words: Oil palm, fresh fruit bunch, color grading, L*a*b* color space, mesocarp oil.

INTRODUCTION

The oil palm, a perennial oil yielding crop, is the richest source of vegetable oils which can produce 4 to 6 MT of palm oil (mesocarp oil) and 0.4 to 0.6 t of palm kernel oil per hectare per annum. The maturity of oil palm fresh fruit bunches (FFB) at harvest is an important factor affecting quantity and quality of oil recovered. In case of immature fruits, the oil content is less which in turn results in low oil extraction ratio (OER). It was revealed (Oo et al., 1986) that 41.4% of mesocarp oil is accumulated between 16 and 20 weeks after pollination and another 18.9% later. Over mature fruits will drop from the bunch which incurs more labour for collection of the same. Otherwise loss of the equivalent quantity of oil would be the result. Further, the free fatty acid (FFA) content of over mature fruit tends to increase rapidly after harvest. Hence, harvesting at correct maturity stage and grading plays a key role in achieving maximum OER. Manual grading can be biased and the farmer may not be convinced of the price of the produce. Development of suitable grading system can help to separate the FFB into distinct groups based on maturity and price fixing could be made on that basis. Hence, a reliable system of maturity evaluation and grading forms the basis for optimizing the oil yield and quality as well as for price fixation of FFB (Alfatni et al., 2008; Sunilkumar and Sparjan, 2010).

Colour is an ideal maturity index which can be measured easily, non-destructively and is distinct at different levels of ripeness for many agricultural commodities. Although, many colour scales were developed for the purpose, the predominant one used for fruit and vegetable grading is Hunter 'Lab' or CIE L*a*b*. L* a* b* is the set of standards adopted by the International Commission on Illumination (CIE: *Commission*

*Corresponding author. E-mail: sunilk.icar@gmail.com. Tel: +91 8812259532/524. Fax: +91 8812259531

International de l'Eclairage) in order to define the color in absolute terms and is a widely used and accepted colour measurement system. It is a simplified cube root version of the Adams-Niclearson space produced by plotting the quantities of L* a* b* in rectangular coordinates. The L* refers to lightness or darkness of the colour; a* indicates the change from Red to Green colour and b* indicates the change between Yellow and Blue. Standard colour chips are available for assessment of maturity of including peaches (Delwiche and Baumgardner, 1985) and colour charts are used to assess tomatoes (McGlasson et al., 1986; U.S.D.A, 1975). Colorimeter showed potential for maturity assessment of tomatoes (Yang et al., 1987). Reports suggested that that there is positive association between oil content and colour development in oil palm (Choong et al., 2006; Razali et al., 2008). The Malaysian Palm Oil Board indicated the possibility of using a colour meter for objective grading of oil palm FFB (Omar et al., 2003; Razali et al., 2011). A Lab color space based prediction model for maturity of Granny Smith apple was developed (Tijskens et al., 2010).

Machine vision system of grading could be developed based on the standard color values that reflect oil content in the mesocarp. The prediction model would form the basis of grading different categories of FFB depending on color and the current understanding is that total oil content is a measure of true ripeness (Rajanaidu et al., 1988). A machine vision system was developed (Xu and Zhao, 2010) for strawberry grading which used a* channel as dominant color criteria with 88.85 accuracy in grading. The CIE LAB color space was employed for evaluating egg plant quality (Chong et al., 2008). A machine vision system based on RGB color values was developed for automated sorting of pomegranate arils (Choong et al., 2006). Extraction of features like calyx color, size and shape for grading of egg plant through machine vision was developed (Chong et al., 2008).

Alfatni et al. (2008) analyzed color density to determine the ripeness of bunch based on RGB color model to distinguish between ripeness categories of oil palm FFB; and he found overall relationship between content based on Pearson co relations r^2 is 0.84.

The present study was aimed at analyzing the changes in color and oil content of fruits at varying stages of ripeness and establishing their relationship. The association between oil content and color of fruit bunch could be employed in developing models for non destructive estimation of oil content in the oil palm fresh fruit bunch. This would help avoid laborious and time consuming laboratory method of oil estimation and can help mechanise the grading procedure.

MATERIALS AND METHODS

There are mainly two fruit types in oil palm based on color: *Nigrescence* as well as the *Virescence* type. During ripening the fruit color of *Nigrescence*, changes from black /dark purple to dark red while in case of *virescence* the color changes from dark green to deep orange and hence they were studied separately. The present paper deals with the measurement of color and development of prediction models for *virescence* type which is having distinct color changes during ripening. The ripeness stages were decided according to the description provided by Malaysian Palm Oil Board (MPOB) with required modification.

The experiment was conducted by harvesting bunches at varying ripeness stages viz. unripe, under ripe, ripe and over ripe of Tenera variety grown under irrigated conditions. Color parameters were measured in two scales viz. in CIE L*a* b* color space as well as in RGB values. Different bunch samples were used for measurement of color with respect to different scales. Hunter colorimeter D25LT was used for obtaining color values on Lab scale. The bunches were cleaned for dirt and placed on the sample holder position in such way that the middle portion of the bunch was focused and then the bunch was rotated to collect images/values from three positions along the same circumference. The instrument was standardized by using standards (perfect reflecting difusser) given by the Hunter lab Associates. Standardization is done by placing the black glass at the sample port and then setting the scale which is reflected to a calibrated standard white tile (TS-102030).

For RGB values, the images of bunch with varying ripeness stages from unripe to over ripe stages were captured (avoiding irregular colored portions) using Sony DSC-F828 digital camera. The distance between camera and bunch sample was kept constant and images were captured following the method suggested by Choong et al. (2006). The pixel size was 1280 × 960. The images were then converted into three basic colors (RGB) using Adobe Photo shop 7.0. The intensity of each color was recorded by performing histogram analysis which counts the total number of pixels in each grayscale value and graphs it. Then, mean of three images taken from three positions along the same circumference was taken as value of a particular sample.

Laboratory analysis were carried out simultaneously using the mesocarp samples to determine the change in oil content (Soxhlet method) on wet weight basis at each ripeness (color) stage under study. Statistical analysis of the data was performed by descriptive analysis, correlation analysis and linear regression models were developed through Step wise as well as Enter method using SPSS version 17.0

RESULTS AND DISCUSSION

L* a* b* values and oil content

The total mesocarp oil content varied from 6.46 to 68.13% with a standard deviation of 16.09 (Table 1). The high variance in oil content could be attributed to the presence of significant number of unripe bunches having low oil content. With respect to L*, values ranged from 34.24 to 52.03 with standard deviation of 4.16. The a* values, which stands for the change from green to red, had second highest variance ranging from -7.56 to 33.92 with a standard deviation of 9.87. The b* values varied from 3.09 to 49.54 with a standard deviation of 6.774. The variance was maximum for oil content which was followed by a* and b*. Correlation with oil content was positive and significant for a* (0.85) followed by, L*/b* (0.53) and a*/b* (0.36), whereas the correlation was significantly negative for L* (0.64) and b* (0.30).

Table 1. Descriptive statistics for L*a*b* values.

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Oil (%)	104	6.46	68.13	42.50	16.09	259.04
L*	104	34.24	52.03	42.78	4.16	17.31
a*	104	-7.56	33.92	23.00	9.87	97.44
b*	104	3.09	49.54	37.84	6.77	45.88
L*2a*	104	1.01	12.97	1.25	1.17	1.36
L*/b*	104	-19.60	4.60	0.42	4.68	21.86
a*/b*	104	-.24	8.67	0.69	0.85	0.73

Table 2. Descriptive statistics for RGB values.

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Oil (%)	50	0.35	60.50	39.96	17.47	305.26
Red	50	57.69	230.06	134.72	43.02	1851.023
Green	50	39.41	114.74	77.29	21.58	465.77
Blue	50	14.56	81.95	42.72	14.59	213.14
Red/Green	50	0.91	2.90	1.79	0.48	0.23

Table 3. Linear regression models with L*a*b* and their diagnostic attributes.

Model no.	Equation	R^2	Adjusted R^2	Std error of the estimate	R^2 change	P value
1	Oil (%)=10.537+1.39a*	0.726	0.724	8.46	0.73	**
2	Oil (%)=64.076+1.159a*-1.127L*	0.791	0.787	7.43	0.07	**
3	Oil (%)=77.9-1.576L*+0.566a*+0.529b*-10.727 L*/a*-0.086 L*/b*+18 a*/b*	0.801	0.789	7.39	0.80	**

RGB values and oil content

The mean oil content varied from 0.35 to 60.50% with an average of 39.96 and standard deviation of 17.47 (Table 2). The red color values ranged from 57.69 to 230.06 with an average of 134.72 and standard deviation of 43.024. Correlation analysis indicated that positive and significant association exist between oil content and Red/Green ratio (0.76) followed by Red (0.56). Whereas Blue values showed negative association (0.316) with oil content. Further, Green and Red/Green values showed indirect positive association with oil content through Red. Similar correlation of oil content with most of the color values was reported earlier (Alfatni et al., 2008) using individual fresh fruit bunch images in oil palm.

Model development

L a* b* values*

Linear regression was performed by Enter as well as Stepwise methods for developing suitable prediction models for oil percent based on the fruit surface color and the models are presented in Table 3. The regression standardized normal P-P plot is presented in Figure 1.

RGB values

Different models could explain 57 to 66% variation in fruit surface color. Of these (Table 4), model 2 and 3 could be considered promising where adjusted R^2 was high and R^2 change was low. In case of model 4, though adjusted R^2 was equally good, the R^2 change was also more and hence excluded from validation stage. The model 1 was having comparatively less efficacy of prediction. The regression standardized histogram and normal P-P plot are presented in Figure 2.

Model validation

Model based on L a* b* values*

For validation of the model, different data sets of 26 values were used (Table 5). The variance component was more or less equal to that of the original data set for

Table 4. Linear regression models with RGB and their diagnostic attributes.

Model no.	Equation	R^2	Adjusted R^2	Std error of the estimate	R^2 change	P value
1	Oil (%)=-9.233+27.49R/G	0.579	0.571	11.45	0.579	**
2	Oil (%)=-32.73+30.991R/G+0.233G	0.646	0.631	10.62	0.066	**
3	Oil (%)=-57.812+37.054G+0.318B	0.689	0.669	10.05	0.043	**
4	Oil (%)= - 6.571+.012R+.210G+.320B+36.29R/G	0.689	0.662	10.16	0.689	**

Table 5. Descriptive statistics for L*a*b* values of validation data.

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Oil (%)	26	2.69	60.50	42.21	16.56	274.14
L*	26	34.60	50.48	42.60	3.95	15.56
a*	26	-6.56	33.17	22.06	11.51	132.50
b*	26	24.28	48.68	37.29	6.17	38.11
L*/a*	26	-17.00	4.21	0.41	4.39	19.31
L*/b*	26	1.02	1.65	1.16	0.149	0.02
a*/b*	26	-0.21	1.09	0.61	0.36	0.13

Table 6. Descriptive statistics for RGB values of validation data.

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Oil (%)	69	23.48	59.41	43.69	9.89	97.89
Red	69	86.81	189.15	134.28	29.19	852.45
Green	69	38.09	107.14	74.99	19.81	392.38
Blue	69	27.47	61.47	39.35	9.02	81.33
Red/Green	69	1.15	2.50	1.85	0.37	0.14

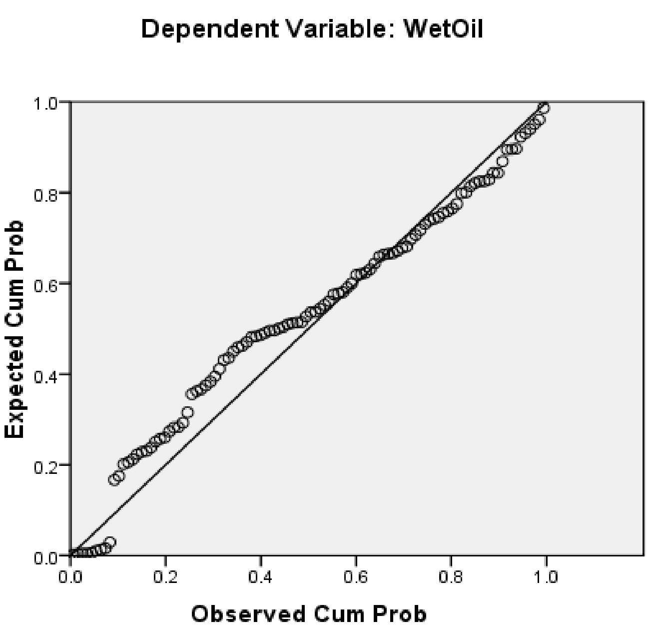

Figure 1. Normal P-P plot of regression standardized residual.

most of the parameters. The fit between observed and predicted oil percent was 0.88 for model 1 (Figure 3) and 0.89 for model 2 (Figure 4), which indicated good accuracy of prediction. This is very high for a heterogeneous biological material like oil palm FFB. The result was in agreement with the findings of Xu and Zhao (2010) in case of strawberry grading.

Model based on RGB values

Validation of the Model 2 was carried out with a different data set of 69 values and the descriptive statistics are presented in Table 6. The oil content varied from 23.48 to 59.41% with a mean of 43.68 and standard deviation of 9.89. The variance components are comparatively lower for the validation data set than that used for model development. The variance for red, green, Blue color values as well as red to green ratio was lesser for validation data set. The variance of oil content was reduced to 32% of the original data set. The relation between observed oil and predcted oil as per model 2 is given in

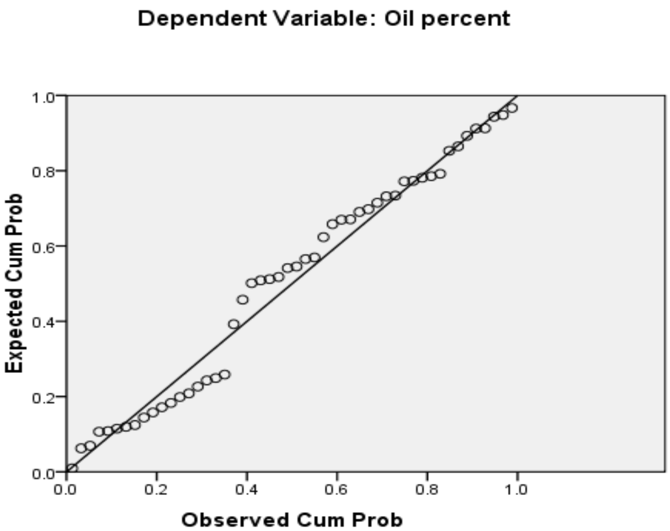

Figure 2. Normal P-P plot of regression standardized residual.

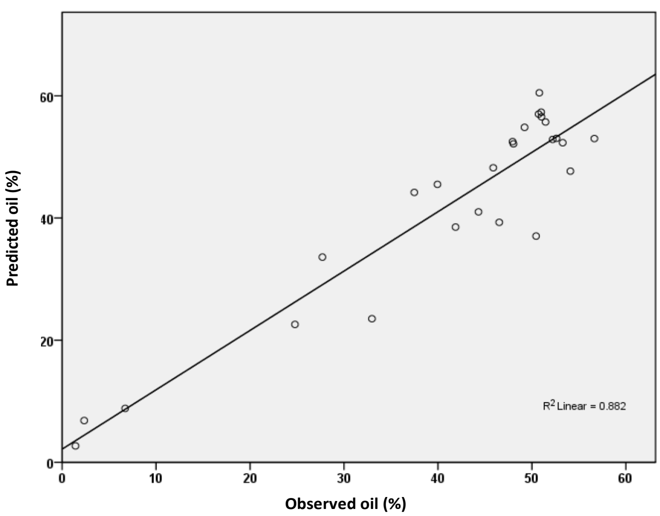

Figure 3. Validation of model 1.

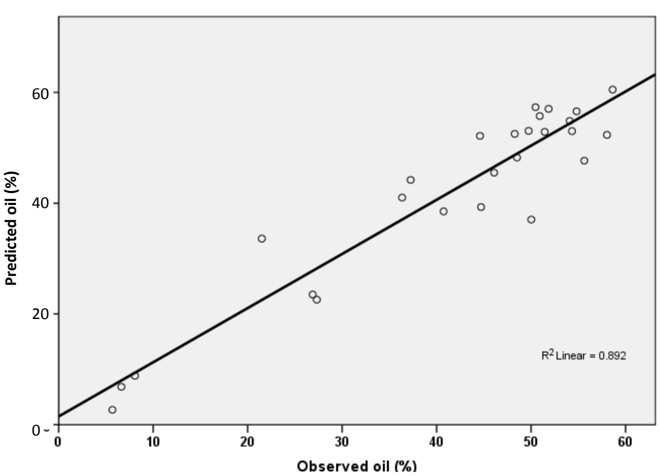

Figure 4. Validation of model 2.

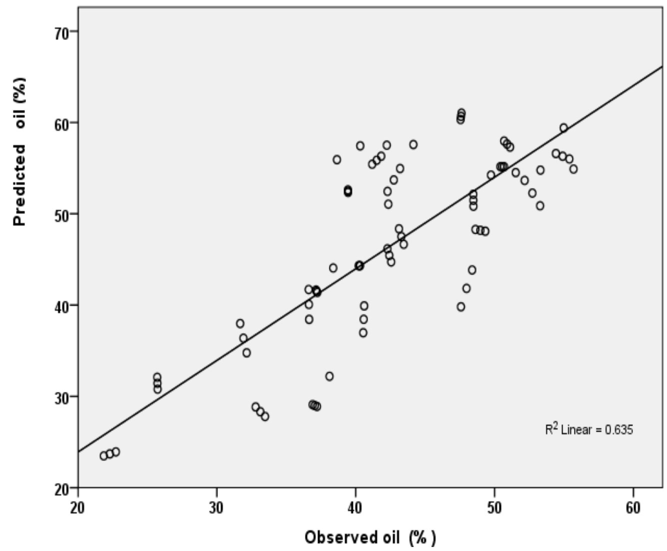

Figure 5. Validation of RGB model 3.

Figure 5. The fit for the two values was 0.63 using the model. Oil (%)=-57.812+37*Green+0.31*Blue, indicating reasonable accuracy for prediction purpose. The oil content of fruit in mesocarp and digital value was increased with increasing the stages of maturity which was also found by Abdullah et al. (2002), Omar et al.(2003), Rashid et al. (2004), Choong et al.(2006) and Balasundram et al.(2006). Thus it could be established that from L*a*b* values of the FFB images has strong relationships with oil content of mesocarp.

Conclusion

The oil palm is a very labour intensive crop and harvesting operations account for 76 to 85% of total labour cost (Balasundram et al., 2006). Present maturity assessment is based on the number of fruits fallen and normally five fruits is the standard. However, while five fruits are visible on the ground, many more must have fallen and got trapped in the frond (leaf) bases in the crown. Moreover, fruits from the outer layer of the bunch which are having maximum oil in the mesocarp are lost in this way, aggravating oil loss. Harvesting of under ripe bunches lead to reduction in extractable oil (OER). As a result of present study, prediction models were developed to estimate the oil content through non destructive means. The model viz., Oil (%)=64.076+1.159a*-1.127L* was the most promising and the same could be validated with accuracy of 89%. This will help in proper assessment of maturity by non destructive means and hence enable timely harvesting. Moreover the models could be incorporated in gadget like colorimeter for rapid and reliable maturity assessment in field. This will also be useful for mechanization of oil palm FFB harvesting through computer vision system.

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