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Prediction of Color Level and Chlorophyll Content of Corn (*Zea mays* L.) Leaves by Using Mobile Phone Cameras

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Abstract. This study aimed at designing a method to determine color level of corn leave and to estimate chlorophyll content using mobile phone cameras. The image of the leafs are captured with hand phone camera, and then the R, G, B color components are extracted. Four levels of color levels were used as those of leaf color card issued by IRRI. As for the natural light compensation, the colors of the Indonesian national inhabitant ID card were used as color references. The leafs were placed on the ID card, captured together, and then the leaf color level is determined by the variation of the grey levels of the leaves and the color references. The chlorophyll content were measured with SPAD chlorophyll meter. The average accuracy of leaf color prediction were 81.48% for sweet corn and 76.82% for hybrid corn under various field luminance, while the accuracy were 94.45% under a fixed 1500 lux luminance. The accuracy of chlorophyll prediction was very low with and $R^2 = 0.4762$ for sweet corn and $R^2 = 0.5284$ with national ID card references for hybrid corn. This low results were relatively contrast with the prediction from manual measurement of leaf color level, where the correlation coefficients were $R^2 = 0.8466$ for sweet corn and $R^2 = 0.8506$ for hybrid corn.

1. Introduction

Early stage of precision farming is characterized by variable rate fertilizer application referring to the plant appearance. Leaf color is an easy way to predict of nutrient sufficiency status of plant, even with human eyes. Leaf color chart (LCC) is a simple technology created for determining the leaf color level (LCL) and then used as a reference for determining the N fertilizing dose. Variable N fertilizing rate based on LCC reference has been applied in India, it was found that the N fertilizer and pesticide requirement decreased [1]. For maize, the use of LCC for fertilizing dose give better yield as compared to blanket dose [2].

With current wide spread of mobile phone technology, and the possibility of using mobile phone camera to capture leaf images, the LCC tool can be replaced by the phone camera. At the same time, related applications can be added into the mobile phone. The merit of using mobile phone camera is its practicability, and it is available at all time as it is always brought by farmers.

Some researches have been done to recognize the color level of leaf, as well to determine the fertilizing dose based on the predicted leaf color level. An Android application to predict leaf color level and determine N fertilizing dose has been developed [3]. The leaf color is determined based color value (CV) which is derived from RGB channels. A considerable high accuracy was obtained. Another researcher extracted the RGB, HSV, and L^* , a^* , b^* channels to predict leaf color level [4]. It was found that the G, b^* , and V single channel give good accuracy, while combination of two channels give better accuracy. In another research [5] found that L^* , a^* , b^* channels give a low RMSE and high determination coefficient in predicting SPAD values.

Along with using automatic digital camera of mobile phone, environment light condition much affect the captured images. Therefore the data of leaf color is difficult to obtain [6]. In order to recognize the leaf color, reference colors are required. [7] used a white paper and palm skin as



the reference colors. White paper is not practical since it is not available at all time for the farmers, while the palm skin is reliable since its color may vary over different farmers. This research try to overcome those problems by introduction new tools for reference colors. The objectives of the research was to develop methods to predict leaf color level of corn leaves and to predict chlorophyll content (SPAD index) of the leaves by using hand phone cameras.

2. Research Method

2.1. Materials and Instruments

Materials used in this research were corn leaves with various color levels. The leaves were taken from corn plants which were intentionally cultivated with various fertilizer treatments making various levels of color levels from yellowish to dark green. Fives brands of Android mobile phones were used to capture the images of the leaves. As for the standard color levels, the 4-levels leaf color chart issued by IRRI (International Rice Research Institute) were used. The chart contains 4 levels of color, from yellowish, light green, green, and dark green named levels '2', '3', '4', and '5' respectively. The hand phones and the leaf color chart are shown in figure 1.

As reference colors, the Indonesian electronic ID card were used. The card has 3 colors in its drawing: blue (ocean), yellow (eagle), and green (island). The card were used because of its practicability, all farmers bring it all the time. For chlorophyll content measurement, the Minolta SPAD were used.

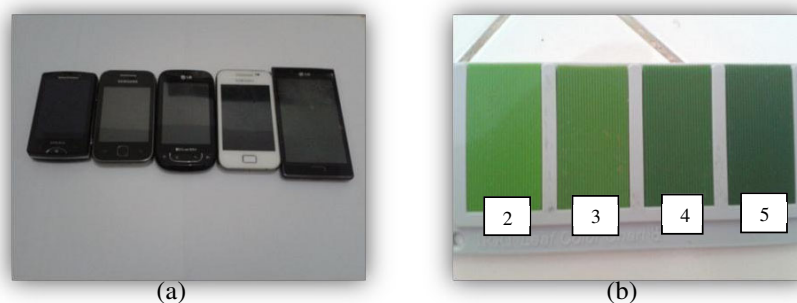


Figure 1. The five brands of Android hand phones (a) and IRRI 4-level leaf color charts (b)

2.2. Image Capturing and Color Level Formulation

Images of corn leaves were captured as the following way. A part of corn leaf was placed on the electronic ID card as shown in figure 2. The leaf and the card are captured together, the color of four points are taken: leaf, ocean, eagle, and island colors. The ocean, eagle, and island colors will become the reference color for the leaf color. As the natural light vary, the change in leaf color will be followed by the changes of other colors.

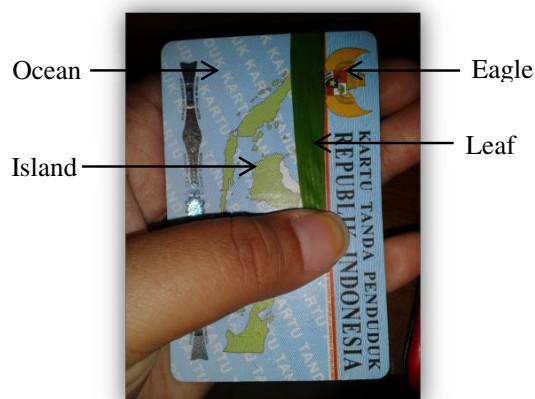


Figure 2. Position of corn leaf on the ID card for image capturing

Over the changes of the four color, the trend of changes are predicted to be in regular order. When one color tends to become lighter, other colors will become lighter. On the opposite, when one color tends to become darker, other colors will become darker too. Therefore, the difference of the darkness (indicated by grey scale) of two colors are seemly constant. The formulation are as follows:

$$\text{IF } GO - GL = [a_i, b_i]; \text{ GE - GL} = [c_i, d_i]; \text{ GI - GL} = [e_i, f_i] \text{ THEN CL} = i \dots\dots\dots (1)$$

$$GL, GO, GE, GI = (R + G + B) / 3 \dots\dots\dots (2)$$

Where GL : grey scale of leaf image
 GO : greasy scale of ocean image
 GE : grey scale of eagle image
 GI : grey scale of island image
 a_i, b_i, \dots, f_i : constants for color level i
 i = predicted color level : 2,3,4,5

The true leaf color levels were measured manually using the IRRI 4-level leaf color chart. Thousands of corn leaves were collected for calibration process until a consistent $a_i, b_i, c_i, d_i, e_i, f_i$ constants were obtained, and thousands other were collected for validation process.

Image capturing were done in the morning 6.00-10.00 AM and afternoon 3.00-5.00 PM under various environment brightness ranging from 200 to 12000 lux. Three crop ages were selected: before the first fertilizing (9-12 days after sowing), before the second fertilizing (21-25 days after sowing), and before the third fertilizing (32-36 days after sowing).

2.3. Chlorophyll Content Formulation

With the same samples used for calibration of equation 1 and 2, the leaves were also measured with SPAD instrument in order to measure the chlorophyll content. The relationship of leaf color level and chlorophyll content were formulated with linear regression, both the manual measurements and the image-based predictions.

3. Results and Discussions

3.1. Calibration and Validation of Color Level Prediction

Calibration process is intended to obtain the constants $a_i, b_i, c_i, d_i, e_i, f_i$ in equation 1. The best combinations of the constants are shown in table 1.

Table 1. Constants obtained from calibration process

Leaf color level - LCL (i)	Hybrid corn						Sweet corn					
	GE-GL		GI-GL		GO-GL		GE-GL		GI-GL		GO-GL	
	a_i	b_i	c_i	d_i	e_i	f_i	a_i	b_i	c_i	d_i	e_i	f_i
2	24	55	49	79	79	99	44	65	64	84	84	104
3	56	74	80	89	100	115	66	75	85	99	105	115
4	75	85	90	99	116	129	76	85	100	112	116	126
5	86	110	100	126	130	150	86	100	113	125	127	152

After the calibration process, images of new leaves were captured for validation process. As shown in table 2, for example, in predicting 376 leaves with LCL 2, 315 leaves of hybrid corn were predicted correctly, while 60 leaves were recognized as LCL 3 making the accuracy was 83.78%. Low accuracy was shown by LCL 5, many of the leaves were recognized as LCL 4. This is because the fact that the colors of LCL 4 and LCL 5 are similar (Figure 1b). Here the natural light affect the result of prediction as the true color data is difficult to be obtained.

A special experiment was carried out in order to eliminate the various environment effect. The image capturing were done in a constant 1500 lux light condition. The accuracy is shown in

table 3. Higher accuracies were obtained, but still the accuracy of LCL 5 was still the worst.

Table 2. Validation of the prediction model

Measured LCL	Sample number	Hybrid corn				Accuracy	Sample number	Sweet corn					
		Number of Sample Predicted as LCL						Number of Sample Predicted as LCL					
		2	3	4	5			2	3	4	5		
2	376	315	60	0	0	83.78	756	613	122	2	0	81.08	
3	4064	234	3505	320	3	86.25	2171	149	1833	167	4	84.43	
4	1926	10	176	1615	121	83.85	2714	42	288	2219	146	81.76	
5	136	2	11	25	98	72.06	105	2	11	22	63	60.00	
Average						81.48	Average						76.82

Table 3. Accuracy of LCL prediction at 1500 lux luminance

Measured LCL	Sample number	Number of Sample Predicted as LCL				Accuracy
		2	3	4	5	
2	232	222	10	0	0	95.69
3	292	2	11	271	7	92.81
4	254	0	10	240	4	94.49
5	131	0	0	15	115	87.79
Average						92.69

Accuracies among telephone brands were similar. The different were probably because of the different in automatic color compensation, in which different brand may have different self light adjustments. As shown in table 4, capturing in random brightness showed lower accuracies as compared to those in constant brightness.

Table 4. Accuracy of LCL prediction among telephone brands

Telephone Brand	Accuracy at various condition (%)		
	Hybrid corn, Random brightness	Sweet corn, Random Brightness	Random corn, Fixed brightness 1500 lux
1	78.00	76.00	94.50
2	78.25	72.50	93.75
3	76.00	73.50	93.50
4	84.00	70.50	92.50
5	75.50	72.50	89.75

3.2. Prediction of Chlorophyll Content

Relation of LCL and SPAD Index are formulated in linear regression models. Figure 3 shows the relation between manually measured LCL and SPAD Index. The determination coefficient are relatively high: 0.8506 for hybrid corn, and 0.8466 for sweet corn. These determination coefficients are considerably higher those of telephone-measured LCL as shown in figure 4 figuring 0.4762 for hybrid corn and 0.5284 for sweet corn. The lower values those of telephone-measured LCL are clearly caused by errors in the prediction of the LCL (table 3 and table 4)

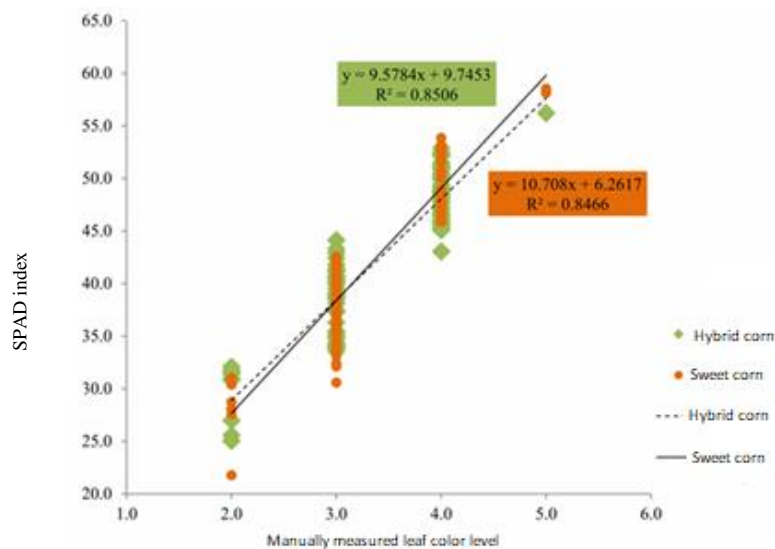


Figure 3. Relationship between manually-measured LCL and SPAD index

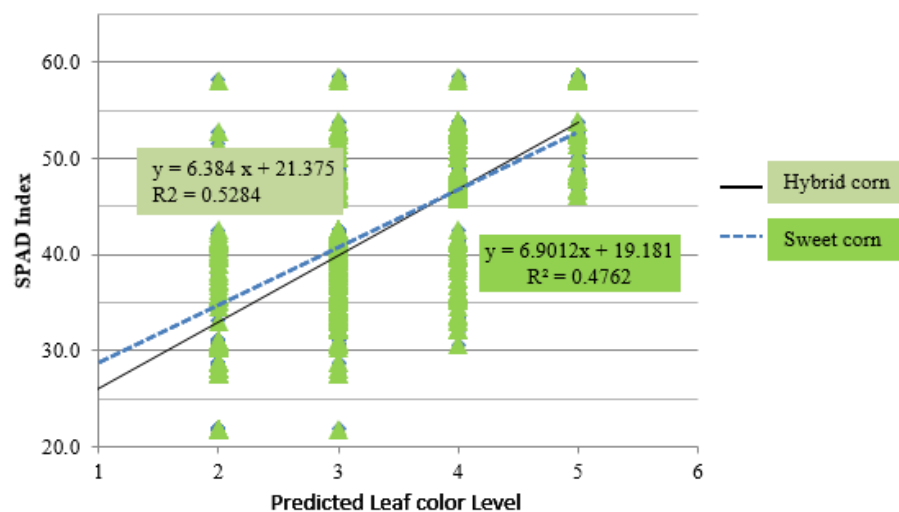


Figure 4. Relationship between telephone-measured LCL and SPAD Index

4. Conclusions

It can be concluded that:

1. Different brand of mobile phone give different color detection as expressed with R,G,B components making different results of leaf color level prediction. A unique calibration process is required for each hand phone brand.
2. Reference colors using national ID Card gave a moderate agreement in predicting leaf color level as compared with manual measurement. Natural light variation still affects the color prediction.
3. Prediction of SPAD index by using leaf color chart has a relatively good linear agreement with $R^2 = 0.8506$ for hybrid corn and $R^2 = 0.8466$ for sweet corn, but with mobile phone camera it has low agreements with $R^2 = 0.5284$ for hybrid corn and $R^2 = 0.4762$ for sweet corn.

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