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A Low-cost Image Processing Based Technique to Estimate Chlorophyll in Winter Wheat

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***Abstract*- This paper presents a fast low-cost image processing method for the prediction of chlorophyll content in BARI gom, a winter wheat variety in Bangladesh. SPAD-502 was used as chlorophyll meter in this work and pictures of wheat leaf were taken by Smart Phone Camera with small adjustments. It is found that in the late vegetative stage, the "(a*-b*)" index from L*a*b* color model has the most significant correlation with SPAD-502 chlorophyll data compared to other indexes from L*a*b* and HSV color model. Moreover, an equation is developed to calculate the chlorophyll content from "(a*-b*)" color index using linear regression method. Thereafter, the equation is tested against 36 samples in a random manner and an average accuracy of almost 90% is found over the range from 30 to 50.**

Keywords - SPAD-50, Correlation, Linear Regression

I. INTRODUCTION

Wheat has served the modern civilization for years and has played an outstanding role in removing hunger from the world. Approximately, 21 percent of the world's food demand is met by wheat crop [1]. In order to solve the world's food crisis, proper fertilization of wheat should be ensured by the determination of the amount of nitrogen in wheat plant. The information of nitrogen can be assessed by chlorophyll estimation since nitrogen is a vital element in chlorophyll [2]. SPAD-502 is generally used to estimate the chlorophyll content in various plants [3-5]. But, unfortunately, SPAD-502 is very costly. Another way to determine the chlorophyll content in the plant is to use the information of leaf color [6-7].

Almost all the methods applied so far to determine the amount of chlorophyll in wheat from leaf color information are RGB color index based. Kawashima et al. proposed (R-B)/(R+B) as a good tool to estimate wheat chlorophyll content [8], whereas, Jia et al. applied G/(R+G+B) to evaluate winter wheat nitrogen content [9]. Moreover, Adamsen et al. described the linear relationship between G/R and SPAD reading in wheat [10]. RGB color index based technique has been applied to other plants too [11-14]. But, the main drawback of RGB color space is that it is dependent on the device and its' components are highly correlated [15]. On the other hand, L*a*b* and HSV color space are very close to the human eye in the perception of color [16,17] and L*a*b* color space is device independent [16]. However, Hao et al. demonstrated the relation between SPAD reading and color indexes of both RGB and L*a*b* color space in barley and found a satisfactory correlation between L*a*b* color indexes and SPAD data [18].

Therefore, this paper examines L*a*b* and HSV color model's feasibility in winter wheat's chlorophyll estimation. In order to do so, the correlation between HSV and L*a*b* color model's indexes of the wheat leaf images and chlorophyll data of BARI gom, a winter wheat variety in Bangladesh, from SPAD-502 are determined and it is found that "(a*-b*)" index of the L*a*b* color model is most significantly correlated with the amount of chlorophyll. Later, an equation is derived by linear regression method using "(a*-b*)" color index and tested against random samples. The overall accuracy of almost 90% from those testing proves that "(a*-b*)" is a significant tool to estimate chlorophyll content.

II. METHODOLOGY

A. Materials

Wheat was planted in 18 different plots (3 columns and 6 rows) in the wheat field of Sylhet Agricultural University, Bangladesh on 20th November 2017. Six different varieties of wheat (BARI gom 24, BARI gom 26, BARI gom 27, BARI gom 28, BARI gom 29, BARI gom 30) were planted in 6 different plots in each column. The pH parameter of the soil was 4.5 and the Nitrogen fertilization rate was uniform in each plot, 0.5 kg/ha. SPAD-502 data and images were taken on 14th January 2018 in the late vegetative stage. SPAD-502 chlorophyll data were taken for 36 random samples and for each sample, data were taken 15 times by SPAD-502 to make an average. The images of the wheat leaf were taken by 13-megapixel Redmi 3S smartphone camera under natural light at midday from 11.00 a.m.-1.00 p.m. The images were taken in such a way that each image covers only one leaf and images were taken vertically for no shadowing. A piece of white paper was used as background to ease thresholding.

B. Correlation and Linear Regression

Correlation is used to demonstrate the relationship between two distinct variables.

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The correlation between SPAD-502 chlorophyll data and HSV and L*a*b* color model indexes can be calculated using Pearson's correlation formula [19],

$$R = \left(\frac{n\sum_{i=1}^{n} S_i C_i - \sum_{i=1}^{n} S_i \sum_{i=1}^{n} C_i}{\sqrt{\left[n\sum_{i=1}^{n} S_i^2 - (\sum_{i=1}^{n} C_i)^2 \right]\left[n\sum_{i=1}^{n} S_i^2 - (\sum_{i=1}^{n} C_i)^2 \right]}} \right) \quad (1)$$

where, S=SPAD-502 chlorophyll data
C=Color index value
n=Number of data points.

Linear regression method is used in this paper to establish an equation of the amount of chlorophyll in terms of color index. If y is the SPAD-502 Chlorophyll data, x_{kn} = k^{th} color index data of n^{th} point (k is the number of index used; in this paper one index "(a*-b*)" is used to predict chlorophyll content, so k=1), then b, linear regression coefficient, can be determined using equation 2(a). Matrix b measures y value as Y from color index information (equation 2(b)) and the amount of error from this calculation, ε can be measured from equation 2(c). The method is well described by Walpole et al. [20].

$$b = (X^T X)^{-1} X^T y \qquad 2(a)$$

$$Y = Xb \qquad 2(b)$$

$$\varepsilon = |y - Y| \qquad 2(c)$$

Where, $y = \begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_n \end{bmatrix}$, $X = \begin{bmatrix} 1 & x_{11} & x_{21} & . & . & x_{k1} \\ 1 & x_{12} & x_{22} & . & . & x_{11} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ 1 & x_{1n} & x_{2n} & . & . & x_{kn} \end{bmatrix}$

$$X^T X = \begin{bmatrix} n & \sum_{i=1}^{n} x_{1i} & \sum_{i=1}^{n} x_{2i} & . & . & \sum_{i=1}^{n} x_{ki} \\ \sum_{i=1}^{n} x_{1i} & \sum_{i=1}^{n} x_{1i}^2 & \sum_{i=1}^{n} x_{1i}x_{2i} & . & . & \sum_{i=1}^{n} x_{1i}x_{ki} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ \sum_{i=1}^{n} x_{ki} & \sum_{i=1}^{n} x_{ki}x_{1i} & \sum_{i=1}^{n} x_{ki}x_{2i} & . & . & \sum_{i=1}^{n} x_{ki}^2 \end{bmatrix}$$

$$X^T y = \begin{bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_{1i}y_i \\ . \\ . \\ . \\ \sum_{i=1}^{n} x_{ki}y_i \end{bmatrix}$$

C. Image Processing Technique

The correlation between chlorophyll data from SPAD-502 and indexes of HSV and L*a*b* color model is illustrated in this work. HSV and L*a*b* color space and their color indexes acquisition from RGB color space is discussed in [15, 17]. The task can be divided into four sections.

1) Background black Leaf image:

All image processing tasks are accomplished using MATLAB®. At first, RGB leaf image (Fig. 1(a)) is converted to grayscale image which is then converted to binary image. To binarize the grayscale image, the Ostu method is adopted for thresholding [21]. In the binary image, the leaf portion is converted to white (pixel value 1) and background portion to black (pixel value 0). There are often some black spots on the white portion of the binary leaf image which is eliminated by MATLAB function "imfill" (Fig. 1(b) and Fig. 1(c)) which is a morphological reconstruction based algorithm [22]. Finally, the processed binary image is multiplied by the original RGB leaf image to get the background omitted leaf image (Fig. 1(d)). This is the image required to do the analysis.

2) Taking the average L*, a*, b* and H, S, V value for each image:

The nonzero RGB pixel values of the image (the pixel values of leaf only) are taken and converted to L*, a*, b* and H, S, V by MATLAB. After that, the average values of L*, a*, b* and H, S, V are estimated for every image.

3) Finding the Correlation between SPAD data and color indexes:

The correlation between SPAD-502 value and L*a*b* and HSV color indexes are calculated using equation (1).

4) Finding the equation to establish the relation between SPAD data and the best-correlated color index via Linear regression analysis:

An equation is established to determine chlorophyll content via linear regression analysis using equation 2(a) and 2(b).

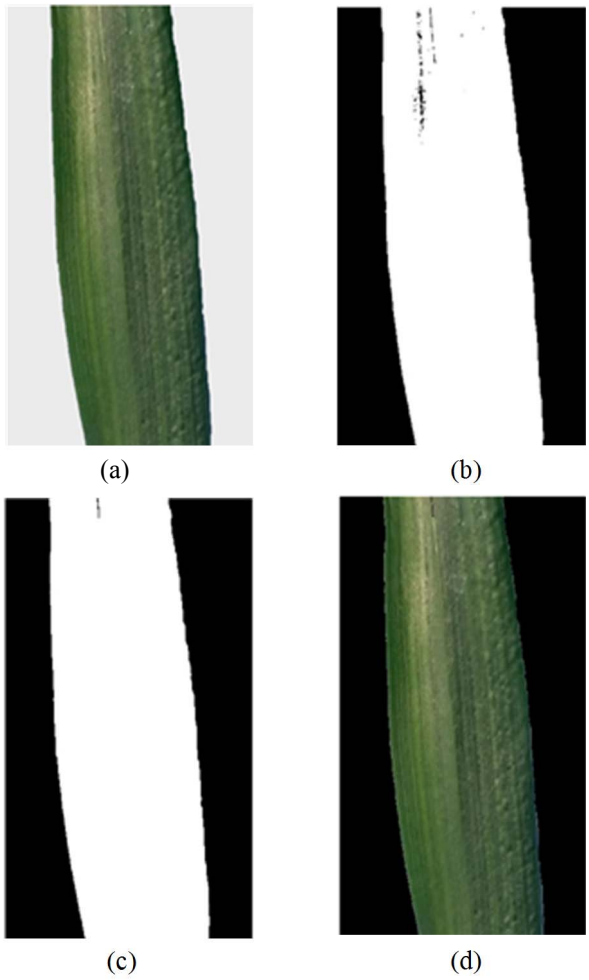

Fig. 1 (a) Captured wheat leaf RGB image (b)Wheat leaf Binary image (leaf portion=white (pixel value=1), background=black (pixel value=0)) with some spot in the leaf portion (c) Wheat leaf Binary image with spot removal (d) Background omitted (black) RGB wheat leaf image.

The flow chart below (Fig-2) briefly illustrates the whole process.

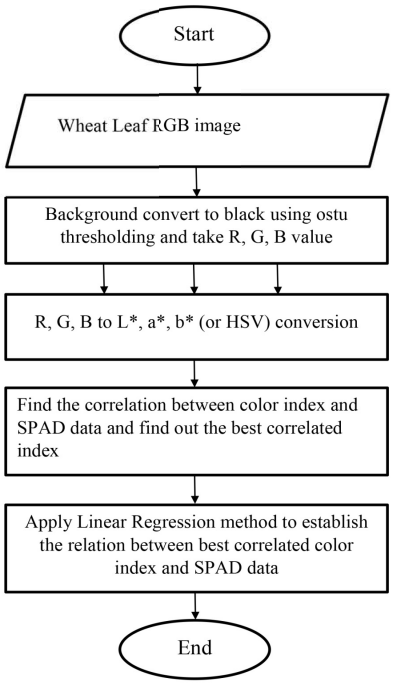

Fig. 2 Flow Chart of the whole process

III. RESULTS AND DISCUSSIONS

36 samples are selected from the earlier stage to find the correlation between the SPAD chlorophyll data and color indexes of L*a*b* and HSV color model in the late-vegetative stage with the presence of natural light. Overall, the SPAD-502 data has a stronger correlation with the L*a*b* model color indexes under natural light in the late-vegetative stage compared to HSV model color indexes. The relation between SPAD-502 chlorophyll data and color index of L*a*b* model ("L*", "a*" and "b*") are depicted in Figs. 3-5. It is seen from the figures that "a*" index data are positively and "L*" and "b*" index data are negatively correlated with SPAD-502 value.

On the other hand, figures 6-8 show the relation between SPAD-502 chlorophyll data and color index of the HSV model (H, S, and V). It is evident from the figures that "H" data are positively and "S" and "V" data are negatively correlated with SPAD-502 value.

The correlation coefficient between SPAD-502 chlorophyll data and 14 color indexes are listed in table I. It is clear from table I that "a*" and "b*" index from L*a*b* color model have a significant correlation with SPAD-502 chlorophyll data (0.604 and -0.644 respectively).

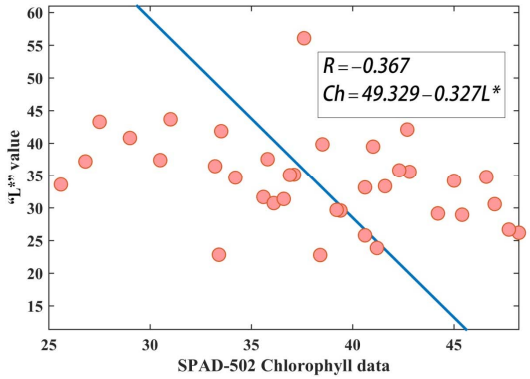

Fig. 3 The relation between SPAD-502 chlorophyll reading and L* index of L*a*b* color model in late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "L*" index by linear regression)

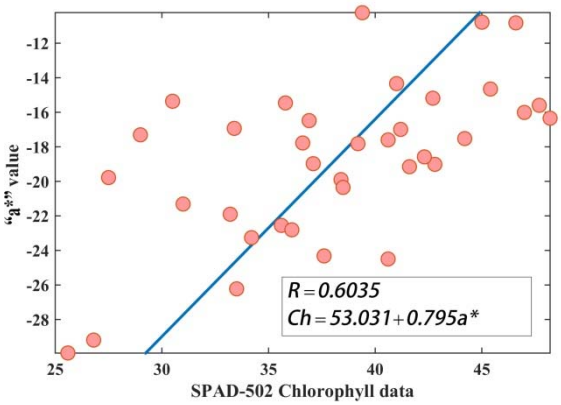

Fig. 4 Relation between SPAD-502 chlorophyll reading and a* index of L*a*b* color model in late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "a*" index by linear regression)

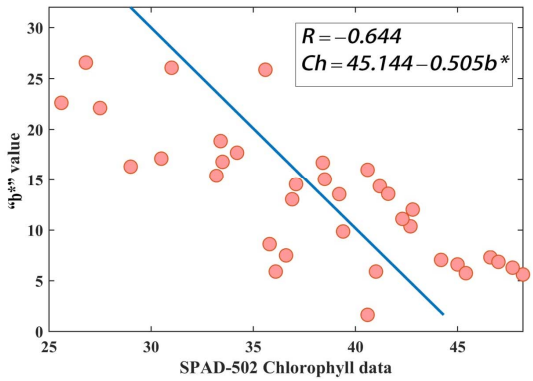

Fig. 5 Relation between SPAD-502 chlorophyll reading and b* index of L*a*b* color model in late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "b*" index by linear regression)

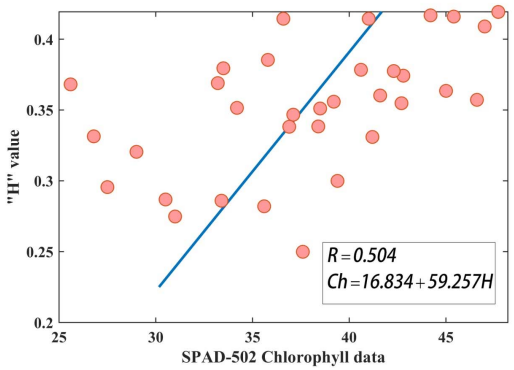

Fig. 6 Relation between SPAD-502 chlorophyll reading and H index of HSV color model in late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "H" index by linear regression)

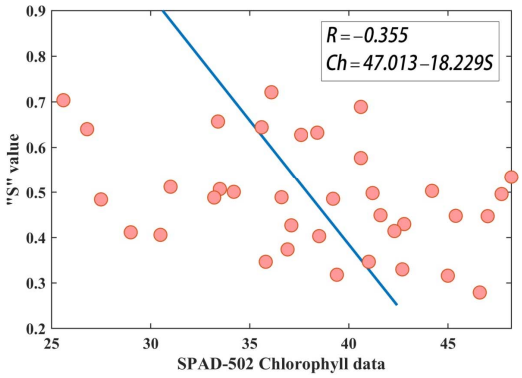

Fig. 7 The relation between SPAD-502 chlorophyll reading and S index of the HSV color model in the late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "S" index by linear regression)

Among the mixture of color indexes, "(a*-b*)" has the greatest correlation of 0.689 which is a good tool to measure chlorophyll data under natural light in late-vegetative stage. Fig. 9 shows the significant relation between "(a*-b*)" and SPAD-502 data. With the help of linear regression method, equation can be formed to calculate the chlorophyll value from color indexes which are shown in the box of Fig 3-9 along with correlation coefficient (*R*).

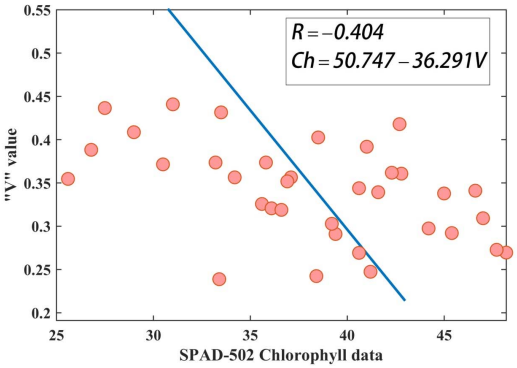

Fig. 8 Relation between SPAD-502 chlorophyll reading and V index of HSV color model in late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "V" index by linear regression)

TABLE I. CORRELATION COEFFICIENT OF DIFFERENT COLOR INDEX AND SPAD-502 READING

Color index	SPAD-502 reading
L*	-0.367
a*	0.604
b*	-0.644
H	0.504
S	-0.355
V	-0.404
L*+ b*	-0.584
a*- b*	0.689
L*- a*	-0.574
a*/b*	0.536
(a*- b*)/(a*+b*)	0.059
S+V	-0.544
H-S	0.534
H-V	0.528

Thereby, equation (3) is established to calculate the chlorophyll value from "(a*-b*)" color index.

$$Ch = 50.245 + 0.371 \times (a^* - b^*) \quad (3)$$

Where, Ch = Chlorophyll value.

The accuracy in the measurement of chlorophyll content via equation (3) is calculated by equation (4) against 36 random samples and listed the average accuracy for five different ranges of SPAD-502 value.

$$\%Acurracy = \left(1 - \frac{Ch - S}{S}\right) \times 100 \quad (4)$$

Where S= SPAD-502 data

It is evident from Table II that for small value of Chlorophyll data (25-30), the overall result is less accurate (78.31%). But for the other ranges of SPAD value except 25-30, average accuracy is greater than 90%. Overall, accuracy increases as the SPAD value increases although there is a small exception in the 45-50 range for less number of samples. Table III compares the performances of this paper with that of other reported works.

TABLE II. ACCURACY IN CHLOROPHYLL MEASUREMENT USING DERIVED EQUATION

Ranges of SPAD-502 value	Number of samples	% Accuracy
25<SPAD≤30	4	78.31
30<SPAD≤35	6	90.73
35<SPAD≤40	11	90.76
40<SPAD≤45	10	93.06
45<SPAD≤50	5	90.37

TABLE III. A BRIEF SUMMARY OF THE DISTINCTION OF THIS PAPER WITH OTHER RELEVANT WORKS

Literature	Plants	Color Model	Contribution	Apparatus required
Kawashima et. Al [8]	Wheat and Rye	RGB	Demonstrated (R-G)/(R+G) is the most significant indicator of chlorophyll content by considering the angle of solar radiation.	Video camera, Video tape, video capture board and a personal computer.
Jia et al. [9]	Wheat	RGB	Doubted between index G and G/(R+G+B) to decide which one is the best detector of chlorophyll content in wheat.	Digital camera and personal computer.
Adamson et. al [10]	Wheat	RGB	Found G/R is linear with SPAD data when determining senescence of wheat using image information.	Digital camera and personal computer.
Hao et al. [18]	Barley	RGB and L*a*b*	Found the correlation with SPAD reading and color indexes of both RGB and L*a*b* color space.	Digital camera and personal computer.
Our Work	Wheat	L*a*b*	Used readily available smartphone camera to determine the chlorophyll content from wheat leaf color information and found "(a*-b*)" index of L*a*b* color model is the best indicator of measuring chlorophyll content under the natural light condition in the late vegetative stage.	Smartphone and a personal computer.

IV. CONCLUSION

The correlation among the SPAD-502 chlorophyll data and color indexes of L*a*b* and HSV model are shown in this work. The chlorophyll information was taken by SPAD-502 in the range 25-50 of six different varieties of BARI gom and Xiaomi Remdi 3S mobile phone camera was used to take the image under the natural light condition from

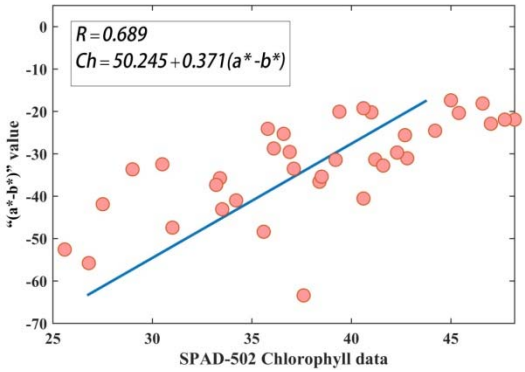

Fig. 9 Relation between SPAD-502 chlorophyll reading and (a*-b*) indexing late vegetative stage under the condition of natural light (Ch= Chlorophyll value calculated from the value of "(a*-b*)" index by linear regression)

11.00 a.m to 1.00 p.m. MATLAB® is used to perform all image processing tasks to modify the captured image. It has been found that, in the late-vegetative stage, "(a*-b*)" index of the L*a*b* color model has the highest correlation with SPAD-502 chlorophyll data and can be used as a tool to measure chlorophyll content. Moreover, the chlorophyll determination by this method has an overall accuracy of more than 90% in the range of 30-50. This image processing technique is free to use and will ease the prediction of chlorophyll amount for mass people.

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