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COLORIMETRIC MEASUREMENTS OF COCOA BEANS (*Theobroma cacao*)

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ABSTRACT

A series of studies have been carried out to develop a simple, easy to use, and affordable device to measure the colour of cocoa beans. The present paper reports the development of the device based on colorimetric principles. An electronic device which enables cocoa smallholders to give an objective "one-figure" indication of the quality of their cocoa beans was described. A sensor was constructed which contained a red light emitting diode (LED) illuminating the target and a silicon photodiode detecting the reflected light. Because of the considerable difference in colour between dried unfermented and fermented cocoa beans, the differences in diffuse reflection of red light (660 nm) could be about 20% and very easy to measure. The method was checked with a spectrophotometer in the fixed mode at 660 nm, which revealed a high correlation coefficient. The sensor was combined with a microprocessor controlled electronic device for fast measurement of cocoa beans without any calculations which automatically counts the number of measured beans and gives the resulting average reflection value.

[*Keywords*: *Theobroma cacao*; cocoa beans; color vision; quality, seed]

INTRODUCTION

Indonesia belongs to the largest cocoa-producing countries in the world. With Cote d'Ivoire (47%) and Ghana (14%) as the largest, Indonesia accounts for 13% of world production of "bulk" cocoa. Sulawesi is responsible for most (75%) of the country's cocoa production. Most of the cocoa beans are produced by smallholders and less by private and state plantations.

Depending on the stage and processes after harvest, cocoa beans are coloured between red/purple (fresh) and deep brown (end of fermentation process). This can be followed by means of colorimetry. Ilangantileke *et al.* (1991) reported that colour measurements are appropriate for the estimation of the quality of cocoa beans. They used in their study a so-called tristimulus colorimeter or chromameter, which determined the colour in terms of "xyz" or "Hunter" L*a*b* -values according to the CIE (International Commission on Illumination - CIE Publication No. 15.2, 1976). In another study, Bonaparte *et al*. (1998) used the same L*a*b* -system to measure some quality characteristics of solar dried cocoa beans in St Lucia. Other studies which used such instruments are described by Diaz-Perez *et al*. (2000) and Krajayklang *et al*. (2000). Chromameters are excellent instruments to assess the colour of objects by scientists in the laboratory with the advantage that the resulting data are standardized worldwide and comparison of data with other studies is very easy. Because of the high price of such instruments and the difficulty in handling, it may not be expected that these instruments can be bought and handled by cocoa farmers.

For reasons of comparison with other farmers or institutions which purchase cocoa beans, the smallholders need an objective indication about his cocoa bean quality by a "one figure" indication. A series of studies have been carried out to develop a simple, easy to use and affordable device to measure the colour of cocoa beans to meet the requirements. The present paper reports the initial development of the device based on colorimetric principles.

MATERIALS AND METHODS

Materials

Fresh cocoa beans were collected from smallholders in Watampone and Polewali in South Sulawesi and measured within three days after harvesting. Dried fermented and unfermented cocoa beans were collected at randomly and kindly delivered by a cocoa trader in Makassar.

Measuring Methods

Reflectance measurements (diffuse reflection) were performed with a sensor containing a light emitting diode (LED) and a photodiode in an optical configuration (Fig.1). In a black plastic housing, two cylindrical holes of 5 mm diameter were drilled . One hole is perpendicular to the surface of the target object (a leaf or cocoa bean) on the opposite end containing a silicon photodiode. The second hole was drilled with an angle of 30^o relative to the first hole containing the LED. Both cylindrical holes join at the surface, where the target is situated, with an aperture of 5 mm diameter.

The LED with a narrow beam of about 7^o illuminates the surface of the target. The sensor does not contain expensive optical components such as lenses and filters. The diffuse reflected light is detected by the photodiode, which is used in the photovoltaic mode. The signal of the photodiode could be measured by a digital voltmeter, which is sensitive in the mV-range or by an adjusted handheld radiometer such as the UVX-radiometer (UVP Inc., San Gabriel, California, USA) as indicated in Fig. 1 as "set-up 1". Based on the data collected by measurements with "set-up 1" and the requirement to measure a great number of beans without calculation of the average reflection by hand, an electronic device was developed for this purpose. The schematic diagram of the electronic device is shown in Fig. 1 as "set-up 2" and is further called pigment-meter in this study. The pigment-meter contains a programmed microprocessor which replaces all actions by hands, such as collecting the reflection data of the measured beans and calculating the average reflection. This can be performed with only two push buttons.

A white standard (Pye Unicam 4013 221 09211) was used as the 100% reflection reference for the calculations of the total reflectance of the target objects. By this procedure, the thermal dependence of silicon photodiode was avoided.

Most measurements were checked with a Pye Unicam SP8-100 spectrophotometer. Some measurements were between 400 and 800 nm (with 10 nm steps) and others in the fixed mode at 660 nm corresponding with the emission of the red LED.

Choice of the Appropriate Wavelength

To look in which region the reflection spectra could be expected, some preliminary measurements were performed with the spectrophotometer between 400 and 800 nm. Three of such measurements are presented in Fig. 2, which are cocoa powder, the upper side of an adult potato leaf, and anthocyanin from an elderberry. The last measurement was done because anthocyanin could play a role in the colour change during the processing of cocoa beans. The reflection spectrum of a potato leaf is also presented because the relative chlorophyll content can also be measured with the pigment-meter (reported elsewhere). Looking at Fig.2, the wavelength of 660 nm

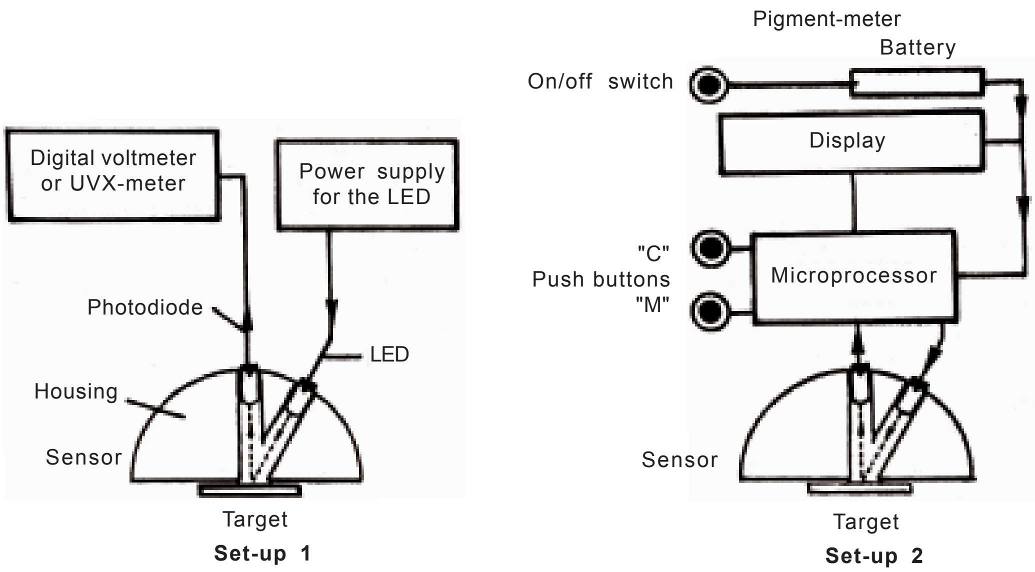

Fig. 1. Schematic diagrams of the reflectance measurement device used in the study. "Set-up 1" is straightforward according to the basic principles of reflectance measurement. In "set-up 2" the same sensor is connected to an electronic device developed for this purpose.

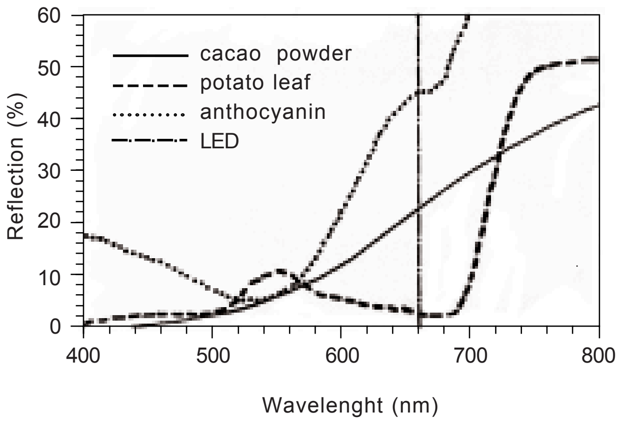

Fig. 2. Three preliminary measurements performed with the Pye Unicam spectrophotometer to make a choice of the appropriate wavelenght of the LED. This figure shows the reflection spectra of cocoa powder, a potato leaf, and anthocyanin from an elderberry. The vertical line gives the chosen wavelenght of the LED at 660 nm.

would be a good choice for the measurements of targets such as cocoa beans, crop leaves, and anthocyanin containing fruits.

To investigate the possibility of measuring cocoa beans at wavelengths other than 660 nm (red), some measurements were done at 470 nm (blue) and 570 nm (green). This could be done by changing the LED in the sensor of Fig. 1 ("set-up 1") to the appropriate colour.

RESULTS AND DISCUSSION

Fresh Cocoa Beans

To characterize the colour of the fresh cocoa beans, measurements were performed at three wavelengths (by changing the LED in "set-up 1") of 470 nm (blue), 570 nm (green), and 660 nm (red). Some cocoa beans have been affected by pod borer (*Conopomorpha cramerella* Snellen). In general, the cocoa beans affected by pod borer are smaller, thinner, and redder than healthy beans.

Measurements were performed with fresh beans harvested from pruned and non-pruned trees. The fresh attacked beans were visually subdivided into three groups: hardly attacked, medium attacked,and strongly attacked. The results of these measurements are presented in Fig. 3. It was shown that measured colour differences are not apparent in the blue and green region, but the trend in colour differences is sufficient to distinguish in the red region.

Dried Fermented and Unfermented Cocoa Beans

These measurements were performed with the same experimental "set-up 1" as described for fresh beans. Two samples of about 100 beans were randomly collected, one sample from dried unfermented and one sample from fermented beans. The differences in colour are obvious due to the browning process by fermentation. The unfermented beans are redder/ purple in colour than the fermented beans.

Measurements of fermented (n=10) and unfermented (n=10) dried cocoa beans in the blue, green and red region are collected in Table 1. Like the measurements with fresh beans, the reflections for dried fermented and unfermented beans in the blue and green regions give less apparent differences in colour. In further experiments, the measurements in the blue and green region were not continued. Measurements at 660 nm only with more beans (93) from the same samples are shown in the last part of Table 1. The mean value of the red reflection amounts 20.7% and 36.6% for the fermented and unfermented beans, respectively.

Table 1. Reflection measurements of dried fermented and unfermented cocoa beans in the blue, green, and red region.

Bean type	Reflection (%)			Number of beans
	Blue 470 nm	Green 570 nm	Red 660 nm	
Fermented	9.8 ± 2.1	11.2 ± 2.5	27.7 ± 7.2	10
Unfermented	10.5 ± 1.9	14.7 ± 2.8	43.7 ± 6.1	10
Fermented	-	-	20.7 ± 5.4	93
Unfermented	-	-	36.6 ± 5.7	93

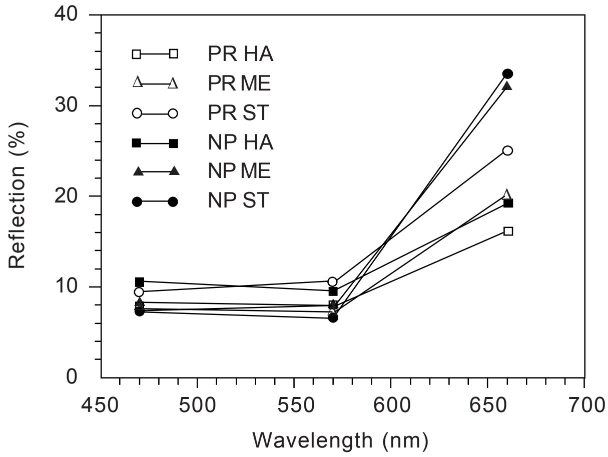

Fig. 3. Reflection of fresh cocoa beans from pruned (PR) and non-pruned (NP) trees. The infested beans were visually subdivided into three groups: hardly attacked (HA), medium attacked (ME), and strongly attacked (ST). The strongly and medium infested beans from non-pruned trees were reddest in colour.

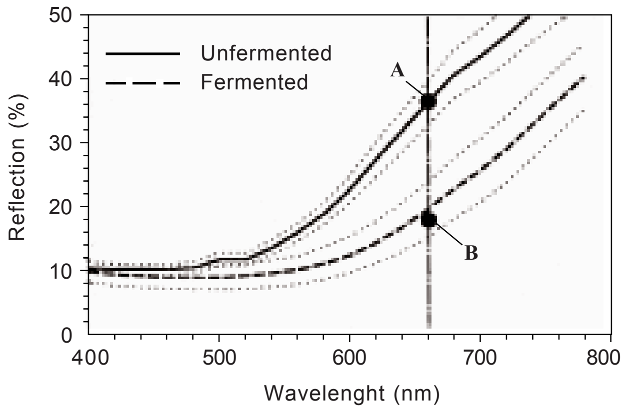

Fig.4. The average reflection spectra at 400-800 nm of 8 fermented and 8 unfermented beans flanked by dotted lines representing a dictance of one standard deviation. Markers A and B represent the reflection of the same beans measured with the pigment-meter at 660 nm.

Comparison of Measurements between Spectrophotometer and Pigment-meter

From the same samples as before, the reflection spectra of dried fermented and unfermented cocoa beans (n=8) were measured on the Pye Unicam SP8-100 spectrophotometer between 400 and 800 nm. In Fig. 4, the average the reflection spectra of the 8 fermented and 8 unfermented beans are shown flanked by dotted lines representing the distance of 1 standard deviation (SD). After measurement in the spectrophotometer, the same 8 cocoa beans were also measured with the pigment-meter, resulting in an average reflection percentage of 36.3 (SD=3.6) for the unfermented and 19.7 (SD=4.2) for the fermented beans. These values are in agreement with the spectrophotometer measurements at 660 nm (the wavelength of the LED in the pigment-meter). The values measured in the preceding experiments with 93 cocoa beans (Table 1) correspond very well to these measurements.

Correlation between Spectrophotometer and Pigment-meter

To investigate the correlation between the spectrophotometer values and the pigment-meter readings, the Pye Unicam spectrophotometer was set into the "fixed-mode" at 660 nm (bandwidth HE and reflection aperture with a diameter of 10 mm). Again every bean of 85 unfermented and 123 fermented ones (same sample as before) was measured in the spectrophotometer and then in the pigment-meter. Results are shown in Table 2.

Considering the small aperture of the pigment-meter (5 mm diameter) relative to the wider aperture of the spectrophotometer (10 mm diameter), which has a four times larger reflection area, the pigment-meter could be more sensitive to a little spot with a colour difference. Notwithstanding the smaller aperture, the results are in good agreement to each other.

The pigment-meter is a digital instrument which is also developed for other measurements, such as the

Table 2. Results of reflection measurement of cocoa beans using spectrophotometer and pigment-meter.

Beans	Number	Reflection (%)		Reflection (counts)[1]
		Spectrophotometer	Pigment-meter	
Fermented	123	19.44 ± 4.9	20	754 ± 199
Unfermented	85	33.18 ± 5.0	20	1270 ± 205

[1]40 counts equals 1% reflection

relative chlorophyll content of crop leaves (Barta *et al.,* 1992; Bullock and Anderson, 1998) and melanin content of the human skin (Oort *et al.,* 1981). In these two cases, the content of the pigment is inversely proportional to the reflection at 660 nm. This means that the instrument must have a high resolution which enables the measurement of such pigments. The analogue signal of the reflection was converted into digital counts in such a manner that 1% reflection equals 40 counts. Such high resolution is not necessary for the measurement of cocoa beans.

During the measurement of one individual cocoa bean, several figures are shown on the display, i.e., the number of the measurement, the average of the reflection of all measured beans, and the value of the last reflection. The last two figures are given in counts. Every next cocoa bean measurement can be started by pressing the push button "C" in Fig. 1. It is not necessary for the smallholder to follow all the figures on the display. He only has to wait for a signal from the pigment-meter (a green light) to continue with measurement of the next bean.

In practice when a number of beans have been measured and applying the "white standard" as last measurement by pressing the push button "M" in Fig. 1, the pigment-meter reading gives the average reflection for all measured beans on the display. In principles the number of measurements is endless. Needless to say that these measurements could also be performed with another detector (such as a digital mV-meter) instead of the pigment-meter, but it needs much more work and calculations.

All measurements (total 208) were used to calculate the correlation coefficient between the reflection percentage of the spectrophotometer and the number of counts of the pigment-meter. The correlation is illustrated in Fig. 5. The linear regression can be represented by: $Y = 36.15\ X + 58.66$ ($r = 0.93$), in which X is the reflection value of the spectrophotometer and Y the number of counts of the pigment-meter.

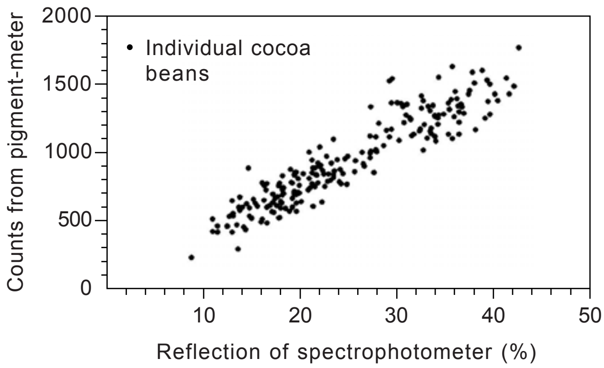

Fig. 5. Correlation between the reflection measurements of the pigment-meter and the spectrophotometer. The pigment-meter is measuring the reflection in "counts"; 40 counts equals 1% reflection.

Colour Frequency Distribution

The colour frequency distribution is described in Table 2. The results are presented in Fig. 6, in which both the measurements of the pigment-meter and the spectrophotometer are used for comparison. The meaning of the Roman numerals is the ranges of reflection with a width of 1 SD of the averages of all the beans (Table 3); SD 5 (%) for the spectrophotometer and 200 (counts) for the pigment-meter. The Roman numeral I represents fully brown and X as fully red and from I to X all colours between brown and red. Both samples, fermented or un-fermented, show a colour distribution with an overlap in the IV to VIII region. The highest values for the number of beans of the fermented and unfermented beans are at a large distance from each other. Be-cause of such colour distribution, the number of beans in a sample should be larger than 100 beans to get significant differences.

Table 3. The meaning of the Roman numerals.

Roman numerals	Spectrophotometer (% reflection)	Pigment-meter (counts)
I	0- 4.9	0- 199
II	5- 9.9	200- 399
III	10-14.9	400- 599
IV	15-19.9	600- 799
V	20-24.9	800- 999
VI	25-29.9	1000-1199
VII	30-34.9	1200-1399
VIII	35-39.9	1400-1599
IX	40-44.9	1600-1799
X	45-49.9	1800-1999

CONCLUSION

Depending on the adequacy and stage of processing (fermentation and drying), the cocoa beans undergo a change in colour. For an experienced farmer, this colour change can visually be judged as a subjected quality indication. But in the communication with other farmers and purchasing agents or organizations, it would be advantageous to use an objective "one figure" indication for the quality. With a simple colorimetric measurement, colour differences between

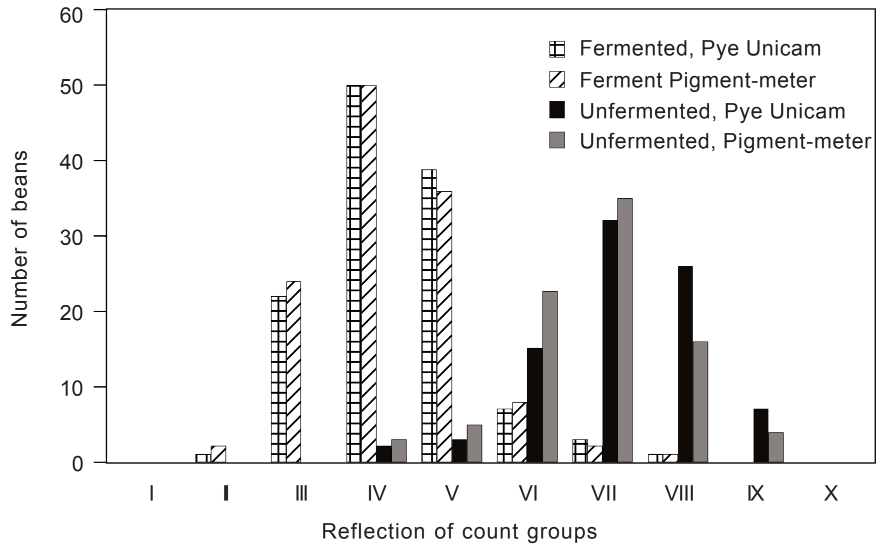

Fig.6. The colour frequency distributions of dried fermented and unfermented cocoa beans. For comparison measurements were done using the pigment-meter and the spectrophotometer, which are in good agreement to each other. The Roman numeral in x-axis represents the colour shift from brown to red.

fermented and unfermented cocoa beans could be detected. It therefore also could be stated that an electronic pigment-meter, which could be handled in a simple way, could be developed and would be of benefit to the small-holders. It can not be expected, however, that farmers use statistical methods to prove the significance of their measurements, but instead they have to use their experience in farming and the proper use of the pigment-meter.

To obtain a "one figure" quality indication, 100 samples are needed to give an adequate result of measurement. The measuring procedure with the pigment-meter is very fast (about 100 beans in 15 minutes) and no calculations are necessary. The last measurement (with the white standard) gives the average reflection percentage of all the cocoa beans of the sample.

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