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A simple and cost-effective method to measure moisture content for multigrain

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Abstract An integrated moisture inspection card was developed for measuring the moisture content of grains. The moisture content of paddy, corn, and soybean influenced the color change of cobalt chloride-coated paper. Experiments using corn and soybean with coated paper were conducted in a jar with head space of 25%, 50%, or 75%, with the lid closed for 30, 45, or 60 minutes. The results showed that the highest color value in corn and soybean was produced with a head space of 75% and a testing duration of 60 minutes (HS75DT60). This differed from paddy, where the highest color value was observed for HS75DT45. This discrepancy explained that corn and soybean are oil crops with a pericarp or seed coat. For all grains, using a testing duration of 45 minutes resulted to increase coefficient of correlation, indicating a better relationship between moisture content and color values. The card production process standardizes the printed RGB color values by converting from the L*, a*, and b* values. Additionally, the card was calibrated its relation to the moisture content of various grains, making it suitable for use in a wide variety of applications.

Keywords: Relative humidity, Color value, Multigrain, Moisture safety, Safe storage

Introduction

It is well known that rice is the most important agricultural product of Thailand. However, corn and soybean are also significant economic crops for Thailand and globally, especially as livestock feed, where corn and soybean meal are the main raw materials in the animal feed industry. Additionally, soybean is extracted into vegetable oil that is widely used in various cooking processes. In 2020, the total global outputs of milled rice, soybean, and corn were 503,946, 351,497, and 1,118,411 thousand tons, respectively. In the same year, Thailand had yields of 21,345, 23, and 4,995 thousand tons, respectively (Agricultural statistics of Thailand, 2021).

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Conventionally in Thailand, corn is planted twice a year and is harvested at the beginning and end of the rainy season. The proportion of the current corn production area is adjusted in accordance with market demand. Planting occurs at the beginning of the rainy season, the end of the rainy season, and in the dry season. If the harvesting period is between the beginning of the rainy season and the late rainy season, the seed moisture content is more than 30% (Chu *et al.*, 2022), and the yield is at risk of having a high moisture content and associated storage problems. Additionally, the high moisture content of corn grain makes the kernels more prone to breakage or ultimately leads to an increase in water content after harvest (Li *et al.*, 2021). Therefore, the seed must be quickly cracked and the moisture content reduced within 48 hours to be safe from unacceptable aflatoxin levels (Aekatasanawan *et al.*, 2015).

Soybeans are planted twice a year in the rainy and dry seasons, with the moisture content after harvest being 34.1-39.9%. The high humidity caused by continuous rainfall encourages field mold growth, leading to deterioration (Deng *et al.*, 2022). There are two methods for soybean moisture reduction: (1) plant drying, which involves drying the whole soybean plant in the field, and (2) grain drying after shelling and separating the soybean seeds from the pods, which is done by labor and a grain thresher. The optimum moisture content for a threshing machine is 13-18% (Taweekul and Sangla, 2022.).

Currently, Thailand produces insufficient corn and soybean to meet the growing annual demand, requiring grain to be imported from other countries. To grow sufficient corn and soybeans with full yield and good quality, farmers must have knowledge of proper cultivation methods, including harvesting and storage.

Grains with a high moisture content after harvesting cannot be immediately stored in sheds because the moisture in the grains is still high, and the respiration rate is high, which results in the release of additional heat that makes it easier for fungi to invade. Food safety and security are very important. For example, farmers in Ghana are encouraged to properly store peanuts to reduce aflatoxin contamination (Martey *et al.*, 2020), and in Tanzania, there are strategies to educate maize farmers about the dangers of aflatoxin (Massomo, 2020). Therefore, the moisture in the grains should be reduced before storage. Farmers should know the moisture level to ensure safe storage of grains, reduce fungal problems, and maintain grain quality. In addition, the moisture content in grains is one of the important qualities used as an indicator of quality and can be applied as a trading condition.

There are several methods for determining moisture content in grain that can be classified as both direct and indirect. Direct methods are very accurate; for example, the hot air oven method, distillation method, and coulometry method (Karl Fischer) (Scholz, 1984). However, these methods take a long time and are less accessible because they require specialized facilities and equipment. Therefore, with these limitations, direct methods are not suitable for farmers but more suitable for research applications. A grain moisture meter for commercial use by farmers should be capable of rapid measurement and easy to use, as well as suitable for a variety of grains, involving capacitance, impedance, and the infrared spectrum (Briggs, 1908; Kandala and Sundaram, 2009; García *et al.*, 2017). Nonetheless, these methods are expensive and not readily utilized by farmers.

Previously, moisture inspection cards have been used only for paddy (Pathaveerat and Pruengam, 2020). The current research studied how the moisture content of corn and soybean affects the color changes of cobalt chloride-coated paper (CCP) and determined the most appropriate conditions in a sealed container and the measuring duration. The study was based on the amount of water transferred from the grain until the vapor pressure of the water held by the product was equal to the water vapor pressure in closed air over a defined period. Consequently, there must be a standard color chart in relation to the moisture content of each grain; however, for ease of use in a wide variety of applications, there should be an integrated moisture inspection card. Therefore, this work aimed to evaluate a moisture inspection card applicable to various grains. Furthermore, this was considered an additional option for evaluating the moisture content of corn and soybean without destroying the sample.

Materials and methods

The moisture content of corn and soybean was determined in three replicates by drying 15 g of sample using a hot air oven (FD240, BINDER, Tuttlingen, Germany) at 103 °C for 72 h according to ASAE Standard S352.2 (ASAE, 2003).

This research was conducted at the Faculty of Engineering at Kamphaengsean, Kasetsart University, Thailand and finished in April 2022.

Preparing cobalt chloride ($CoCl_2 \cdot 6H_2O$)-coated paper (CCP)

The CCP was prepared using methods according to Pathaveerat and Pruengam, (2020). The paper was soaked in cobalt (II) chloride solution for 3 h and the paper was dried in an oven at 60°C for 4h.

Preparation of grains

Corn variety Nakhon Sawan 1 (a feed grain variety) was purchased from the Nakhon Sawan Field Crops Research Center (Nakhon Sawan province, Thailand). The corn had an initial moisture content of around 8% wb. Another grain, soybean variety Chiang Mai 2, was purchased from the Chiang Mai Field Crops Research Center (Chiang Mai province, Thailand). The initial moisture content of the soybean was 8% wb. Soybean is used as an oil crop, and soybean meal is used as animal feed.

The moisture content of the grain samples was adjusted to the range of 10–24% wb using sprayed water droplets to ensure the water would stick to the grain surface. During the spraying of water, the grain was mixed to achieve even conditions throughout each sample. After that, the grains were stored in the refrigerator for 7 days at a temperature of 4-6 °C while still packaged in a plastic bag. The grain was mixed daily for 4 days before the experiment, which involved measuring the moisture content of the grain again (Pruengam, 2016).

Measuring color changes of CCP used to determine grain moisture content

The method consisted of the following steps: The sample of corn and soybean were placed at a moisture content of 10% wb and the CCP for testing in a glass jar (450 ml) with head space levels of 25%, 50% or 75%, respectively as shown in Figure 1.

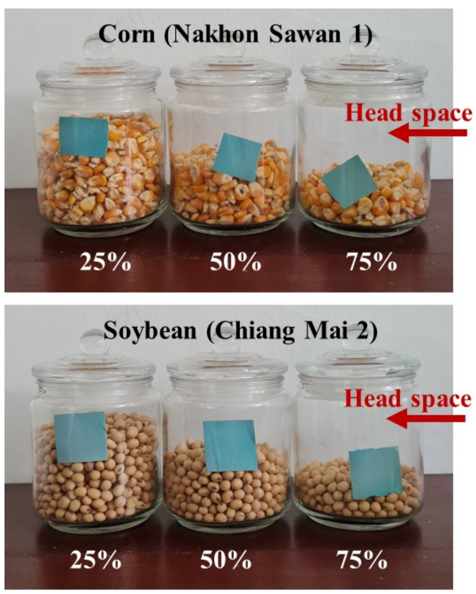

Figure 1. Head space levels or void in top of glass jar above grain

The jar was tightly closed for either 30, 45 or 60 minutes at which time to prevent discrepancies that may occur due to moisture loss when the CCP was taken off the glass jar, the CCP sample must be immediately collected in a seal bag. The grain moisture content was tested at 12, 14, 16, 18, 20, 22 and 24% wb. The reported average of each moisture content was from 3replicate experiments.

Measuring color values of paper coated with cobalt chloride

The color of each CCP sample was examined using a spectrophotometer (Spectro-guide, Sphere gloss, BYK-Gardner, USA). Measurements were based on the CIE L*, a*, b* color system, where L* (lightness) ranges from black (0) to white (100), a* (redness) ranges from redness (positive) to greenness (negative), and b* (yellowness) ranges from yellowness (positive) to blueness (negative). Prior to color measurement, the spectrophotometer was calibrated using a standard white plate with standard values of L* = 93.19, a* = -1.07, and b* = -0.4. It was then set to D65 illuminant conditions (medium daylight) and a 10° standard observer. The reported average of each color measurement was derived from 3 replicate experiments.

Moisture inspection card fabrication for measuring moisture content of multigrain

The color values of the CCP from the spectrophotometer measurement were converted to RGB values using MATLAB (E-paint.co.uk., 2021). The obtained values were used for color image printing. The RGB values of the moisture inspection card for measuring the moisture content of multiple grains were obtained from the average values for corn and soybean, while the RGB values for paddy were obtained from Pathaveerat and Pruengam, (2020). The cards were designed to have a color bar (derived from the RGB values) on the left side for each moisture content and a CCP that can change color on the right side, as shown in Figure 2.

Statistical analysis

All experimental data were analyzed using analysis of variance. The results were presented as mean values with standard deviations. Tukey's multiple comparisons test was applied to establish differences between mean values at a confidence level of 95%. All experiments were performed in duplicate.

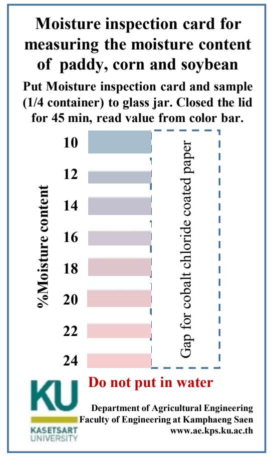

Figure 2. Example of moisture inspection card in English

Results

Paper color change with the influence of moisture content of grain

The preliminary color of the CCP had values of L*= 70.22, a*= -8.37, and b*= -8.89. After adding water until the moisture content of the grain was in the range 10–24% wb, the grain and CCP were left in the jar for 30, 45 and 60 minutes. The dry color of the CCP was blue and gradually changed to pink as the moisture content of the grain increased as seen in Figure 3. The color change became noticeable when the grain moisture content was greater than 14% wb.

All three types of color values (L* for black-white, a* for green-red, and b* for blue-yellow) increased with the increasing moisture content of grain, as shown in Figure 4. The color value ranges for the corn were 63.6 to 85.6, -7.8 to 18.9, and -16.9 to 7.5 for L*, a*, and b*, respectively. There was a substantial increase for soybean in the L*, a*, and b* values, which were in the ranges of 63.3 to 85.2, -7.3 to 18.8, and -17.6 to 8.3, respectively.

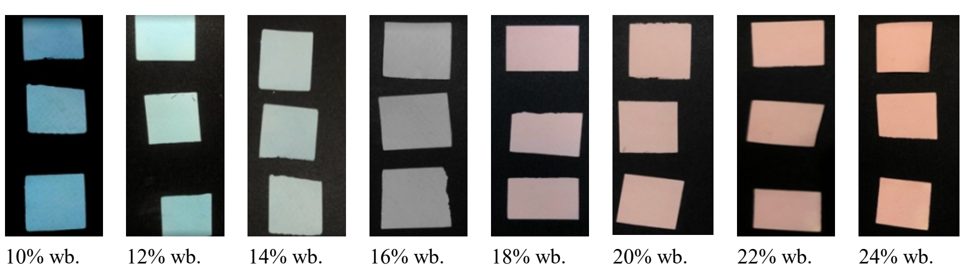

Figure 3. Color change of CCP in glass jar with corn for 45 minutes

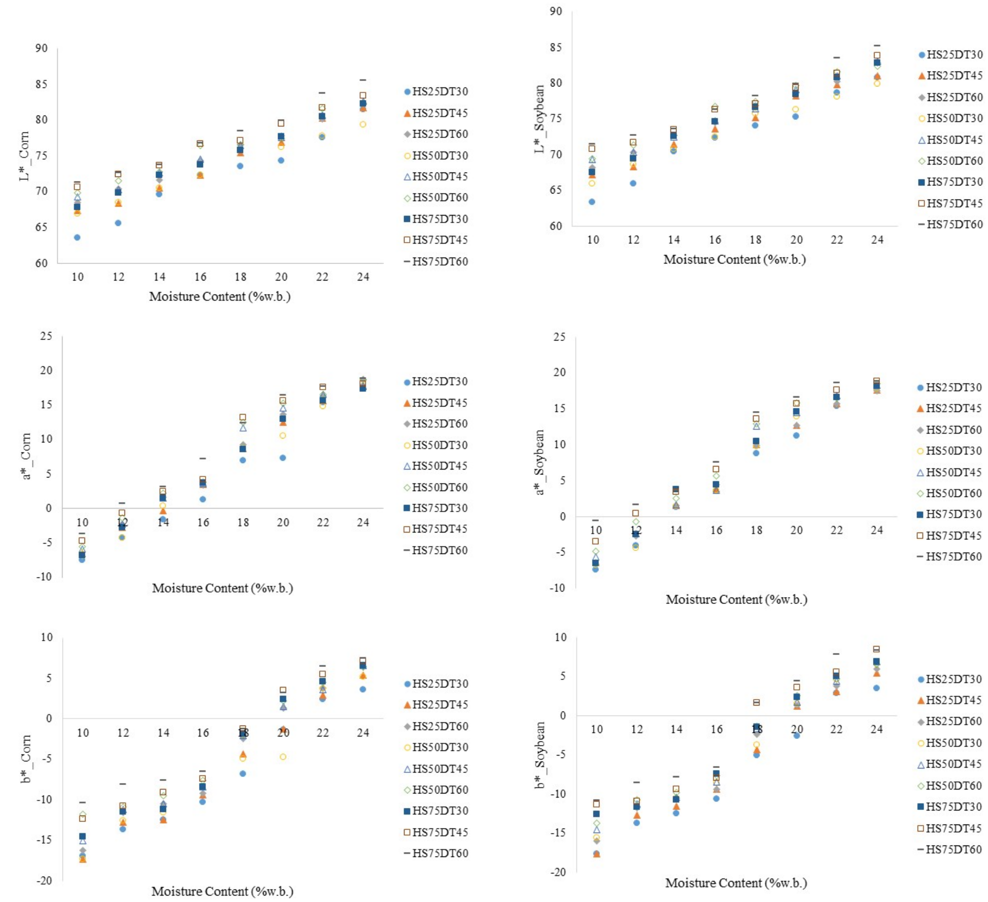

Figure 4. Variation in L*, a* and b* under different experimental conditions
HS25, HS50, HS75 = head space of 25%, 50%, and 75%, respectively.
DT30, DT45, DT60 = testing duration of 30, 45 and 60 minutes, respectively.

The experimental changes in the values of L*, a* and b* of the samples of CCP as a function of the moisture content in the range 10-24% wb were related to the moisture content using the linear regression equations (1)-(6), respectively:

For corn:

$L^* = 1.0054MC + 58.05; \quad R^2 = 0.872 \quad (1)$

$a^* = 1.7715MC - 23.445; \quad R^2 = 0.924 \quad (2)$

$b^* = 1.5645MC - 31.235; \quad R^2 = 0.924 \quad (3)$

For soybean:

$L^* = 1.0342MC + 57.757; \quad R^2 = 0.892 \quad (4)$

$$a^* = 1.7791MC - 22.706; \quad R^2 = 0.949 \quad (5)$$
$$b^* = 1.6089MC - 31.539; \quad R^2 = 0.923 \quad (6)$$

where MC is the moisture content of corn and soybean (% wb).

Paper color change with the influence of head space and testing duration

The relationship between the L* value of the CCP and the moisture content of corn and soybean for durations of 30, 45, and 60 minutes and different head spaces is presented in Table 1. At all moisture content levels for the same testing duration, an increase in head space (the amount of grain in the jar decreased) resulted in an increase in L*. Similarly, for all moisture contents with the same head space, when the testing duration increased, the L* value increased. All experiments, the one with a testing duration of 60 minutes and a heads pace of 75% (HS75DT60) had the highest L* value. Both corn and soybean produced the same results.

Table 1. Values of L* for CCP under different performing conditions

Grain	MC (%wb)	L*								
		HS25 DT30	HS25 DT45	HS25 DT60	HS50 DT30	HS50 DT45	HS50 DT60	HS75 DT30	HS75 DT45	HS75 DT60
Corn	10	63.6^{H}	67.4^{G}	68.5^{E}	66.9^{G}	69.3^{D}	69.8^{C}	67.8^{F}	70.6^{B}	71.3^{A}
	12	65.6^{F}	68.3^{E}	70.4^{C}	68.5^{E}	70.3^{C}	71.6^{B}	69.8^{D}	72.4^{A}	72.7^{A}
	14	69.6^{G}	70.6^{F}	71.7^{E}	70.5^{F}	72.6^{C}	72.7^{C}	72.3^{D}	73.6^{B}	73.8^{A}
	16	72.3^{F}	72.3^{F}	74.3^{D}	72.3^{F}	74.6^{C}	76.4^{B}	73.7^{E}	76.7^{A}	76.8^{A}
	18	73.6^{E}	75.4^{D}	76.5^{C}	75.7^{D}	76.4^{C}	76.6^{C}	75.8^{D}	77.2^{B}	78.4^{A}
	20	74.4^{G}	76.9^{E}	77.9^{C}	76.2^{F}	77.6^{CD}	77.5^{D}	77.7^{CD}	79.5^{B}	79.9^{A}
	22	77.6^{E}	80.2^{D}	80.2^{D}	77.8^{E}	80.7^{C}	81.6^{B}	80.6^{C}	81.8^{B}	83.7^{A}
	24	81.5^{E}	81.7^{E}	82.3^{D}	79.4^{F}	82.6^{C}	82.4^{CD}	82.3^{D}	83.4^{B}	85.6^{A}
Soybean	10	63.3^{G}	67.1^{E}	68.2^{D}	66.0^{F}	69.4^{C}	69.4^{C}	67.5^{E}	70.8^{B}	71.5^{A}
	12	66.0^{F}	68.3^{E}	70.3^{C}	68.6^{E}	70.4^{C}	71.4^{B}	69.5^{D}	71.6^{B}	72.8^{A}
	14	70.4^{D}	71.5^{C}	72.7^{B}	70.8^{D}	72.5^{B}	72.7^{B}	72.6^{B}	73.5^{A}	73.6^{A}
	16	72.4^{D}	73.6^{C}	74.5^{B}	72.5^{D}	74.7^{B}	76.7^{A}	74.6^{B}	76.3^{A}	76.4^{A}
	18	74.1^{G}	75.1^{F}	76.9^{C}	75.7^{E}	76.4^{D}	77.5^{B}	76.7^{CD}	77.1^{BC}	78.3^{A}
	20	75.3^{F}	78.3^{D}	78.7^{CD}	76.3^{E}	79.1^{BC}	79.7^{A}	78.4^{D}	79.3^{AB}	79.9^{A}
	22	78.7^{F}	79.8^{E}	80.3^{DE}	78.2^{F}	81.0^{BC}	81.7^{B}	80.8^{CD}	81.4^{BC}	83.5^{A}
	24	80.9^{D}	81.1^{D}	82.8^{C}	79.9^{E}	83.0^{C}	82.4^{C}	82.9^{CD}	83.8^{B}	85.2^{A}

Different capital superscripts in rows indicate values are significantly different ($p < 0.05$).

An increase in the head space increased the a* value as shown in Table 2. For all values of head space and moisture content of the grains, an increase in the testing duration increased the a* value. The condition of a head space of 75% with a testing duration of 60 minutes (HS75DT60) produced the significantly highest a* value. Both corn and soybean had the same trend for the L* values.

Table 2. Value of a* for CCP under different performing conditions

Grain	MC (%wb)	a*								
		HS25 DT30	HS25 DT45	HS25 DT60	HS50 DT30	HS50 DT45	HS50 DT60	HS75 DT30	HS75 DT45	HS75 DT60
Corn	10	-7.5^{G}	-6.6^{E}	-6.9^{F}	-6.6^{E}	-5.8^{D}	-5.5^{C}	-6.8^{F}	-4.7^{B}	-3.7^{A}
	12	-4.3^{F}	-2.8^{E}	-2.3^{D}	-4.3^{F}	-2.3^{D}	-1.4^{C}	-2.7^{E}	-0.6^{B}	0.7^{A}
	14	-1.6^{E}	-0.3^{DE}	1.6^{BC}	0.4^{D}	1.5^{C}	2.2^{BC}	1.5^{C}	2.5^{AB}	3.2^{A}
	16	1.3^{G}	3.5^{EF}	3.4^{F}	3.5^{EF}	3.6^{DE}	3.9^{C}	3.7^{D}	4.2^{B}	7.2^{A}
	18	6.9^{F}	8.6^{E}	9.2^{D}	8.7^{E}	11.7^{C}	12.5^{B}	8.6^{E}	13.1^{A}	12.3^{A}
	20	7.2^{I}	12.5^{G}	13.6^{E}	10.5^{H}	14.6^{D}	15.2^{C}	13.0^{F}	15.7^{B}	16.4^{A}
	22	15.4^{DE}	15.6^{CDE}	16.3^{BC}	14.9^{E}	16.6^{B}	16.5^{B}	15.6^{CD}	17.5^{A}	17.8^{A}
	24	17.7^{BCD}	17.9^{BC}	18.7^{A}	17.5^{CD}	17.7^{BCD}	18.6^{A}	17.4^{D}	18.1^{B}	18.9^{A}
Soybean	10	-7.3^{F}	-6.3^{E}	-6.6^{E}	-6.8^{E}	-5.6^{D}	-4.8^{C}	-6.5^{E}	-3.4^{B}	-0.6^{A}
	12	-4.0^{E}	-2.3^{D}	-2.7^{D}	-4.3^{E}	-2.4^{D}	-0.7^{C}	-2.4^{D}	0.4^{B}	1.6^{A}
	14	1.4^{C}	1.5^{C}	1.6^{C}	1.4^{C}	1.6^{C}	2.6^{B}	3.8^{A}	3.5^{A}	3.6^{A}
	16	3.5^{D}	3.9^{D}	4.5^{D}	3.6^{D}	3.6^{D}	5.7^{C}	4.4^{D}	6.6^{B}	7.6^{A}
	18	8.8^{F}	10.0^{E}	9.9^{E}	9.8^{E}	12.6^{C}	12.9^{C}	10.5^{D}	13.6^{B}	14.5^{A}
	20	11.3^{F}	12.7^{E}	12.7^{E}	13.9^{D}	14.5^{CD}	15.8^{B}	14.6^{C}	15.7^{B}	16.6^{A}
	22	15.4^{D}	15.7^{D}	15.7^{D}	16.6^{C}	16.8^{C}	16.5^{C}	16.6^{C}	17.7^{B}	18.6^{A}
	24	17.7^{D}	17.6^{D}	17.5^{D}	17.9^{CD}	18.3^{BC}	18.5^{AB}	18.2^{BC}	18.8^{A}	18.8^{A}

Different capital superscripts in rows indicate values are significantly different ($p < 0.05$).

The testing duration and head space affected the CCP color in terms of b* value, as shown in Table 3. All levels of moisture content in the grain's levels were similar to those for in L* and a*.

The highest color value in corn and soybean which produced with a head space of 75% with a testing duration of 60 minutes (HS75DT60). This could be explained by the corn and soybean being oil crops with a pericarp or seed coat (the outer covering of a seed).

Table 3. Value of b* for CCP under different performing conditions

Grain	MC (%wb)	b*								
		HS25 DT30	HS25 DT45	HS25 DT60	HS50 DT30	HS50 DT45	HS50 DT60	HS75 DT30	HS75 DT45	HS75 DT60
Corn	10	-16.9^{G}	-17.4^{H}	-16.3^{F}	-17.3^{H}	-15.1^{E}	-11.8^{B}	-14.6^{D}	-12.4	-10.4^{A}
	12	-13.7^{G}	-12.8^{F}	-11.6^{D}	-12.5^{E}	-11.2^{C}	-10.9^{B}	-11.5^{D}	-10.8^{B}	-8.1^{A}
	14	-12.5^{G}	-12.4^{G}	-10.5^{D}	-11.6^{F}	-10.5^{D}	-9.5^{C}	-11.2^{E}	-9.1^{B}	-7.6^{A}
	16	-10.3^{F}	-9.4^{E}	-9.2^{D}	-8.5^{C}	-8.5^{C}	-7.6^{B}	-8.4^{C}	-7.5^{B}	-6.5^{A}
	18	-6.8^{F}	-4.4^{D}	-2.5^{C}	-4.9^{E}	-2.1^{B}	-1.9^{B}	-1.9^{B}	-1.3^{A}	-1.3^{A}
	20	-1.4^{D}	-1.2^{D}	1.4^{C}	-4.8^{E}	1.6^{C}	2.2^{B}	2.4^{B}	3.5^{A}	3.2^{A}
	22	2.4^{F}	2.9^{E}	3.8^{D}	3.7^{D}	3.6^{D}	4.4^{C}	4.6^{C}	5.5^{B}	6.5^{A}
	24	3.6^{F}	5.4^{E}	6.5^{D}	5.2^{D}	6.6^{D}	6.3^{C}	6.6^{C}	7.2^{B}	7.5^{A}
Soybean	10	-17.6^{G}	-17.6^{G}	-15.9^{F}	-15.6^{F}	-14.5^{E}	-13.7^{D}	-12.6^{C}	-11.3^{B}	-10.8^{A}
	12	-13.7^{F}	-12.7^{E}	-11.8^{D}	-11.6^{D}	-11^{CD}	-10.7^{B}	-11.7^{D}	-10.9^{BC}	-8.6^{A}
	14	-12.5^{F}	-11.6^{E}	-10.5^{D}	-10.5^{D}	-10.4^{D}	-9.8^{C}	-10.7^{D}	-9.4^{B}	-7.8^{A}
	16	-10.6^{E}	-9.3^{D}	-9.4^{D}	-8.6^{C}	-8.5^{D}	-7.7^{B}	-7.4^{B}	-7.9^{B}	-6.6^{A}
	18	-5.0^{F}	-4.4^{E}	-2.4^{C}	-3.7^{D}	-1.7^{B}	-1.3^{B}	-1.4^{B}	1.7^{A}	1.6^{A}
	20	-2.6^{F}	1.2^{E}	1.3^{DE}	1.5^{DE}	1.7^{C}	2.5^{C}	2.4^{C}	3.6^{B}	4.4^{A}
	22	2.9^{F}	3.1^{F}	3.9^{E}	4.6^{D}	4.5^{D}	4.7^{CD}	5.1^{C}	5.6^{B}	7.8^{A}
	24	3.5^{E}	5.5^{D}	6.0^{C}	6.6^{B}	6.9^{B}	6.6^{B}	6.9^{B}	8.5^{A}	8.3^{A}

Different capital superscripts in rows indicate values are significantly different ($p < 0.05$).

Standard color chart from experimental data

The color values of paddy (HS75DT45), corn (HS75DT60) and soybean (HS75DT60) were averaged for comparison with the mean of paddy (HS75DT45), corn (HS75DT45) and soybean (HS75DT45), as shown in Table 4.

Table 4. Average color values of CCP under different moisture contents

Moisture content (% wb)	Case I Paddy (HS75DT45) Corn (HS75DT60) Soybean (HS75DT60)			Case II Paddy (HS75DT45) Corn (HS75DT45) Soybean (HS75DT45)		
	Color	L*, a*, b*	Estimated RGB	Color	L*, a*, b*	Estimated RGB
10		70.8, -3.6, -11.9	157,176,195		70.4, -4.9, -12.8	153, 176, 195
12		72.4, 0.1, -8.1	172,178,192		72.0, -0.8, -9.7	168, 177, 194
14		73.7, 3.1, -7.3	182,180,195		73.6, 2.8, -8.3	181, 179, 196
16		76.6, 7.3, -5.6	199,185,200		76.6, 6.0, -6.3	196, 186, 201
18		78.3, 12.1, -0.3	216,186,195		77.5, 12.1, -0.3	214, 184, 193
20		79.6, 15.8, 3.1	228,187,192		79.3, 15.3, 2.9	226, 186, 192
22		82.9, 17.3, 6.3	240,195,201		81.6, 17.0, 5.2	237, 191, 194
24		83.5, 18.7, 7.2	246,195,197		82.3, 18.5, 7.1	242, 192, 192

For case I:

$$L^* = 1.9046MC + 68.659; \quad R^2 = 0.987 \quad (7)$$

$$a^* = 3.3999MC - 6.447; \quad R^2 = 0.978 \quad (8)$$

$$b^* = 2.8774MC - 15.025; \quad R^2 = 0.974 \quad (9)$$

For case II:

$$L^* = 1.7765MC + 68.648; \quad R^2 = 0.989 \quad (10)$$

$$a^* = 3.5212MC - 7.6111; \quad R^2 = 0.976 \quad (11)$$

$$b^* = 3.0171MC - 16.357; \quad R^2 = 0.978 \quad (12)$$

where MC is the moisture content of corn and soybean (% wb).

In the case of all grains and a duration of 45 minutes (case II), there was an increase in the coefficient of correlation (R^2), indicating that the relationship between moisture content and color values was stronger. Hence, using a head space of 75% for 45 minutes would be sufficient to allow the multigrain moisture content to equilibrate with the relative humidity (RH) in the head space. Additionally, choosing to use 45 minutes for every grain would be convenient. The L*, a*, and b* values of the coated paper were converted to RGB values for color image printing to subsequently produce an integrated moisture inspection card.

Integrated moisture inspection card for measuring moisture content of multigrain

The RH monitoring card used to evaluate the moisture content of paddy, corn and soybean is shown in Figure 5. The production cost of the card was low at about 10 Thai bahts/piece (USD 0.35). The outstanding advantage is that it can be reused by simply drying it in the sun or blowing hot air on it to bring the paper back to its blue color.

Figure 5. Application of moisture inspection card in different types of grains

Discussion

Moisture content is an important factor in the storage and processing of multigrain and agricultural products and is the most important characteristic for maintaining the quality of agricultural products. Furthermore, to maintain quality and prevent grain contamination, it is essential to know the accurate moisture content (Pathaveerat and Pruengam, 2020; Ritula *et al.*, 2014).

Although rice is the most important agricultural product of Thailand, corn and soybean are also significant economic crops both for Thailand and globally. It is well known that small-scale farmers or those in rural areas often cannot afford costly equipment. As a result, many farmers have to sell their products immediately, missing the opportunity to store them for later sale when prices might increase, because they lack devices to monitor humidity.

Previously, a moisture inspection card was used only for paddy (Pathaveerat and Pruengam, 2020). The current research investigated the relationship between the moisture content of paddy and the color change in CCP. To be useful, there must be a standard color chart related to the moisture content of each grain so that it can be applied in a wide variety of applications. Thus, an integrated moisture inspection card is needed.

From the experimental results, the highest color value in corn and soybean was obtained with a head space of 75% and a testing duration of 60 minutes, which differed from paddy, where the highest color value was observed with a head space of 75% and a testing duration of 45 minutes. This difference can be explained by the fact that corn and soybean are oil crops with a pericarp or seed coat. In general, the corn pericarp consists of hemicellulose, cellulose, and lignin (Zilic *et al.*, 2011; Paes, 2006). The seed coat of soybean is largely composed of insoluble carbohydrates, such as hemicellulose, cellulose, and pectin (Damasceno *et al.*, 2022; Mullin and Xu, 2001). Both of these seed coats are permeable to water (Abati *et al.*, 2020; Yang *et al.*, 2018). The seed pericarp prevents water and oxygen absorption (Vicient, 2017), while the high lignin content in the seed coat results in less water absorption (Abati *et al.*, 2020). Furthermore, grain moisture transfer to the surrounding air is more difficult and takes longer compared to paddy.

Although the results for corn and soybean were optimal with a test duration of 60 minutes, it was found that the R^2 values of equations (10)-(12) for the combined data from all three grains were best with a test duration of 45 minutes. Therefore, a test duration of 45 minutes was used as the standard for all three grains.

New technologies for determining and measuring moisture in grains are constantly being developed and applied. The indirect method has been used commercially, with Ajao (2018) reporting the prices of meters in 2018 as USD 100, USD 260, and USD 3,600 for PHL, John Deere, and GAC 2100, respectively. These meters have become increasingly expensive over time, as shown in Table 5.

The integrated moisture inspection card currently developed, which includes an option for evaluating moisture content in corn and soybean, is very low-cost compared to those listed in Table 5. Although the measurement procedure takes 45 minutes to complete, this method is a good alternative. As the objective of the current research was to produce a moisture inspection card applicable to a variety of grains, considerations were also given to affordability for farmers and suitability for use in remote areas. More importantly, it provides farmers with a way to sell their products at higher prices and ensures safe storage.

Table 5. Functional characteristics and price of some indirect methods for grains moisture measurement

Moisture meter	Method/ Operating principle	Applications	Price	
PHL Meter	Uses relative humidity and temperature data to determine the EMC	Hard wheat, soft wheat, yellow corn, soybeans, rough rice, and sorghum	USD 75 (2017) (United States Department of Agriculture, 2017)	USD 100 (2018) (Ajao, 2018)
John Deere	Capacitance	40 different grains	USD 260 (2018) (Ajao, 2018)	USD 340-370 (2022) (Green Part Store, 2022)
GAC 2100 m	Capacitance	Oil seeds, vegetable seeds, grass seeds, beans, cereals,	USD 3,600 (2018) (Ajao, 2018)	USD 5,200 (2022) (Spray Smarter, 2022)

The moisture content of corn and soybean was effectively estimated using the discoloration of CCP. Blue color indicated low moisture diffusion from the grain, while pink paper indicated higher moisture diffusion. The highest color values in corn and soybean were obtained using a head space of 75% with a testing duration of 60 minutes (HS75DT60), which differed from paddy, where the highest color value was achieved with the same head space but a shorter testing duration of 45 minutes (HS75DT45). This difference can be explained by the fact that corn and soybean are oil crops with a pericarp or seed coat. The highest color values for each grain were averaged for comparison. Considering all grains with a test duration of 45 minutes, the results showed an increase in the coefficient of correlation (R^2) for the relationship between moisture content and color values for corn and soybean compared to a testing duration of 60 minutes, and for paddy with a testing duration of 45 minutes. Therefore, the optimal measurement procedure using this method involves filling the grain to 1/4 of the container (a head space of 75%) and allowing it to remain for about 45 minutes for the relative humidity (RH) to equilibrate with the moisture in the air gap of the grain. Additionally, 45 minutes is a convenient duration for grains in general.

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