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ABSTRACT

To ensure the best quality in coffee beans, accurate and effective instrument and process of moisture content (MC) monitoring is very critical. Inaccurate process and instruments in MC determination may mean considerable quantitative and qualitative losses. It may prevent farmers and processors to command premium selling price. In the Philippines, empirical method is still the most common practice but accuracy with this practice varies because of different standards. It is also highly dependent on human perception. Moreover, prohibitive cost of imported moisture meters inhibits the local coffee farmers and traders from acquisition of available technologies. Inaccuracy, complicated operations, after-sales services and availability of spare parts are among other reported concerns in the use of imported moisture meters.

This project developed a simple, portable yet accurate coffee MC meter to address the subjectivity of empirical method and aimed to offer a less-expensive and locally-made MC measuring tool. The developed prototype adopted a capacitive sensor oscillator circuit and can measure both green coffee beans (gcb) and parchment coffee. The prototype comprised of two-concentric cylinder test chamber, where whole coffee beans are placed; metal encasement containing the circuit and other peripherals; and control and measurement panel. It was micro-controller based, with LCD read-out which displays MC reading and battery life. Validation and field testing results indicated that the prototype unit MC meter was sufficiently accurate for Arabica, Liberica and Robusta varieties. Fabrication cost was estimated at PhP 14,000.00. This is 40% to 60% cheaper than the imported coffee moisture meters.

INTRODUCTION

Determination of moisture content at various stages of coffee production is one of the keys to quality and cost control. Inefficient and ineffective process and instruments in moisture content (MC) determination may mean huge quantitative and qualitative losses in the entire coffee industry. Drying, storage, marketing and roasting are four important aspects of coffee handling where moisture content plays an important role (Gautz, 2008).

Moisture measurement at the end of drying is essential to follow up drying course and decide whether it is achieved or not (FAO, undated). Coffee is dried from approximately 60% to 12% moisture content. Drying below this level may result to monetary losses. Just like any other dried grains, coffee must be stored in dry and cool conditions with moisture content level from 15% to 11% for optimum storage and quality roasting. Storing coffee with higher moisture content may involve high risks of mold growth and Ochratoxin A (OTA) production (FAO, undated).

Moreover, marketing coffee with higher moisture content contains unnecessary tons of weight which may equate to additional transport cost (FAO, undated). Temperature and length of roasting coffee are based on moisture content of 12% to 13%. Above these values, roasting requires more energy and might be incomplete. Below these values, beans might end up being over-roasted. Moisture content monitoring is also very critical in the hulling process. Too high MC (16% and above) slows down the motor of the hulling machine while too low MC makes the beans brittle resulting to broken beans.

In the Philippines, empirical method is the most common practice in determining moisture content of coffee beans. Problem in high moisture content of coffee produced by farmers is attributable to inaccuracy of measuring the MC of their product using empirical method. In an attempt to address this inaccuracy problem in MC determination, Idago (2011) introduced and tested an imported prong-type electronic meter in the Cordillera region. Although the instrument showed promising result, further improvement is needed to come up with a simple and low-cost moisture meter for coffee beans. Inherent to being imported, difficulty in after sales services of electronic meters was also expressed by the end-users. Similar type of moisture meters by a local distributor based in Pampanga, was taken off the shelves for reported inaccuracy in moisture reading.

This project was proposed for the development of a non-destructive, capacitance type moisture meter for green coffee beans and parchment coffee in partnership with a local electronic company. The project aimed to provide an alternative, inexpensive, simple yet accurate MC level meter to address the subjectivity and slow process of empirical moisture content determination commonly used by farmers and small traders.

OBJECTIVES

General:

The project aimed to develop a non-destructive moisture meter for coffee beans.

Specific:

1. Evaluate the technical performance of existing moisture meters for coffee beans;
2. Establish design parameters for the development of a non-destructive moisture meter for coffee beans;
3. Come up with a prototype unit non-destructive moisture meter for coffee beans; and
4. Evaluate the performance of the prototype unit moisture meter for coffee beans in terms of technical and operational efficiency.

REVIEW OF LITERATURE

Several methods are employed to determine the moisture content of coffee: the empirical evaluations, the primary method, and secondary method. Empirical evaluation refers to methods such as biting, shaking, crunching, commonly used by both producers and small traders. The internationally accepted standard method for determining moisture in coffee is the loss of weight on heating (oven method). This method involves tedious laboratory procedures and long oven-drying periods, rapid methods for moisture measurement have been essential in the grain and seed trade (Nelson, 2011). On the other hand, existing electronic meters that measure the dielectric constant of products are generally expensive and can only be accessed by big traders for commercial transactions (Gautz, 2008).

The amount of moisture in coffee parchment and beans is important for two reasons: (1) coffee that is too high or too low in moisture will not maintain high cupping quality, and (2) the traded commodity is coffee, not water. Green coffee that is high in moisture (greater than 12 percent wet basis) can deteriorate due to bacteria, mold, or yeast, especially if the seed is killed. If the seed remains alive, enzymatic activity will cause the cupping quality to change. In any case, the parchment coffee moisture level should be lowered to below 12% soon after harvest. When the ambient relative humidity is about 7%, coffee beans will gradually equilibrate to about 12% moisture. Thus green bean coffee is generally dried to 12%, and bought and sold at this moisture percentage. If the bean dries to below 9% moisture, it will shrink enough to become distorted, which will give the appearance of low-quality coffee (Gautz, 2008).

Methods of determining moisture content of coffee

According to FAO (undated), the methods of determining moisture content in coffee can be divided into three broad categories:

Direct measurement. Water content is determined by removing moisture and then by measuring weight loss. The most accurate method of measuring grain moisture content, it uses an ISO-specified protocol to dry a prepared sample of ground grain in a special laboratory oven (ISO712). The weight lost during drying is used to calculate the moisture of the sample.

Indirect measurement. An intermediate variable is measured and then converted into moisture content. Building up calibration charts before applying indirect measurements is a prerequisite. This method measures the electrical properties of moisture in products being measured such as resistance and capacitance to ensure accuracy of the reading obtained. Most commonly known in this method is the use of moisture meter.

Available moisture meters measure an electrical property related to moisture content, rather than grain moisture itself. Some of the measuring instruments using this principle are: hygrometers measuring the electrical resistance of the grain and hygrometers measuring the dielectric constant of the grain.

Hygrometers are electric devices which allow the moisture content of a sample of grain to be directly and immediately read on a dial. Hygrometers measuring the electric resistance of grain are portable instruments that are relatively imprecise but extremely practical and inexpensive. The more expensive and complex hygrometers that measure the dielectric constant of grain are generally used in big storage centres and for commercial transactions.

Empirical measurement. This refers to methods such as biting, shaking, crunching, and commonly used by both producers and small traders. These empirical measurements are both indirect and subjective. Surveys carried out during the 'Enhancement of Coffee Quality through the Prevention of Mould Formation' project have shown that these subjective methods of moisture determination to be insensitive over the range 12–20% moisture content, and therefore unsuitable for determining the end of drying (i.e. when coffee has a maximum of 12% moisture), or for verifying that coffee in the marketing chain is at a safe moisture content.

These methods, based on individual experience, do not give a true objective measurement, but estimate the degree of moisture by subjective sensory perception of some of the grain's characteristics. Some assess the fluidity of the grain by trying to push an open hand into a fairly big grain mass contained in a bag or in a thick layer of bulk grain.

Although these empirical methods are employed mainly by farmers, they ought to be progressively replaced by the use of instruments that permit a true measurement of the moisture content of grain. The use of empirical methods in storage centres or during commercial transactions should be emphatically opposed (Nelson, O S. 1999).

What grain moisture meters measure

Most of the information in this section were taken from the write up of Lee (2006) accessed at www. nist.gov.

Water is a good insulator. Insulators have tightly bound electrons and can store electrical charges. A dielectric or electrical insulator is a material that is highly resistant to the flow of electrical current. Capacitance is a measure of the amount of electric charge stored (or separated) for a given electric potential. Capacitance exists between two conductors insulated from one another. A dielectric constant can be determined by measuring the capacitance of a capacitor (two conductors or plates) with air between the plates, then measuring the capacitance with a dielectric material between the plates. The ratio of these measurements is used to determine the dielectric constant. The dielectric (capacitance) technology used in many grain moisture meters is based on the principle that a functional relationship exists between the moisture content of grain and its dielectric constant. As grain increases in moisture content (water), its dielectric constant increases. The rate at which the dielectric constant increases as grain moisture increases is not the same for all grain types; therefore, a unique calibration equation must be developed for each grain type to be measured.

Moisture meters based on the dielectric principle typically incorporate a test cell in the form of an electrical capacitor, that is, two conductors separated by an insulator. When the cell is empty, only air separates the two conductors, and the insulator is air. When a grain sample to be measured is placed between the conducting surfaces of the test cell, the grain displaces most of the air. By sensing the change in the electrical characteristics of the capacitor due to the dielectric properties of the grain sample, the meter can predict the moisture content of the sample. Because the bulk density and the temperature of the grain sample also affect the electrical characteristics of the grain-filled test cell, the meter must measure these parameters and apply the necessary corrections.

Electronic meters

Moisture content affects the electrical properties of materials. These properties include the inductance, resistance, and capacitance of the sample. The electrical characteristics also change with the temperature, density, and chemical make-up of the sample. This is why a good moisture meter measures density and temperature as well as the electrical characteristics (Venkatesh et al., 2005).

Repeatability is perhaps the most important characteristic of a meter. You should get approximately the same reading for a sample if it is presented (poured out and put back in) several times. The variability of readings from a sample presented several times to the meter (repeatability) is the real accuracy of the meter and cannot be eliminated by calibration. A meter can be made more precise by taking the average of the same sample presented multiple times. Moisture meters that measure inductance are rare. In general, measuring electrical inductance is difficult and usually expensive, although this is changing with advances in electronics.

Measuring electrical resistance is easy and inexpensive. The sample of beans may be placed in a container, with two electrodes in contact the beans. Sometimes the electrodes are like needles and can be inserted into a bag. The problem with using resistance measurements with coffee is the same as with all granular materials: the electrical path is inconsistent, depending on the pressure on the sample and the placement of the grains relative to each other. Most resistance moisture meters are not very accurate because making the measurement repeatable is difficult.

The most-used moisture meters for coffee are adapted grain meters that measure capacitance. An electrical capacitor consists of two plates separated by some insulating material. The rate that an electrical charge can be built up on the capacitor depends on the material between the plates, if nothing else changes. The material can be air or coffee, among other things. Temperature, bulk density, and moisture content of the coffee determine how it acts as a dielectric, or capacitor separation material.

Modern capacitance moisture meters measure temperature, bulk density, and capacitance. Some use a cup with a cone inside it to hold the sample; the outside of the cup is one “plate” of the capacitor, and the inside cone is the other. A temperature sensor is located in the cup. The volume of the cup is fixed, and the meter weighs the cup. Filling the cup evenly and consistently is handled in different ways. Some meters sense the fill rate and flash a warning. Others use funnels with snap doors. Using an internal microprocessor, the meter calculates the moisture content according to a calibration curve for the particular material.

METHODOLOGY

Needs assessment and characterization of existing moisture meters for coffee

Focus group discussions (FGDs) and key informant interviews (KII) were done in the provinces of Batangas, Cavite, Davao Oriental, Oriental Mindoro, Laguna, Quezon Province and Bukidnon to validate the specific needs of the industry in moisture content determination and at the same time gather technical information in the design of moisture meters for coffee beans. Coffee postharvest operations where moisture content determination is most critical, were identified. Inventory and technical evaluation of existing coffee moisture meters were also done.

Development of the prototype coffee moisture meter

Hardware Component

After a series of design concepts, the project came up with the final prototype unit as shown in Figures 1 and 2. The prototype unit was a capacitance-type moisture content meter composed primarily of three parts: (1) two-concentric cylinder test chamber where a 200-grams test samples were placed; (2) an encasement which contains the circuit, menu panel (for overall control and measurement) and other peripheral parts; and (3) a discharge outlet where measured test samples are disposed. A handle was also provided for ease of handling and mobility.

The menu panel as shown in Figure 3 was provided with 5-button selector panel for coffee type (green coffee beans or parchment coffee) and varieties of coffee to be measured. Each button is numbered from 1 to 5 with corresponding legend. It is micro-controller based with LCD read out panel.

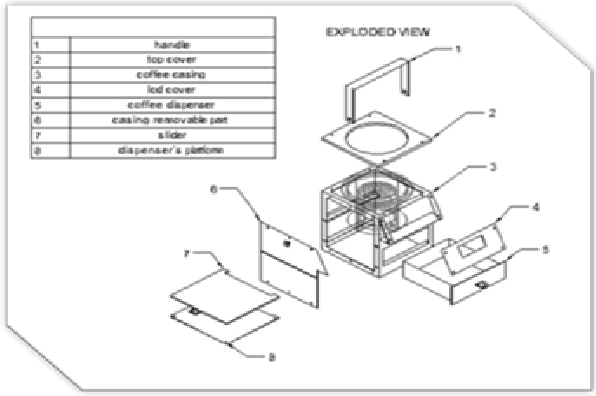


Figure 1. CAD-generated exploded view of the prototype unit coffee moisture meter

Figure 2. The prototype unit non-destructive coffee moisture meter

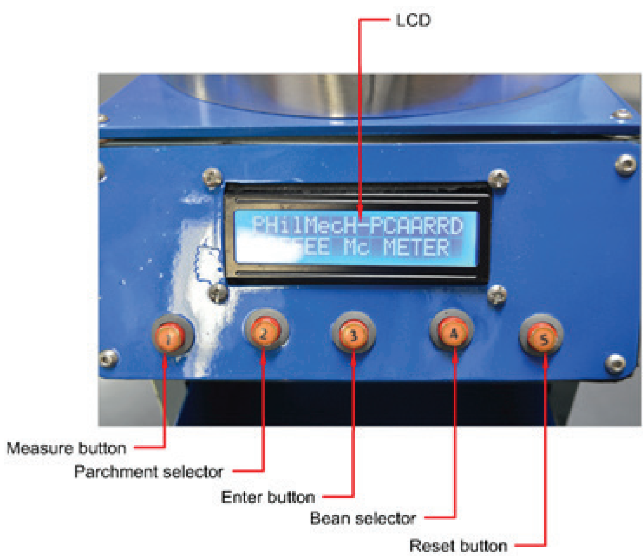


Figure 3. Menu panel and legend of the prototype unit coffee moisture meter

Circuit system and software component

Shown in Figure 4 is the functional block diagram of the coffee moisture meter. The hysteresis circuit sets the two threshold voltages of the comparator and forced the circuit to oscillate. The RC circuit sets the oscillation period while the voltage across the capacitor depends on the voltage produced by the positive input voltage of the comparator in which the hysteresis circuit is being placed. The generated frequency is then calibrated by the internal calibration of the PIC micro-controller.

The accuracy of the circuit depends on this internal calibration. A simple mathematical calculation is done to scale the period into moisture content in % and display that value on a display screen. The coffee moisture content meter measures the dielectric constant of coffee samples.

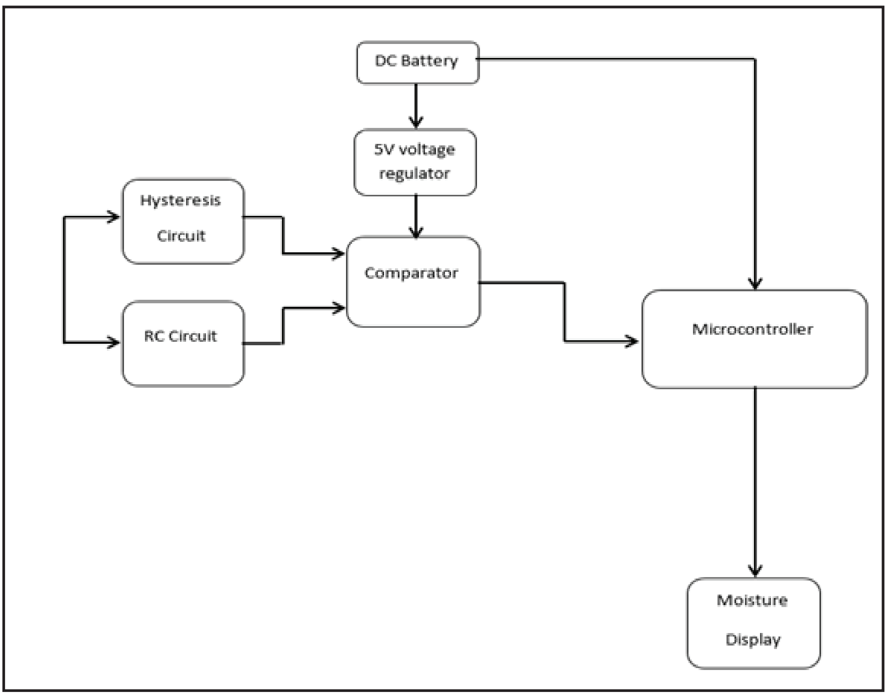


Figure 4. Functional block diagram of the circuit system

The system also uses a trimmer resistor capable to adjust the system for high precision instead of precision resistors. A 9V DC battery is fed through a 5V voltage regulator to provide power to the whole circuit. The system selected Assembly programming language to facilitate the code of coffee moisture meter. It is a low level programming language for computers, microcontrollers, microprocessors and other programmable devices.

Model calibration and validation process

Calibration equations was derived from frequency outputs measured from coffee samples of *Coffea arabica, Coffea liberica* and *Coffea canephora* varieties, with known moisture contents varying from 6% to 18% for green coffee beans and from 10% to 40% for parchment coffee. Freshly harvested and de-pulped coffee samples were cleaned and pre-conditioned, by air-drying the coffee samples to its desired moisture content. Moisture content measurements were based on the ASAE S352.2 (2000) procedure on standard oven-drying method. Pre-conditioned samples were then placed in plastic containers and kept in room condition and individually withdrawn during each calibration tests. Shown in Figure 5 is the laboratory measurements done using the developed circuit with an oscilloscope where resulting frequency readings were initially displayed. A total of 229, 170 and 93 data points for Arabica, Liberica and Robusta green coffee bean samples, respectively from varying moisture content levels were generated. Likewise, a total of 245 and 96 data points for parchment coffee of Arabica and Liberica, respectively from different moisture content levels were generated. No measurement for parchment coffee was conducted for Robusta variety where dry process method is being practiced by farmers. The method involves immediate drying of freshly harvested coffee cherries without de-pulping.

Based on the experimental results, a regression analysis was conducted to develop calibration equations for both green coffee beans and parchment coffee for all the three coffee varieties.

(a)

(b)

Figure 5. Calibration tests conducted for coffee beans (a) and coffee parchments (b) for the prototype unit test chamber of the non-destructive coffee moisture meter

For model validation, a total of 90, 67 and 57 data points for Arabica, Liberica and Robusta varieties of varying moisture contents were gathered for green coffee beans while a total of 121 and 43 data points for Arabica and Liberica coffee parchments with different moisture contents were gathered. The predicted moisture contents were compared with oven moisture content values.

Technology Performance Evaluation of Prototype Coffee Moisture Meter

This activity was conducted to establish the operating characteristics of the prototype unit non-destructive coffee moisture meter. Performance evaluation was done in a controlled laboratory setting for precision and accuracy. Measured moisture contents for both green coffee beans and parchment coffee were compared to oven-dried samples based on ASABE Standards S352.2 (2000) moisture content determination method. A total of 30 samples each for green coffee beans and parchment coffee per variety with different moisture content levels were used as test samples.

Test Samples

Well-cleaned coffee samples comprised of three adjacent 2% moisture content intervals within a range of 6% moisture contents as stated in the test procedure of the International Organization of Legal Metrology (OIML, 2009) were used for the evaluation. For uniformity of application, each 2% moisture content intervals was used including the 14%, which is considered to be the most critical moisture content level in seeds and grains.

Accuracy and Precision

Three sets of 10 samples each for the 2% moisture content intervals or a total of 30 samples were used for each coffee variety to test the performance of the prototype unit non-destructive coffee moisture meter. Grain samples were subjected and compared to the reference oven method to evaluate the performance of the coffee moisture meter in terms of accuracy and precision.

Accuracy of the coffee moisture meter was measured in two parameters: (1) moisture error, and (2) Standard Deviation of the Difference, SDD between the prototype coffee moisture meter and the standard oven method. Procedures and method for both parameters were based on OIML TC17 (2006) with the given equations below:

$$\bar{y} = \frac{\sum_{i=1}^{n}(\bar{x} - r_i)}{n} \tag{1}$$

$$SDD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}} \tag{2}$$

where:
$\bar{y}$ = average overall, y_i
y_i = $\bar{x} - r_i$
x_i = average coffee moisture meter value for sample $_i$ (3 replicates)
r_i = reference moisture content value for sample $_i$
n = number of samples per 2 % moisture interval

Precision of the prototype non-destructive coffee moisture meter was measured by (1) Repeatability and (2) Reproducibility. Repeatability is defined as the Standard Deviation, SD of three replicates calculated for each sample in a 2% moisture content interval and pooled across samples (OIML, 2006). The equation used is given below:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{3}(x_{ij}-\bar{x}_i)^2}{2n}} \qquad (3)$$

where:

x_{ij} = coffee moisture meter value for sample i and replicate j

$\bar{x}_i$ = average of the three moisture values for sample i

n = number of samples per 2% moisture content interval, (n=10)

Likewise, reproducibility was measured between readings of the prototype moisture meter operated by two (2) different persons at the same time, place and condition, expressed as SDD_1. The tests were done in three replicates with 10 sets each of the 2% moisture content intervals. The equation used is shown below:

$$SDD_1 = \sqrt{\frac{\sum_{i=1}^{n}(d_i-\bar{d})^2}{n-1}} \qquad (4)$$

where:

d_1 = $\bar{x}_i^{(1)} - \bar{x}_i^{(2)}$

$\bar{x}_i^{(1)}$ = mean of three replicates for sample i on operator 1

$\bar{x}_i^{(2)}$ = mean of three replicates for sample i on operator 2

$\bar{d}$ = mean of the d_1

n = number of samples in all 2% moisture content ranges

Due to insufficient samples of parchment coffee, precision tests were conducted for green coffee beans only.

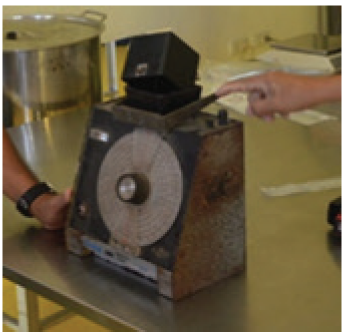
RESULTS AND DISCUSSION

Existing coffee moisture meters

All coffee farmer and grower respondents were into emprical method of moisture content determination. As shown in Figure 6, there were at least four types of moisture meters used by traders/cooperatives and processors for coffee moisture content determination.

Moisture Meter 1

Moisture Meter 2



Moisture Meter 3

Moisture Meter 4

Figure 6. Respondents' existing moisture meters for coffee

Description and technical performance of the abovementioned coffee moisture meters are summarized in Table 1. Among the available types of coffee moisture meters, it seemed that price is directly proportional with accuracy and reliability (Table 1). Comparison of moisture content readings of existing coffee moisture meters to oven method disclosed that MC Meter 1 had the lowest average MC difference of 0.85% while MC Meter 4, had the highest MC difference of 4.25%.

Table 1. Description and performance of existing moisture meters for coffee.

Moisture Meter	Measurement Range (% mc)	Commercial Price (PhP) '000	Moisture content difference* (% w.b.)	
			Range	Average
1	1 to 35	150 to 180	0.25 to 1.10	0.85
2	5 to 40	15 to 25	2.75 to 5.40	3.85
3	11 to 21	100 to 120	0.43 to 1.80	1.10
4	10 to 21	50 to 70	2.30 to 6.20	4.25

* based from the reference air-oven method

Calibration tests

Coffea arabica (Arabica)

Calibration data points generated from Arabica variety during the laboratory experiments are shown in Figures 7 and 8 for green coffee beans and parchment coffee, respectively. Results showed that the oven moisture content values decreased with increased frequency values for both green coffee beans and parchment coffee. The relationship appeared non-linear over the data points generated for green coffee beans while a linear relationship was generated for parchment coffee.

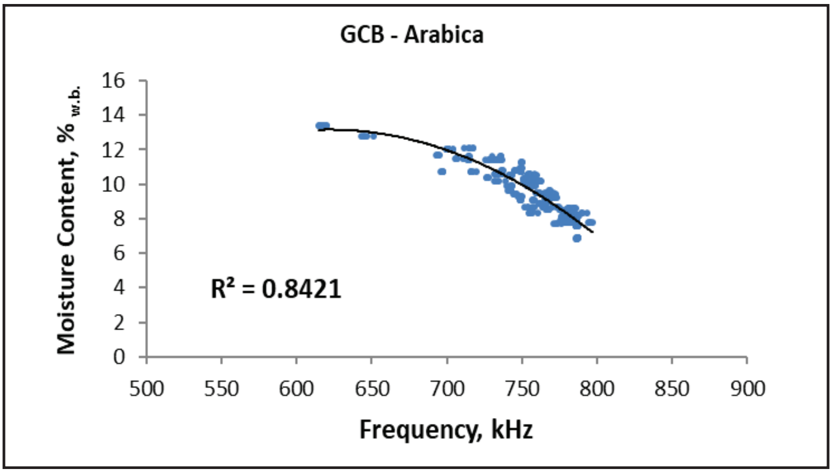


Figure 7. Calibration data generated for green coffee beans, Coffea Arabica

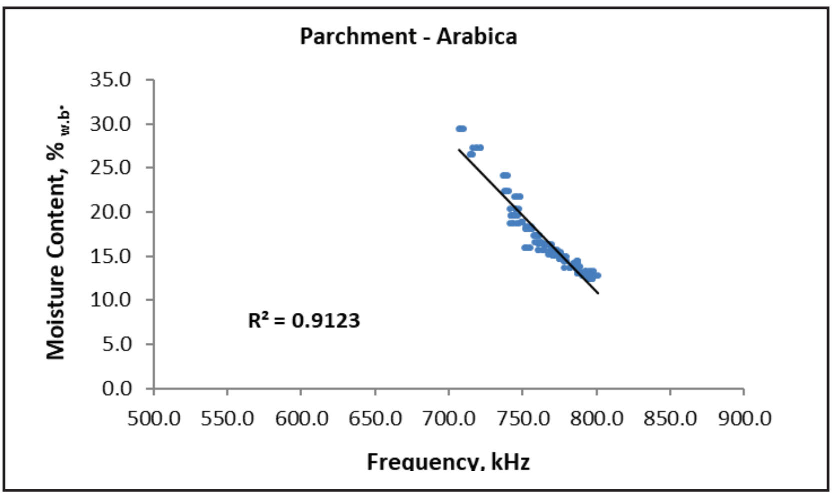


Figure 8. Calibration data generated for coffee parchment, Coffea Arabica

Using regression methods, the following calibration models were developed for green coffee beans (5) and parchment coffee (6), respectively:

$$\boldsymbol{MC = -0.0002F^2 + 0.2401F - 61.46} \quad (5)$$

$$\boldsymbol{MC = -0.1719F + 148.6} \quad (6)$$

where:

MC = moisture content, % wet basis;
F = frequency measured, kHz

For *Coffea Arabica*, the equations have relatively high correlation of determination (R^2) of 0.84 and 0.91 for green coffee beans and parchment coffee, respectively. Likewise, the equations have reasonably low standard error of estimates (SEE) at 0.83 and 0.85 for gcb and parchment coffee, respectively which indicates that the calibration equations as fitted over the frequency and moisture content data points were relatively adequate for both gcb and parchment coffee.

Coffea liberica (Liberica)

Calibration data points generated from Liberica variety during the laboratory experiments are shown in Figures 9 and 10 for green coffee beans and parchment coffee, respectively. An increasing frequency values as oven moisture content values decreased was observed for both green coffee beans and parchment coffee. The relationship appeared linear over the data points generated for both green coffee beans and parchment coffee.

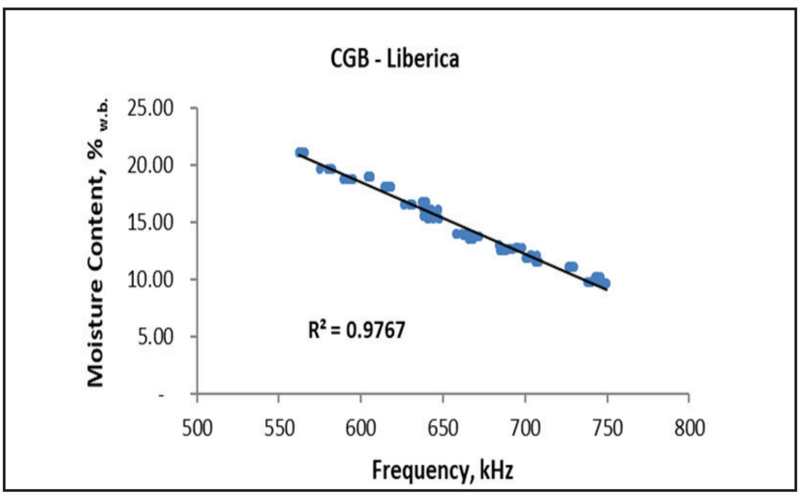


Figure 9. Calibration data generated for green coffee beans, *Coffea liberica*

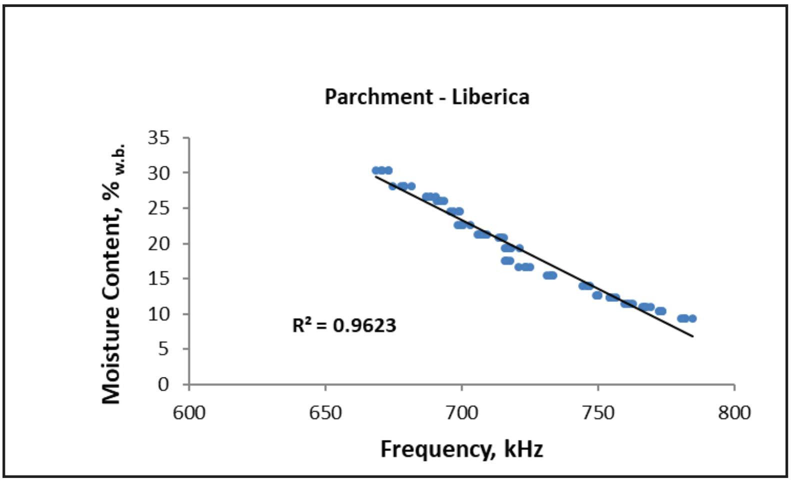


Figure 10. Calibration data generated for coffee parchment, *Coffea liberica*

Using linear regression methods, the following calibration equations were developed for green coffee beans (7) and parchment coffee (8), respectively:

$$\boldsymbol{MC = 56.33 - 0.063F} \qquad (7)$$

$$\boldsymbol{MC = 159 - 0.1939F} \qquad (8)$$

where:

MC = moisture content, % wet basis;
F = frequency measured, kHz

The equations have relatively high correlation of determination (R2) of 0.98 and 0.96 for green coffee beans and coffee parchments, respectively. Likewise, the equations have relatively low standard error of estimates (SEE) at 0.86 and 0.84 for gcb and parchment coffee, respectively. This is an indication that both calibration equations as fitted over the frequency and moisture content data points were relatively adequate for *Coffea liberica*.

Coffea canephora (Robusta)

Calibration data points for Robusta variety was generated for green coffee beans only and is shown in Figure 11. Result showed that the oven moisture content values decreased with increased frequency values. The relationship appeared linear over the generated data points for green coffee beans.

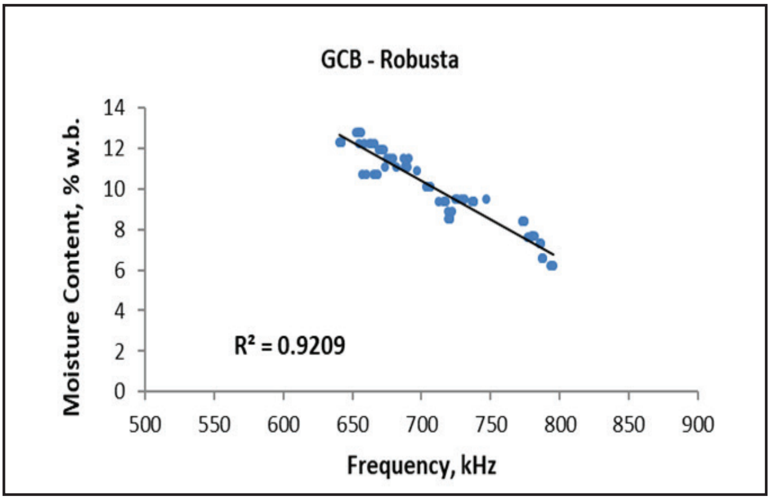


Figure 11. Calibration data generated for green coffee beans, *Coffea canephora*

Using linear regression method, the calibration equation below was developed for green coffee beans of Robusta variety:

$$\boldsymbol{MC = -0.0378F + 36.859} \qquad (8)$$

where:

MC = moisture content, % wet basis;
F = frequency measured, kHz

The equation yielded a relatively high correlation of determination (R2) of 0.92 as well as a relatively low standard error of estimate (SEE) at 0.81 which indicates that the calibration equation as fitted over the frequency and moisture content data points were relatively adequate for *Coffea canephora*.

Validation tests

Coffea arabica

Laboratory tests using new set of coffee samples were done to validate the performance of calibration equations of the prototype test chamber for each coffee type and variety. Presented in Figures 12 and 13 were the resulting comparative tests for the prototype unit coffee moisture meter as compared to oven moisture content measurement and the residual plot against predicted values of moisture content respectively. A total of 96 gcb were generated and indicated relative good fit for gcb of Arabica coffee variety. The residual plot shown in Figure 13 appears to indicate that the residual values are randomly distributed with a mean square value of 0.63, still an indication that the calibration model of the prototype coffee moisture meter was relatively adequate in predicting the moisture content of green coffee beans.

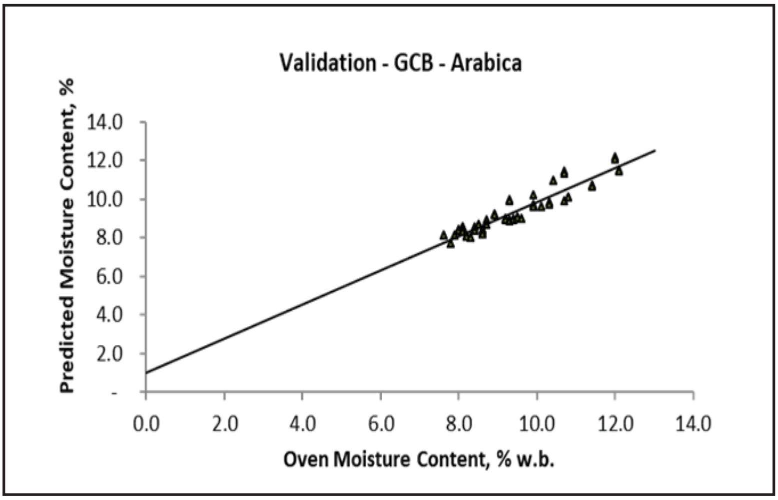


Figure 12. Comparison of Arabica green coffee beans moisture contents measured between oven method and prototype unit coffee moisture meter

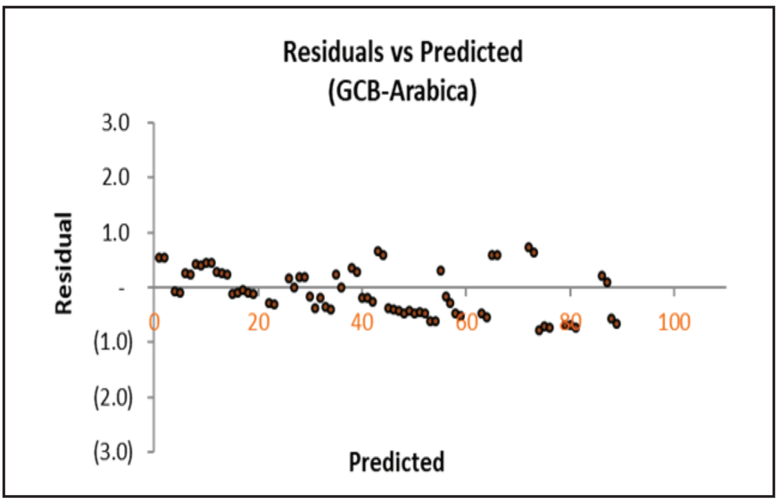


Figure 13. Residuals plot against the predicted values of Arabica green coffee beans moisture content using prototype unit coffee moisture meter

The performance of the prototype unit coffee moisture meter for parchment coffee is shown in Figures 14 and 15. A total of 75 parchment coffee readings were generated and indicated an equally good fit for coffee parchments of Arabica coffee variety. Furthermore, Figure 15 indicated that residual values are randomly distributed with a mean square value of 0.57, an indication that the calibration model of the prototype unit coffee moisture meter was relatively adequate in predicting the moisture content of Arabica parchment coffee.

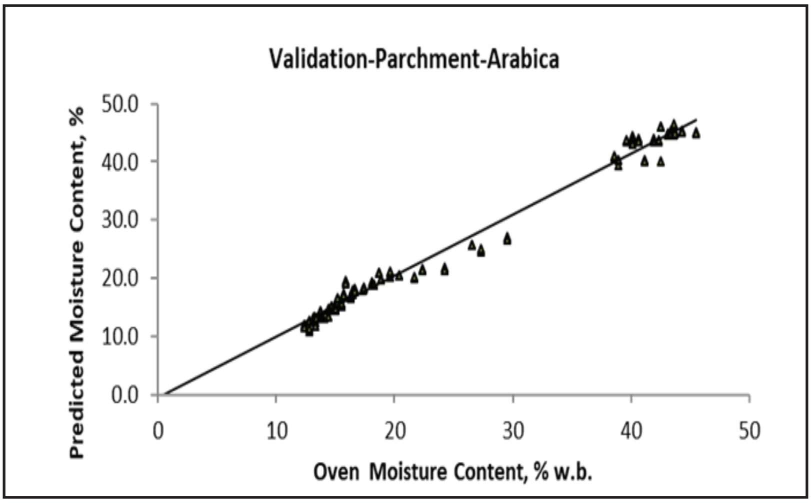


Figure 14. Comparison of Arabica coffee parchments moisture contents measured between oven method and the prototype unit coffee moisture meter

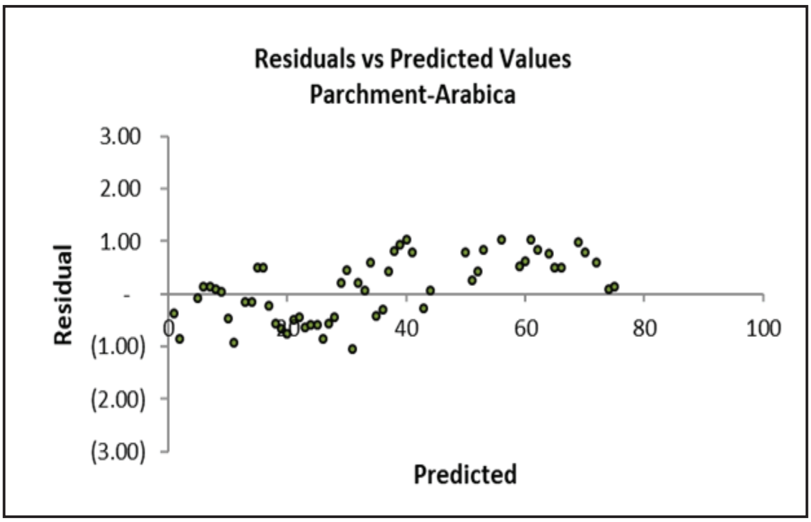


Figure 15. Residuals plot against the predicted values of Arabica coffee parchment moisture content using the prototype unit coffee mc meter

Coffea liberica

Presented in Figure 16 and 17 are the resulting comparative tests for the prototype unit coffee moisture meter as compared to oven moisture content measurement and the residual plot against predicted values of moisture content, respectively. A total of 72 gcb were generated and indicated relative good fit for gcb of Liberica coffee variety. In Figure 17, the residual plot seemed to indicate that the residual values are randomly distributed with a mean square value of 0.63.

This was an indication that the calibration model of the prototype coffee moisture meter was relatively adequate in predicting the moisture content of green coffee beans.

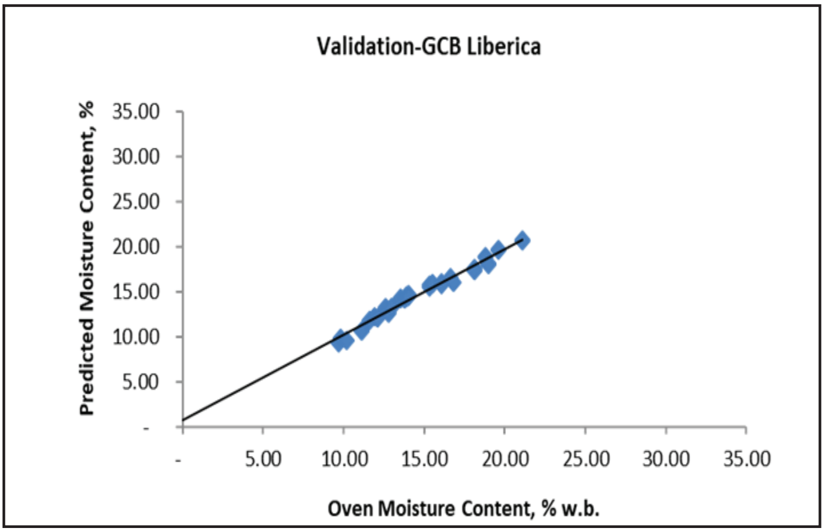


Figure 16. Comparison of Liberica gcb moisture contents measured between oven method and the prototype unit coffee moisture meter

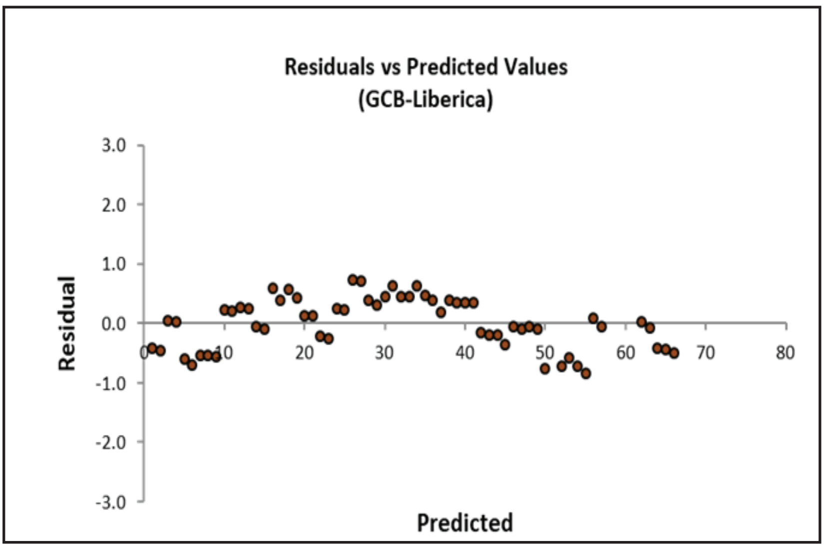


Figure 17. Residuals plot against the predicted values of Liberica gcb moisture content using the prototype unit coffee moisture meter

Similarly, Figures 18 and 19 show the performance of the prototype unit coffee moisture meter for parchment coffee. A total of 43 parchment coffee readings were generated and indicated an equally good fit for parchment coffee of Liberica variety. Figure 19 seemed to indicate that residual values are randomly distributed with a mean square value of 0.67, an indication that the calibration model of the prototype unit coffee moisture meter indeed was relatively adequate in predicting the moisture content of Liberica parchment coffee.

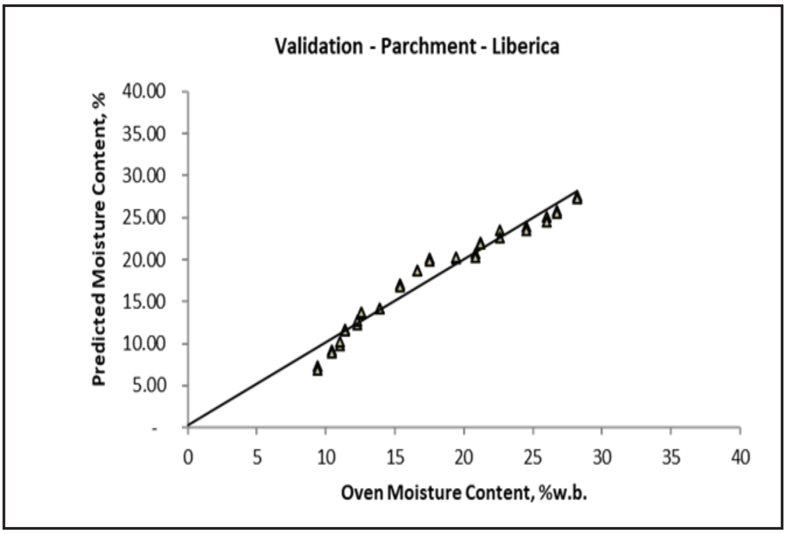


Figure 18. Comparison of Liberica parchment coffee moisture contents measured between oven method and the prototype unit coffee moisture meter

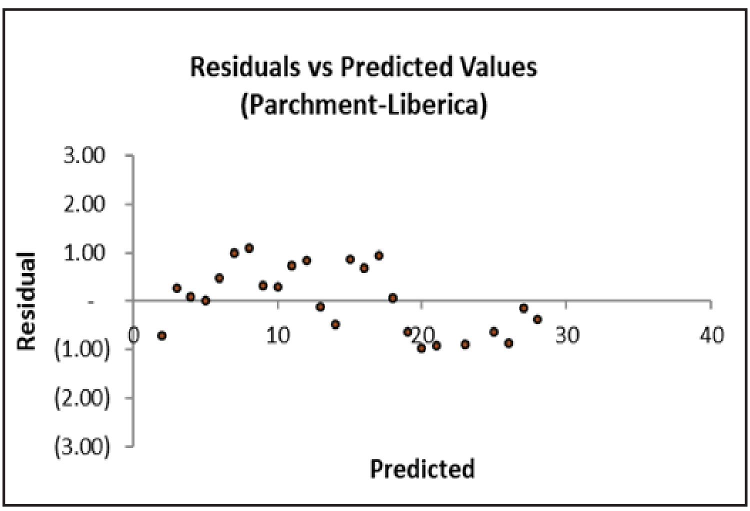


Figure 19. Residuals plot against the predicted values of Liberica coffee parchments moisture content using the prototype unit coffee mc meter

Coffea canephora

Shown in Figures 20 and 21 were the resulting comparative tests for the prototype unit coffee moisture meter as compared to oven moisture content measurement and the residual plot against predicted values of moisture content respectively. A total of 58 gcb were generated and indicated a relative good fit for gcb of Robusta coffee variety. Also shown in Figure 21, the residual plot indicated that the residual values are randomly distributed with a mean square value of 0.68. This was an indication that the calibration model of the prototype coffee moisture meter was relatively adequate in predicting the moisture content of Robusta parchment coffee.

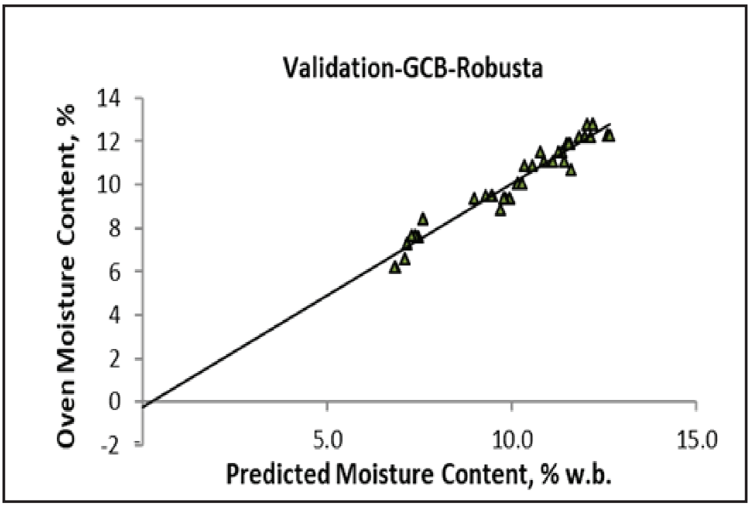


Figure 20. Comparison of Robusta green coffee beans moisture contents measured between oven method and the prototype unit coffee moisture meter

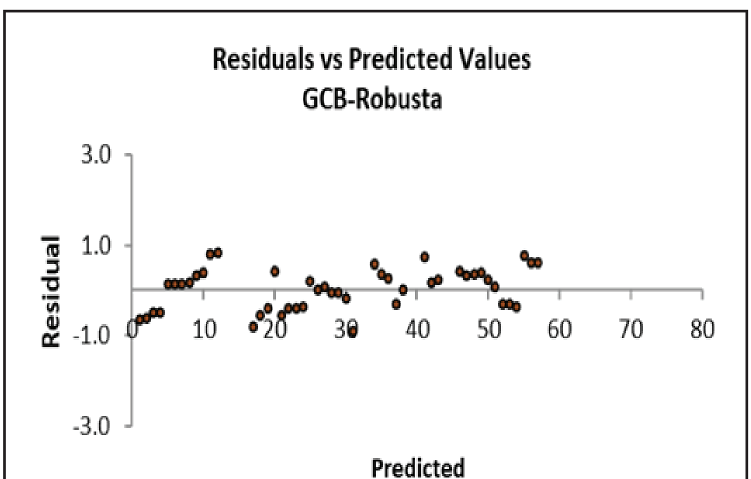


Figure 21. Residuals plot against the predicted values of Robusta green coffee beans moisture content using the prototype unit coffee mc meter

Accuracy and Precision

Performance evaluation results for green coffee beans as shown in Table 2, generated an indicative accuracy of the prototype unit non-destructive coffee moisture meter. Moisture Error ($\bar{y}$) as a function of accuracy was computed to be on the average of 0.14%, 0.16% and 0.15% for Arabica, Liberica and Robusta, respectively. Standard deviation of differences, SDD was also measured to be 0.41 %, 0.42% and 0.45%, for Arabica, Liberica and Robusta varieties respectively. Both findings were within the set standards of 0.70% maximum permissible measurement error (MPEs) of 0.70%, for field evaluation (OIML, 2009).

Table 2. Test of accuracy of the prototype unit coffee moisture meter, green coffee beans

			MC Reading, %			
Coffee Variety	**Moisture Range, %**	**No. of sample by 2% MC interval**	**Reference (Oven)**	**Prototype Coffee MC Meter**	**MC error, % ($\bar{y}$)**	**SDD, %**
	8 to 10	10	8.93	8.70	0.12	0.37
Arabica	10 to 12	10	11.00	10.76	0.16	0.47
	12 to 14	5	13.21	12.97	0.14	0.40
				Mean	***0.14***	***0.41***
	8 to 10	4	9.55	9.75	0.22	0.38
Liberica	10 to 12	10	11.30	11.11	0.15	0.43
	12 to 14	10	12.94	13.18	0.12	0.44
				Mean	***0.16***	***0.42***
	8 to 10	10	9.09	9.33	0.18	0.55
Robusta	10 to 12	10	11.15	10.93	0.16	0.47
	12 to 14	10	12.43	12.64	0.11	0.32
				Mean	***0.15***	***0.45***

Likewise, the same evaluation for parchment coffee of both Arabica and Liberica varieties had resulted to a relatively accurate performance of the non-destructive coffee moisture meter with 0.22%, and 0.18% for Arabica and Liberica varieties, respectively. For Standard deviation of differences, SDD was also measured to be 0.55 %, 0.47%, for Arabica and Liberica varieties, respectively. It can be noted that SDD for moisture content ranges of 10% to 12%, was slightly above the MPEs that can be attributable to the insufficient number of samples for the specific MC level. However, average findings were still within the set standards of 0.70% permissible error for field evaluation as defined by OIML (2009).

Table 3. Test of accuracy of the prototype unit coffee moisture meter, parchment coffee

			MC Reading, %			
Coffee Variety	Moisture Range, %	No. of sample by 2% MC interval	Reference (Oven)	Prototype Coffee MC Meter	MC error, % ($\bar{y}$)	SDD, %
Arabica	10 to 12	4	11.59	11.88	0.29	0.50
	12 to 14	10	13.15	13.35	0.20	0.61
	14 to 16	10	15.21	15.03	0.18	0.55
				Mean	***0.22***	***0.55***
Liberica	10 to 12	4	10.90	11.14	0.24	0.73
	12 to 14	10	12.93	13.09	0.16	0.35
	14 to 16	10	15.30	15.15	0.15	0.33
				Mean	***0.18***	***0.47***

Repeatability and reproducibility tests as a measure of precision for the prototype unit coffee moisture meter were done for green coffee beans only. No conclusive result can be derived from the insufficient volume of parchment coffee subjected to the tests. Shown in Table 4 is the result of precision tests conducted for all three varieties of green coffee beans; the prototype unit coffee moisture meter has proven its technical viability in terms of repeatability computed at an average of 0.09% which is within the maximum permissible measurement error of 0.35%. However, Arabica variety with SDD1=0.62% fall short of meeting the maximum permissible measurement error for reproducibility set at 0.42% (OIML, 2009) while the other two varieties of Liberica and Robusta performed well, both at 0.25%. This could be attributed to insufficient volume of samples during the conduct of the test.

Table 4. Precision tests conducted for green coffee beans, all varieties.

			Precision, %	
Coffee Variety	Moisture Range, %	No. of sample by 2% MC interval	Repeatability Std Dev. (SD)	Reproducibility Std Dev. of Diff. (SDD_1)
Arabica	8 to 10	10	0.03	0.58
	10 to 12	10	0.04	0.51
	12 to 14	5	0.17	0.78
		Mean	***0.08***	***0.62***
Liberica	8 to 10	4	0.10	0.16
	10 to 12	10	0.15	0.38
	12 to 14	10	0.09	0.22
		Mean	***0.11***	***0.25***
Robusta	8 to 10	10	0.06	0.20
	10 to 12	10	0.11	0.34
	12 to 14	10	0.09	0.26
		Mean	***0.09***	***0.25***

Based from the tests conducted, technical specifications of the prototype unit non-destructive coffee moisture meter for both green coffee beans and parchment coffee of Arabica, Liberica and Robusta varieties is summarized in Table 5.

Table 5. Technical specifications of the prototype unit non-destructive coffee moisture meter

PARTICULARS		PARAMETERS
Measurement Principle	:	capacitance
Applications		
- Type		Green coffee beans (GCB) and parchment coffee
- Varieties	:	Arabica, Liberica, Robusta
Measurement Range		
- GCB	:	8% to 18%
- Parchment	:	10% to 40%
Mean MC Error*, %		
- GCB	:	0.15
- Parchment**	:	0.20
Repeatability*, %		
- GCB	:	0.09
Resolution, %	:	0.10
Sample size, g	:	200
Type of display	:	LCD read-out panel
Power supply	:	9-Volts DC battery
Unit size	:	
- Dimension, cm		16L x 15W x 18H
- Weight (inc. hopper),kg		2.5
Other accessories	:	Loading hopper
	:	Measuring cup

** based on International Organization of Legal Metrology (OIML/TC17) test procedures and standards*

*** excluding Robusta variety*

Moreover, the prototype unit non-destructive coffee moisture meter has lower capital investment compared with existing moisture meters in the market. The production cost amounted approximately to PhP 14,000.00, 40% to 60% cheaper than the imported coffee moisture meters.

CONCLUSION AND RECOMMENDATION

Results of the study revealed that all coffee farmer and grower respondents practice emprical method of moisture content determination. They do not use any objectve device. On the other hand, there were at least four types of moisture meters used by traders, cooperatives and processors. It was also found out that price is directly proportional with accuracy and reliability among the inventoried type of coffee moisture meters based on the technical evaluation conducted between actual moisture content readings and standard oven method.

A non-destructive, capacitance type coffee moisture meter for three coffee varieties namely: *Coffea arabica, Coffea liberica* and *Coffea canephora* was developed using capacitive sensor oscillator circuit to measure moisture contents of both green coffee beans (gcb) and coffee parchments. Calibration experiments conducted presented good relationships between frequency and moisture content readings with relatively high coefficient of determination and low standard error of measurements. Results of validation tests showed that the meter is sufficiently accurate for all three coffee varieties for both green coffee beans and coffee parchments. Further, accuracy and precision tests conducted for the prototype unit non-destructive coffee moisture meter yielded a moisture content error, $\bar{y}$ of 0.15% and 0.20% for green coffee beans and parchment coffee, respectively. Likewise, repeatability tests, SD was computed at 0.09% for green coffee beans. Both results have met the standard set by the International Organization of Legal Metrology (OIML, 2006).

The conduct of further field testing is recommended to include Excelsa variety as well as validation of technical performance of parchment coffee for Arabica and Robusta varieties.

ACKNOWLEDGMENT

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NOTES

About PHilMech

The Philippine Center for Postharvest Development and Mechanization, known then as the National Postharvest Institute for Research and Extension (NAPHIRE), was created on May 24,1978 through Presidential Decree 1380 to spearhead the development of the country's postharvest industry.

As a subsidiary of the National Grains Authority in 1980, the agency's powers and functions were expanded in line with the conversion of NGA to the National Food Authority.

In 1986, PHilMech moved to its new home at the Central Luzon State University compound in Muñoz, Nueva Ecija.

The agency was transformed from a government corporation into a regular agency through Executive Order 494 in 1992. It was renamed the Bureau of Postharvest Research and Extension (BPRE).

For years now, PHilMech is engaged in both postharvest research, development and extension activities. It has so far developed, extended and commercialized its research and development outputs to various stakeholders in the industry.

With Republic Act 8435 or Agriculture and Fishery Modernization Act (AFMA) of 1997, PHilMech takes the lead in providing more postharvest interventions to empower the agriculture, fishery and livestock sectors.

Pursuant to Executive Order 366 or the government's rationalization program in November 2009, BPRE became the Philippine Center for Postharvest Development and Mechanization (PHilMech) with twin mandates of postharvest development and mechanization.

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