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Validation of a Portable Resistive-Sensor Corn Moisture Meter against a Standard Grain Meter

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ABSTRACT: Measuring the moisture content of corn kernels was a critical aspect of post-harvest handling, as moisture content directly affected product quality and shelf life. This study validated a portable resistive-sensor-based instrument for measuring corn kernel moisture content by comparing its readings with those obtained using a standard grain moisture meter. The validation involved ten corn kernel samples with moisture contents ranging from 12% to 14% on a wet basis. Each sample was measured using both the standard moisture meter and the portable resistive-sensor instrument under identical conditions. Measurements obtained from the two devices were compared to evaluate their agreement using the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The results showed that the portable resistive-sensor instrument achieved an MAE of 0.42% and an RMSE of 0.44% relative to the standard device. These low error values demonstrated that the developed instrument produced consistent measurements and accurately tracked variations in corn kernel moisture content. In addition to its measurement accuracy, the instrument offered several practical advantages, including a simple design, relatively low implementation cost, portability, rapid measurement, and suitability for on-site corn quality assessment. Overall, the resistive-sensor-based instrument provided an economical, practical, and readily implementable alternative for moisture measurement, with potential applications in supporting the drying and storage of agricultural commodities.

KEYWORDS: Grain moisture meter; moisture content; resistive sensor; validation.

1. Introduction

Moisture content was one of the most important quality parameters in agricultural commodities and their processed products, such as grains, paddy, rice, corn, and charcoal, because it directly affected product quality, shelf life, processing efficiency, and safety. Excessive moisture content could accelerate deterioration, reduce product quality, and increase the risk of microbial growth, making moisture monitoring an essential component of post-harvest handling and drying processes [1–4]. In general, the recommended moisture content for grain storage and marketing was approximately 12–14% on a wet basis to maintain product stability during distribution and storage [1]. Moisture content represented the proportion of water contained in a material and could be expressed on either a wet or dry basis. Therefore, selecting an appropriate measurement method was essential to ensure reliable quality control.

The reference method for determining moisture content generally involved oven drying according to AOAC standards because of its high accuracy and established reliability. However, this method was destructive, required a relatively long analysis time, and depended on laboratory facilities, making it unsuitable for rapid field measurements and real-time monitoring [1]. To overcome these limitations, several non-destructive or rapid moisture-measurement technologies were developed based on the electrical and electromagnetic properties of materials, including resistive, capacitive, microwave, and radio-frequency sensing methods. These approaches enabled faster measurements and provided opportunities for integration with automated monitoring systems [2, 5–9].

The resistive sensing method determined moisture content based on the relationship between electrical resistance and the water content of agricultural materials. Previous studies demonstrated that resistance-based grain moisture measurement systems could achieve absolute errors of approximately ±0.5% within a moisture range of 10–35% and operating temperatures between −20 and 50 °C [2, 5]. Furthermore, resistive sensing approaches combined with machine-learning models were reported to predict grain moisture content with an RMSE of approximately 0.64% [7]. Despite these promising results, existing resistive sensor-based moisture meters faced several limitations, including dependence on sensor contact conditions, sensitivity to grain density and moisture distribution, limited calibration procedures, and insufficient validation against standard commercial moisture meters. These limitations could reduce measurement reliability when the instruments were applied to grains under conditions different from those used during laboratory calibration.

The development of low-cost microcontroller-based systems enabled the design of portable moisture-measurement devices using sensors such as the YL-69 integrated with Arduino platforms. Previous studies, for example, developed Arduino Uno-based grain moisture meters capable of displaying moisture values digitally through an LCD interface, providing a simple and portable approach to grain quality assessment. Several prototypes of corn and grain moisture meters based on YL-69 resistive sensors and microcontrollers showed maximum errors of approximately 1–5% [8]. However, these studies generally focused on prototype development and basic functional performance, whereas comprehensive validation through statistical comparison with standard grain moisture meters remained limited. In addition, several existing systems did not sufficiently address practical requirements for field applications, including measurement consistency, ease of operation, portability, and quantitative assessment of measurement errors.

In addition to electrical sensor-based methods, spectroscopic techniques such as near-infrared spectroscopy (NIRS) were investigated as rapid and non-destructive approaches for predicting moisture content in agricultural commodities. However, NIRS required relatively expensive and complex optical instrumentation, which could limit its application at the farm and small-industry levels [10–12]. Other modern techniques, including capacitive and microwave-based sensors, also provided rapid and non-destructive measurements but required careful calibration to ensure measurement accuracy and consistency [13–18]. Therefore, despite advances in moisture-sensing technologies, there remained a considerable need for portable instruments that were simple, inexpensive, accurate, and user-friendly for farmers, small-scale industry operators, and drying-process personnel. Such instruments could facilitate rapid moisture monitoring, data collection, and process-control applications for commodities such as rice, corn, paddy, and charcoal [9, 10, 12].

From an instrumentation perspective, measuring devices were required to demonstrate adequate precision and accuracy through systematic testing, calibration, and validation. Although various grain moisture meter designs had been reported, many remained relatively complex or expensive for implementation at the smallholder level. More importantly, studies specifically validating low-cost, resistive sensor-based portable instruments against standard grain moisture meters using quantitative error metrics, such as Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), remained limited. This limitation represented an important research gap in determining whether simple and inexpensive portable instruments could provide sufficiently reliable measurements for field-level applications.

Therefore, this study aimed to validate the performance of a portable resistive sensor-based corn kernel moisture meter by comparing its measurements with those obtained using a standard grain moisture meter. The proposed instrument incorporated a calibrated measurement approach, and its performance was evaluated using MAE and RMSE to quantify measurement accuracy and agreement with the reference instrument [1–3]. Through this validation, the study sought to determine whether a low-cost resistive sensing system could provide sufficiently accurate and consistent moisture measurements while maintaining the practical advantages of portability, rapid operation, and suitability for field-level post-harvest quality monitoring.

2. Materials and Methods

2.1. Research Design.

This study employed a quantitative experimental approach to evaluate and validate the performance of a portable corn kernel moisture measurement instrument based on a resistive sensor. The developed instrument was compared with a standard grain moisture meter used as the reference device to determine the accuracy, consistency, and agreement of the measurement results. The experimental design was selected because it enabled direct comparison between sensor outputs and reference moisture content values under controlled testing conditions, thereby allowing an objective evaluation of measurement errors and instrument performance [1, 2]. The experimental validation process consisted of several sequential stages, including sample preparation, reference measurement, portable sensor measurement, data recording, statistical analysis, and performance evaluation. Initially, corn kernel samples were prepared by adjusting their moisture contents within the target testing range. Each sample was first measured using a calibrated standard grain moisture meter to obtain the reference moisture value. The same sample was subsequently measured using the developed resistive sensor-based portable instrument. The paired measurements obtained from both instruments were recorded and analyzed to determine the level of agreement between the developed instrument and the reference device.

A total of 10 corn kernel samples with moisture contents ranging from 12% to 14% on a wet basis were used in the experiment. Each sample was measured in triplicate to minimize random measurement variation and improve data reliability. The mean of the three measurements was used for subsequent statistical analysis. The sample size was selected to represent variations in moisture content within the target application range and to provide paired observations for evaluating measurement consistency and error characteristics. Before validation testing, the resistive sensor-based instrument underwent a calibration procedure in which sensor resistance responses were correlated with moisture values obtained using the standard grain moisture meter. The calibration process involved recording sensor outputs at different moisture levels and establishing a conversion relationship between electrical resistance and moisture content. The resulting calibration equation was subsequently applied to convert sensor readings into estimated moisture content values.

The overall validation workflow is presented in Figure 1, illustrating the sequence from sample preparation and reference measurement to portable sensor measurement, data acquisition, calibration, statistical analysis, and final performance evaluation. The accuracy of the developed instrument was evaluated using the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). Additional agreement analyses were performed using linear regression, the coefficient of determination (R^2), and Bland–Altman analysis. Linear regression was used to evaluate the relationship between measurements obtained from the portable instrument and the reference device, while R^2 indicated the degree of variation explained by the regression model. Bland–Altman analysis was used to assess systematic bias and the limits of agreement between the two measurement methods. Together, these analyses provided a comprehensive assessment of the accuracy, agreement, and practical suitability of the proposed portable moisture measurement system. This research did not involve human participants or animals; therefore, specific ethical approval was not required. All experimental procedures were conducted using agricultural samples in the form of corn kernels (*Zea mays* L.) under controlled laboratory conditions.

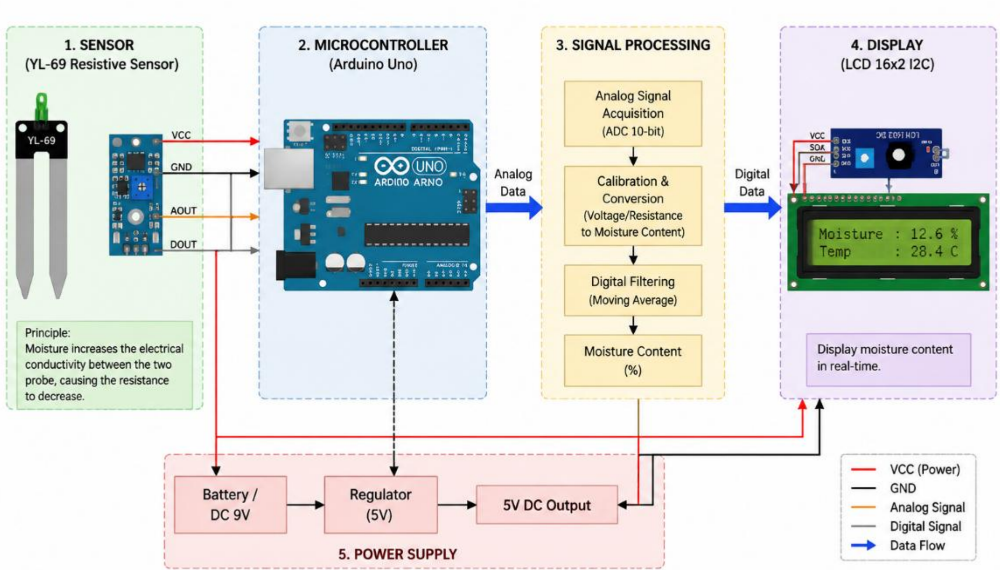

Figure 1. Diagram of Moisture Content Measuring Device with YL-69 Sensor.

2.2. Data Source and Variables.

The research data consisted of the moisture contents of corn kernels measured using two instruments: a standard grain moisture meter as the reference device and the developed portable resistive sensor-based instrument. The primary variable was corn kernel moisture content, expressed as a percentage on a wet basis (%). Additional variables included the electrical resistance response of the sensor and the digital output displayed on the LCD. The samples consisted of corn kernels with different moisture contents within the target testing range. These variations were obtained by naturally adjusting the moisture content of the corn kernels before measurement. The measurements obtained from the two instruments were paired for subsequent comparison and statistical analysis.

2.3. Research Instruments and Devices.

The main instrument used in this study was a moisture measurement device based on a YL-69 resistive sensor connected to an Arduino Uno microcontroller as the main system controller. The YL-69 sensor detected changes in the electrical resistance of the corn kernels associated with variations in moisture content. The Arduino Uno processed the analog sensor signal and converted it into an estimated moisture content value, which was subsequently displayed on a 16 × 2 LCD module. The working principle of the resistive sensor was based on the relationship between the electrical conductivity/resistance of a material and its moisture content, an approach that has been widely applied to moisture measurement in agricultural materials [2, 5, 8]. A standard grain moisture meter calibrated by the manufacturer for grain moisture measurement was used as the reference instrument. Supporting equipment included a power supply, connecting cables, and sample containers to maintain stable and consistent measurement conditions.

2.4. Data Collection Procedure.

Data were collected through a series of laboratory measurements using corn kernel samples with moisture contents ranging from 12% to 14% on a wet basis. Each sample was first measured using the standard grain moisture meter to obtain the reference moisture content. The same sample was subsequently measured using the developed portable resistive sensor-based instrument. Each measurement was performed in triplicate, and the resulting paired data were used to compare the performance of the developed instrument with that of the reference device. The measurement procedure using the standard grain moisture meter is illustrated in Figure 2. The same prepared corn kernel samples were subsequently tested using the developed instrument to ensure that the comparison was based on equivalent sample conditions. All measurements were conducted under relatively constant laboratory conditions to minimize the effects of environmental temperature and humidity on the sensor readings. The sensor output generated by the YL-69 sensor was processed by the Arduino Uno and recorded as research data for subsequent statistical analysis.

Figure 2. Measurement of corn kernel moisture content using the standard grain moisture meter.

2.5. Data Analysis Method.

Data analysis was performed by comparing the moisture content values obtained using the developed portable instrument with those measured using the standard grain moisture meter. The measurement accuracy of the developed instrument was evaluated using the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), which are commonly used to assess the performance of measuring instruments and moisture prediction models [3, 7]. MAE was used to determine the average absolute difference between the moisture content measured by the developed instrument and the corresponding reference value, whereas RMSE provided a measure that assigned greater weight to larger measurement errors. Lower MAE and RMSE values therefore indicated better agreement between the developed instrument and the reference measurements.
Mathematically, MAE and RMSE were expressed as follows:

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |y_{i-\hat{y}_i}| \quad (1)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (y_{i-\hat{y}_i})^2} \quad (2)$$

where yi is the reference moisture content value from the grain moisture meter, ŷi is the moisture content value measured by the portable instrument, and n is the number of measurement samples. The MAE indicates the average absolute error, while the RMSE provides information on the magnitude of the squared error, which is sensitive to large deviations. The smaller the MAE and RMSE values, the better the accuracy of the developed instrument. In addition, the suitability of the measurement results was analyzed by comparing the average value and measurement difference for each sample to assess the consistency of the resistive sensor readings with the standard device.

2.6. Software and Data Processing.

Microcontroller programming was performed using the Arduino IDE with the C/C++ programming language. Data visualization and graph preparation were conducted using OriginLab, while data processing, including the calculation of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), was performed using Microsoft Excel. Microsoft Excel was also used for descriptive statistical analysis and comparison of the measurement results obtained from the developed instrument and the standard grain moisture meter. This approach was selected because it provided a simple, transparent, and reproducible method for evaluating the performance of the developed instrument. The Arduino IDE interface used for programming and configuring the microcontroller is shown in Figure 3. The program was developed to process the analog signal generated by the YL-69 resistive sensor and convert the sensor response into moisture content values for display on the LCD.

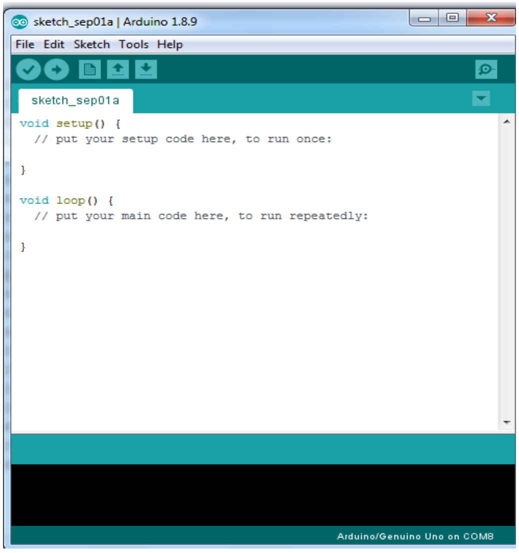

Figure 3. Arduino IDE Interface Used for Programming the Portable Moisture Measurement Instrument.

3. Results and Discussion

The performance of the developed resistive sensor-based portable instrument was evaluated by comparing its corn kernel moisture measurements with those obtained using a standard grain moisture meter. As described in the methodology, ten corn kernel samples with moisture contents ranging from approximately 12% to 14% on a wet basis were measured under the same laboratory conditions. Each sample was measured in triplicate, and the mean values were used for subsequent analysis. The evaluation focused on measurement consistency, accuracy, and agreement between the developed instrument and the reference device. Direct comparison, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), linear regression, the coefficient of determination (R^2), and Bland–Altman analysis were used to assess instrument performance..

3.1. Comparison of Moisture Content Measurement Results.

The moisture content measurements obtained using the developed resistive sensor-based instrument and the standard grain moisture meter are presented in Table 1. It showed relatively small differences between the two measurement methods. In general, the developed instrument produced slightly lower moisture content values than the standard grain moisture meter. However, the differences remained relatively consistent across the tested samples, indicating that the developed instrument responded systematically to variations in corn kernel moisture content.

Table 1. Comparison of Corn Kernel Moisture Content Measured using the Standard Grain Moisture Meter and the Developed Resistive Sensor-Based Instrument.

Sample	Standard Grain Moisture Meter (%)	Developed Instrument (%)
1	13.2	12.9
2	13.2	13.1
3	13.5	13.4
4	13.7	13.6
5	13.7	13.6

The slightly lower readings could be associated with differences in the measurement principles and calibration procedures of the two instruments. The standard grain moisture meter used a manufacturer-established calibration, whereas the developed instrument estimated moisture content based on changes in electrical resistance through direct electrode contact with the corn kernels. Resistive measurements can be affected by electrode contact, kernel arrangement, sample density, and moisture distribution [2, 5, 8]. The relatively consistent differences across the samples suggested the presence of a small systematic bias rather than random measurement instability. This finding indicated that further refinement of the calibration equation could potentially reduce the difference between the developed instrument and the reference device.

3.2. Measurement Trend and Sensor Response.

The measurement trends obtained using the developed instrument and the standard grain moisture meter are presented in Figure 3. The developed instrument followed a trend similar to that of the standard grain moisture meter. As the moisture content measured by the reference device increased, the values obtained using the developed instrument also generally increased. This similar pattern demonstrated that the YL-69 resistive sensor was responsive to variations in corn kernel moisture content within the tested range.

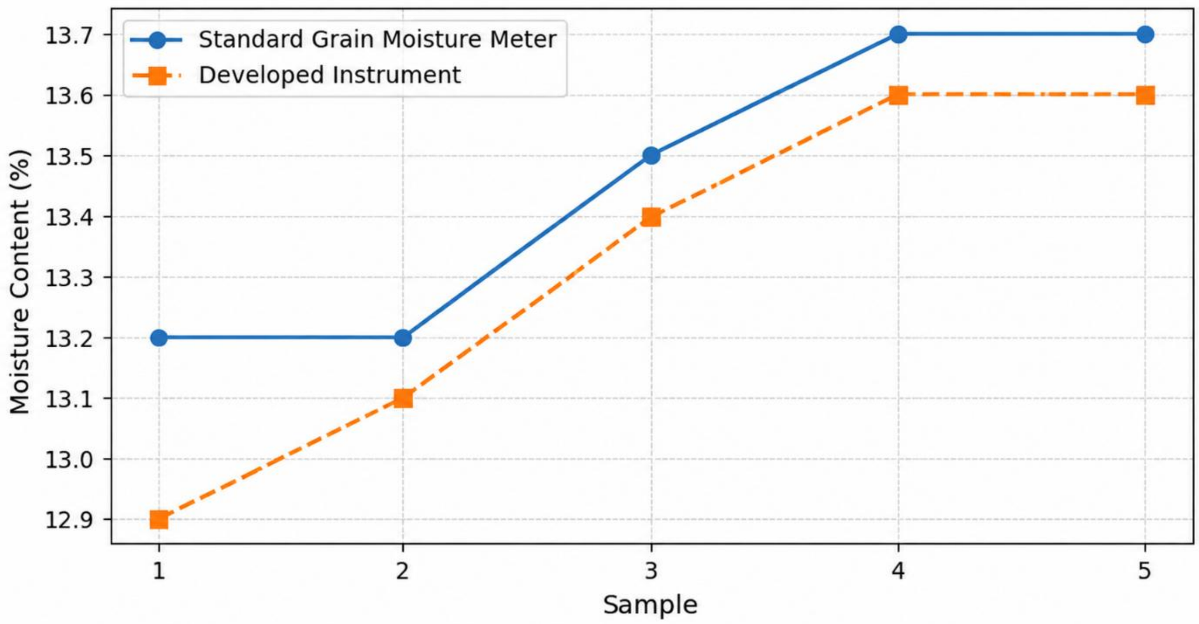

Figure 3. Comparison of corn kernel moisture content measurement results between the standard device and the resistive sensor-based test device.

This response was consistent with the operating principle of resistive moisture sensing. Increasing water content alters the electrical conductivity and resistance of agricultural materials, resulting in a corresponding change in sensor output [2, 5]. As described in the methodology, the calibration relationship was used to convert the electrical response of the YL-69 sensor into estimated moisture content values. Nevertheless, small deviations between the two measurement profiles were observed. These differences could have resulted from variations in electrode contact, kernel orientation, packing density, and moisture distribution within the samples. Because the YL-69 sensor depended on direct contact with the material, differences in the physical arrangement of the kernels could influence the electrical pathway between the electrodes and consequently affect the sensor response. Environmental conditions may also have contributed to measurement variation. Temperature can affect electrical resistance, while ambient humidity may influence surface moisture and sensor response [8, 9]. Although measurements were conducted under relatively constant laboratory conditions, these factors should be considered when extending the instrument to field applications.

3.3. Accuracy and Agreement Analysis.

The accuracy of the developed instrument was quantitatively evaluated using MAE and RMSE, following the analytical procedure. The analysis produced an MAE of 0.42% and an RMSE of 0.44% relative to the standard grain moisture meter. The MAE represented the average absolute difference between the moisture content measured using the developed instrument and the corresponding reference value. Therefore, an MAE of 0.42% indicated that the portable instrument differed from the reference measurements by approximately 0.42 percentage points of moisture content on average. RMSE gave greater weight to larger deviations and therefore provided complementary information regarding measurement error [3, 7]. The relatively small difference between the MAE and RMSE values suggested that the measurement errors were reasonably consistent across the tested samples. If one or more samples had produced substantially larger errors, the RMSE would have increased more strongly relative to the MAE. The close values therefore suggested that no extreme measurement error strongly influenced the overall performance.

Linear regression and the coefficient of determination (R^2) were also used to evaluate the relationship between the two measurement methods. A high R^2 value would indicate that changes in moisture content measured using the standard instrument were closely followed by the developed instrument. However, R^2 represents association rather than measurement agreement and should therefore be interpreted together with MAE, RMSE, and Bland–Altman analysis. Bland–Altman analysis provided further assessment of agreement by examining the differences between paired measurements relative to their mean values. The tendency of the developed instrument to produce slightly lower values than the standard device suggested a small negative systematic bias. Therefore, the combined use of error metrics, regression, and agreement analysis provided a more complete assessment than relying solely on correlation.

The results were generally comparable with previous resistive moisture-sensing studies. Resistance-based grain moisture measurement systems have been reported to achieve errors of approximately ±0.5% under specific operating conditions [2,5], while resistive sensing combined with machine-learning approaches achieved an RMSE of approximately 0.64% [7]. Other Arduino- or YL-69-based prototypes reported errors of approximately 1–5% [8]. The MAE of 0.42% and RMSE of 0.44% obtained in the present study therefore demonstrated promising performance within the investigated moisture range. However, comparisons among studies should be made cautiously because differences in commodities, moisture ranges, sensors, calibration methods, and reference measurements can affect reported accuracy.

3.4. Practical Performance, Limitations, and Future Improvement.

The developed instrument offered practical advantages in addition to its relatively low measurement error. The combination of a YL-69 resistive sensor, Arduino Uno microcontroller, and LCD display provided a relatively simple and accessible measurement system. The instrument also enabled rapid moisture estimation without requiring complex laboratory equipment, indicating its potential for routine monitoring during corn drying and storage.

However, several limitations should be considered. First, the validation was restricted to a relatively narrow moisture range of approximately 12–14% on a wet basis. Although this range is relevant to grain storage, it does not represent the broader moisture conditions encountered during harvesting and drying. Second, only ten corn kernel samples were evaluated. A larger number of independent samples would provide stronger evidence regarding measurement accuracy, repeatability, and reproducibility.

The sensor response could also be influenced by corn variety, kernel size, packing density, electrode contact, temperature, and ambient humidity. Therefore, future studies should evaluate the instrument using different corn varieties and a wider moisture range under both laboratory and field conditions. Improved electrode design, temperature compensation, and more robust calibration models could further improve measurement consistency.

Validation against a recognized reference method, particularly the standard oven-drying method, would also provide stronger evidence of absolute measurement accuracy. Future work should additionally investigate repeatability, reproducibility, calibration drift, and long-term sensor stability.

Overall, the developed resistive sensor-based instrument successfully tracked changes in corn kernel moisture content within the tested range. The MAE of 0.42% and RMSE of 0.44% indicated relatively small deviations from the standard grain moisture meter. These findings demonstrated the potential of the developed instrument as a simple, portable, and relatively low-cost system for corn kernel moisture monitoring, although broader validation remains necessary before wider field application.

4. Conclusions

This study successfully validated the performance of a portable instrument for measuring corn kernel moisture content using resistive sensors, comparing results with a standard grain moisture meter. The analysis showed that the developed instrument consistently represented changes in moisture content and demonstrated good conformity with the reference tool, thereby achieving the research objectives of evaluating the accuracy and feasibility of portable instruments. This finding confirms that the resistive sensor approach, integrated with a microcontroller, can be used as a practical, fast, and economical moisture content measurement solution for field applications, especially at the level of farmers and small industries, to support the control of the drying and storage processes of agricultural commodities. Scientifically, the results strengthen the use of the electrical resistance characteristics of materials as a representative parameter for estimating moisture content in corn kernels. However, the study's limitations include a limited number of samples and a narrow range of test conditions, so a wider calibration is needed across various environmental conditions and moisture content variations. Future research is recommended to test the instrument at a larger scale and integrate it with automation or IoT-based monitoring systems to enhance its reliability and flexibility in modern postharvest systems.

Author Contributions

All authors contributed equally to the conception and design of the study, methodology development, experimental investigation, data collection, data analysis and interpretation, validation, manuscript preparation, review, and editing. All authors read and approved the final version of the manuscript and agreed to be accountable for the integrity of the work.

Data Availability

The data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing financial or non-financial interests that could have influenced the work reported in this manuscript.

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