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Portable analogue-based electronic moisture meter for root-crop chips

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Abstract: Moisture content regulation of root crops is crucial in post-harvest processing operations, not only in the price stipulation but also to avoid aflatoxin contamination. To prolong their storage life, they are processed into dried chips to extend their usability in feed formulations and starches. In this study, we use the capacitance-based method to evaluate the performance of an analogue-based electronic meter for the cassava, sweet potato, and taro chips. The meter was calibrated against the oven-drying method, yielding high R^2 values of the different root crops. The established calibration models were validated and revealed high R^2 values with 0.9580 for the cassava, 0.9958 for the sweet potato, and 0.9798 for the taro. The trendline equations are $y = 59.44x^{0.56}$, $y = 54.38x^{0.47}$, and $y = 52.94x^{0.62}$, respectively. The results revealed that the moisture meter is capable of reading the moisture content on a weight basis (% MC_{wb}) with accuracy and reliability at specified limits of 8% < x < 69% for the cassava, 15% < x < 59% for the sweet potato, and 9% < x < 57% for the taro. This study presents the performance of a portable analogue-based moisture meter as a reliable and accessible solution to small-scale operations, especially for farmers, offering an on-site rapid moisture content measurement in root crop processing.

Keywords: capacitance-based; moisture content; root crop processing; dielectric property; regression analysis; post-harvest technology

Root crops, such as the cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), and taro (*Colocasia esculenta*), are edible underground crops that plays significant roles in sustainable agricultural products due to their adaptability, versatility, and resilience to natural calamities and

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climate change. Root crops are widely cultivated and processed into dried chips for food and industrial use (Deguchi et al. 2021; Krajang et al. 2021; Fanelli et al. 2023; Ferdaus et al. 2023; Mustacisa-Lacaba et al. 2023), especially in low– and middle–income families in a developing country such as the Philippines (Roa et al. 2008; Liu et al. 2014). However, monitoring the moisture content of root crops poses concerns for small-scale operations, especially when storing the products, as it causes rapid deterioration and instability of the material (Kihurani & Kaushal 2016). To extend the storage life of root crops, they are traditionally processed into dried chips. Chipping is achieved when fresh root crops are reduced into thinly sliced or granular chunks and dried to about 12% moisture content wet basis (Amoah et al. 2022; Carvalho et al. 2023). However, although traditional moisture measurements, such as the oven-drying method, are precise, they are time–consuming and impractical for small-scale operations (Prain et al. 2019). Commercial moisture meters for root crop chips are not yet available. An indirect method, such as a capacitance-based measurement, involves the dielectric properties related to the moisture in the product. This method is much quicker and non-destructive, where the electrical conductivity response from the product is utilised (Nath & Ramanathan 2017; Zambrano et al. 2019).

Most of the electronic circuits of the existing moisture meters employ electrical signals obtained from the product (Sinon & Martinez 2004; Rai et al. 2005; Armstrong et al. 2017; Odedeyi et al. 2020; Gu et al. 2021). Low–cost systems are an option nowadays, particularly because of their adaptability and applicability to small–scale operations. Hence, this study aims to evaluate the performance of an analogue-based moisture meter designed for root crop chip applications.Specifically, this study aims to *(i)* establish the correlation between the actual moisture content of the root crop chips and the electrical capacitance readings obtained by the meter and *(ii)* formulate and evaluate appropriate mathematical models that validate the accuracy of the electronic moisture meter.

MATERIAL AND METHODS

Moisture meter design and principle. The moisture meter (Figure 1A) operates based on the electronic capacitance through the dielectric properties of the root crop chips. It converts them into an electronic signal by a parallel-plate capacitor sensor housed in a rectangular chamber (two single-sided 10 cm × 4 cm copper clads, 1.40 cm spacing). The basic instrumentation of the moisture meter follows the differential capacitive sensing method previously described by Sinon and Martinez (2004) and Rai et al. (2005). In this system, the electronic circuity uses two oscillators: a variable oscillator that detects changes in the dielectric properties of the samples and a reference oscillator that maintains a fixed frequency. The outputs of the two oscillators feed the individual buffer circuits to isolate the signals and allow independent operation. The buffered signals are processed through a differential amplifier utilised as a voltage comparator, which takes the algebraic sum of the two (inverting and non-inverting) inputs, and the meter readings are observed through the scale display of the meter. A 9 V battery was provided to power the circuit, which ensures portability and ease of use. A control knob was used to set the indicator to a zero reading to reduce the errors.

Root crop samples and moisture calibration. Locally available fresh harvested root crops, such as cassava, sweet potato, and taro, underwent peeling and washing to remove soil particles and other foreign matter. The peeled sweet potato, cassava, and taro were sliced using a manually operated slicing machine (Figure 1B), which is designed to produce granular–form chips (Figure 1C). The thickness of the chips ranged from 1.0–1.40 cm, which was based on the spacing of the conducting plates and also typically based on the chipping dimensions for drying and storage (Alonso et al. 2000; Yadollahinia & Jahangiri 2009). In this study, 7–10 root crop chips (grouped) were stacked side by side within the adequate space of the sensor chamber. The size irregularity of the chips was considered when the samples were inserted into the sensor chamber. The root crop chips (grouped samples) were dried in an oven at 50 °C, and moisture readings (MRs) were recorded at set intervals until they reached a stable weight. The meter readings were recorded simultaneously from the actual moisture content (MC) values of 10 to 20 different moisture content levels of the root crop chips (i.e., cassava, sweet potato, and taro). The varying MC levels are observed from the fresh chips (initial reading) until the chips achieve an acceptable final dried form

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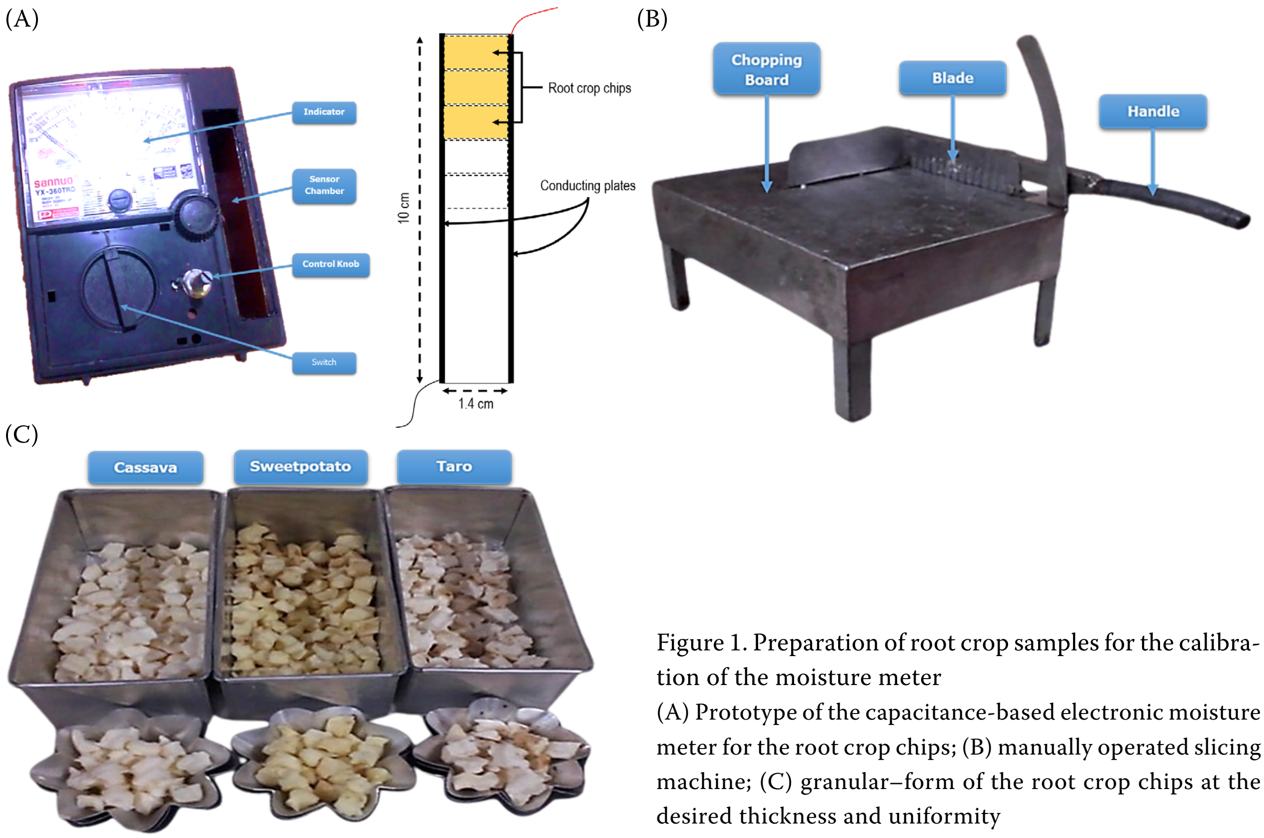

Figure 1. Preparation of root crop samples for the calibration of the moisture meter

(A) Prototype of the capacitance-based electronic moisture meter for the root crop chips; (B) manually operated slicing machine; (C) granular–form of the root crop chips at the desired thickness and uniformity

(final reading). The observation stopped after three successive readings of the root crop chips no longer varied significantly. The experiment was replicated three times. Additionally, the moisture content on a wet basis (%MC_{wb}) was calculated against the standard oven-drying method.

Statistical analysis. A regression analysis was implemented to establish the calibration models for each root crop in which the highest R^2 was obtained. Using a new set of samples, the established models were validated using the meter readings (MRs) and the measured actual moisture content (oven method). The root mean square error (RMSE) was calculated to measure how far the predicted moisture wet basis was from the actual (oven) moisture content.

RESULTS AND DISCUSSION

Calibration of the moisture meter. In the calibration process, the meter readings (μF) were calibrated against the actual (oven-drying method) moisture content (% MC_{wb}) using a regression analysis. Given its corresponding R^2 and trendline equations, the power regression models (Figure 2) provided the best-fit models to the three root crop chips, that reflects high R^2 values indicating a strong predictive capability with 0.9792 for the cassava, 0.9950 for the sweet potato, and 0.9867 for the taro. The equation models for calibration are $y = 0.0014x^{1.5305}$ for the cassava chips, $y = 0.0002x^{2.1044}$ for the sweet potato chips, and $y = 0.0017x^{1.5990}$ for the taro chips. The power regression models align closely with the experimental data throughout the varying moisture content levels. These models confirm that the capacitance-based measurement is appropriate for predicting the moisture content of root crop chips at varying moisture levels. However, the differences in the calibration imply different calibration requirements for each root crop due to the variations in the composition and density (Rashwan et al. 2024).

Validation and model performance assessment. The calibration models were validated using another set of samples, and the obtained meter readings (MRs) were compared to the actual moisture content (MC) values of the root crop chips, as shown in Figure 3A. The following regression equations were obtained: $y = 59.44x^{0.56}$, $y = 54.38x^{0.47}$,

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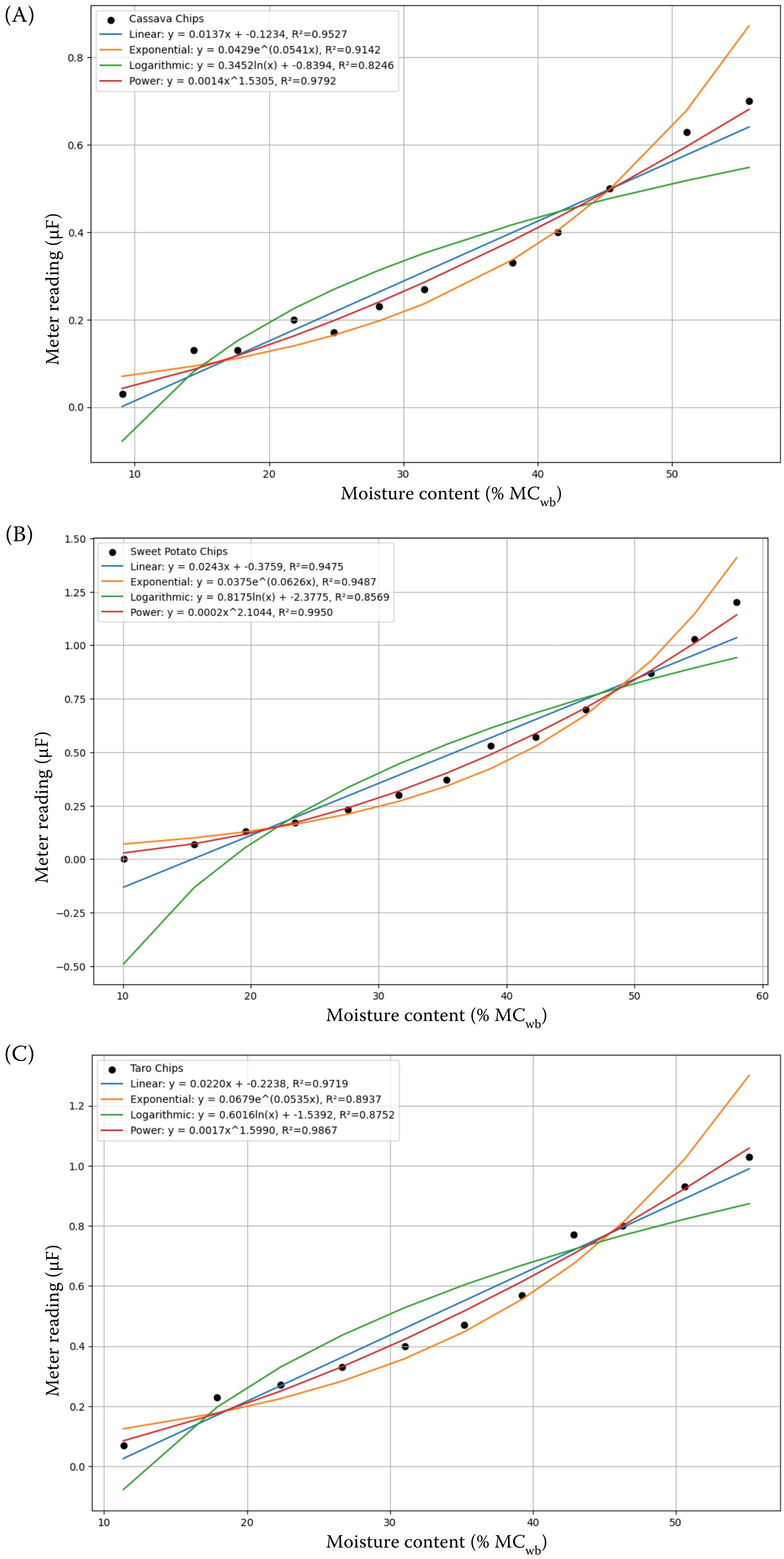

Figure 2. Calibration plots of the regression models

(A) cassava; (B) sweet potato; (C) taro chips

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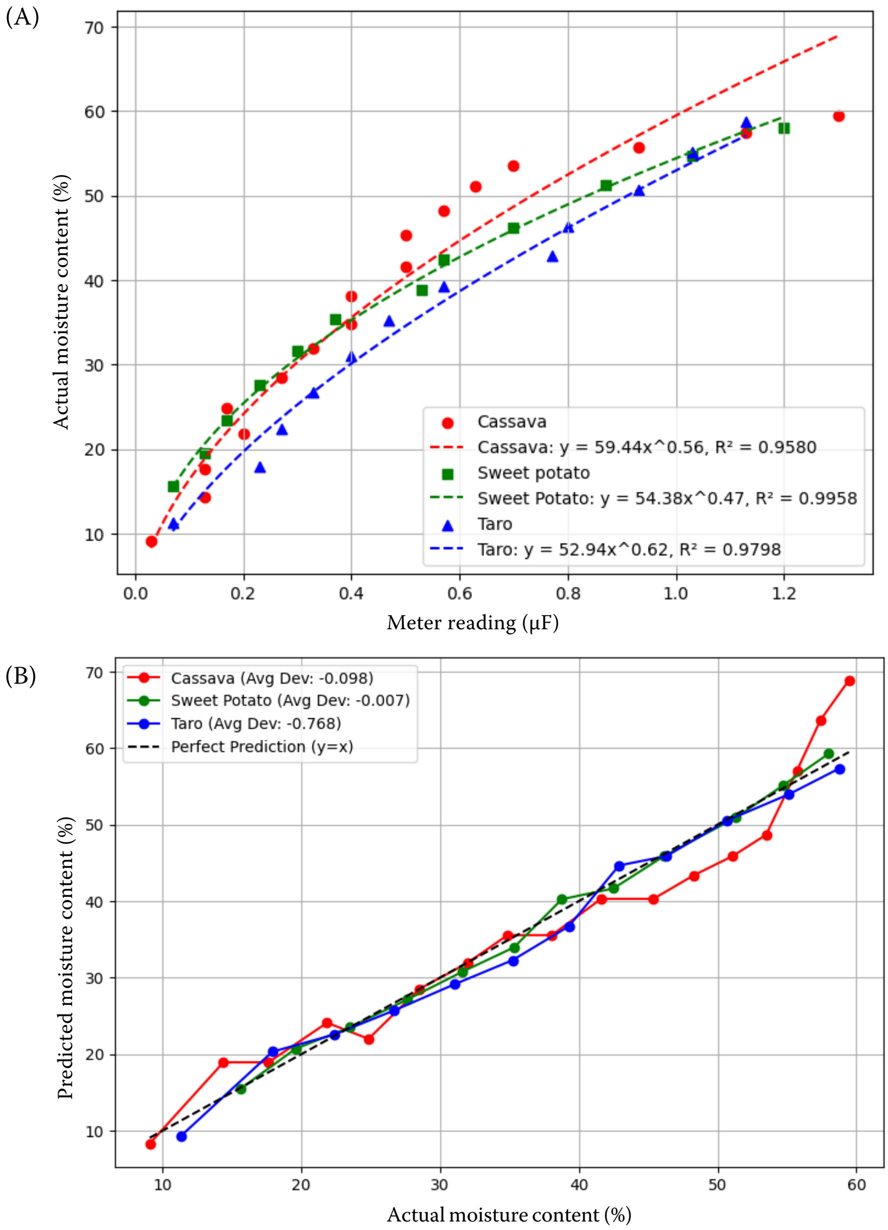

Figure 3. Validation of the analogue-based moisture meter for root crop chips
(A) Validation plots of the power regression models; (B) comparison of the actual (oven) and predicted moisture content for the validation of the cassava, sweet potato, and taro chips

and $y = 52.94x^{0.62}$ with the R^2 values 0.9580, 0.9958, and 0.9798 for the cassava, sweet potato, and taro, respectively. The high R^2 values reflect a strong positive correlation between the MR and the actual MC. As observed, the sweet potato chips exhibit the best fit (highest) model, while the cassava chips have a slightly lower fit, and the taro chips show a steep trend but remain strong. These differences suggest that the moisture retention and detection are different due to the root crops' different structural or composition properties (Himeda et al. 2012; Xu et al. 2023; Chen et al. 2024). These results reveal that the mathematical models obtained and considered in the validation tests are sufficiently repeated, as indicated by their high R^2 values.

Based on the evaluation of the predicted measurement (Figure 3B), the moisture meter demonstrates high accuracy in the 10% to 40% moisture content (wet basis). The predicted values in this range were closely aligned with the reference line (y = x), which showed minimal deviation from the actual moisture content values. However, the moisture content levels at < 10% and > 40%, particularly in the cassava and taro chips, deviated more.

Error analysis. The performance of the moisture meter was further evaluated by comparing the predicted (meter readings) MC values with the actual (oven-determined) MC values. As shown in Figure 3B, the predicted moisture content for the sweet potato has the highest accuracy with a mean

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deviation of –0.007, followed by the cassava with predicted values consistently close, corresponding to a lower mean deviation of –0.098 despite the lower R^2. On the other hand, the taro is the least accurate due to the high fluctuations in the predicted values, leading to the largest deviation of –0.768, even if the R^2 trend is high. This means that the predicted model for taro chips produces a better trend fit but has a wider spread of data points, corresponding to a larger significant error.

Furthermore, the R^2 values, predictability and root mean square error (RMSE) are provided in Table 1. Based on the validation results, the sweet potato samples exhibited the highest prediction accuracy and had a consistent result with a high R^2 value, low deviation, and lowest RMSE value of 0.8617. The sweet potato samples provide a better trend fit with precise and low error predictions. However, the taro model produces a significant deviation, which underpredicts the moisture content. This means the errors are more consistent than those of the cassava model, but it showed 95.71% predictability, producing a better trend fit.

On the other hand, the cassava model has the most inconsistent predictions. It has the lowest R^2 and lowest predictability of 89.23%. Also, it has the highest RMSE with 4.0068, even with a lower deviation compared to the taro model; the high RMSE and standard deviation suggest a larger error spread. This means that the cassava chips need to be recalibrated significantly.

Practical implications and future considerations. This study evaluated the performance of an analogue-based moisture meter in monitoring the moisture content of the cassava, sweet potato, and taro chips using a capacitance-based method. The results showed that the obtained equations from the power regression models for each root crop chip samples can closely predict the actual moisture content. The moisture meter can read the moisture content on a wet basis (% MC_{wb}) at specified limits of 8–69% for cassava chips, 15–59% for sweet potato chips, and 9–57% for taro chips. The moisture meter's predicted MCs align with the recommended moisture content for root crop chips. Cassava chips should have minimum moisture at around 14–17% (Pornpraipech et al. 2017), while taro chips for flour production should be below 12% (Kaur et al. 2011). Sweet potato chips are best for preservation at ≤ 10% at ≥ 75 °C (Gonçalves et al. 2023), but the meter remained effective within the 15–59% range that showed the highest accuracy in the evaluation process.

The accuracy of the capacitance-based moisture measurement depends on the crop type and the range of the moisture content detected. Our study demonstrated high correlation values for sweet potato and (R^2 = 0.9958) with lower accuracy observed in the cassava and taro with R^2 values of 0.9580 and 0.9798, respectively. Our study relates to previous literature that utilised dielectric and capacitance-based moisture methods. For instance, Kandala and Sundaram (2010), Korkua and Sakphrom (2020), and Rai et al. (2005) explored capacitive measurements for peanuts and corn, palm wood, and grains, respectively. They found that the accuracy was highest in the moisture content (wet basis) levels at 5–25% but still struggled in higher MCs, which caused higher discrepancies in the results. Furthermore, the findings of our study suggest that the capacitance-based moisture meter for root crop chips is most reliable within the 10–40% MC levels but still requires calibration adjustments when moisture readings are below < 10% or higher than 40% moisture content levels.

In this study, several factors affect the performance and accuracy of the moisture meter, including the plate sensor size and spacing, the type of crop being tested, and other factors. The larger the plate area and the closer the plate spacing, the stronger the conductivity of the electrons, which increases the meter's sensitivity. The granular sizes of the samples can add discrepancies in the readings due to their size irregularities. Samples with large thicknesses or sizes have a higher moisture content, which leads to inconsistencies in the readings since it creates air gaps and a larger surface area. Additional factors, such as air gaps, act as additional capacitors, while humidity and tem-

Table 1. Performance metrics of the formulated models for the different root crop chips

Root crop chips	R^2	Difference	Standard deviation	Predictability (%)	Root mean square error	Bias
Cassava	0.9580	-0.098	4.014	89.23	4.0068	–0.1018
Sweetpotato	0.9958	-0.007	0.862	97.67	0.8617	–0.0067
Taro	0.9798	-0.768	1.563	95.71	1.7420	–0.7683

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perature can affect the meter readings (Kandala & Sundaram 2010; Korkua & Sakphrom 2020). Further enhancement or modification of the sensor is required to ensure stability and accuracy of the meter reading. There should be an adjusting unit that would eliminate air spaces and give compaction that would render firmness in the reading.

While the study did not account for identifying the root crop variety, the findings reflect that the meter is effective for small-scale on-site rapid moisture detection. Future research may explore variety-specific calibrations or integration with digital technologies such as IoT technologies, enabling broader use in small-scale operations, including end-user evaluation to show an acceptability rating.

CONCLUSION

This study presents that the evaluation of the portable analogue-based moisture meter resulted in high R^2 values of 0.9580 for the cassava, 0.9958 for the sweet potato, and 0.9798 for the taro. The moisture meter was highly capable of reading the moisture content on a wet basis (% MC_{wb}) at specified limits of 8% < x < 69%, 15% < x < 59%, and 9% < x < 57%, respectively. As the discussion section indicates, the predicted MCs align well with the recommended moisture content for root crop chips. The findings from this study also highlight the reliability of the moisture meter within the range of 10–40% moisture content (wet basis) for the root crop chips (i.e., cassava, sweet potato, taro). By providing alternative solutions to monitor the moisture content, the moisture meter's performance was satisfactorily capable of giving the actual moisture content. The simple operation of the meter makes it valuable for small-scale and resource-limited operations that need a reliable, field-ready solution to reduce post-harvest losses.

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REFERENCES

Alonso L., Viera M.A., Best R., Gallego S., García J.A. (2000): Artificial cassava drying systems. In: Ospina B., Ceballos H. (eds): Cassava in the Third Millennium: Modern Production, Processing, Use, and Marketing Systems, Centro Internacional de Agricultura Tropical, Cali: 427–438.

Amoah F., Bobobee E., Addo A., Darko J., Akowuah J. (2022): A review of mechanical cassava peeling and its adoption by processors. The Ghana Engineer, 22: 23–38.

Armstrong P.R., McNeil S., Manu N., Bosomtwe A., Danso J.K., Osekre E., Opit G. (2017): Development and evaluation of a low-cost probe-type instrument to measure the equilibrium moisture content of grain. Applied Engineering in Agriculture, 33: 619–627.

Carvalho G.R., Santos K.C., Guedes J.S., Bitencourt B.S., Rojas M.L., Augusto, P.E.D. (2023): Drying of roots and tubers. In Elsevier eBooks: 587–628.

Chen L., Li K., Mou X., Liu Z., Jiang H., Mabrouk M., Pan J., Atwa E.M. (2024). Evaluating the impact of moisture content and loading orientation on the geometrical characteristics and mechanical behavior of cassava tubers. Agronomy, 14: 2254.

Deguchi M., Ito S., Motohashi R., Arai E. (2021): Effects of taro (*Colocasia esculenta L. Schott*) drying on the properties of taro flour and taro flour products. Food Science and Technology Research, 27: 369–379.

Fanelli N.S., Torres-Mendoza L.J., Abelilla J.J., Stein H.H. (2023): Chemical composition of cassava-based feed ingredients from South-East Asia. Animal Bioscience, 36: 908–919.

Ferdaus M.J., Chukwu-Munsen E., Fogue A., Da Silva R.C. (2023): Taro roots: an underexploited root crop. Nutrients, 15: 3337.

Gonçalves E.M., Pereira N., Silva M., Alvarenga N., Ramos A.C., Alegria C., Abreu M. (2023): Influence of air-drying conditions on quality, bioactive composition and sensorial attributes of sweet potato chips. Foods, 12: 1198.

Gu H., Liu L., Butnor J.R., Sun H., Zhang X., Li C., Liu X. (2021): Electrical capacitance estimates crop root traits best under dry conditions – a case study in cotton (*Gossypium hirsutum* L.). Plant and Soil, 467: 549–567.

Himeda M., Njintang Y.N., Gaiani C., Nguimbou R.M., Scher J., Facho B., Mbofung C.M. (2012): Physicochemical and thermal properties of taro (*Colocasia esculenta* sp) powders as affected by state of maturity and drying method. Journal of Food Science and Technology, 51: 1857–1865.

Kandala C.V., Sundaram J. (2010): Non-destructive measurement of moisture content using a parallel-plate capacitance sensor for grain and nuts. IEEE Sensors Journal, 10: 1282–1287.

Kaur M., Kaushal P., Sandhu S.K. (2011): Studies on physicochemical and pasting properties of taro (*Colocasia esculenta L.*) flour in comparison with a cereal, tuber and legume flour. Journal of Food Science and Technology, 50: 94–100.

Kihurani A.W., Kaushal P. (2016): Storage techniques and commercialisation. In: Sharma H.K., Njintang, N.Y., Sin-

https://doi.org/10.17221/15/2025-RAE

ghal R.S., Kaushal (eds): Prigati Tropical Roots and Tubers: Production, Processing and Technology, John Wiley & Sons Ltd., New Jersey: 253–280.

Korkua S.K., Sakphrom S. (2020): Low-cost capacitive sensor for detecting palm-wood moisture content in real-time. Heliyon, 6: e04555.

Krajang M., Malairuang K., Sukna J., Rattanapradit K., Chamsart S. (2021): Single step ethanol production from raw cassava starch using a combination of raw starch hydrolysis and fermentation, scale-up from 5-L laboratory and 200-L pilot plant to 3000-L industrial fermenters. Biotechnology for Biofuels, 14: 68.

Liu Q., Liu J., Zhang P., He S. (2014): Root and tuber crops. In: Neal K., Van A. (eds): Encyclopedia of Agricultural and Food Systems, Academic Press, Oxford: 46–61.

Mustacisa-Lacaba M., Villanueva R., Tadios L.K., Tan N. (2023): Increasing sweet potato (*Ipomoea batatas*) root crop yield based scientific participatory research. ASEAN Journal of Scientific and Technological Reports, 26: 24–35.

Nath D., Ramanathan P. (2017): Non-destructive methods for the measurement of moisture contents – a review. Sensor Review, 37: 71–77.

Odedeyi T., Poole C., Liu X., Kassem A., Oyebode G., Ismail R., Darwazeh I. (2020): a low-cost instrument for estimating the starch content of cassava roots based on the measurement of RF return loss, 2020 IEEE International Symposium on Circuits and Systems (ISCAS), Oct 10–14, 2020, Seville: 1–5.

Pornpraipech P., Khusakul M., Singklin R., Sarabhorn P., Areeprasert C. (2017): Effect of temperature and shape on drying performance of cassava chips. Agriculture and Natural Resources, 51: 402–409.

Prain G., Naziri D. (2019): The role of root and tuber crops in strengthening agri- food system resilience in Asia. A literature review and selective stakeholder assessment. Food Resilience Through Root and Tuber Crops in Upland and Coastal Communities of the Asia- Pacific (FOODSTART+) Project. Lima: Peru. International Potato Center: 66.

Rai A.K., Kottayi S., Murty S.N. (2005): A low cost field usable portable digital grain moisture meter with direct display of moisture (%). African Journal of Science and Technology, 6: 97–104.

Rashwan A.K., Younis H.A., Abdelshafy A.M., Osman A.I., Eletmany M.R., Hafouda M.A., Chen W. (2024): Plant starch extraction, modification, and green applications: A review. Environmental Chemistry Letters, 22: 2483–2530.

Roa J., Kadohira M., Bergantin R., Bolatete J., Yamauchi A. (2008): Farmers' decision making strategies on selecting rootcrop varieties in the Visayas Region, Philippines. Research Bulletin of Obihiro University, 29: 1–12.

Sinon F., Martinez A. (2004): Development of an electronic moisture meter for abaca fiber. Annals of Tropical Research, 26: 96–113.

Xu X., Wu S., Chen K., Zhang H., Zhou S., Lv Z., Chen Y., Cui P., Cui Z., Lu G. (2023): Comprehensive evaluation of raw eating quality in 81 sweet potato (*Ipomoea batatas* (L.) Lam) varieties. Foods, 12: 261.

Yadollahinia A., Jahangiri M. (2009): Shrinkage of potato slice during drying. Journal of Food Engineering, 94: 52–58.

Zambrano M.V., Dutta B., Mercer D.G., MacLean H.L., Touchie M.F. (2019): Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review. Trends in Food Science & Technology, 88: 484–496.

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