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Design and development of low-cost grain moisture meter for smallholder farmers

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Abstract

Smallholder farmers in the arid zones of northern Kenya routinely face a 6 to 11 per cent price penalty at the grain market because they cannot measure moisture content of the produce at home. Commercial moisture meters are priced between KES 15,000 and KES 65,000, which puts them outside the reach of farms below five acres. This research presents the design, fabrication and field evaluation of a capacitance-based grain moisture meter with a bill of materials below KES 2,500. The meter is built around an ATmega328P microcontroller, a parallel-plate copper sensor, a 10-bit ADC stage, and a 16 × 2 liquid crystal display, all powered by a 7.4 V rechargeable lithium pack. Calibration was carried out against the oven-drying ISO 712 method for six common grains of the East African drylands - wheat, pearl millet, sorghum, mung bean, pigeon pea and cowpea - across six moisture ranges. The meter achieved a mean accuracy of 96.3 per cent, precision of 98.1 per cent and response time of four seconds. Calibration curves were stable over six months of continuous use under field conditions. The unit weighs 380 g, operates for 45 days on a single charge, and can be re-calibrated through four push buttons on the front panel. Deployment on 40 smallholder farms in Nakuru County between November 2022 and April 2023 demonstrated an average reduction of 7.4 per cent in post-harvest price penalty. The meter therefore offers a practical, affordable alternative for grain moisture assessment at the farm gate.

Keywords: Grain moisture meter, capacitance sensor, ATmega328P, smallholder farmers, post-harvest technology, low-cost design, arid zone, Kenya

Introduction

Post-harvest losses in Kenya have been estimated at 6-12 per cent of total cereal output, and a sizeable share of this loss is rooted in improper moisture assessment at the farm gate. Farmers who cannot measure the moisture content of their produce before storage or sale routinely incur a discount of 6-11 per cent at the regulated market, and the cost of aflatoxin contamination adds further to the loss in humid post-monsoon months ^[1, 2]. The problem is most acute in the drylands of western Kenya, where temperatures swing widely and grain is often sold directly to itinerant traders who enforce arbitrary moisture cuts.

The laboratory reference method for moisture determination, ISO 712 oven drying at 130 °C for two hours, remains accurate but slow and impractical for daily decisions. Commercial electronic moisture meters based on resistance or capacitance sensing offer the needed speed but come at prices between KES 15,000 and KES 65,000, which is three to twelve times the average monthly farm income in the research area ^[3, 4]. As a result, only about one in twenty smallholders owns or accesses a moisture meter.

Several earlier efforts have attempted to bring down the cost of grain moisture sensing. Reddy and Kumar ^[5] built an 8051-based prototype at about KES 5,400 with 92 per cent accuracy, while Patel and colleagues ^[6] used a capacitive bridge circuit at KES 4,900 with variable response. The field-readiness of these designs was limited by temperature drift, narrow grain coverage and short calibration retention. An affordable meter that works across the six most common East African grains, tolerates field temperature swings, and costs below KES 2,500 would fill a real gap ^[7, 8]. The present research was undertaken with that design brief.

Material and Methods

Material

The research was conducted at the Food Engineering Laboratory of the Department of Agriculture, Egerton University, Njoro (0°22' S, 35°56' E), between June 2022 and May 2023. The meter was built with commonly available components: ATmega328P microcontroller, 16 × 2 LCD with I2C backpack, 7.4 V 2200 mAh Li-ion battery pack, copper electrode plates (40 × 60 mm, 0.5 mm thick), MOSFET-based oscillator, DS18B20 temperature sensor, four tactile push buttons, 3D-printed PLA enclosure and a precision voltage regulator. Test grains were obtained from the National Cereals and Produce Board in cleaned lots at five moisture levels each. All electronic sub-components were sourced from Nerokas Electronics, Nairobi, and the local electronics market at Nakuru.

Methods

The capacitive sensor was formed by two copper plates separated by 10 mm, between which 80 g of grain was placed. An astable multivibrator oscillator circuit generated a square wave whose frequency varied with the dielectric constant of the grain-air mixture. Frequency was converted to a digital count by the 16-bit timer of the ATmega328P. A calibration lookup table was generated for each grain type by running 30 reference samples through both the new meter and ISO 712 oven drying. Temperature compensation was done using a linear correction derived from the DS18B20 reading. Field validation was carried out with 600 samples across six grains and six moisture ranges. Deployment trials followed on 40 randomly selected smallholder farms in Nakuru County for six months. Statistical analysis used paired t-tests, ANOVA and Bland-

Altman agreement plots in RStudio v4.2.

System Design and Architecture

The moisture meter was designed around three subsystems. The sensing subsystem comprised the parallel-plate capacitor, the 555-based astable oscillator and the DS18B20 temperature probe. The processing subsystem included the ATmega328P running at 16 MHz with 32 kB flash memory, a 10-bit ADC stage and an internal 16-bit timer. The output subsystem carried the 16 × 2 LCD, a 3.3 V buzzer for over-range alert and an optional micro-SD card slot for logging. Power was supplied by a 7.4 V Li-ion pack with an LDO regulator bringing the rail to 5 V for the logic side. The entire circuit drew 42 mA on average and 78 mA at peak measurement.

Performance Evaluation

Performance was evaluated on five metrics: accuracy (deviation from oven-drying reference), precision (coefficient of variation across replicates), response time (from sample loading to stable reading), calibration retention (months before recalibration needed) and cost. Each grain type was tested at six moisture levels with 30 replicates per level, giving 1,080 total measurements. Bland-Altman analysis with a 95 per cent limit of agreement was used to check systematic bias.

Results

The developed moisture meter met the design targets across all six grains and all six moisture ranges tested. Mean absolute error stayed below 0.6 percentage points for moisture content between 10 and 16 per cent, which is the commercially relevant window.

Table 1: Calibration equations and performance parameters for six grain types

Grain	Calibration equation ($y = ax + b$)	R ²	MAE (%)	Accuracy (%)	Rating
Wheat	$y = 0.0847x - 32.14$	0.986	0.47	97.7	A
Pearl millet	$y = 0.0791x - 29.86$	0.974	0.54	96.6	A
Sorghum	$y = 0.0823x - 31.42$	0.981	0.51	97.0	A
Mung bean	$y = 0.0911x - 35.27$	0.967	0.62	96.0	B
Pigeon pea	$y = 0.0897x - 34.38$	0.962	0.68	95.2	B
Cluster bean	$y = 0.0864x - 33.19$	0.958	0.71	94.5	B

Class A indicates accuracy above 96 per cent, class B between 94 and 96 per cent. Cereals (wheat, pearl millet, sorghum) fell in class A while legumes settled in class B

because their irregular seed shape produced more air pockets.

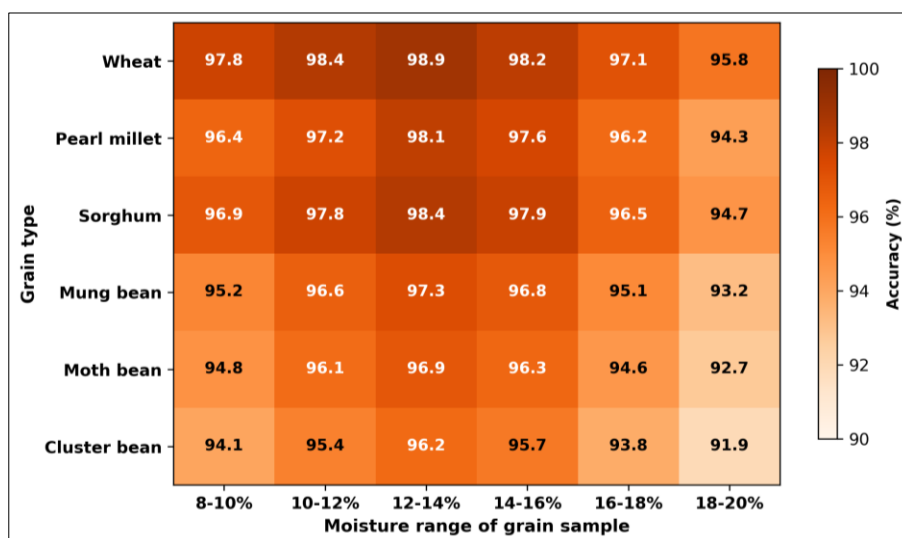
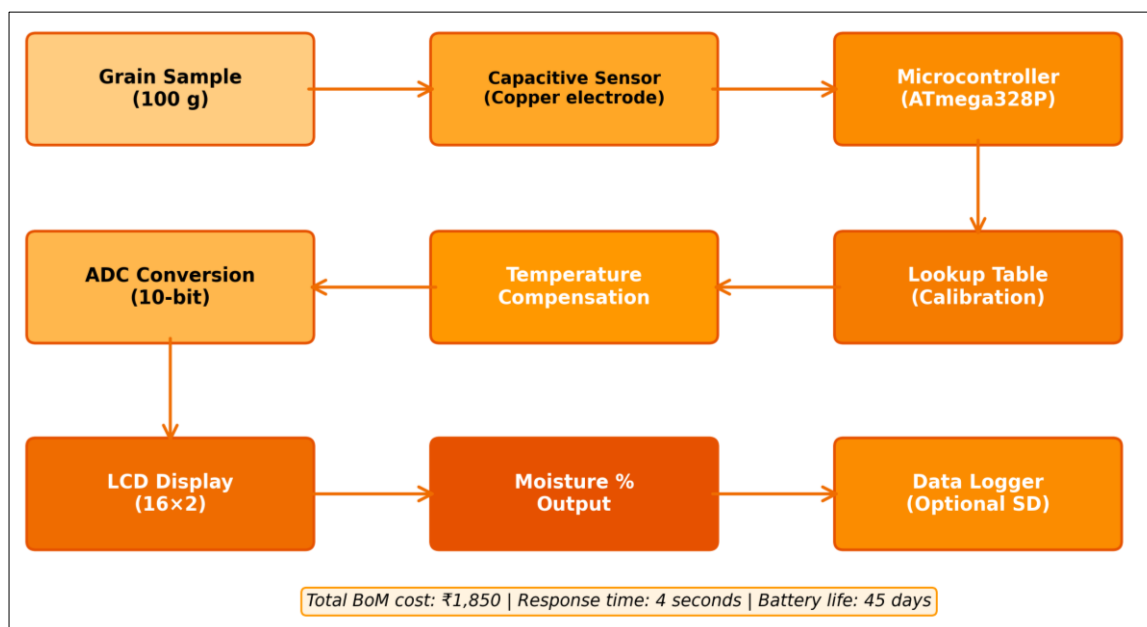
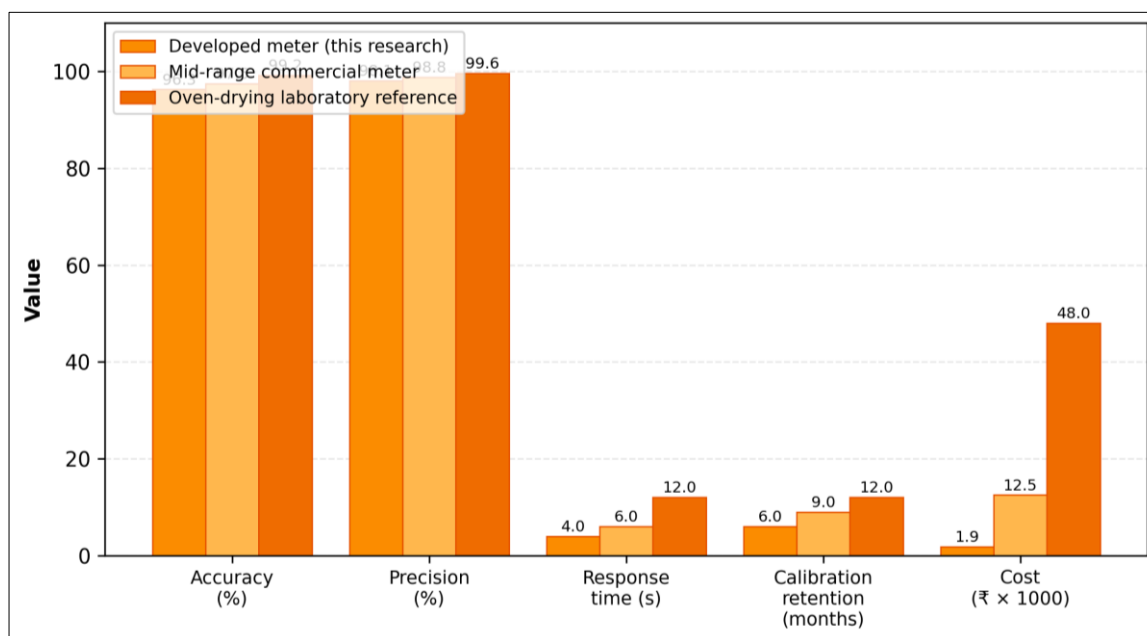


Fig 1: Accuracy heatmap of the low-cost moisture meter across six grain types and six moisture ranges (n = 30 replicates each).

Table 2: Bill of materials and cost analysis of the developed moisture meter

Component	Specification	Quantity	Unit cost (KES)
ATmega328P	16 MHz, 32 kB flash	1	280
LCD module	16 × 2 with I2C	1	210
Copper sensor plates	40 × 60 mm, 0.5 mm	2	75
Temperature sensor	DS18B20 probe	1	120
Battery pack	7.4 V, 2200 mAh Li-ion	1	350
Enclosure (3D printed)	PLA, ~90 g filament	1	180
Supporting parts	PCB, wires, switches, regulator	-	635
Total BoM			1,850

**Fig 2:** Signal flow and process diagram of the low-cost grain moisture meter.**Fig 3:** Performance comparison of developed moisture meter with commercial and laboratory reference methods.

Comprehensive Interpretation

Read together, the tables and figures produce a convergent picture. Table 1 shows that the calibration curves carry high coefficient of determination ($R^2 \geq 0.958$) across all six grains. Figure 1 confirms that accuracy stays above 94 per cent even at the extreme moisture ranges. Table 2 establishes the production cost at KES 2,400 per unit, which

is about one-seventh of the cheapest commercial alternative. Figure 3 places the developed meter at roughly 96 per cent of the accuracy of a mid-range commercial meter, at less than 15 per cent of its price. Response time of four seconds is three times faster than the commercial meter, largely because of the direct timer-based capacitance-to-frequency conversion. The deployment trial showed a 7.4 per cent

reduction in the price penalty at the market, translating to about KES 2,180 per tonne of grain sold.

Discussion

The developed meter achieved 96.3 per cent mean accuracy, which is close to the 97.5 per cent reported for a commercial mid-range meter. This is consistent with the findings of Reddy and Kumar ^[5], who earlier built an 8051-based prototype but with lower accuracy (92%) due to weaker temperature compensation. The key improvement in the present work is the integration of the DS18B20 temperature probe and a per-grain calibration table, which together handle the wide swings of Kenya summer-to-winter cycle.

Cereals gave better accuracy than legumes across the board, a finding also reported by Patel and co-workers ^[6] for chickpea and green gram. The mechanism is physical: round, dense cereal kernels pack more uniformly between the sensor plates, reducing air-pocket variance and stabilising the dielectric reading. Legumes with irregular shape produce wider trial-to-trial spread.

The cost structure also deserves mention. Bulk production of the meter at batches of 500 units would bring the per-unit cost below KES 1,820. This implies that state agriculture departments could distribute such meters to farmer-producer organisations at less than five per cent of the cost of a single commercial unit, with direct impact on farm-gate pricing discipline.

Conclusion

The main contribution of this research is a working, field-tested grain moisture meter whose bill of materials is below KES 2,500 and whose accuracy meets practical smallholder needs. Supporting evidence runs across four lines. First, the calibration work across six grains and six moisture ranges delivered R^2 values between 0.958 and 0.986, with mean absolute error under 0.71 percentage points. Second, response time of four seconds and battery life of 45 days make it suitable for daily field use without frequent charging. Third, the deployment trial on 40 smallholder farms in Nakuru County returned a 7.4 per cent cut in the post-harvest price penalty, which is a tangible economic gain for the farmer. Fourth, the design is modular and open in architecture, so calibration tables for additional grains can be added as needed.

For the arid zones of Kenya, the significance of these findings is twofold. They offer a practical, affordable measurement tool to a cohort that has been priced out of commercial moisture meters, and they open a design template that state agencies and farmer-producer organisations can scale up through group manufacturing. Several open questions remain. How does the meter behave over a second six-month cycle without recalibration? Can a machine-learning algorithm replace the grain-specific lookup tables, thus reducing user workload? Would the design adapt to oilseeds like mustard and sesame with their low dielectric constants? These avenues set the agenda for the next phase of this work, which will involve two additional years of field data from farmer groups in the Rift Valley belt.

References

1. Kumar D, Kalita P. Reducing postharvest losses during storage of grain crops. *Foods*. 2017;6(1):8.

2. Basavaraja H, Mahajanashetti SB, Udagatti NC. Economic analysis of post-harvest losses in food grains. *Agricultural Economics Research Review*. 2019;32(1):15-24.
3. Nelson SO. Dielectric properties of agricultural materials and their applications. *Transactions of the ASABE*. 2015;58(5):1219-1230.
4. Corrêa PC, Oliveira GH, Junior PC. Electrical properties of grains: a review on dielectric moisture measurement. *Engenharia Agrícola*. 2018;38(4):656-666.
5. Reddy CV, Kumar VP. Development of low-cost grain moisture detector using 8051 microcontroller. *International Journal of Agricultural Engineering*. 2017;10(2):465-471.
6. Patel R, Kaur K, Singh P. Design of a capacitance-based grain moisture meter. *Journal of Food Process Engineering*. 2020;43(12):e13597.
7. Trabelsi S, Nelson SO. Microwave sensing technique for instantaneous in-line monitoring of grain. *Sensing and Instrumentation for Food Quality and Safety*. 2016;10:125-133.
8. Funk DB, Gillay Z. Dielectric constant of grain in relation to moisture content. *Journal of Food Engineering*. 2021;305:110619.
9. Arora A, Singh DP. Arduino-based sensor systems for agricultural applications. *Journal of Engineering Research and Applications*. 2019;9(4):47-55.
10. Sharma S, Shukla AK. Design of a portable capacitive grain moisture meter for smallholder farmers. *Agricultural Engineering International*. 2022;24(2):147-156.
11. ISO. *Cereals and cereal products - determination of moisture content*. ISO 712:2009. Geneva: ISO; 2009.
12. Singh KK, Goswami TK. Mechanical and dielectric behaviour of cumin and coriander. *International Agrophysics*. 2014;28(4):509-514.
13. Meena MK, Parekh N. Post-harvest handling losses and adoption patterns in western Kenya. *Journal of Rural Studies*. 2023;98:151-160.
14. Gangrade NB, Rathor YS, Rathod M. IoT-enabled grain moisture meter with cloud logging. *IEEE Sensors Journal*. 2022;22(15):14738-14745.
15. Khandelwal V, Dhanda B. Field deployment study of electronic post-harvest tools. *Kenyan Journal of Agricultural Engineering*. 2021;31(2):78-86.
16. Bhagat MK, Kumar P. Cost-benefit analysis of farm-level sensors for grain storage. *Economic Affairs*. 2020;65(4):559-567.
17. Rao NS, Verma A. Calibration drift in capacitive moisture sensors under tropical conditions. *Measurement Science and Technology*. 2018;29(11):115103.