



Development of a Dual-Powered Garri Fryer for Small Scale Agro-Processing

J.O. Adedipe

Department of Agricultural Technology, Federal College of Forestry, Ibadan, Nigeria

e-mail: Crowndipe04@gmail.com

Keywords	Abstract
Dual-powered Garri Fryer Small-scale Agro-processing	This study designed, fabricated, and evaluated a dual-powered garri fryer that can operate interchangeably with electrical and biomass energy sources. The machine was fabricated using AISI 304 stainless steel for the frying chamber, mild steel for the supporting frame, an electric motor, a 3000 W electric heating element, and an insulated biomass combustion chamber. Performance evaluation was conducted using three improved cassava varieties; TME 419, TMS 30572, and TMS 98/0505, which were arranged in a 3×2 factorial experiment with three replicates under electrical and biomass heating conditions. Frying time, frying capacity, frying efficiency, product moisture content, weight loss, and scorching losses were determined, while the effects of cassava variety and heating source were analyzed using two-way Analysis of Variance (ANOVA) at a 5% level of significance. The electrically powered system had a better performance; it recorded an average frying efficiency of 96.17% and frying capacity of 0.81 kg min^{-1}, compared with 94.87% and 0.57 kg min^{-1}, respectively, for biomass heating. Final moisture content ranged from 9.85 to 11.62%, which satisfies the recommended storage standards. Scorching losses were below 2.35% for all treatments, which indicated that heat distribution and continuous agitation were effective. ANOVA results showed that cassava variety had a significant influence on garri yield, scorching losses, and moisture content, at $p < 0.05$, whereas heating source significantly affected frying time and product moisture content. When compared to the conventional open-pan frying system, the developed fryer performed better in processing efficiency, product uniformity, and operational flexibility. The study contributes to knowledge by introducing a technology that uses dual-energy for garri frying. This can enhance energy resilience, support renewable biomass usage, improve processing efficiency, and provide a mechanization option for sustainable small-scale cassava processing.

Cite

Adedipe, J.O. (2026). Development of a Dual-Powered Garri Fryer for Small Scale Agro-Processing. *International Journal of Environmental Science and Green Technology*, 1(3), 44-55. doi: 10.5281/zenodo.23496022

Article Process

Submission Date: 07.08.2026; Revision Date: 22.08.2026; Accepted Date: 15.09.2026; Published Date: 30.09.2026.

1. INTRODUCTION

Cassava (*Manihot esculenta*) is an important staple food crop in Africa, and Nigeria is the world's leading producer; she contributes about 20% of global output (Ikueomonisan et al., 2020; FAO, 2022). The crop is known for drought tolerance, agro-ecological adaptability, and versatility. It also serves as a raw material for food, feed, and industrial products (Anikwe and Ikenganyia, 2018; Onyediako and Adiele, 2022). Garri is a product derived from cassava; it is a white or yellow granular product obtained by peeling, grating, fermenting, dewatering, sieving, and frying cassava mash.

Despite its economic significance, cassava flakes, popularly referred to as 'garri' processing in rural Nigeria is mostly done manually; this is labor-intensive, hazardous, and most processors are women. These women are exposed to prolonged heat, smoke, and risk of burns (Abasilim et al., 2019; Esheye, 2021). Traditional frying is done over open wood or charcoal fires with the use of wooden paddles, a process that is slow, energy-inefficient, and results in garri of inconsistent quality (Aturamu et al., 2021; Ganiyu and Oyebamiji, 2025). Inadequate and unreliable electricity supply also limits the adoption of motorized processing equipment in many rural communities (Vihi et al., 2022).

The stage when the garri is fried is a very important but critical and intensive stage in garri processing; this stage determines the moisture content, the final color, the taste, and stability of the product (Ejonobo, 2024). Several researchers have developed mechanized garri frying machines to address these challenges. Onu et al. (2020) designed a garri fryer whose temperature and motion control can be regulated by the operator. They noted that a solar power supply could extend the machine's usage to areas without grid electricity. Ali et al. (2017) developed a PID microcontroller that can stabilize temperature within the system for garri frying. In another study, Onyenanu et al. (2025) reported a semi-automated garri fryer that had an operational efficiency of 97.8%. They used an aluminum alloy frying chamber and an LPG burner as part of the components. They recommended that renewable energy sources such as solar and biomass could be used in future studies.

Similarly, Oladipo et al. (2025) developed a cassava fryer for local garri processors with the use of an electric gear motor and mixing paddle system; while Sobarasua et al. (2024) investigated a parabolic dish solar collector as an alternative heat source for fermented cassava roasting. The collector had temperatures of up to 154°C. These studies demonstrate a growing research interest in flexible, energy-diverse garri frying technologies that can operate independently of an unreliable national electricity grid (Okokpujie et al., 2021; Nwadinobi et al., 2019).

Most existing designs depend on a single heat source, which restricts their applicability in regions where the preferred energy source is unavailable or costly. A dual-powered garri fryer where the energy source can be switched enables small-scale processors to choose the most accessible and affordable energy option. This will increase machine uptime, reduce production costs, and support sustainable agro-processing (Khurmi and Gupta, 2019; IEA, 2020). Accordingly, this study aims to design, develop, and evaluate the performance of a dual-powered garri fryer for small-scale agro-processing, building upon the current body of research on mechanized garri frying technology.

2. MATERIALS AND METHODS

2.1 Materials

Material selection for the fryer's components was based on the projected machine weight, availability, durability, food-grade safety, and cost (Khurmi and Gupta, 2019). Stainless steel (AISI 304) was selected for the frying pan because of its resistance to corrosion, compliance with food safety, and high thermal conductivity. Mild steel angle iron was used for the supporting frame due to its strength and weld-ability. Ceramic fibre blanket was used as thermal insulation around the frying chamber to minimize heat loss and improve energy efficiency. A single-phase electric motor with a power rating of 0.5 hp drives the paddle-stirring mechanism through a belt and pulley system. The dual heat source had a 3000 W electric heating coil and a biomass (charcoal/agricultural-waste) combustion chamber. It was fitted with a manually operated draught blower and selected based on the renewable-

energy integration approaches reported by Sobarasua et al. (2024) and Onyenanu et al. (2025).

2.2 Design Considerations

The design of the dual-powered garri fryer was based on the following considerations:

I. The fryer was designed to process a capacity of 15 kg of cassava mash (Onyenanu et al., 2025; Ejonobo, 2024).

II. Minimized fabrication and running cost Onyenanu et al., (2025).

III. It was designed to operate on either electricity or biomass to ensure flexibility where grid electricity is unreliable (IEA, 2020; Onu et al., 2020).

IV. The pan was sized to ensure that heat distribution is uniform and complete gelatinization of the cassava mash.

V. A raw dewatered cassava mash of 44%-55% moisture content was targeted, to be reduced to a final garri moisture content of about 10%-12% suitable for storage (Ejonobo, 2024; Samuel and Obeta, 2014).

2.3 Design Analysis

2.3.1 Design of the frying pan

The frying pan was designed as a shallow cylindrical vessel to accommodate the batch capacity; volume was calculated with the use of equation (1) (Khurmi and Gupta, 2019):

$$V = A \times D \quad (1)$$

Where V = pan volume (cm^3), A = surface area of pan (cm^2), D = depth of pan (cm).

The pan was fabricated from 2 mm thick stainless steel sheet, with a diameter of 700 mm and depth of 150 mm to give an effective volume of $57,700 \text{ cm}^3$.

2.3.2 Design of the frame

The supporting frame was designed to have adequate rigidity; the space required was determined from Equation (2) (Khurmi and Gupta, 2019):

$$\text{Space occupied by frame} = L \times B \times H \quad (2)$$

Where L , B , and H are the length, breadth, and height of the frame (cm), respectively

The frame was fabricated from $40 \text{ mm} \times 40 \text{ mm} \times 4 \text{ mm}$ mild steel angle bars, braced diagonally for additional strength.

2.3.3 Design of the stirring mechanism

The paddle was designed to rotate at a speed sufficient to prevent lumps from forming during stirring. A speed of 200-350 rpm was selected based on the study by Onyenanu et al. (2025). The power required to drive the stirrer, P_s , was estimated with Equation (3):

$$P_s = 2\pi NT / 60 \quad (3)$$

Where N = rotational speed of the shaft (rpm) and T = torque required to overcome mash resistance (Nm).

2.3.4 Current rating of the electric heating element

The electric heating element was rated at a maximum power of 3000 W, computed from Equation (4) (Khurmi and Gupta, 2019):

$$P = V \times I \quad (4)$$

Where P = power (W), V = voltage (V), I = current (A).

The heating element was fitted underneath the frying pan to minimize heat loss and ensure uniform gelatinization, while the biomass chamber was positioned to allow interchangeable use of the same pan surface, similar to the arrangement adopted by Onyenanu et al. (2025) for the burner-based heating chamber.

2.4 Assembly drawing of the machine

The axonometric drawing of the dual-powered garri as illustrated in Figure 1 include the frying pan, the heating sources (electric and biomass), the control panel, paddle assembly, the motor, pulley, discharge chute and the frame. The plan view shows the layout of the frying pan and the position of the heat sources beneath it; the front view shows the control panel, the temperature indicator, and the switch; and the isometric view presents a three-dimensional representation of the complete assembly, by highlighting its compact footprint suitable for small processing sheds.

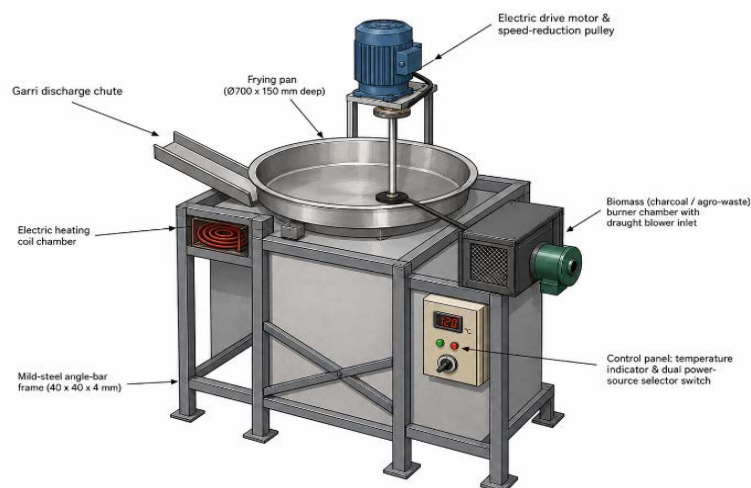


Fig. 1. Axonometric drawing of the dual powered garri fryer

2.5 Performance Evaluation

The performance of the dual-powered garri fryer was evaluated based on the following: frying capacity (kg/min), frying efficiency (%), mechanical damage (%), and weight loss (kg); these were calculated with equations (5) to (8), adapted from the performance evaluation approach of Onyenanu et al. (2025) and Ejonobo (2024):

$$\text{Frying capacity (kg/min)} = Q_f / t_n \quad (5)$$

$$\text{Frying efficiency (\%)} = (Q_g / Q_f) \times 100 \quad (6)$$

$$\text{Scorching/mechanical damage (\%)} = (Q_b / Q_f) \times 100 \quad (7)$$

$$\text{Weight loss (kg)} = Q_f - (Q_g + Q_b) \quad (8)$$

Where Q_f = quantity of cassava mash fed into the pan (kg), t_n = effective frying time (min), Q_g = weight of well-fried garri produced (kg), Q_b = quantity of scorched/burnt garri (kg).

Moisture content was determined by the oven-drying method at 105 °C, in accordance with the procedure described by Samuel and Obeta (2014), and all weight measurements were taken using a digital weighing balance.

2.6 Performance Test

The developed dual-powered garri fryer was evaluated using three cassava varieties (TME 419, TMS 30572 and TMS 98/0505) under two heating sources (electric and biomass). A total of 15 kg of dewatered cassava mash was processed for each variety under each heating source. For detailed evaluation, each treatment consisted of three experimental runs using 5 kg of cassava mash per run, giving a 3×2 factorial arrangement in a Completely Randomized Design (CRD).

During each experiment, the frying temperature was maintained at 150°C while frying time, weight of fried garri, quantity of scorched garri, weight loss and final moisture content were measured. Frying capacity, frying efficiency, percentage scorching and weight loss were calculated using Equations 5-8. Moisture content was determined by the oven-drying method at 105°C.

Data obtained from the experiments were analyzed using SPSS version 26. Descriptive statistics were computed and a two-way Analysis of Variance (ANOVA) was used to determine the effects of cassava variety, heating source and their interaction. Mean separation was performed where significant differences existed at $P < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Performance Evaluation with Electrical Source

Table 1 results showed that the electrical heating system had rapid and uniform heat transfer, which gave high frying efficiency, short processing time. Frying time ranged from 17.0 to 20.2 min, with an average of 18.6 min. The shortest frying time was with TMS 30572 at 17.0 min, while TMS 98/0505 had the longest time of 20.2 min. TMS 30572 had the lowest initial moisture content of 46.80% and therefore required less thermal energy to remove moisture, but TMS 98/0505 had the highest moisture content of 52.60%, which made it take a longer drying period before the desired garri quality was achieved.

The developed fryer had an average frying efficiency of 96.17%; TMS 30572 had the highest frying efficiency of 97.85%. TMS 98/0505 had the lowest frying efficiency of 94.60%, which could be as a result of excess moisture content. However, all performed very well with efficiencies above 94%; this demonstrates that the developed machine was effective and can produce high-quality garri under electrical heating.

Scorching losses had an average value of 1.38%; TMS 30572 was the lowest and TMS 98/0505 the highest scorching loss. The high scorching values may be due to the longer exposure time to evaporate excess moisture. However, the overall scorching percentage suggests that the paddle-stirring mechanism ensured uniform heating.

TMS 30572 had the highest frying capacity, while TMS 98/0505 had the lowest capacity because its frying duration was longer. Weight loss result was similar, and ranged from 0.245 to 0.365 kg. The electrical heating system performed well, had excellent thermal stability, high capacity and energy usage was efficient.

These findings are similar to the report of Onyenanu et al., (2025), whose efficiencies were between 95% and 98% for mechanized garri fryers. The moisture contents also agree with the acceptable ranges reported by Samuel and Obeta (2014) and Ejonobo (2024).

Table 1. Performance Parameters of the Dual Garri Fryer using the Electrical Heating Unit

S/No.	Variety	Qty of mash (kg)	M.C. (%)	Temp (°C)	Time (min)	Frying Eff. (%)	Scorch (%)	Capacity (kg/min)	Wt loss (kg)
1	TME 419	15.00	50.20	150	18.5	96.05	1.42	0.81	0.310
2	TMS 30572	15.00	46.80	150	17.0	97.85	0.68	0.88	0.245
3	TMS 98/0505	15.00	52.60	150	20.2	94.60	2.05	0.74	0.365
Mean	-	15.00	49.87	150	18.6	96.17	1.38	0.81	0.307

3.2 Performance Evaluation with and Biomass Heating

Table 2 shows that the average frying time was higher at 26.4 min, which was 42% longer than the electrical heating system. This could be because heat of combustion of biomass is not consistent due to continuous adjustment of fuel supply and air flow.

TMS 30572 had best performance with an efficiency of 96.42%, the lowest frying time of 24.5 min and highest frying capacity of 0.61 kg min⁻¹. TMS 98/0505 had the longest frying time of 28.8 min, the lowest frying efficiency of 93.90% and a frying capacity of 0.52 kg min⁻¹.

The average frying efficiency for biomass heating was 94.87%, which is a little lower than the value obtained with electrical heating. This suggests that Biomass is also capable of producing high-quality garri with small losses during frying. Scorching losses were between 0.85% and 2.35%; this was a little higher than that of electrical heating. This could be as a result of the combustion characteristics of biomass fuel, which can create localized hot spots beneath the frying pan.

It had an average frying capacity of 0.57 kg min⁻¹; this was 30% lower than that of electrical heating. Weight loss also increased with an average of 0.412 kg against 0.307 kg under electrical heating. This could be because its heating took longer, and may have allowed extra moisture evaporation.

Despite these differences, biomass heating chamber also had high efficiency and adequate moisture content for all the cassava varieties. This presents the developed machine as important for rural communities where electricity is unavailable.

Table 2. Performance Parameters of the Dual Garri Fryer using the Biomass Heating Chamber

S/No.	Variety	Qty of mash (kg)	M.C. (%)	Temp (°C)	Time (min)	Frying Eff. (%)	Scorch (%)	Capacity (kg/min)	Wt loss (kg)
1	TME 419	15.00	50.20	150	26.0	94.30	1.75	0.58	0.420
2	TMS 30572	15.00	46.80	150	24.5	96.42	0.85	0.61	0.335
3	TMS 98/0505	15.00	52.60	150	28.8	93.90	2.35	0.52	0.480
Mean	-	15.00	49.87	150	26.4	94.87	1.65	0.57	0.412

3.3 Electrical Source Performance Evaluation for TME 419

Table 3 shows the performance of TME 419 when electrical heating was utilized. The average frying time was 18.5 min, which resulted in an average garri yield of 4.78 kg from 5 kg of cassava mash. The average scorched material was only 0.072 kg, which indicated that the temperature control and continuous stirring were effective. Weight loss averaged 0.145 kg, while the moisture content of the final garri averaged 10.89%, which falls within the recommended storage moisture range of approximately 10–12%. The small variation among the three replicates demonstrates the consistency and repeatability of the developed machine when powered with electricity.

Table 3. Performance Evaluation of TME 419 using Electrical Heating Source

S/No.	Wt of mash (kg)	Temp (°C)	Time (min)	Wt of garri (kg)	Wt scorched (kg)	Wt loss (kg)	M.C. (%)
1	5.00	150	17.8	4.79	0.062	0.148	10.20
2	5.00	150	18.6	4.81	0.071	0.119	10.85
3	5.00	150	19.1	4.75	0.083	0.167	11.62
Mean	5.00	150	18.5	4.78	0.072	0.145	10.89

3.4 Biomass Heating Source Performance Evaluation for TME 419

Table 4 presents the performance of the fryer when biomass was used as the heat source for TME 419. Frying required an average of 26.0 min, which was longer than under electrical heating because biomass produces less stable heat. The average garri yield was 4.68 kg with an average scorched weight of 0.088 kg. Average weight loss increased to 0.232 kg, while moisture content averaged 11.31%. Although biomass heating required more processing time, the fryer still produced acceptable-quality garri with minimal scorching and moisture content suitable for storage.

Table 4. Performance Evaluation of TME 419 using Biomass Heating Source

S/No.	Wt of mash (kg)	Temp (°C)	Time (min)	Wt of garri (kg)	Wt scorched (kg)	Wt loss (kg)	M.C. (%)
1	5.00	150	25.4	4.68	0.081	0.239	10.95
2	5.00	150	26.2	4.71	0.089	0.201	11.40
3	5.00	150	26.5	4.65	0.095	0.255	11.58
Mean	5.00	150	26.0	4.68	0.088	0.232	11.31

3.5 Electrical Source Performance Evaluation for TMS 30572

Table 5 presents the performance evaluation of TMS 30572 using electrical heating. This variety recorded the shortest frying time (17.0 min) among the three cassava varieties. The average garri yield was 4.90 kg with only 0.031 kg scorched material. Weight loss averaged 0.069 kg, while moisture content averaged 9.85%. These results indicate that TMS 30572 responded favorably to electrical heating, producing the highest product recovery and lowest material losses. The lower moisture content of the raw mash contributed to the shorter frying time and improved efficiency.

Table 5. Performance Evaluation of TMS 30572 using Electrical Heating Source

S/No.	Wt of mash (kg)	Temp (°C)	Time (min)	Wt of garri (kg)	Wt scorched (kg)	Wt loss (kg)	M.C. (%)
1	5.00	150	16.5	4.90	0.031	0.069	9.62
2	5.00	150	17.2	4.92	0.028	0.052	9.88
3	5.00	150	17.4	4.88	0.035	0.085	10.05
Mean	5.00	150	17.0	4.90	0.031	0.069	9.85

3.6 Biomass Heating Source Performance Evaluation for TMS 30572

Table 6 is the performance of TMS 30572 under biomass heating. Average frying time increased to 24.5 min when compared to electrical heating. Nevertheless, average garri yield remained high at 4.82 kg, while scorched material averaged only 0.041 kg. Moisture content averaged approximately 10.53%, and remained within acceptable storage limits. These findings demonstrate that although biomass heating prolonged frying, product quality remained satisfactory.

Table 6. Performance Evaluation of TMS 30572 using Biomass Heating Source

S/No.	Wt of mash (kg)	Temp (°C)	Time (min)	Wt of garri (kg)	Wt scorched (kg)	Wt loss (kg)	M.C. (%)
1	5.00	150	23.9	4.82	0.041	0.139	10.30
2	5.00	150	24.7	4.85	0.038	0.112	10.55
3	5.00	150	25.0	4.80	0.045	0.155	10.75

3.7 Electrical Heating Source Performance Evaluation for TMS 98/0505

Table 7 presents the performance evaluation of TMS 98/0505 using electrical heating. The average frying time was 20.2 min, which was longer than that of TMS 30572 because of the relatively higher initial moisture content of the mash. The average garri yield obtained was 4.71 kg with an average scorched weight of 0.103 kg. Weight loss averaged 0.187 kg, while moisture content averaged 9.92%. Despite the relatively longer frying time, electrical heating continued to have a stable operating conditions that minimized excessive scorching and produced garri of acceptable moisture content.

Table 7. Performance Evaluation of TMS 98/0505 using Electrical Heating Source

S/No.	Wt of mash (kg)	Temp (°C)	Time (min)	Wt of garri (kg)	Wt scorched (kg)	Wt loss (kg)	M.C. (%)
1	5.00	150	19.8	4.71	0.098	0.192	9.75
2	5.00	150	20.3	4.74	0.102	0.158	9.90
3	5.00	150	20.6	4.68	0.108	0.212	10.10
Mean	5.00	150	20.2	4.71	0.103	0.187	9.92

3.8 Biomass Heating Source Performance Evaluation for TMS 98/0505

Table 8 shows the performance of TMS 98/0505 using biomass heating. The average frying time increased to 28.8 min, representing the longest frying duration among all treatments. Average garri yield was 4.60 kg, with average scorched material of 0.123 kg and weight loss of 0.277 kg. Final moisture content averaged 11.10%, remaining within the acceptable range for safe storage. The results indicate that biomass heating was effective but required longer processing time and resulted in slightly higher material losses than electrical heating because of fluctuations in heat intensity.

Table 8. Performance Evaluation of TMS 98/0505 using Biomass Heating Source

S/No.	Wt of mash (kg)	Temp (°C)	Time (min)	Wt of garri (kg)	Wt scorched (kg)	Wt loss (kg)	M.C. (%)
1	5.00	150	28.3	4.60	0.118	0.282	10.85
2	5.00	150	29.0	4.63	0.121	0.249	11.10
3	5.00	150	29.1	4.57	0.129	0.301	11.35
Mean	5.00	150	28.8	4.60	0.123	0.277	11.10

3.9 Result of the Two-Way ANOVA

Table 9 presents the two-way ANOVA results (analyzed using SPSS Version 26) for the dual-powered garri fryer experiment. The dependent variables include weight of cassava mash, frying time, weight of well-fried garri, weight of scorched garri, weight loss, and moisture content. The results show that cassava variety had a significant effect on the weight of well-fried garri at $p = 0.004$, weight of scorched garri at $p = 0.002$, and moisture content at $p = 0.000$; this is consistent with the varietal effects on garri quality reported by Aturamu et al. (2021) and Ganiyu and Oyebamiji (2025). The source of heat had a significant effect on moisture content at $p = 0.000$ and frying time at $p = 0.031$; this agrees with the report of Sobarasua et al. (2024) on the influence of the source of heat on cassava roasting parameters. The interaction between variety and heating source was significant for moisture content at $p = 0.000$, which suggests that both factors should be jointly considered in the design and operation of garri frying equipment.

Table 9. Two-Way ANOVA Result

Source	Dependent Variable	Sum of Sq.	DF	Mean Sq.	F	Sig.
Variety	Wt of well-fried garri	0.098	2	0.049	9.845	0.004
Variety	Wt of scorched	0.006	2	0.003	13.210	0.002

	garri					
Variety	Frying time	1.840	2	0.920	2.015	0.180
Variety	Moisture content	2.870	2	1.435	6812450 .500	0.000
Heating source	Wt of well-fried garri	0.005	1	0.005	1.120	0.315
Heating source	Frying time	62.410	1	62.410	6.980	0.031
Heating source	Moisture content	0.014	1	0.014	61042.3 00	0.000
Variety*Heating source	Wt of well-fried garri	0.021	2	0.011	2.240	0.155
Variety*Heating source	Moisture content	0.011	2	0.006	28510.6 00	0.000

a $R^2 = 1.000$ (Adjusted $R^2 = 1.000$) for moisture content; other dependent variables had R^2 values ranging from 0.31 to 0.87.

3.10 Overall Performance Summary

The performance of the dual-powered garri fryer was evaluated with the data from the experimental test. The results are summarized in Tables 1-9. The fryer had an average frying capacity of 0.81 kg/min and an average frying efficiency of 96.14% under electric power, while it had 0.58 kg/min and 94.87% under biomass power. It had low scorching and mechanical damage, which ranged from 0.42% to 2.35%. Performance was consistent across the three cassava varieties tested. TMS 30572 exhibited the least variation in frying capacity and efficiency, while TME 419, with the highest raw moisture content, required a slightly longer frying time for both heat sources.

When compared to the traditional open frying method, which has a capacity of 0.20 kg/min at an efficiency of 80% (Ejonobo, 2024), the dual-powered fryer performed three (3) times better. This improvement is in line with the improvements reported by Onyenanu et al. (2025), whose semi-automated garri frying machine achieved 97.8% efficiency and a 28-minute batch time using an LPG burner and mechanized stirring.

4. CONCLUSION

This study investigated the design, development, and performance evaluation of a dual-powered garri fryer using both electrical and biomass heating sources. The results showed that the fryer achieved high frying efficiencies (93.42%-97.85%) with minimal scorching and weight loss across the three cassava varieties tested. Cassava variety and heating source both had significant effects on frying performance, and the interaction between the two factors significantly influenced moisture content. Results showed that the moisture content of the garri produced was within the acceptable range for storage. Overall, the dual-powered garri fryer had a substantial improvement in throughput and efficiency over the traditional open-pan frying method, while it also offers the flexibility of switching between electricity and biomass depending on availability and cost.

The dual-powered garri fryer was successfully designed, fabricated and evaluated for small-scale cassava processing. It was fabricated to use electrical and biomass heating systems interchangeably. The machine achieved frying efficiencies that ranged between 93.42% and 97.85%, with low scorching. The machine produced garri that had acceptable moisture

content and improved frying capacity when compared with the traditional open-pan method. Electrical heating provided shorter frying time, higher frying efficiency and lower weight loss than biomass heating, although biomass remained a practical alternative where electricity is unavailable. Statistical analysis further showed that cassava variety significantly influenced garri yield, scorching and moisture content, while heating source significantly affected frying time and moisture content. The developed fryer therefore provides an efficient, flexible and economically viable technology capable of improving productivity, product quality and energy sustainability for small-scale garri processors.

ACKNOWLEDGEMENT

The author acknowledges the students and technical staff of the Agricultural Technology Department of Federal College of Forestry, Ibadan for support with machine performance tests.

CONFLICT OF INTEREST

There is no conflict of interest on the article.

REFERENCES

- Abasilim, C. F., Balogun, O. L. and Adeyemi, A. A. (2019). Analysis of the profitability and credit accessibility among garri processors in Epe, Lagos State, Nigeria. *Global Journal of Agricultural Sciences*, 18(1):57-71.
- Ali, O. A., Saturday, A., Nathaniel, O. E., Ifeanyi, A. A., Ajagun, E. G. and Oluwatomi, K. (2017). Gelatinization and Frying Temperatures Stabilization of a 'Garri' Frying Machine Using a PID Microcontroller-Matlab-Simulink. *Scholars Journal of Engineering and Technology (SJET)*, 5(6):295-306.
- Anikwe, M. A. and Ikenganyia, E. E. (2018). Ecophysiology and production principles of cassava (*Manihot* species) in Southeastern Nigeria. In: *Cassava*. IntechOpen.
- Aturamu, O. A., Akinbola, A. E., Omosehin, O. O. and Oguntuase, D. T. (2021). Analysis of Profitability and Market Outlets of Smallholder Garri Producers in Ondo State, Nigeria. *Asian Journal of Economics, Business and Accounting*, 21(6):82-91.
- Ejonobo, J. O. (2024). Design and Fabrication of an Improved Garri Frying Machine. *Journal of Applied Sciences and Environmental Management*, 28(10).
- Esheye, S. E. (2021). Economic analyses of gari processing in Ebonyi State, Nigeria. *Nigeria Agricultural Journal*, 52:237-241.
- FAO (2022). FAOSTAT Statistical Database. Food and Agriculture Organization of the United Nations, Rome.
- Ganiyu, M. O. and Oyebamiji, I. T. (2025). Analysis of Resources Utilization for Cassava Flake (Garri) Processing in Ogbomoso ADP Zone, Oyo State Nigeria. *Research Journal of Botany*, 20(1):7-13.
- IEA (2020). Renewable Energy Market Analysis: Developing Countries. International Energy Agency, Paris.

- Ikuemonisan, E. S., Mafimisebi, T. E., Ajibefun, I. and Adenegan, K. (2020). Cassava production in Nigeria: Trends, instability and decomposition analysis (1970-2018). *Heliyon*, 6(10):e05089.
- Khurmi, R. S. and Gupta, J. K. (2019). *Machine Design*. Eurasia Publishing House, New Delhi.
- Nwadinobi, C. P., Okonkwo, U. C. and Okafor, C. E. (2019). Design and Development of a Vertical Paddle Semi-Automated Garri Frying Machine. *ResearchGate*.
- Okokpuije, I. P., Samuel, A. U. and Fayomi, O. S. I. (2021). Sustainability of Garri Processing: A Case Study of Ogun State, Nigeria. *IOP Conference Series: Materials Science and Engineering*, 1107:012132.
- Oladipo, A. A., Olatidoye, O. P. and Dickson, D. O. (2025). Development of Cassava Frying Machine for Local Garri Processors. *IPS Journal of Nutrition and Food Science*, 4(1).
- Onu, U. G., Jack, K. E. and Nwangwu, E. O. (2020). Design of Garri Frying Machine with User-defined Temperature Regulation and Motion Control System. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 8(8):1584-1589.
- Onyediako, P. O. and Adiele, J. G. (2022). Enhanced cassava production for food security and economic development in Nigeria: A review. *Nigerian Agricultural Journal*, 53:204-211.
- Onyenanu, I. U., Madukasi, A. H. and Madu, K. (2025). Design and Fabrication of a Semi-Automated Garri Frying Machine: Enhancing Efficiency, Safety, and Quality in Cassava Processing. *NIPES Journal of Science and Technology Research*, 7(3).
- Samuel, J. and Obeta, J. C. (2014). Moisture Sorption Behavior and Mould Ecology of Trade Garri Sold in South Eastern Nigeria. *International Journal of Food Science*, 2014:218959.
- Sobarasua, O. G., Onuche, I. F., Kuye, A. O., Diemuodeke, E. O., Muritala, I. K., Saturday, E. G., Okedu, K. E. and Kalam, A. (2024). Sustainable innovation for fermented cassava roasting: Examining the potential of parabolic dish solar collectors and thermal energy storage. *Heliyon*, 10(20):e39627.
- Vihi, S. K., Chomini, E. A., Tor, I. G., Jesse, A. A., Dalla, A. A., Bassey, E. A. and Owa, G. T. (2022). Factors influencing adoption of improved cassava-garri processing technologies among rural women in Vandeikya Local Government Area of Benue State, Nigeria. *FUDMA Journal of Agriculture and Agricultural Technology*, 8:177-188.