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# Development and Performance Evaluation of a Cassava Flour (Gari) Frying Machine

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**Abstract:** *In a world where poverty is paramount, and childhood malnutrition is a pandemic without much attention paid to it, cassava products, especially gari, have saved many households from starvation by providing the necessary nutritional needs. This research focuses on developing a machine to cook and dry gari (garification) for final consumption. The machine uses an electric heating element as the primary heat source and a charcoal stove as an alternative heat source. The gari is processed in a stainless steel chamber, where eccentrically positioned paddles ensure an even and homogeneity of the product. The machine developed has an operational efficiency and throughput capacity of 83% and 12.6 kghr-1, respectively. The machine developed will assist in mitigating the world's hunger crisis and provide employment in the food and beverage industry.*

**Keywords:** *Cassava, Drying, Efficiency, Gari, Garification, Machine, Throughput*

## INTRODUCTION

Agricultural products are gaining popularity recently, especially in developing countries such as Nigeria, due to economic diversification. This is due to the unpredictable price of crude oil in the global market and overdependence on crude oil for national survival (Ikuemonisan *et al.*, 2020; Oladebeye *et al.*, 2018; Ajayi and Olukunle, 2010). The popular agricultural products generated in Nigeria include maize, palm oil, tomato, onion, pepper, cocoa, yam, cassava, etc. Cassava (Manihot esculenta) is the fourth most staple food globally, especially in Africa, after rice, wheat, and maize (Adekunle *et al.*, 2018; Oti and Obi, 2018; Marcio, 2000). Nigeria is the world's largest producer of cassava, and as of 2018, the country produces about 59.5 million tones per year (Ikuemonisan *et al.*, 2020). The cassava crop all over the world is currently shifting from a mere subsistence crop grown in peasant fields to a viable crop grown in large plantations. Cassava production has increased due to its low-cost source of edible carbohydrate that can be processed into various delicacies for human and animal feeds. A well-planned strategy for developing and utilizing cassava products can incentivize farmers, crop vendors, and food processors to increase their incomes. It can also provide food security for households producing and consuming cassava and cassava products.

Several local products have been derived from cassava: flour (gari), fufu, chips/pellets, and lafun. However, some industrial products like starch and alcohol have also been derived from cassava (Adekunle et al., 2018; Oti and Obi, 2018; Marcio, 2000) as major agricultural products. Cassava and its derivatives, such as Gari and starch, are found in the daily meals of West African people and other developing nationals. Gari has a slightly fermented flavor and a creamy-white flour appearance (Oladebeye *et al.,* 2018). In the developing world, especially West Africa, there are several ways Gari can be prepared for a meal. It can be soaked in hot water to make a meal called "Eba," which is taken along with soup, depending on an individual's choice. It can also be soaked in cold water for drinking.

The processing of cassava into its finished products takes several tedious steps. According to Ajayi and Olukunle, (2018), Oti and Obi, (2018), the processing techniques of cassava into gari involve peeling, washing, grafting, fermenting, dewatering, sifting, and simultaneous drying and cooking (Codexs, 2019; Olaniran and Adeleke, 2018; Adetunji et al., 2013; Adegun et al., 2011; Ajao and Adegun, 2009; Odigboh and Ahmed, 1984). Several mechanized machines have been developed to enhance gari's production process and minimize the stress and energy wastage in the production of the consumable. The most critical unit operation that determines the quality of the final product in gari production is the frying operation (garification). Garification involves repetitively pressing, scrapping, and stirring sifted cassava mash over a hot plate at 120 to 200 ºC. Heat transfer from the hot plate results in the toasting of the gari particles, while starch pressed out from the granules coats the gari particles and is partially gelatinized to form an enveloping tin film. In garification, machines have been designed but have not entirely given satisfactory performance and efficiency. In a survey carried out by Davies *et al.,* (2008), more than 40% of machines in the small-scale gari processing industries have been abandoned due to high operational and maintenance costs, the inexperience of the users, and scarcity of spare parts.

Oti and Obi, (2018) developed a garification machine that dries and cooks gari simultaneously. The machine was developed using an agitator and crankshaft mechanism. The garification chamber was made of a U-shaped trough, and the machine heat source was a charcoal stove. The efficiency and operating capacity of the machine are 93.57% and 17.30 kghr-1, respectively. Although this efficiency and capacity are an outstanding achievement, the entire design of the machine is cumbersome and not easily maintained. Therefore, it is unsuitable for rural users, where most gari products are processed. Ajayi and Olukunle, (2010) also developed a gari frying machine, which uses an auger conveyor mechanism to ensure homogenous frying of the gari. The conveyor was powered by a three-phase 1.5 kW electric motor at 20-100 rpm. The machine's efficiency was 71.4% and had a frying capacity of 20.4 kghr-1. The machine's performance was low; therefore, an improved version would be advantageous. Olayanju *et al.,* (2018) developed a gari fryer, which could process gari at 6.6 kghr-1 and an efficiency of 75%. The machine developed burns natural gas as a primary heat source and charcoal as an alternative heat source, and the gari is fried in a pan and stirred manually. Nwadinobi *et al.,* (2019) developed a semi-automatic gari fryer and obtained a throughput capacity of 20.66 kghr-1 and an efficiency of 66%. The machine uses an electric heating element as a heat source and charcoal as an alternative heat source. This machine is similar to the one developed in this article but with lower efficiency. In achieving a stone-free gari, Adegun *et al.,* (2011) mechanized the whole gari processing procedure using locally fabricated materials, and overall efficiency of 82% was reported for the machine. Due to the complex design, the earlier designed and fabricated machines are associated with high operational and maintenance costs. The scarcity of machine parts had led to an unnecessary breakdown of garification machines. Therefore, this study aimed to develop a garification machine and objectively improve and eliminate the challenges associated with previously developed machines. The study ensured simple design, efficiency, easy maintenance, and lesser upkeep costs.

## MATERIALS AND METHODS

### 2.1 Materials

The materials used in this study include stainless steel, mild steel, cast iron, heat element, charcoal, electric motor, temperature controller, copper windings, bolts, and nuts. These materials were sources from Oko-Erin, Ilorin, Kwara State.

### 2.1 Methods

The step-by-step methods adopted in the design, construction, and performance evaluation of the cassava flour frying machine are discussed in this section.

#### 2.2.1 Design consideration

The essential factors considered in the design and construction of the cassava frying machine include the following:

*Cost:* the design and construction of the machine must be affordable.

*Availability of Material and Part:* the machine was constructed using locally available materials to replace the part quickly.

*Working Temperature:* The working temperature was regulated using a temperature controller to avoid caking and burning the flour and ensure that the heating was uniform.

*Assembly Method:* A semi-permanent assembly technique was adopted for easy coupling and maintenance of the machine.

*Agitation:* Adequate agitation process ensured for pressing and breaking of the lumps formed during garification.

*Heating Methods:* A dual heating method was considered using charcoal and electric heating methods.

*The Capacity of the Machine:* the amount of gari the machine can produce at a given time.

*Ergonomics:* the comfort, safety, and health of the operator were considered in the design and construction of the machine- proper insulation, smooth finishing, and use of an electric motor for the turning process.

#### 2.2.2 Design calculation

*Frying chamber*

The garification chamber is a pan that can process 0.015 $m^3$ volume of gari at a batch; it has a height of 75 mm and a diameter of 500 mm. It is fabricated using stainless steel due to its exceptional corrosion resistance and high resistance to wear. It is the specified metal material used in the food industry, where the food will contact the metal. The volume of the frying chamber can be obtained using Equation 1 (Adekunle et al., 2019).

$$V = \pi r^2 h \quad (1)$$

where,
V = volume of the frying chamber
r = radius of the frying chamber (0.250 m)
h = height of the frying chamber (0.075 m).
Therefore,
$V = 0.015\ m^3$

*Determination of the Weight of Gari in the Frying Chamber*
The maximum weight of gari in the frying chamber for single batch of production is calculated using Equation 2.

$$W = m \times g;\ m = \rho / v \quad (2)$$

where, $\rho$ = Density of gari (1509 $kg/m^3$ ) (Sanni et al., 2009),
$m$ = mass of gari
$v$ = volume of the frying chamber ( 0.015 $m^3$)
W = weight of gari
g = acceleration due to gravity (9.81 $m/s^2$)
By compution,
W = 218 $N$

*Heat required for the Frying*
The heat required for garification is calculated using Equation 3.

$$Q = MC\Delta T \quad (3)$$

where,
Q = quantity of heat required
M = mass of cassava mash in the cylinder (22.22 $kg$)
C = specific heat capacity of cassava mash (1.598 J/kgoC)
ΔT = temperature change (60 °C).
Therefore,
Q =2098.8 W

*Frying Time*
The time required for frying 218 $N$ of cassava flour is calculated using Equations 4-6.

$$\Delta Q = KA((T_2 - T_1)/L) \quad (4)$$

$$\Delta t = (\Delta ML_h)/Qt \quad (5)$$

$$A = 2\pi rh + 2\pi r^2 \quad (6)$$

where,
ΔQ = rate of heat transfer
K = Thermal conductivity of mash (0.2)
S = surface area of the cylinder
$T_1$= Frying temperature (60 °C)
$T_2$ = ambient temperature (30 °C)
L = thickness of the mash in the cylinder (0.05 m)
A is the area of the frying chamber (1.964 $m^2$)
r = radius of the frying chamber (0.250 m)
h = height of the frying chamber (0.075 m)
$L_h$ = latent heat of transformation, and
Δt = frying time.
By computation,
Δt = 8.9 s.

*Power required Conveying the Mash*

The power required for conveying the cassava flour is calculated using Equations 7-11.

$P = W/(\Delta t)$ (7)

$W = \sum Fx$ (8)

$Fx = Ma$ (9)

$a = \Delta V/\Delta t$; $V = x/t$ (10)

$Fr = Mn$

$N = Mg$ (11)

where,

P = power required to convey the cassava flour

W= work done in conveying the flour (112.54 Nm)

$\Delta t$ = frying time

$\sum F$ = sum of the forces involved in doing work (101.94N)

m =mass of the cassava mash

a = acceleration of the flour (0.023 $m/s^2$)

$\Delta v$ = velocity of the flour (0.21 m/s)

$\Delta t$ = frying time

x = distance covered by the cassava flour

t = time taken to cover the distance

$\mu$ = coefficient friction (0.47)

N = normal force acting on the cassava four (215.82 n)

Fr = frictional force (101.43 N)

and g = acceleration due to gravity (9.81m/S^2).

Therefore,

P = 12.5 watts

The torque due to the electric motor's power is calculated using Equation 12.

$T = P/w$ (12)

where,

w is the angular velocity (4.2 rad)

T = torque

and P = power.

By computation

T = 2.97 Nm

*Gear Design*

A spur gear was used in transmitting power from the electric motor to the paddles. The speed of the gear and power are calculated using equations 13 and 14, respectively.

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (13)$$

$$P = \frac{2\pi N_2 T}{60} \quad (14)$$

### 2.2.3 Determination of the moisture content of the gari lump

The moisture content of the gari lump was determined using a moisture analyzer (model: PMC 50/1). One gram of gari lump was placed in the moisture analyzer for analysis. The percentage moisture content was displayed on the screen at the end of the analysis.

## 2.3 Fabrication and Assembly of the Machine

The garification machine consists of the parts listed in Table 1, and the primary heat source is an electric element and a charcoal stove as an alternative heat source. The electric element was adopted as the primary heat source to provide a more sustainable source of power, as charcoal is discouraged due to the carbon footprint it presents to the surroundings. In addition, an electric element was used to reduce deforestation and land erosion resulting from the falling of forest trees for charcoal production. Gari lumps containing 45-60 wb% moisture are charged into the cooking pan. The gari is continuously stirred with the paddles, powered by a 1 HP electric motor (adopted based on the specification of the electric motor available in the market) rotating at 20 rpm to achieve even distribution of heat, uniform gain size, and ensure the gari is adequately cooked. The electric motor is bolted to the motor base and is oriented upwards. Gears connect the rotating shaft and paddle to the electric motor. The motor base is welded to the machine's body frame, maintaining a height of 310 mm between the cooking pan and the electric motor. The cooking pan has a diameter of 500 mm and is located beneath the paddle. The charcoal chamber is beneath the cooking pan. To prevent heat loss and conduction through the machine's body, the space between the inner wall of the frying pan and mild steel is insulated with fiberglass. The system is surrounded by the body base stand that extends from the frying pan's edge. Inside the base stand, a thermocouple senses the temperature and relays it to the temperature gauge on the control panel. The temperature control panel is located on the machine's right side for ease of use. The exhaust pipe/chimney is located on the left-hand side of the machine, where it releases smoke into the atmosphere. Figure 1a shows the isometric view of the machine, while Figure 1b shows a section of the machine to reveal the electric heating element. Figure 2 shows the schematic of the gears and paddles, while figure 3 shows the pictorial representation of the fabricated machine.

### 2.3.1 Paddle

The rotating paddle in Fig. 2 is fabricated from stainless steel material. It is attached to the shaft, driven by a gear mounted, and driven by another gear attached to the electric motor. The shaft is 480 mm long with a radius of 120 mm. Four paddles of length 130 mm were attached to the shaft such that they were turned eccentrically. Figure 2 shows the schematics of the design and setup of the gears and paddles.

### 2.3.2 Exhaust Chimney/Vent

The exhaust pipe takes away the smoke produced in the charcoal chamber or wood combustion during the frying operation. It has its inlet/suction port located at the side of the frying chamber of the blower, and it is made from mild steel. It has a length of 700 mm and a radius of 7.5 mm.

### 2.3.3 Discharge Port

As shown in Fig.1, the discharge port is located at the front of the garification pan's base. The discharge chute is raised when a specific batch of cassava mash is garified. As the paddle rotates, the gari discharges, and a new batch of cassava mash is introduced into the garification pan.

### 2.3.4 Electrical Components

The electrical components are carefully chosen to perform the specific function of the design goal. Electrical components such as a regulator, heating element, thermocouple, thermostat, electric motor, and wire connection are used to achieve the machine's electrical design goal. For maximum efficiency, high-quality types are used.

Copper wires are commonly used for wired connections because of their high conductivity, durability, and low cost. The on/off switch and temperature gauge are external components.

Table-1 Machine parts and materials

| S/N | Parts | Materials used | Justification |
|---|---|---|---|
| 1 | Garification pan/chamber | Stainless steel | Good corrosion resistance, availability |
| 2 | Discharge port | Stainless steel | Good corrosion resistance |
| 3 | Motor frame | Mild steel | Lower cost, good strength |
| 4 | Electric motor | Cast iron with windings | Manufacturer specification, availability |
| 5 | Bolts | Mild steel | Manufacturer specification |
| 6 | Bearings | Cast iron | Manufacturer specification |
| 7 | Frame support | Mild steel | Lower cost, good strength, availability |
| 8 | Lagging/insulating material | Fibreglass | Good heat resistance/insulator |
| 9 | Paddle and shaft | Stainless steel | Good corrosion resistance/strength |
| 10 | Gears | Cast iron | Manufacturer specification |
| 12 | Exhaust pipe/chimney | Mild steel | Lower cost, good strength, availability |
| 13 | Charcoal chamber | Cast iron | Lower cost, a good conductor |

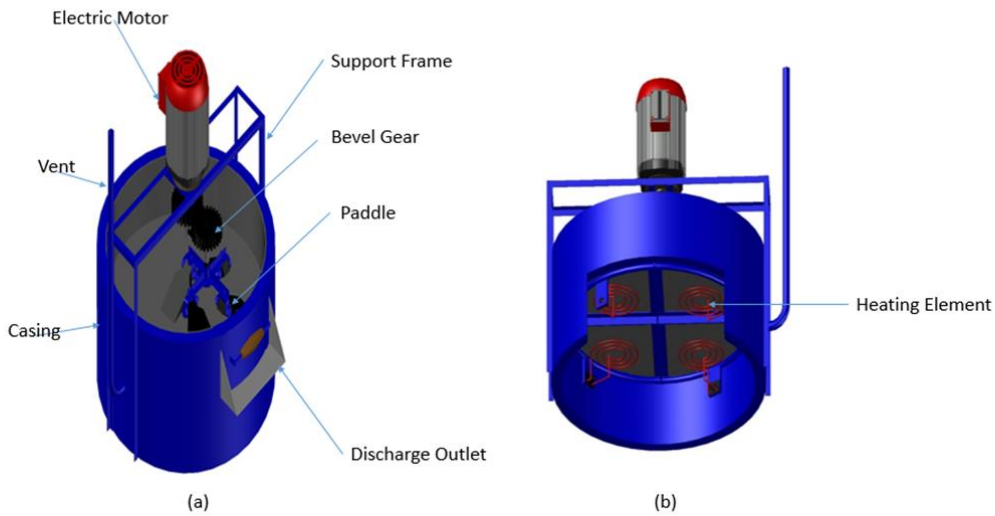


Fig.1 (a) Isometric view of garification machine (b) Bottom view of garification machine

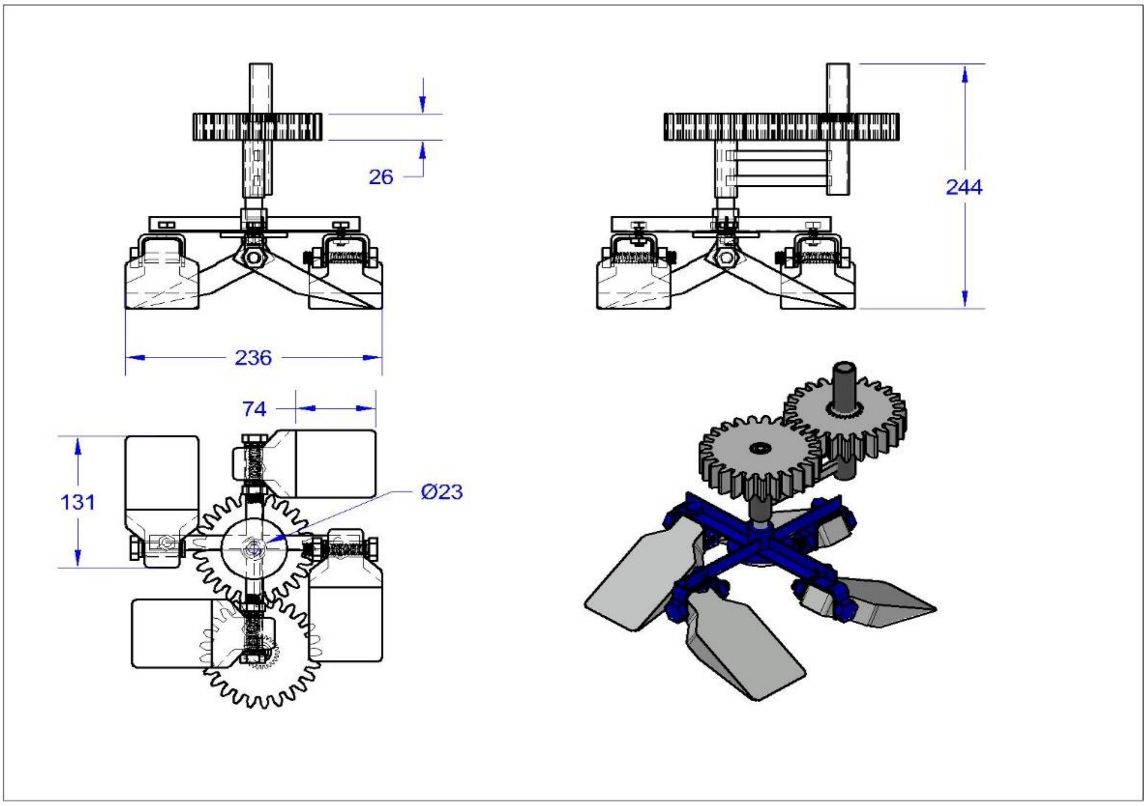


Fig. 2 Schematics of gears and paddles

Fig. 3 Pictorial representation of the fabricated machine

## 2.4 Performance Evaluation of the Machine

The machine was tested for its performance by accessing the performance of the machine's throughput and functional efficiency using equations 15 and 16. However, the machine's efficiency can also be calculated in terms of the time taken for garification. According to Oti et *al.* (2010), the average time taken for the garification process is twenty minutes but might differ with different heat sources and heat intensity. The efficiency of the produced machine in terms of time taken to garify is shown in equation 17.

$$T_p = \frac{M_0}{\nabla t} \times 100 \qquad (15)$$

$$O_p = \frac{M_0}{M_i} \times 100 \qquad (16)$$

$$\eta = \frac{T_0}{T_i} \times 100 \qquad (17)$$

where,
$T_p$ is the throughput efficiency
$M_0$ is the final mass of gari after cooking
$\nabla t$ is the frying time
$M_i$ is the initial mass of gari mash
$O_p$ is the operational efficiency
$\eta$ is the machine's efficiency using garification time
$T_0$ is the time the machine takes for garification, and
$T_i$ is the standard time for garification.

# RESULTS AND DISCUSSION

After carrying out the necessary test, the machine performed satisfactorily. Its final product conforms to all standards, such as Codex, (2019) and the Nigerian Industrial Standard, (1983), with an average grain size of 2 mm. The garification chamber has a volume of 0.015 m3, and it can handle gari with a mass of 22 kg per batch as calculated using equations 1 and 2.

## 3.1 The Efficiency of the Machine

Fig. 4 shows the relationship between mashed gari added during cooking against time. Masses of gari at the rate of 2 kg were added every ten minutes to avoid lumps, as done by Ajayi *et al.* (2014). The throughput capacity of the machine is 12.6 kghr-1 as calculated using equation 15. Fig. 4 further shows that the higher the volume of gari required to be dried, the higher the time necessary. The machine's operational efficiency is calculated from the 42 kg mass of gari cooked, which was reduced to 35.16 kg, giving an operating efficiency of 83% as calculated using equation 16. Furthermore, the operational efficiency in terms of time is calculated using the average time to garify 2 kg of gari, which is ten (10) minutes, against the standard time of twenty (20) minutes, to give a 50% efficiency.

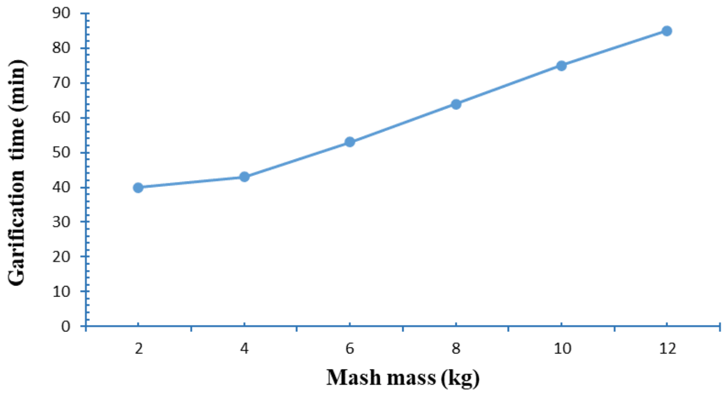

Fig. 4 Relationship between garification time and gari mash

### 3.2 Effect of charcoal on the Cooking of Gari

Three different masses of charcoal (3 kg, 5 kg, and 7 kg) were used separately to fry the same mass of cassava mash (10 kg) of 45 wb% initial moisture content. The final moisture content was 16.2%, 12.4%, and 9.2%. This shows that the heat intensity was low during the garification when 3kg charcoal was used. The gari particles could not gelatinize. When 7 kg charcoal was used, the gari developed lumps and burnt due to excessive heat. The 5 kg charcoal was found to be adequate from visual inspection. The optimum heat required for proper cooking of gari is 3006 kJ as calculated using equation 3.

## CONTRIBUTION TO KNOWLEDGE

The design and fabrication of a gari-producing machine have been done in this research. The machine's efficiency has been improved over other machines existing in works of literature. Furthermore, electric heating elements have been incorporated to help reduce carbon emissions.

## CONCLUSION

The design and fabrication of a garification machine with improved performance over previously fabricated machines will undoubtedly improve the economy and increase food security. The machine developed has an operational efficiency of 83% and a throughput efficiency of 12.6 kghr-1. The machine can work efficiently using the two heat sources, the charcoal stove and the electric heating element.

## CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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