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Effect of Modifying Traditional Heat Source on Garifying Time and Particle Composition of Gari Grains

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ABSTRACT: Obtaining gari grain that is comparable with that obtained using traditional garifying method but at a reduced time besides eliminating inherent drudgery in the garifying process is the focus of this research. To investigate, this research modified the traditional woodfire with a 3600 watts electric heating element and incorporated a motorized turner. Test was conducted with mash samples of 1 to 4kg in increment of 0.5kg at varied speeds on the modified garifier. Data on temperature and garifying time on masses fed into the garifier was collected using temperature meter and stop watch while data on particle composition of the garified sample with respect to the varied speeds was isolated in a sieve analysis and compared with those of traditional woodfire method. Data collected was analyzed using two tail t-test and analysis of variance (Anova). Result showed no significant difference on garifying time and particle size distribution between the modified garifier and woodfire with equal masses fed at lower turning speed of 30rpm. However, at higher turning speed of 90rpm, there was a significant difference in time and particle size composition in both cases. A lower shaft speed was recommended and redoubling of the components in series to obtain advantage of throughput capacity over wood fire at equal time.

KEYWORDS: Gari heating element, Garifying time, Particle composition, Turning speed

I. INTRODUCTION

Garri is a creamy white granular product of garified cassava mash and as reported by [1], it has a slightly fermented flavour and a slightly sour taste. It is consumed in several ways and fortified with supplements of the consumer's interest. Garri is the most popular of the Cassava end products in Africa [2,3]. The method of preparing garri involves peeling of the root, washing and grating. The resultant pulp is put in a porous sack and placed under a load. The dewatered and fermented lump is pulverized, sifted and the resulting semi dried mash is garified in a pan.

The final product obtained from the traditional method of garifrying are regarded by many locals as not too hygienic, because of the crude method involving the use of shallow-cast iron pan over woodfire and also the use of calabash section as a tool for vigorously pressing and turning of the sieved mash against the hot surface of the garifying pan while sitting awkwardly by the fireplace [4,5,6,7].

The traditional method of garifrying is the dominant in the rural communities of cassava producing states in Nigeria. The method comes with its peculiar challenges such as heat and uncontrollable smoke emanating from the wood fire, distress from sitting posture and from manipulation of the mash with calabash section [8,9]. On the other hand, the throughput capacity of the traditional technique is very low, while energy spent is very high besides contributing to deforestation [10]. Even with various improvements and modifications, researchers are of the view that the process is still labour intensive and time consuming [11,6].

Although the traditional method of garification is characterized by some level of discomfort, the procedure and skill displayed during the garification process cannot be overlooked by any mechanized effort. Disregard of the traditional skill and not taking into account the specifications of the existing technology has continually led to less efficient design and inability to produce a generally acceptable gari processing plants [1].

Noteworthy therefore, is the observation of [8], that the efficiency of gari frying is dependent on the skill of the operator and that merely stirring cassava mash over a fire could generate a product which may resemble garri but will not be acceptable to consumers.

II. REVIEW OF LITERATURE

Garrprocessors are looking forward to some technological advancement in development of garifying machine that will feed a specified quantity of cassava mash into a pan and by the push of a button, set the temperature, the timer, motor speed and discharge quality garri without any discomfort to the operator at a set time. This has been the driving force behind the effort of various researchers in attempt to mechanizing garifrying operation and some of these efforts have yielded result both from industry and higher institutions such as those of: Federal Institute of Industrial Research, Oshodi (FIIRO), RAIDS (Rural Agro- Industrial Development Scheme), University of Nigeria Nsukka (UNN) and UNIBADAN (University of Ibadan) all in Nigeria and a host of other [12,13].

Several others have also developed and applied quite a number of indigenous techniques in a bid to improve on the performance of garri fryers [14,15,16,17,13]. However, Garri processing in Nigeria is mostly accomplished using the traditional wood fire method as reported by [6],[18],[13] and [19]. Their findings generally revealed that limited number of mechanized garri processing plants available in Nigeria have the capacity to simulate the traditional method of garifrying to optimize the quality of garri produced for consumption in the country.

In the face of the global food crisis worsened by growing concerns of the COVID-19 pandemic, the need for improvement of existing garifrying machines is of essence. Hence, this research is carried out with the objective of developing a garifying machine incorporating modified heat source, determine if there is difference in garifying time with equal masses of dewatered cassava mash (DCM) fed and also in particle composition of gari grain of different masses of DCM fed into the garifier compared to those obtained using traditional method, determine favourable turning speed and ascertain the machine effectiveness in reducing drudgery in the garifying process.

2.1 Shaft Design

The shaft for turning and pressing masses of dewatered cassava mash (DCM) fed into the garifying pan was designed to transmit 1.5 KW of power from a motor at 120 rpm. Torque transmitted by the shaft was given by [20] as:

$$M_t = \frac{P \times 60}{2\pi N} \quad (1)$$

Where: M_t = Transmitted torque (Nmm)
P = Input motor power

The shaft is solid and made of mild steel. The diameter was designed based on AMSE code formula:

$$d^3 = \left(\frac{16}{\pi S_s}\right) \times \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \quad [20] \quad (2)$$

Where:
d = diameter of shaft (mm)
 M_t = Torsional moment (Nmm)
 M_b = bending moment (Nmm)
 k_b = combined shock and fatigue factor applied to bending moment
 k_t = combined shock and fatigue factor applied to torsional moment
 S_s = allowable stress N/mm²

$$M_t = \frac{P \times 60}{2\pi N} = \frac{1500 \times 60}{2\pi(120)} = 143 Nm = 143 \times 10^3 Nmm \quad (3)$$

The shaft was subjected to bending moment due to the weight of the turning and pressing bracket and the cassava mash. The garifying pan in which the shaft turns is of cylindrical shape of length 50cm and radius 20cm. Volume of cylinder $V_c = \pi r^2 L$ (4)

$$V_c = \pi \times (0.2)^2 \times 0.5 = 0.0628 m^3$$

It was considered that if dewatered cassava mash (DCM) occupy ¼ of this volume, then:

$$\text{mass of the DCM, } M_m = \rho V_m \quad (5)$$

Where: V_m = volume of DCM in the cylinder (mm³)
 ρ = bulk density of DCM (kg/mm³)

$$M_m = 709 \text{ kg/m}^3 \times 0.0157 \text{ m}^3 = 11 \text{ kg}$$

Load on shaft = $(M_{bs} + M_m)g = (2 + 11) 9.81 = 128 \text{ N}$



Where: M_{tb} = mass of turning and pressing bracket

The load on the shaft was treated as simply supported with maximum bending moment occurring at $M_b = \frac{WL}{4}$ (6)

$$= \frac{128 \times 500}{4} = 15,696 Nmm$$

$$d^3 = \left(\frac{16}{\pi 56}\right) \times \sqrt{(1.5 \times 15,696)^2 + (1 \times 143000)^2}$$

Shaft diameter $d = \sqrt[3]{13005} = 24mm$

2.11 Design of belt length

The shaft output speed was 90 rpm

Transmission ratio: $i = \frac{n_1}{n_2}$ (7)

$$= \frac{120}{90} = 1.3$$

Where n_1 = input speed, rpm, and n_2 = output speed, rpm

Standard pulley sizes used based on this transmission ratio were:

Input pulley $D_1 = 90$ mm and Output pulley $D_2 = 118$ mm

Belt speed (m/s) $V = \frac{D_1 \times n_1}{19100}$ [20] (8)

$$= \frac{90 \times 120}{19100} = 0.57m/s$$

The nominal range of centre distance c was determined from:

$$D_2 < C < 3(D_2 + D_1)$$
 (9)

Substituting the values, centre range = $118 < C < 624$

Specified centre to centre of pulley was 595mm

Belt length was determined from the relation:

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4c}$$
 [20] (10)

Where: L = trial belt length, C = centre to centre of pulleys 595mm

D_1 = input pulley diameter 90mm and D_2 = output pulley diameter 118mm

$$L = 2(595) + 1.57(208) + \frac{(28)^2}{4(595)}$$

$$L = 1190 + 327 + \frac{7.84}{2380}, L = 1517mm$$

The nearest standard belt length of 1525mm was specified.

2.12 Design of the electric heating element

The surface area of the garifying pan to be heated by the heating element, was give by

$$LW \text{ cm}^2$$
 (11)

where L = length of the pan and W = width of the pan (Circumference for cylindrical pan)

Available voltage $V = 230v$

A single wall outlet permits a maximum of 16A

Power $P(\text{watt}) = \text{Voltage } V(\text{volts}) \times \text{Ampere } I(\text{Amp}) = 230v \times 16A = 3680\text{watt}$

This means that the maximum heating element that can operate from a single outlet is rated 3680watts. Since the surface area to be heated is LW , for a W/cm^2 , the power needed to heat $LW\text{cm}^2$ is $LW(\text{watts})$. Two 1800w ring heating elements, 3600watt was used.

2.2 Analysis of response of cassava mash (heat transfer from the heating element)

The heating element was operated at a temperature t_1 , generating heat flow. This heat was transferred to cassava mash by conduction through the pan thickness t . The surface of the pan was at a temperature t_2 . The conductive heat transfer was expressed by Fourier's law

:

$$q = kA \frac{dT}{s}$$
 (12)

where: q = heat transfer (W), A = heat transfer area (m^2), k = thermal conductivity of the material ($\text{W}/\text{m}^\circ\text{C}$),



dT = temperature difference across the material (°C,) and s = material thickness (m) [21, 22]

From the relation, the temperature at the surface of the pan was obtained at time t₂ seconds

2.3 Heat Required for Drying

$$t_2 = \frac{qs}{kA} + t_1 \tag{13}$$

Heat loss by the heating element = heat gained or required for drying [23, 22]

$$VI t = MC\Delta T \tag{14}$$

Where V = voltage across the heating element circuit, I = current, t = time, M = mass of cassava mash in the pan

C = specific heat capacity of the mash and ΔT = temperature range

The time required for drying was estimated using equation (15) [12]

$$\frac{\Delta Q}{\Delta t} = KA \frac{(T_2 - T_1)}{S} \tag{15}$$

= heat rate of transfer, K = thermal conductivity of mash, A = surface area of cylindrical pan

T₁ = ambient temperature, T₂ = drying temperature and S = thickness of the mash in the pan

III. MATERIAL AND METHOD

The following were used to design and develop the motorized electrically fired garifying machine: electric motor with speed reducer, solid shaft, transmission belt, pulleys, electric heating element, thermocouple probe, temperature meter and the garifying pan.

3.1 Material construction and operation procedure

The garifier was made of galvanized pan formed into a semi-cylindrical shape, measuring 50cm x 40cm diameter. The turner and presser which served as the calabash section of the traditional garifier was made from a flat metal strip 6cm x 20cm welded together to form a rectangular section on the shaft. The electric heating elements was arranged and supported on a rectangular platform of metal frame work with four legs raising it to a height of 60cm from the ground. The garifying pan with its contents was screwed on to this platform such that the heat generated from the heating element was conducted to the pan from the bottom. The shaft 24 mm and carrying the turner lay symmetrically longitudinal at the bowel of the garifying pan. The turner and the presser are arranged along the shaft such that they can scrape the pan as they rotate and turn the cassava mash.

During operation, a sample cassava mash was weighed. The initial temperature of the pan and the mash was taken using the thermocouple probe. The temperature meter connected to electricity read 30°C. The electric heating element was then switched on and the heat was transferred to the pan by conduction. The weighed cassava mash was fed into the pan when the temperature meter read 45°C. At this time the motor speed, reduced to four test speeds of 90, 60, 30 and 10 rpm, by gear reducer was started. The motor connected to the shaft by the pulley and carrying the turning and pressing hand presses and lift the cassava mash as it rotates. Test was conducted on cassava mash of 1kg – 4kg in 0.5kg increment. The temperature meter connected to the thermocouple and the stop clock recorded the temperature change and time respectively. An optimum temperature for drying each sample and the corresponding time was recorded. The optimum temperature was a temperature beyond which the drying garri will burn rapidly. At this temperature the current to the heating element was cut off so that the garri dries with a falling temperature to preheat range and before reconnection is made for the next batch at a temperature monitored by the sensor, the sample in the pan was discharged through a slot at the bottom of the pan that is open at the point of discharge. The mass of dry garri discharged and time of discharge as well as temperature changes during the process were recorded. Figures 1 and 2 shows orthographic and isometric representation of the machine and Figure 3 shows the pictorial presentation of the constructed machine in operation.

Item	Description
1	Heating
2	Dry gari exit point
3	Batch t ransfer hopper
4	Gari turner and presser
5	Turner shaft
6	Bearing
7	Pulley
8	Transmission belt
9	Mash transfer guard
10	Gear reducer
11	Support
12	Insulator
13	Garifying pan
14	Element connector
15	Discharge guide
16	Electric motor

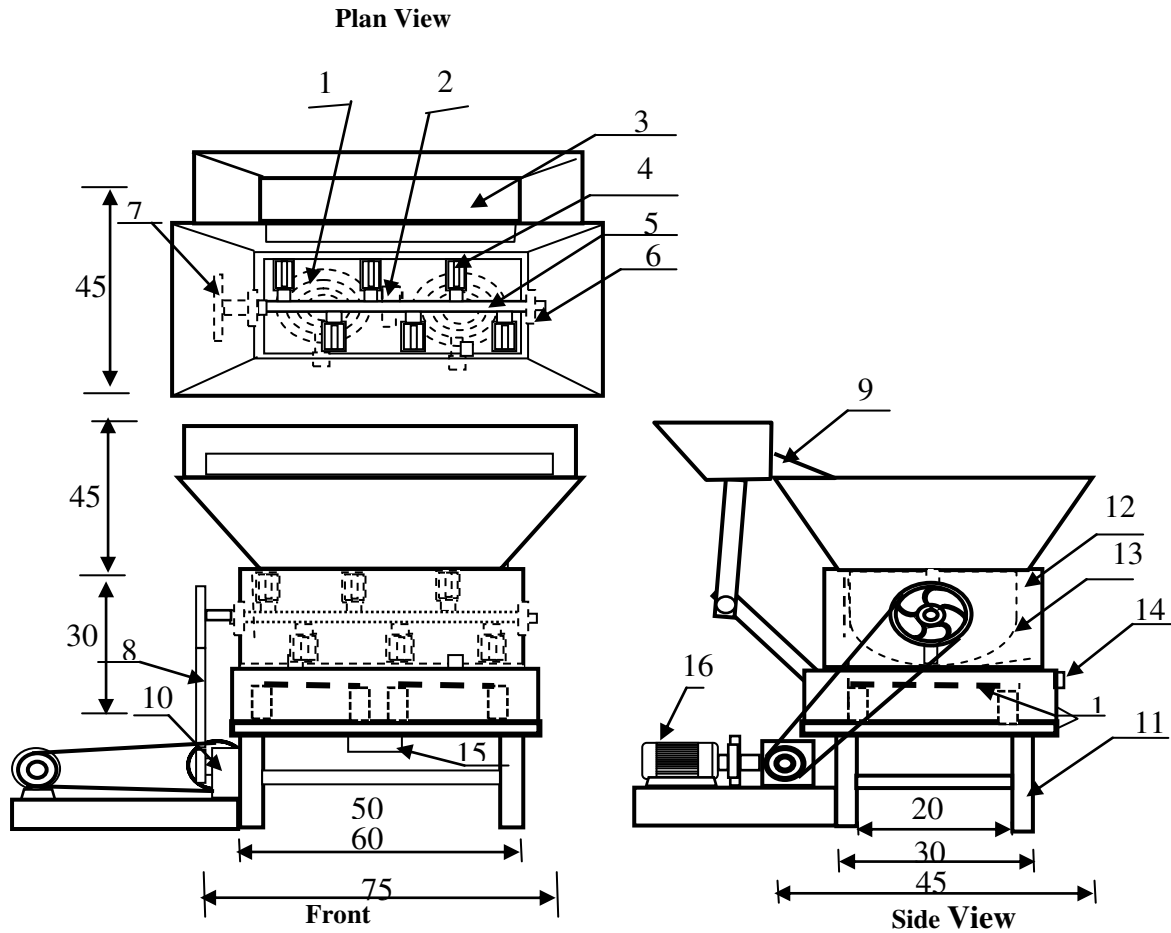


Fig. 1: Orthographic projection of the garfiar

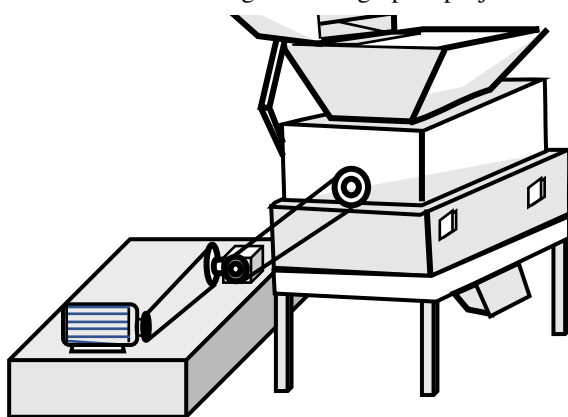


Fig. 2: Isometric representation of the garfiar



Fig. 3: The garfiing machine in operation

Also, the sample masses were garfied alongside the developed garfiar in a traditional setup of cast iron pan with calabash section and woodfire.

3.2 Evaluation of garfied sample and data analysis

Garfied sample from 2kg and 4kg batch from electrically fired heating element and wood fire as well as garfied sample from the four test motor speeds were fed into IS 460 Sethi standard test sieve of diameters 1.70, 1, 0.85, 0.35, 0.30, 0.20mm and pan and agitated for 10 minutes to determine particle size variation,



Data obtained from record of garifying time and particle size distribution was analysed using Excel data analysis for two tail t- test and analysis of variance (anova)

IV. RESULTS AND DISCUSSION

Table 1 shows the result of key measured parameter of the electrically fired garifying machine

Table 1: Summary of measured parameters of the electrically fired garifier

Batch size (kg)		Wt of moisture removed	Frying Time		Initial Temp.	Final Temp.	Frying Rate
wet	Fried	(kg)	min	seconds	Preheat(°C)	(°C)	Kg/s
1.0	0.62	0.38	14	840	45	85	4.5 x10 ⁻⁴
[1.5	0.93	0.57	16	960		90	5.9 x10 ⁻⁴
2.0	1.32	0.70	18	1080		96	6.5 x10 ⁻⁴
2.5	1.64	0.86	22	1320		99	6.6 x10 ⁻⁴
3.0	1.92	1.08	25	1500		105	7.2 x10 ⁻⁴
3.5	2.32	1.18	27	1600		116	7.4 x10 ⁻⁴
4.0	2.52	1.48	30	1800		120	8.2 x10 ⁻⁴

and figure 4 shows the relationship of the frying time and weight of moisture removed.

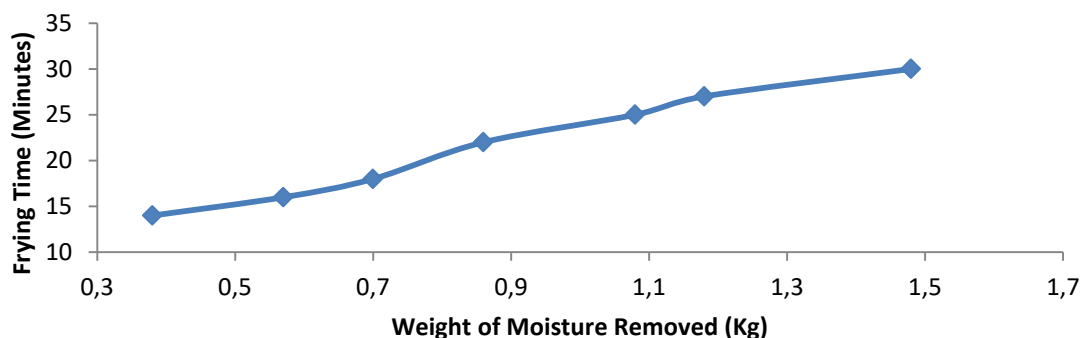


Figure 4: Relationship between Frying Time and Weight of Moisture removed

This result shows that the higher the mass of mash fed into the garifier, the higher the moisture evaporated, the higher the time and temperature required for evaporation and drying of the samples.

Table 2, shows the time required to garify the sieved mash using the developed electrically fired garifying machine and compared to the time required to garify equal mass using wood fire.

Table 2: Garifying time for sieved cassava mash using electric fired element and wood fire

Mass kg	Electric fired element (Garifying time)					wood fire(Garifying time)				
	Replications		Mean	SD		Replications			Mean	SD
1.0	14	16	13	14.3	1.53	12	11	13	12	1.0
1.5	17	16	15	16	1.0	15	14	15	14.7	0.58
2.0	18	19	17	18	1.0	19	21	18	19.3	1.53
2.5	22	23	21	22	1.0	21	27	25	24.3	3.06
3.0	25	24	26	25	1.0	25	28	30	27.5	2.52
3.5	27	28	26	27	1.0	32	31	31	31.5	0.58

4.0	30	31	29	30	1.0	33	32	34	33	1.0
t-Stat	0.56									
t-Crit	2.26									
Decision	Reject (No significant difference)									

Figure 5 shows the relationship between garifying time and mass of dewatered cassava mash garified drawn from table 2.

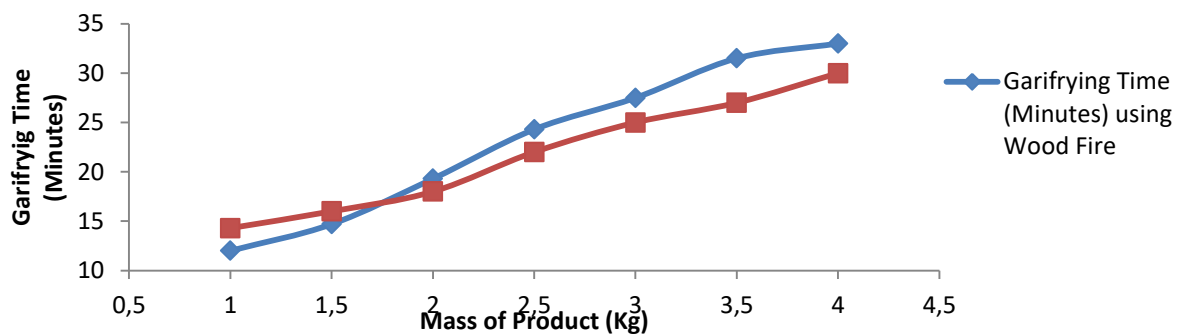


Figure 5: Relationship between Garifying Time and Mass of Product

As shown the t- stat for the comparison at 5% level of significance is less than that of t-critical, explaining the decision to reject the hypothesis that the time required to garify equal mass of sieved DCM using the electrically fired garifier differ significantly compared to the time spent using wood fire. Alternatively, the electric fired element does not offer advantage of time over wood fire for equal masses, correspondingly, the garifying time of the electrically fire garifier relates to the report of [13], that the garifying time for traditional process ranges from 30-35 minutes for a sample mash up to 5kg. Obviously, for cassava mash to turn to garri the processes of heat absorption, gelatinization, gradual segregation of bonded particle by turning and pressing must be complete for a given mass and temperature irrespective of source of heat input. However, the advantage of the electrical fired garifier lies in the fact that the major drudgery in garri frying process is eliminated namely irritation of smoke and scorching heat from firewood as well as energy spent during turning and pressing and overall discomfort resulting from seating posture of the processor during garifying process.

In Table 3, the particle size composition of gari sample obtained using the traditional wood fire method is compared with that obtained using the motorized electrically fired method at batch of 2kg and 4kg.

Table 3: Comparison of garri particles obtained using electric fired element and woodfire

	2kg mass fed		4kg mass fed	
	Wood fire method	Electric fired method	Wood fire method	Electric fired method
Particle size of garified samples	0.32	0.31	0.31	0.20
	0.39	0.38	0.38	0.24
	0.49	0.47	0.47	0.27
	0.60	0.58	0.58	0.31
	0.72	0.68	0.68	0.40
	0.83	0.79	0.79	0.44
	1.02	0.94	0.94	0.49
Mean (M)	1.38	1.25	1.25	0.64
SD	0.72	0.68	0.68	0.37
	0.35	0.30	0.30	0.15



t-stat	0.26	2.47
t-crit	2.14	2.23
Decision	Reject (No significance)	Accept

The result shows that the garri grain in both cases at lower input mass fed of 2kg does not differ significantly as the t-stat is less than t-critical but differs significantly at higher input mass fed of 4kg, as the t-stat is greater than t-critical at 5% level of significance. This means that at lower input mass the developed electrically fired garifier can produce comparable and acceptable garri grain as those of woodfire whereas at higher input mass of 4kg the gari grain produced will not be as acceptable in terms of grain size comparably. This is attributed to the fact that in the traditional method the wood fire is manually increased with increase in mass fed at the discretion of the skillful processor whereas with the electric fired element, the heat spread to individual particle from the heating element of 3600watts is reduced with increase mass fed, except a heat sensor is incorporated to adjust heat input at various changes of temperature in the garifying chamber.

Table 4 highlights the effect of varying turning speed on garifying time. The table shows a progressive decrease in garifying time with increase in turning speed and table 5 shows the

Table 4. Garifying Time for different shaft rpm at 4kg mass fed

	Turning speed (revolution per minutes)				
	10rpm	30rpm	50rpm	70rpm	90rpm
Garifying Time	29	25	23	18	17
	29	24	24	20	19
	28	26	21	17	14
Total	86	75	68	55	50
Mean	28.67	25	22.67	18.33	16.67
Variance	0.33	1.0	2.33	2.33	6.33

result of the analysis of variance (anova). From the table, the F value of the garifying time at different turning speeds is greater than the F-critical at 5% level of significance and 14 degree of freedom, indicating an appreciable difference among the population mean of the garifying time.

Table 5: Anova table of garifying time with different turning speeds.

Source of variation	SS	Df	MS	F	P- Value	F Crit
Between group	286.30	4	71.56	29.01	1.76E-05	3.48
Within group	24.67	10	2.46			
Total	310.9	14				

This difference can be explained on the bases of particle segregation and loss of bonding with increase in turning speed. With increase in turning speed, segregated particles exposed to the pan heat, dry faster compared to when the gelatinizing mash is moved in bond at a lower turning speed.

Table 6 shows particle size composition of gari grain discharged at the 5 test turning speeds. There is observed progressive decrease in mean particle size as the turning speed is increased

Table 6: Particle sizes of garified sample at different turning speeds

	Particle size at different turning speeds (rpm)				
	10rpm	30rpm	50rpm	70rpm	90rpm
	0.44	0.34	0.32	0.30	0.20
	0.65	0.40	0.37	0.33	0.23
	0.70	0.55	0.47	0.40	0.26
	0.81	0.68	0.60	0.49	0.29
	0.88	0.80	0.70	0.65	0.38
Particle size	0.92	0.88	0.75	0.71	0.44

composition	0.98	0.91	0.80	0.75	0.48
	1.12	0.99	0.92	0.82	0.59
Total	6.5	5.56	4.93	4.45	2.87
Mean	0.81	0.69	0.62	0.56	0.36

The associated anova in table 7 of the relationship, shows that the difference in the particle sizes is significant as the F value is greater than the F-critical at 5% level of significance.

Table 7: Anova of particle size at different turning speeds

Source of variation	SS	df	MS	F	P- Value	F Crit
Between group	0.912	4	0.23	5.44	0.0016	2.64
Within group	1.467	35	0.042			
Total	2.379	39				

However, the particle composition of the garified sample with turning speeds of 10 and 30rpm compares closely with those of wood fire unlike those of 50, 70 and 90 rpm indicating that lower shaft speed of turning, scooping and pressing should be considered where motorized method is used. Also, physical observation of the product reveals that the garri from lower shaft speed is more creamy or milky in colour because it absorbs heat more than the others. The products from 50rpm and especially 90rpm are more whitish and dustier. This can be explained because to form garri, there must be formation of lumps which appears during gelatinization. Allowing the gel formation gives rise to agglomeration of particles and bonding into small grains. With higher speed however, the particles are not allowed ample time to gelatinize and by exposing the inadequately gelatinized particle to the pan temperature produces dust-like particles. This finding agrees with [1] on acceptability of particles produced by earlier gari producing plants and explains why earlier mechanized garifier did not produce acceptable gari grains. Most likely, they used higher shaft speed that prevented adequate gelatinization thereby segregating mash to fine particle or they may have used higher mass fed that may not be commensurate to machine capacity thereby preventing even distribution of heat content to the isolated fine particles. No doubt the designers of those plants may not have taken into account the specifications of the existing local technology in gari frying [1, 13].

Additionally, in the traditional setting, the turning of the mash in the pan using the calabash section is not continuous but intermittent at a speed regulated base on the skill and the observation of the processor. The research result which favoured using a lower shaft speed is in line with [17] and [16] who reported using a lower paddle speed of 20rpm for a better product. But as observed by [8] simply selecting a shaft speed for stirring the cassava mash over any heat source could yield a product which may look like garri but will not be acceptable to consumers. This implies that more needs to be done besides selecting lower continuous turning speed. A speed control mechanism for turning with a waiting and resume turning timer base on batch fed and pan temperature should be incorporated to a motorized garifier to produce grain sizes that meets consumers need.

V. CONCLUSION

Electrical heating element can be substituted for woodfire in garri frying process thereby eliminating its effect on discomfort and deforestation. The developed electrically fired garifier does not have advantage of time saving over woodfire for equal mass and temperature but is preferable because the electric motor, the connected shaft with the turner, electrical heating element, effectively replaces human effort and stress involved in using woodfire method for garification. With the machine, the operator is relieved from smoke and heat which is a characteristic of the traditional method. The particle distribution of garified samples in both cases compared favourably at lower mass fed but differ significantly at higher mass fed. Also, the particle size of garri produced at lower shaft speed does not have significant difference compared to that produced using woodfire suggesting best shaft speed for motorize method.

For the developed garifier to have advantage of time over that of woodfire, the machine with its components should be redoubled, in that case, the machine will have advantage of higher throughput capacity over the traditional method at equal time. A speed control mechanism for turning with a waiting and resume turning timer base on batch fed and pan temperature should be incorporated to the machine to produce grain sizes that meets consumers need. A heat sensor should also be incorporated to automatically adjust heat input to the mash in the pan at various changes of temperature in the garifying chamber as a result of input batch change.

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