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Development And Performance Evaluation Of An Automated Batch Process Garification Machine

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ABSTRACT: An automated garification machine comprising a conical hopper with feed gate, garification trough, discharge chute,paddle-press conveyor, heating chamber, air blower, temperature regulators,3HP electric motor, variable speed reducer, starter control paneland auto-control devicewas developed. The machine which was fabricated using locally sourced standard materials, is a batch process garification machine incorporated with a mechanism forintermittent addition of sifted cassava mash into the garification trough, which are distinct features of the manual garification operation that were neglected in existing technologies.Performance test of the machine indicated throughput, throughput efficiency, garification efficiency, heat energy utilization efficiency and specific energy consumption of 17.30kg/hr., 93.57%, 57.66% 64.32% and 349.01kJ/kg respectively at paddle-press conveyor speed, initial temperature of trough, cooking and drying trough temperatures of 20rpm, 58^{o}C, 70^{o}C and 100^{o}C respectively.Adoption of this innovation is recommended because the machine produced gari that hasmoisture content, acidity level and grain size of11.98%, 0.753% and 2.0mm respectively, which are in line withCodex Standard for gari.

KEYWORDS: Cassava, gari processing, garification machine, intermittent addition, batch process,

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I INTRODUCTION

Cassava (*manihot esculenta crantz*) is a very important staple food crop grown throughout the lowland tropics. It has gained popularity in sub-Saharan Africa because of its valued role as a food security crop (Oduro and Ellis, 2000). In Nigeria, cassava production has increased since 1960 after the country's independence from Great Britain and since 2005, Nigeria has consistently been ranked the world largest producer of cassava, with its 2013 production capacity estimated to be about 53 million tonnes (FAOSTAT, 2013). The majority of the cassava tubers produced in Nigeria is processed into various local foods such gari, fufu, lafun, etc., with little left for the industry. According to Philips *et al*., (2004), about 84% of cassava produced in Nigeria in 2001 was consumed as food, while only 16% was utilized as industrial raw materials. Among the different types of food that are processed from cassava tubers, gari is the most dominant (Ohimain*et al*., 2013). This is because of its ready-to-eat attribute and the different forms in which it can be reconstituted and consumed. Also, the fact that gari has a long shelf life compared to other food products from fresh cassava tuber, makes it the most commonly traded cassava product. Knipseheer*et al*. (2007) estimated that about 70% of cassava produced in Nigeria were processed into gari. Hence, of the 53 million tonnes of cassava produced in Nigeria in 2013, about 37.1 million tonnes were converted into gari.

Processing of fresh cassava tubers into gari involves the unit and sequential operations of peeling, washing, grating, fermenting, dewatering, sifting and garification .Peeling is the removal of the outer surface (cortex) of a cassava tuber; washing is the cleaning of the peeled tubers with water; grating is the crushing of the washed tubers into pulp by using graters before allowing some period for its partial fermentation of the grated mash, while pressing constitutes dewatering of the grated cassava mash to a moisture content of between 40% to 45% wet basis (Kolawole *et al*., 2007). Sifting involves cake breaking and sieving of the dewatered cassava mash to remove lumps (Okorji, *et al*, 2003), while garification constitutes simultaneous cooking and drying of the sifted cassava mash (Odigboh and Ahmed, 1984). These unit operations involved in the production of gari from cassava tubers have been successfully mechanized apart from peeling and garification. Successful mechanization of cassava peeling is constrained by the irregular profiles of cassava tubers, as a result of this, peeling of cassava tubers is still done manually by women and children using knives. However, the successful development of a mechanized garification system will depend on how best the distinct features of the manual garification operation, which has been adjudged as the method that produces the best quality gari (Igbeka, 1995), were replicated on the mechanized system. Garification is the most critical unit operation in gari processing because the quality of the gari to a large extent depends on it. The manual operation is very tedious, unhygienic with low throughput compared to the investment of time, money and human energy. Thus, a garification system that will produce gari which has the same quality attributes like the gari processed using the manual process in terms of grain size, moisture content and acidity level, with relatively high throughput compared to the manual process is desired.

Efforts towards achievement of these objectives in mechanized garification process by Odigboh and Ahmed, 1984; Igbeka and Akinbolade, 1986; Igbeka 1995; Gbasouzor and Maduabum, 2012; Olagoke*et al*, 2014 are acknowledged. Though these existing garification machines were developed from the observation of the manual process, however, the quality attributes of the gari processed from them stillfalls short of the standard specifications recommended by Codex (1989) and Oti *et al*., (2010) at different levels. Thus, the need to re-examine and compare thoroughly the features of garification operation both in the manual and the existing mechanized methods, to ascertain the features of the manual method that were not properly incorporated in the existing mechanized systems. It is apparent that some previous researchers had erroneously assumed garification to be the same as dehydration/drying while others had taken it to be just roasting. Roasting is the action of cooking something in an oven or over an open fire, drying is a method of food preservation in which the food is dried.Whereas, garification is a simultaneous cooking and drying operation, where the sifted cassava mash is first cooked with the moisture in it and then dried to a moisture content of 13-10% wet basis before reducing to 12-8% wet basis on cooling (Odigboh and Ahmed, 1984; Igbeka*et al*, 1992; Gbasouzor and Maduabum, 2012; Olagoke*et al*, 2014). Although, most recent garification machine developers are aware of simultaneous cooking and drying operations involved in the garification process, none considered the effects of intermittent addition of the sifted cassava mash during the cooking stage in their design as observed in the manualprocess. In addition, manual garification operation is a batch process operation and not the concept of continuous flow process being adopted by most researchers (Igbeka and Akinbolade, 1986; Igbeka, 1995; Gbasouzor and Maduabum, 2012).

In manual garification operation, the operator introduces an initial quantity of sifted cassava mash into the garification pan which has been preheated to a temperature of about 60^{o}C, then with a spatula-like puddles of calabash or wooden sections, the operator continuously stirs and presses the sifted cassava mash against the hot surface of the garification pan. As the pan is continuously heated underneath, the cassava mash is cooked with its moisture content and during this process, the moisture dehydrates and is no longer sufficient to properly cook and gelatinize the product before the drying stage of the garification process. Thus, at this point, the operator intermittently adds more sifted cassava mash into the pan to provide moisture to properly cook the cassava mash, reduce the formation of large lumps and also, to increase the batch quantity of the garification operation during the cooking stage. During the cooking stage, the garification temperature is relatively kept constant within the range of 70-80^{o}C, and after the last addition of cassava mash into the garification pan, the garification temperature is increased and also kept relatively constant within the range of 100-120^{o}C, to further cook and dry the gari to the desired moisture content before it is removed from the toasting pan. The duration of this manual garification operation is between 25 to 40 minutes, depending on the experience of the operator, source of heat, and the batch quantity which is within the range of 5-10kg of sifted cassava mash, depending on the operator's strength. The truth remains that the manual garification cannot cope with the emerging gari demand, which requires mechanized systems for higher and timely output. Therefore, based on the need to properly cook and gelatinize the cassava before drying the product to the desired moisture content and the effects the intermittent additions of the sifted cassava mash during the cooking stage has on the quality of the gari produced, this study developed an automated batch process garification machine which will replace the tedious, low throughput and unhygienic manual garification process which presently seems to be the only option left for many medium scale gari processors.

II MATERIALS AND METHODS

2.1Description of the Improved Machine

The automated batch process garification machine (Fig.1) comprises of the main frame,feed hopper, cassava mash agitator, feed gate, garification trough, paddle-press conveyor, discharge chute, heating unit, variable speed reducer, electric motor, starter control panel and automatic control device.The main frame is formed from angle iron and serve as the main supporting structure upon which other component parts of the machine are mounted. The conical hopper through which sifted cassava mash is fed into the machine is fabricated from stainless steel plate. The cassava mash agitator driven by a crank mechanism is positioned inside the hopper, which enables the free flow of the moist mash into the trough of the machine. Below the hopper is a reciprocating feed gate fabricated from plywood, with the inner surface covered with thin aluminum sheet. One end of the feed gate is fastened to two springs which is attached to one side of the trough, while the free end of the gate is fitted with linkage through which the feed gate is pulled open by the feed gate opener driven by ratchet wheel/pulley and belt drives. The ratchet wheel ensures the intermittent flow of sifted cassava mash into the garification unit.The garification unit comprises of the U-shaped trough and the paddle conveyor assembly. The trough is formed from aluminium plate and has a square hole with cover at the right end of its curved surface, which is fitted with a chute through which the gari is discharged from the trough after each batch of garification operation.The paddle conveyor assembly comprises of the shaft, membrane and paddles (pressing, scraping and conveying paddles). The paddles were fabricated from stainless steel plate welded to M10 stainless steel bolt fitted with a lock nut, while M10 stainless nuts are welded in three rows along the body of the membrane, which is fabricated from 40mm diameter stainless steel pipe. These nuts enable the paddles to be screwed into position along the membrane and locked down with the lock nut. The membrane is welded to the shaft, which is directly coupled to the output shaft of the speed reducer with flange coupling, while on the input shaft of the speed reducer is mounted a pulley, through which the electric motor drives the speed reducer via V-belt/pulley drive. Under the garification trough is the heating chamber, inside which, the charcoal stove is installed.The front, rear and side covers of the heating chamber are double walled with mild steel plate, with fiberglass separating the inner and outer walls to reduce heat loss from the heating chamber. The rear and side covers are bolted to the main frame, while the front cover, which serves as the door of the heating chamber is hanged with hinges on the main frame. On the lower part of the left end cover of the heating chamber is a rectangular hole, through which the air from the centrifugal fan is ducted to the air chamber below the stove. This automated batch process garification machine is automatically controlled by two limit switches connected to forward and backward contactors, which actuate the forward, stop and reverse movement of the paddle screw conveyor, enabling to and fro movement of the cassava mash along the trough during gasification process. The to and fro movement of the cassava mash along the troughensures that the residence time of the cassava mash on the continuously heated garification trough is sufficient to properly cook, gelatinize and dry the product before it is discharged from the machine.

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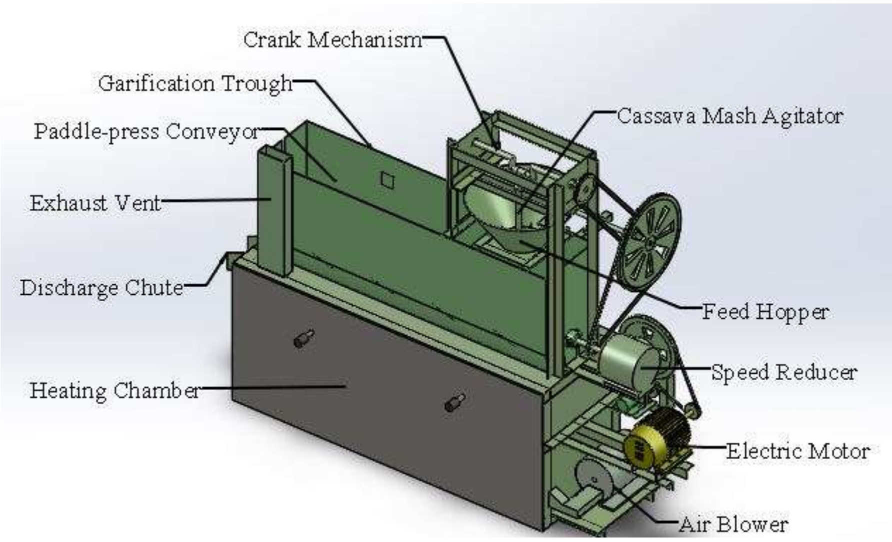

Fig. 1: Automated batch process garification machine

2.2 Design Analysis of Automated Batch Process Garification Machine

2.2.1 Design considerations

The automated batch process garification was designed and developed based on the following considerations:

i. The rate at which the cassava mash is intermittently added into the trough and the number of intermittent additions will be controlled by the initial position of the feed gate from a fixed point on the guide rail and the duration of the forward motion of the paddle pressing-conveyor.

ii. The constant temperature required for the garification operation, is regulated by a variable thermostat, which de-energizes or energizes the air blower immediately the temperature of the trough exceeds the maximum limit or goes below the minimum limits, during the cooking or drying stages of the garification process.

iii. To shield the content of the feed hopper away from heat radiation, the outer wall of the hopper is covered with fiberglass enclosed by aluminium foil.
iv. The minimum quantity of sifted cassava mash, to be processed in one batch of garification process using the machine, will be relatively higher compared to the maximum quantity processed manually. And the drying stage of the garification process commences immediately the content of the feed hopper is emptied into the garification trough.

2.2.2 Analysis of the mass capacity of garification trough

The volume capacity of the feed hopper depends on the volume capacity of the garification trough as well as the volume occupied by a row of paddles. The minimum quantity of sifted cassava mash in terms of mass required in the garification trough during each batch of garification was thus derived from the mass-density-volume relationship (Equation 1).

$$m = \rho v \tag{1}$$

Where $\rho =$ density and $v =$ volume.

To ensure that the cassava mash is properly stirred for even distribution of heat inside the garification trough and for design purpose, it was assumed that the sifted cassava mash will occupy one-quarter of the volume of the dissected cylinder from which the curved surface of the U-shape trough was formed, the effective mass capacity of the garification trough, m_o was determined as 17.57kg from Equation (2).

$$m_o = \rho_1 \times \frac{\pi r^2 l}{8} \tag{2}$$

Where ρ_1(441.3kg/m^3) is the bulk density of dewatered cassava mash at a moisture content of 45% wet basis (Oyerinde&Olalusi, 2011); r (0.25m) radius of the U-shaped trough and l (1.5m) length of the trough.

2.2.3 Analysis of the heat energy required for garification

The quantity of heat, Q_g required to cook and dry and dry the cassava mash during the garification process was determined as 12,250kJ using the relation in equation (3) by Earle (1983).

$$Q_g = [(m_o C_o \Delta T) + (m_{wrem.} \times h_w)] \tag{3}$$

$$\Delta T = T_2 - T_1 \tag{4}$$

$$m_{wrem.} = m_t - m_{w1} \tag{5}$$

$$m_{w1} = m_1 \times m_o \tag{6}$$

$$m_t = \frac{m_d}{(1-m_2)} \tag{7}$$

$$m_d = m_o - m_{w1} \tag{8}$$

Where, $C_o$is the specific heat capacity of cassava mash at moisture content of 45%wb,given as 4.14kJ/kgK. (Oyerinde and Olalusi, 2011); T_1 is the initial temperature of the trough before heating (27^{o}C); T_2 is the maximum temperature attained by the trough (100^{o}C); m_{wrem} is the moisture removed from the cassava mash during the garification process; h_w is latent heat of vaporization of water, which is 2257 kJ/kgK. (Earle. 1983); m_1 is the initial decimal moisture content of the cassava mash (45%wb); m_2 final decimal moisture content of gari (12%wb), m_t mass of gari expected from each batch of garification and m_d is the mass of dry matter in the sifted cassava mash.

2.2.4 Design and Selection of Transmission Systems

The transmission shafts and drive mechanism of the automated garification machine are shown in Fig. 2.

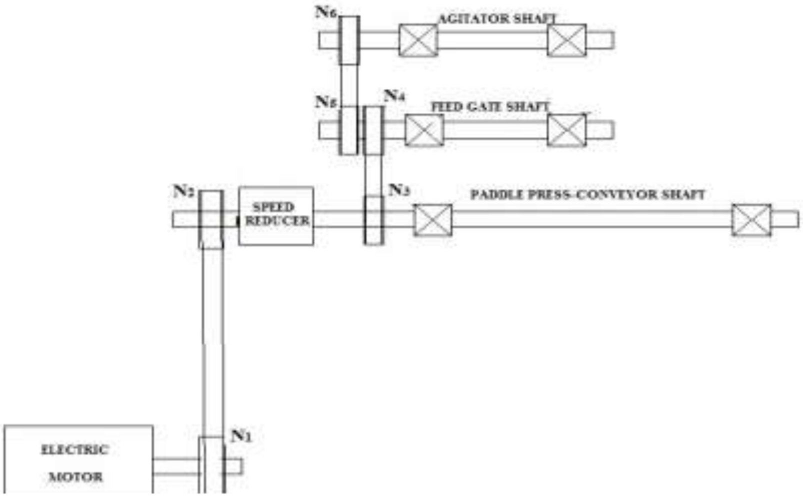

Fig. 2: Drive/Transmission system of the garification machine

From careful observation of the manual garification operation, the rate at which the cassava mash is being pressed, scraped and stirred on the toasting pan is relatively slower compared to the rated speed of the available prime mover that will drive the machine. Thus, the speed selected for the design of the paddle-press conveyor shaft was assumed to be between 10rpm to 100rpm. Since the rated speed of the of the prime mover (AC electric motor) is 1450rpm and due to its availability, cost and performance, a 100mm diameter mild steel pulley is mounted on the electric motor shaft, therefore the range of velocity ratio, VR of the electric motor/paddle-press conveyor, and the minimum and maximum pulley diameters required on the paddle-press conveyor shaft were determined as 145 to 14.5, 14500mm and 1450mm using Equation (9). Due to these very large pulley diameters required for the paddle-press conveyor shaft, a variable speed reducer with speed range of 10rpm to 100rpm and 5rpm step interval now driven by the AC motor, via belt/pulley drive is coupled directly to drive the paddle-press-conveyor, which in turn drives both the feed gate opening device and the cassava mash agitator shafts. With 100mm diameter mild steel pulley mounted on the input shaft of the speed reducer, the velocity ratio, VR of the electric motor/speed reducer drive was therefore, determined as 1 using Equation (9). Also, the velocity ratio of the paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives were assumed to be 5 and 0.5 respectively, while a second pulley of 150mm diameter is fixed on the feed gate shaft to drive the agitator shaft through a v-belt/pulley drive, a ratchet wheel welded to a 65mm pulley is keyed to the paddle-press conveyor shaft, through which the feed gate opener shaft is driven via another v-belt/pulley drive. The maximum/minimum diameter of the pulley to be mounted on the feed gate opener driven shaft and the pulley diameter for the agitator driven shaft were also determined from Equation (9) as 325mm/130mm and 75 respectively.

$$VR = \frac{N_1}{N_2} = \frac{D_2}{D_1} \tag{9}$$

Where N_1 and N_2 constitutes the driving and driven pulleys' speed while D_1 and D_2 are the pulleys' respective diameters. The design center distances, C between the adjacent pulleys of the paddle-press conveyor/feed gate opener and the feed gate opener/cassava mash agitator drives were determined as 285.10mm and 283.50mm respectivelyusing the relation in Equation (10) by Khurmi and Gupta (2005). Since the design center distance computed for the electric motor/speed reducer drive using equation (10) is too small, to ensure that the electric motor is placed not too close to the heating chamber, 500mm was selected as the minimum center distance for the adjacent pulleys of the electric motor/speed reducer drive. Also, the electric motor is will be mounted on an adjustable base.

$$C = \frac{1.5D_2}{(VR)^{1/3}} \tag{10}$$

The design length of the belt drives was computed as 1300mm, 1182.73mm and 920.32mm respectively, for the electric motor/speed reducer, paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives using Equation (11), hence, type 'A' V belts of standard pitch lengths of 1331mm, 1204mm and 925mm were also respectively selected for these drives, since each drive transmits less than 3.75kW power (IS: 2494-1974; Khurmi and Gupta 2005).

$$L = 2C + 1.57\,(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \tag{11}$$

Consequently, the exact center distances between the adjacent pulleys of the paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives of these machine were determined as 251.45mm and 280.93mm respectively using equation (12) (Sharma and Aggarwal, 2006).

$$C = P + \sqrt{P^2 - q} \tag{12}$$
$$P = \frac{L}{4} - \frac{\pi}{8}(D_2 + D_1) \tag{13}$$
$$q = \frac{(D_2 - D_1)^2}{8} \tag{14}$$

The angle of lap, θ, of the drives were computed as 180° (3.14rad.), 117.74° (2.05rad.) and 164.66° (2.87rad.) respectively for the electric motor/speed reducer, paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives using Equation (15), while the belts' speed for the drives were respectively determined as 7.60m/s, 0.34m/s and 0.30m/s for electric motor/speed reducer, paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives using Equation (16).

$$\theta = 180 - 2\left[\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)\right] \tag{15}$$
$$v = \frac{\pi D_2 N_2}{60} \tag{16}$$

Tensions on the tight side, T_i/slack side, T_j of the belts for electric motor/speed reducer, paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives were determined as 163.86N/9.03N, 170.10N/25.66N and 170.10/12.05 respectively from equation (17), (18), (19) and (20).

$$T_i = T_{max} - T_c \tag{17}$$
$$T_{max} = \sigma \times a \tag{18}$$
$$T_c = mv^2 \tag{19}$$
$$2.3 \log \frac{T_i}{T_j} = \mu \theta cosec\beta \tag{20}$$

Where T_{max} and T_c are the respective maximum and centrifugal tension of the belts while the groove angle,β, coefficient of friction between the pulleys and the belts,μ, maximum safe stress, σ, mass per unit length, m and the cross sectional area, a, of the belts were obtained from IS: 2494-1974 standard Khurmi and Gupta (2005) as 19^0 0.3, 2.1N/mm^2, 0.108kg/m and 81mm^2 respectively.

*Beamboy*software was used for the force analysis (Fig. 3 to 5) of all the transmission shafts of this machine. T_1, $T_3 T_5$ and T_2, T_4, T_6 constitutes the respective tight and slack side tensions of the electric motor/speed reducer, paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drive belts. The result of this analysis indicated 25N-m, 64N-m and 22N-m as the maximum bending moments, M_b on the paddle-press conveyor, feed gate opener and the cassava mash agitator shafts respectively. While the maximum twisting moment, M_t on the paddle-press conveyor, feed gate opener and the cassava mash agitator shafts were determined as 4.70N-m, 11.85N-m and 5.93N-m respectively using Equation (21) by Khurmi and Gupta (2005).

$$M_t = \left(T_i - T_j\right)\frac{D_2}{2} \tag{21}$$

Since the transmission shafts of this machine are mild steel shafts and are also subjected to fluctuating loads, the design diameters of the shafts were determined as 18.30mm, 25.02mm and 17 60mm for the paddle-press conveyor, feed gate opener and the cassava mash agitator shafts respectively using maximum shear stress relation given in Equation (22) by Burr and Cheatham (2002) and Sharma and Aggarwal (2006). Thus, standard 20mm, 30mm and 20mm diameter shafts were consequently selected for the respective shaft.

$$d = \left[\frac{16}{\pi\tau}\left(\sqrt{(K_b M_b)^2 + (K_t M_t)^2}\right)\right]^{\frac{1}{3}} \tag{22}$$

Where τ (42N/mm^2), K_b (2) and K_t (1.5) are allowable Shear Stress for steel shaft with provision for key ways, combined shock and fatigue factor for bending and twisting moments respectively (Khurmi and Gupta, 2005).

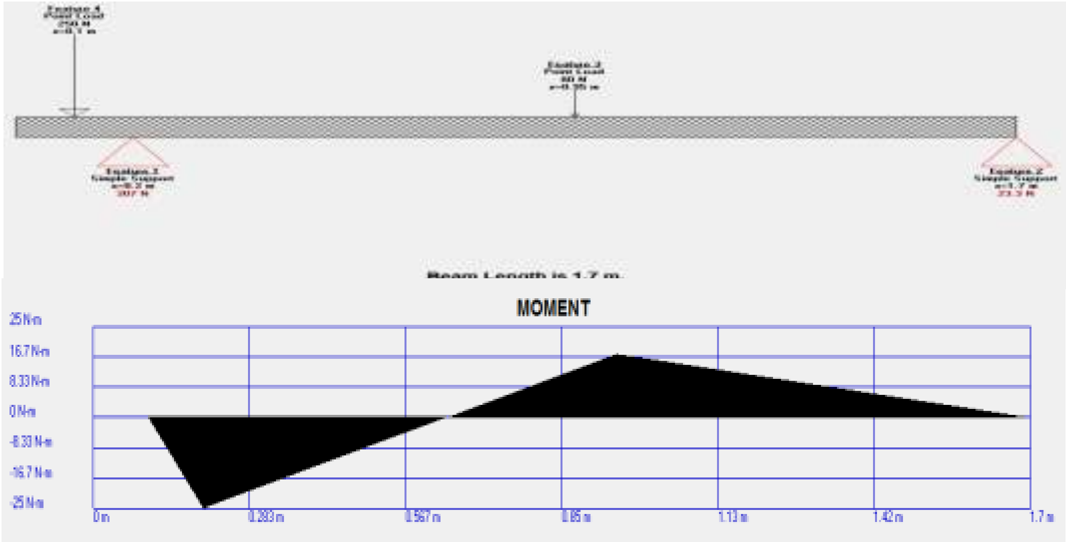

Fig. 3: Force analysis of the paddle-press conveyor

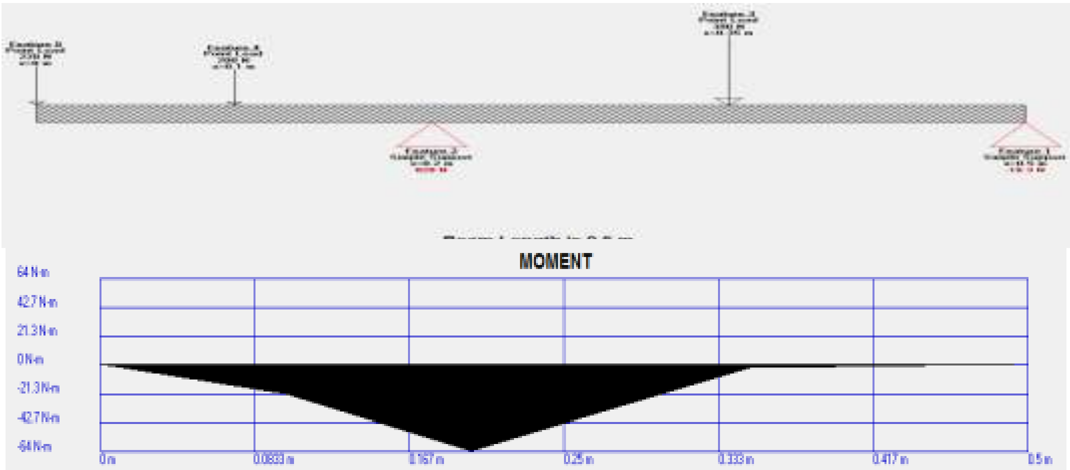

Fig. 4: Force analysis of the feed gate opener shaft

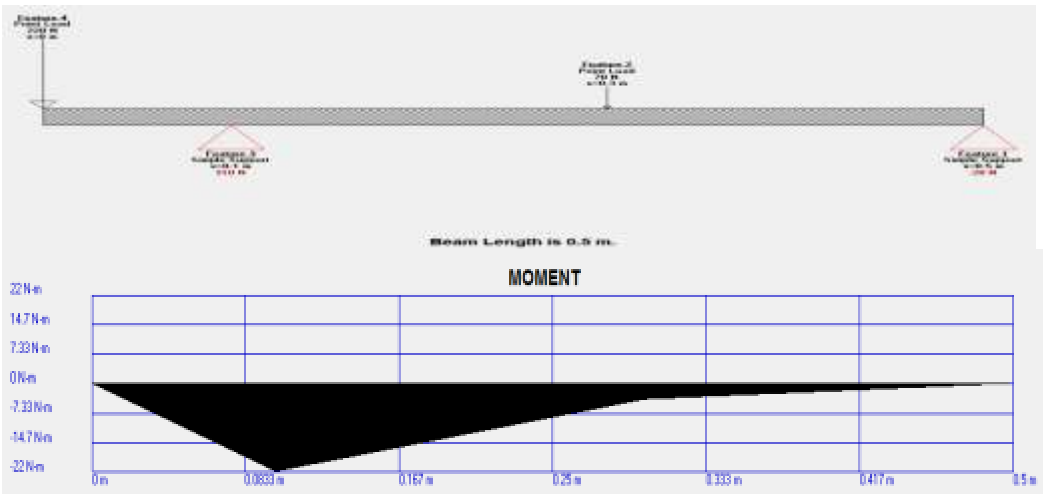

Fig. 5: Force analysis of the cassava mash agitator shaft

2.2.5 Selection of Prime mover

The Power, P_1, required to convey the mash forward/backward along the length of the garification trough was determined as 1330.48W using the relation in Equation (23).

$$P_1 = \frac{mgl}{t} \times n \tag{23}$$

Where n and t are the number of times the cassava mash is moved forward/backward along the trough throughout a batch of garification process and was assumed to be 20 times and 40 minutes repectively. The power requirement for the operation of the electric motor/speed reducer, paddle-press conveyor/feed gate opener and feed gate opener/cassava mash agitator drives were determined as 16.21W, 49.11W, 47.42W respectively using the relation in Equation (24) given by Khurmi and Gupta (2005).

$$P = \left(T_i - T_j\right)v \tag{24}$$

Since the machine is driven by a single electric motor, therefore summing up the power requirements and taking the load factor of electric motor, η_m as 0.75, 3HP electric motor was selected for the operation of the machine.

2.3Performance Test Procedure

The effect of the initial temperature of the garification trough, speed of the paddle-press conveyor, mass of sifted cassava mash added intermittently, time interval for intermittent addition, temperature of the trough during the cooking stage,temperature of the trough during the cooking stage and angle of inclination of the conveying paddles on the garification process were first investigated. The moisture content (M), grain size $(G.S)$ and the total acidity $(T.A)$ of the processed gari were also determined.Thereafter, the garification capacity, TP; garification efficiency, η_g and heat energy utilization efficiency, η_E were determined.Sifted cassava mash of moisture content 45% wet bulb used for the performance test on the garification machine were processed from cassava tubers procured from Ndioro market in Ikwuano, Abia state, Nigeria. In the first test,the initial temperature of the garification trough at five levels was used.In the first trial of this test, 5kg of sifted cassava mash was put into the garification trough already heated to 45^{o}Cand processed for 20 minutes with the temperature of the trough not exceeding 80^{o}C during the process,while the paddle-press conveyoris operatingat the design speed of 20 rpm.A Sample of the processedgari is then analyzed to determine the moisture content,grain size and acidity level. This procedure was repeated with the trough temperature at 50^{o}C, 55^{o}C, 58^{o}C and 60^{o}C. Secondly, five different trials were carried out in which the speed of the paddle-press conveyor was operated at 10, 15, 20, 25 and 30rpm. In each trial, 5kg of sifted cassava mash is put into the garification trough preheated to a temperature obtained from the first experiment, and processed for 25minutes with the temperature of the trough also not exceeding 80^{o}C througout the process. Similarly,a sample of the processed gari is then analyzed to determine the moisture content, grain size and acidity level.

The moisture content of 5g processed gari sample was determined in each test using drying oven method at 105ºC (AOAC, 1990). The empty weight of the container was known, thereafter, the gari sample was turned into the container and re-weighed before it was placed in the drying oven. At an interval of 30minutes, the sample was always checked and weighed. The experiment ends when the sample starts changing colour and a constant weight are noticed over a period of time, thus the samples moisture content was computed using the relation in Equation (25)

$$\frac{W_1 - W_2}{W_2} \times 100 \tag{25}$$

Where,W_1 is the initial weight of sample and,W_2 is the constant weight of sample**.** The grain sizes of the processed gari samples collected at the end of each experiment were determined by placing 300g of each gari samples in the uppermost sieve of a particle size shaker (Endocotts Model BS410/196 Test Sieve Shaker, London, England). The shaker was fitted with eight sieves, with standard mesh sizes of 9.51mm, 6.73mm, 4.76mm, 4.00mm, 2.00mm, 1.41mm, 1.00mm and 0.50mm respectively. The sieving was done for 10 minutes. Gari samples retained on each mesh were weighed and computed as percentage retention. Whilethe acidity level was evaluated as the total titratable acidity, expressed as percentage of the lactic acid content of gari and was determined following (FAO, 1970) method. Each test involves dissolving 5g of processed gari sample collected at the end of each garification process in 100 ml distilled water and allowed to stand for 30 minutes in a beaker. Thereafter the solution was filtered with Whatman filter paper before titrating 25ml of the filtrate against 0.1moles of NaOH, using phenolphthalein as indicator. The percent titratable acidity of each specimen was computed as using the relation in Equation (26) by (Owuamanam *et al*, 2011).

$$T.A(\%) = 0.01X \tag{26}$$

Where; X is mean titre value. In the third test, a 3^3Factorial Experiment involving the trough temperatures during cooking and drying stages of the garification process was used. And in this test, 10kg of sifted cassava mash was loaded into the hopperand the machine operated at initial trough temperature obtained from the previous experiments. In the first trial, the cooking and drying temperatures were maintained at 60^{o}C and 80^{o}C respectively, throughout the 30 minutes duration of the garification process while in the second and third trials, the machine was operated at a drying temperatures of 100^{o}C and 120^{o}C.After each trial, gari samplescollected at the end of the garification process were analyzed to determine their moisture contents, grain

sizes and acidity levels. This experiment was again repeated forcooking temperatures of 70°C and 80°C respectively.
Similarly, a 3^3Factorial Experiment involving the quantity of mash added intermittently into the garification trough and the time interval for the intermittent addition during the garification process was used. In this test, 17.5kg of sifted cassava mashwas loaded into a basin from which specific quantitieswere added intermittently into the machine. In the first trial, 2kg of sifted cassava mash was added intermittently at 1 minuteinterval while the machine was operated for 30 minutes at the cooking and drying temperatures obtained from the previous experiment. Also, the cooking stage lasted for 20 minutes into the operation. This experiment was also repeated for 2 and 3 minutes time intervals, after which, gari samples collected at the end of the garification process were analyzed to determine their moisture contents, grain sizes and acidity levels. The same experiment was again repeated with 3kg and 4kg of sifted cassava.

Finally, the machine was tested three times with the quantity of cassava mash added intermittently and time interval obtained from the previous experiment, with 20 minutes as the duration of the cooking stage and 35 minutes as the garification time.Before commencing each trial, the initial mass of charcoal loaded into the stove was weighed with a digital scale and recorded.Also the gari samples collected at the end of the garification process were analyzed to determine their moisture contents, grain sizes and acidity levels.The mass of gari collected, m_g, and the mass ofunburnt charcoal retained inside the stove were also weighed and recorded as per each run, after which thethroughput, $TP\ (kg/h)$, throughput Efficiency,η_{TP} (%), garification efficiency, $\eta(\%)$, heat energy utilization efficiency, η_E (%) and specific energy consumption, $SE\ (kJ/kg)$of the machine were determined using Equation (27), (28), (29), (30) and (31) respectively.

$$TP\ \ (kg/hr)\ = \frac{m_g}{t} \times 60 \tag{27}$$

$$\eta_{TP}\ (\%) = \frac{m_g}{m_t} \times 100 \tag{28}$$

$$\eta(\%) = \frac{m_g}{m_o} \times 100 \tag{29}$$

$$\eta_E(\%) = \frac{Q_1 - Q_2}{Q_1} \times 100 \tag{30}$$

$$SE\ (\frac{kJ}{kg}) = \frac{Q_1 + Pt}{m_g} \tag{31}$$

$$Q_1 = CV_f \times m_f \tag{32}$$

$$Q_2 = \frac{Q_g}{m_f} \tag{33}$$

Where Q_2, CV_f, m_f,m_g,tP are the heat generated in the heating chamber, calorific value of the charcoal being 405.7 kJ/kg.(Kulla and Obi, 2005),mass of charcoal used for the garification, mass of gari collected, garification time and sum of input power for the AC electric motor, DC electric motor and the air blower electric motor assuming power factor of 80%.

III. RESULTS AND DISCUSSION

Fig. 7show that the grain size of the processed gari increased as the initial temperature of the garification trough increased from 50°C to 60°C, while moisture content and acidity level of the gari reduced with an increase in the initial temperature of the garification trough. However, at the initial trough temperature of 58°C, gari of 2.0mm grain size was processed, thus, in line with CODEX, which recommended coarse grain size of 2.0mmas the best, due to consumers demand. Therefore 58°C was selected as the initial temperature of the garification trough.

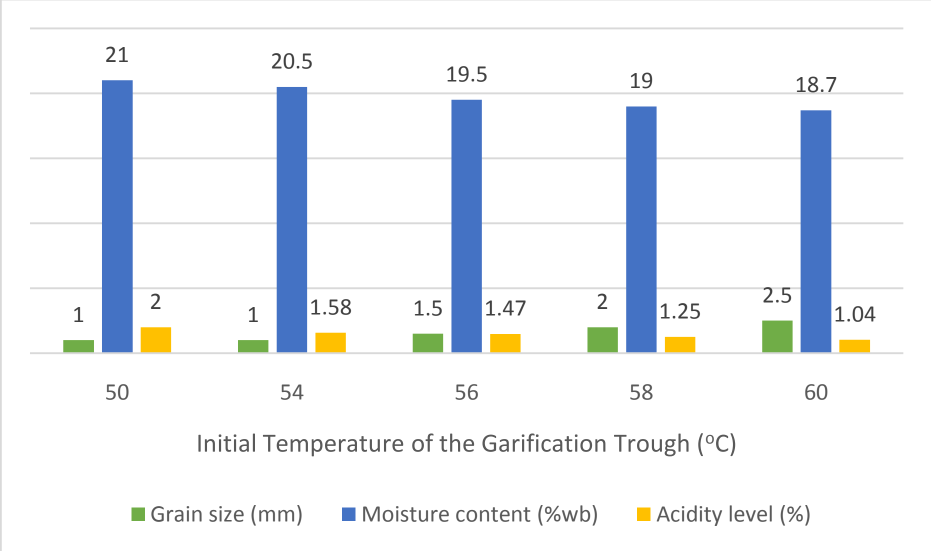

Fig. 7: Effect of initial trough temperature on quality attributes of the processed gari

Similarly, Fig. 8 indicates thatgrain size of the gari processed decreased as the paddle-press conveyor speed increased from 10rpm to 30rpm, while moisture content and acidity level of the gari increased with an increase in the paddle-press conveyor speed. Also, the acidity level of the gari decreased with increase in the garification time. However, since the grain size of 2.0mm was observed at a paddle press speed of 20rpm, therefore the design speed of this machine was also selected for its operation.

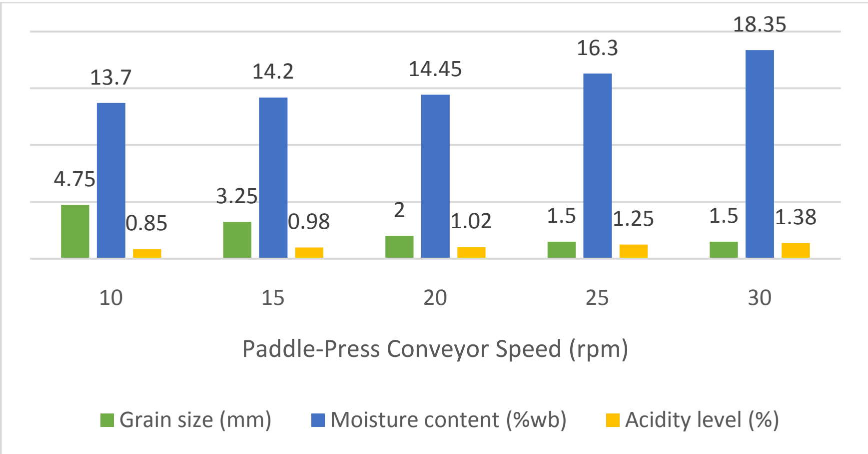

Fig. 8: Effect of paddle-press conveyor speed on quality attributes of the processed gari

Fig. 9 shows that as both cooking and drying temperatures were increased from 60^{o}C to 80^{o}C and from 80^{o}C to 120^{o}C respectively, moisture content and acidity level of the processed gari reduced accordingly. While the grain size of the gari increased with an increase in both cooking and drying temperatures of the garification process. The table also indicates that at drying temperature of 120 ^{o}C, the moisture content of the processed gari decreased below 12% wet bulb which is the standard recommended by CODEX, and also the colour of the gari processed at this temperature changed from creamy white to brownish, indicating that the heat is in excess. While at cooking and drying temperatures of 70^{o}C and 100^{o}C respectively, the grain size, moisture and acidity level are within the recommended value. Therefore, 70^{o}C and 100^{o}C were selected as the machines' cooking and drying temperatures respectively.

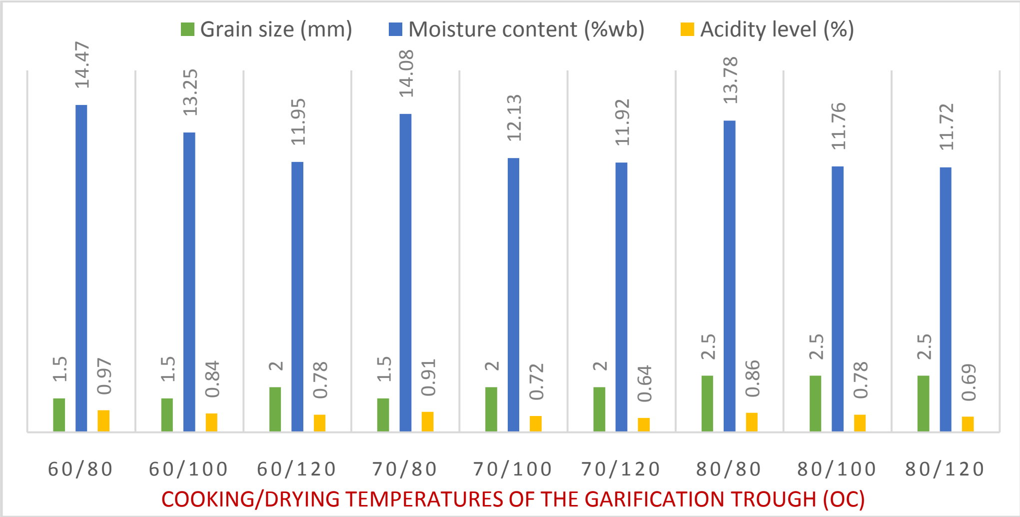

Fig. 9: Effect of the trough temperatures during the cooking and drying stages of the garification process on quality attributes of the processed gari

Fig. 10 indicated that moisture content, grain size and acidity level of the gari processed were significantly affected by the quantity of cassava mash added intermittently and time interval for the intermittent addition. As the mass of sifted cassava mash added intermittently and the time interval for the intermittent addition increases from 2kg to 4kg and 1minutes to 3minutes respectively, the grain size of the gari processed increased from 1.5mm to 3.0mm and further reduced to 2.5mm when the a 4kgmash was processed at time intervals of 2 and 3minutes, while moisture content and acidity level decreases with increase in both quantity of cassava mash added intermittently and time interval for the intermittent addition. However, the grain size and moisture content of the gari processed with 3kg of cassava mash added intermittently at 2 minutes interval agreed with CODEX standard, also its acidity level is relatively low compared to others with high moisture content.

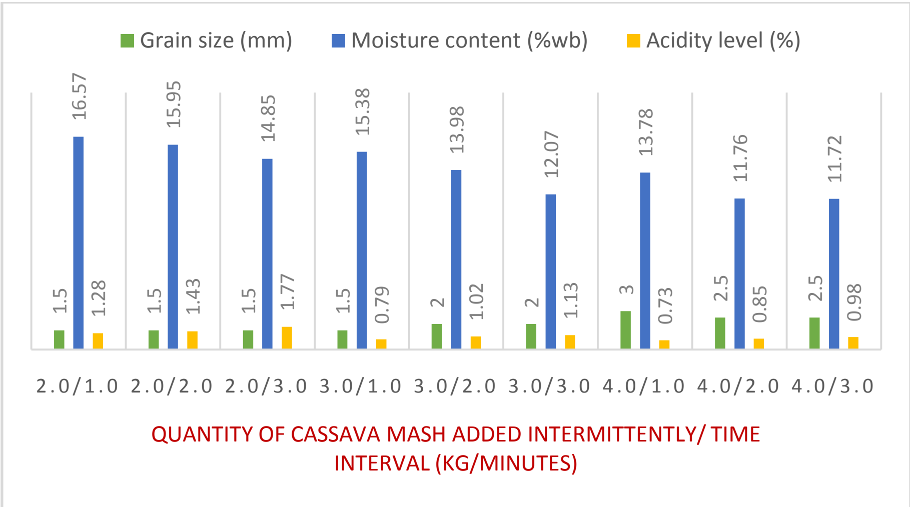

Fig. 10: Effect of the quantity of cassava mash added intermittently and time interval for the intermittent addition on quality attributes of the processed gari.

Table 1 shows the results of the throughput, throughput efficiency,garification efficiency,heat energy utilization efficiency and specific energy consumptionexperiment. 17.30kg/hr., 93.57%, 57.66%, 64.32% and 349.01 constitutes the respective average throughput, throughput efficiency, garification efficiency, heat energy utilization efficiency and specific energy consumption of the garification machine at a garification time of 35 minutes.

Table1: Evaluation of garification capacity, garification and heat energy utilization efficiencies.

	Experimental Runs			
Evaluation Parameters	**1**	**2**	**3**	**Average**
Mass of sifted cassava mash processed in each batch, m_o (kg)	17.5	17.5	17.5	**17.5**
Garification time t (min)	35	35	35	**35**
Mass of gari expected from each batch, m_t (kg)	10.94	10.94	10.94	**10.94**
Mass of gari collected, m_g(kg)	10.09	10.08	10.10	**10.09**
Mass of gari retained in the trough after garification,m_r (kg)	0.84	0.86	0.83	**0.843**
Mass of charcoal loaded into the stove, m_{f1} (kg)	12	12	12	**12**
Mass of charcoal retained after garification, m_{f2} (kg)	3.7	3.4	3.6	**3.57**
Mass of charcoal utilized for garification, m_f (kg)	8.3	8.6	8.4	**8.43**
Heat generated in the heating chamber, Q_1(kJ)	3367.31	3489.02	3407.88	**3421.40**
Heat absorbed by the cassava mash , Q_2(kJ)	1239.53	1193.67	1227.46	**1220.22**
Input power of the motors, P $(kJ/sec.)$	2.8601	2.8601	2.8601	**2.8601**
Acidity level, $T.A$ (%)	0.74	0.77	0.75	**0.753**
Grain size, $G.S$ (mm)	2.0	2.0	2.0	**2.0**
Moisture content, M(%wb)	11.94	12.02	11.97	**11.98**
Throughput, TP $(kg/hr.)$	17.30	17.28	17.31	**17.30**
Throughput Efficiency, η_{TP} (%),	93.60	93.45	93.67	**93.57**
Garification Efficiency, η(%)	57.66	57.60	57.71	**57.66**
Heat Energy Utilization Efficiency, η_E (%)	63.20	65.79	63.98	**64.32**
Specific energy consumption, SE (kJ/kg)	343.65	356.06	347.32	**349.01**

IV. CONCLUSION

An automated batch process garification machine which replicated the manual technique of garification as desired by gari processers was designed and developed. This machine eliminated the problems associated with the existing garification machines and produced gari with quality attributes comparable to the standard recommended by CODEX. It also improved on the quantiy of gari produced per hour.Performance test of the machine indicated throughput, throughput efficiency, garification efficiency,heat energy utilization efficiency and specific energy consumption of17.30kg/hr, 93.57%,57.66% 64.32% and 349.01kJ/kg respectively at paddle-press conveyor speed, initial temperature of trough, cooking and drying trough temperatures of 20rpm, 58^{o}C, 70^{o}C and 100^{o}Crespectively, when 17.5kg of sifted cassava mash with quantity of cassava mash added intermittently and time interval for the intermittent addition of 3kg and 2 minutes respectively was processed for 35 minutes. Thus this innovation is recommended for medium and large scale gari processers.

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