Development of a Combined Milling and Sifting Machine for use in Pupuru (Cassava flour) Processing Plant

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ABSTRACT

The concern of the entire nation over the need to ensure food security is continually becoming more apparent every day. Hence, this has led researchers, industrialists, investors and government agencies to begin aggressively develop series of devices to reduce the level of drudgery associated with processing, and formulation of varieties of food items to enhance food productivity and quality. *Pupuru*, a derivative of cassava, is one of the foodstuffs whose global demand is on the increase but its production is at low pace as a result of the crude techniques and implement utilize in its post-processing. Post-processing of cassava into *pupuru* involves series of stages, ranging from peeling to packaging. Combination of two or more of these processing stages is one of the potential measures of enhancing the productivity of the product, and financial benefits of the stakeholders. This study focused on the development and performance evaluation of a combined milling-sifting machine for use in 5.0 kg/batch Pupuru processing plant. the machine comprises a gear reduction motor, milling chamber, vibrating tray and sets of extension spring connected in parallel for magnifying the vibration produced during operation. The results of the performance revealed that the throughput capacity and sifting efficiency of the machine range between 69.30 – 82.92 kg/h and 86.30 – 95.30 % when used to process feedstock with moisture content in the range of 5 – 6 %. It was observed that the performance of the machine improves with reduction in the feedstock moisture content. It was concluded that the incorporation of the machine into pupuru processing line would enhance the yield and quality to meet the ever-increasing global demand for cassava flour

Keyword: food security, pupuru, global demand, post processing, benefits, combined milling-sifting machine, performance

INTRODUCTION

The world population is steadily increasing day-by-day; it is estimated to reach approximately 10.9 billion by 2100 (United Nation World Population Fact, 2019). To sustain this ever-increasing populace, adequate provision for abundant food supply is essential; as it has been one of the basic ingredients for the survival of every living being (Nag, 2008). Proper steps of ensuring food security entails starting with planning to grow crops and taking relevant decisions during post-harvesting stages to prevent food spoilage, such as devising right preservative measures to prevent growth of pathogens or prolong their shelf life. Food preservation is a process of enhancing the shelf life of food and ensuring food security (Adegoke and Afolabi, 2016). It is one of the major advances in human history (Seydi, 2020).

Food crops are highly perishable due to their high moisture content. Cassava (*Manihot esculentus, Crantz*) is one of the root crops with growing food and industrial applications, but loses its value when not immediately subjected to post-harvest processing as a result of its high moisture content of 62.5 – 75.4 % (Kajuna *et al*., 2001) and short postharvest life of less than 72 hours (Agiriga and Madu, 2016). Cassava plays a vital role in the world food security because of its capacity to survive under marginal soil conditions and its tolerance to drought (Ovat *et al*., 2018). To overcome these shortcomings, require prompt implementation appropriate strategies and technology for postharvest processing and utilization. Cassava, when processed yields different derivatives, depending on the sequence of processing stages employed; notable among these products are *garri, fufu, lafun, pupuru*

Pupuru is a traditional fermented, smoked-dried cassava food consumed in South-western Nigeria. It" is commonly consumed by the people living in the riverine areas of the western, southern, eastern and the middle belts of Nigeria, where it is also known as "*Ikwurikwu*" (Aboaba *et al*., 1988). *Pupuru* is different from other fermented cassava products like *gari, fufu, lafun and akpu* based on the processing method (Wakili and Benjamin, 2015).

The traditional processing of cassava *(Manihot esculenta)* into "*pupuru*" involves series of stages ranging from peeling of tubers, steeping of peeled tubers in stream water for period of 4-6 days for fermentation process to take place, dewatering, pressing/mashing, smoking of the hand-moulded ball(s) on perforated platform fired underneath with heaps of firewood, scrapping of the formed brownish -black outer coating, to milling and sieving for the purpose of separating the chaff from the edible fine flour .

According to Odetokun *et al.*, (1998), about 4 - 6 million of people in Nigeria and other African countries eat pupuru not only as a result of its energy value, but because of its high protein/nutrient, which is greater than the other products and reduced cyanide content. Currently, *pupuru* flour is fast becoming a foreign exchange earner due to its new status, which is also being enhanced as it is considered as a close substitute to wheat flour. Based on the daily rise in the demand for it, mechanization of the stages, starting from planting to post-harvesting stages reduce the challenges confronting the processors. Mechanization allows large quantity of items to be processed with minimum number of people within short time. In the processing of cassava to pupuru, Various researches have since been reported on the processing of cassava to pupuru.

Nwaigwe *et al.* (2012) evaluated the performance of a modified milling machine developed for converting cassava chips into flour. The results of the evaluation revealed that the machine had an efficiency of 82.3 % with fineness modulus of 0.31 and capable of particulating chips to average particle size of 0.075 mm, compared results 2.35 and 0.085 mm obtained with existing hammer mill.

Adeshina and Bolaji (2013) studied the effect of moisture content on the flour yield and mill recovery at different moisture contents when milled cassava chips with different milling methods. The results revealed that the pin milling method produced complete flour yield and recovery.

Adewumi et al., (2019) investigated the effect of modification on the functional and pasting properties of pupuru subjected to chemical modification by acetylation and phthalation. The study utilized Fourier transform infrared (FTIR) to determine the functional and pasting properties of modified and native pupuru. The results of the study showed that phthalation reduces the hydroxyl content, water absorption capacity, swelling properties and water solubility, but acetylation increases them dor modified pupuru. The

However, few studies have been conducted on milling and sifting of pupuru prior to packaging; this necessitated the reason for embarking on this research

MATERIALS AND METHOD

Materials

The materials used for executing the research are fabrication materials and experimentation materials, otherwise called the feedstock. The Fabrication materials, basically, include: a gear reduction motor, stainless steel related items (2 mm thick sheet, shaft, electrode, bolts and nuts), bearings, the experimentation materials include the feedstocks (lumps/ balls of dried pupuru) and the instrumentations. The acquisition was done based on the results of the design analysis and appropriate engineering standards The fabrication materials were procured from designated engineering stalls with Lagos (Owode and Alaba Markets) and Oyo (Gate in Ibadan) states. The instrumentations were gotten from the Central Workshops of Departments of Mechanical and Civil Engineering, of The Federal University of Technology, Akure (FUTA.).

Method

Design consideration

While design encompasses the task of creating the plan which enables a product to be made in such a way that it not only meets the stipulated conditions but also permits its production in the most economical way, according to Sharma and Kamlesh (2003) A variety of factors are required for a reliable-based design to meet the design specification. The following factors were considered in the design process of the combined milling-sifting machine:

(i) The relevant physical and mechanical properties of feedstock (pupuru lumps);
(ii) Overall cost of developing it which should be affordable for small-scale enterprise;
(iii) Availability and suitability of the materials used for developing the machine to enhance quick replacement of malfunctioning part(s) and prevent contamination;
(iv) The maintenance and repair of the machine can be carried out with ease, and
(v) The dimensions, speed, capacity and efficiency of the machine

Design Assumptions

The following assumptions were considered in the course of developing each sub-unit of the system (milling and sifting), according to: KWS Screw Conveyor Engineering Guide;); Jurandir (2020)

(i) Trough loading factor (φ) of the tray is 30 %;
(ii) Correction factor for 5^{o} trough inclination is 1.15;
(iii) Density of dried pupuru is in the range of 470 – 640 kg/m^3 (470 kg/m^3 assumed);
(iv) Material factor (γ_f) for the feedstock is 1.0;
(v) Efficiency of the electric motor (η_e) is 50 %;
(vi) Isolation efficiency of the sifting unit is 20 %;
(vii) Speed of electric motor is 1440 rpm;
(viii) Steady state amplitude of the spring is 20 mm;

Design Analysis

The machine comprises the following units, feeding system (screw conveyor), milling (grinding) and sifting (sieving); each of the components of the sub-units were selected based on the outcomes of the calculated data and relevant engineering standards.

Bin

The bin serves as the entrance for the feedstock. However, in order to avoid feedstock spillage when the machine is in operation, extra volume to cater for this was, it was designed with loading factor (φ_t) of 25 %. Therefore, the hopper capacity $V_h$can be obtained with equation (2), according to Apeh et al (2021)

$$V_h = (1 + \varphi_t)\frac{m_f t_r}{60.\rho_f} \qquad (2)$$

where: m_f is the rated capacity of the plant (kg/h); t_r is the feedstock residence time (minute), and $\rho_f$is the feedstock density

The geometrical dimensions of the hopper can be determined with equation (3), based on iterations:

$$V_h = \frac{h.w_h}{2}[a + b] \qquad (3)$$

where: h, w_h, a and b are height, width, top length and bottom length of the hopper

Milling Chamber Design

The geometrical dimension of the milling chamber was determined with equations (4) to (6) with respect to the rated capacity at trough factor of φ %.

$$v_{ac} = v_{th}[1 + 0.01\varphi] = \pi R^2 \mathrm{h} \qquad (4)$$

For the purpose of preventing seizure of the vibratory, clearance (t) was introduced between the outside wall of the vibratory tray and internal wall of the milling chamber. The dimensions of the vibratory tray were determined with equations (5) – (7)

$$v_t = v_{th}[1 + 0.01\varphi] \qquad (5)$$

$$d_{Ot} = D_{im} - 2t \qquad (6)$$

$$d_{it} = \lfloor d_{Ot} - 2t_p \rfloor - 2T \qquad (7)$$

The internal pressure of the milling chamber is calculated by equation (8) as described by Khurmi and Gupta, (2005).

$$\tau_{max} = \frac{P_i d_o}{d_o^2 - d_i^2} \qquad (8)$$

The thickness of the milling (T) can be determined with equation (9), as described by Thakore and Bhatt (2009)

$$T = \frac{P_i d_i}{2\sigma j - P_i} + c \qquad (9)$$

Design and Selection of vibrating element (spring)

In order to facilitate effective agitation of the sifting unit without the use of active vibrator, the usage of sets of extensions springs (passive) arranged in parallel around the periphery of the tray to amplify the motion of the vibrating tray, which serves as the screen and a temporary bin for the charged quantity of the feedstock under the applied force, was considered. Assuming the value of the force transmissibility is T_r (in %), stiffness of the springs is k_s (N). The properties of the springs were determined with equations (10) to (12) described by Bhatia (2008); Alok (2010); Singiresu (2011)

$$\mathrm{r} = \sqrt{\frac{1 + T_r}{T_r}} = \frac{\omega}{\omega_n} = \frac{2\pi N}{60}\sqrt{\frac{\delta_{st}}{g}} = \sqrt{\frac{2-R}{1-R}} \qquad (10)$$

$$\omega_n = \sqrt{\frac{k_{eq}}{m_t}} \qquad (11)$$

$$k_{eq} = n_s k \qquad (12)$$

Determination of the size of the electric Motor

The force required to be exerted by the prime mover to enhance swinging of the feedstock for effective milling and sifting comprises the gravitational force due to the mass of the charged feedstock, rotational force, frictional force and spring force causing pressure difference in the end of the rotating shaft. The total force can be determined with equation (13), according to Basu and Pal (2008); Rao (2010)

$$F_T = W_f + (1 + \mu)\frac{mv^2}{r} + \frac{4W}{\pi D^2} \qquad (13)$$

The torque generated due to rotational motion of the drying chamber is given by equation (14)

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$\tau_T = F_T . r$ (14)

The actual power rating of the motor required to mill and generating the imbalance required for sifting the pulverized charged feedstock was estimated by equation (15)

$P_m\ (hp) = 1.34 \frac{\tau_T * \omega}{n_m}$ (15)

Table 1 presents summary of the calculated and adopted data utilized for selecting, fabricating the individual components and assembled the combined milling-sifting machine

Table 1: Summary of the design equations, calculated and adopted data

s/n	Particular	Equation No.	Calculated	Adopted
			Data	
1	Rated Volume (x $10^{-3}\ m^3$)	2	5.90	5.00
2	Chamber Diameter (mm)	4	550	550
3	Milling Thickness(mm)	9	1.85	2.00
4	Power electric motor (hp)	15	1.01	1.50
5	Number of, spring	10.11, 12	6	6

Figures 1 and 2 shows the Isometric and exploded views of the developed machine produced with SolidWorks CAD software.

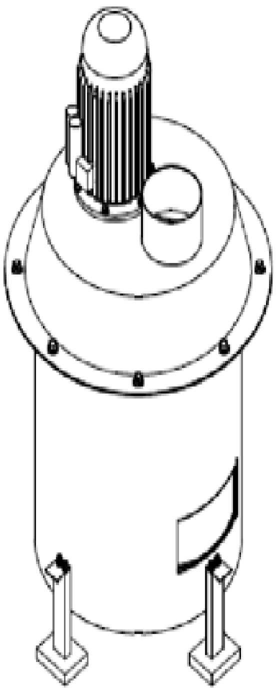

Figure 1:: Isometric and exploded view of developed combined milling and sifting machine

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Parts list			
s/n	Particular	s/n	Particular
6	Tray top flange	12	Extension spring
5	M10 x 25 mm bolts	11	Discharge chute cover
4	Top cover	10	Body
3	Blade	9	Inclined tray
2	Ø40 mm stainless shaft	8	Sieve
1	Electric motor	7	Sieve holder

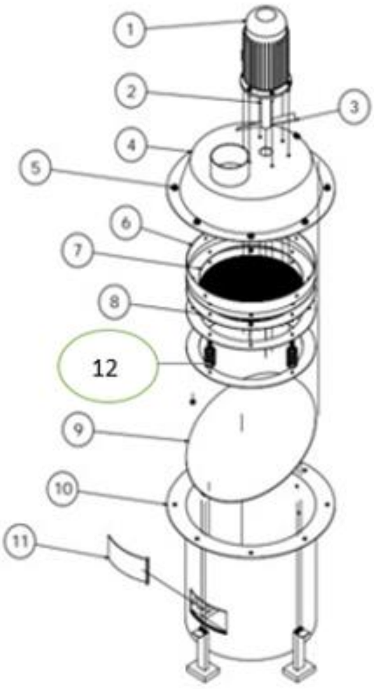

Figure 2: Exploded view of developed combined milling-sifting machine

Performance evaluation parameters

The performance of developed combined milling and sifting machine would be evaluated based on the throughput capacity and sifting efficiency.

Throughput capacity (Q_m), otherwise called the milling rate, is defined as the ratio of the mass of the feedstock charged (m_f) into the machine to the time taken (t_m) to complete the operation. It can be determined with equation (16)

$$Q_m \ (in\ kg/h) = \frac{m_f}{t_m} \qquad (16)$$

Sifting efficiency ($ή_m$): Sifting efficiency is defined as the ratio of the mass of the feedstock sieved/sift (m_s) to the total mass of the charged into the unit (m_f); it is given by equation (17)

$$ή_m \text{ (in \%)} = 100\,\frac{m_s}{m_f} \qquad (17)$$

Fabrication Exercise

A 1.5 hp/230 V/60 Hz electric motor was used in driving the machine. Individual components of the machine were cut into sizes as specified in their respective detailed engineering and working drawings were cut into sizes with cutting (Model: Bosch grinder, GWS-20-230H) and Guillotine (Model: GMC) machines. The rolling of the housing and vibratory tray cylinders were the prescribed sizes with rolling machine (Model: R044CH). Machining (facing, step turning, and parting-off) of the shaft to was carried out with Lathe machine (Model: GMC04410BGF). All the welding exercise was done with stainless electrode (Gauge 10) and performed using manual metallic arc welding machine (Model: Power/Plus, EX-1-400). The rotating shaft (after step turned) was centrally held in positioned with a piece of 206 thrust bearing to facilitate proper rotation, and prevent shaft wobbling/daggling.

The fabrication exercise was carried at the central Workshop of the Department of Mechanical Engineering of The Federal University of Technology, Akure. (FUTA), Nigeria. Plate 1 presents the picture of the developed combined milling-sifting machine.

Plate 1: Picture of the developed combined milling and sifting machine

Machine Description and principle of operation

The combined-sifting-milling machine is a single shaft rotary device that consists mainly of driving motor, vibratory tray, pieces of extension springs, slopy (inclined) tray, blades and the housing with a chute (inlet and door). The motor transmits power directly to the shaft on which the blades are mounted. As the name of the machine implies, it consists of two sub-units – milling unit and sifting unit.

When in operation, feedstock is charged into the machine through the inlet chute located on one side of the top cover plate beside the electric motor. The milling operation occurs by the rotation of the blades, fastened to the shaft keyed to the motor shaft, which simultaneously stir and swing the feedstock within the vibratory tray. Due to the fact that the dried lumps of the charged feedstock are friable, they got reduced in sizes or fragmented into particles. The milling process proceeds as soon as the particles are still in contact with blades, but begins to decline or stops as the pulverized feedstock gets descended and moved further away from the blades or its tip. The sifting/sieving process takes place by the to-and-fro oscillatory motion of the vibratory tray (screening tray), mounted on pieces of extension springs and secured in position by three (3) pieces of M10 x120 bolts and nuts which permits irt to move only along the vertical direction. This oscillatory motion caused particles characterize with sizes smaller than the mesh apertures to exit and get discharged into the inclined tray, otherwise called the slopy tray, positioned under it. The sieved (sifted). Slopy and the other part of the machine, below the vibratory tray, serves as a temporary silo for the pulverized feedstock prior to further operation feedstock (*pupuru* fluor) is collected. Off-loading of the milled and sifted feedstock (pupuru flour) is done by sliding sideway the door located on the machine side, immediately at the lower section of the slopy tray

Selection of Mesh sizes for sifting

Sieving is the process of separating fine material from coarse material by means of a meshed or perforated vessel. The tool for performing this task is called sieve. The opening, otherwise called the aperture, is a series of gauges which reject or pass particles as they are presented to the aperture. According to FAO (2023) cassava flour should have a fine texture and particle sizes ranging from 60 (250 μm) – 200 (75 μm) mesh and flour that particles pass through a 60 mesh should not be less than 95 %. Based on this, experimentation regarding the

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sifting process was conducted with three mesh sizes, 80 mesh (180 μm), 20 (850 μm) and 8 mesh (2.36 mm), according to Advantech Manufacturing, Inc (2001).;

Performance evaluation procedure

Prior to the commencement of the experimentation, measured mass (200 g) of the procured feedstock was taken to the Research Laboratory of the University to determine its moisture content ($\emptyset 1$ %) and the sieve (mesh No: 60) was secured on the vibratory tray Afterward, the machine was switched on, allowed to run for 5 minutes in order to detect any malfunctioning and make correction immediately.

At the commencement, known mass (5.0 kg) of the feedstock, was then weighed with a digital weighing balance (Model No.: SF-400) and filled into three bags tagged A1, B1 and C1. Samples tagged A1The machine was then used to process sample A1. At the expiration of the processing, the time taken to process sample A1 was noted with a stopwatch (Model). Side door of the machine was afterward opened to facilitate offloading of the processed (milled and sieved) flour and the mass determined. More so, the chaff left in the vibratory tray was packed and its mass noted with a balance. The procedure was repeated with B1 and C1 but with the screen replaced with sieves of mesh numbers 80 and 8 in succession. the experimentation was replicated with similar mass of feedstock but with moisture content ($\emptyset 2$ %),

RESULTS AND DISCUSSION

Table 2 presents summary of the experimental results

Table 2: Summary of the experimental results

Sample/ MC (i)	Mesh size (ii)	Mass (iii)	Time (iv)	Capacity (v)	Sieved (g) (vi) (vii)		Retained (ix) x)		Unaccountable (xi) xii)	
(%)		(kg)	(s)	(kg/h)	(g)	(%)	(g)	(%)	(g)	(%)
A (6)	A1(0.180)	5.0	260	69.23	4315	86.30	310	6.20	375	7.50
	B1(0.800)	5.0	239	73.31	4518	90.36	280	5.60	202	4.04
	C1(2.300)	5.0	222	81.08	4743	94.86	210	4.20	47	9.20
B (5)	A2(0.180)	5.0	256	70.31	4432	88.64	350	7.06	218	4.36
	B2(0.840)	5.0	235	76.60	4647	92.94	280	5.60	73	1.48
	C2(2.300)	5.0	217	82.95	4765	95.30	210	4.20	25	1.25

Pulverization is one of the processing stages involved in the post-processing of agro-crops. It entails particulation or particle size reduction (grinding or milling) and categorization / separation of the particles into different sizes through the use of sieve of different apertures, depending on the particle sizes desired.

A combined milling-sifting machine for use in 10.0 kg/batch *pupuru* processing plant to reduce the challenges of stakeholders engaging in pupuru processing and improve the quality of the product with the intention of meeting the global demand has been developed. The original intention of this study was to evaluate the performance of the machine with feedstock (product) obtained within the processing line. However, due to the fact that the construction of these machines is ongoing, samples of the feedstock were sourced from designated *pupuru* stalls in Ilaje area of Ondo State but their respective moisture contents (MC) determined, at the

Research Laboratory of the Federal University of Technology, Akure (FUTA), prior to the commencement of the experimentations

From Table 2 column (v), the throughput capacity ranges between 69.23 – 82.95 kg/h, the highest productivity occurred with moisture content of 5 % when screen with mesh No 8 (aperture size 2.300) was used. The increase in the productivity as the moisture content reduces and mesh size (aperture) increases could be attributed to the fact that at reduced moisture content the inter-particle liquid bridges particle is reduced which lead to reduction in their cohesiveness (Hwabin *et al*, 2018); lumps of feedstock become friable due to the decrease in their green strength and this make them to fragment easily because the green strength of food particles reduces with decrease in the moisture. More so, as the mesh aperture increases, additional more space is created for more particles to pass These results aligns with the findings of Majdi and Taha (2007) that increased moisture increase the axial dimensions, surface area, static coefficient, hence reduction in productivity; Anyanwu *et al.*, (2021) that throughput capacity increases as the moisture content of feedstock reduces, and Olajide *et al*, (2016) who reported that the milling efficiency depends on the moisture content of the feedstock

From column (vii), the results showed that the machine has the least sieving efficiency of 86. 30 % at moisture content (MC) of 6 % with 0.184 mesh size, and maximum of 95.30 % at MC of 5 % and 2.300 mish size. It was observed that the sieving efficiency increases with increase in mesh sizes but reduction in MC. This variation in the sieving efficiency could be attributed to the fact that (i) at increased MC, some particles (powder) characterized with high MC would block the sieve apertures making it difficult for more particles to be sieved; the presence of high MC in the lumps often makes the fiber to increase in size (swell up), weight (mass), stick them together, obstruct the flowability and ultimately reduce the sieving efficiency. This result agreed with the findings of Balasubramanian et al, (2011) that increase in moisture content promote the production of more medium-sized particles, instead of dine particles capable enough to easily exit the sieve pores; (ii) at reduced MC, more particles lose their water content, reduce in density and become shrink which favour availability of more fine particles to be sieved. More so, the progressive increase in the sieving efficiency with increase in the mesh sizes can be attributed to the fact that with more space more particles are able to exit the mesh apertures alongside with the fine particle and this accounts for why product (samples) sieved with screen of increased mesh sizes are mixture of fine and medium or coarse particles. the sieves.

The results of the fraction of the feedstock that could not be accounted for, as detailed in columns (xii) and (xiii) show that the uncountable loss decreases as the moisture content reduces and mesh opening increases. This reduction could be attributed to the fact the entire processes occurred within a confined space which made it hard for any of the particulated samples to be blown-off by wind, and particles or lumps characterized with high moisture contents are more available unsieved and easily thrown-off via the waste outlet of the machine caused by the centrifugal action of the spinning blades

CONCLUSION

A combined milling and sifting machine that can be used for achieving these dual tasks in a *pupuru* processing plant, including other agro-allied plant(s) when incorporated was designed and fabricated. The sifting unit utilizes sieves held with the vibratory tray with temporary fasteners, this permits sieves of sieves of different mesh apertures to be installed and used. The usage of mesh of different number would permit the machine to be used for sifting materials (feedstock) to varied particle sizes. This study also demonstrated how factors, moisture content of feedstock and mesh sizes affect the performance of milling and sifting systems.

Benefit of Study

This research aimed at alleviating the physical strain and fatigue that are frequently experienced day-by-day by the processors of cassava to *pupuru* flour and its allied products, caused through the usage of manual/traditional techniques and crude implement to achieve pulverization of dried pupuru lumps. The development of this machine to perform these dual tasks, milling and sifting, would reduce the financial costs incurred by the stakeholders when a machine with mono-function is acquired. The incorporation of this machine into *pupuru* processing plant would reduce the drudgery bedeviling the traditional methods, enhance the yield and quality to meet the ever-increasing global demand for cassava flour (*pupuru*).

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