Evaluation of a modified multipurpose cassava processing machine for size reduction

Nasirembe Wanjala[1]* Rotich E[1] Ruttoh R[1] Nyakach S[2] Maingi S Cheboswony R[1] Sevu M[1]

1. Kenya Agricultural and Livestock Research Organization
2. Egerton University

* E-mail of the corresponding author: *nasirembew@yahoo.com

The research is financed by the Kenyan Government through the Kenya Climate Smart Agricultural Project

Abstract

The production of cassava (*Manihot esculenta*) is considered an important alternative to a reduction in food scarcity around the world. Kenya is rapidly gaining prominence due to the declining production of staple foods, especially maize and wheat. Though still considered a poor man's food, the usage of cassava has greatly diversified in terms of both industrial and domestic applications. This coupled with the introduction of improved varieties and better farming options calls for innovative ways of handling the increasing volumes of fresh cassava tubers to minimize post-harvest losses. One of the important postharvest processes is size reduction which is achieved by either chipping or grating. Improved production methods alone are not adequate to solve the issues of field losses in cassava production. Factors affecting the efficiency of size reduction operation include operator experience, disc type, disc speed, cutting clearance and moisture content. Conventionally, this has been done manually but due to the inherent problems, the use of machines is being encouraged through the development and adoption of chipping/grating machines. In this study, the machine developed was dual-powered and allowed conversion from a chipper to a grater and vice versa as need be. It has a capacity of 162.15kg/h and 81.62 kg/h when chipping and grating respectively. The chipping process consumed less power averaging 0.0034 kW/kg compared to 0.0075 kW/kg used in the grating and these chips dried faster than manually worked cassava.

Keywords: Cassava, post-harvest, chipping, grating, dual power

DOI: 10.7176/ISDE/13-1-06
Publication date: June 30th 2023

1. Introduction

Cassava (*Manihot esculenta*) is a major food crop for both humans and livestock and is commonly grown in the tropics. In Africa it is considered an important source of energy in human diet, which plays a major role in alleviating food crises because of its efficient production of food energy, year-round availability, tolerance to extreme stress conditions hence suitability to prevailing farming and food systems [1]. Nutritionally, cassava contains potassium, iron, calcium, vitamin, folic acid, sodium, vitamin C, vitamin B-6 and protein [2]. The first import of cassava to Africa was by the Portuguese from Brazil in the eighteenth century, but now cassava is cultivated and consumed in many countries across Africa, Asia and South America [3]. [4]. Although more emphasis is given to the roots at harvest, the stem and the leaves have also been used by some farm families as firewood and vegetables respectively. The cassava roots serve as a food reserve during periods of food shortage due to its long harvest window. Harvesting can be done from between 7 to 24 months after planting [5]. This sometimes makes cassava to be treated as a subsistence crop because of partial harvesting.

Cassava tubers cannot be stored for long in their fresh form because they are highly perishable [6]. [7]. [8]. [9]. The roots have a short shelf life and therefore proper post-harvest handling is critical in order to minimize deterioration and ensure final product quality. To reduce post-harvest physiological deterioration (PPD) in cassava roots due to poor post-harvest storage methods, it is imperative to process the roots into dry, shelf-stable edible forms [10]. Post-harvest processing of cassava increases its value by improving palatability and facilitating the marketing of more acceptable hygienic quality products Effect of temperature and shape on drying performance of cassava chips [11]. Upon harvesting, the cassava roots are peeled, washed and where need be; chipped or grated and dried before milling is done. These operations are often done manually by the farmers as observed during a situational analysis carried out in Busia and Kisumu counties, Kenya. However manual processing of cassava requires high labour input and often results in poor quality [12]. Due to the projected increase in cassava production in Kenya arising from awareness campaigns, development and distribution of high-yielding, fast-maturing, disease-tolerant varieties coupled with the need to reduce post-harvest losses, meet market demands, minimize drudgery and generally make cassava post-harvest handling more appealing to the youth, development and adoption of mechanization technologies for cassava post-harvest handling remains a viable option, [13]. Therefore, it has been necessary to develop other means of utilizing the surpluses and improve on the post-harvest handling processes. This calls for effectual mechanization whose degree of adoption depends on the size of the land and the availability of machines for each unit operation involved in cassava processing [14].

Cassava size reduction processes include chipping, grating and milling. Chipping and grating are aimed at increasing the surface area for faster drying. These processes are differentiated by the product size distribution and the machine used. A number of size reduction machines have been developed and tested. [15] tested a motorized tuber chipping machine which was tested for chipping capacity, efficiency and uniformity of the chips being 6.6 kg/min, 78.2% and 21.8% respectively. [16] developed an electric cum manual cassava chipping machine and tested based on varied speeds and size of the chips. [17] reported that the size reduction method of cassava root caused a significant difference in the colour of unfermented cassava flour. Grated cassava root resulted in higher lightness than sliced (chipped) root. Chipping speed of 300rpm was found to be most efficient resulting in chip sizes of 10 – 22 mm and 20 mm for motorized and manual operations respectively. A variety of cassava grating and chipping have also been developed and promoted in Kenya notably through the support of Gorta – Self Help Africa (SHA) and Farm Concern International (FCI) the farmer aggregation centres and commercial villages although scanty data is available on their performance. The existing machines can be modified to improve on functionality and make them more appealing for adoption by the farmers and other stakeholders. The main objective of this study is to evaluate the performance of two types of size-reduction blade machines. Specific objectives were to establish performance indices for the blades, identify performance indices with reference to portability due to power source and economic viability and compare the performance of the two.

1.1 Methodology

1.1.1 Study Site

The prototype of the modified grating-chipping machine was fabricated at the Kenya Agricultural and Livestock Research Organization – Agricultural Mechanization Research Institute (KALRO - AMRI) in Katumani, Kenya. The modifications were based on the shortcomings initially identified through both on-station and field evaluations involving existing graters and chippers where performance data were collected and analyzed. Farmers and extension staff being important stakeholders were involved during the evaluation and their input was incorporated into the modification. Evaluation of the modified chipper-grater was undertaken at the Kenya Agricultural and Livestock Research Organization – Dairy Research Institute in Naivasha located at latitude 0.69006 S and 36.40246 E in Nakuru County, Kenya. The fresh cassava used as raw materials were obtained from the KALRO-Food Crops Research Center's farm in Njoro, Kenya.

2 Materials and Methods

2.1 Machine Description

Hopper - The hopper is an inlet through which peeled and cleaned tubers are fed into the size reduction chamber. It is made up of stainless steel (SS) pipe of 75 mm diameter and 3mm thick, towering 300 mm above the tray, the pipe hopper limits the throwback of cassava particles which at times drops in eyes of the operator. Some particles cut by a chipper or grater are randomly thrown away in all directions. Those directed to the spout reach the collector while those that come backward are thrown to the wall of the pipe hopper and lose the energy to emerge at 50cm hence falling through the design exit spout

Tray- Measures 48mm × 32mm × 40mm made from SS and a thickness of 3mm. on which peeled and cleaned tubers are held for quick feeding

Shaft- A shaft of length mm and diameter 25.4mm made from mild steel (MS), It rests on two pillow block bearing size 205, and holds a pulley which reduces the speed from either power source gasoline engine or motor as necessary. Three horse powers are adequate in chipping and grating but the smallest gasoline engine available in the market within the experimental operation area was a 7.5hp one. The shaft is held in place by crab screws on the pillow block bearings. The axial slide of the shaft will make a variation in the thickness of the chipped material.

Chipper disc -The chipper disc of diameter, 310mm and thickness of 3mm is the heart of the chipper. The disc needs to be heavy to carry a lot of cutting inertia. The disc also has to be balanced, this is critical. The knives are made by slicing into the cutting disc and bending it out of alignment to the disc plane to enable Chipping Perforated Disc The grater disc is very similar to the chipper disc but the cutting mechanism which in this case emanates from the difference in shape and size of the holes.

V-Belts -A V-belt is a rubber belt used for driving mechanisms in an engine or motor A V-belt must be the right size, extending slightly out of the pulley groove. There are two B-class belts used in this machine. B-35 and B-63 for motor and gasoline engine respectively.

Electric Motor-An electric motor of 3hp is an electrical machine that converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and electric current in a wire winding to generate force in the form of torque applied on the motor's shaft.

Engine-A gasoline engine is an internal combustion engine, four cycle, of 7.5hp designed to run on gasoline. Gasoline engines can often be adapted to also run on fuels such as liquefied petroleum gas and ethanol blends (such as E10 and E85). Most petrol engines use spark ignition, unlike diesel engines which typically use compression ignition. Another key difference to diesel engines is that petrol engines typically have a lower compression ratio

Main frame - It is made of angle iron 40 × 40 mm, the overall dimension was 800 mm length, 635 mm, 5.5 mm breadth and 450 mm width. The motor frame with 90 mm length, 5.5 mm breadth and 450 m. The frame gives support to the shaft, and gasoline engine and motor The machine was designed for dual power source i.e. electric motor and gasoline engine to improve its portability with respect to power source an allowance was provided where one of the power sources could easily be disconnected based on farmer preferences especially under fixed (permanent) installation conditions. The machine was also designed to accommodate different cutting mechanisms (grating blade or chipping blade) for the size reduction process. The feed hopper was designed for cylindrical shape to contain the fresh cassava and reduce backflow. The outlet spout was designed to confine the chips/grates ensuring ease of collection hence reduced spillage. During the evaluation, the machine was connected to a power supply coupled to a power meter for electric motor operation. Figure 1(a) shows the engine-motor, frame, hopper and tray arrangement while Figure 1(b) shows the power connection through a watt meter. Figures 2(a) and 2(b) shows cutting blades for chipping and grating respectively. The specifications of the various components are summarized in Table 1.

Figure 1 (a) Motor and engine arrangement

Figure 1 (b) Power meter

Figure 2(a) Chipper blade

Figure 2(b) Grater blade

Table 1: Machine Specifications

Description	Quantity
Motor-rated power (kW)	1.49
Engine-rated power (kW)	5.59
Motor-rated speed (rpm)	2950
Engine-rated speed (rpm)	3600
Motor Drive pulley diameter(mm)	63.5
Engine Driven pulley diameter (mm)	76.2
Driven pulley (mm)	152.4
Chipper blade diameter (cm)	31
Grater blade diameter (cm)	31
Hopper diameter (mm)	76.2
Spout L*W (mm)	127*76.2

2.2 Data Collection

Cassava was manually peeled, washed and weighed using a balance sensitive to 0.1g before the size reduction process. The operating speeds were measured at the drive and driven pulleys both for the electric motor and gasoline engine setups using a digital tachometer as shown in Figure 3. The power requirement rate was measured three times using a power meter and averaged in watts. For the engine, the fuel tank was filled before operation and the amount used to top up at the end was measured as fuel consumed in liters.

Figure 3 Measuring the engine rotational speed using a digital

Based on the measured data, performance parameters derived for both the chipper and grater included throughput which was the amount of raw cassava processed per unit time compared to manual chipping; energy demands for the machine (fuel consumption per unit workload in ml/kg or electric power per unit workload in kWh/kg); drying rate for manually chipped cassava against machine chipped cassava under similar environmental conditions

2.3 Size Distribution Analysis

The freshly grated/chipped cassava was lightly sun-dried in order to minimize adhesiveness between the grates or chips. Size distribution of the chips was done using a set of sieves of varying perforation sizes (25, 10, 5 mm). Figures 3(a) and (b) shows a set of sieves used and the separation process respectively. The sieve perforation sizes were plotted against the % passing in order to obtain the D10, D30, D50 and D90 being the perforation sizes corresponding to 10, 30, 50 and 90 % finer respectively. These values were used to compute the coefficient of uniformity (Cu) and the span value (SD) to describe the relative size distribution within the processed samples.

Plate 3(a): Set of Sieves

Figure 3(b): Separation process

2.4 Data Analysis
Each experiment involved three runs. Statistical analysis was carried out on data collected using the t-test in which the means were compared for significant difference at $\alpha = 0.005$, one-way test based on the following hypothesis;
Ho: $\mu1=\mu2$ No significant difference exists between the mean for treatments
Ha: $\mu1>\mu2$ A significant difference exists between the mean for treatments with a negative sign of the calculated t-statistic indicating that $\mu1<\mu2$.
Comparisons were made based on mean throughput per unit time for electric motor chipping vs. engine chipping; electric vs. engine grating; chipping vs. grating irrespective of power source; electric vs. engine operation irrespective of the cutting mechanism and the power consumed per unit throughput in kWh/kg during chipping against that for grating.
According to [18], the effective capacity of the grater is calculated by directly weighing the commodity to be grated, in this test the material used is coconut (kg) divided by the time required for grating (hours), which is expressed through Eq. as follows:
KEP=m/t
where, KEP = Effective capacity of grating (kg/h);
m = the weight of the commodity to be shredded (kg);
t = grating time (hour).
2.5 Results and Discussions
The results of the measurements taken during the evaluation were as shown in Table 2. These were means based on three replications for each treatment. From these results, the corresponding means for chipping/grating rate and power consumed/fuel per unit throughput were computed and the results obtained as in Table 3 below.

Table 2

Power source	**Blade type**	**Speed without load (rpm)**		**Speed with load (rpm)**		**Average mass fed (g)**	**Time taken (sec)**	**Power (W)/ fuel consumed (ml)**
		Drive pulley	**Driven pulley**	**Drive pulley**	**Driven pulley**			
Electric	Chipper	3178	1428	2938	1469	2700	52	634.2
Electric	Grater	2728	1556	2428	1556	2736	113.7	647.7
Gasoline	Chipper	3276	1435	3118	1409	2910	77.7	34.85
Gasoline	Grater	3651	1590	3118	1435	2790	135.7	34.85

Table 3: Derived Data

Power source	**Blade type**	**Chipping/grating rate (kg/hr.)**	**Power consumed (kWh/kg)**	**Fuel consumed (l/kg)**
Electric	Chipper	189.30	0.0034	N/A
Electric	Grater	86.79	0.0075	N/A
Engine	Chipper	137.45	-	0.12
Engine	Grater	75.15	-	0.13

Chipping and grating varied according to the source of power and by implication, shaft speed. Generally chipping had higher values; 189.30 and 137.45kg/h for electric and gasoline chippers respectively while grating was 85.79

and 75.15 for electric and gasoline chippers respectively. From these results, it was observed that generally chipping consumed less power/fuel per unit throughput compared to grating while use of an electric motor drive resulted in higher processing rates both for chipping and grating than the engine drive. To evaluate whether differences were statistically significant, the data was subjected to one-way t-test at α = 0.005 and the results are summarized as in Table 4.

Table 4: t-Test Results

	Chipping (kg/h)		**Grating (kg/h)**		**Mode of cutting irrespective of drive (kg/h)**		**Power source irrespective of mode of cutting (kg/h)**		**Power consumed (kWh/kg)**	
Statistic	Electric	Engine	Electric	Engine	Chipper	Grater	Electric	Engine	Chipping	Grating
Mean	186.7	137.5	88.08	75.19	162.15	81.63	137.41	106.38	0.0034	0.0075
Variance	793.21	484.56	60.12	104.68	310.33	1.8	177.41	247.21	1.6E-07	9.2E-07
df	4		4		2		4		3	
t Stat	2.382		1.740		7.894		2.608		-6.642	
P(T<=t) one-tail	0.038		0.078		0.008		0.0297		0.0035	
t Critical one-tail	2.132		2.132		2.920		2.132		2.353	

It was noted that the chipping rate using an electric motor was significantly higher than when an engine was used to provide the drive while in the grating, no significant difference was observed in the mean throughput per unit of time. Based on the mode of cutting, there was a significant difference between the mean throughput per unit time when cassava was chipped compared to grating irrespective of the drive mechanism. This is attributed to the fact that grating results in much smaller materials than chipping and hence take longer to process. This is compared closely to the findings by [19] where the highest chipping capacity obtained was almost double the grating capacity when an automated combined cassava grater/slicer was evaluated. They obtained 167.67 kg/h and 80.7 kg/h for chipping and grating capacities respectively while for the present evaluation, the corresponding mean values were 162.15 kg/h and 81.63 kg/h.

An evaluation on the effect of prime mover used during cutting irrespective of whether it was by grating or chipping, electric motor drive resulted in an average capacity of 137.41 kg/h which was significantly higher than the 106.38 kg/h obtained when an engine drive was used. This is despite the rated power being lower than the rated engine power. The chipping process also consumed less power averaging at 0.0034kW/kg compared to 0.0075 kW/kg used in the grating. This conforms with Rittinger and Kick's laws which both predict the energy required for size reduction is a function of the initial and final sizes of the material. Grating results in smaller materials compared to chipping hence the higher power requirement. Effect of machine chipping on the drying rate of cassava chips

Samples of machine-chipped and hand-chipped cassava were spread out over an area of 1 m^2. The initial and final masses after open sun drying for 3.57 hours are presented in Table 5. From these, the computed moisture loss rates were 0.23 g/s and 0.14 g/s for motor chipping and hand chipping respectively. Machine chipping results in smaller cassava pieces hence higher surface area exposed to the natural drying conditions.

Table 5: Comparing the drying rate of cassava chips

Parameter	**Machine chipping**	**Hand chipping**
Initial Mass of chips (g)	2.43	2
Drying area in (m^2)	1	1
Drying material depth in (mm)	3	3
Drying time (h)	3.67	3.67
Final Mass of chips (g)	1.59	2
Drying rate (g/s)	0.23	0.14

2.6 Size distribution analysis

The chipped/grated cassava was analyzed for size distribution. The grading curves are presented in Figures 4(a), (b) (c) and (d) for chipping and grating respectively. From these, the coefficient of uniformity (Cu) and span (SD) were computed and the results obtained are summarized in Table 6 below. From these, it is noted that cassava from grating was more uniformly graded (more fines) than the chips which were a well-graded distribution. For ease of handling, for example; drying, packaging, uniform grade would be preferred.

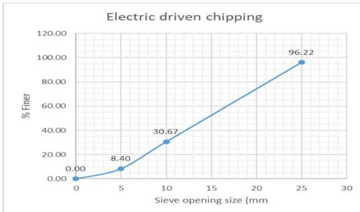


Figure 4 (a) Chipping curve from electric power source

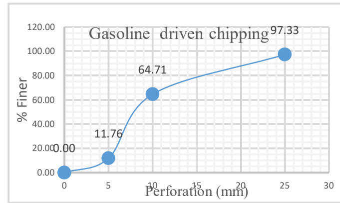
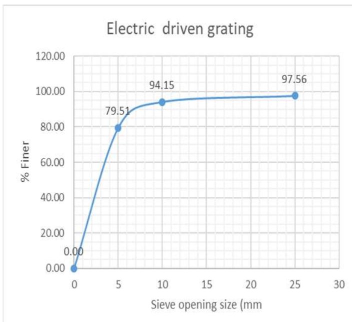


Figure 4 (d) Grading curve from gasoline power source



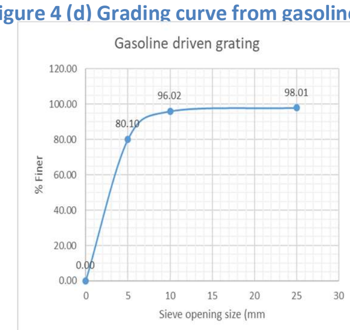


Figure 4 (c) Grading curve from electric power source

Figure 4 (b) Chipping curve from gasoline power source

Table 6:Coefficients of Uniformity span value and particle size distribution

Opening size (mm)	**Grating**		**Chipping**	
% Finer	**Electric**	**Gasoline**	**Electric**	**Gasoline**
D_{90}	7	6.5	21	23.5
D_{60}	3.5	3.5	9	16.5
D_{50}	3	3	8	14.5
D_{30}	1.8	1.8	6.5	10
D_{10}	0.5	0.5	5	5
SD = $(D_{90}-D_{10})/D_{50}$	2.17	2.00	2.00	1.28
Cu = D60/D10	7.00	7.00	1.80	3.30

2.7 Conclusion and Recommendation

Machine chipping/grating saves time and particulates cassava tubers which dry faster than those produced through hand chipping. This makes it possible to handle larger volumes of fresh cassava during mass production as envisaged by the increased interest in the cassava value chain Kenya and other parts of the globe. The modified machine can use both electric and gasoline power making it adoptable to on grid and off grid locations. In addition, the gasoline engine enables use off grid where the cassava is being harvested by the individual farmers. Due to the increased chipping/grating capacity farmers can use it on a rotational basis or have it permanently installed at an aggregation Centre from where the cassava is size reduced, dried and marketed. The farmer volumes should be established to match machine size workload.

References

1. Karydas, Andreas Germanos, et al. "An IAEA multi-technique X-ray spectrometry endstation at Elettra Sincrotrone Trieste: benchmarking results and interdisciplinary applications." *Journal of Synchrotron Radiation* 25.1 (2018): 189-203.
2. Giami, Sunday Y. "Compositional and nutritional properties of selected newly developed lines of cowpea (Vigna unguiculata L. Walp)." *Journal of Food Composition and Analysis* 18.7 (2005): 665-673.
3. *Nhassico, D., Muquingue, H., Cliff, J., Cumbana, A. and Bradbury, J.H., 2008. Rising African cassava production, diseases due to high cyanide intake and control measures.* Journal of the Science of Food and

Agriculture, 88*(12), pp.2043-2049.*

4. *Githunguri, C., Gatheru, M. and Ragwa, S., 2019. Cassava production and utilization in the coastal, eastern and western regions of Kenya.* Handbook of Cassava, *p.41.*
5. *MacKenzie, Darryl I., et al. "Estimating site occupancy rates when detection probabilities are less than one."* Ecology *83.8 (2002): 2248-2255.*
6. *Morgan, Natalie K., and Mingan Choct. "Cassava: Nutrient composition and nutritive value in poultry diets." Animal Nutrition 2.4 (2016): 253-261.*
7. *Cooke, R. D., J. E. Rickard, and A. K. Thompson. "The Storage of Tropical Root and Tuber Crops cassava, Yam and Edible Aroids." Experimental Agriculture 24.4 (1988): 457-470.*
8. *Sunmonu, M. O., M. M. Odewole, and A. A. Ibrahim. "Investigation of disease incidence and nutritional storability of cassava roots under different storage techniques." Journal of Research in Forestry, Wildlife and Environment 8.4 (2016): 18-29.*
9. *Saravanan, R.A.J.U., Ravi, V., Stephen, R., Thajudhin, S.H.E.R.I.F.F. and George, J., 2016. Post-harvest physiological deterioration of cassava (Manihot esculenta)-A review.* Indian J. Agric. Sci, 86*(11), pp.1383-1390.*
10. *Pornpraipech, P., Khusakul, M., Singklin, R., Sarabhorn, P. and Areeprasert, C., 2017. Effect of temperature and shape on drying performance of cassava chips.* Agriculture and Natural Resources, 51*(5), pp.402-409.*
11. *Aji, I.S., James, E., Ejovwoke, A. and Mshelia, D.A., 2013. Development of an electrically operated Cassava slicing machine.* Arid Zone Journal of Engineering, Technology and Environment, 9, *pp.90-95.*
12. *Pingali, P., 2007. Agricultural mechanization: adoption patterns and economic impact.* Handbook of agricultural economics, 3, *pp.2779-2805.*
13. *Jimoh, M. O., and O. J. Olukunle. "An automated cassava peeling system for the enhancement of food security in Nigeria." Nigerian Food Journal 30.2 (2012): 73-79.*
14. *Daniel, Ipilakyaa T., Yanshio E. Terngu, and Gundu D. Terfa. "Design, Construction and Testing of a Motorized Tuber Chipping Machine." European Journal of Advances in Engineering and Technology 4.6 (2017): 492-496.*
15. *Awulu, J.O., Audu, J. and Jibril, Y.M., 2015. Development of cassava (Manihot) chipping machine using electric motor cum manual operation.* J. Harm. Res. Eng, 3, *pp.78-84.*
16. *Doporto, María C., et al. "Physicochemical, thermal and sorption properties of nutritionally differentiated flours and starches." Journal of Food Engineering 113.4 (2012): 569-576.*
17. *Oriaku, E.C., Agulanna, C.N. and Ossai, E.N., 2015. Design and performance evaluation of a double action cassava grating machine.* Journal of Emerging Trends in Engineering and Applied Sciences, 6*(3), pp.196-203.*
18. *Malomo, Sunday A., Rong He, and Rotimi E. Aluko. "Structural and functional properties of hemp seed protein products." Journal of food science 79.8 (2014): C1512-C1521.*
19. *Daniel, I.T., Terngu, Y.E. and Terfa, G.D., 2017. Design, Construction and Testing of a Motorized Tuber Chipping Machine.* European Journal of Advances in Engineering and Technology, 4*(6), pp.492-496.*