KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

STANDARDISATION OF THE GRATING SURFACE OF CASSAVA GRATERS FOR GARI

BY

DEBORAH OPANDOH

APRIL, 2015

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A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY IN

PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE AWARD OF

MASTER OF SCIENCE (FOOD AND POST HARVEST ENGINEERING)

COLLEGE OF ENGINEERING

APRIL, 2015

DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no materials previously published by another person nor material which has been accepted for the award of another degree of the University, except where due acknowledgement.

DEBORAH OPANDOH …..

(PG 7818312) Signature Date

Certified by

PROF EBENEZER MENSAH ....

Supervisor Signature Date

Certified by

DR GEORGE YAW OBENG .... Date

Supervisor Signature

Certified by

Prof. S. K. AGODZO ……………………………… Date

Head of Department Signature

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to God Almighty for his immense grace and sustenance throughout my two year degree programme.

Secondly, I wish to express my profound appreciation to my supervisors, Professor Ebenezer Mensah and Dr George Yaw Obeng for their patience, suggestions, criticisms and understanding and for reading through my project report.

I am grateful to IDIN-MIT for their material grant support and also, Professor Benjamin Linder, Katherine Maschan and Gabrielle Waldman Fried all of Olin College of Engineering for their help and support.

I also wish to express gratitude to workers of the Agricultural Engineering workshop at KNUST, Mr. C.K. of the Department of Pharmaceutics for helping me with my particle size analysis, Mr. Akwetey of the Department of Electrical Engineering, KNUST and Felicia of Accra Town who helped in making the grated mash into gari.

I wish to also acknowledge the assistance of 'Doctor' of Suame magazine for his patience and help in the making of all the three grating surfaces. May God bless you.

Finally, I thank all lecturers of the Department of Agricultural Engineering Department, especially, Mr. Aveyire and Mr. Akowuah who helped with their advice to make this project a success.

DEDICATION

I dedicate this project to my mother, Mrs. Paulina Opandoh. You are indeed a great woman.

Thank you for all the encouragement and support. God richly bless you.

ABSTRACT

Cassava is the third largest source of food carbohydrates in Africa after rice and maize. It is drought tolerant and gives reasonable yields where other crops do not grow well, thus, acting as a famine reserve. Nonetheless, cassava undergoes post harvest physiological deterioration (PPD) after three days of harvest. Therefore, there is the need to process it within three days after harvesting. Grating of cassava is one of the popular means of processing. Cassava is grated and processed into gari; a popular meal in West Africa, especially in Ghana and Nigeria. Modifications have been made on graters to improve and increase its efficiency. However, it is observed that, there is no standard in the making of the grating surface (teeth) of these graters. Manufacturers of these graters sometimes produce the teeth in a dense random form. Materials for making these food processing surfaces are usually mild steel which rust with time although stainless steel is sometimes seen. The grating of cassava for gari does not always give the desired size of mash. Replacement of teeth is somewhat cumbersome as there is no laid down procedure for making the grating surface; thus, the need to standardize the grating surface of the cassava grater. In this project, a survey was done to know the existing patterns of cassava grating surfaces in three regions of Ghana; Western, Central and the Ashanti regions. From the knowledge gathered from surveys and review of literature, three grating surfaces were designed and fabricated. They were tested on an already existing grater design. Results after the mash was made all the way into gari by a particular processor (to ensure some level of consistency) were compared to three already existing teeth, two of which were saw toothed and the other punched using a mechanical shaker. In the process of standardizing the grating surface of the cassava grater, important factors such as tooth size, inter tooth spacing, tooth angle and material type were considered. The recommended tooth diameter was ±0.04mm from 3.01mm while the inter tooth spacing

was ±0.08mm from 8.05mm. The brick form of arrangement of teeth is also preferred to ensure effective contact between the cassava and the grating surface.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Cassava sometimes described as the 'bread of the tropics' (Adams et al., 2009) is the third largest source of food carbohydrates in Africa after rice and maize (Pattiya and Sattibak, 2012). It is a major staple food in the developing world, providing a basic diet for over half a billion people (Grubben et al., 2014). Nigeria is the world's largest producer of cassava, while Thailand is the largest exporting country of dried cassava. The cassava root is long and tapered, with a firm homogeneous flesh encased in a detachable rind, about 1mm thick, rough and brown on the outside. The flesh is usually chalk-white. Cassava undergoes postharvest physiological deterioration (PPD) once the tubers are separated from the main plant. It continues until the entire tuber is oxidized and blackened within two to three days after harvest, rendering it unpalatable and useless (Adjekum, 2006). Thus, it is prudent to process the crop within three days after harvest. Cassava roots are edible but contain cyanide, which is poisonous. This is reduced when the roots are processed.

Processing provides cassava producers with additional market opportunities, beyond simply selling the fresh roots. Traditional methods of processing cassava roots can result in poor quality products that contain unacceptable levels of cyanide, as well as being contaminated by foreign matter and disease-causing agents. Proper processing converts fresh cassava roots into safer and more marketable products by reducing cyanide levels in the processed products, prolonging shelf life, reducing post-harvest losses of fresh cassava roots and avoiding contamination of the products (Okechukwu et al., 2012).

Gari, produced from fresh cassava roots is dry, crispy, yellow to creamy-white and granular. Processing of cassava roots into gari involves peeling, washing, grating roots into mash, de-watering mash into wet cake (fermentation occurs at this stage), sieving wet cake into grits and roasting grits into gari (Okechukwu et al., 2012). However, after sieving wet cake into grits, it is observed that, a lot of grits do not pass through the sieve due to their large size. The grits which do not pass through the sieve may result from improper tooth pattern and size of the grater's rotor. The larger grits are undesirable and would therefore have to undergo another size reduction process. This increases production time and cost. It is also observed sometimes, the presence of discoloured mash after grating (not because of bad cassava) is due to a rusty drum as a result of improper drum material or an unclean drum.

The making of the grating surface or teeth of the grater is time consuming, thus manufacturers of graters give the teeth making work to others to do. These people who make the teeth may or may not have experience. Those without the right experience do not use the right punch size and/ or sharpness. Some manufacturers make the teeth without any initial marking out, thus randomly punching the teeth. Marking out the tooth pattern allows for proper positioning of the teeth.

Since the making of grating surface is time consuming, most manufacturers prioritize ease of manufacture and minimal cost of designs over efficiency, durability and safety. Also, as there are no standards in making of grating surfaces, a standard grating surface cannot be assured when there is the need for replacement. Therefore, there is the need for standardization to ensure interchangeability, uniformity, quality and efficiency in the making of grating surface.

1.2 Aims and Objectives

1.2.1 Aim

The aim of this project was to standardize the design of a cassava grating surface to improve efficiency and ensure interchangeability.

1.2.2 Specific Objectives

The specific objectives were to:

1. Survey existing cassava grating surfaces on the Ghanaian market to determine tooth diameter and inter tooth spacing
2. Analyze collected data from the survey
3. Design an effective grating surface using locally available materials with focus on teeth pattern (linear or random), tooth diameter and inter tooth spacing.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Grating is the transformation of cassava tubers into pulp. Usually, peeled cassava is fed into the hopper then to the grating drum which rotates at a constant speed. The most common graters are made of the horizontal axis cylinder with serrated metal surface. The abrasion action of the cylinder surface grinds against the cassava roots and reduce them to a mash. (Olumide, 2004).

2.2 Stone Graters

Small stone flakes have been presumed to be from manioc grater boards by Caribbean's. This inference is based on analogy with tropical rain forest groups who use stone toothed boards to grate bitter manioc. The teeth of these graters based on ethnographic evidence, replication experiments and use-wear analysis are small, bipolar flakes made of quartzite, porphy, obsidian or any other stone and could break with conchoidal or semi conchoidal fracture. The lengths of the teeth varied from 2 to10mm with one or more pointed ends. They could be flat, blocky, triangular or pyramidal in shape. The choice of stone was based on availability of suitable material. Grater teeth production and insertion into board was an exclusive female activity and was passed on from mother to daughter. Ethnographic evidence showed that, a large grater (about 1.5m long) could last for about 35 years. Refurbishing of the board was done after 10-15 years. Both light and dark quartzites of the same technical properties are used to obtain a decorative pattern on the face of the finished grater board (Gonzalez et al., 2014)

2.2.1 Making of the Grater Teeth

After collection of desired stone type, reduction is done by hitting the stones with the dull edge of an axe on a soft ground until a pile of irregular fragments of 2-5cm in diameter are obtained. The debris is discarded. The fragments are further broken with a large carpenter's hammer in the depression (8-10cm wide) of a solid concrete anvil. This is done in a light fast striking motion. To prevent materials from flying out, a ring of rags wrapped with coils of palmetto- leaf fibre is placed around the socket.

The fragments are sieved through a coarse mat to further remove dust and debris. Larger fragments are further reduced. Appropriate and suitable fragments are selected; they must be round but with a sharp projecting end. Softer stones may be usable but these tend to wear out faster.

Retouching of the selected fragments is done with an old 7 inch triangular file or an old machete on top of a metamorphic rock about 20x15x5 cm on the lap. Light striking of the tooth at this stage removes granular debitage, removes flaked or cracked fragments and creates a sharp edge which fits into the hole of the board surface. Boards are made by men with mahogany or cedar (about 50cm long). Holes for the teeth are made with a hammer and a nail in a circular decorative pattern traced on the board. Each tooth is placed in a hole by tapping a file on a 6 inch nail with a flattened end placed on top of the teeth. The teeth around the edges of the board are set first. Overall, 26 and 144 utilized and unutilized teeth respectively are produced. It was used to grate cassava, coconut, plantain and sweet potato for about 34 years. The 144 utilized teeth are all small, 2-7mm, blocky with a few sharp edges but steep angled arrisses to grate roots. For insertion, one edge is slightly pointed (Gonzalez et al., 2014).

Walter, prior to the above report, provided the only detailed account of the grater tooth manufacture by Taruma women of British Guiana.

Block- on – block reduction of large(4-20kg) porphy is followed by a direct free hand percussion of the product yielding 1 to $1^1/_2$ inch long and $^1/_{16}$ inch uniformly thick flakes. These are further reduced by bipolar technique with the board serving as an anvil. A machete blade is used as a percussor. A final retouch is attained using a bipolar technique and then tapped into prepared holes of the wooden board and then sealed with plant resins. The end products were pyramidal; more flattened with opposite sides being broader and were fixed in the board teeth with their broad axes parallel to the long axes of the board

The stone toothed grater and insertion of teeth into graters have been described by other authors; Farabee (1918 and 1924), Goldman (1963), ImThurn (1883), Taylor (1951), Whiffen (1915) and Wilbert (1972).

Wilbert (1972), states that a single board may contain as many as 3,000 individual teeth. Grater teeth varied with board material type and board type;

- Waiwai with dimensions ranging from 5.5 to10mm
- Black Carib ranging from 6 to10mm

  (Gonzalez et al., 2014)

Walker, independent of Wilk's ethnographic research, carried out a lithic replication experiment; reduction used at the archaeological site at St. Kitts, West Indies was replicated. Large cortical flakes were detached from rounded beach cobbles of chert by direct free hand percussion. This is followed by a bipolar reduction of cortical flakes, split cobble and direct free hand cores. Some of the bipolar flakes were retouched using a smaller anvil and hammer stone to produce small, straight flakes for insertion into the simulated grater board.

Percentages of the end and by- products of the technological attributes of the replicated sample and archaeological assemble when compared, confirm a reduction sequence similar to that described by Roth per historic Antilleans.

The simulated grater board was made by inserting two separate set of teeth into a board at opposite ends. One set had mostly large, irregularly shaped teeth with some thin, blocky and curved teeth. These had dimensions; 10-20mm length, 1-6mm thickness extending between 3-9mm above the binding matrix. This was used to grate about 3.6kg of cassava, sweet potato and *mtabaga*. It was observed that less damage was suffered by blockier flakes than thin and curved flakes when tapped into place during insertion. The second set; smaller, uniformly sized and spaced tooth had dimensions of 10mm length and 1-3mm thickness which extended 2-6mm above matrix and was used to grate 1.2kg of peeled cassava. (Gonzalez et al., 2014).

2.3 Traditional Graters

Over the years, several designs to reduce the stress in the manufacture and use of graters have been developed. The traditional method of grating cassava was by pounding it in a mortar with a pestle. Later, artisans developed hand graters. In most traditional and remote areas, hand graters are still used. This is made of tin or galvanized iron with perforations usually done with a 3mm nail and hammer. This leaves a raised jagged flange on the underside. The sharp protruding rims of the nail openings are turned outside and then mounted onto a flat piece of wood (Habibat, 2004).

Using hand graters can however be laborious, time consuming and dangerous. It takes about 10 to15 working hours to grate a tonne of peeled cassava (Adenuga and John, 2014). The peeled cassava is grated after an hour of washing to drain off excess water for easy handling, otherwise roots become too slippery to handle. Care and some skill are needed when grating manually to avoid grating of the fingers. Also, it is not possible to grate the whole root. About

3-5% is left ungrated (Adenuga and John, 2014). A skillful person is able to grate only about 20kg/h.

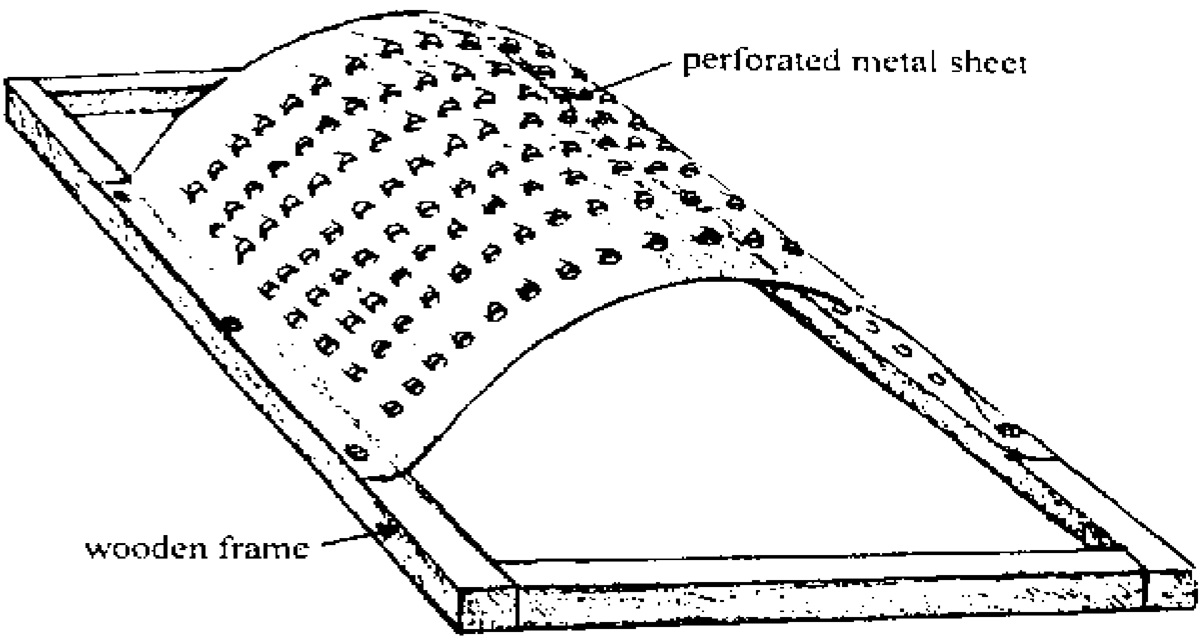

Figure 2.1: A Hand Grater

(Franklin, 2003)

Another type of grater that can be made locally is the nail grater, widely used in the Sago industry but less often used for roots. There are various designs; nails are held in a metal or wooden drum. The more nails there are, the better the grater works. A 20cm diameter grater of this type can run up to about 1500 rpm.

In larger factories, two curved plates are made from a 6mm steel plate in which each covers half of the circumference of the steel drum, typically 40cm diameter and 50cm long. These graters can be driven at 1500 rpm (Cecil, 1992).

2.4 Improved Graters

These are owned by either individual contractors who grate at a fee or by a group of processors. The major intervention in cassava processing in Ghana was the introduction of a medium-scale motorized cassava grater by the Agricultural Engineers Ltd in 1966. The cassava grater presented a great innovation in cassava processing since grating is central to traditional processing of cassava in Ghana. Since then, several equipment manufacturers including engineering firms, research institutes, university departments, small-scale artisanal shops, blacksmiths and mechanics have developed and produced various types of cassava processing equipment (FAO, 2005).

Farmers are able to utilize mechanized graters because diesel and gasoline are readily available. Mechanized graters have therefore shifted labour constraints from grating to the labour intensive tasks of harvesting, peeling and roasting. Also, the introduction of graters has eliminated stacking and fermentation of peeled cassava and therefore saves time. Nonetheless, existing graters have to be improved upon (FAO, 2008).

A survey by Davies et al., (2008) of the Department of Agricultural and Environmental Engineering of the Niger Delta University reveals that grating constitute 46.9% of cassava processing.

2.4.1 Pedal Operated Engines

These are usually used in areas where electricity accessibility is a problem. It consists of a pedal chain mechanism which is connected to a belt drive which turns the shaft on which the grater drum is mounted. It usually has a capacity of 60kg/h. The belt drive mechanism transmits power and speed from the chain drive to the drum. A flywheel which serves as a reservoir of energy is connected to the transmission system. This machine makes use of the gravitational movement of the cassava as well as the gradual movement during grating. The following mathematical considerations were made:

$$T = \frac{P}{\omega} \text{ ……………equation 2.1}$$

where

T=Torque

P=Power

ω = angular acceleration

and $\omega = \frac{2\pi N}{60}$ ……………equation 1a

$$T_e = \frac{\pi}{16} \times \tau \times D_s^3 \qquad \text{……………… equation 2.2}$$

where

T_e = equivalent twist moment

τ = permissible shear stress of the shaft material

D_s = diameter of the shaft

And

$$T_{e=} \sqrt{M^2 + T^2} \qquad \text{…………… equation 2.3}$$

M= maximum bending moment

Also,

$$D_e N_e = D_d N_d \qquad \ldots\ldots\ldots\ldots \text{equation 2.4}$$

where

D_e = diameter of driver pulley

D_d = diameter of the driven pulley

N_e = speed of driver in rpm

N_d = speed of driven in rpm

$$L = \frac{\pi(D_d + D_e)}{2} + 2C + \frac{(D_d - D_e)^2}{4C} \ldots\ldots\ldots\ldots \text{equation 2.5}$$

where

L= length of belt

C= distance between the centres of the two pulleys

$$\theta = (180° - 2\alpha)\left(\frac{\pi}{180}\right) \text{rad} \ldots\ldots\ldots\ldots \text{equation 2.6}$$

θ = lap angle of belt over pedal driver pulley

And

$$\alpha = \text{Sin}^{-1}\frac{(D_e - D_d)}{2C} \ldots\ldots\ldots\ldots \text{equation 2.7}$$

(Ajao et al., 2013)

2.4.2 Dual- Operational Mode Machine

Ndaliman (2006), in his design of a dual- operational mode machine (operated both manually and electrically), sought to improve on the design of Adejumo (1995) who designed a wooden grater which was low in durability and had an effective performance of 60%.

Thus, his design was made mostly of mild steel and had efficiencies of 92.4% and 91.4% when operated manually and electrically respectively. The following design considerations were made; a hopper with a rectangular cross- section, a cylindrical grating drum and a solid circular shaft.

When operated electrically, the machine is coupled to an electric motor by a V-belt pulley on the shaft. On the other hand, when operated manually, a steer is used to set the drum. However, a piece of wood had to be used to press the drum to prevent scattering due to vibration of the machine. The grating efficiency was calculated as follows;

$$\eta_g = \frac{W_r}{W_f} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots \text{equation 2.8}$$

where

$$\eta_g = \text{grating efficiency}$$

$W_r = \text{total weight recovered}$

$W_f = \text{total weight fed in}$

(Ndaliman, 2006)

However, mild steel could rust with time and consequently, affect the quality of grated mash.

2.4.3 NASENI Mobile Cassava Grater

The NASENI Mobile Cassava Grater produced by the Scientific Equipment Development Institute (SEDI) in Enugu, Nigeria, has materials for construction appropriately selected to satisfy functional and hygienic requirements. The contact surfaces are made of stainless steel. The grater comprises of the main frame, hopper, tyre on wheel, grating drum, shoot, pulley and a 6.6Hp mover. It has a capacity of 300-500kg/h. the prime mover can be cooled with water. It has dimensions of 46. 74m length, 25.4m width and 40.64m height.

2.4.4 ARCADEM Grater

The ARCADEM Grater, produced by ARCADEM Africa Regional Centre for Engineering Designs and Manufacturing, Ibadan, Nigeria, also has a grating drum made of stainless steel while the hopper and chute are made of either painted mild steel or galvanized/stainless steel. It has a power drive of 5.2Hp petrol or diesel engine and can run a matching electric motor. It has a production capacity of 1t/h and dimensions (mm) of 1090 height, 1000 length and 460 width.

2.4.5 STARRON Cassava Grater

The STARRON Cassava Grater, produced by Starron Nigeria Limited, Lagos, Nigeria is also made of stainless steel, is mobile and has a 3 or 5Hp engine (petrol or diesel) and can be operated electrically. It has a production capacity of 150kg/h which is relatively low and a fuel consumption of 1L/h. The overall dimensions (in centimeters) are 111.76×91.44×60.96 and costs from N65, 000 to N75, 000 which is rather expensive for a 150kg/h capacity grater. (IITA et al., 2005).

2.4.6 The JAHN Grater

The Jahn grater consists of a rotating drum on which replaceable serrated flat blades, similar to saw blades are mounted. The individual blades are made up of steel about 1mm thick and available for different lengths such as 10, 20 and 30 cm. They are 2cm wide with a teeth along each long side. The teeth may be 2 or 3mm deep with tips of 1.5 to 2.5mm apart (Cecil, 1992).

2.4.7 NIJI-LUKAS Electrical Grater

The NIJI-LUKAS Electrical Grater produced by NIJI Nigerian Limited though with a capacity of 300kg/h is operated only electrically. This means an extra cost of buying or hiring a generator would have to be incurred otherwise, grating activity would have to remain stand still until there is power again. It operates on a 3 phase, 5Hp and 1400 rpm motor. It has the following dimensions (centimeters); 76.2×76.2×106.68 and costs US$1347.80 which is also quite expensive.

(USAID Nigeria, 2005)

2.4.8 The IITA 202

The IITA 202 Model designed by Y.W. Jeong is made of mild, galvanized or stainless steel. Bend shears are used to bend metals to fit into the appropriate component sizes. Cutting and drilling of metals are done with a shaft followed by machining of metal and metal components to size with a centre or combine lathe. To make the drum, the metal is cut to a circumference preferred by the manufacturer and then rolled with a rolling machine to form a cylindrical shaped drum. This is then knotted to keep it in shape. Perforations are then made with either a machine or a nail. The chute is cut and shaped to fit the entrance of the rolling grater. (IITA, 2005)

2.4.9 GF IITA

It has the following components; a pressing board, hopper, clearance adjustment board, grating roller, mainframe, transport wheel and an engine (mainly a petrol engine). The grating drum is mobile with a removable two wheel assembly, an oval shaped hopper with the aim of reducing spillage of the grated cassava dough, a hand held press to make the operator use less effort and also, to increase contact between cassava and grating drum. The ends of the grating drum run centrally and are housed in 'pillow-block' bearings. The clearance adjustment boards which 'slide' through a slot in between two bolts loosen to fit the board. Rigidity and design of the board enable uniform size of grated cassava. This design has been modified by KNUST and the GRATIS foundation with the GF IITA 202 design and is not very different from the IITA 202 (Nuer, 2010).

COMPONENT PARTS LIST

Item	DESCRIPTION	QTY	Item	DESCRIPTION	QTY
1	BASE PLATE, 6 thk. x 75 x 75 M.S. Plate	4	8	HOR'Z. FRAME, 5 thk. x 50 x 300 lng. M. S. ∠- Bar	1
2	CONNECTING BAR, 5 thk. x 25 x 300 lng. M. S. ∠- Bar	2	9	HANDLE, 32 Ø B.I. Pipe	1
3	VERT. FRAME, 5 thk. x 50 x 600 lng. M. S. ∠- Bar	4	10	SHAFT, 19 Ø CRS	1
4	HOR'Z FRAME, 5 thk. x 50 x 400 lng. M. S. ∠- Bar	3	11	ROLLER, 168 O.D. B.I. Pipe	1
5	HOR'Z FRAME, 5 thk. x 50 x 800 lng. M. S. ∠- Bar	2	12	FLANGE, 3 thk. M.S. Plate	2
6	CONNECTING BAR, 5 thk. x 25 x 800 lng. M. S. ∠- Bar	2	13	GRATING PLATE, Ga. 16 G.I. Sheet	1
7	GUIDE BRACKET, 3 thk. x 25 M.S. Flat Bar	2	14	POP RIVET, 3 Ø x 10 lng. (Qty. determined on assembly)	

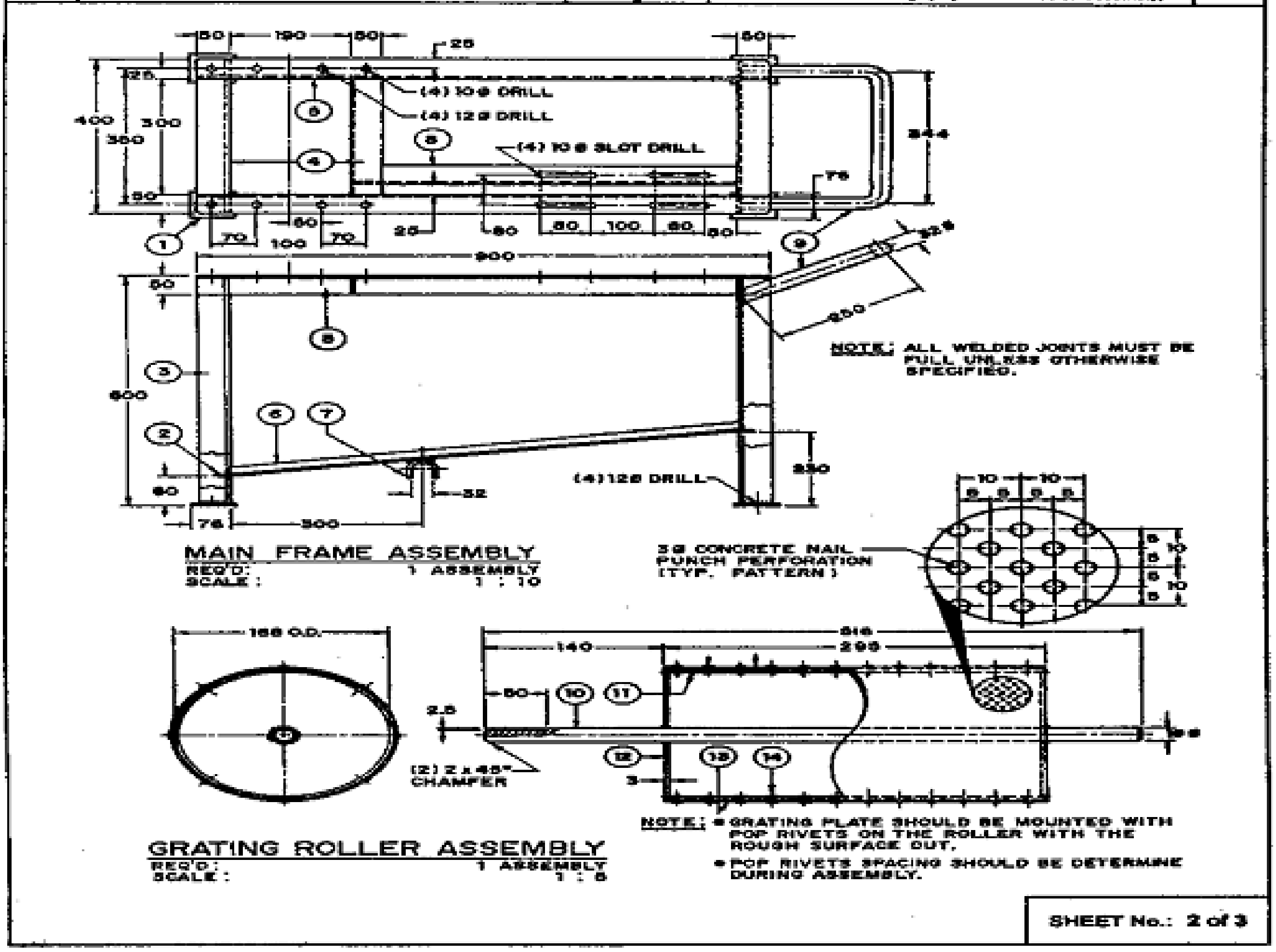

Figure 2.2: IITA 202 describing component parts and dimensions and how grating plate should be mounted

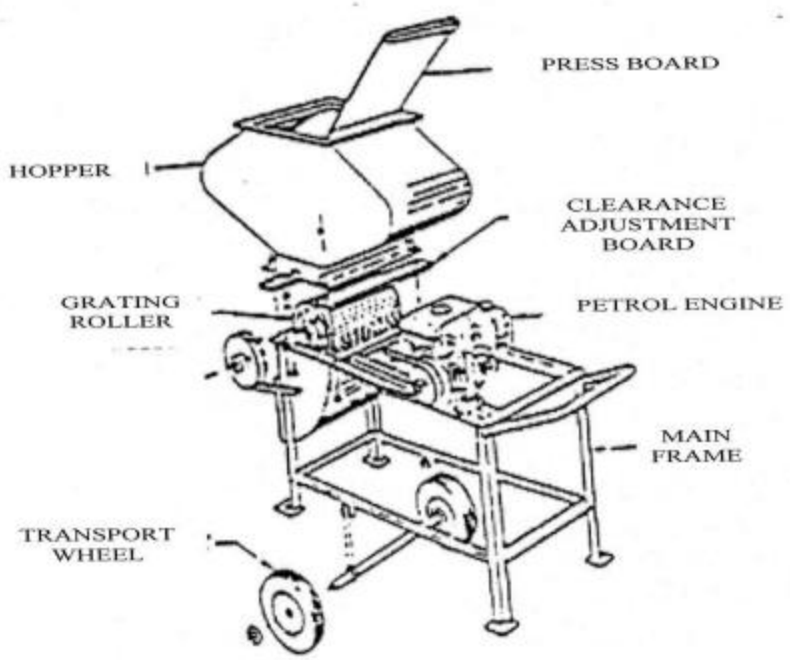

Figure 2.3: The GF IITA 202

(Nuer, 2010)

2.4.10 Other Designs

Also available are graters by the Intermediate Technology Development Group in Nigeria produced in the early 1970's which used hacksaw blades and other simple spare parts mounted on a vertical disc. The Wadwha disc grater (operated by paddling) in Ghana and driven by a 5Hp engine consisting of a disc shaped wooden block to which a perforated metal sheet is nailed is available. The discs run at 1550rpm, is self-cleaning and has a throughput of 500kg/h. Also in Sierra- Leone is a vertical drum grater by Tikonko Agricultural Extension Centre powered by a 4Hp electric motor or diesel engine with a throughput of 300-1000kg/h. Cameroon also has Cylindrical power graters designed by CENEEMA

In as much as manufacturers would want to improve on materials used in making graters, it can be said that due to the high cost of appropriate materials (e.g. stainless steel) and the inability of processors to afford the high priced graters even though they need such high quality materials, there is almost always a compromise on the use of materials such as stainless steel in order to make graters affordable. It can also be said that, in order to ensure durability and sustainability, strength, suitability and local availability have to be considered when choosing material for design. (Adegun et al., 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Survey materials such as a tape measure, a digital camera, a thread and a magnet were used. The tape measure was used for taking measurements of tooth diameter and inter tooth spacing of grating drums at the various cassava processing sites. The digital camera was used for taking shots of grating drums and processes involved in making grating surfaces. In order to check if the material for making the grating surface was stainless steel, a magnet was used as stainless steel containing nickel inhibit magnetic properties.

Stainless steel was entirely used for the construction of the grater on which the designed grating surfaces were tested except the stand. Galvanized steel was used for making the legs/ stand of the grater as it had no direct contact with the food to be processed

During processing of the cassava, equipment such as a variable motor and a tachometer were used. The variable motor was used for varying the speed of the rotor of the grater through a belt. The tachometer was also used for checking the speed of the variable motor. Since the grated cassava was made all the way into gari, processing equipment such as a press was used for dewatering the grated mash. Woven sieves were also used for checking the fineness of the grated mash. A weighing scale was used for weighing cassava before grating, grated mash and the coarse grate after sieving.

3.2 Methods

3.2.1 Survey of existing graters in three regions of Ghana

A survey was carried out by interviews at selected processing sites across three regions of Ghana; Western, Central and Ashanti regions to take measurements of tooth diameter and inter tooth spacing on the grating surfaces and know how they affect the particle sizes of the grated cassava.

In the Western region, grating sites at Esuogya, Kwesimintsim, Effiakuma, Apremdo and Kojokrom were visited. In the Ashanti region of Ghana, three grating sites at Accra Town near Opoku Transport in Kumasi, Konongo, Pekyerekye and Adumkrom were surveyed. A single grating site in the Central region was surveyed.

During the survey, observations were also made on tooth pattern (linear or random) and sharpness of grater (number of times cassava is passed though to achieve desired results). Also, operators of these existing graters were asked about their observations on existing grating surfaces.

3.2.2 Survey of Manufacturing Sites

A survey was carried out at ten manufacturing sites, particularly, at Suame magazine in Kumasi. Several manufacturers were met and the following were observed and asked;

- What manufacturers take into consideration before making teeth
- How they make drum teeth i.e. the processes they go through to make the teeth
- Which parameters of the drum they take measurements on and which ones they do not during manufacturing.
- What materials they use in making the drum and why they use them
- How long it takes for them to make the teeth of the drum.

3.2.3 Survey of Gari Processors

A survey was carried out also at two major gari processing sites in the Ashanti region of Ghana. Processors were asked about their views on existing graters and what they think manufacturers and grater operators must also do with regards to grating surfaces. They were also asked about how the quality (in terms of particle size) of gari they produce is affected by these grating surfaces.

3.2.4 Calculation and Analysis of Surveyed Data

After taking measurements of the diameter of teeth and inter tooth spacing, calculations on the mean of each measured parameter at each processing site was determined. The means of the various measured parameters were then calculated. The standard deviations and standard error of the means were also calculated. All calculations were done using Microsoft excel.

3.2.5 Design of Grating Surfaces and Experimentation

Three grating surfaces with varied inter tooth spacing and tooth diameter were designed. The tooth angle for each grating surface was 45° to ensure effective contact between the cassava and the grating surface. The three designed grating surfaces were produced by a teeth manufacturer at Suame Magazine. The designed grating surfaces were then coded AA, BB and CC. Three varied speeds; 600,650 and 700 rpm were used in the operation of each of the three designed grating surfaces as the available motor could produce a maximum speed of 700 rpm. Operation of the three designed grating surfaces was carried out at the Department of Agricultural Engineering workshop, KNUST.

The processes involved in producing the grating surfaces included:

1. The preparation of material by straightening with a hammer and cutting into right size,
2. Marking out of pattern and
3. Punching of the teeth with a hammer and punch.

Figure 3.1: Preparation of Material

Figure 3.2: Marking out of sheet

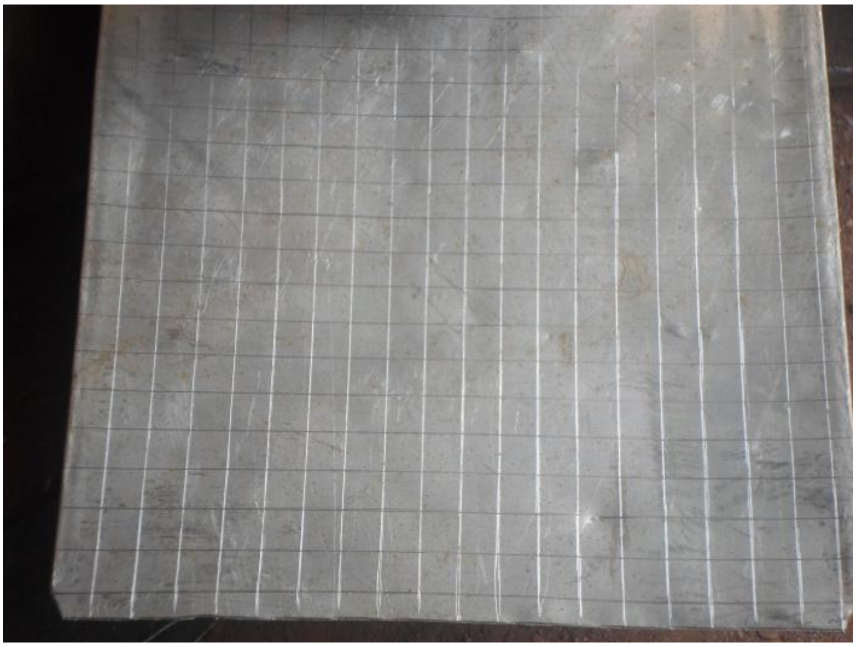

Figure 3.3: Marked out pattern on metal sheet

Figure 3.4: Punching process

Figure 3.5: Punched sheet

The punch used in making grating surfaces has the following details;

Length: 127mm

Diameter of punch: 38.1 mm

Diameter around tip: 9.53 mm

A photograph of the punch used in making the grating surfaces is shown in Figure A9 in Appendix 1

The Upper and Lower Limits for both the tooth diameter and the inter tooth spacing of the selected design were also calculated;

$\mathrm{UL} = \mu + (SE \times 1.96)$ …………..equation 3.1

where

UL= Upper Limit

$\mu = \text{mean}$

SE= Standard Error of the Mean

Also,

LL= $\mu - (\mathrm{SE} \times 1.96)$…………equation 3.2

where

LL= Lower Limit

μ = Mean

SE= Standard Error of the Mean

(Forbes et al., 2010)

3.2.6 Particle Size Analysis of Various Gari Produced

Particle size analysis of the gari was done at the Department of Pharmaceutics at KNUST using a mechanical shaker. One hundred and fifty grams (150g) of each sample was analyzed at amplitude of 90 for 20 minutes. The gari of all six grating surfaces used were then analyzed for fineness modulus, average particle size and uniformity coefficient.

Fineness Modulus (FM) rates a sample on how rough or smooth it is on a scale of one (1) to seven (7) with 7 being coarse. Fineness Modulus is determined using the equation below

$\mathrm{FM} = \frac{\sum \mathrm{RF}}{100}$…………equation 3.3

where

R= weight of gari retained on sieve

F= multiplication factor

The Average Particle Size (APS) is calculated as

$\mathrm{APS} = 0.0041 \times 25.4\mathrm{mm} \times 2^{\mathrm{FM}}$ …………………. equation 3.4

where

FM= fineness Modulus

Uniformity coefficient is the degree of variation in the size of the grains that constitute a granular material; the ratio of (a) the diameter of a grain of a size that is barely too large to pass through a sieve that allows 60% of the material (by weight) to pass through to (b) the diameter of a grain of a size that is barely too large to pass through a sieve that allows 10% of the same material (by weight to pass through).

$\mathrm{UC} = \frac{\mathrm{D}_{60}}{\mathrm{D}_{10}}$…………..equation 3.5

where

UC= uniformity coefficient

D_{60} = the diameter of a grain of a size that allows 60% of the material to pass through

D_{10} = the diameter of a grain of a size that allows 10% of the material to pass through

Efficiency of the grater (η_g) was also calculated in terms of weight of cassava after grating (W_r) and cassava fed in grater (W_f). The efficiencies for the three designed grating surfaces were calculated using equation 3.6 below

i.e. $\eta_g = \frac{W_r}{W_f} \times 100$……………..equation 3.6

3.2.7 Limitations of The Work

In the Western region, some processors at the grating sites did not allow for pictures and measurements to be taken. This happened in the bigger grating sites. The operators of these sites were unwilling to open up because; they did not want to get involved with 'an agent'from a food regulatory agency who could get them into trouble, as they were not operating using the appropriate sanitary conditions, changing worn out teeth of graters, using right materials for graters and other reasons best known to the processors.

Also, during review of literature, information on grating surfaces, especially, tooth diameter and inter tooth spacing was very minimal. However, most literature gathered talked about general grater dimensions such as length and width. With regard to grating surfaces, drum length and circumference were discussed and sometimes, the speed of the motor.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Survey of Existing Graters

Results from the sixteen (16) surveyed cassava grating sites showing mean values of measurements for tooth diameter and inter tooth spacing are presented in Table 4.1.

The maximum mean tooth diameter was 4mm while the minimum mean tooth diameter was 2mm. The minimum value for the mean inter tooth spacing was 4mm while the maximum value was 12.5mm.

Table 4.1: Grater Dimensions at Surveyed Grating Sites

Site Number	Location	Mean Tooth Diameter (mm)	Mean Inter Tooth Spacing (mm)	Inter-tooth Spacing: Tooth Diameter
		Western Region		
1	Esuogya 1	4	7.5	1.86
2	Esuogya 2	4	7.5	1.88
3	Kwesimintsim 1	4	4	1
4	Kwesimintsim 2	3.8	4	1.05
5	Effiakuma 1	2.5	7.3	2.92
6	Effiakuma 2	3.5	8.5	2.43
7	Effiakuma 3	3.2	12.5	3.91
8	Apremdo 1	3.5	10.2	2.91
9	Apremdo 2	3.2	10.5	3.28
		Central Region		
10	Kotokoraba	2	5.8	2.90
		Ashanti Region		
11	Konongo 1	2.5	6.5	2.60
12	Konongo 2	3.2	6.8	2.13
13	Kojokrom	3.4	6.4	1.88
14	Adumkrom	2.8	7.3	2.61
15	Pekyerekye	3.3	8.7	2.64
16	Accra Town	4	9.5	2.38

From Table 4.1, the range of mean tooth diameter values (2 to 4mm) is quite wide and is likely to be a cause of the wide range of particle sizes of gari on the market. The range of the mean inter tooth spacing values (4-12.5mm) is also too wide and likely to affect the number of teeth on the drum to affect grating; the wider the inter tooth spacing, the fewer the number of teeth on drum to affect grating. Also, there are more teeth on the drum to effect grating if the inter tooth spacing is not too wide.

Table 4.2 shows the calculated mean, standard deviation and standard error of the tooth diameter and average inter tooth spacing of the sixteen (16) grating surfaces surveyed.

Table 4.2: Analysis of Surveyed Data

Parameters	Tooth Diameter (mm)	Inter- tooth Spacing (mm)
Mean(π)	3.3	7.4
Standard Deviation (σ)	0.6	1.8
Standard Error (SE)	0.06	0.18
Upper Limit [π+(SE×1.96)]	3.42	10.93
Lower Limit [π-(SE×1.96)]	3.18	3.87
Mean ± standard deviation(π±σ)	3.3±0.6	7.4±1.8
Mean±2(Standard Deviation)	3.3±2(0.6)	7.4±2(1.8)

For the tooth diameters surveyed, the mean was 3.3mm with a standard deviation of 0.6mm. This means that, the distribution of tooth diameters surveyed was from about 2.7mm to 3.9mm. The standard error of the mean was 0.06. The margin of error (at 95% confidence) from the mean tooth diameter was ±1.2mm from 3.3mm (i.e.2.1mm to 4.5mm). This falls within the range of 2mm to 7mm for stone graters reported by Walker and Wilk (1979) and closer to Jahn's grater whose tooth diameter ranges from 2mm to 3mm reported by Cecil (1992). Also, the IITA 202 and the GF IITA designs have teeth made with a 3mm concrete nail for making the perforations (Nuer, 2010). The Upper limit for the surveyed tooth diameters was 3.42mm and the Lower limit, 3.18mm.

For the inter tooth spacing, the minimum value was 4mm while the maximum value was 12.5mm. The mean inter tooth spacing was 7.4mm while the standard deviation was 1.8mm. This means that, most of the mean inter tooth spacing values recorded ranged from about 5.6mm to about 9.2mm. The standard error of the mean was 0.18. The margin of error, at 95% confidence from the mean inter tooth spacing (7.4mm) was ±3.6mm (i.e. 3.8mm to 11mm). This range for inter tooth spacing is too wide and could be as a result of random punching of teeth without an initial marking out. The Upper limit was 10.93mm and the Lower limit was 3.87mm which are quite wide. This means that, there do not seem to be any definite range for inter tooth spacing for cassava grating surfaces. This wide range is likely to affect the number of teeth on a grating surface (i.e. the wider the tooth spacing, the fewer the number of teeth), thus affecting the contact time between the cassava and grating surface. For a grating surface with a wider inter tooth spacing, there would be fewer teeth to effect grating, thus, an increased grating time.

4.1.2 Survey of Manufacturing Sites

Ten manufacturers of graters and grater teeth were met on site at the Western and Ashanti regions, mostly at Suame magazine and the following were gathered;

- The brick arrangement of teeth is most desired by customers as it ensures effective contact between the cassava and grating surface, thus reducing grating time.
- The making of the teeth or grating surface of graters is time consuming. Therefore, most grater manufacturers used inexperienced apprentices to make the grating surfaces by punching with a hammer and a nail/ punch in a dense random pattern without marking out. Making of the teeth pattern usually requires about two to three hours.
- Most grater manufacturers use mild or galvanized steel to make the grating surface unless ordered by restaurant operators for cassava mashing into fufu where they use

stainless steel. Some even use any white material as the customers do not know the difference between a white metal and stainless steel. Notwithstanding, the materials used in the making of the teeth is dependent on the customer's choice as the better the material, the more expensive it is.

4.1.3 Survey of Gari Processors

Twenty five gari processors were also interviewed for their views on existing graters. Some of the information gathered include:

1. Saw toothed grating surfaces produce coarser grates.
2. Gari processors have to break the coarse grates with the tip of their fingers to effect size reduction otherwise re-grating has to be done.
3. Saw toothed grating surfaces grate faster but produce coarser grates as compared to punched grating surfaces.
4. When the grating surface becomes blunt, it produces very coarse grates which are undesirable and have to be re-grated which means extra cost incurred.

4.1.4 Design Specifications and Criteria

Three grating surfaces with the following specifications were designed based on calculations and analysis from the collected data from the conducted survey.

Table 4.3: Specifications of Designed Grating surfaces

Grating Surface	Average Inter-Tooth Spacing (mm)	Average Tooth Diameter (mm)	Angle (°C)	Material Used	Material Thickness (mm)
AA	8	2	45	Stainless steel	1.5
BB	8	3	45	Stainless steel	1.25
CC	12	2	45	Stainless steel	1.25

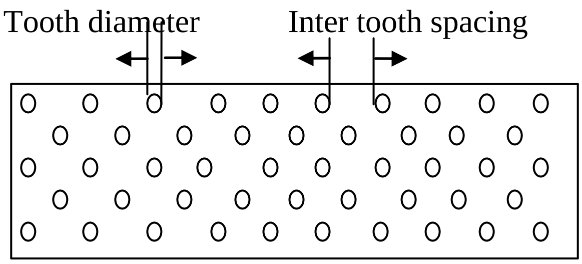

Figure 4.1: Grating Surface Dimensions

The best design was selected based on the result from the following

- Weight of cassava before grating
- Weight of cassava after grating
- Fineness of mash(determined by feel of mash on finger tips of gari manufacturers)
- Weight of coarse grate (this weight is determined after pressing and sieving of the grated cassava)
- Average particle size of gari produced from a particular grating surface

4.1.5 Results From Grating Surfaces

Figure 4.2 is a graph of speed against time for grating surface 1(AA). At 600 rpm, it takes 686 seconds to grate 6.5 kg of cassava. At 650 rpm, the grating time reduces to 434 seconds and then 346 seconds at 700rpm.

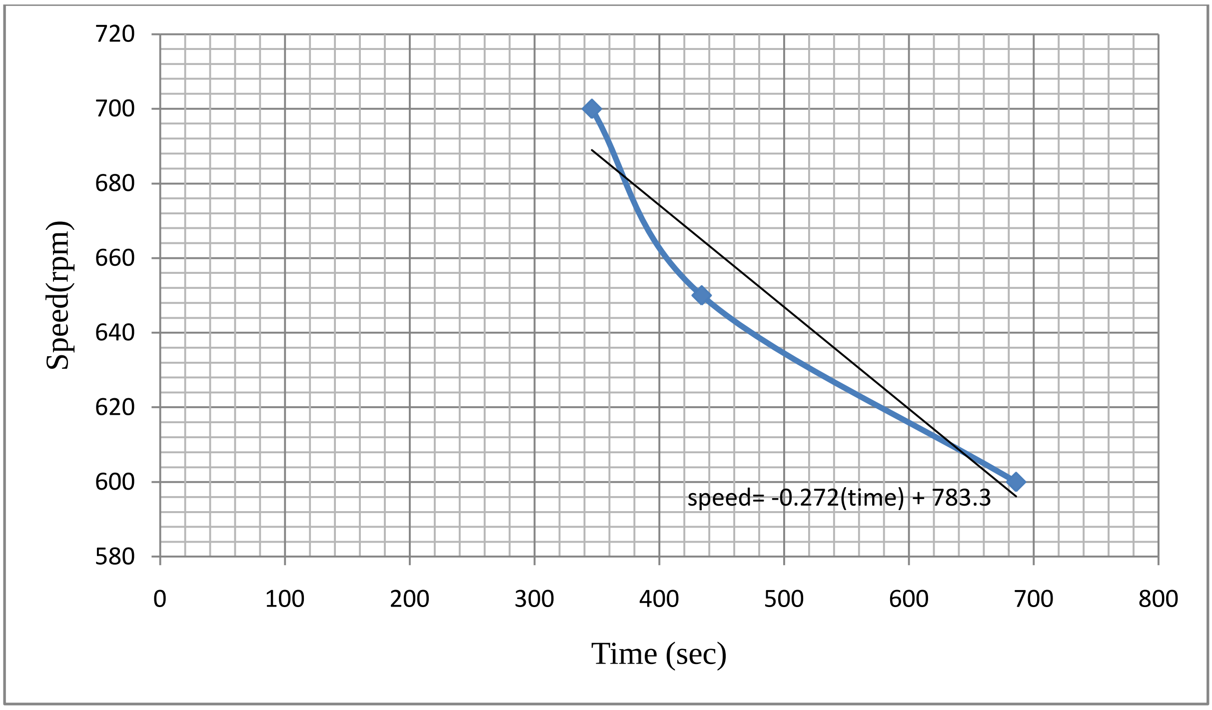

Figure 4.2: A Graph of Speed Against Time For Grating Surface 1

Figure 4.2 above shows a graph of speed against time for grating surface 1 where there is a decrease in grating time with speed. The equation of the curve is

Speed=-0.272(time)+783.3 …………………….……….. equation 4.1

Figure 4.3 shows a graph of the % cumulative weight of gari from grating surface 1 retained at each aperture size of sieve. The percentage weight of gari retained at an aperture size of 2360 µ was 0.14%. It then cumulated to 3.57% at 1700 µ and then to 15.72% at 1180 µ. At 850 µ, it cumulated slightly to16.62% and then cumulated sharply to 75.81% at 425 µ. At 250 µ, it cumulated to 96.36% and then to 99.53% at 180 µ. Finally, at 75 µ, it cumulated to 100%. No gari was found on the bottom pan of the mechanical shaker.

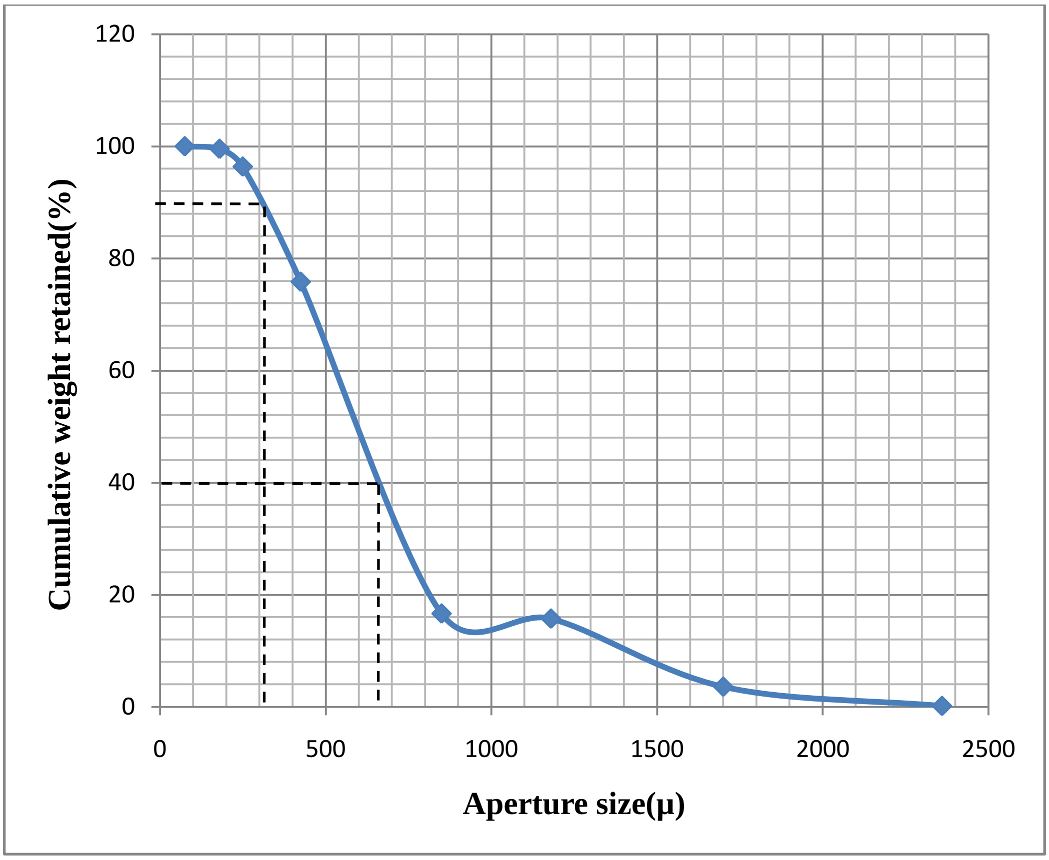

Figure 4.3: Particle Size Analysis For Grating Surface 1

From Figure 4.3, 40% of the cumulative weight retained (i.e. 60% passing) corresponds to 682.13µ and 90% of the cumulative weight retained (i.e. 10% of the cumulative weight passing) also corresponds to 304.16µ. Therefore, the uniformity coefficient is 2.24. This value of uniformity coefficient for gari from grating surface1 when compared to sand falls within the range of coarse sand; 0.63 to 2mm (ISO 14688-1).

Also, the fineness modulus (FM),on a scale of 1 to 7(1 being very fine and 7 being very coarse) obtained for the gari produced from grating surface 1 was 4.08 which is quite high and the average particle size was 1.76mm.

Figure 4.4 shows a graph of grating speed against time for grating surface 2. At 600 rpm, it took 342seconds to grate 6.5 kg of cassava. At 650 rpm, the grating time reduced to 215 seconds and then reduced again to 102 seconds at 700 rpm.

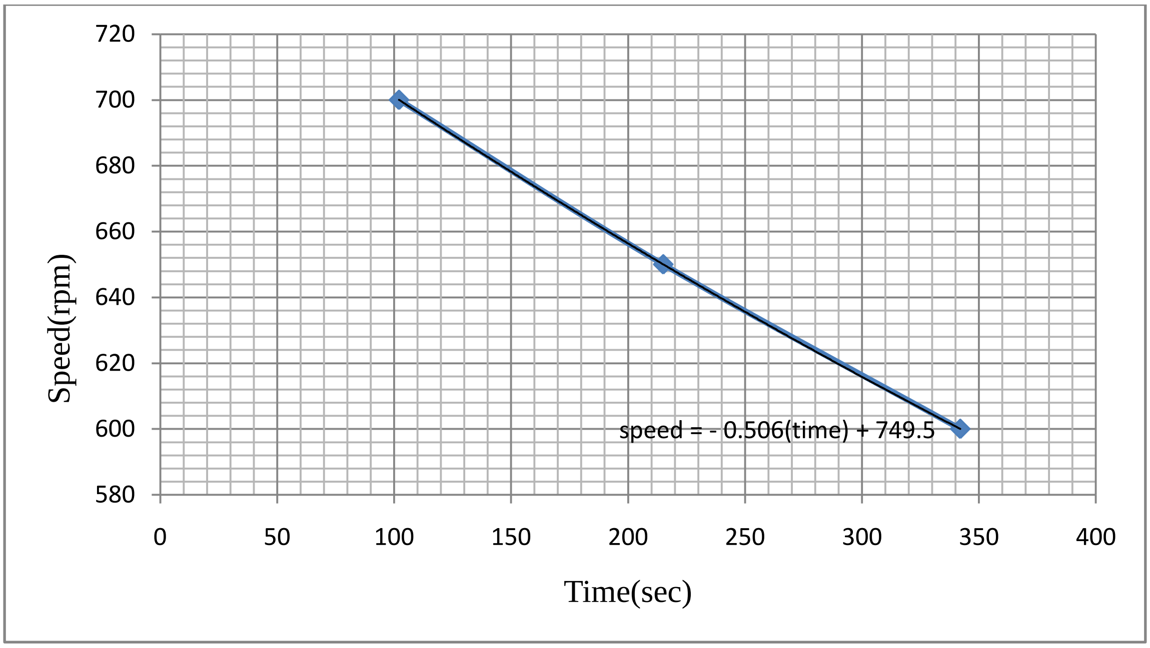

Figure 4.4: A Graph of Speed Against Time For Grating Surface 2

Figure 4.4 shows a graph of speed against time for grating surface 2 where there is a decrease in grating time with increased speed. The equation of the curve is

speed = - 0.506(time) + 749.5…………………………. equation 4.2

Figure 4.5 shows a graph of the % cumulative weight of gari from grating surface 2 retained at each aperture size of sieve. The percentage weight of gari retained at an aperture size of 2360 µ was 0.15%. It then cumulated to 2.55% at 1700 µ and then to 10.43% at 1180 µ. At 850 µ, it cumulated slightly to10.63% and then cumulated sharply to 69.31% at 425 µ. At 250 µ, it cumulated to 94.55% and then to 98.58% at 180 µ. Finally, at 75 µ, it cumulated to 100%. No gari was found on the pan of the mechanical shaker.

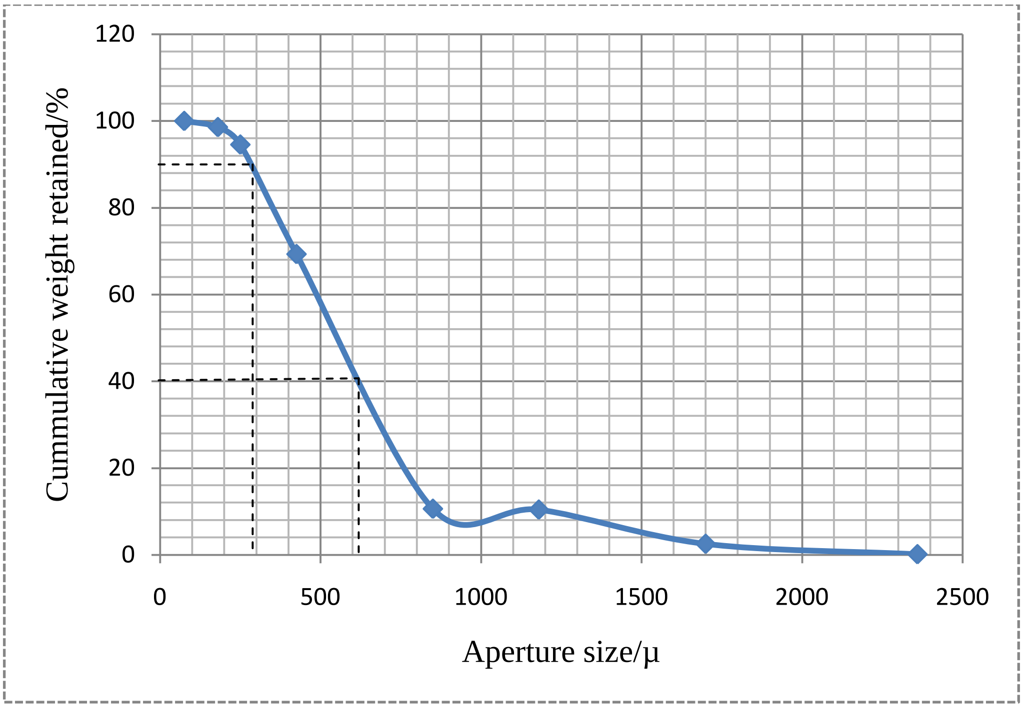

Figure 4.5: A graph of the cumulative weight of gari from Grating Surface 2 retained on standard sieves

From Figure 4.5, 40% of the cumulative weight retained (i.e. 60% passing) corresponds to 637.61µ and 90% of the cumulative weight retained (i.e. 10% of the cumulative weight passing) also corresponds to 281.55µ. Therefore, the uniformity coefficient was 2.26. This value of uniformity coefficient for gari when compared to sand also falls within the range of coarse sand.

The fineness modulus (FM),on a scale of 1 to 7(1 being very fine and 7 being very coarse) obtained for the gari produced from grating surface 2 was 3.86 and the average particle size was 1.51mm.

The results obtained from grating surface 2(BB) indicates a decrease in particle size of gari as compared with that from grating surface 1 though grating surface 1 had a smaller tooth diameter of 2mm. This is because, the grated mash from Grating surface 1(AA) was too fine for the purpose of gari making. If the mash is too fine, it is difficult to control the particle size during roasting and clods are formed, thus resulting in a bigger particle size of gari.

Figure 4.6 is a graph of speed against time for Grating surface 3 (CC). At 600 rpm, it took 296 seconds to grate 6.5 kg of cassava. At 650 rpm, the grating time reduced to 238seconds and then reduced again to 141seconds at 700rpm.

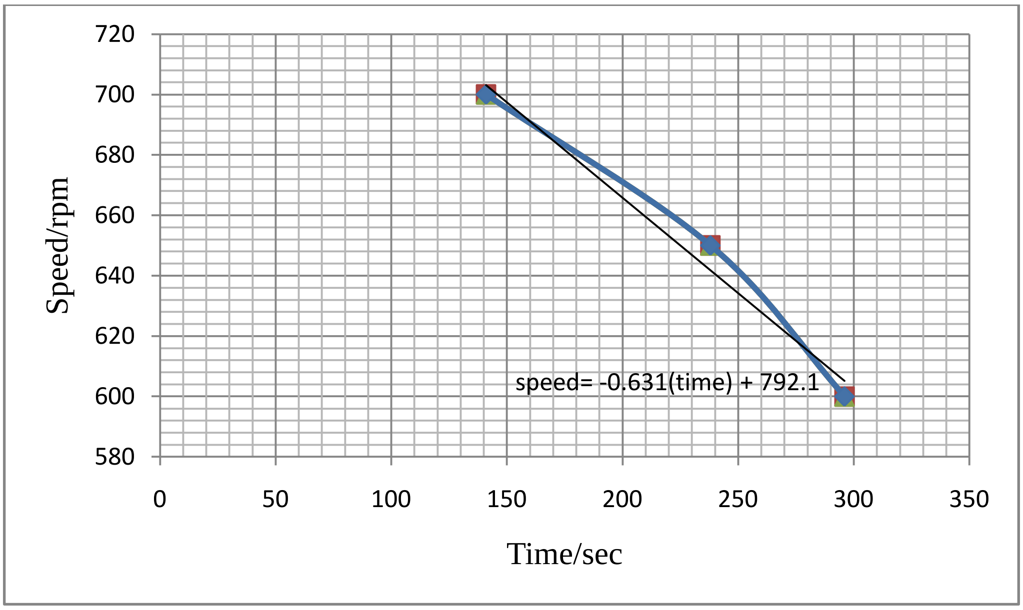

Figure 4.6: A Graph Of Speed Against Grating Time For Grating Surface 3

Figure 4.6 shows a decrease in grating time with increased speed and the equation of the curve is speed= -0.631(time) + 792.1........................equation 4.3

It was observed that the grating time reduced with increased speed.

Figure 4.7 shows a graph of the % cumulative weight of gari from grating surface 3 retained at each aperture size of sieve. The percentage weight of gari retained on an aperture size of 2360 µ was 0.01%. It then cumulated to 2.71% at 1700 µ and then to 11.56% at 1180 µ. At 850 µ, it cumulated slightly to11.57% and then cumulated sharply to 63.46% at 425 µ. At 250 µ, it cumulated to 90.81% and then to 97.06% at 180 µ. Finally, at 75 µ, it cumulated to 100%. No gari was found on the pan of the mechanical shaker.

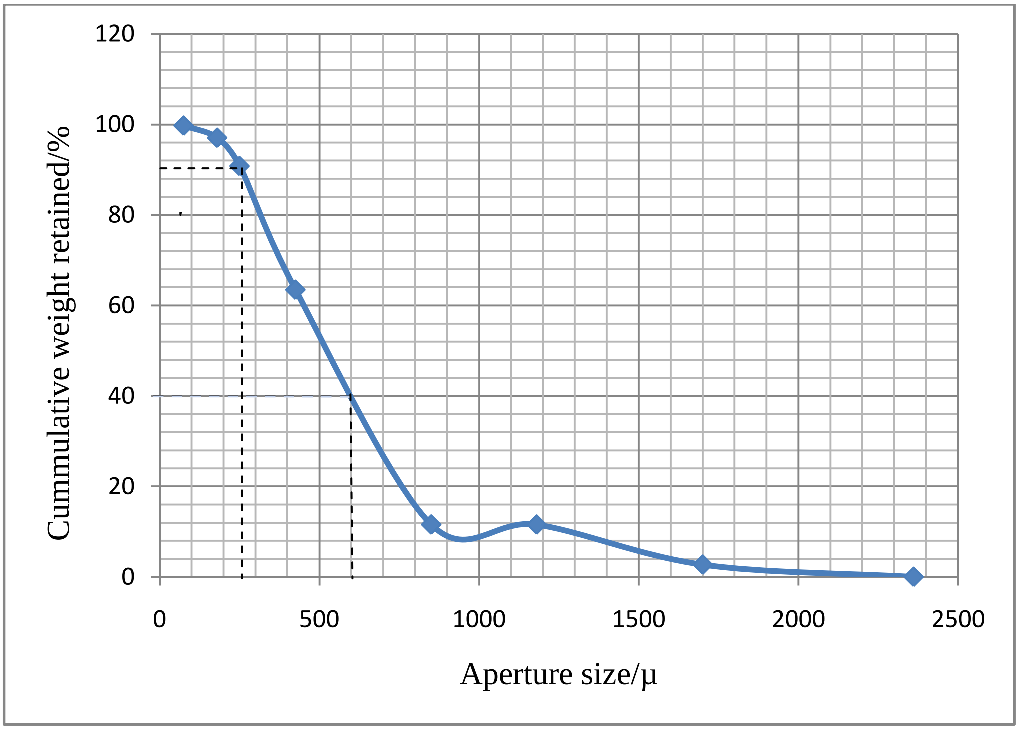

Figure 4.7: Cumulative weight of gari produced from Grating Surface 3 retained on standard sieves

From Figure 4.7, 40% of the cumulative weight retained (i.e. 60% passing) corresponds to 617.15µ and 90% of the cumulative weight retained (i.e. 10% of the cumulative weight passing) also corresponds to 254.25µ. Therefore, the uniformity coefficient was 2.43. The value of uniformity coefficient for gari from grating surface 3 when compared to sand falls within the range of coarse sand (0.63-2mm).

Also, the fineness modulus (FM),on a scale of 1 to 7(1 being very fine and 7 being very coarse) obtained for the gari produced from grating surface 3 was 3.77 and the average particle size was 1.42mm.

Three already existing grating surfaces, coded DD, EE and FF used by gari processors were also used to grate cassava and roasted into gari. The motors used for DD, EE and FF were not variable. The following were observed;

Figure 4.8 is a graph of the percentage cumulative weight of gari from grating surface 4(DD) retained on several aperture sizes of sieves; the percentage weight of gari retained at an aperture size of 2360 μ was 0.5%. It then cumulated to 5.43% at 1700 μ and then to 16.59% at 1180 μ. At 850 μ, it cumulated to 17.05% and then cumulated sharply to 70.26% at 425 μ. At 250 μ, it cumulated to93.37%, then to 97.79% at 180 μ and then lastly to100% at 75 μ.

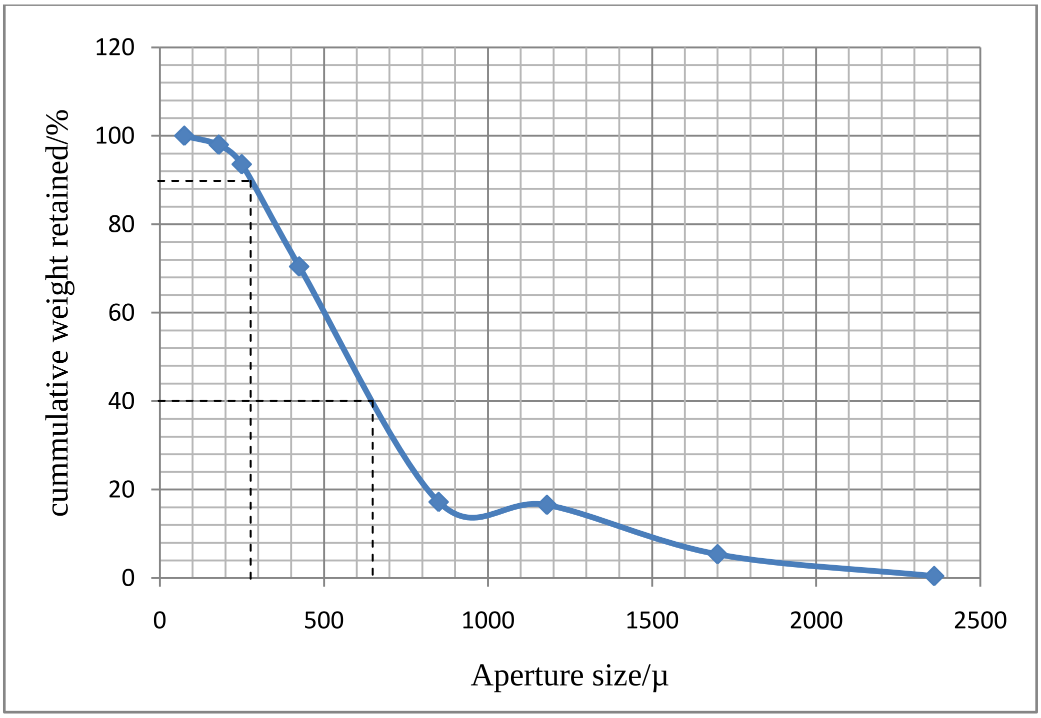

Figure 4.8: A graph of the cumulative weight of gari from Grating Surface 4(DD) retained on standard sieves

From Figure 4.8, 40% of the cumulative weight retained (i.e. 60% passing) corresponds to 668.29μ and 90% of the cumulative weight retained (i.e. 10% of the cumulative weight passing) corresponds to 277.03μ. Therefore, the uniformity coefficient is 2.41. This value of uniformity coefficient when compared to sand also falls within the range of coarse sand (0.63-2mm).

The fineness modulus (FM), on a scale of 1 to 7(1 being very fine and 7 being very coarse) obtained for the gari produced from grating surface 4(DD) was 4.02. This means, the gari from grating surface 4(DD) was quite coarse. The average particle size was 1.69mm.

Figure 4.9 is a cumulative frequency curve representing the cumulative weight of gari from grating surface 5(EE) retained on standard sieves. The percentage weight of gari retained at an aperture size of 2360 µ was 0.29%. It then cumulated to 5.32% at 1700 µ and then to 15.71% at both 1180 µ and 850 µ. It cumulated sharply to 73.65% at 425 µ and then to 94.30% at 250 µ, 98.24% at 180 µ and then lastly to100% at 75 µ.

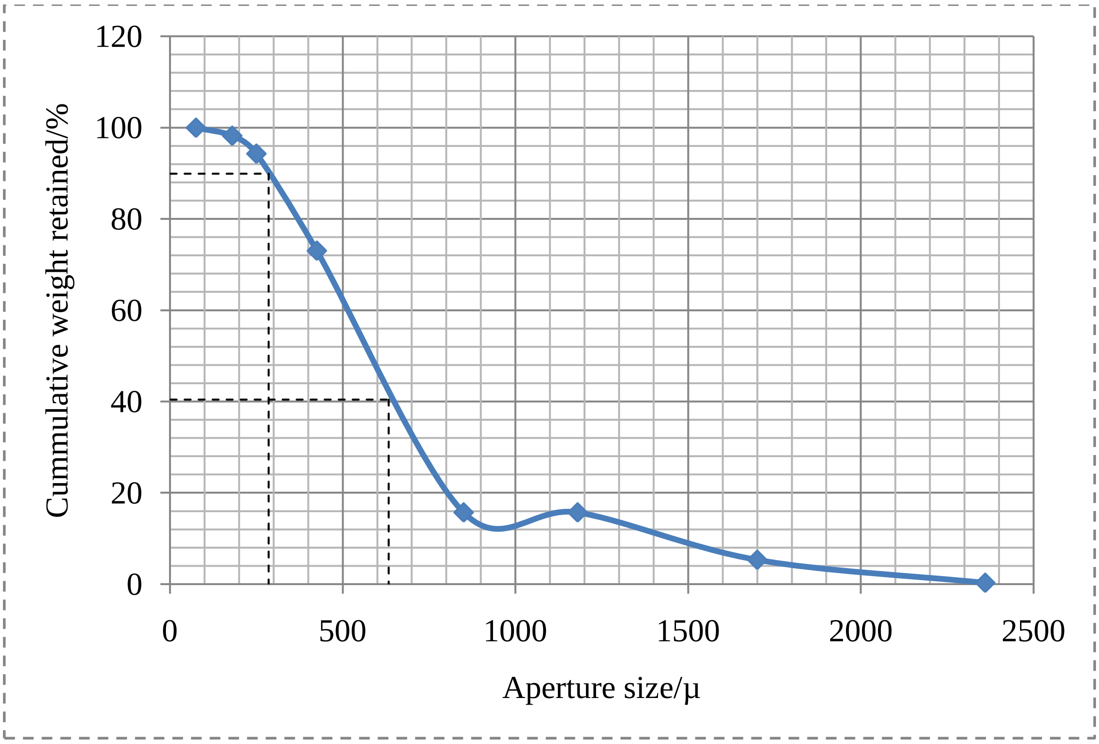

Figure 4.9: Cumulative weight of gari from Grating Surface 5(EE) retained on standard sieves

From Figure 4.9, 40% of the cumulative weight retained (i.e. 60% passing) corresponds to 602.03µ and 90% of the cumulative weight retained (i.e. 10% of the cumulative weight passing) corresponds to 270.36µ. Therefore, the uniformity coefficient is 2.23. This value of uniformity coefficient (2.23) when compared to sand falls within the range of coarse sand.

The fineness modulus (FM), on a scale of 1 to 7 obtained for the gari produced from grating surface 4(DD) was 4.02. The average particle size was 1.70mm.

Figure 4.10 shows the graph representing the % weight of gari retained for each aperture size for grating surface 6 (FF). The percentage weight of gari retained at an aperture size of 2360 µ was 0.26%. It then cumulated to 4.27% at 1700 µ and then to 15.08% at 1180 µ. It cumulated to 15.09% at 850 µ and then cumulated sharply to 73.65%. At 425 µ, the cumulative weight of gari retained was 71.23% and then rose to 94.14% at 250 µ. At 180 µ, it cumulated to 98.01% and then lastly to100% at 75 µ.

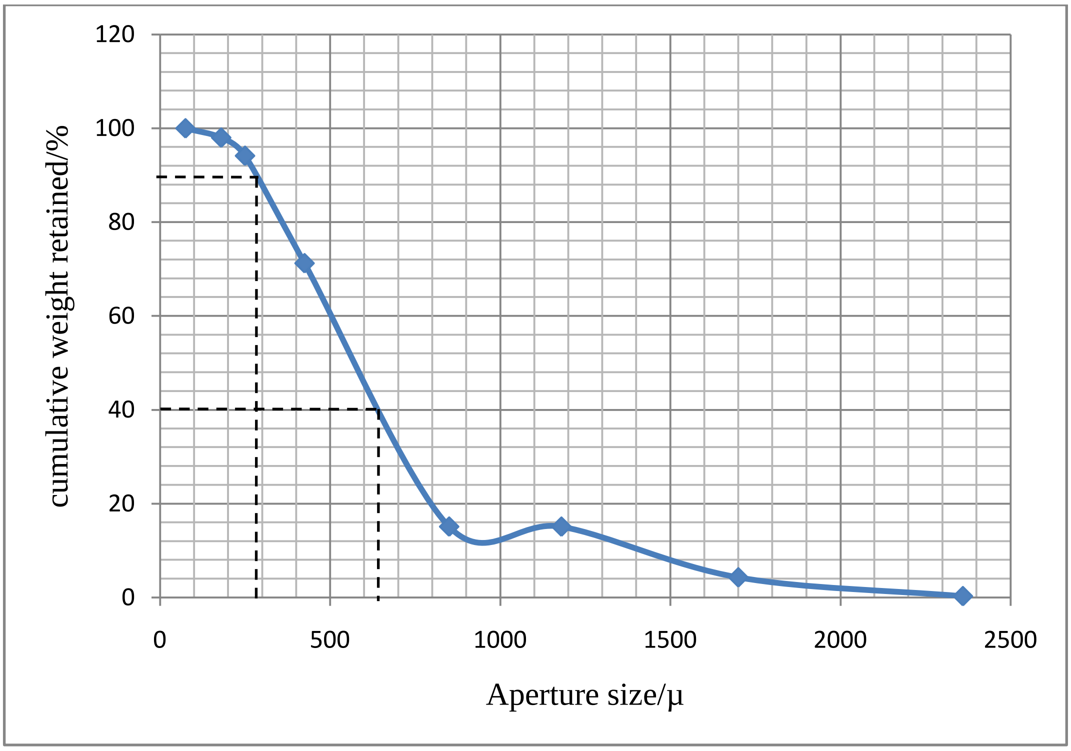

Figure 4.10: Cumulative weight of gari from Grating Surface 6(FF) retained on standard sieves

From Figure 4.10, 40% of the cumulative weight retained (i.e. 60% passing) corresponds to 661.42µ and 90% of the cumulative weight retained (i.e. 10% of the cumulative weight passing) also corresponds to 281.62µ giving a uniformity coefficient of 2.35

This value of uniformity coefficient (2.35) when compared to sand falls within the range of coarse sand.

Also, the fineness modulus (FM), on a scale of 1 to 7 obtained for the gari produced from grating surface 6(FF) was 3.98 and the average particle size was 1.64mm.

In Table 4.4, the fineness modulus, uniformity coefficient, average particle size of gari from grating surfaces and comments from producers and consumers are indicated; the highest fineness modulus was seen for gari from grating surface 1(AA) while the lowest was seen for gari from grating surface 3(CC). The lowest average particle size was 1.42mm which was obtained for gari from grating surface 3(CC) while the highest average particle size was 1.76mm which was recorded for gari for grating surface 1(AA). The uniformity coefficients for all six samples of gari were within the range of coarse sand; 0.63-2mm (ISO 14688-1).

Table 4.4: Evaluation Criteria of Gari from Designed Grating Surfaces And Grating Surfaces Existing On the Market.

Grating Surface	Average Tooth Diameter (mm)	Average Inter-Tooth Spacing (mm)	Average Particle size (mm)	Fineness modulus	Uniformity coefficient	Gari Producers Observation	Gari Consumer /Buyers Observation	Remarks
AA	2	8	1.76	4.08	2.24	Mash too fine for gari.	Gari should have smaller particle size	Not accepted
BB	3	8	1.51	3.86	2.26	Mash good for gari and produces fewest coarse grates	Gari is good for all purposes	**Accepted**
CC	2	12	1.42	3.77	2.43	Mash too fine	Gari is quite fine and cannot serve all purposes	Not accepted
DD	NA	NA	1.69	4.02	2.41	Mash good for gari but too much coarse grate	Gari should have smaller particle size	Not accepted
EE	4	4	1.70	4.02	2.23	Mash good for gari and produces few coarse grates	Gari should have smaller particle size	Not accepted
FF	NA	NA	1.64	3.98	2.35	Mash good for gari but produces fewer coarse grates	Gari should have smaller particle size	Not accepted

NB: Grating surfaces 4(DD) and 6(FF) were saw toothed so there were no measurements for tooth diameter and inter tooth spacing.

Based on comments and acceptability from both producers (by the feel at the finger tips by experienced producers) and consumers of gari (through the sales of all gari types side by side), grating surface 2(BB) was chosen as the best design. This is because; it produced mash of a desired texture/ fineness for the making of gari. Also, it produced gari of a particle size desired by consumers. Grating surface 2(BB) produced gari of an average particle size of

1.51mm, a fineness modulus of 3.86 and a uniformity coefficient of 2.26. The other grating surfaces produced a mash either too fine or with lots of coarse grates.

4.2.1 Relation between Tooth Diameter and Average Diameter of Gari

A 3mm nail is usually used in the making of the teeth through punching with the help of a hammer (Habibat, 2006). This influenced the design of tooth size around 3mm. Two grating surfaces with an average tooth diameter, 2mm but different inter tooth spacing were designed. Another grating surface with an average tooth diameter of 3mm was designed. These were compared with a grating surface of average tooth diameter of 4mm(EE) already on the market and two saw toothed graters (DD and FF) and the following were observed;

For desired particle size of gari (in terms of diameter)

$$2\text{mm} < d_t \leq 3\text{mm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation 4.1}$$

where

d_t = average tooth diameter

If $d_t > 3\text{mm}$ ………………………….. equation 4.1a

coarser grates are produced and $d_g > 1.5\text{mm}$

where

d_g=Average diameter of gari

This was observed in the particle size of gari produced from the mash of Grater 5(EE) which had

d_t=4mm and

d_g = 1.70mm

If $d_t < 3mm$……………………..equation 4.1b

It is difficult to make mash into gari as mash will be too fine

At $d_t=2mm$,

$1.4mm<d_g<1.8mm$…………………. equation 4.1c

This was observed for grating surfaces AA and CC

The variation in d_g is as a result of the mash being too fine. This makes it difficult to make it into gari. The extent of fineness of mash produced from a 2mm tooth grater makes it desirable for dough and not gari. When made into gari by two different people, gari of average particle sizes of 1.76mm and 1.42mm were produced.

For $d_t=4mm$, $d_g=1.70mm$, which is not so desirable.
For the saw toothed graters, $d_g \geq 1.69mm$.
This average particle size of gari is too big and thus would have to be re-sieved with a smaller sized sieve to get the right size of gari. The gari which does not pass through this sieve would then have to be re- grated.

Of all the six graters used, gari produced from Grating Surface 2(BB) was generally accepted by both processors and consumers. It was said by processors that $d_g=1.5mm$ can be used for any gari meal. This was done by allowing customers to choose which type they preferred.

4.2.2 Analysis of Designed Grating Surface 2(BB)

Information on the second designed grating surface, BB is presented in Table 4.4; the highest tooth diameter measured was 3.2mm and the lowest, 2.8mm. The average tooth diameter was 3.01mm. For the inter tooth spacing, the highest value measured was 8.3mm and the lowest value was 7.9mm with a mean inter tooth spacing of 8.05mm

Table 4.5: Tooth Diameter and Inter Tooth Spacing For Grating Surface 2 (BB)

Parameter	Value(s)
Tooth Diameter Measured	3.0, 2.9, 3,3, 3.1, 3, 2.9, 3.1, 3.2, 3, 2.9, 2.8, 3, 3.1,3, 3.1, 3, 3
Number of measured parameters	18
Highest Diameter Measured	3.2mm
Lowest Diameter Measured	2.8mm
Mean Diameter	3.01mm
Inter- Tooth Spacing measured	8.1, 8.1, 8, 7.9, 7.9, 8, 8, 8.3, 8.2, 7.9, 8.1, 8.1
Number of measured parameters	12
Highest Parameter Measured	8.3mm
Lowest Parameter Measured	7.9mm
Mean Inter- Tooth Spacing	8.05mm

The range of values for tooth diameter measured (2.8mm to 3.2mm) is quite close and is likely to produce a uniform distribution of particle size for the grated mash. The average tooth diameter was 3.01mm with a standard deviation of 0.09mm. This means that most of the values of the tooth diameter on the drum is likely to be from 2.92mm to 3.10mm which is good enough to ensure a uniform distribution of particle size of grated mash. The standard error calculated was 0.02mm.The calculated tolerance was also ±0.04mm from the mean. Therefore, the Upper Limit was 3.05mm and the Lower limit, 2.97mm.This means, for a tooth surface to be accepted, the diameter of its teeth must range from 2.97mm to 3.05mm. When this range is compared to that of the surveyed data (3.18mm to 3.42mm), it is observed that, the limit for the surveyed ones is higher (±0.12mm) as compared to ±0.04mm.

The range of values for inter tooth spacing for Grating Surface 2(BB) is close when compared to that of the surveyed grating surfaces. This is as a result of the initial marking out before punching. The standard deviation was 0.12mm with a standard error of 0.04mm, thus making the value of the standard deviation reliable. The calculated tolerance of the inter tooth spacing was ±0.08mm from the mean. Therefore, the acceptable range of values for the inter tooth spacing must be from 7.97mm to 8.13mm. The range for the surveyed data (3.87mm to 10.93mm) when compared to that of Grating Surface 2(BB) is higher.

4.2.3 Speed of Motor, Time and Efficiency

In the experiment conducted, three varied speeds were used; 600rpm. 650rpm and 700rpm.It was however observed (by the feel of the fingers by experienced gari processors) that the speed of the grating surface had no relation with the fineness of the mash produced. However, it had effect on the time for grating and the total amount of cassava (mash) recovered.

With respect to time, t, the lower the speed of the motor, S_m, the longer the time used in grating.

i.e. $S_m \propto \frac{1}{t} \dots\dots\dots\dots\dots\dots. (4.2)$

However, grating time could be affected by

i. effective contact between the cassava and the grating surface
ii. tension between the belt
iii. size of cassava to be grated

Effective contact between the cassava and the grating surface was effected by the pressing board and the clearance adjustment board. However, at a low speed, when a greater pressure is applied on the pressing board to effect contact between the cassava and the grating surface, the grating surface can stop moving and this could affect grating time by increasing it.

Tension in the belt,(T), connecting the motor to the grater also influences the time(t)for grating. Ensuring a smooth, effective and efficient grating operation, in terms of the influence of the belt includes;

i. aligning the grater horizontally with the motor

ii. ensuring the grater remains firm and still to the ground. This is achieved by either using a load to keep the grater still or concreting the stand/ legs of the grater to the floor.

When these are done, there is effective transmission of power from the motor through the belt to the grater to effect rotation of the drum. Otherwise, an increase in grating time is experienced as the belt may sag due to movement of the grater.

Efficiency of the grater (η_g), when calculated in terms of weight of cassava retrieved (W_r) and cassava fed in grater (W_f), is seen to increase with speed. This is shown in the calculation of the efficiencies for the three designed grating surfaces

i.e. $\eta_g = \frac{W_r}{W_f} \times 100$

For grater 1,

$$\eta_g(600\text{rpm}) = 89.23\%$$

$$\eta_g(650\text{rpm}) = 96.92\%$$

$$\eta_g(700\text{rpm}) = 96.92\%$$

$$\text{where } \eta_g(650\text{rpm}) = \eta_g(700\text{rpm}) > \eta_g(600\text{rpm})$$

For grater 2,

$$\eta_g(600\text{rpm}) = 92.31\%$$

$$\eta_g(650\text{rpm}) = 96.92\%$$

$$\eta_g(700\text{rpm}) = 96.92\%$$

$$\text{where } \eta_g(650\text{rpm}) = \eta_g(700\text{rpm}) > \eta_g(600\text{rpm})$$

For grater 3,

$$\eta_g(600\text{rpm}) = 87.69\%$$

$$\eta_g(650\text{rpm}) = 93.85\%$$

$$\eta_g(700\text{rpm}) = 96.92\%$$

$$\text{where } \eta_g(700\text{rpm}) > \eta_g(650\text{rpm}) > \eta_g(600\text{rpm})$$

4.2.4 Material Type and Thickness In Relation To Efficiency

The survey revealed that, most grater teeth manufacturers use mild steel (Figure 10). This is not appropriate for contact surfaces of food products as they rust with time, thus, affecting the quality of the processed food. This affects the wholesomeness of the product.
Not only does stainless steel have the minimum possible rusting effect but also has a greater sharpness effect when compared to mild steel which is usually used by manufacturers.

In all three grating surfaces designed, stainless steel was used. This is appropriate for processing food as it does not rust as in the case of mild steel.

As the type of material for making the grating surface is important, so is the thickness of the material used. In the punching process, it is observed that the thicker the material, the more difficult it is to punch and the longer the punching time. Also, the thicker the material, the less sharp the grating surface.

For AA, a material (stainless steel) of thickness 1mm was used. For BB and CC, a material of thickness 1.25mm was used. The punching process for AA was easier and took a shorter time to complete (95 minutes). It also had a sharper grating surface (observed with the feel of the fingers) as compared to BB and CC.
With respect to sharpness of grating surface, it was also observed that, the greater the value of the depth of punch, the sharper the grating surface, but the bigger the tooth diameter. In order to avoid a big tooth diameter which is undesirable, it is recommended therefore that a material of thickness 1mm should be used to produce the sharpness effect desired while ensuring ease of punching, thus reducing punching time.

4.2.5 Surface for Effective Punching

During the survey process, it was observed that many manufacturers place the material to be punched on the bare floor. This is inappropriate as the grating surface can get dirty and subsequently contaminate the cassava to be grated.

Others also place them on a concreted floor. A concreted floor is hard and is likely to make the grating surface less sharp.

The punching of the designed grating surfaces was done on a wooden platform. The wood for this platform is not too hard so it allows for effective punching of the grating surface. This is also easy to clean after punching. It is therefore good to use a wooden platform rather than the bare or concreted floor.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In line with the objectives of the study, a survey of existing grating surfaces was done in three regions of Ghana. Measurements of tooth diameter, inter- tooth spacing, length of the drum and circumference of the drum were taken. From the survey conducted, the highest mean tooth diameter recorded was 4mm while the lowest was 2mm. The highest tooth diameter was recorded at Esuogya and Kwesimintsim, both in the Western region and Accra Town in the Ashanti region. The lowest tooth diameter was recorded at Kotokoraba in the Central region. The highest mean inter tooth spacing recorded was 12.5mm while the lowest was 4mm and these were recorded at Effiakuma and Kwesimintsim respectively both in the Western region.

The collected data from the survey were analyzed using Microsoft excel to determine the mean, standard deviation and standard error of all measured parameters. The mean tooth diameter, mean inter tooth spacing, drum length and drum circumference of all surveyed grating surfaces were 3.3mm, 7.4mm, 188mm and 371.1mm respectively with corresponding standard deviation values of 0.6mm, 1.8mm, 26.8mm and 92.9mm and standard error values of 0.06mm, 0.18mm, 6.7mm and 23.23mm respectively. Also, the inter tooth spacing was seen to be two to three times the size of the tooth diameter. The drum diameter was also nearly twice the length.

After analysis of the collected data, three grating surfaces were designed using varied tooth diameters and inter tooth spacing and the best design was selected based on preference of both gari manufacturers and consumers. The following conclusions were made after selection of the best design:

1. A tooth diameter of about 3.01mm with a tolerance of ± 0.04mm produces a desired particle size of gari of about 1.5mm; a tooth diameter less than 2.97mm is likely to produce a very fine mash which is difficult to make into gari. A tooth diameter greater than 3.05mm produces coarse grates and subsequently, bigger particle sizes of gari which is undesirable.
2. An inter tooth spacing of about 8.05mm with a tolerance of ± 0.08mm is also acceptable. The wider range of inter tooth spacing on the market (4-12.5mm) as a result of lack of an initial marking out should therefore be narrowed to 8.05±0.08mm
3. The random pattern of teeth at an angle of 45° is preferred as it ensures effective contact between the cassava and the grating surface and reduces grating time.
4. At a grating speed of 700rpm, effective grating with minimal use of time was ensured. This is because at an increased grating speed, grating time decreased with an increased efficiency.
5. The use of stainless steel for the making of the grating surface would ensure suitability and wholesomeness of grated mash for gari production as it is more resistant to corrosion. Stainless steel is also distinctively hard, resistant to abrasion and resistant to deformation at elevated temperatures (Degarmo et.al., 2003)

The particle size analysis of gari for all six grating surfaces showed similar trends; the uniformity coefficient of all six samples of gari was within the range of coarse sand; 0.63-2mm (ISO 14688-1).

5.2 Recommendations

1. Training of cassava grating surface manufacturers by the Department of Agricultural Engineering through seminars on the right methods for making grating surfaces using the recommended dimensions

2. Also, a jig should be made using the recommended tooth dimensions in the making of a cassava grating surface to ensure interchangeability.

3. Studies on other materials as options which can be afforded by processors and also safe for making cassava grating surfaces should be carried out.

4. Further studies on punch for making the teeth of cassava grating surfaces should be carried out.

5. It is also recommended that the Ghana Standards Authority widens the scope of this study to other regions of Ghana to aid in the standardization process.

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Appendix 1: Some Surveyed Grating Surfaces

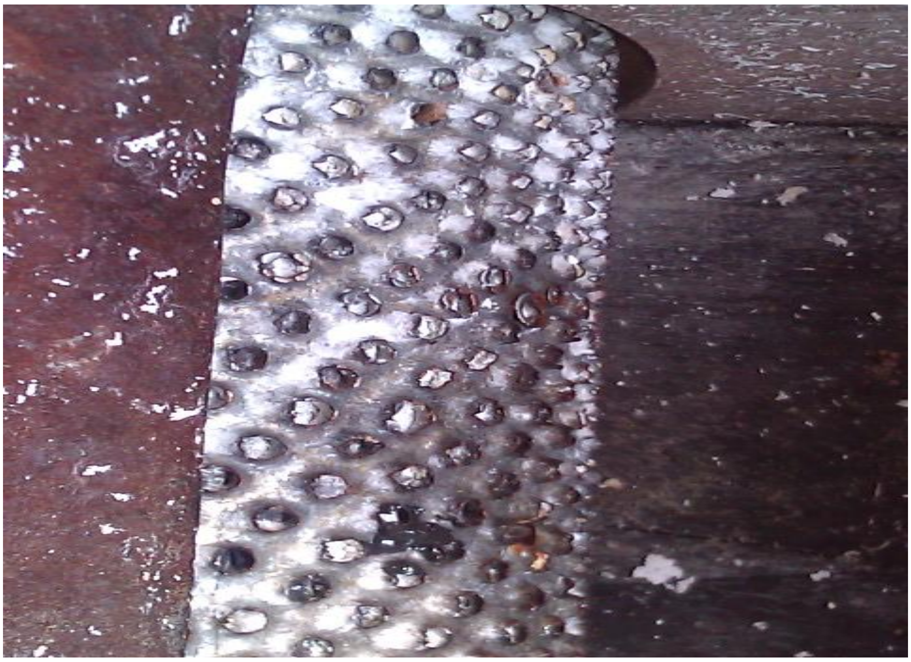

Figure A 1: Grating Surface of Drum at Esuogya site 1

Figure A2: Grating Surface of Esuogya Grater 2

Figure A3: Grating Surface for K1

Figure A4: Grating Surface for K2

Figure A 5: Grating Surface for Accra Town Site One(DD)

Figure A 6: Grating Surface for Accra Town Grating Site two (EE)

Figure A7: Saw For Making Grating Surfaces DD and EE

Figure A8a

Figure A8b

Figure A8: Hand and Powered grating surfaces used at Pekyerekye in the Ashanti Region

Figure A9: Punch for Making Holes

Figure A10: Grating surface rusting with time

Appendix 2: Grating Time and Speeds for Designed Grating Surfaces

Table A1: Grating Time Taken for Three varied Speeds Using Designed Grating Surface 1(AA)

Weight before grating(kg)	Speed(rpm)	time taken (sec)	weight after grating(kg)	weight of coarse grate (kg)
6.5	600	686	5.8	
6.5	650	434	6.3	1.5kg
6.5	700	346	6.3	

Table A2: Grating Time Taken for Three varied Speeds Using Designed Grating Surface 2(BB)

Weight of cassava before grating(kg)	Speed (rpm)	Time taken(sec)	Weight of cassava after grating(kg)	Weight of coarse grate(kg)
6.5	600	342	6.0	
6.5	650	215	6.3	1.5
6.5	700	102	6.3	

Table A3: Grating Time Taken for Three varied Speeds Using Designed Grating Surface 3(CC)

Weight Before Grating(kg)	Speed(rpm)	Time Taken(sec)	Weight After Grating(kg)	Weight Of Coarse Grate (g)
6.5	600	296	5.7	
6.5	650	238	6.1	135.27
6.5	700	141	6.3	

Appendix 3: Particle Size Analysis of Gari From Various Graters

Table A4: Particle Size Analysis of Gari From Grating surface 1

Sieve number	Aperture size/μ	% weight retained/g (R)	Cumulative weight retained	Multiplication Factor (F)	RF
8	2360	0.14	0.14	8	1.09
12	1700	3.43	3.57	7	24.02
16	1180	12.15	15.72	6	72.88
20	850	0.90	16.62	5	4.51
40	425	59.19	75.81	4	236.77
60	250	20.55	96.36	3	61.66
80	180	3.17	99.53	2	6.34
200	75	0.46	99.99	1	0.46
Pan	-	0	99.99	0	0
		100	99.99		**407.74**

Table A5: Particle Size Analysis of Gari From Grating surface 2

Sieve number	Aperture size/μ	% weight retained/g (R)	Multiplication Factor (F)	RF
8	2360	0.15	8	1.2
12	1700	2.4	7	16.8
16	1180	7.88	6	47.28
20	850	0.2	5	1
40	425	58.68	4	234.72
60	250	25.24	3	75.72
80	180	4.03	2	8.06
200	75	1.41	1	1.41
Pan	-	0	0	0
		100		**386.2045**

Table A6: Particle Size Analysis of Gari From Grating surface 3

Sieve number	Aperture size/μ	% weight retained/g (R)	Multiplication factor (F)	RF
8	2360	0.01	8	0.08
12	1700	2.70	7	18.9
16	1180	8.85	6	53.1
20	850	0.01	5	0.05
40	425	51.89	4	207.56
60	250	27.35	3	82.05
80	180	6.25	2	12.5
200	75	2.68	1	2.68
Pan	-	0	0	0
		100		**376.92**

Table A7: Particle Size Analysis of Gari From Grating surface 4

Sieve number	Aperture size/μ	% weight retained/g (R)	Multiplication factor (F)	RF
8	2360	0.5	8	4
12	1700	4.93	7	34.51
16	1180	11.16	6	66.96
20	850	0.66	5	3.3
40	425	53.21	4	212.84
60	250	23.11	3	69.33
80	180	4.42	2	8.84
200	75	2.02	1	2.02
Pan	-	0	0	0
		100		**401.8**

Table A8: Particle Size Analysis of Gari From Grating surface 5

Sieve number	Aperture size/μ	% Weight Retained/g(R)	Multiplication Factor(F)	RF
8	2360	0.29	2.32	2.32
12	1700	5.03	35.21	35.21
16	1180	10.39	62.34	62.34
20	850	0	0	0
40	425	57.34	229.36	229.36
60	250	21.25	63.75	63.75
80	180	3.94	7.88	7.88
200	75	1.75	1.75	1.75
Pan	-	0	0	0
		100		**402.61**

Table A9: Particle Size Analysis of Gari From Grating surface 6

Sieve number	Aperture size/μ	% weight retained/g (R)	Multiplication Factor (F)	RF
8	2360	0.2600	8	2.08
12	1700	4.0139	7	28.10
16	1180	10.8148	6	64.89
20	850	0.0067	5	0.03
40	425	56.1408	4	224.56
60	250	22.9077	3	68.72
80	180	3.8738	2	7.75
200	75	1.9803	1	1.98
pan	-	0	0	0
		100		**398.11**

Appendix 4: Information On Tooth Diameter and Inter tooth Spacing Values from Survey

Table A12: Tooth Diameter and Inter Tooth Spacing Values From Survey

Surveyed site	Tooth diameter (mm)	Inter tooth spacing (mm)
Esuogya 1	4.5, 4.2, 3.8, 4, 3.7, 3.8	7.5, 7.5, 7.7, 7.4, 7.6, 7.5, 7.2
Esuogya 2	3.9, 4.2, 3.8, 3.9, 4, 4.1	7.5, 7.6, 7.6,7.2, 7.6,7.4, 7.5, 7.4
Kwesimintsim 1	3.8, 4.0, 4.0, 3.9, 4.2, 4.1, 4.0	3.8, 4.2, 4, 3.9, 4, 3.9, 4.1, 3.8
Kwesimintsim 2	3.6, 3.8, 3.7, 4, 4, 3.7	3.5, 4, 4.2, 4.5, 3.8, 4
Effiakuma 1	2.7, 2.5, 2.5, 2.6, 2.2, 2.5	7.3, 7.3, 7.2, 7.4, 7.4, 7.2, 7.2
Effiakuma 2	3.5, 3.7, 3.6, 3.4, 3.3, 3.3	8.4,8.6, 8.5, 8.5, 8.4, 8.6, 8.4
Effiakuma 3	3.3, 3.2, 3.2, 3.5, 3, 3	8.5,8.6, 8.5, 8.4, 8.7, 8.4, 8.4
Apremdo 1	3.5, 3.5, 3.8, 3.4, 3.4, 3.4,	10, 10.2, 10.2, 10.3, 10.4
Apremdo 2	3.1, 3.1, 3.3, 3.2, 3.4, 3.2, 3.1	10.5, 10.4, 10.4, 10.5, 10.6, 10.6
Kotokoraba	1.8, 2, 2.2, 2.3, 1.9, 1.8	5.8, 6.0, 5.9, 5.8, 5.7, 5.6,
Konongo 1	2.5, 2.5, 2.7, 2.6, 2.3, 2.4	6.5, 6.4, 6.5, 6.6, 6.5. 6.6, 6.1
Konongo 2	3.4, 3.4, 3.2, 3.2, 3, 3.1, 3.1	6.7, 6.7, 6.9, 7, 6.7, 6.8, 6.6
Kojokrom	3.5, 3.4, 3.4, 3.6, 3.3, 3.2	6.5, 6.4, 6.3, 6.6, 6.4, 6.5, 6.1
Adumkrom	2.8, 2.9, 2.8, 2.9, 2.7, 2.7	7.2, 7.3, 7.2, 7.4, 7.3, 7.4
Pekyerekye	3.2, 3.4, 3.4, 3.3, 3.2, 3.3	8.5, 8.7, 8.8, 8.7, 8.8
Accra Town	4, 4.1, 3.9, 4.1, 4, 3.9, 4	8.5, 9, 9.5, 10.2, 12.0, 9.6, 10.1
Mean	**3.32**	**7.42**
Standard Deviation	**0.60**	**1.82**