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FIELD MEASUREMENTS AND STATISTICAL ANALYSIS OF PERFORATED GRATING SURFACES FOR GRATING FRESH CASSAVA INTO MASH IN GHANA

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ABSTRACT

Processing of cassava into mash requires grating of fresh cassava tubers through the abrasive action of the grating surfaces of cassava graters that grind against the cassava and transforms it into mash. Over the years, improved cassava graters have been designed and made available on the market. In spite of improvements in design, there are no standards for the manufacture of grating surfaces and this affects interchangeability of the product. Mechanised grating of fresh cassava into mash contributes to reduce post-harvest losses of cassava, increase its shelf life and improve food security. However, majority of the cassava grating surfaces are poorly made with substandard measurements that affect the desired particle size of mash for gari, a staple food for millions of people in West Africa. This study assessed cassava grating surfaces focusing on the abrasive elements (tooth diameter and inter-tooth spacing). Qualitative data were gathered from local metal fabricators and female gari processors in separate focus group discussions. The purpose was to gather the narratives underlying the issues being studied so as to complement and enrich the quantitative data. 112 tooth diameters and 112 inter-tooth spacing of perforated cassava grating surfaces were randomly measured in 16 different study areas in 3 regions of Ghana, namely Western, Central and Ashanti. Results from the qualitative data showed that grating of cassava was done repeatedly (about 2-3 times) before reaching the desired particle size of mash for gari. Most customers desire grating surfaces that ensure effective contact between the cassava and the metal grating surface to reduce grating time. Results from the field measurements showed high variation in existing tooth diameters (min=1.80, max=4.50 mm) and inter-tooth spacings (min=3.50, max=12.00 mm) that resulted in non-uniform particle size of cassava mash. Using statistical analysis, tooth diameters (min=3.18, max=3.42mm) and inter-tooth spacings (min=7.12, max=7.78mm) were determined at 95% confidence interval. For practical purposes, tooth diameter of 3 mm and inter-tooth spacing of 8 mm are recommended. The availability of such data will contribute significantly to standardise perforated cassava grating surfaces to achieve product interchangeability and desired quality of grated mash for gari. This will contribute to improve the manufacture of cassava graters and sustainable gari processing business in Ghana and Africa.

Key words: Fresh cassava, cassava grating surface, gari, food quality, Ghana

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INTRODUCTION

Cassava is sometimes described as the 'bread of the tropics' [1]. It is the third largest source of food carbohydrate in Africa after rice and maize [2]. It undergoes postharvest physiological deterioration once the tubers are separated from the main plant and become unpalatable within two to three days after harvest [3]. Consequently, it is prudent to process the crop within three days after harvest. Processing provides cassava producers with additional market opportunities, beyond simply selling the fresh tubers [4]. Cassava can be transformed into two principal products, flour and gari from new and traditional varieties [5]. Gari is made from fresh cassava tubers that have been grated into a mash, which is fermented, sieved and roasted into creamy-white grainy food product.

Processing of fresh cassava into mash requires grating of cassava through the abrasive action of the grating surface which grinds the cassava into mash [6]. Traditional methods of grating fresh cassava include pounding with pestle and mortar and use of hand graters. Hand graters are made from tin or galvanized sheet metal with perforations made with 3mm nails, which leave a raised jagged flange on the underside [5]. The sharp protruding rims of the nail openings are turned outside and then mounted onto a flat piece of wood [7]. The use of hand graters is laborious, time-consuming and dangerous. Care and skills are needed to avoid grating of the fingers. When using hand graters about 3-5% of cassava is usually wasted [8].

Over the years, improved cassava grating machines have been designed and made available on the market [9]. These include pedal operated engine, dual operational mode machines, the Jahn type grater, the International Institute of Tropical Agriculture (IITA) 202, the GRATIS Foundation (GF) IITA 202. The Jahn type 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 at different lengths of 10, 20 and 30 cm. They are 2cm wide with teeth along each long side. The teeth may be 2 or 3 mm deep with tips of 1.5 to 2.5 mm [10].

In spite of improvements in the design of cassava graters, there are no standards for the fabrication of grating surfaces and this affects interchangeability of the product. The concept of interchangeability allows easy fabrication of new parts and repair of existing ones. In several instances, if a grating drum becomes defective or the grating surface gets worn out, the entire machine is sent back for repair or scrapped. There is, therefore, the need for continuous research to generate data and information for standardisation and enhancement [11]. This study, therefore, sought to assess cassava grating surfaces with focus on two key variables: tooth diameter and inter-tooth spacing. These variables when analysed, standardised and implemented by the Ghana Standard Authority can contribute to achieve the desired particle size of the mash and sustainable gari processing business in Ghana.

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MATERIALS AND METHODS

Study areas and methods

Using both qualitative and quantitative approach, this study sought to randomly assess cassava grating surfaces for analysis and standardisation. One hundred and twelve tooth diameters and 112 inter-tooth spacings of cassava grater drums were randomly measured in 16 study areas in 3 regions of Ghana (Western, Central and Ashanti regions). The study areas are listed in Tables 2(a) and (b) below. Qualitative pieces of information were gathered from 10 metal fabricators and 25 female gari processors in separate focus group discussions. The purpose of the qualitative approach was to gather the narratives underlying the issue being studied so as to complement and enrich the quantitative data collected in the study areas.

Materials

Steel rule, tape measure and digital Vernier calliper were used for measuring inter-tooth spacing and various tooth diameters. Digital camera was used for taking pictures of existing cassava grating drums (see Figure 3 for pictures of grating surfaces at Esuogya 1 and Esuogya 2 communities).

Theoretical Considerations

Operations involved in cassava processing

The operations involved in cassava processing depend on the end product desired [5]. Among the major steps involved in the processing of cassava into mash and gari include peeling, grating, dewatering/fermentation, sieving and roasting or frying (figure 1). Grating is usually carried out after ensuring that the peeled cassava tubers are thoroughly washed. The cassava tubers are traditionally grated into a mash or pulp as part of the process to remove cyanide and make the crop safe for consumption [4]. Since traditional cassava graters are slow, labour intensive and can easily injure the fingers, efficient mechanized graters that use grating drum are needed to produce a sufficient quantity of cassava mash to meet market demand and standards [4].

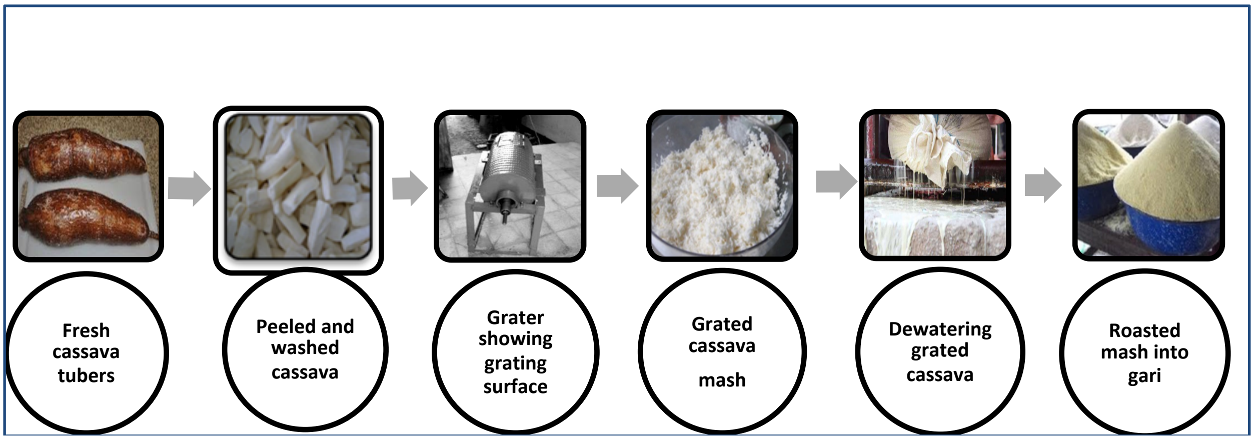

Figure 1: Major steps involved in processing fresh cassava into mash and gari

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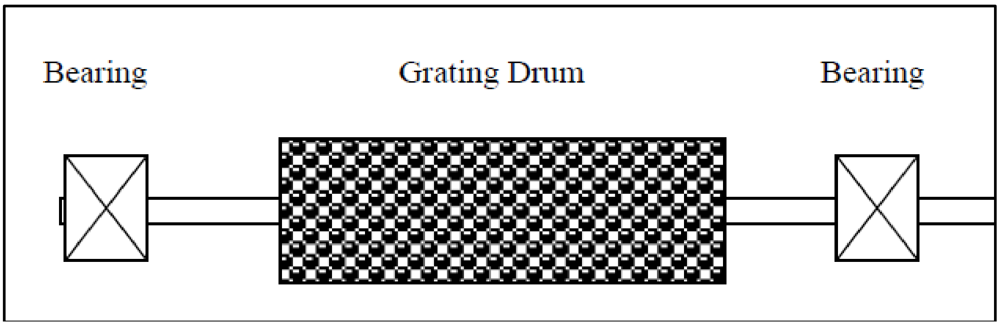
Grating unit

This unit consists of the shaft, perforated metal surface, rolled sheet, circular discs and rivet pins. The grating drum is formed by passing the shaft through the rolled cylindrical sheet metal that is welded in place. This drum is then wrapped with the perforated metal grating surface that is usually riveted firmly in place to form the grating drum. Figure 2 shows a schematic view of cassava grater drum showing metal grating surface and bearings (adapted from Adetunji and Quadri [12]).



Source: Adapted from Adetunji and Quadri (2011) [12]

Figure 2: Schematic view of cassava grater drum showing grating surface

Central limit theorem

To provide the basis for analysing the empirical data and derive the needed theoretical accuracy, we focus on the distribution of the sample data; and for large sample data where the sample size n≥30 (usually at least 30). Now as the sample size of the grating surfaces n=112 for tooth diameter and n=112 for inter-tooth spacing are large, the distribution of the sample means more closely approximate a normal distribution [13]. And converges toward the centre of the distribution, regardless of the population from which the samples were drawn. Even though we might not know the shape of the distributions where our data comes from, the central limit theorem says that we can treat the sampling distribution as if it were normal distribution. Therefore, we consider using the central limit theorem as elaborated by Kelly and Donnelly [13].

Let $x_1, x_2..., x_n$ be a random sample from a distribution with (finite) mean μ and (finite) variance σ^2. If the sample size n is "sufficiently large," then:

- Sample mean $\bar{x}$ follows an approximate normal distribution
- Mean $\bar{X} = \dfrac{X1 + X2 + X3, ..., + Xn}{n} = \dfrac{\sum_{i=1}^{n} Xi}{n}$ (1)

  Where n= sample size

- Standard deviation of the sample mean, $\sigma_{\bar{x}} = \dfrac{\sigma}{\sqrt{n}}$ (2)

  Where σ= standard deviation of the population mean

- Z-score for the sample means is calculated based on the formula

$$Z_{\bar{x}} = \frac{Xi - \bar{x}}{\sigma\bar{x}} \quad (3)$$

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The confidence intervals for the mean with large samples and standard deviation of the sample mean will be:

- Lower limit = $\bar{x} - Z_c\sigma_{\bar{x}}$ upper limit = $\bar{x} + Z_c\sigma_{\bar{x}}$ (4)

Measures of variation: error bars and coefficient of variation
***Inferential error bars*:**
It is important that we separate the good data from the bad data. This is done using inferential error bars. According to Cumming *et al.* [14] a big advantage of inferential error bars is that their length gives a graphic signal of how much uncertainty there is in the data: The true value of the mean (M) estimated could plausibly be anywhere in the 95% confidence interval. Wide inferential bars indicate large error; short inferential bars indicate high precision. In general, error bars give a general idea of how precise a measurement is, or conversely, how far from the reported value the true (error free) value might be [15].

Coefficient of variation
The coefficient of variation (CV) is useful when comparing two data sets that are not exactly alike, especially if the different data sets are not measured using the same units [13]. It measures the percentage of variation in data relative to the mean of the data. To calculate the CV for a population, the following formula is used:

- Coefficient variation CV = $\left(\frac{\sigma}{\bar{x}}\right) 100\%$ (5)

Where $\sigma =$ standard deviation and $\bar{x}$ = mean

Statistical data analysis
Statistical data analysis focused on tooth diameter and inter-tooth spacing. Methods and tools for statistical analysis included: the use of error bars; grouped frequency distribution; frequency curve; central tendency; dispersion and measures of variation; empirical rule for normal distribution; and confidence intervals. Error bar analysis was used as the first step to verify how large or small data uncertainty and variability were. To provide a graphical representation of the data and analytical guide for corrective action, frequency distribution, frequency curve, central tendency, 68-95-99.7 rule and confidence interval were employed for data analysis. Normal distribution template in Microsoft Excel 2010 (originally by W.F. Coleman, 1997 and adapted by Drier [16]) was used to plot the various normal distributions for this paper. Differences at P<0.05 were considered significant for all statistical analysis.

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RESULTS AND DISCUSSION

Qualitative information from fabricators and gari processors

The fabricators

Table 1 presents summarised qualitative information gathered from metal fabricators and gari processors. The data indicates that among the major performance indicators that the fabricators were concerned about from end-users feedback included effective system of grating of cassava and reduced grating time. Further, in regard to the fabrication of the metal grating sheets, the fabricators were concerned about drudgery associated with the existing fabrication process and the length of time (about 2-3 hours) that is taken to finish perforating one metal grating surface. Although, perforating the sheet metals takes a long time to finish partly because inexperienced young people are engaged to perform the task, the finished product turns out to be substandard. This results in random irregular teeth sizes and unequal inter-tooth spacing that produce ineffective grating and inconsistent particle size of cassava mash.

Materials being used for fabricating the perforated grating surfaces include mild steel, galvanized steel and stainless steel. However, stainless steel tend to be costly than mild and galvanised steels and this makes customers go for cheaper options. The problem is that cassava produces a large amount of cyanogenic glycosides so in selecting materials for construction, adequate care must be taken to use materials that do not degrade or corrode easily due to the acidic content of cassava. Therefore, for food processing stainless steel is the preferred material. Stainless steel has better surface finish that will influence functional performance and make the grating surface easy to clean, and thus keep away the risk of corrosion.

Women gari processors

In many economies, women's knowledge and contribution to the food and agricultural industry is well documented in literature [17, 18, 19]. In this paper, women's knowledge on food quality is demonstrated by their preference for specific particle size of cassava grates. According to the women gari processors as presented in Table 1, they prefer smooth and fine textured mash for processing into gari. After grating with machine, coarse grates that do not meet the desired expectation are broken down with their fingertips to reduce the particle sizes, otherwise grating is done 2 or 3 times before reaching the desired particle size and quality. The point here is that poorly perforated metal grating surfaces are likely to produce non-uniform coarse grates that do not meet the desired particle sizes of cassava mash. In general, gari samples with large aggregate sizes generally tend to have high moisture content after roasting which may affect storability of the samples while gari with smaller aggregate size displayed lower moisture contents and therefore displayed better storability [20].

Again, when the grating surface teeth become blunt very coarse grates are produced and grating is repeated over and over at extra time and cost, which is unsustainable. Therefore, there is the need for continuous research to improve cassava grating surfaces to achieve the desired particle size of mash for the processing of gari. In their studies on the physicochemical, functional and sensory properties of gari, Udoro *et al.* [21] used

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moderately fine textured gari as their control sample. Moderately fine-textured gari is preferred by most customers in Ghana [22]. According to the Sierra Leone Standard for gari (SLS 8: 2010), gari shall be of uniform particle size as much as possible and about 80% of the particle should range 0.5-1 mm for fine-sized gari to 1-1.25 mm for medium-sized gari [22, 23].

Field measurement of existing perforated metal grating surfaces

Measured tooth diameters and inter-tooth spacing of cassava grating surfaces in the 16 study areas are shown in Tables 2 (a) and (b). The results indicated that the tooth diameter ranged from 1.8 to 4.5 mm with mean and standard deviation values varying from 2.0 ± 0.2 mm to 4.0 ± 3.4 mm. Measured inter-tooth spacing ranged from 3.5 to 12.0 mm with mean and standard deviation values varying from 4.0 ± 0.1 mm to 10.5 ± 0.1 mm. The wide range of inter tooth spacing values could be as a result of random punching of the grating surface teeth without an initial marking out of the metal surface.

Figure 3 shows visual images of the metal grating surfaces that were surveyed in the study areas of Esuogya 1 and Esuogya 2. The grating surfaces appear clumsy with several irregular surface teeth that are made on mild steel or galvanized steel materials. These teeth were made by inexperienced apprentices who employ hammer and nail or punch to perforate random holes without any well designed pattern for marking out.

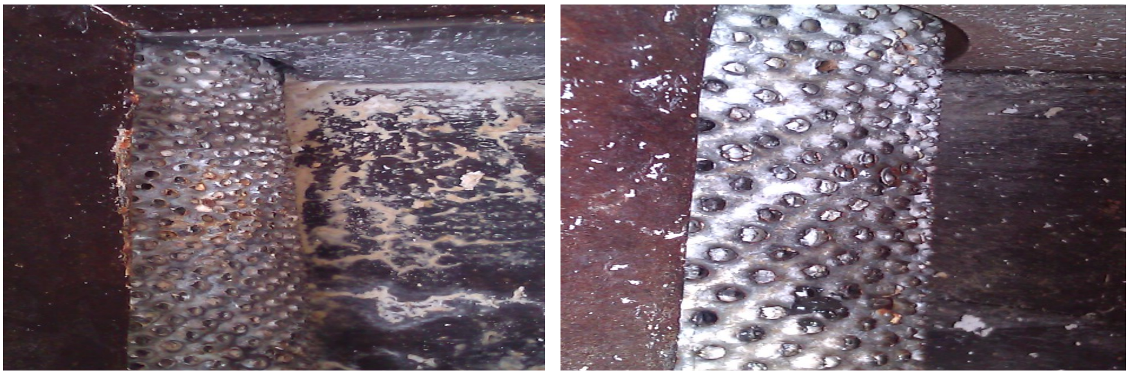

Figure 3: Cassava grating surfaces at Esuogya 1 and Esuogya 2 communities

In figure 4 the plots showed some level of variability in the sample data on tooth diameters and inter-tooth spacing that were collected from the field. Hence, there was the need to use error bars to provide a graphical representation of the variability.

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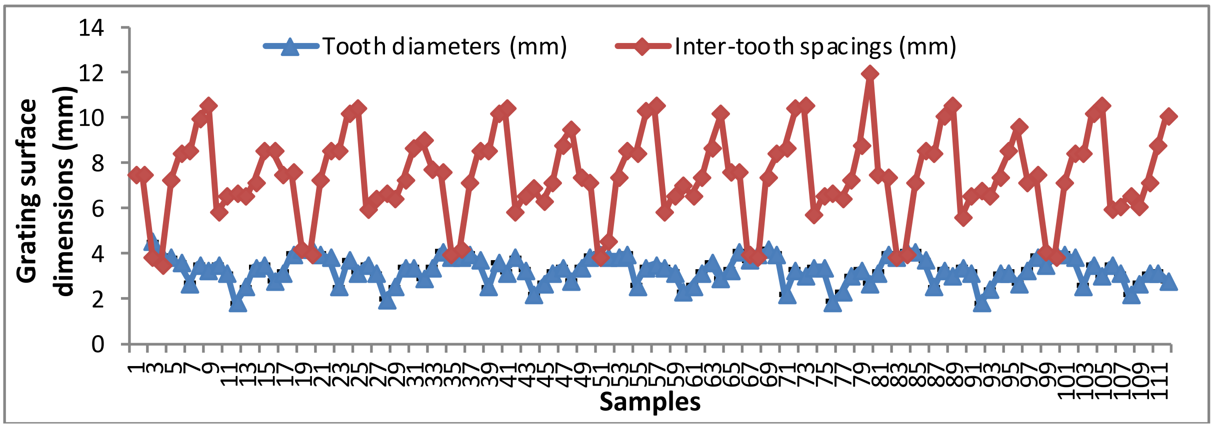

Figure 4: Plot of raw sample data of tooth diameters and inter-tooth spacings

Error bars

By plotting the mean of the measured values by study area the errors or uncertainty in the measured data were visibly demonstrated as shown in figure 5 below. To visually compare the two variables, inferential error bars were used. Figure 5 displays the error bars of the mean tooth diameter and mean inter-tooth spacing with one standard deviation. From the graphs, it is observed that the error bars of the mean inter-tooth spacing are longer than those of the mean tooth diameter. This means that inter-tooth diameter data indicate more uncertainty, hence indicated large errors than tooth diameter data.

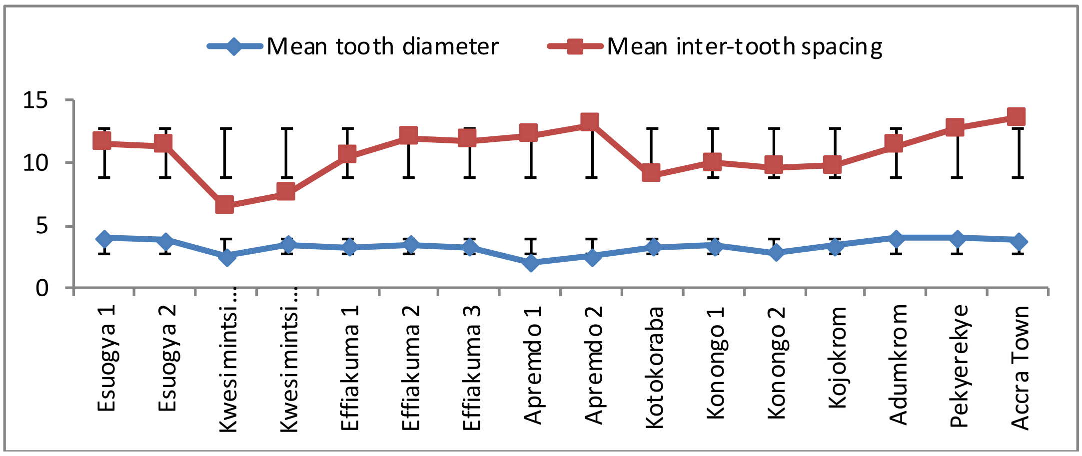

Figure 5: Error bars of tooth diameter and inter-tooth spacing

Grouped frequency distribution

Tables 3(a) and (b) show the frequency distributions of the tooth diameters and inter-tooth spacing. The two frequency distributions show where most of the data are grouped: 3.0-4.1 mm for tooth diameters and 5.1-9.8 mm for inter-tooth spacing. Such frequency distributions may be represented graphically as shown in figures 6. In this analysis, the use of frequency distribution is helpful to guide decisions on quality. Frequency distribution is a practical method for analysing the quality of a production process in terms of product specifications limits. It also provides a graphical and analytical guide for corrective action [24].

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Frequency curves

Figure 6 is a graphical representation of the frequency distribution data presented in Tables 3(a) and 3(b). The two graphs are series of curved lines that join the cell mid points with heights proportional to their frequencies. By placing trend lines on the bar plots it is observed that curves appear like 'disturbed' normal curves, that is, the curves are skewed [24]. Figure 6 shows a curve with the left tail longer than the right tail (negative skewness). It is observed that most of the data are concentrated on the right side of the distribution. Here, the median (3.40 mm) is greater than the mean (3.32 mm). Again, in Figure 6 the right tail is longer than the left tail and hence skewed towards the right (positive skewness). In this case most of the data are concentrated on the left side of the distribution. The mean (7.45 mm) is greater than the median (7.40 mm) as depicted in Table 4 below.

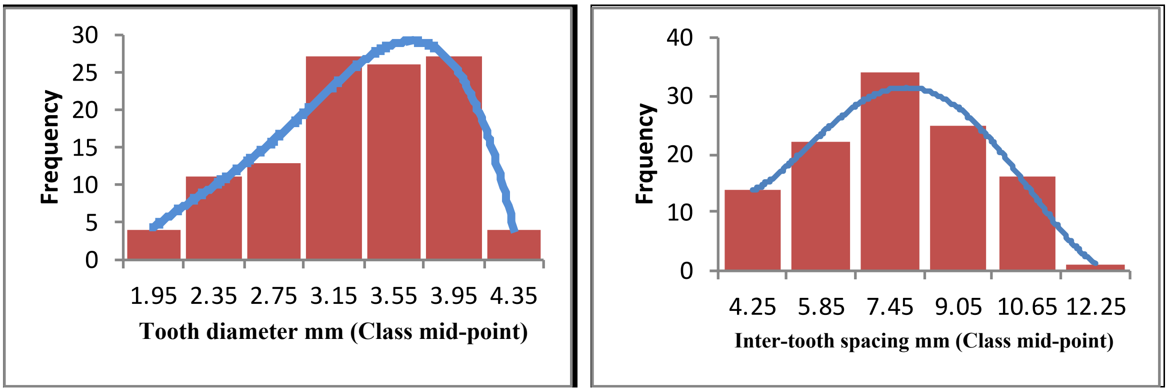

Figure 6: Frequency curves of tooth diameters and inter-tooth spacings

Central tendency, dispersion and measures of variation

Central tendency: mean, median and mode

To understand the centre of the data, the mean (M), median (M_d) and mode (M_o) can be very useful for the statistical quality control analysis of the data. Table 4 shows the following central tendency values for tooth diameter (M=3.32 mm; M_d=3.40 mm; M_o=4.00 mm). For inter-tooth spacing (M=7.45 mm; M_d= 7.40 mm; M_o=7.2 mm).

Dispersion: standard deviation and standard error

Using the standard deviation, Table 4 indicates wider spread in data (SD=1.80 mm) for inter-tooth spacing when compared to the spread in data (SD=0.50 mm) for tooth diameter. Standard error (SE) is the standard deviation of the sample mean. It quantifies how precisely the true mean of the population is known. It takes into account both the value of the Standard deviation and the sample size [13]. In Table 4 the standard error values were SE=0.06 (tooth diameter) and SE=0.17 (inter-tooth spacing).

Measures of variation: coefficient of variation

To find the variation in the data relative to the mean, coefficient of variation (CV) was used. Coefficient of variation is the ratio of sample standard deviation to sample mean – lower CV values are more consistent than higher CV values [13]. In Table 4 for tooth diameter the computed values of coefficient of variation (CV=18.07%), while that for inter-tooth spacing was (CV=24.16%). As a result of the fact that tooth diameter data has

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lower CV=18.07% than that of inter-tooth spacing data CV=24.16%, the tooth diameter data are more consistent than that of inter-tooth spacing.

The empirical rule and confidence interval

Figures 7(a), 7(b) and 7(c) present the normal distribution curves and percent of the population in a given range for both the tooth diameter and inter-tooth spacing values using their means and standard deviations. If it is assumed that the data are normally distributed (bell-shaped curve), then the following empirical rule (or 68-95-99.7 rule) applies [13, 24]:

- 68.3% of all values fall within mean ± one standard deviation **(M±1s)** of the data as shown in Figure 7(a).
- 95.4% of all values fall within mean ± two standard deviations **(M±2s)** of the data as shown in Figure 7(b).
- 99.7% of all values fall within mean ± three standard deviations **(M±3s)** of the data as shown in Figure 7(c).

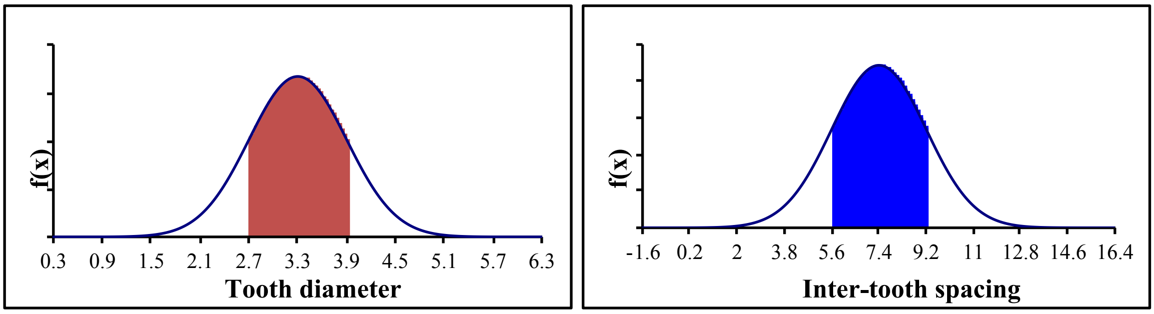

Figure 7(a): Normal distribution showing 68.3% of observations in the range (M±1s)

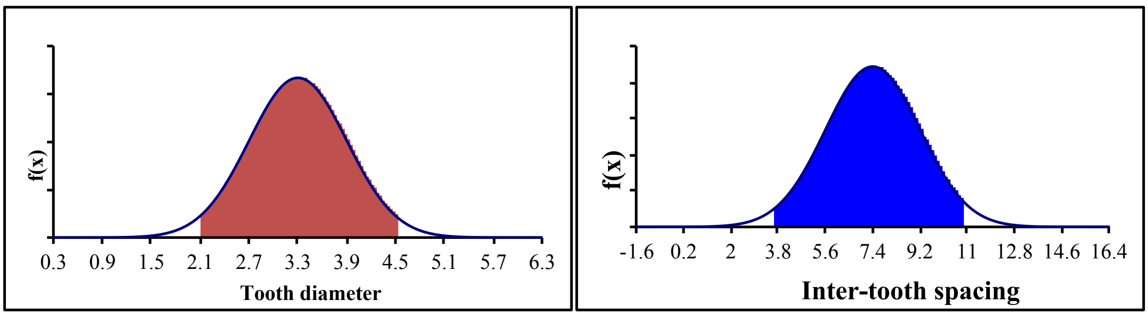

Figure 7(b): Normal distribution showing 95.4% of observations in the range (M±2s)

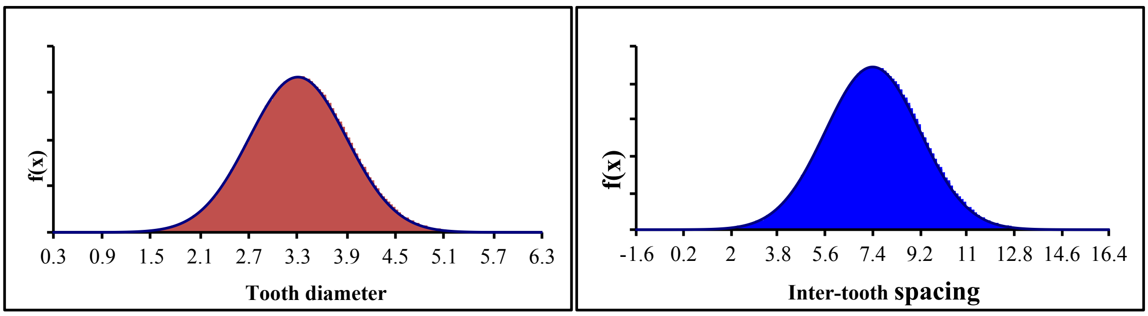

Figure 7(c): Normal distribution showing 99.7% of observations in the range (M±3s)

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For the fabrication process to be standardised and working within the 95% confidence interval, it is anticipated that about 95% of all the tooth diameter and inter-tooth spacing values will fall within mean ± 2 standard deviations. An important role of statistics is to draw conclusions about a population based on information gathered from a sample of that population. Thus, in order to contextualise the computations done on the study samples, confidence intervals (CI) play a key role by quantifying the accuracy of the population estimates [13]. Table 5 shows 95% confidence intervals of 3.18 to 3.42 mm for tooth diameter and 7.12 to 7.78 mm for inter-tooth spacing. The confidence intervals indicate we can be 95% confident that the means for the entire population of tooth diameter and inter-tooth spacing fall within the stated range.

Summary results

Table 6 is a summary of the study results before and after statistical analysis. From the results obtained using the empirical rule (or 68-95-99.7 rule) and confidence interval, it is important that the data are made reasonably practicable to reflect realities on the ground given that most of the fabricators do not have high precision tools to achieve the desired tolerance. Therefore, for practical applications, the data from the statistical analysis indicate tooth diameter of 3.0 mm and inter-tooth spacing of 8 mm as shown in figure 8. These values are consistent with modern cassava graters such as IITA 202 whose teeth diameters are found to be perforated using concrete nails of diameter 3mm and inter-tooth spacing of 5 to 10 mm [25].

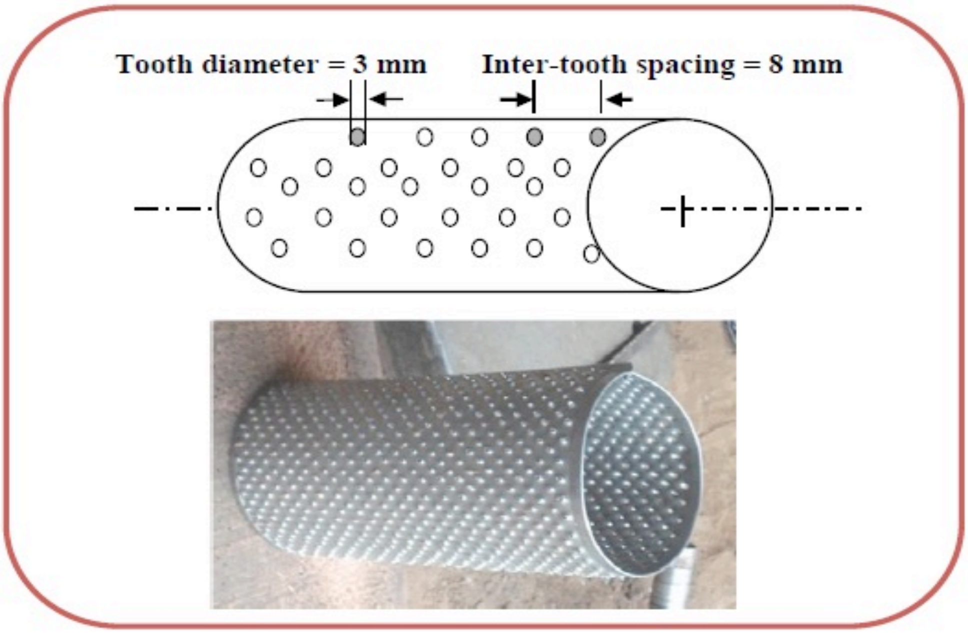

Figure 8: Metal grating sheet showing the tooth diameter and inter-tooth spacing

CONCLUSION

In this study, both quantitative and qualitative data were gathered for analysis. The purpose of the qualitative approach was to gather narratives underlying the central issue being studied so as to guide and complement the quantitative measurements. For the purpose of assessing cassava grating surfaces with focus on analysing tooth diameters and inter-tooth spacing for improvement, the following conclusions are drawn. The narrative and information from the qualitative approach provided significant insights into needs and opportunity identification, which guided the study to focus on the two variables of interest – tooth diameter and inter-tooth spacing. We can be 95% confident that the means for the entire population of tooth diameters and inter-tooth spacing are most likely to fall within the upper and lower limits of 3.18 - 3.42 mm for tooth diameter and 7.12 - 7.78 mm for inter-tooth spacing.

However, it is important that we make the data reasonably practicable to reflect the realities on the ground, given that most small fabricators in West Africa and some developing countries may not have the requisite precision tools to achieve the desired tolerance. Hence, for practical purposes, we recommend tooth diameter of 3 mm and inter-tooth spacing of 8 mm. The above stated data will be employed to standardise cassava grating surface teeth. Improved cassava grating surface is likely to help gari processors to achieve the desired particle size in one grating cycle and reduce grating time. These findings are a significant contribution to the standardisation of grating surface of cassava graters for grating cassava into mash for gari processing. The study findings will also contribute to ensure interchangeability of cassava grating surfaces to improve performance and uniformity of the particle size of cassava mash into moderately-fine textured gari that is preferred by most people in Ghana.

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Table 1: Qualitative information from fabricators and gari processors

	Fabricators feedback
FABRICATORS	• Metal grating surface that appears like tightly-packed tooth bricks is the most desired by customers as during grating it ensures effective contact between the cassava and the metal grating surface to reduce grating time.
	• The making of grating surface teeth of cassava graters is labour intensive and time consuming. Therefore, making of teeth pattern usually requires about 2-3 hours.
	• Inexperienced apprentices usually make the grating surfaces by employing a hammer and nail/punch to perforate random holes without marking out.
	• Mild steel and galvanized steel are the materials used by most fabricators. However, if restaurants place an order for a metal grating surface for mashing of cassava into fufu (local food), then stainless steel is used. Some even use any silver-like sheet metal as customers do not know the difference between other sheet metal materials and stainless steel.
	• Sheet metals for the fabrication of grating surface teeth depend on customer's choice since stainless steel is more expensive than mild and galvanised steels.
	Gari processors feedback
WOMEN GARI PROCESSORS	• Saw-toothed grating surfaces grate faster but produce coarser grates as compared to the existing punched grating surfaces.
	• We break coarse grates with the fingertips to reduce particle size otherwise grating is done 2 or 3 times to achieve the desired particle size and quality.
	• If the grates are too coarse they are sieved several times to reach the desired particle size. Most customers prefer moderately fine-textured gari.
	• When the grating surface teeth become blunt very coarse grates are produced and grating is done over and over at extra cost.
	• There is the need for a sustainable technology that can grate our cassava once.

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Table 2(a): Measured tooth diameter by study area

Study area	Tooth diameter (mm)							Mean	Standard deviation
Esuogya 1	4.5	4.2	3.8	4.0	3.7	3.8	3.5	4.0	0.34
Esuogya 2	3.9	4.2	3.8	3.9	4.0	4.1	4.0	4.0	0.13
Kwesimintsim 1	3.8	4.0	4.0	3.9	4.2	4.1	4.0	4.0	0.13
Kwesimintsim 2	3.6	3.8	3.7	4.0	4.0	3.7	3.8	3.8	0.15
Effiakuma 1	2.7	2.5	2.5	2.6	2.2	2.5	2,6	2.5	0.17
Effiakuma 2	3.5	3.7	3.6	3.4	3.3	3.3	3,5	3.5	0.16
Effiakuma 3	3.3	3.2	3.2	3.5	3.0	3.0	3.0	3.2	0.19
Apremdo 1	3.5	3.5	3.8	3.4	3.4	3.4	3.5	3.5	0.14
Apremdo 2	3.1	3.1	3.3	3.2	3.4	3.2	3.1	3.2	0.12
Kotokoraba	1.8	2	2.2	2.3	1.9	1.8	2.2	2.0	0.21
Konongo 1	2.5	2.5	2.7	2.6	2.3	2.4	2,7	2.5	0.14
Konongo 2	3.4	3.4	3.2	3.2	3.0	3.1	3.1	3.2	0.15
Kojokrom	3.5	3.4	3.4	3.6	3.3	3.2	3.2	3.4	0.15
Adumkrom	2.8	2.9	2.8	2.9	2.7	2.7	2,8	2.8	0.09
Pekyerekye	3.2	3.4	3.4	3.3	3.2	3.3	3.2	3.3	0.09
Accra Town	4.0	4.1	3.9	4.1	4.0	3.9	4.0	4.0	0.08

Table 2(b): Measured inter-tooth spacing by study area

Study area	Inter-tooth spacing (mm)							Mean	Standard deviation
Esuogya 1	7.5	7.5	7.7	7.4	7.6	7.5	7.2	7.5	0.16
Esuogya 2	7.5	7.6	7.6	7.2	7.6	7.4	7.5	7.5	0.15
Kwesimintsim 1	3.8	4.2	4.0	3.9	4.0	3.9	4.1	4.0	0.13
Kwesimintsim 2	3.5	4.0	4.2	4.5	3.8	4.0	3.8	4.0	0.32
Effiakuma 1	7.3	7.3	7.2	7.4	7.4	7.2	7.2	7.3	0.09
Effiakuma 2	8.4	8.6	8.5	8.5	8.4	8.6	8.4	8.5	0.09
Effiakuma 3	8.5	8.6	8.5	8.4	8.7	8.4	8.4	8.5	0.12
Apremdo 1	10	10.2	10.2	10.3	10.4	10.1	10.2	10.2	0.13
Apremdo 2	10.5	10.4	10.4	10.5	10.6	10.6	10.5	10.5	0.08
Kotokoraba	5.8	6.0	5.9	5.8	5.7	5.6	6.0	5.8	0.15
Konongo 1	6.5	6.4	6.5	6.6	6.5	6.6	6.1	6.5	0.17
Konongo 2	6.7	6.7	6.9	7	6.7	6.8	6.6	6.8	0.14
Kojokrom	6.5	6.4	6.3	6.6	6.4	6.5	6.1	6.4	0.16
Adumkrom	7.2	7.3	7.2	7.4	7.3	7.4	7.2	7.3	0.09
Pekyerekye	8.5	8.7	8.8	8.7	8.8	8.5	8.8	8.7	0.13
Accra Town	8.5	9	9.5	10.2	12.0	9.6	10.1	9.8	1.12

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Table 3 (a): Frequency distribution of tooth diameter

Tooth diameter (mm)	Upper class limit (mm)	Mid-point (mm)	Frequency	Cumulative frequency
1.8 - 2.1	2.1	1.95	4	4
2.6 - 2.9	2.9	2.75	13	28
3.0 - 3.3	3.3	3.15	27	55
3.4 - 3.7	3.7	3.55	26	81
3.8 - 4.1	4.1	3.95	27	108
4.2 - 4.5	4.5	4.35	4	112
			∑f = 112	

Table 3 (b): Frequency distribution of inter-tooth spacing

Inter-tooth Spacing (mm)	Upper class limits (mm)	Mid-point (mm)	Frequency	Cumulative Frequency
3.5-5.0	5.0	4.25	14	14
5.1-6.6	6.6	5.85	22	36
6.7-8.2	8.2	7.45	34	70
8.3-9.8	9.8	9.05	25	95
9.9-11.4	11.4	10.65	16	111
11.5-13.0	13.0	12.25	1	112
			∑f = 112	

Table 4: Central tendency, dispersion and measures of variation

	Tooth diameter	**Inter- tooth spacing**
Number of observations (n)	112	112
Minimum value	1.80	3.50
Maximum value	4.50	12.0
Median (M_d)	3.40	7.40
Mean (M)	3.31	7.45
Mode (M_o)	4.00	7.20
Standard deviation (SD)	0.50	1.80
Coefficient of variation (CV)	18.07%	24.16%
Standard error (SE)	0.06	0.17

Table 5: Confidence intervals for the mean: upper and lower limits of data

	Tooth diameter	**Inter- tooth spacing**	**Remarks**
Upper Limit [M+(SE×1.96)]	3.42	7.78	For 95% confidence limits
Lower Limit [M-(SE×1.96)]	3.18	7.12	For 95% confidence limits
Mean ± 1standard deviation (M±1s)	3.31 ± 1 (0.50) (2.81 to 3.81)	7.45 ± 1 (1.80) (5.65 to 9.25)	Contains approximately 68.3% of the observations
Mean ± 2 standard deviation (M±2s)	3.31 ± 2 (0.50) (2.31 to 4.31)	7.45 ± 2 (1.80) (3.85 to 11.05)	Contains approximately 95.4% of the observations
Mean ± 3 standard deviation (M±3s)	3.31 ± 3 (0.50) (1.81 to 4.81)	7.45 ± 3 (1.80) (2.05 to 12.85)	Contains approximately 99.7% of the observations

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Table 6: Summary results

	Field data	
Field data	Tooth diameter	1.80 - 4.50 mm
	Inter-tooth spacing	3.50 - 12.00 mm
	After statistical analysis	
Empirical Rule	Tooth diameter	2.81 - 3.81 mm
	Inter-tooth spacing	5.65 - 9.25 mm
Confidence Interval	Tooth diameter	3.18 - 3.42 mm
	Inter-tooth spacing	7.12 - 7.78 mm
For practical application	Tooth diameter	3 mm
	Inter-tooth spacing	8 mm

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