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A Comparative Technique for Performance Evaluation of Hammer Mill and Disk Mill in Yam Flour Processing

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Abstract

Grinding (Particle size reduction) of biomass is an age-long operation that is performed during the preparation process of certain food products. Among the grinding mill machines mostly used for this operation are hammer mill and disk mill. Being that the nature of biomass affects the performance and choice of grinding-mill machine to be adopted, it is imperative to compare and select appropriate grinding mill machine that is efficient and effective. In this paper, a comparative technique to evaluate and select appropriate grinding mill machine for particle size reduction of dried white yam (Dioscorea rotundata) is proposed. Hammer mill and disk mill machines were selected for consideration. Two white yam species (Benue and Delta Yam) were prepared into dried chips and ground using the selected mills. Among the attribute (performance parameters) considered are crushing time, particle size distribution and energy consumed. A measure of performance (Index I) based on the comparative technique was formulated and used in evaluating the performance of the two mills. In the hammer mill, index I recorded 2721.2 and 3719.82 par/kWh for Benue Yam chips at screen size 4 and 6 mm, respectively, while 2647.89 and 3472.01 par/kWh was recorded for Delta yam chips at screen size 4 and 6 mm, respectively. Index I values for the Disk mill were 2536.25 and 2433.42 par/kWh at 1.2 mm clearance distance for Benue Yam chips and Delta Yam chips, respectively. The results indicated that hammer mill performed better overall than the disk mill. The comparative technique was found suitable in the evaluation of the performance of the mills. It is recommended that hammer mill be adopted.

Keywords

Comparative Technique, Hammer Mill, Disk Mill,

Performance Assessment of Mills

1. Introduction

Grinding, milling, shearing, shredding, pulverizing, etc. are operations that are carried out on food products to reduce their particle size. According to [1] [2] [3], particle size reduction of solid food is widely carried out in various food industry when creating smaller particles from larger particles of the same material. Stone milling was the only way to make grain into flour for millennia [4]. Thus an assembly of these stones for grinding purposes was constituted as a tool called hand-quern. Hand-quern became the first tool that was used in ancient times to grind food items (e.g., wheat grains). It consisted of two round flat stones where one is placed above the other. The upper stone was turned by a wooden handle and wheat was trickled in through a hole in the center. As the upper stone turns, meal came out around the edge [5]. Large scale milling necessitated the replacement of hand-quern with roller wheel mill around 1000 BC [6]. Though the roller wheels at that time were driven by slaves or animals, over the years, roller mills were improved upon and driven by wind or water power (now known as wind mill or water mill). Some of these mills are still in operation to date.

In contemporary times, grinding (particle size reduction) of food products into flour is performed using several modern grinding and milling mills such as disk mill, hammer mill, roller mill, ball mill, etc. The choice of mill used usually depends on the mill's effectiveness, suitability for food products and users' preference. Among the most widely used mills for food products grinding are hammer mill and disk mill. Hammer mills are widely used in processing industries because of their ability to finely grind a large variety of materials in comparison to other milling machines [7] [8] [9] [10]. Hammer mills use a combination of impact, shear, and compression forces during size reduction, with the largest proportion due to the impact [11] [12] [13]. However, Hammer mill takes a longer time and high speed to produce fine particles (flour) which in turn consumes a lot of energy per kilogram of flour produced. Disk milling is a continuous process and mainly utilizes shear force to induce biomass defiberization [14] [15]. Disk milling is scalable but has high energy consumption [16]. However, more time is spent grinding using disk mill due to a low feed rate.

Energy consumption is an important factor in particle size reduction of food products. The amount of energy used may affect the cost of the finished product. Reference [17] indicated that the power requirements for grinding biomass are related to biomass selection, initial and final particle sizes (geometric mean diameter), moisture content and feed rate of the material. Higher energy consumption during particle size reduction could result in high cost per unit of the finished food product. It is important to note that the characteristics (e.g., density, hardness, brittleness and moisture content) of food products slated for particle size reduction can affect the choice of the mill to be used. Consequently, selecting appropriate mills that will be economical and effective becomes imperative.

Traditionally, machine performance is rated or compared by two major terms (or indexes) called *effectiveness* and *efficiency*. Machine effectiveness deals with the degree of success in achieving a desired result. For instance, the effectiveness of a wood cutting machine is a measure of its cutting time. Effectiveness does not consider the resources used in achieving desired result, as such, it is not a sufficient measure to be used only in comparing the performance of two or more machines. On the other hand, Machine efficiency is about the best use of resources, inputs, to achieve maximum output. Machine efficiency may be expressed as the ratio of its actual output over designed output or by its work output over work input. Machine efficiency measure is usually dimensionless, meaning that the output unit carries the same dimension as the input unit. Efficiency measure is sufficient in comparing machine performance. However, it is much better to compare machine performance using efficiency along with its effectiveness.

In particle size reduction of food products, the effectiveness of a mill may be measured by the milling time, particle size distribution of the milled product or both. A mill is considered effective if it has a lower milling time and also gives the desired particle size of milled product. Efficiency of a mill can be measured by evaluating the actual milling time and particle size distribution of the milled products with the designed milling time and particle size distribution, respectively.

The performance rating of a mill varies when fed with various food products. Manufacturers of mills usually specify their performance range for certain categories of products. Food products mostly captured are grains (e.g., wheat, corn, beans, sorghum, millet, etc.), as such, the mill effectiveness in crushing other starchy foods not specified (e.g., dried yam and plantain chips) is unknown. Also, efficiency and effectiveness data provided on the name plate or user's manual may be insufficient in determining the suitability of the mill for crushing these unspecified food products.

Yam flour is a common ingredient in African dishes. An example of African food where yam flour is used is Amala. Amala is prepared using white yam (Dioscorea rotundata) flour as basic ingredient [18] [19] [20]. Processing yam tubers into flour require certain processes and specialized type of grinding mills due to its nature in dried state. Dried yam chips are usually soft, tough and with little brittleness. Thus, grinding this product (dried yam chips) into flour may be challenging and uneconomical if appropriate mill is not used.

In Nigeria, disk grinding mill is mostly used to grind dried yam chips into flour. Most of the disk grinding mills used are locally designed and fabricated, and do not have information on product range and performance. Consequently, operators or users of this machine (mill) only operate on the notion that the machine is effective (*i.e.*, by physical inspection), and with little economic consideration. Hammer mill can be effective in crushing yam chips into flour if properly designed. However, comparing its effectiveness and efficiency with that of the disk mill might be challenging due to varying design specification and the challenge of establishing a common base point for analysis. On this note, this study proposes a comparative technique in determining the suitability of hammer mill and disk mill for particle size reduction of dried yam chips.

2. Material and Methods

2.1. Procedure

Two varieties of white yam (Dioscorea rotundata) tubers were procured from a local market within Ibadan metropolis. The two yam varieties are Benue and Delta Yam: *Benue is a state in the middle belt region of Nigeria, it boasts of large-scale varieties of agricultural produce, as such, it is usually referred to as the food basket of the nation. Benue state cultivate agricultural produce such as yam, sweet potato, maize, mango and orange. Yam variety cultivated in Benue state is usually called Benue Yam. The name tag (Benue Yam) is due to its specie, unique nature and sweetness. On the other hand, Delta is a state in the southern region of Nigeria. It is one of the Niger Delta States with abundance of petroleum deposits (crude oil and natural gas). The upper lands of Delta state cultivate several agricultural products such as cassava and maize. Delta state boast of fertile soil for the cultivation of white yam. Yam cultivated in Delta state is of high grade and usually called Delta Yam.*

The procured yam tubers where peeled with kitchen knife and washed with clean tap water. Thereafter, it was chopped into chips of uniform shapes, size and thickness. The chips were immersed in hot water (100˚C) for 10 minutes after which they were placed on an oven tray and dried at controlled temperature of 60˚C for 72 hours. The dried chips were collected from the oven dryer at 12.5% moisture content and set for crushing.

Three samples of dried Benue Yam chips denoted as X_{H4}, X_{H6} and X_D, weighing two hundred and fifty grams (250 g) each, were measured for crushing. Samples X_{H4} and X_{H6} were crushed using hammer mill while sample X_D was crushed using disk mill. Similarly, three samples of dried Delta Yam chips denoted as $Y_{H4,}$ Y_{H6} and Y_D, weighing two hundred and fifty grams (250 g) each, were measured for crushing. Samples Y_{H4} and Y_{H6} were crushed using hammer mill while sample Y_D was crushed using disk mill.

Samples were crushed separately, screen size four (4) was used when crushing samples X_{H4} and Y_{H4}, while screen size six (6) was used when crushing samples X_{H6} and Y_{H6} in the hammer mill. Each crushed sample was separated with sieves of various sizes. The sieve size used were 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 425 μm, and zero particles. Among the parameters considered during crushing were crushing time, energy consumed and particle size distribution. The weight of each particle size as separated by the sieve for each crushed sample was determined and the percentage weight composition (WC) was obtained. See **Table 1** for obtained values of weight of particle size and weight composition.

Table 1. Particle size distribution for the Hammer mill and Disk mill

FOOD SAMPLE	HAMMER MILL			DISC MILL		
	Sample X_{H4}; Screen size = 4 mm			**Sample X_D**		
	Particle Size	**Weight [g]**	**WC (%)**	**Particle Size**	**Weight [g]**	**WC (%)**
Benue yam (chips)	6.70 mm	-	-	6.70 mm	-	
	4.75 mm	-	-	4.75 mm	-	0.0
	2.36 mm	9.70	3.88	2.36 mm	-	0.0
	1.18 mm	45.30	18.12	1.18 mm	4.12	1.65
	600 µm	49.40	19.76	600 µm	29.81	11.92
	425 µm	22.30	8.92	425 µm	26.40	10.56
	Zero particle	121.50	48.64	Zero particle	189.31	75.72
	Total weight	**248.20**		**Total weight**	**249.64**	
	Sample X_{H6}; Screen size = 6 mm					
	6.70 mm	-				
	4.75 mm	5.84	2.34			
	2.36 mm	31.65	12.66			
	1.18 mm	52.17	20.87			
	600 µm	54.16	21.66			
	425 µm	26.22	10.49			
	Zero particle	78.03	31.21			
	Total weight	**248.07**				
Delta yam (chips)	**Sample Y_{H4}; Screen size = 4 mm**			**Sample Y_D**		
	Particle Size	**Weight [g]**	**WC (%)**	**Particle Size**	**Weight [g]**	**WC (%)**
	6.70 mm	-		6.70 mm	-	
	4.75 mm	-	0.0	4.75 mm	-	0.0
	2.36 mm	10.70	4.28	2.36 mm	-	0.0
	1.18 mm	49.21	19.68	1.18 mm	5.60	2.24
	600 µm	52.30	20.92	600 µm	38.80	15.52
	425 µm	19.10	7.64	425 µm	31.20	12.48
	Zero particle	117.20	46.88	Zero particle	174.08	69.63
	Total weight	**248.51**		**Total weight**	**249.68**	
	Sample Y_{H4}; Screen size = 6 mm;					
	6.70 mm	-				
	4.75 mm	12.43	4.9			
	2.36 mm	37.34	14.94			
	1.18 mm	58.63	23.45			

Continued

	600 µm	43.06	17.22	
	425 µm	21.27	8.51	
	Zero particle	75.69	30.28	
	Total	**248.42**		-

2.2. Hammer Mill

The capacity of a machine to grind particles depends on the power rating of the machine, and also the final size and moisture content of the resulting particles [21]. Hammer mill uses high-velocity rotating shafts to impart kinetic energy to the processed material. **Figure 1** shows the diagram of the hammer mill used. It consists of a hopper, inspection door, driving shaft, hammers, screen, discharge outlet, electric motor and support stand/base. Five horse power (HP) electric motor with a revolution of 1460 rpm was used to drive the mill. Detachable screen sizes of hole diameter four (4) and six (6) mm were selected and used.

2.3. Disk Mill

The disk mill works on the principle of impact and friction. **Figure 2** shows the diagram of the mill. It consists of a hopper, Driving shaft, conveyor shaft, conveyor housing, grinding plate housing, grinding plates, plate clearance adjuster, Lock nut clamping bolt, electric motor, iron stand/base. It is driven by a three (3) HP electric motor with a revolution of 1460 rpm.

2.3. Performance Parameters

2.3.1. Crushing Time

The time it took the mill to grind each sample was recorded as crushing time. This time was recorded using a stop watch.

2.3.2. Energy Consumption

For a mill that is driven with an electric motor, the energy consume is a measured of the electric energy drawn or used by the motor. This may be expressed as:

$$\text{Energy consumed,} \quad E = \left(0.746 \times HP \times Z \times t\right) / Eff. \quad (1)$$

where,

E—Energy consumed in kilowatt hour (kWh);

HP—Electric motor horse power as stated on the name plate;

Z—Load percentage;

t—Crushing time in hours;

Eff.—Electric motor efficiency.

A single phase AC electric motor was used to drive the mills (hammer mill and disk mill).

Figure 1. Diagram of the hammer mill.

Figure 2. Diagram of the disk mill.

Electric motor specification as used is as follows:

Motor specification for hammer mill: *HP* = 5; *Eff.* = 85%; Load percentage (Z) = 63%;

Motor specification for disk mill: *HP* = 3; *Eff.* = 85%; Load percentage (Z) = 81%.

See **Table 2** for obtained and computed values of crushing time and energy consumed respectively.

2.3.3. Particle Size Distribution

The hole diameter of sieve determines the particle size distribution of crushed samples. When crushed samples are sieved, various particle sizes as defined by the sieve hole are obtained. The weight of each particle size becomes a factor in computing the particle size distribution. Thus, the weight composition (WC) of each particle size in a given crushed sample becomes a measure of particle size distribution. See **Table 1** for particle size distribution of samples.

Determination of Number of Particles

Number of particles is a conception that is used in this work to measure the fineness of the crushed samples. The higher the number of particles, the better the quality or fineness of the crushed sample. To determine the number of particles, the following expressions are made.

Let,

N = number of sieve to be used for segregation;

k = number of particle size. Where, $k \le N$;

n = grade of sieve size, where $n = 1, 2, 3, \cdots, k$;

(Note: Sieve size is graded from 1 *to k*).

Therefore,

$$\text{Weight Composition}(\text{WC}) = \frac{\text{weight of each particle size}}{\text{weight of uncrushed sample}} \times 100 \quad (2)$$

$$\text{Number of particle} = n \times \text{WC} \quad (3)$$

$$\text{Total number of particle} = \text{Sum total of number of particle} \quad (4)$$

2.3.4. Formulation of Index I

Other than efficiency, the ratio of output to input can also be used to express performance in another form. In grinding operations, particle size distribution is an output measure that determines the effectiveness of grinding mill. A modified form of particle size distribution as used in this paper is the number of particle. Here, number of particles measures the fineness of crushed samples. Similarly, energy consumed by a mill in the course of milling operations is an input measure that is used in the evaluation of mill efficiency. Thus, by combining these two parameters as a ratio of total number of particles to energy consumed, we obtained a new performance index, (PI) called Index I.

Mathematically,

$$\text{Index I} = \text{Total number of particles/energy consumed (par/kWh)} \quad (5)$$

2.4. Step-Wise Approach of the Technique

Step 1: Determine the crushing time per sample;

Step 2: Compute for the energy consumed during crushing per sample;

Step 3: Determine the number of sieve (N) to be used for segregation;

Step 4: Determine the number (k) of particle size segregated;

Step 5: Allocate 'n' to sieve size in the order of decreasing sieve size;

Step 6: Determine the weight of each particle size in each sample;

Step 7: Determine the percentage weight of each particle size in each sample;

Step 8: Determine the number of particle $n \times$ WC for each sample;

Step 9: Determine the total number of particle for each sample;

Step 10: Compute for Index I (*i.e.*, PI).

3. Result and Discussion

Table 1 shows the Particle Size Distribution or weight composition (WC) of samples from hammer mill and disk mill. For sample X_{H4}, the particle size distribution at 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm and zero particles sieve sizes were 0.00 g, 0.00 g, 9.70 g, 45.30 g, 49.40 g, 22.30 g and 121.50 g respectively. That rendered in percentage, equals 0.0%, 0.0%, 3.88%, 18.12%, 19.76%, 8.92% and 48.64% respectively.

For sample X_{H6}, the particle size distribution at 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm and zero particles sieve sizes were 0.00 g, 5.84 g, 31.65 g, 52.17 g, 54.16 g, 26.22 g and 78.03 g respectively. That rendered in percentage, equals 0.0%, 2.336%, 12.66%, 20.87%, 21.66%, 10.49% and 31.21% respectively. For sample X_D, the particle size distribution at 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm and zero particles sieve sizes were 0.0 g, 0.0 g, 0.0 g, 4.12 g, 29.81 g, 26.40 g, and 189.31 g respectively. That rendered in percentage, equals 0.0%, 0.0%, 0.0%, 1.65%, 11.92%, 10.56% and 75.72%. For sample Y_{H4}, the particle size distribution at 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm and zero particles sieve sizes were 0.00 g, 0.00 g, 10.70 g, 49.21 g, 52.30 g, 19.10 g and 117.20 g respectively. That rendered in percentage, equals 0.0%, 0.0%, 4.28%, 19.68%, 20.92%, 7.64% and 46.88% respectively. For sample Y_{H6}, the particle size distribution at 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm and zero particles sieve sizes were 0.00 g, 12.43 g, 37.34 g, 58.63 g, 43.06 g, 21.27 g and 75.69 g respectively. That rendered in percentage, equals 0.0%, 4.97%, 14.94%, 23.45%, 17.22%, 8.51% and 30.28% respectively. For sample Y_D, the particle size distribution at 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm and zero particles sieve sizes were 0.0 g, 0.0 g, 0.0 g, 5.60 g, 38.80 g, 31.20 g, and 174.08 g respectively. That rendered in percentage, equals 0.0%, 0.0%, 0.0%, 2.24%, 15.52%, 12.48% and 69.63% respectively.

The corresponding grinding time and energy usage of each mill on the yam chip samples is shown in **Table 2**. From **Table 1**, result of weight composition of each sample is used to compute for the number of particle size in each sample. The result of number of particle size of each sample is shown in **Table 3**.

In **Figure 3**, the result of hammer mill and disk mill performances are shown. The number of particles obtained was higher in disk mill compared to hammer mill. However, Benue Yam specie produced higher number of particles in disk mill compared to Delta Yam specie. This characteristic indicated that Benue

Table 2. Grinding time of food samples and energy usage.

FOOD SAMPLE	HAMMER MILL				DISC MILL			
	Screen Size	Time		Energy consumed (kWh)	Clearance Distance (mm)	Time		Energy consumed (kWh)
		(min)	Hr			(min)	Hr	
Benue Yam (chips)	4	3.81	0.0635	175.55	1.2	6.21	0.1035	220.73
	6	2.43	0.0405	111.97				
Delta Yam (chips)	4	3.85	0.0642	177.49	1.2	6.35	0.1058	225.64
	6	2.49	0.0415	114.73				

Table 3. Weight composition and number of particle size per sample.

FOOD SAMPLE	HAMMER MILL				DISC MILL			
	Screen size = 4 mm				**Particle Size**	***n***	**WC (%)**	**No. of Particle (n × WC)**
	Particle Size	***n***	**WC (%)**	**No. of Particle (*n* × WC)**				
Benue Yam (chips)	6.70 mm	-	-	-	6.70 mm	-	-	-
	4.75 mm	1	0.0	0.0	4.75 mm	1	**0.0**	**0.0**
	2.36 mm	2	3.88	7.76	2.36 mm	2	**0.0**	**0.0**
	1.18 mm	3	18.12	54.36	1.18 mm	3	**1.65**	**4.95**
	600 μm	4	19.76	79.28	600 μm	4	**11.92**	**47.68**
	425 μm	5	8.92	44.6	425 μm	5	**10.56**	**52.8**
	Zero particle	6	48.64	291.84	Zero particle	6	75.72	454.32
	Total			**477.84**	**Total**			**559.75**
	Screen size = 6 mm							
	Particle size	***n***	**WC (%)**	**No. of Particle (*n* × WC)**				
	6.70 mm	-	-	-				
	4.75 mm	1	2.34	2.34				
	2.36 mm	2	12.66	25.32				
	1.18 mm	3	20.87	62.61				
	600 μm	4	21.66	86.64				
	425 μm	5	10.49	52.45				
	Zero particle	6	31.21	187.26				
	Total			**416.62**				
Delta Yam (chips)	**Screen size = 4 mm**				**Particle Size**	***n***	**WC (%)**	**No. of Particle (n × WC)**
	Particle Size	***n***	**WC (%)**	**No. of Particle (*n* × WC)**				
	6.70 mm	-	-	-	6.70 mm			
	4.75 mm	1	0.0	0.0	4.75 mm	1	**0.0**	
	2.36 mm	2	4.28	8.56	2.36 mm	2	**0.0**	
	1.18 mm	3	19.68	59.04	1.18 mm	3	**2.24**	**6.72**
	600 μm	4	20.92	83.68	600 μm	4	**15.52**	**62.08**
	425 μm	5	7.64	38.2	425 μm	5	**12.48**	**62.4**
	Zero particle	6	46.88	281.28	Zero particle	6	**69.63**	**417.78**
	Total			**470**	**Total**			**548.98**
	Screen size = 6 mm							

Continued

Particle Size	n	WC (%)	No. of Particle ($n \times$ WC)
6.70 mm			
4.75 mm	1	4.9	4.9
2.36 mm	2	14.94	29.88
1.18 mm	3	23.45	70.35
600 µm	4	17.22	68.88
425 µm	5	8.51	42.55
Zero particle	6	30.28	181.68
Total			**398.24**

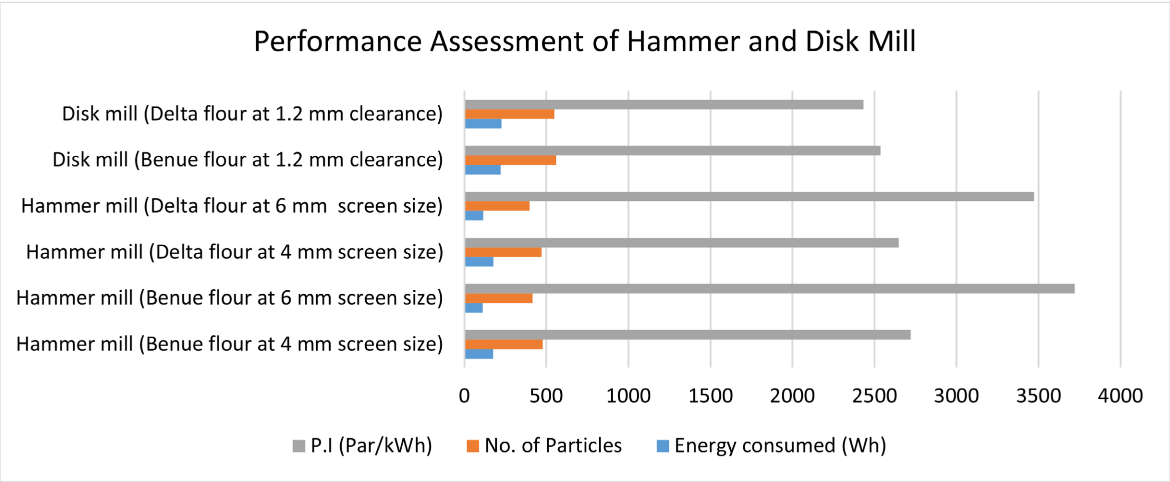

Figure 3. Performance assessment of hammer mill and disk mill.

Yam specie is more brittle when dried compared to Delta Yam specie, making it more suitable and desirable for yam flour production than Delta Yam specie. The hammer mill produced higher number of particles in screen size 4 mm than screen size 6 mm. Benue Yam specie recorded the highest number of particle in each screen size of the hammer mill.

It was observed that on the overall, the disk mill consumed the highest energy compared to the hammer mill. Benue Yam specie recorded lesser energy consumption across the mills compared to Delta Yam specie, signifying appreciable characteristics. In the hammer mill, the highest energy consumption was recorded in screen size 4 mm for Delta Yam specie. This indicated that the smaller screen of hammer mill consumed more energy during milling than the higher screen size.

The performance indexes of the mills showed that hammer mill performed better in the overall on Benue Yam specie in screen size 6 mm, followed by Delta Yam specie on screen size 6 mm of the hammer mill. This performance was traced to the low energy requirement of the hammer mill. The disk mill recorded the least performance according to the new index (Index I). However, Benue Yam specie still performed better in disk mill compared to Delta Yam specie. Across the various screen sizes of the hammer mill, Benue Yam specie performed better. Screen size 6 mm recorded better performance for hammer mill than screen size 4 mm for all species of yam chips sample.

4. Conclusion

Comparative analysis of food grinding/milling machine performance on certain (unspecified) food items may be challenging especially where scanty or no performance information about the machine is available. Consequently, this study proposes a comparative technique to address such a scenario. Here, the performance of disk mill and hammer mill with no prior performance information in grinding dried yam chips into flour was evaluated. Comparative analysis technique to determine the best machine for grinding dried yam chips (sample) was carried out. Among the samples considered are two species of dried white yam chips (Benue Yam and Delta Yam species). The result showed that Benue Yam specie was more suitable than Delta Yam specie. The disk mill produced much finer particle sizes with higher energy consumption than the hammer mill. However, PI showed that the hammer mill performed better than the disk mill overall. This method is recommended for use in performance assessment of food grinding mill machines.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Brennan, J.G. (2005) Chapter 15. Mixing, Emulsification and Size Reduction. In: Brennan, J.G., Ed., *Food Processing Handbook*, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 513-558. https://doi.org/10.1002/3527607579.ch15

[2] Reid, C.B., Forrester, J.S., Goodshaw, H.J., Kisi, E.H. and Suaning, G.J. (2008) A Study in the Mechanical Milling of Alumina Powder. *Ceramics International*, **34**, 1551-1556. https://doi.org/10.1016/j.ceramint.2007.05.003

[3] Mugabi, R., Byaruhanga, Y.B., Eskridge, K.M. and Weller, C.L. (2019) Performance Evaluation of a Hammer Mill during Grinding of Maize Grains. *Agricultural Engineering International*: *CIGR Journal*, **21**, 170-179.

[4] Wight, H. (2011) The History and Processes of Milling. https://www.resilience.org/stories/2011-01-25/history-and-processes-milling

[5] Grainmaker Mills (2019) A Brief History of Milling. https://grainmaker.com/a-brief-history-of-milling

[6] Bakeinfo (2021) Wheat and Milling History. https://www.bakeinfo.co.nz/facts/wheat-milling/wheat-milling-history/

[7] Basiouny, M.A. and El-Yamani, A.E. (2016) Performance Evaluation of Two Different Hammer Mills for Grinding Corn Cobs. *Journal of Soil Sciences and Agricultural Engineering*, **7**, 77-87. https://doi.org/10.21608/jssae.2016.39322

[8] Bitra, V.S.P., Womac, A.R., Chevanan, N., Mui, P.I., Igathinathane, C., Sokhansanj, S. and Smith, D.R. (2009) Direct Mechanical Energy Measures of Hammer Mill Comminution of Switchgrass, Wheat Straw, and Corn Stover and Analysis of Their Particle Size Distributions. *Powder Technology*, **193**, 32-45. https://doi.org/10.1016/j.powtec.2009.02.010

[9] Henderson, S.M. and Perry, R.L. (1976) Agricultural Process Engineering. 3rd Edition, Avi Publishing Co. Inc., Westport.

[10] Scholten, R.L. and McEllhiney, R.R. (1985) The Effects of Prebreaking in Hammer Mill Particle Size Reduction. Paper No. 85-3542, ASAE, St. Joseph.

[11] Austin, L.G. (2002) A Treatment of Impact Breakage of Particles. *Powder Technology*, **126**, 85-90. https://doi.org/10.1016/S0032-5910(02)00044-X

[12] Probst, K.V., Ambrose, R.P.K., Pinto, R.L., Bali, R., Krishnakumar, P. and Ileleji, K.E. (2013) The Effect of Moisture Content on the Grinding Performance of Corn and Corncobs by Hammer Milling. *Transactions of the ASABE*, **56**, 1025-1033. https://doi.org/10.13031/trans.56.9996

[13] Saravacos, G.D. and Kostaropoulos, A.F. (2002) Handbook of Food Processing Equipment. Springer Science, Business Media, New York. https://doi.org/10.1007/978-1-4615-0725-3_1

[14] Da Silva, A.S.A., Inoue, H., Endo, T., Yano, S., and Bon, E.P.S. (2010) Milling Pretreatment of Sugarcane Bagasse and Straw for Enzymatic Hydrolysis and Ethanol Fermentation. *Bioresource Technology*, **101**, 7402-7409. https://doi.org/10.1016/j.biortech.2010.05.008

[15] Hideno, A., Inoue, H., Tsukahara, K., Fujimoto, S., Minowa, T., Inoue, S., Endo, T., and Sawayama, S. (2009) Wet Disk Milling Pretreatment without Sulfuric Acid for Enzymatic Hydrolysis of Rice Straw. *Bioresource Technology*, **100**, 2706-2711. https://doi.org/10.1016/j.biortech.2008.12.057

[16] Ortega-Rivas, E. (2012) Size Reduction. In: Barbosa-Canovas, G.V., Ed., *Nonthermal Food Engineering Operations*, Springer, New York, 71-87. https://doi.org/10.1007/978-1-4614-2038-5_4

[17] Mani, S., Tabil, L.G. and Sokhansanj, S. (2002) Grinding Performance and Physical Properties of Selected Biomass. Paper No. 026175, ASAE, St. Joseph.

[18] Yusuf, A.B., Fuchs, R. and Nicolaides, L. (2017) Consumer Acceptability of Modified and Traditionally Produced Amala from Fermented Orange-Fleshed Sweet Potato. *African Journal of food Science*, **11**, 183-188. https://doi.org/10.5897/AJFS2017.1564

[19] Ojokoh, A.O. and Adeleke, B.S. (2019) Processing of Yam Paste (Amala): A Product of Fermented Yam (*Dioscorea rotundata*) Flour. *International Annals of Science*, **8**, 87-95. https://doi.org/10.21467/ias.8.1.87-95

[20] Ukpabi, U.J., Omodamiro, R.M., Ikeorgu, J.G. and Asiedu, R. (2008) Sensory Evaluation of Amala from Improved Water Yam (*Dioscorea alata*) Genotypes in Nigeria. *African Journal of Biotechnology*, **7**, 1134-1138.

[21] Mohamed, T.H., Radwan, H.A., Elashhab, A.O. and Adly, M.Y. (2015) Design and Evaluate of A Small Hammer Mill *Egypt. Journal of Agricultural Research*, **93**, 481-496.

Abbreviations

Par—Particles