Application of Hammer Mill as Granulator and Pulveriser for Fermented-Pressed Cassava Mash

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Abstract
Hammer mill grated cassava paste, pressed-fermented mash was granulated by hammer mill, HH; granulated conventionally, HB. Similarly, conventionally grated cassava paste, pressed-fermented mash was granulated conventionally, BB; granulated using hammer mill, BH. Each of the parts HH, HB, BB and BH above were replicated into three, each designated HH1. HH2 and HH3 …. BH1, BH2 and BH3 to make 12 samples and 2 x 4 factorial design. Each pulverised was oven dried for moisture contents' determination on dry basis, also each sample was fried into gaari. Bulk densities and some physical properties of the pulverised and gaari samples were determined and they were subjected to sieving analysis. The results showed that **s**ize reduction ratio achieved in all the treatments were done properly and accordingly. Mean values of the coarse, medium and fine particles of the pulverised and gaari samples in all the treatments were statistically different from each other. Significant ($p<0.05$) differences were observed between the results of weights of cassava flour, gaari and different treatments. Hammer mill grated but granulated and pulverised by conventional method had the highest rank for all the physical properties of gaari samples with lowest fibre content, lowest moisture content and highest bulk density. There were stronger correlations (with higher R^2 values) between the different processes and the weights of the cassava flour and gaari so produced per local measure used. The combined processes of hammer mill and conventional BH had the highest 89.1% (medium + fine particles) for gaari while the highest was 86.52% (medium + fine particles) for combination in HB for the pulverised samples.
Keywords: fermented cassava mash, gaari, granulated, hammer mill, pressed cassava mash, pulverised

1.0 Introduction

Hammer mills break up materials by means of revolving beaters which either swing or rigidly connected, the material then passes through perforation underside the beaters on its way to the product hopper. Beaters when fixed are usually 1 – 2 inch apart and rotate at a speed of 2,500 – 4,000 rpm depending on the diameter at the tip of the hammer. At empty, hammer mill can run at 4 – 8 hp without any damage to their beater, burr mill or attrition mills cannot be run by such electric motor but 1- 2 hp when empty. Hammer mills are relatively simple in construction, they are available in large range of sizes, the mills wear do not greatly affect their efficiency (Ademokoya and Samuel, 2014; Nwaigwe et al, 2012; Henderson and Perry, 1982). Foreign matter doesn't affect or easily damage the beaters and running them emptily does not damage the mills, moreover, their repair costs are low compare to that of burr or attrition mill (Lamidi, 2006; Perry and Don, 1998). However, they have been found not to produce uniform grinding due to their high rpm, their initial cost of construction is too high for local farmers and their power requirements may be higher too than what a local farmer or subsistent farmer may practice.

How does hammer mill do the work of reduction ratio to any material put in it? Through explosion due to impact of the hammers and attrition between lumps or particles of the materials being ground, the housing and the grinding elements, cutting is done to the materials. The edge of the hammers and the attrition and rubbing actions are some of the ways it does it work (Nasir, 2005). Why may hammer mill be suitable for granulating and pulverising cassava pressed mash? The advantages of hammer over its disadvantages are more when compare to other mills, besides, it may not do well in milling peeled cassava into paste, but do well for granulation of the pressed mash (Nwaigwe et al, 2012). Size reduction processes need a lot of energy to overcome frictions and energy in form of heat is dissipated to the product, thereby wasting energy from the mill to the product in milling, how would hammer mill overcome these problems? The energy needed is to transform, deform and to reduce size of solid body and it is expended in form of plastic and elastic deformation. As the mills do the work, they were designed to self-provide themselves with resistances against (1) friction/impact on rubbing surfaces; (2) strain of the machine elements and (3) heating-up cause by operation on the material. More energy is expended on these resistances in operation to overcome them.

Efficiency of the hammer mill can be increased by (1) decreasing elastic strain in the material of its working tool, this will automatically increase their resistance to wear; (2) decreasing the number of deformation cycles of the materials to be ground and (3) decreasing breaking stress of the working tool materials, (Lamidi, 2006).

Hammer mill consists of the hopper, the milling chamber, the discharge unit and the frame. *The hopper* is the feeding unit of the mill through which fermented pressed cassava mash is fed into the machine. It is a truncated pyramid made up of 6mm thick mild-steel plate having dimension of 300 x 400 mm at the top, 160 x 400 mm basal chute and vertical height of 200 mm. The hopper is inclined at 45^o to the horizontal. *The milling chamber* contains separated gang of 27 hammers, in this hammer mill, they were swinging (in other mills, they may be fixed) on pivoted shafts born by *four separator discs* mounted at 120^0 space along the circumference and anchored on a rotor shaft. *The beaters* were held in position by 36 spacers and were made up of heat-treated high carbon steel plate of 60 N/mm^2 strength (Juzt and Scharkus, 2003), each beater of dimension 130 mm x 55 mm x 8 mm and 25 mm drilled holes at both ends through which it pivoted and fixed on the separator disc for easy swinging. *The spacer* were made up of steel pipe, separator discs were made up of medium-carbon steel plate cut in circular shapes and welded permanently on the rotor shaft.

The screen is made up of a 6 mm thick mild steel plate cut to a size of 420 x 1320 mm and rolled into half cylinder. Holes of 3.5 mm were drilled at 6 mm square distance on the entire screen and suspended internally on the bottom of the milling chamber at a radius of 210 mm and 5 mm clearance from the tips of the beater. *The rotor shaft* was made from medium-carbon steel rod of 55 mm x 700 mm and turned to 50 mm x 600 mm and supported by two plummer bearings fixed on the frame. It was driven by 7.5hp, 1450 rpm three-phase electric motor. *The discharge unit* is inclined 200 mm x 150 mm x 150 mm chute made up of 6 mm thick mild-steel plate welded to the bottom chamber corresponding to the suspended inner plate in which the crushed material flows. *The frame* supports the machine, made from heavy-duty angle-iron cut into 350 mm length and welded to the bottom of the milling chamber at a height of 250 mm to the base.

Hammer mills have been designed and constructed in various dimensions in local market as well as in research institutions and Universities in Nigeria like Nigerian Centre for Agricultural Mechanisation (NCAM), Ilorin, Obafemi Awolowo University, Ile-Ife and local manufacturers. Some have been imported too to the country from countries like Germany and India. Hammer mills have been used for crushing cocoa pods into livestock feed, it has been used for milling maize and have been used for milling peeled cassava for gaari making. However, as many gaari and cassava flour that are found in the local markets, burr mills were still used for their grating despite all the enumerated advantages of the hammer mills above. Hands were commonly used for their granulation/pulverising of pressed-fermented cassava mash by local gaari processors which make it drudgery. Why is mash cassava still granulated/pulverised manually by gaari/cassava flour processors? Is this because of the differences in the finest of the particles of gaari/cassava flour produced in both cases? Do we have differences in their odour/flavour? Are the farmers aware of the benefits of hammer mill over the burr mill or vice-versa? Could it be that farmers awareness are not enough regarding the use of hammer mill in grating, granulating and pulverising the fermented and pressed cassava mash? Thus, the objective of this paper was based on the studies of cassava particles made into gaari using both hammer mill for granulating/pulverising of its pressed and fermented mash; conventional gaari making using manual granulating by hands, pulverising using local sieves and comparing them with gaari from local markets which were manual granulation/pulverising.

2.0 Materials and Method

Hammer mill and burr mill (conventional method) were separately used to grate peeled cassava in the same quantities. The same breed of cassava was used throughout. They were both hydraulically pressed and left to ferment for five days to become pressed-fermented cassava mash. A part of hammer mill grated and pressed-fermented mash was granulated and pulverised by hammer mill, designated HH, another part of hammer mill grated and pressed-fermented mash was granulated conventionally, denoted HB. Similarly a part of conventionally grated and pressed-fermented mash was granulated and pulverised conventionally, designated BB and another part of burr mill grated and pressed-fermented mash was granulated and pulverised using hammer mill, it was denoted BH. Each of the parts HH, HB, BB and BH above were replicated into three designated HH1. HH2 and HH3 …. BH1, BH2 and BH3 to make 12 samples and 2 x 4 factorial design.

In each of the 12 samples, granulated and pulverised samples were taken. So also, another sample for each of the 12 was fried into gaari using the same frier, at the same time, using the same method throughout to have the same conditions for all the gaari produced from all the samples. Colour and odour of the granulated and pulverised samples were investigated before their moisture contents were researched into. Next was their moisture contents' determination, the 12 pulverised samples taken were of the same quantities, they were all oven-dried at 45^{0}C simultaneously until constant weights for each were got; time for each to reach the constant weight was recorded. The 45^{0}C was selected and the material was dried between 3-4 days such that the process will not be hygroscopic. Time for each of the 12 pulverised/granulated samples to get to constant weights were recorded and shown in Figure 2. However, time taken to fry the pulverised/granulated samples to gaari through gelatinisation were not recorded since these granulates were fried simultaneously in different friers (local with fire burning under pan) using the same time period.

Moisture contents, Mc were calculated based on dry basis in grammes. The moisture contents, Mc of gaari produced in all the samples/replicates were also computed on dry basis. Bulk densities were computed for each sample of the granulated and pulverised using graduated measuring cylinder with a known initial weight and filled with samples in each case to 25 ml mark, compacted with the device made for it, then filled to 100 ml mark.

Besides, the physical properties of the samples investigated upon above, particle size distribution analysis was done for both the granulated and gaari made. All the samples were subjected to sieving analysis. The sieves were arranged as required with the mechanical shaker fitted. British BS410 series sieving was used, with the arrangement from the highest sieve hole descendingly to the lowest seventh, a pan was the eighth in each case. The sieves were categorised into group of three: the first and the second into a group to retain coarse particles, the third and the fourth sieves, a group to take care of the medium and the fifth, sixth and seventh to retain the finer particles. The essence of this arrangement was to be able to establish the finess moduli and the uniformity indices of the samples. Finess modulus is the average finess of particles, the low finess (or index) indicate finely ground and higher finess indicate coarse materials. Uniformity index shows the distribution of the fine and the coarse materials. Since, the research was concerned about the application of hammer mill to the granulations of pressed and fermented cassava mash, samples HH and BH and their replicates would be used to justify the efficiency of the hammer mill.

Moreover, the final weights of the samples (simultaneously oven-dried and fried samples through the same time) were taken immediately to avoid moisture absorption for both the pulverised/granulated and gaari were done to compare their weights. Their average values calculated based on local measuring pans popularly called "*congo*" and were shown in Figures 2 and 3. Furthermore, percent crude fibre in each of the samples was found, a sieve mesh 2.36 mm diameter hole was used to sieve 100 g of each sample. This was done carefully in such a way that no fine particle was allowed to mix up with the fibre in the pan.

The characteristics and the dimensions of the hammer mill used were given in the Table 1. Analysis of the results was done using SAS (2008) and the mean values obtained were separated using Duncan Multiple range tests.

3.0 Results and Discussion

The characteristics and dimensions of the shaft of the hammer mill used in the research are shown in Table 1. Since some discharge screens have 5 mm, others have 3.5 or 3 mm, the hammer mill in used here had 3 mm. this was to make the sieved particles from either pulverised or fried to be finess. This hammer mill was a big one, constructed locally.

The colour of the pulverised and the granulated samples were normally white as expected. Also, the gaari produced were with normal colour after frying, the same thing happened in their flavours, panels of judges made up of 5 local processors and experienced market women were selected to test them. This could testify to the fact that the processes involved did not affect the colour and flavour/odour of the samples.

Table 2 shows the physical properties (± standard error) per sample for different treatments at experimental period. The ranking shows the combination of the hammer mill and the conventional processes BH having higher rank than other treatments as it had the first, second and third positions in the moisture content (lowest), first and second positions in the bulk density (highest) and crude fibre (lowest) for the gaari samples. Also, the combination of the conventional and hammer mill processes HB have higher rank than other treatments as it had the first, second and fourth positions in the moisture content (lowest), second position in the bulk density (high) for the pulverised/granulated samples ready for cassava flour. The next sample to HB was the BB, conventionally grated, granulated and pulverised, HH and BH samples were with low bulk densities, higher moisture and crude fibre contents. Both BH and HB were better than HH when compare as the latter was always in 9th, 10th or 11th position in ranking.

Gaari with higher moisture content will have less shelf life, incapable of swelling up during moulding in boiling water and generally not good. Moisture content of the particle is a function of the particle sizes of the samples, either the pulverised or the gaari. The grated mash at the product hopper is a function of the hammers, swinging or fixed; the speed of the mill; the sizes of the discharge screens. The reasons may be due to the fact that the hammer mill grated mash was not finer enough and consequently when granulated and pulverised will still contain the coarse particle. It may also be due to the fact that the hammers were not fixed, had they, the results might have been better in terms of the particle sizes. It couldn't be because of the speed since the same speed was used for all the samples in their respective times. The panel of judges were individually asked to select the best gaari sample from 10 samples provided, it was done individually and independently as each entered the room, the best gaari selected had moisture content, bulk density and crude fibre respectively given in the Table as 6.70, 0.61 and 2.50. These are close to values approved by Federal Institute of Industrial Research, Oshodi, (FIIRO) in Lagos, Nigeria. Also, comparing these values with the values from local markets of cassava flour and gaari, HB, BH end products were better. It may be surmised that farmers may expect more returns from their processes when hammer mill granulates and pulverises only the fermented and pressed cassava mash rather than grating and granulation, especially if the finished gaari product for market were not due for further sieving just because of fear that such sifted may be a waste.

Particle analysis revealed the percentages retained in coarse, medium and fine groupings of the pan arranged for the separations. The size reduction ratios achieved in the processes were evident in the magnitudes of the uniformity indices, ui, got in each case. When the uniformity indices were rounded up to the nearest 10%, the HH had 10:60:30 and 20:60:20 (coarse: medium: finer) respectively for the pulverised oven-dried sample and the fried gaari, Tables 3, 4. The gaari particle size analysis evidently testified to the size reduction ratio found previously in the pulverised as the medium and finer was 90%: 80%, the difference might have been because some particles might have clinged together during frying, this did affect the result.

The same thing did not happen in the case of BH, BB and HB in their pulverised and gaari particles analysed. The BH had 20:70:10 and 10:80:10 (coarse: medium: finer) respectively for the pulverised oven-dried sample and fried gaari; the BB had 20:60:20 and 10:80:10 (coarse: medium: finer) respectively for the pulverised (Tables 3, 4) oven-dried sample and the fried gaari and the HB had 20:60:20 (coarse: medium: finer) for both pulverised oven-dried sample and fried gaari. While the HH, BH and BB had their size reduction ratio differences in the pulverised and fried samples, the HB was not. Again, the analysis evidently testified to the size reduction ratio found previously in the pulverised as the medium and finer was 80% : 80%, the same ratio means that although some particles might have clinged together during frying, this did not affect the result implying that the size reduction ratio was not apparent but real and through.

Figure 2 shows that BB, BH and HB had lesser time for their pulverised samples to dry with average values 72.33±0.58 hrs, 77.0±1.0 hrs and 77.0±1.0 hrs respectively compare to HH which had 89.67±0.58 hrs. The reason for this may be because of the level of size reduction the products passed through since drying time is a function of size reduction. The particles could have been bigger in case of HH that led to higher time of drying.

Table 5 revealed how the mean values of the coarse, medium and fine particles of the pulverised and gaari samples in all the treatments: HH, BH, BB and HB, were statistically different from one another in their respective experiments. It may be surmised that processes be it hammer mill only or conventional or their combinations, either for grating or pulverising/granulating did affect the nature of the end products of dried cassava that is made into cassava flour and fried cassava made into gaari. Again, the combined processes of hammer mill and conventional BH had the highest percentage of 89.10 medium and fine particles for gaari while the highest was 86.52 medium and fine for such combination in HB for the pulverised samples. Implying that combining the use of hammer mill and conventional may be able to result in higher end products of either gaari or cassava flour than only the hammer mill or conventional manual treatment.

The reason for this may be due to the level of the operating conditions of the hammers or the manual processes. It may also be due to the fact that cassava has more different moisture contents at different periods of the year or different stages of their growth which may also affect their grating, fermentation or their pulverising/granulation. For instance, at the beginning of the rainy season, when the cassava plants are sprouting new leaves, their moisture contents in them is more than some other periods of their existence on the farm, this may simply be because of the fact that for any 1% increase in the climatic variables, there may be more than an 100% increase in the output (Nwakor et al., 2013). In this case, as the tubers swell up, to increase in yield, the moisture contents increase and the processes of the hammers or manual grating or granulating mash become less easy. It may also be due to another reason earlier observed by Nwakor et al., (2013) that majority of climatic variables were highly significant in root and tuber crop production at $p < 0.01$ and $p<0.05$ significant levels in Nigeria.

For Figures 2 and 3, the results of the regression analysis show that there were stronger correlations ($R^2 = 0.99$ in each case) between the time used for drying samples of the granulates of pressed cassava mash and different processes on one hand; and between the use of different processes for the granulation of pressed cassava mash and the weights of the end products (per local '*congo*' of the products) in the other hand. The regression equations as shown in equations 1-3 revealed stronger relationships between the independent variable Y (different processes) and time, hrs T of the end products. Similarly, the regression equations as shown in equations 4 and 5 revealed stronger relationships between the independent variable Y (different processes) and weights X of the end products. It may be surmised that the higher R^2 values got for all the processes revealed that they may be good when used provided good managerial hands are used with good expertise hands and favourable climatic conditions. Moreover, the gaari fried at all treatments had more weights than the pulverised despite measuring out the same weights for the two different processes initially. The reason may be because one was dried and the other one was fried.

For Figure 2

$$Y_{pulverised} = -1E\text{-}12T^3 + 5T^2 - 29T + 1.4 \qquad R^2 = 0.99 \qquad (1)$$

$$Y_{pulverised} = 0.333T^3 + 1.5T^2 - 18.83T + 107 \qquad R^2 = 0.99 \qquad (2)$$

$$Y_{pulverised} = 0.333T^3 + 1.5T^2 - 18.83T + 106 \qquad R^2 = 0.99 \qquad (3)$$

For Figure 3

$$Y_{gaari} = 24.66X^3 - 219X^2 + 600.3X + 1474 \qquad R^2 = 0.99 \qquad (4)$$

$$Y_{pulverised} = -35.5X^3 + 285.5X^2 - 678X + 2108 \qquad R^2 = 0.99 \qquad (5)$$

The oral interview conducted to answer some questions raised earlier, among the 100 farmers, cassava flour and gaari processors inclusive that were interviewed, 75% were not aware of the use of hammer mill for grating peeled cassava despite its many advantages. They were aware of the conventional burr mill, others were careful not to give answers. Also, 80% gaari and cassava flour processors were not aware of hammer mill's usefulness in granulating/pulverising of its pressed, fermented mash, the manual processes of breaking the mash, even beating it with rod were still in use. Few that were aware through extension officers as reported by them do not keenly subscribed to hammer mill usage just because they think its grating leaves more fibre in the product than using burr mill and if to pulverise/granulate with it, much may be wasted. This show that to remove the drudgery associated with their works, more efforts are needed for their awareness and its provision especially to be avoidable for local processors.

4.0 Conclusion and Applications

The following conclusions were arrived at:

1. Size reduction ratio achieved in all the treatments were real and through.
2. Mean values of the coarse, medium and fine particles of the pulverised and gaari samples in all the treatments were statistically different from one another.
3. Significant ($p<0.05$) different was observed between the weight of end products, cassava flour, gaari and different processes.
4. Combination of hammer mill grated but granulated and pulverised by conventional method HB had the highest rank for all the physical properties of the samples with lowest fibre content, lowest moisture content and highest bulk density.
5. There were stronger correlations between the different processes and the weights of the cassava flour and gaari so produced per local measure used with higher R^2 values.

Combining the use of hammer mill with the conventional sifters or designing the hammer mill with sieve holes of less than 3.0 mm may be able to give higher bulk density gaari of low moisture content and low crude fibre in the cassava flour or gaari to be produced. Thus burr mill grated cassava tubers and hammer mill for pulverising and granulating pressed and fermented cassava mash or vice versa or still the hammer mill grated and hammer mill granulated pressed fermented cassava mash may be recommended for farmers on the farms. Hammer mills of fixed hammers may also give higher end products so desired but with adequate hammer speed especially as they give better end products than those made by conventional methods.

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Table 1: Characteristics and dimensions of the shaft of the hammer mill

Characteristics of the hammer mill	Dimensions of shaft and the hammers
Rated speed of the electric motor = 1400 rpm, Speed of the driven pulley (unloaded) = 1800 rpm, Speed of the driven pulley (loaded) = 1750 rpm, Rated power of the motor (5.5 kW) = 7.33 hp Diameter of the driver pulley = 270 mm Diameter of the driven pulley = 150 mm Diameter of the sieves in the discharge screen = 3 mm Width of the discharge screen (in form of arc of a circle) = 195 mm Length of the discharge screen = 60 mm	Length of the shaft (longer uniform part) = 305 mm Length of the shaft (smaller uniform part) = 120 mm Total length of the shaft = 125 mm Diameter of the shaft (big end) = 40 mm Length of the carrier rod = 180 mm Diameter of the carrier rod = 70 mm Thickness of the hammer = 5 mm Width of the hammer = 50 mm Length of the hammer = 140 mm

Table 2: Some physical properties of the pulverised and gaari samples

Sample	Moisture content, %				Bulk Density, g/ml				Crude fibre, %			
	Pulvd	Rk	Gaari	Rk	Pulvd	Rnk	Gaari	Rnk	Pulverised	Rnk	Gaari	Rnk
HH1	65.8	11th	7.10	9th	0.80	12th	0.60	8th	2.30±0.02	11th	2.50±0.02	12th
HH2	65.6	10th	7.20	11th	0.82	8th	0.60	8th	2.31±0.03	12th	2.52±0.04	13th
HH3	66.0	12th	6.98	7th	0.81	10th	0.61	5th	2.36±0.01	13th	2.50±0.00	11th
BH1	61.6	9th	6.00	**1st**	0.81	10th	0.63	**1st**	2.10±0.02	8th	1.80±0.02	**1st**
BH2	60.8	7th	6.20	**3rd**	0.83	7th	0.62	**2nd**	2.05±0.01	7th	1.85±0.04	**2nd**
BH3	61.4	8th	6.12	**2nd**	0.86	6th	0.61	5th	2.15±0.04	9th	1.90±0.00	4th
BB1	45.5	**3rd**	7.00	8th	0.89	4th	0.59	10th	1.80±0.02	**2nd**	1.90±0.02	5th
BB2	46.0	6th	7.10	9th	0.90	**2nd**	0.58	11th	1.90±0.02	**3rd**	1.93±0.00	10th
BB3	46.4	5th	7.20	11th	0.91	**1st**	0.62	2nd	1.78±0.06	**1st**	1.89±0.02	**3rd**
HB1	44.1	**1st**	6.80	4th	0.88	5th	0.58	11th	2.00±0.02	4th	1.90±0.02	7th
HB2	45.4	**2nd**	6.91	6th	0.82	8th	0.59	9th	2.02±0.01	6th	1.92±0.02	9th
HB3	46.1	4th	6.82	5th	0.90	**2nd**	0.62	**2nd**	2.20±0.01	10th	1.90±0.05	8th
panel	66.0	12th	7.20	11th	0.81	10th	0.61	5th	2.00±0.02	4th	1.90±0.02	5th

Pulvd- pulverised; Rk- rank; panel- values from panel of judges of their most widely chosen sample

Table 3: Percent weight retained, %wt and Uniformity Indices, ui, of the Pulverised oven-dried samples

Sieve no. (mm)	**HH**		**BH**		**BB**		**HB**	
	%wt	ui	%wt	Ui	%wt	ui	%wt	Ui
8 (2.36mm)	3		4.0		5.6		3.8	
10 (1.67mm)	10.5		13.5		10.9		13.8	
		13.5		17.5		16.5		17.6
20 (0.83mm)	34.3		32.7		30.2		30.1	
28 (0.59mm)	28.3		37.7		32		33.4	
		60.6		70.4		62.2		63.5
65 (0.295mm)	21.3		8.2		17.1		15.5	
100 (0.21mm)	3		3.8		4		2.8	
120 (0.147mm)	1.6		0.1		0.2		0.6	
Pan	0		0		0		0	
		25.9		12.1		21.3		18.9

%wt: percent weight retained; ui: uniformity index

Table 4: Percent weight retained, %wt and Uniformity Indices, ui, of the Gaari produced from samples

Sieve no. (mm)	**HH**		**BH**		**BB**		**HB**	
	%wt	ui	%wt	ui	%wt	ui	%wt	Ui
8 (2.36mm)	5		4.8		3.6		5.8	
10 (1.67mm)	12.5		3.5		3.9		13.6	
		17.5		8.3		7.5		19.4
20 (0.83mm)	29.1		40.8		43.2		32.1	
28 (0.59mm)	29.6		38.7		36		29.3	
		58.7		79.5		79.2		61.4
65 (0.295mm)	20.2		9.1		10.1		16.3	
100 (0.21mm)	3		2.9		3		2.8	
120 (0.147mm)	1.6		0.2		0.2		0.1	
Pan	0		0		0		0	
		23.8		12.2		13.3		19.2

%wt: percent weight retained; ui: uniformity index

Table 5: Mean values of particle sizes' uniformity indices of the pulverised and gaari samples, n =12

Treatments	Pulverised			Gaari		
	Coarse	medium	fine	Coarse	medium	Fine
HH	16.27 ± 1.92^{a}	64.18 ± 4.32^{ab}	19.55 ± 5.75^{b}	13.18 ± 6.15^{bc}	69.70 ± 11.20^{c}	17.12 ± 5.41^{abc}
BH	14.52 ± 3.86^{a}	68.50 ± 8.41^{ab}	16.98 ± 6.90^{b}	10.90 ± 4.48^{c}	75.45 ± 6.67^{ac}	13.65 ± 2.25^{bc}
BB	15.10 ± 3.05^{a}	67.77 ± 5.78^{ab}	17.13 ± 3.34^{b}	12.73 ± 4.57^{bc}	70.25 ± 5.05^{c}	17.02 ± 4.40^{abc}
HB	13.48 ± 3.81^{a}	70.39 ± 6.03^{ab}	16.13 ± 3.57^{b}	12.83 ± 2.27^{bc}	71.12 ± 6.03^{c}	16.05 ± 3.57^{abc}

Mean values with the same superscripts along the same row within the two columns of pulverised and gaari are not significantly different ($p< 0.05$)

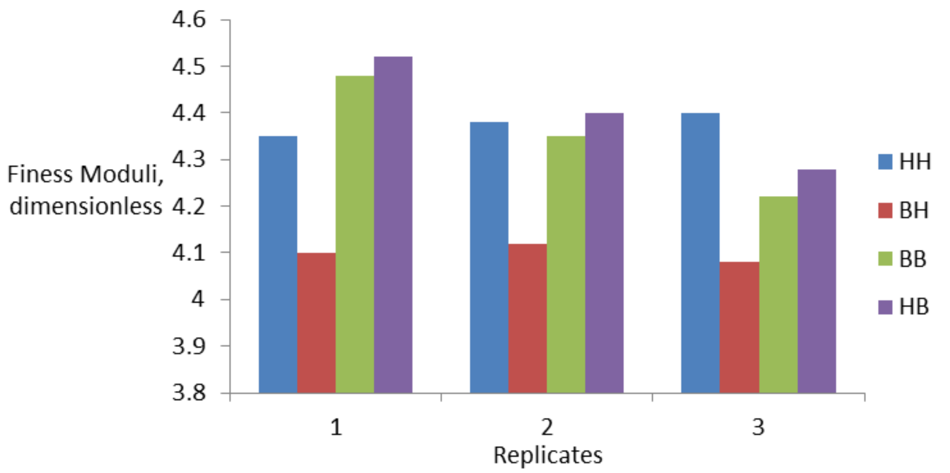

Figure 1: Finess moduli of the replicates of different samples

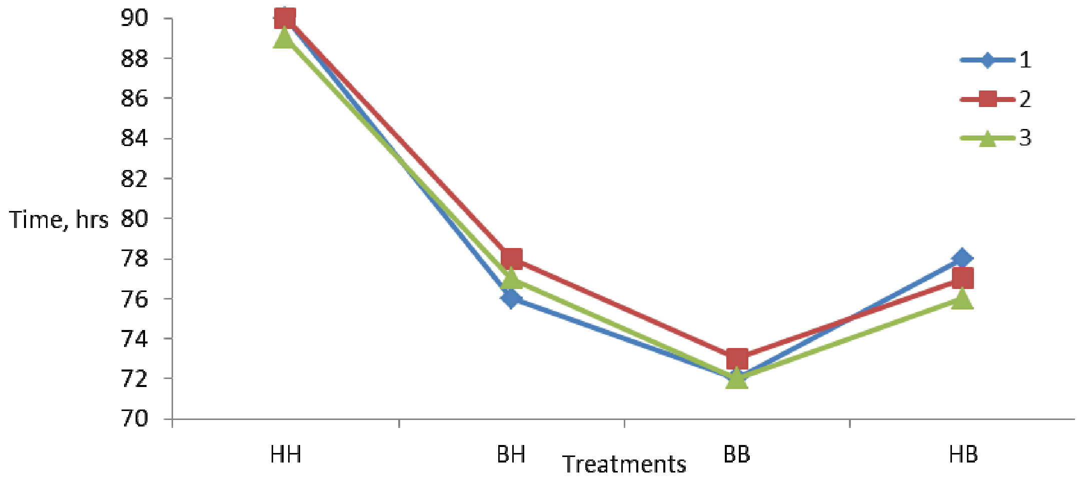

Figure 2: Time, hrs for pulverised/granulated samples in replicates 1, 2 and 3 to reach constant weights in drying

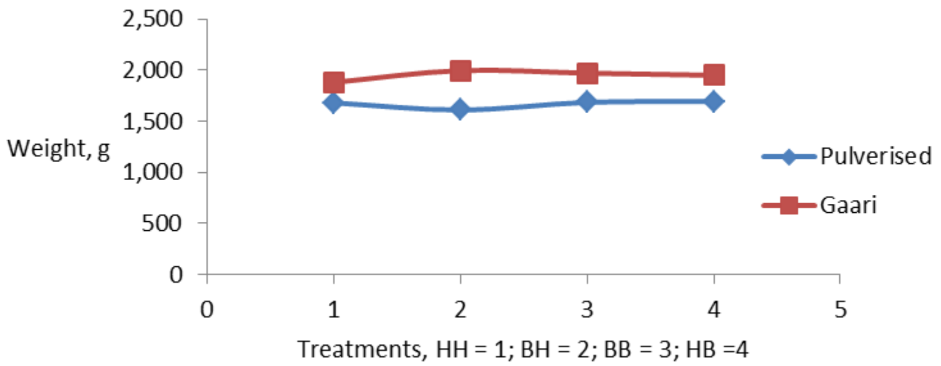

Figure 3: Weights in g for different treatments.