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ORIGINAL RESEARCH ARTICLE

EFFECT OF NUMBER OF BEATERS ON THE PERFORMANCE OF HOUSEHOLD HAMMER MILL

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ABSTRACT
A hammer mill with three different hammers having 2, 4 and 6 beaters was developed and evaluated. Maize and guinea corn were crushed at 3 different angular speeds of the hammer rotations (2600 rpm, 3000 rpm and 3400 rpm). Each beater was fixed on the shaft at a time and machine was started. As soon as the machine reached the required speed, 500g of sample was fed into the crushing chamber through the feed hopper. The final product was collected, weighed. Fuel consumed during the operation and the time taken were recorded. The process was replicated 3 times for both maize and guinea corn using the 3 hammers. The result obtained during the evaluation revealed that the average milling efficiency and specific fuel consumption (sfc) for 6 beaters, 4 beaters and 2 beaters were 83.5 % and 3.8 l/h, 72.47 % and 2.07 l/h and 60.19 % and 0.94 l/h respectively. The average milling efficiency and sfc for maize and guinea corn were 72.18 % and 2.45 l/h and 71.93 %, 2.09 l/h respectively. Number of beaters and angular speed of beaters and their interactions significantly affected the milling efficiency at 5 % level. Number of beaters, angular speed of beaters, sample type and their interactions significantly affected the sfc at 5 % level.

1.0 Introduction

Most of our staple foods in Nigeria are cereals and dried tubers. These products need to be processed before storage, transported and consumed. The major processing method is size reduction after drying. Dabbour et al. (2015) reported that grinding is one of the most important and energy-consuming processes in cereal industry, and that this process consumes from 70% of total power during the feed production and up to 90% for wheat flour milling. The grinding energy requirements depend on kinematical and geometrical parameters of the grinding machine and physical properties of the ground material (Dabbour et al. 2015). Ajaka and Adesina, (2014) evaluated a small laboratory hammer mill with minerals (dolomite and granite). Their results however indicated that the new machine can perform better in terms of products with improved design. The objectives of grinding grain are to increase digestibility or palatability, and to facilitate mixing with other constituents of the ration (Culpin, 1982). There are different methods of grinding these products depending on the level of development in the area. According to Culpin (1982), grinding of grain has been practiced since very early times, when a device resembling a pestle and motor was employed in the production of meals for human consumption. The first mills were modification of this device, in which grains were fed through an opening in a disc-shaped stone which was cause to rotate upon another. The gradual development of this type of mill over thousand years has led to the evolution of the buhr-stone mills. Buhr-stone mills are so termed because of the grooves (buhrs) which are cut on the grinding faces of the two disc-shaped stones. As one stone revolves upon the other, grain fed in at the centre passes towards the periphery being gradually ground in the process.

Gujja (2016) modified the conventional hammer mills base on their short comings, such as the enlargement of screen holes due to wear, corrosion, clogging which reduces the efficiency of the hammer mill, wet materials become elastic and therefore absorb most of the impact energy of the hammer without breaking the grain among others. The solution proffered to these problems include: changing of sieve screen with endless sieve that is dimensionally controlled, introduction of fan to induced forced convection and rapid drying of material. This greatly increased the efficiency of the machine but incorporation of several parts to the machine made it complex that skilled personnel is required to performed maintenance on the machine and this can be hardly found in the rural areas, hence the machine is not suitable to be used in the rural area. In very remote areas the use of the traditional grinding stone or pestle and mortar is very common, while in some villages and cities the commercial grinding machine (grinding plates discs) were used. These commercial hammer mills are too bulky and very expensive to run and they are designed for very large scale production or big companies such as breweries, feed mills and flour mills. Due to the recent sensitization of the public on the need for self-employment/entrepreneurship, small scale industries that need smaller hammer mills are increasing in number. Therefore, this study investigates the effect of the number of beaters on performance of a small household hammer mill capable of handling small quantities of product at a very low cost.

2. Materials and Methods

2.1 Machine Description and Operation

The hammer mill consists of feed hopper which is connected to the crushing chamber through the seed inlet throat. The crushing chamber that houses the hammer and the sieve is connected to the discharge chute. The two components were mounted on the main frame and a spark ignition (SI) engine is mounted on the frame. The hammer is mounted on the shaft of the SI engine which passes through the crushing chamber. Plate 1 shows the photograph of the machine.

Plate 1: Photograph of the hammer mill

To operate the machine, the machine is actuated by starting the SI engine and the speed is adjusted to the required speed by adjusting the throttle of the SI engine. As soon as the machine reaches the required speed the product to be crushed is poured inside the hopper and allowed to pass through the crushing chamber where it is hit by the beaters. The hammer continues hitting the product until the size is reduced to the size of the sieve that is between the hammer and the discharge chute. The fine particles that passed through the sieve are then collected through the discharge chute.

2.2 Experimental Setup

The materials used for the performance evaluations of the machine are maize (zea mays Linn) and guinea corn (sorghum bicolor L. Moench). Other testing apparatus are digital tachometer (to measure the angular velocity), stop watch (to measure the time), weighing balance (10 kg) and burette (500ml) (to measure fuel consumed).

The crushing chamber of the machine was opened and the required hammer was mounted on the shaft. The fuel hose was removed from the fuel tank and connected to a burette for accurate measurement of fuel consumed during the machine's operation. The burette was filled with fuel (petrol) above the calibration on the burette.

2.3 Performance Evaluation

The performance evaluation was carried out following similar procedures described by Mohammed et al. (2015) and Hadi et al. (2017). Fifty kilogram (50 kg) each of the two samples (maize and guinea corn) were bought from Maiduguri Monday market. The samples were cleaned by removing unwanted matters. The cleaned samples were subdivided into fragments of 500 g each and were kept for evaluation. The storage moisture contents of both stored sample (maize and guinea corn) were determined using the method described by Oluwole et al. (2016) and were found to be 13% and 14% respectfully. 500 g of maize was poured into the hopper and the machine was switched on by starting the spark ignition engine that powers the machine. The speed was adjusted and measured with a tachometer, as the machine reaches the required operating speed, the gate at the hopper throat was opened to allow the samples to flow into the crushing chamber and the initial reading on the burette and initial time were taken and recorded. At the end of the operation, the final time, burette reading (fuel consumed) and mass of crushed sample were taken and recorded. This was replicated 3 times for both samples (maize and guinea corn) at 3 different speeds (2600, 3000, and 3400 rpm) and using 3 different hammers (2, 4 and 6 beaters). The results obtained were tabulated and the milling efficiency and specific fuel consumption (sfc) were calculated.

The milling efficiency of the machine was obtained from Equation (1)

$$\eta_M = {M_a}/{M_b} \; x \; 100\; \% \qquad (1)$$

Where:

η_M = the milling efficiency, %

M_a= the mass of sample after milling, g

M_b= the mass of sample before milling, g

The Specific Fuel Consumption (sfc) was calculated using Equation (2)

$$sfc = {V_{fuel}}/{t} \qquad (2)$$

where: V_{fuel}=volume of fuel consumed during operation, litre

t = time to complete operation, hour

These results were statistically analysed, Analysis of varience (ANOVA) was conducted to test for significance difference on the observations made and regression equations generated using a

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statistical software design expert 11. A factorial design involving three factors (samples, angular speeds and number of beaters) and three replicates (2x3x3x3) was used to analyse the two response (sfc and milling efficiency), making a total of 54 runs.

3. Results and Discussion

The results of the performance test carried out on the hammer mill are presented in Table 1. It is observed from this table that hammer with 6 beaters gave the highest milling efficiency and highest fuel consumption. While hammer with 2 beaters recorded lowest fuel consumption and milling efficiency. The average milling efficiency and sfc for 6 beaters, 4 beaters and 2 beaters were 83.5% and 3.8 l/h, 72.47% and 2.07 l/h and 60.19 and 0.94 l/h respectively.

Table 1: Results of the Performance Test of the Hammer

Run	Numbers of Beaters	Angular Speed (RPM)	Samples	Specific Feul Consumption (sfc) (l/h)	Percentage Milled (%)	Run	Numbers of Beaters	Angular Speed (RPM)	Samples	Specific Feul Consumption (sfc) (l/h)	Percentage Milled (%)
1	2	2600	maize	0.52	60	28	4	2600	Guinea corn	1.47	72
2	2	2600	maize	0.52	63	29	4	2600	Guinea corn	1.55	78
3	2	2600	maize	0.56	65	30	4	2600	Guinea corn	1.64	77
4	2	3000	maize	0.95	60	31	4	3000	Guinea corn	1.82	70
5	2	3000	maize	1.01	62	32	4	3000	Guinea corn	1.95	72
6	2	3000	maize	1.05	60	33	4	3000	Guinea corn	2.03	73
7	2	3400	maize	1.26	59	34	4	3400	Guinea corn	2.12	64
8	2	3400	maize	1.34	58.4	35	4	3400	Guinea corn	2.29	68
9	2	3400	maize	1.41	58	36	4	3400	Guinea corn	2.4	63
10	2	2600	Guinea corn	0.57	60	37	6	2600	maize	2.8	78
11	2	2600	Guinea corn	0.51	63	38	6	2600	maize	2.86	81
12	2	2600	Guinea corn	0.55	65	39	6	2600	maize	2.85	80
13	2	3000	Guinea corn	0.92	60	40	6	3000	maize	3.8	82
14	2	3000	Guinea corn	0.94	59	41	6	3000	maize	3.92	81
15	2	3000	Guinea corn	0.98	58	42	6	3000	maize	4	80
16	2	3400	Guinea corn	1.19	58	43	6	3400	maize	5.65	88
17	2	3400	Guinea corn	1.24	58	44	6	3400	maize	5.83	84
18	2	3400	Guinea corn	1.34	57	45	6	3400	maize	5.84	82
19	4	2600	maize	1.79	78	46	6	2600	Guinea corn	2.2	84

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20	4	2600	maize	1.84	78.4	47	6	2600	Guinea corn	2.23	86
21	4	2600	maize	1.88	80	48	6	2600	Guinea corn	2.22	76
22	4	3000	maize	2.03	76	49	6	3000	Guinea corn	3.16	82
23	4	3000	maize	2.08	72	50	6	3000	Guinea corn	3.18	78
24	4	3000	maize	2.22	70	51	6	3000	Guinea corn	3.17	90
25	4	3400	maize	2.64	70	52	6	3400	Guinea corn	4.84	92
26	4	3400	maize	2.74	71	53	6	3400	Guinea corn	4.87	90
27	4	3400	maize	2.82	72	54	6	3400	Guinea corn	5.04	89

Table 2 presents the ANOVA table for the milling efficiency. It is observed that number of hammers (A), hammer speed (B) and their interactions (AB) significantly affected the milling efficiency at 5% level, while that of the samples(maize and guinea corn) are not significant.

Table 2: ANOVA for 2FI model for Percentage Milled

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	5174.28	6	862.38	69.23	< 0.0001	significant
A-beater	4890.67	1	4890.67	392.60	< 0.0001	
B-speed	51.36	1	51.36	4.12	0.0480	
C-samples	0.8563	1	0.8563	0.0687	0.7943	
AB	190.41	1	190.41	15.28	0.0003	
AC	40.96	1	40.96	3.29	0.0762	
BC	0.0278	1	0.0278	0.0022	0.9625	
Residual	585.49	47	12.46			
Lack of Fit	331.41	11	30.13	4.27	0.0004	significant
Pure Error	254.08	36	7.06			
Cor Total	5759.77	53				

Figures 1 and 2 show the response surface plots of milling efficiencies of guinea corn and maize respectively as a function of hammer speed and number of beaters. It is obvious from these figures that the milling efficiency increased as the number of beaters increased. This is as a result of higher number of beaters hitting the samples. However, milling efficiency decreased with the increase in harmer speed. This is probably because of the loses as a result of high speed

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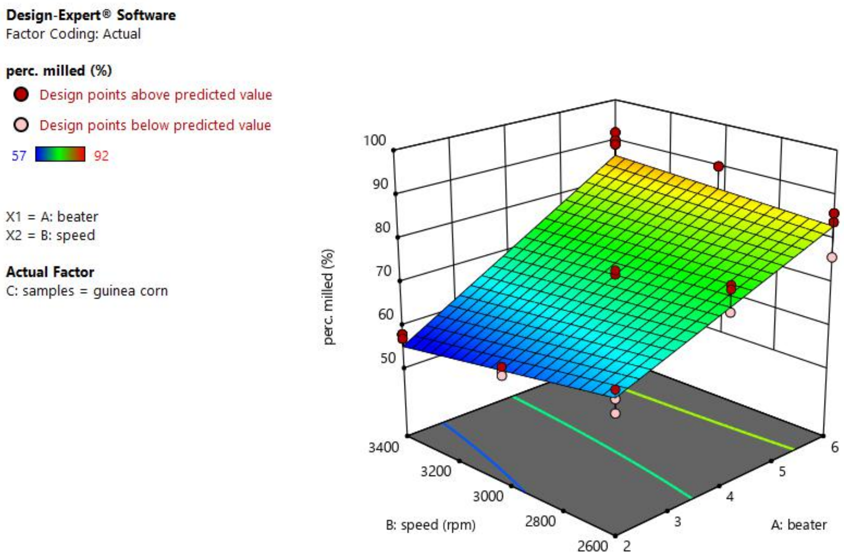

Figure 1: Effects of hammer speed and number of beaters on percentage guinea corn milled

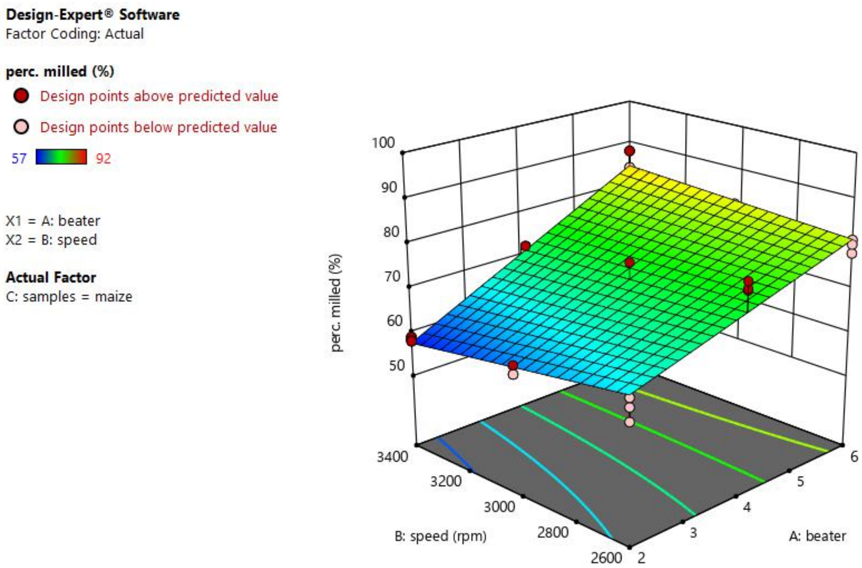

Figure 2: Effects of hammer speed and number of beaters on percentage maize milled

The regression equation for percentage of milling is presented in Equation (3)

$$\eta_M = 72.05 - 11.66A - 1.19B - 0.1259C - 2.82AB - 1.07AC - 0.0278BC \quad (3)$$

R^2 0.8983

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1, the middle levels are coded as 0 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Table 3 presents the ANOVA table for the specific fuel consumption (sfc). It is observed that number of hammers (A), hammer speed (B), samples (C) and their interactions (AB) and (AC) significantly affected the sfc at 5% level. This is because as the number of hammers increase, the weight of the beater increased as a result the power requirement also increases thereby increasing the fuel consumption of the machine.

Table 3: ANOVA for Quadratic model for Specific Fuel Consumption (sfc)

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	103.76	8	12.97	220.19	< 0.0001	significant
A-beater	73.96	1	73.96	1255.61	< 0.0001	
B-speed	19.21	1	19.21	326.19	< 0.0001	
C-samples	1.77	1	1.77	30.13	< 0.0001	
AB	6.37	1	6.37	108.06	< 0.0001	
AC	1.09	1	1.09	18.48	< 0.0001	
BC	0.0642	1	0.0642	1.09	0.3021	
A^2	1.06	1	1.06	18.00	0.0001	
B^2	0.2315	1	0.2315	3.93	0.0536	
Residual	2.65	45	0.0589			
Lack of Fit	2.43	9	0.2703	44.55	< 0.0001	significant
Pure Error	0.2184	36	0.0061			
Cor Total	106.41	53				

P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, A^2 are significant model term because their p-values are less than 0.0500.

Figures 3 and 4 show the response surface plots of sfc for guinea corn and maize respectively. It is obvious from the figures that the sfc increased as the speed and number of beaters increased. This is as a result of increase in weight of the beaters that requires higher torque to spin the hammers. Figure 5 shows the sfc of the machine when using 6 beaters at angular speed of 3400 rpm, as generated by design expert 11 software. It is obvious from this figure that more fuel consumed when milling maize than when milling guinea corn, this is probably because maize is harder and bigger than guinea corn.

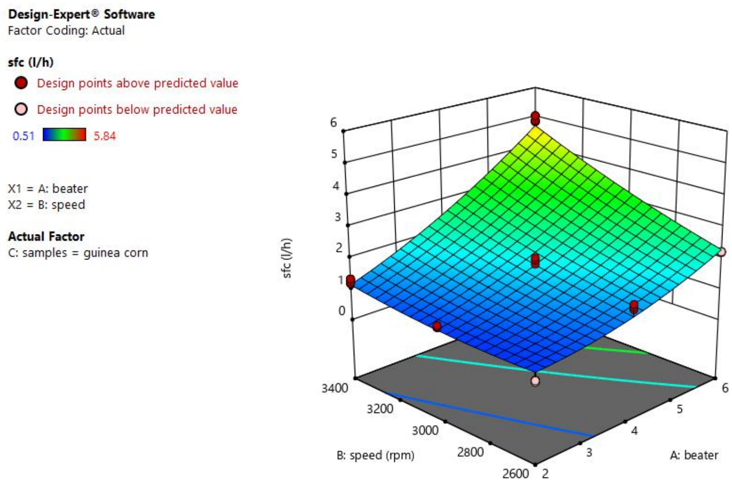

Figure 3: Effects of hammer speed and number of beaters on sfc for percentage guinea corn milled

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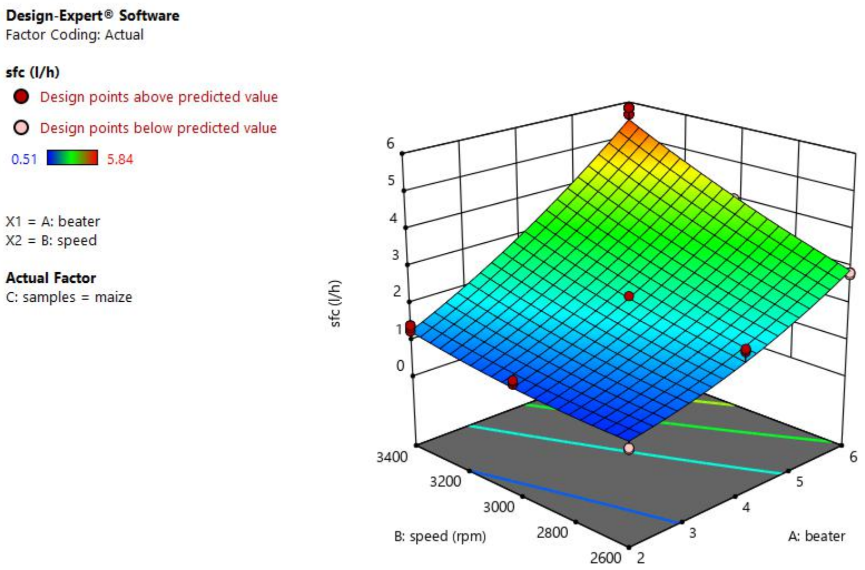

Figure 4: Effects of hammer speed and number of beaters on sfc for percentage maize milled

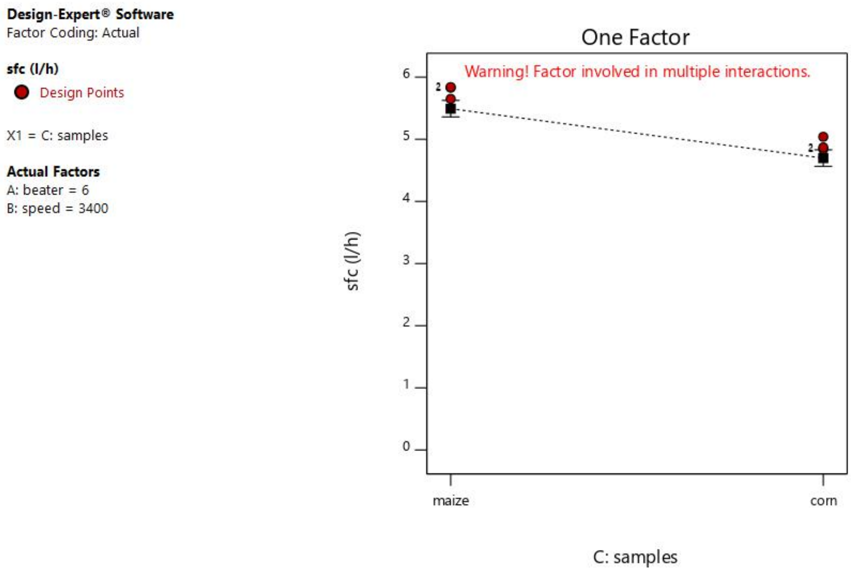

Figure 5: sfc for milling maize and guinea corn

The regression equation for the sfc is presented in Equation (4).

$$Sfc \quad = 1.98 + 1.43A + 0.7306B - 0.1813C + 0.5150AB - 0.1739AC + 9.2972A^2 \qquad (4)$$

R^2= 0.9751

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1, the middle levels are coded as 0 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

4. Conclusion

At the end of the evaluation of the household hammer mill, it is concluded that:

The average milling efficiency and sfc for 6 beaters, 4 beaters and 2 beaters were 83.5 % and 3.8 l/h, 72.47 % and 2.07 l/h and 60.19 % and 0.94 l/h respectively.

The average milling efficiency and sfc for maize and guinea corn were 72.18 % and 2.45 l/h and 71.93 %, 2.09 l/h respectively.

Number of beaters and angular speed of beaters and their interactions significantly affected the milling efficiency at 5 % levelof significance.

Number of beaters, angular speed of beaters, sample type and their interactions significantly affected the sfc at 5 % levelof significance.

Regression equations for percentage of sample milled and sfc were generated to predict the performance of the hammer mill.

At the end of the evaluation of the household hammer mill, the following recommendations were made:

Carry out the design modification of the household hammer mill

Evaluate effects of sample moisture content on machine performance

Evaluate effects of hammer clearance from the screen on machine performance.

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