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PERFORMANCE EVALUATION OF A LOCALLY FABRICATED HAMMER MILL ACQUIRED BY INTERNATIONAL INSTITUTE FOR CROPS RESEARCH IN SEMI-ARID TROPIC (ICRISAT), KANO – NIGERIA.

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ABSTRACT

A hammer mill is a machine used to crush materials into smaller pieces by the repeated blows of hammers. Hammer mills are often employed in agricultural industries for size reduction such as in feed mills and flour mills for both livestock and human food production. There are substantial numbers of hammer mills fabricated locally to aid food production in Nigeria. Some of the problems associated with locally fabricated hammer mills are lack of adequate performance parameters such as the machine throughput capacity, milling efficiencies and quality of milled flour. International Institute for Crops Research in Semi-Arid Tropic (ICRISAT) is an international organization which conducts agricultural research for rural development. The research station of the organization in Kano, Nigeria, acquired some locally fabricated hammer milling machines to be promoted among small and medium scale farmers, but detailed performance data of the machines are not available. The present research is a collaboration between ICRISAT Kano research station and the Department of Agricultural and Environmental Engineering, Bayero University, Kano. The research is aimed at addressing the problems of lack of performance parameters by evaluating the performance of ICRISAT hammer mills I to attain better utilization of the machine. The machine was evaluated using sorghum, millet and soybeans with a factorial design in a completely randomized design, (CRD). The performance indices were milling efficiency, machine capacity, milling losses, fineness modulus, and the average size of grain. The independent variables considered were the cylinder speeds at three levels, 800 rpm, 900 rpm and 1000 rpm and the feed rates at two levels 2.5 and 5kg min^{-1} for all the crops. Sorghum has the highest value of milling efficiency, machine throughput capacity, average grain size and fineness modulus, followed by millet and then soybeans. Soybeans crop milling has higher values of losses followed by millet and then sorghum. For Sorghum, the mean values for machine efficiency, machine capacity, losses, fineness modulus, and the average size of grain ranged from 76.63 – 92.36%, 45.13 – 69.11kg/hr, 7.64 – 23.37 %, 3.05 – 4.87 and 0.86 – 3.05 mm *respectively. The results show that the feed rate and speed are significant at 1% level on machine milling efficiency, machine throughput capacity, losses, fineness modulus, coarse and fine particles and average grain size. The least significant difference shows that as the speed increased, the values of machine milling capacity and milling losses increased but values of milling efficiency, fineness modulus and average grain size for all the crops decreased. But as the feed rate increases, milling efficiency decreases while machine milling capacity, milling losses, fineness modulus and average grain size increase with the increase in feed rate.*

Keywords: Hammer mill, ICRISAT, performance evaluation, milling efficiency.

1. INTRODUCTION

The present world population is 7.7 billion, three quarter live in developing countries where cereals play the leading dietary role (United Nations, Department of Economic and Social Affairs, Population Division, 2019). The need to process cereals which is a complex process gave rise to various processing techniques. However, the principal procedure among the processes is milling. Milling entails grinding the grains so that it can be easily cooked and rendered into an attractive foodstuff. The processing of cereals can be done by using a milling machine to ensure the processed cereals availability not only in time but also in the right quantity. Hammer mill is designed for grinding, and sieving all kinds of cereal grains, such as maize, wheat, millet, corn, sorghum, soybeans. It can also process non-cereal materials such as dry cassava tuber and yam tuber.

Cereal processing is complex. In ancient times, cereal grains were crushed between two stones and made into crude cake. But the advent of modern automated systems employing steel material such as hammer mills has revolutionized the processing of cereals and their availability as human foods and other purposes (Hunt,1983). Through milling machine, size reduction of agricultural products such as maize, millet, sorghum, soybeans and wheat into their flours to obtain local foodstuff like semovita, semolina, *tuwon masara, tuwon dawa, tom-brown, soy milk, biski, brabusco*, were made possible. Milling is the process of reducing grains into powder using mills. There are different types of mills namely: attrition (burr) mills, roller mill, ball mill, hammer mill, etc. A hammer mill is used to crush aggregate material into smaller pieces by the repeated blows of hammers. The hammer mill has not only been used in grain milling but also has applications in numerous other industries such as fruit juice production, sawmills, shredding scrap yards as well as waste management. However, the performance of the modern hammer mills could further be enhanced through performance evaluation.

The availability of efficient hammer mills at an affordable price especially in the Northern part of Nigeria where a large quantity of grain is produced remains a challenge. Despite the effort of importing different types of hammer mills over the years, such machines have a complex design, difficulty in maintenance, lack of spare parts, or costly beyond the reach of farmers (Onokpe *et al*, 2000). Notwithstanding the numerous works and intellectual effort directed towards improving existing hammer mills by research institutes in Nigeria, the challenge remains existent. Some of the problems associated with locally fabricated hammer mills are lack of adequate performance parameters such as the machine throughput capacity, milling efficiencies and quality of milled flour. Towards solving the stated problems, International Institute for Crops Research in Semi-Arid Tropic (ICRISAT) acquired some hammer milling machines to be promoted among small and medium scale farmers, but detailed performance data of these machines are not available. The data obtained can be used by ICRISAT to guide the processors on which machine is best for milling different crops, what to expect from each machine and how to achieve optimum performance. This research work is aimed at addressing the problems of lack of performance parameters by evaluating the performance of a locally fabricated Hammer Mills acquired by ICRISAT, Kano labelled Hammer Mills I to attain better utilization.

The objectives of the work are:

i. To conduct a performance evaluation of hammer mill I in terms of milling efficiency, throughput capacity, and milling losses using three different crops (soybeans, millet and sorghum).
ii. To determine the quality of milled flours in terms of average grain size, fineness modulus and uniformity index for the three crops.

2. MATERIALS AND METHOD

The experiments of this study were conducted at ICRISAT Kano - Nigeria and Processing laboratory, Department of Agricultural and Environmental Engineering Bayero University, Kano. The materials used for this study are shown in Table 1.

Table 1: Materials and Specifications of ICRISAT Hammer mill I

Materials	Specifications	Quantity
Crops	Soybeans (TGX 1835-10E Millet (Super Sosat) Sorghum (CSR 01)	135 kg 135 kg 135 kg
Prime Mover	Power output 4.34 kW	1
Digital Weighing Balance	Precision 0.01g	1
Tachometer	Model –TS 6000	1
Digital stopwatch	Model –T 590	1
Oven	Model Sm-150	1
Measuring cylinder		1
Set of sieves	Model –SS15	1
Fuel	Diesel	4800 ml

2.1 Description of ICRISAT Hammer Mill I

The ICRISAT Hammer mill I was purchased by ICRISAT, Kano in the year 2014 to promote the small/medium scale farmer's enterprises and to overcome drudgery and losses and also provide high output of their products. The machine (Plate 1) mainly consists of the feed hopper, power unit, crushing chamber, delivery chute, and frame. The feed hopper is rectangular and it is the point that delivers the material into the crushing chamber where the grinding process takes place. The power unit consists of a prime mover, belt and pulley system which drives hammer bars in the crushing unit. The prime mover rated output power is 4.34 kW, rated speed 2600 rev/min and net weight is 60 kg. The crushing chamber consists of swinging hammer bars that rotate at high speed. The hammers hit (impact force) material fed into the crushing chamber through the hopper. The material is impacted by the hammer bars and expelled through screens in the drum through the delivery chute. The frame is the component on which all other parts are assembled.

Plate 1: ICRISAT Hammer mill I

2.2 Conduct of Experiments

The machine was switched on and the required speeds of 800, 900 or 1000 rpm was adjusted on the prime mover using a tachometer and grains were fed through the tangential opening at the required feed rate and the duration for milling was recorded at a particular speed and feed rate until all the grains have been milled. The milled grains were collected through the outlets while the un-milled grains and other losses were collected from the machine and weighed. Various performance indices were calculated using the formulae in equations 1-5.

i. Milling Efficiency

It is the ratio of the mass of output material to the mass of input material (in percentage) (Mott, 1980). It is denoted as;

$$Me\ (\%) = \frac{m_p}{m_g} \times 100 \quad (1)$$

Where,
Me = Milling efficiency (%)
m_p= mass of the milled product (kg)
m_g= mass of grains (kg)

ii. Milling Capacity

It is the mass of material milled per unit time (Mott, 1980). It is denoted by:

$$Mc = \frac{m_p}{T_m} \quad (2)$$

Where,
Mc = Milling capacity (kg/h)
T_m= Time taken to mill the grain (h)

iii. Losses During Milling

Losses were determined by subtracting the mass of milled product from the mass of grain (Mott, 1980). It is represented as:

$$L = m_g - m_p \quad (3)$$

Where,
L = Losses (kg)

iv. Determination of Fineness Modulus (FM)

The fineness modulus which indicates the uniformity of ground products was determined by adding the weight fractions retained above each sieve divided by 100 (Sahay & Singh, 1999).

$$FM = \frac{\sum(\text{cumulative \% retained on specific sieves})}{100} \quad (4)$$

v. Determination of Particle Size

Tyler meshes were used to determine particle size. In the analysis of milled products, a set of standard sieves were arranged sequentially according to size with the smallest sieve and then the pan at the bottom and the set was placed on a sieve shaking machine for 5 minutes. Particle size distribution was expressed as a percent retained by weight on each sieve size to obtain the fineness modulus and the particle size was obtained using:

Particle size= $1.0414\ (2)^{FM}$ (mm) (5)

where FM is fineness modulus (Sahay and Singh, 1999)

vi. Determination of Uniformity Index

Determination of uniformity index was determined based on the percentage of the sample of grain remaining on each of seven screens (3/8, 4, 8, 14, 28, 48 & 100 mesh) in the pan after shaking The uniformity index is expressed in ratio of three (3) figures representing the coarse, medium and fine particles the sum of which should always be equal to ten. For example, the ratio of 1:6:3 represents the proportionate amounts of coarse, medium and fine particles, respectively in a particular sample of ground feed and thus expresses the uniformity index of the sample. The material remaining after a test on the 3/8, 4 and 8 mesh screens shall be designated as 'coarse' that remaining on the 14 and 28 mesh screens as 'medium' and that on the 48 and 100 mesh screens and in the pan as 'fine'. Table 2 presents a typical example to illustrate the method used in determining and expressing uniformity index.

Table 2: Illustration of a typical uniformity index

A Screen Mesh	B % of the material on each screen	C Totals of column B	D Results of column C	E Results In column D converted to the nearest whole no
3/8 4 8	Coarse 1.0 2.5 7.0	10.5/10	1.05	1
14 28	Medium 24.0 35.5	59.5/10	5.95	6
48 100 Pan	Fine 22.5 7.5 0.0	30.0/10	3.00	3

The values 1:6:3 from column E express the uniformity index of the sample from the above determinations.

2.3 Experimental Design and Data Analysis

The experiment is a factorial design in a completely randomized design, (CRD), involving two variables, speed, (S), at three levels and feed rate, (F), at two levels. Moisture content, (M), was constant. Speeds used were selected based on experience and available literature.

These were 800, 900 and 1000 rpm. Feed rates of 2.5 and 5 kg/min were used. The results obtained from the experiments were subjected to statistical analysis using GENSAT software version 9.0 for the analysis of variance in respect of the various performance indices. LSD was used to further analyze significant factors.

3. RESULTS AND DISCUSSION

Table 4 presents the mean values for the performance indices of ICRISAT Hammer mill I using the three different crops sorghum, millet and soybeans. For Sorghum, the mean values for machine milling efficiency, machine throughput capacity, losses, fineness modulus, and average grain size ranged from 76.63 – 92.36%, 45.13 – 69.11 kg/s, 7.64 – 23.37%, 3.05 – 4.87 and 0.86 – 3.05 mm respectively.

Table 4: Mean values of performance indices for ICRISAT Hammer Mill l

Feedrate (kg/min)	Speed (rpm)	Crop	Machine Efficiency (%)	Machine Capacity (kg/hr)	Losses (%)	Fineness Modulus	Average Grain Size D (mm)
2.50	800	1	92.36	45.13	7.64	4.58	2.49
5.00	800	1	89.93	54.69	10.07	4.87	3.05
2.50	900	1	84.12	60.27	15.88	3.24	0.99
5.00	900	1	80.96	65.43	19.04	3.58	1.24
2.50	1000	1	78.653	64.12	21.35	3.05	0.86
5.00	1000	1	76.63	69.11	23.37	3.27	1.02
2.50	800	2	88.12	43.91	11.88	4.03	1.70
5.00	800	2	84.31	50.12	15.69	4.36	2.13
2.50	900	2	85.64	55.22	14.36	3.55	1.22
5.00	900	2	82.09	55.72	17.91	3.87	1.52
2.50	1000	2	79.13	60.25	20.87	2.94	0.79
5.00	1000	2	75.00	65.03	25.00	3.14	0.91
2.50	800	3	76.38	27.61	23.62	2.18	0.48
5.00	800	3	73.45	30.60	26.55	2.46	0.58
2.50	900	3	69.98	33.46	30.02	1.57	0.30
5.00	900	3	67.55	36.68	32.45	1.85	0.38
2.50	1000	3	61.42	39.34	38.58	1.19	0.23
5.00	1000	3	59.63	45.87	40.37	1.64	0.33

The mean values for millet crop ranged from 75.00 – 88.12%, 43.91 – 65.03 kg/s, 11.88 – 25.00 %, 2.94 – 4.36 and 0.79-2.13 mm for machine milling efficiency, machine throughput capacity, losses, fineness modulus, and average grain size respectively. The mean values for soybeans crop ranged from 59.63 – 76.38%, 27.61 – 45.87 kg/s, 23.62 – 40.37 %, 1.19 – 2.46 and 0.23-0.58 mm for machine milling efficiency, machine throughput capacity, losses, fineness modulus, and average grain size respectively. These values for the crops under study are comparable with those found by other researchers (El Shal *et al*, 2010; Mohammed *et al*, 2015).

Table 5 presents the results of the analysis of variance (ANOVA) for the performance of ICRISAT Hammer mill I. The results show that the crop, feed rate and speed are significant at 1% level on machine milling efficiency, machine throughput capacity, losses, fineness modulus, coarse and fine particles and average grain size except for feed rate and speed which is not significant on medium particles. Two ways interactions; crop*feed rate, crop*speed and feed rate*speed are highly significant (1% level) on machine efficiency, machine capacity, losses, coarse, medium and fine particles and average grain size, fineness modulus is significant at 5% level for crop*feed rate and crop*speed except for feed rate*speed on machine efficiency, milling losses and fineness modulus and crop*feed rate on coarse and medium particles and feed rate*speed on fine particles while the third-order interaction is highly significant to machine efficiency, machine capacity, losses, average grain size, coarse and medium particles and significant at 5% on fineness modulus and fine particles.

Table 5: ANOVA for Performance Evaluation of ICRISAT Hammer mill I

	M.EFF	M. CAP	LOSSES	FM	AGS	Coarse	Medium	fine
CRP	12320.73**	5386.70**	12320.73**	17438.04**	3560.58**	103.19**	106.82**	950.79**
FDRT	1040.61**	585.76**	1040.61**	1003.67**	36.72**	21.33**	0.05ns	42.91**
SPD	6226.398**	1936.41**	6226.39**	5516.24**	2502.26**	109.04**	1.26ns	156.18**
CRP*FDRT	25.76**	17.85**	25.76**	3.78*	34.03**	0.15ns	0.95ns	4.62**
CRP*SPD	186.938**	35.51**	186.93**	297.36*	596.84**	15.56**	8.21**	7.87**
FDRT*SPD	2.22ns	24.07**	2.22ns	0.75ns	33.35**	5.25**	3.76*	0.27ns
CRP*FDRT*SPD	3.98**	14.53**	3.98**	10.84*	8.66**	4.70**	6.11*	2.76*

* =significant at 5%. ns = not significant ** = significant at 1%

Further analysis using LSD ranking (Table 6) shows that, as the speed increased from 800 to 1000 rpm, the values of machine milling capacity and milling losses increased but values of machine efficiency, fineness modulus and average grain size for all the crops decreased. This agrees with the findings of many researchers (Probst, 2013; Dabbour *et al,* 2015; El Shal *et al,*2010 and Sidhu *et al.,* 2018). It was noticed that an increase in speed was accompanied by an increase in machine throughput capacity because the frequency of impact and consequently rubbing action of the grains was more severe at higher speed, thus the milling increased. The decrease in milling efficiency with increasing cylinder speed all other factors being constant could be attributed to the fact that according to the design, the hammer mill is equipped with a large breaker plate in the upper section of the grinding chamber which exposes the product to multiple impacts. The ground product exits the mill through the screen at the bottom. This design avoids circulation of the ground product in the grinding chamber which will reduce efficiency. Clogging of the screen also reduces machine efficiency. The increase in grain losses at higher speed is due to an increase in the sticking of powdery materials to the wall of the crushing hammer and some strains that did not pass through the screen. An increase in speed means higher impact which results in a finer grind and smaller grain size.

Table 6: LSD for Ranking of Speed on Parameters for ICRISAT Hammer mill I

SPD (rpm)	Machine Efficiency (%)	Machine Capacity (kg/hr)	Losses (%)	Fineness Modulus	Av. Grain Size (mm)	Coarse	Fine	Medium
			Sorghum					
800	91.147 a	49.908 a	8.853 c	4.725 a	2.671a	7.000a	1.333c	1.667c
900	82.540 b	62.850 b	17.460 b	3.407 b	1.078b	4.333b	3.500a	2.167b
1000	77.640 c	66.614 c	22.360 a	3.162 c	0.907c	3.167c	3.333b	3.500a
			Millet					
800	86.213 a	47.016 c	13.787 c	4.197 a	1.862a	5.000a	1.333c	3.667a
900	83.867 b	55.470 b	16.133 b	3.710 b	1.323b	4.333b	2.333b	3.333b
1000	77.067 c	62.644 a	22.933 a	3.040 c	0.833c	3.667c	3.500a	2.833c
			Soybeans					
800	74.917 a	29.106 c	25.083 c	2.319 a	0.515a	3.536a	5.930c	0.534a
900	68.767 b	35.069 b	31.233 b	1.711 b	0.319a	2.645b	7.029b	0.326c
1000	60.525 c	42.608 a	39.475 a	1.417 c	0.270a	2.035c	7.619a	0.346b

Values with the same letters in the same column for each crop are not significantly different at 5% level, while values with different letters in the same column for each crop are significantly different at 5% level.

LSD ranking in Table 7 shows that as the feed rate increases, machine milling efficiency decreases. Conversely, machine milling capacity, milling losses, fineness modulus and average grain size increase with an increase in feed rate. These observations are in line with the findings of Balasubramanian *et al.* (2011) and Ramappa *et al,* (2011).

Table 7: LSD for Ranking of Feed rate on Parameters for ICRISAT Hammer mill I

Feed rate kg/min	Machine Efficiency (%)	Machine Capacity (kg/hr)	Losses (%)	Fineness Modulus	Av. Grain Size (mm)	Coarse	Fine	Medium
		Sorghum						
2.5	85.044 a	56.506 b	14.956 b	3.623 b	1.397a	4.556b	2.889a	2.556a
5.0	82.507 b	63.075 a	17.493 a	3.907 a	1.715b	5.112a	2.556b	2.333b
		Millet						
2.5	84.298 a	53.129 b	15.702 b	3.507 b	1.201b	4.000b	2.889a	3.111b
5.0	80.467 b	56.958 a	19.533 a	3.791 a	1.470a	4.667a	1.889b	3.444a
		Soybeans						
2.5	69.261 a	33.470 b	30.739 b	1.646 b	0.319b	2.489b	7.109a	0.402a
5.0	66.878 b	37.719 a	33.122 a	1.986 a	0.417a	2.989a	6.610b	0.401b

Values with the same letters in the same column for each crop are not significantly different at 5% level, while values with different letters in the same column for each crop are significantly different at 5% level.

The decrease in milling efficiency as a result of increased feed rate for all the crops may be attributed to the fact that at higher feed rates, there would be crop stream material build-up in the machine. The increase in machine capacity with an increase in feed rate, all other factors being constant could be because the machine capacity is a percentage or fraction of the feed rate. Hence it is expected to increase when the feed rate is increased. The increase in losses with the increase in feed rate is due to more fine powdered material that gets lost in the air during the grinding process. From both Tables 6 and 7, Sorghum has the highest value of milling efficiency, machine throughput capacity, average grain size and fineness modulus this is followed by millet and then soybeans. Soybeans crop milling has higher values of losses followed by millet then sorghum.

3.1 Conclusion

A hammer mill for milling grains acquired by the International Crop Research Institute for the semi-arid tropics (ICRISAT) was evaluated using sorghum, millet and soybean to determine its performance in terms of machine milling efficiency, throughput capacity, milling losses, fineness modulus average grain size and uniformity index. Using the variables: cylinder speeds at three levels: 800 rpm, 900 rpm and 1000 rpm and the feed rates at two levels: 2.5 and 5 kg/min for all the crops. It can be inferred that machine milling efficiency, throughput capacity, milling losses, fineness modulus, average grain size and uniformity index were significantly influenced by all the independent variables. Sorghum has the highest value of milling efficiency, machine throughput capacity, average grain size and fineness modulus this is followed by millet and then soybeans. Soybeans crop milling has the higher values of losses followed by millet and then, sorghum. For Sorghum, the mean values for machine efficiency, machine capacity, losses, fineness modulus, and the average size of grain ranged from 76.63 – 92.36%, 45.13 – 69.11 kg/hr, 7.64 – 23.37 %, 3.05 – 4.87 and 0.86 – 3.05 mm respectively.

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