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Effects of Feed Rate and Moisture Content on the Performance of a Developed Axial Flow Millet Thresher

[1]Sada, A.M, *[2]Saleh, A, [2]Muhammed, U.S. and [2]Yunusa, S.U.

[1] Department of Agricultural Engineering and Irrigation, National Agricultural Extension and Research Liaison Services, Ahmadu Bello University, Zaria, Nigeria

[2] Department of Agricultural and Bio-resource Engineering, Ahmadu Bello University, Zaria, Nigeria

*Corresponding author, e-mail address: salehaminu@gmail.com **(+234803 577 4780)**

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Abstract: *A performance study was conducted with two 1 m³ capacity anaerobic digester for producing biogas from cow dung and kitchen waste. The entire structure was constructed of fiber-reinforced plastic. Following construction and assembly, the biogas digestion unit was checked for 30 days to ensure the digester's success for both biowastes. In each digester, 2.5 kg cow dung and kitchen waste were diluted with water in the ratio 1:1 and subjected to a fourty five days retention time to prepare a slurry of 15% and 20% total solid. Results presented an average per day gas yield of 0.35 m³ for cow dung and 0.20 m³ for the kitchen waste at an average substrate temperature of 32 °C while the daily ambient temperatures varied from 29 °C to 31 °C and a pH of 6.50 to 7.40 for the cow dung and 4.91 to 7.1 for the kitchen waste. The study shows that the biogas generated by the anaerobic digestion of cow dung is high which has an average production of 0.32 m³ per day. Whereas the average generation of biogas from kitchen waste is 0.20 m³ per day.*

Keywords: Millet, Cylinder speed, Feed rate, Threshing efficiency, cleaning efficiency

INTRODUCTION

Millet is one of the principal food sources in arid and semi-arid regions of the world (Obilana, 2005). Onwueeme and Sinha, (1991) reported that air-dried grain millet contains approximately 12.4% water, 11.6% protein, 5% fat, 67.1% carbohydrate, 1.2% fibre and 2.7% ash, hence it is considered to be a nutritious and healthy food. Millet is also the most drought-resistant of all the cereals thus being the only crop that survive well in drier regions without supplementary irrigation (Wudiri and Fatobi, 1991). According to FAO, (2022). Nigeria is the third leading millet producing country in the world and the leading producer in Africa followed by Niger and Mali with a production capacity of about 4 million tons per annum representing about 13.4% of total world production. Products from millet vary depending on people's taste and cultural preference. One of the common traditional products made from millet in Nigeria is *'kunu'*, a non-alcoholic beverage. Millet crop is also being used in Nigeria for making traditional dishes like *tuwo*, *waina*, *ogi*, *eko* and other local desserts such as *koko/pap*, *fura* and so forth (Adeyemi and Umar, 1994). In addition, the stalk and other residues of the millet are used as animal feed and in roofing of rural mud houses. Similarly, millet has superior nutritional values than other cereals (Obilana, 2005).

Threshers operation is a very vital component of farm mechanization; if not done timely all effort made by farmers and inputs given to crops goes wasted. A mechanical thresher is a machine designed to separate the grains from the stalk. During threshing, crop is fed between the threshing drum and the concave where it is subjected to a high degree of impact and frictional force which detach grain from the panicle, while the mechanical cleaning of grain is done by the cleaning unit which comprises of a shaker and a blower (Amir, 1990). The prevailing methods of threshing millet in Nigeria are mostly traditional which entails either beating the heads with sticks on the ground or in sacks repeatedly until all the grains are detached from the heads, or using a mortar and pestle. This process usually damages the grain, introduces impurities such as sand, stone and chaff. It is also laborious and time consuming, and may take up to 1 hour to clean 10 kg of millet grain (Kajuna, 2001). Despite the effort of importing different types of threshers over the years such machines have low adaptability to the farming system, unaffordable, difficult to maintain, complex in design and lack of spare parts or costly beyond the reach of the farmers in addition to required skill personnel for operation (Lawan, 2008). This research work is aimed at addressing such problems by redesigning some of the components to improve on the performance.

MATERIALS AND METHODS

The materials and instruments that were used in this study include a digital stopwatch (make/model - Enko/kk-5853) used to record time during performance evaluation of the machine, laser digital tachometer (NEIKO - DT-838) used to determine the peripheral speed of the cylinder, and an electronic weighing scale (Baykon - BX21-TSX150, sensitivity of 0.01 kg) used in weight measurements. The test material that was used for evaluation was SAMMIL 1 variety of pearl-millet commonly grown by farmers popularly in most millet producing states of Nigeria purchased from an out-grower farmers at Turare village in Dutsin-ma LGA of Katsina.

A. Description of the Thresher

The developed thresher consists of a hopper, threshing unit, fan unit, and cleaning unit. Its dimensions are: over-all height 1300 mm, length of the drum 560 mm, width of 500 mm, height up to the upper end of feeding chute of 960 mm, with the clearance between drum and concave of 5 mm. The diesel engine used for the operation has a power rating of .25hp and a maximum speed of 2000 rpm. The thresher is comparatively small in size and has less weight that could be easily moved from one field to another.

B. Performance Evaluation of the Thresher

During threshing operation, the performance of the thresher was evaluated by varying the moisture content of the crop (14, 12 and 10%), the feeding rate (3, 4, 5, 6 and 7 kg/min) and speed of the engine (600, 700, 800, 900 and 1000 rpm) in order to determine the optimum threshing efficiency, cleaning efficiency, mechanical grain damage, scattered loss and throughput capacity.

C. Computation of the Performance Parameters

Determination of Moisture Content

The moisture content of the test material (SAMMIL 1 variety of pearl-millet) was determined using the standard oven-dried method in accordance with the ASAE (1998). The initial and final weights of the millet sample before and after oven drying were measured using the electronic balance. The threshed millet grains were oven dried at 105^0C for 72 hours as recommended by Okey *et al.* (2016). Three levels of crop moisture contents were used for the performance evaluation of the thresher.

The three levels of moisture contents were used (14, 12 and 10%, wet basis). The expression below was used for the determination of the moisture content as suggested by Mohsenin (1980) as:

$$M_{wb} = \frac{(W_w - W_t)}{W_w} \times 100 \quad (1)$$

where:
M_{wb} = crop moisture content (%),
W_w = weight of grains before oven-drying in grams
W_t = weight of grains after oven-drying in grams.

Threshing Efficiency
The threshing efficiency of the millet thresher was determined using the relationship outline by FAO (1994) as:

$$T_e = 100 - \frac{W_u}{Wb} \times 100 \quad (2)$$

where:
T_e = Threshing efficiency (%),
W_u = weight of unthreshed grain (kg)
W_b = Total millet grain input per unit time by weight in kg

Cleaning Efficiency
The cleaning efficiency of the modified millet thresher was determined using the expression outline by FAO (1994) as:

$$C_E = \frac{(W_T - W_c)}{W_T} \times 100 \quad (3)$$

where:
C_E = cleaning efficiency (%)
W_T = Total weight of grain and chaff received at the grain outlet in kg
W_C = Weight of chaff at main outlet in kg

Mechanical Grain Damage
Mechanical grain damage of the modified millet thresher was determined using the expression outlined by FAO (1994) as:

$$M_d = \frac{W_d}{W_g} \times 100 \quad (4)$$

where:
M_d = mechanical grain damaged (%),
W_d = Weight of damaged grains collect at main outlet in kg
W_g = total weight of grain in the sample in kg

Scatter Loss
The scattered loss was determined using the relationship outline by FAO (1994) as:

$$S_l = \frac{W_L}{W_t} \times 100 \quad (5)$$

where:
S_l = Scattered loss expressed (%)

W_L = Quantity of grains scattered around the thresher after threshing operation (kg)
Wt = Total millet grain output per unit time in weight (kg)

Throughput Capacity

The throughput capacity was determined using the expression outline by FAO (1994) as:

$$T_c = \frac{Q_f}{T} \quad (6)$$

where:
T_c = Throughput capacity (kg/hr),
Q_f = Quantity of grain collected at the grain outlet (kg)
T = Time taken to thresh in hr.

RESULTS AND DISCUSSION

Table-1 shows the mean values of the performance of the thresher showing the effects of feed rate at different moisture content levels.

Table-1 Values of performance parameters

Moisture content (%)	Feed rate (kg/min)	T_e (%)	C_E (%)	M_d (%)	S_l (%)	T_c (kg/hr)
14	3	93.87	90.07	1.03	2.40	111.83
14	4	93.32	89.53	1.10	2.36	113.04
14	5	95.01	91.54	1.20	2.38	112.04
14	6	95.05	91.56	1.23	2.30	110.32
14	7	94.94	91.41	1.29	2.25	108.21
12	3	95.46	91.52	0.73	2.72	127.65
12	4	94.58	90.84	0.82	2.63	120.43
12	5	96.67	93.11	0.93	2.61	122.17
12	6	96.61	93.02	1.03	2.57	120.58
12	7	96.53	92.88	1.09	2.49	127.61
10	3	96.52	94.14	0.60	3.41	160.39
10	4	95.83	93.59	0.70	3.02	159.32
10	5	97.08	95.69	0.80	3.11	161.48
10	6	97.99	95.76	0.90	2.95	158.47
10	7	97.92	95.60	1.00	2.84	161.55

T_e = Threshing efficiency, C_E = Cleaning efficiency, M_d = Mechanical damage, S_l = Scattered loss, $\mathbf{T_c}$ = Throughput capacity

D. Effects of Feed Rate on Threshing Efficiency at different Moisture Contents

Fig. 1 presents the effect of feed rate on threshing efficiency at different moisture contents. The highest threshing efficiency of 97.92% was obtained at 7kg/min with the least moisture content of 10% (wet basis). The lowest threshing efficiency of 93.87% was obtained at 3kg/min when the moisture level was 14% (wet basis). It could be deduce from this that the threshing efficiency increased with decrease in moisture content and feed rate. This could be attributed to the fact that at lower crop moisture content, less amount of impact force is required to detach the kernel from the stock. Increasing the feed rate beyond the optimum may also lead to grain blockage. This trend agrees with the result obtained by Simonyan (2009) and Akintayo (2015), when both researchers reported that the highest threshing efficiencies at the feed rate levels were obtained at the lowest moisture content. In this study, the R^2 values of 0.579, 0.510, and 0.592 (Figure 1) respectively obtained for 10, 12 and 14% moisture content, this implies that there is a moderate correlation between feed rate and threshing efficiency. This was because as the feeding rate increases, grain losses/damage and threshing efficiency deceases. The results did not also contradict the findings of Saleh *et al.* (2022) while evaluating the performance of a groundnut decorticator.

E. Effects of Feed Rate on Cleaning Efficiency at different Moisture Contents

Fig. 2 shows the effect of feed rate on cleaning efficiency at different moisture levels. Results obtained indicates that at 10% crop moisture content the cleaning efficiency increased from 93.59% to 95.6% when the feed rate was increased from 3 to 7kg/min. Also at 12% crop moisture, the cleaning efficiency increased from 90.84% to 93.11% while at 14% the cleaning efficiency increase from 89.53% to 91.56%. It was observed from the results at 10% and 12% crop moisture levels that there was increase in cleaning efficiency with increase in feed rate as compare to that at 14% moisture content. This phenomenon is related to the fact that high impact forces on the crop as a result of high rotational speed tends to reduce the stalk into smaller pieces thereby improving the separation of the grain from the stalk. This results is in agreement with what was obtained by Akintayo (2015), where the cleaning efficiency range from 88.4 to 96.9%. Also, R^2 values of 0.627, 0.609, and 0.565 were obtained for 10, 12 and 14% moisture content (Fig. 2), shows that there was a good linear relationship between feed rate and cleaning efficiency.

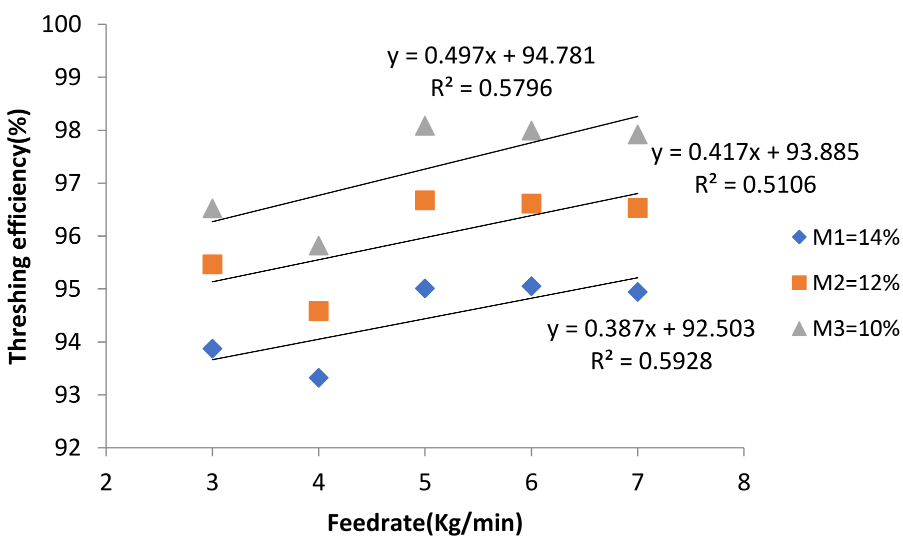

Fig. 1 Effects of feed rate versus threshing efficiency at different moisture contents

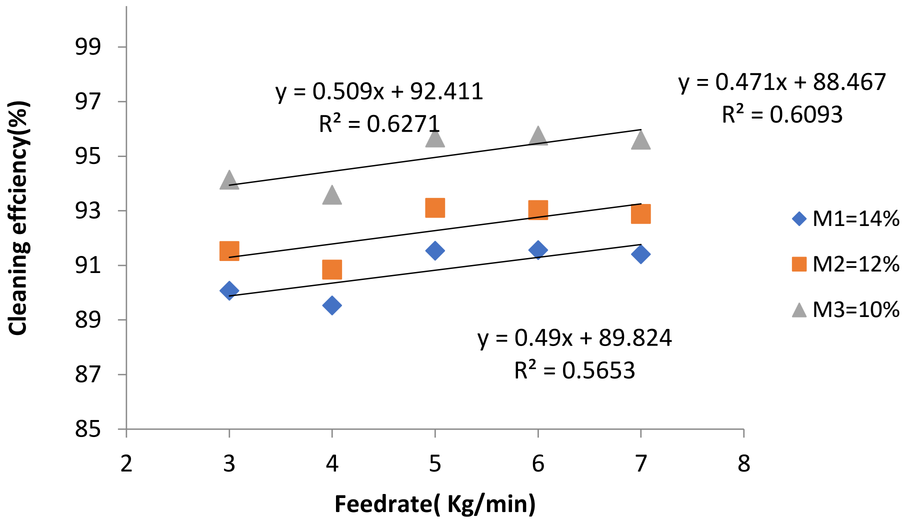

Fig. 2 Effects of feed rate against cleaning efficiency at different moisture contents

F. Effects of Feed Rate on Mechanical Grain Damage at different Moisture Contents

Fig. 3 illustrates the effect of feed rate on mechanical grain damage at different moisture levels.it could be observed that at 10% moisture content the least grain damage of 0.6% was obtained at 3kg/min feed rate while the maximum grain damage of 1% was obtained with 7kg/min feed rate. Similarly at 14% moisture content, the least grain damage of 1.03% was obtained with 3kg/min feed rate while the maximum grain damage of 1.29% was obtained using 7kg/min feed rate. This implies that the mechanical grain damage increased with feed rate at all levels of moisture. The increase in mechanical grain damage with increase in feed rate might be due to the presence of more materials in the threshing chamber with increase in feed rate. This trend is similar to an earlier study conducted by Akintayo (2015) where the values obtained ranges from 2.38 to 2.82% f grain damage at various crop moisture contents. Other researchers such as Ndrika (1994), Kamble (2003) and Abarchi (2011) obtained similar results. Also, R^2 values of 0.973, 0.991, and 1 were obtained for 10, 12 and 14% moisture content (Fig. 3), indicates that there is a strong correlation between feed rate and mechanical grain damage.

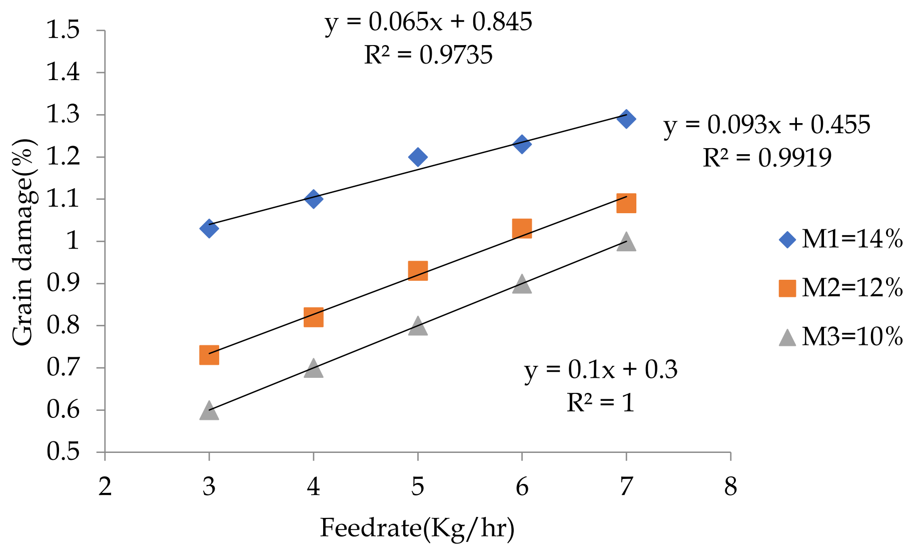

Fig. 3 Effects of feed rate versus grain damage at different moisture contents

G. Effects of Feed Rate on Scatter Loss at different Moisture Contents

Fig. 4 depicts the effects of feed rate on scatter loss at different moisture contents. The maximum scatter loss of 3.41% was obtained at 10% moisture content and at 3kg/min feed rate, while the least scatter loss of 2.25% was obtained at 7kg/min and at highest crop moisture content of 14% (wet basis). This results of this study is similar to that of Ndrika (1994) where the scatter loss of 3.5 to 4.5% was reported. However, other researchers such as Akintayo (2015) and Yakubu *et al.* (2020) obtained scatter losses within the range of 18.9 to 37.3%, Gbabo *et al.* (2013) obtained values ranging between 11.4 to 27.4 %. R^2 values of 0.783, 0.954, and 0.848 were obtained for 10, 12 and 14% moisture content (Fig. 4) implies that there is a good linear relationship between feed rate and scatter loss.

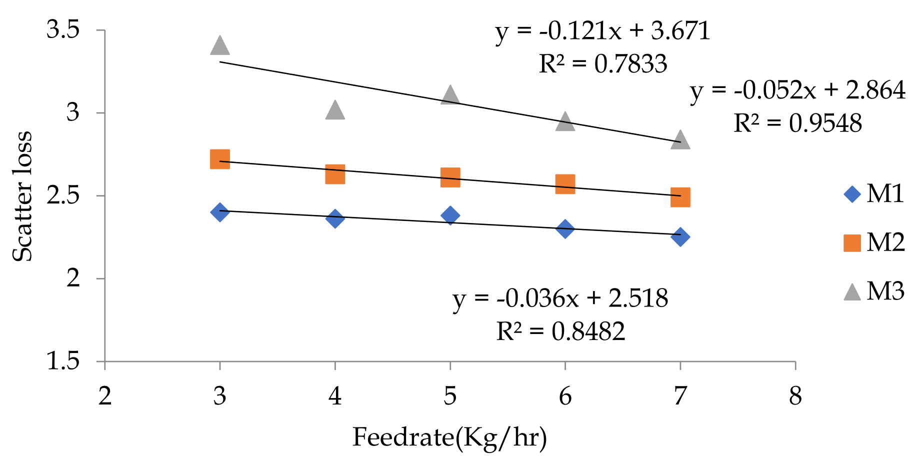

Fig. 4 Graph of feed rate against scatter loss at different moisture contents

H. Effects of Feed Rate on Throughput Capacity at different Moisture Contents

Fig. 5 shows the effect of feed rate on throughput capacity at different moisture content.

It could be deduced from this that the throughput capacity at 14% moisture content gave the minimum values at all the feed rates evaluated while the maximum values of throughput capacities were obtained at 10% moisture content at all levels of feed rates evaluated. The general trend observed in this study was that the throughput capacity increases with increase in feed rate at the various moisture contents, thus implies that the lower the crop moisture content the higher the throughput capacity. This is in agreement with the result obtained by Ndrika (1994), Akintayo (2015) and Yakubu *et al.* (2020) who reported that throughput capacity increases with increase in feed rate at the different moisture levels. R^2 values of 0.029 was obtained at 10% moisture content (Fig. 5) indicates that there is poor correlation between feed rate and throughput capacity, while R^2 values of 0.701 was recorded at 12% implies that there is good correlation between feed rate and throughput capacity. Similarly, R^2 values of 9E-06 was obtained for 14% moisture content shows that there is a weak correlation between feed rate and throughput capacity. This was because throughput capacity increase as moisture content increases due to the fact that at low moisture contents, it is easier for the grains to be detached from the stalk at lower moisture levels thus increasing the throughput capacity. The result obtain is in perfect agreement with findings of Ishola and Hassan (2021) when they evaluated a livestock pulverizer. The results did not also contradict the findings of Saleh and Akande (2021) while determining the effects of screen aperture on groundnut decortication.

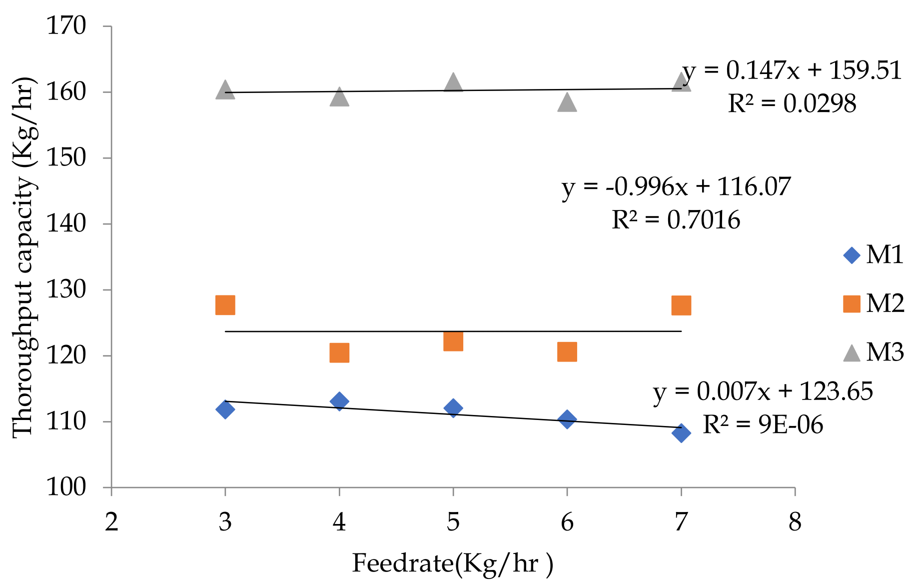

Fig. 5 Graph of feed rate versus throughput capacity at different moisture contents

CONCLUSION

This study evaluated the effects of feed rate and moisture levels on the performance of a developed millet thresher. Three moisture contents (14, 12 and 10%), five feed rates (3, 4, 5, 6, and 7kg/min) and five cylinder speeds (600, 700, 800, 900 and 1000 rpm) were considered. The study observed that feed rate and moisture content has significant effects on the performance of the millet thresher. The threshing efficiency increased with decrease in moisture content and feed rate while cleaning efficiency increase with increase in feed rate. However mechanical grain damage and throughput capacity increases with increase in feed rate at all levels of moisture. Results obtained also shows increase in scattered loss with increase in feed rate at the least moisture content.

CONTRIBUTION TO KNOWLEDGE

This study has established that feed rate and moisture content has significant effects on the performance of the developed millet thresher. This would enable the millet processor to obtain increased threshing efficiency with appropriate moisture content and feed rate in order to add value of the produced for increased income.

DECLARATION OF CONFLIT OF INTERST

The authors declare no competing interest

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