Australian Journal of Basic and Applied Sciences, 5(5): 759-767, 2011
ISSN 1991-8178

Development and Testing of a Prosopis Africana Pod Thresher

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Abstract: Prosopis africana is an under utilized tree crop with immense medicinal and industrial values. Manual threshing of the pods to extract the seeds is uneconomical, time consuming, associated with drudgery and low output capacity. A motorized *Prosopis africana* pod thresher was designed, fabricated and assessed for performance. The main components of the thresher include hopper, threshing unit, cleaning fan and the frame. The best threshing performance index of 92.55 % which comprises of 98.03 % threshing efficiency, 94.45 % cleaning efficiency, 2.36 % seed loss and 1.59 % mechanical damage index was obtained. A combination of 1200 rpm cylinder speed, 1200 rpm fan speed, 30 kg/h feed rate and 16 % wb moisture content of the pods is recommended for optimum results. The thresher has a capacity of 70 kg/h. The performance of this thresher has indicated the possibility of exploiting the full industrial potential of Prosopis africana pods and seeds.

Key words: Prosopis africana, drudgery, threshing performance index.

INTRODUCTION

Prosopis africana (also known as African mesquite) is the only specie of prosopis that is indigenous to tropical Africa. The methanol stem bark extract of Prosopis africana is used for anti-inflammatory and pain relief medicine in human. Likewise, the tannins and dye in the bark is utilized in the leather industry (Ayanwuyi *et al.*, 2010). The leaves and stem are used for treating toothache. The fruits (pods) are used as fodder for ruminant animals (Amusa *et al*., 2010). In the middle belt states of Nigeria, fermented Prosopis africana seeds are popularly used as food seasoning. It is a source of low cost protein. Gels that could be used for pharmaceutical tablet formulation is obtained from Prosopis africana gum. The endocarp gum of Prosopis africana seed contains high content of galactose and mannose. Galactose is a special type of natural sugar that gives sustained energy for a longer time compared to other sugar. Mannose is important for treatment of urinary tract infections (Achi and Okolo, 2004). Likewise, the seeds have been reported to have 4445 kcal/kg of food energy which is higher than the 2500 to 3000 kcal/kg daily requirement by human (Barminas *et al*., 1998). The exploitation of cheap agricultural materials to manufacture industrial products will enhance the development of rural agro-based economy (Kronbergs, 2000; Sain and Panthapulakkal, 2006). The full potential of the *Prosopis africana* pods and seeds has not been fully exploited due to the labourious task of threshing the seeds out of the pods. The pods are more or less cylindrical in shape. They are 10-12 cm long with diameter of 2-3 cm. They are blackish, glossy and thick walled. Each seed is contained in a compartment and there are a total of 10-12 seeds in a pod. The pods do not split open when dry. The ripe pods are hand picked or harvested by shaking off the ripe pods from the tree branches (Helen and Moctar, 2007).

In order to thresh the Prosopis africana pods, the protective pod is broken to separate the enclosed seed from other plant materials. Traditionally, the pods are kept in sacks and beaten with sticks or pounded in a mortar in order to release the seeds from the pods. However, this method is uneconomical, time consuming and labour intensive. Furthermore, there is high damage to the seeds and the output is comparatively low and energy demand is high. The Prosopis africana seeds are usually separated from the chaff and other effluent by winnowing. This process can only be done where there is a high current of wind but some seeds are lost to the chaff.

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Against the backdrop of the human drudgery associated with the traditional manual threshing of *Prosopis africana* pods and the resultant high cleaning losses, there is the need to develop an appropriate threshing machine for these processes. A threshing machine for Prosopis africana seeds was developed and evaluated (Raji and Akaaimo, 2005). Unfortunately, the machine produced some unthreshed Prosopis africana pods and had a least seed loss of 11 %. Furthermore, best performance parameters of the machine were not specified. Considering these shortcomings and the earlier mentioned industrial potentials of Prosopis africana, it is necessary to develop a machine that will have better machine performance parameters. Therefore, the objectives of this research were to design, fabricate and evaluate a motorized Prosopis africana pods thresher that will have higher performance efficiencies and minimal seed loss. It is expected that the development of this thresher will pave way for further researches into the potentials of Prosopis africana.

MATERIALS AND METHODS

2.1. Design Consideration:

Information on the physical properties of pods, seeds and other agricultural materials is fundamental for the design and construction of post harvest processing equipment like thresher (Pradhan *et al*., 2009; Sharma *et al*., 2010). Some of these physical and engineering properties of the pods and the seeds include moisture content, grain/straw ratio, size and angle of repose of the seeds and the pods. The cylinder speed, fan speed, threshing capacity, feed rate, cylinder-concave clearance and power requirement could be established after due measurement of the physical properties of the crop and the review of available technical literatures (Ndirika, 1993). The physical and engineering properties of Prosopis africana have been investigated (Adigun and Alonge, 2000; Akaaimo and Raji, 2006). Their results were used in the selection of some design parameters of the thresher.

The behaviour of seeds and contaminants in air stream is as a result of differences in their aerodynamic properties. For separation purposes, the light seeds and impurities must be carried away and the good seeds must fall through the air stream for collection (Henderson and Perry, 1966). This assertion informed the preliminary test carried out to estimate the volume of air required for separation of the chaff and the seeds of Prosopis africana. The test equipment comprised of a centrifugal fan blowing air into a vertical tunnel equipped with a variable air inlet adjuster and pitot–static tube connected to an electronic manometer (Digitron, model 2002P, England). The cross-sectional area of the tunnel was 0.096 m^2. The tunnel was built with mild steel sheet but one side was covered with 2 mm thick transparent plastic material for observation. Air current was monitored in the tunnel with the pitot-static tube mounted inside the tunnel below a screen holding the Prosopis africana seeds and chaff. The output ports of the pitot-static tube were connected to the pressure measurement ports of the manometer. With this arrangement, the differential pressure of the air current was measured. Using the cross-sectional area of the tunnel and the differential pressure of 373.5 Pa, volumetric flow-rate of 2.4 m^3/s was obtained from calculation. This is the volumetric flow-rate that a blower must have in order to successfully separate the seeds of *Prosopis africana* from the chaff.

2.2. Description of the Machine Components:

The main features of the Prosopis africana pods thresher include the hopper, transmission unit, threshing unit, chaff outlet, centrifugal fan, seed outlet and the supporting frames (Figure 1).

The hopper is trapezoidal in cross section. It forms the feeding chute through which pods of Prosopis africana are fed into the threshing unit. The material of construction was 2 mm mild steel sheet. The transmission unit consists of two pulleys, four bearings, two shafts and two vee belts. Each of the threshing unit and the fan carries one pulley and two bearings.

The threshing unit consists of the cylinder, perforated concave, studs on both the cylinder and the concave. The cylinder is made of mild steel sheet metal formed into 100 mm diameter cylinder. The concave is made of mild steel sheet rolled into 180 mm diameter cylinder .The threshing cylinder was placed inside the concave. The threshing cylinder has four rows of studs welded strongly on its surface and at right angle to the cylinder. The concave has 12 mm diameter holes spaced all over its surface. It also has two rows of studs. Clearance between the free ends of the studs on the threshing cylinder and the concave was maintained at 5 mm. The threshing unit is covered with two square plates to prevent loss of seeds during threshing.

The fan is stationed below the perforated concave. The exit of the fan is at right angle to the direction of flow of the materials (seeds and chaff) from the threshing unit. It is a straight blade centrifugal fan with six blades. The structural frame forms the mounting support for all the units. It is made of (40 x 40 mm) mild steel angle iron. The other frames attached to this main frame are the frames of the electric motor and that of the fan. They are both made of (30 x 30 mm) mild steel angle iron.

2.3. Design of Machine Components:

The required physical and engineering properties of *Prosopis africana* pods and seeds were obtained from Adigun and Alonge (2000) and Akaaimo and Raji (2006). The maximum intermediate diameter of the pod of Prosopis africana was given as 39 mm. Hence a cylinder concave clearance of 40 mm was chosen for the machine. It was claimed that the maximum angle of repose of the seeds on the galvanized steel sheet was 22.71°.

Hence an inclination angle of 30° was chosen for the chaff outlet chute. This was to allow any seed thrown into the chute to easily roll back to the seed outlet. The diameter of the grate in the concave was chosen to be 12 mm because the mean diameter of the seed was given as 9.88 mm. A maximum bioyield force of 46 N for Prosopis africana pods deduced by Adigun and Alonge (2000) was used in the design and selection of threshing shaft diameter and size of the studs in the threshing units.

From the design calculation, a minimum shaft diameter of 20 mm was obtained. Using the values of volumetric flow-rate of 2.4 m^3/s, air velocity of 24.96 m/s and differential pressure of 373.5 Pa obtained by the use of the electronic manometer and calculation, other parameters concerning the dimensions of the centrifugal fan were calculated. Also the minimum diameter of the fan shaft was obtained as 12 mm from calculation. The design and selection of the entire component were carried out in accordance to standard engineering practice. The designed machine is capable of 70 kg/h throughput. Detailed dimensions of the machine are shown in figure 2.

2.4. Principle of Operation of the Machine:

The thresher works on rotating impact principle. *Prosopis africana* pods are fed uniformly into the hopper. The pods fall by gravity on the rotating cylinder and are threshed by impact of the studs and are whirled round between the perforated concave and the rotating cylinder. The chaff and the seeds fall through the concave openings and are directed to the seed outlet by the configuration of the casing.

Just before falling on the seed collector, the fan's air stream blows off the chaff through the chaff outlet chute leaving behind the clean seeds on the seed collector. The seed collector is opened at intervals to discharge the seeds through the clean seed outlet. This arrangement was aimed at allowing some dwell time for the mixture of the seeds and chaff to be properly separated.

2.5. Performance Test Procedure:

After considering the relative importance of the machine and crop factors that are directly related to the performance of a thresher and the available experimental materials at hand, four factors were selected for the performance test: Cylinder speed (C), Fan speed (S), Moisture content (M) and Feed rate (F). Ripe pods of Prosopis africana were harvested from selected trees at different locations on the campus of University of Ilorin, Permanent site, Ilorin, Nigeria. The tree branches were given some shaking in order to obtain sample needed for the test. The moisture content on wet basis of Prosopis africana pods was determined using the oven drying method. A sample 300g of Prosopis africana pods were then dried in a hot-air oven (Memerth, model 500, W.Germany) at 130 °C for 6 hours. Then, they were left in the desiccators for 1 hour to cool down, after which they were weighed by using Sartorios B1205 digital electronic balance with reading accuracy of 0.0001 g. This method of moisture content determination is based on the specification of American Society of Agricultural and Biological Engineers (ASABE) standard (ASABE Standards, 2010). The initial and final weights were taken and moisture content computed. The whole process was replicated five times with different samples of Prosopis africana pods and average was taken. The moisture content obtained was 21 % wb.

At the beginning of the performance test, 64 kg of Prosopis africana pods at 21% moisture content were used for some parts of the test involving this level of moisture content. Manual threshing of 1 kg of Prosopis africana pods was done in five replicates. This was used to establish the average seed to chaff ratio. It was found to be 0.128. The remaining pods were sun-dried until their moisture content dropped to 16 % wb. Another 64 kg of the pods out of the remaining was used for the parts of the test involving this level of moisture content. Also, manual threshing of 1 kg of Prosopis africana pods was done in five replicates. This was used to establish the average seed to chaff ratio. This time, it was found to be 0.118. A 4 x 4 x 2 x 2 factorial experiment in split plot design was employed. Based on the recommendation in the technical literature, the selected factors and their respective levels are presented in table 1. The aim of this factorial experiment was to simultaneously examine all combinations of all factor levels on the performance of the machine.

The pulley ratio method was used to achieve variable speed for the fan and the cylinder. A digital hand tachometer (Compact CT6, U.K) was used to get the actual speed for each pulley size.

For each experimental run, the following measurements were taken:
(i) Time of test run, T minutes.
(ii) Weight of threshed seeds at main outlet per unit time, B (kg)
(iii) Weight of threshed seeds at all other outlet per unit time, C (kg).
(iv) Weight of unthreshed seed at all outlet per unit time, D (kg)
(v) Weight of damaged seeds collected at all outlet per unit time, E (kg)
(vii) Weight of chaff in seed outlet per unit time, G (kg)
(vii) Weight of all seeds (whole, damaged and unthreshed) at chaff outlet per unit time, H (kg) Seed/ Straw ratio (q) = 0.128 (constant for 21% moisture content level) but (q) = 0.118 (constant for 16% moisture content level)

The followings expressions used were taken from the Nigerian Industrial Standard Test Code for grain threshers prepared by Standard Organization of Nigeria (1997).

(i) Total seed input per unit time, A (kg); A = B + C + D (kg) (1)

(ii) Threshing Efficiency, $E_T = \left(1 - \frac{D}{A}\right)100$ % (2)

(iii) Cleaning Efficiency, $E_C = \left(1 - \frac{q \times G}{A}\right)100$ % (3)

(iv) Percentage seed loss, $E_L = \left(\frac{H}{A} \times 100\right)$% (4)

(v) Mechanical damage index, $E_D = \left(\frac{E}{A} \times 100\right)$ % (5)

(vi) Threshing performance index, TPI = $100 \times E_C E_T \left[1 - E_D E_L\right]$ (6)

Where E_C = Cleaning efficiency (in decimal)
E_T = Threshing efficiency (in decimal)
E_D = Mechanical damage index (in decimal)
E_L = Percentage seed loss (in decimal)

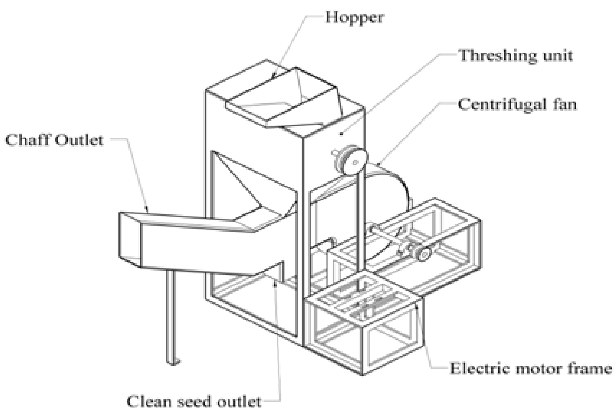

Fig. 1: Isometric view of the Prosopis africana pods thresher.

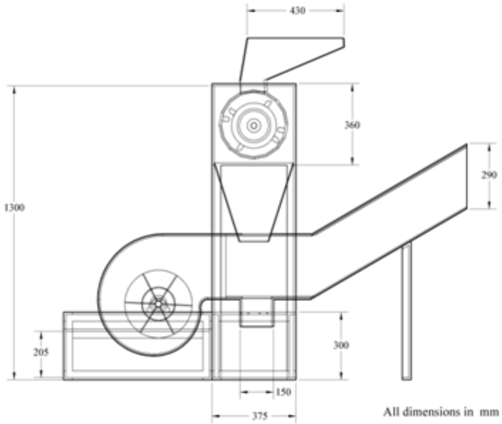

Fig. 2: Front view of the Prosopis africana pods thresher.

Table 1: Parameters and their values used in the test.

Factors	Levels	
Cylinder Speed	C= 600 rpm	C_2 = 800 rpm
	C_3 = 1000 rpm	C_4 = 1200 rpm
Fan Speed	S = 1200 rpm	S_2 = 1500 rpm
	S_3 = 1800 rpm	S_4 = 2100 rpm
Feed rate	F = 20 kg/h	F_2 = 30 kg/hr
Moisture Content	M = 16 %wb	M_2 = 21 %wb

RESULTS AND DISCUSSION

The test results obtained from the 4 x 4 x 2 x 2 factorial experiment in split plot design for the performance indices of the machine are as follow. The various performance indices used for testing the thresher were threshing efficiency, cleaning efficiency, percentage seed loss, mechanical damage index and threshing performance index. Analysis of variance (ANOVA) in split plot design was conducted for each of these performance indices with GenStat statistical software version 10.

3.1. Threshing Efficiency:

Analysis of variance for the threshing efficiency shows that the cylinder speed and moisture content are significant at 1 % confidence level. The interaction of fan speed and moisture content; the interaction of cylinder speed, fan speed and feed rate were only significant at 5% confidence level. It can be deduced from figure 3 that increase in the cylinder speed resulted in increase in threshing efficiency. This may be due to the fact that at higher speed, the energy impacted on the pods increases causing higher threshing efficiency. The highest average threshing efficiency was 98.40 %. Therefore threshing efficiency is favoured by high cylinder speed and low moisture content. This result is in the same trend as the results obtained by Raji and Akaaimo (2005) and Chukwu (2008).

3.2. Cleaning Efficiency:

The analysis of variance for the cleaning efficiency revealed that the cylinder speed; fan speed; the interaction of moisture content and fan speed; the interaction of cylinder speed and feed rate, the interaction of fan speed and feed rate; the interaction of cylinder speed, fan speed and feed rate are significant at 1 % alpha level. Whereas feed rate, the interaction of cylinder speed, moisture content and feed rate; the interaction of cylinder speed, fan speed, moisture content and feed rate were only significant at 5 % alpha level. Figure 4 indicates that at fan speed of 1800 rpm and 2100 rpm, the cleaning efficiency were stable as the cylinder speed increased. However at fan speeds of 1200 rpm and 1500 rpm, the cleaning efficiency increased with increase in cylinder speed except at cylinder speed of 800 rpm where there was a slight drop. But the cleaning efficiency at the fan speed of 1500 rpm was far higher than that at the fan speed of 1200 rpm. This could be due to the fact that as the cylinder speed increased the chaff that could have been otherwise left behind in the seed outlet were further broken down by the cylinder and hence blown off by the fan.

The two-factor interaction of the cylinder speed and the fan speed resulted in higher cleaning efficiency at higher levels of both speeds as shown in figure 4. The highest cleaning efficiency of 99.82 % was achieved at a fan speed of 2100 rpm and a cylinder speed of 1200 rpm. However, with reference to figure 5, there are an accompanying higher percentage of seed losses at these levels of speed. In line with the claim of Bedane *et al*., (2008), seeds at high speed air stream have high kinetic energy of escaping through the chaff outlet. Hence, a combination of cylinder speed and fan speed having a corresponding minimal a percentage grain loss need to be sought for.

3.3. Percentage Seed Loss:

The analysis of variance for the percentage seed loss depicts that fan speed; moisture content; the interaction of cylinder speed and fan speed; the interaction of cylinder and moisture content; the interaction of fan speed and moisture content; the interaction of fan speed and feed rate, the interaction of cylinder speed, fan speed, moisture content and feed rate were significant at 1 % alpha level.

However, the interaction of cylinder speed, moisture content and feed rate is significant at 5 % alpha level. It can be deduced from figure 5 that the percentage seed loss was virtually stable as the cylinder speed increased. The lowest achievable percentage seed loss was 1.69 % at a fan speed of 1200 rpm. On the contrary, the percentage seed loss increased with an increase in the fan speed. This was due to the fact that the direction of flow of the air stream from the fan was perpendicular to the direction of the discharged materials from the threshing unit. Therefore, there was a side drift of the seeds towards the chaff outlet. Hence, some seeds escape with the chaff. This results is in agreement with the results reported by Raji and Akaaimo (2005) and Kushwaha *et al*. (2005).

3.4. Mechanical Damage Index:

The analysis of variance for the mechanical damage index shows that fan speed; moisture content; the interaction of cylinder speed, fan speed and moisture content; the interaction of cylinder speed, fan speed and feed rate; the interaction of cylinder speed, moisture content and feed rate; the interaction of cylinder speed, fan speed, moisture content and feed rate are significant at 1 % alpha level. Whereas, feed rate; the interaction of fan speed and moisture content; the interaction of fan speed, moisture content and feed rate are significant at 5 % alpha level. From figure 6, the mechanical damage index decreased with increasing fan speed. The lowest value of mechanical damage index of 1.02 % was obtained at both moisture content levels. However, the lower moisture content of 16 % (wb) resulted in generally higher mechanical damage index. The trend of this result is similar to what was observed by Kushwaha *et al*. (2005).

3.5. Threshing Performance Index:

The averages values of the various performance indices obtained from the two replicates of the 64 combinations of the different levels of factors used in the factorial experiment were computed. Those selected combinations with the best four threshing efficiency or cleaning efficiency with corresponding lower values of percentage seed loss or mechanical damage index were selected. The threshing performance index for each of these combinations was calculated. The threshing performance index is analogous to seed processing efficiency used by Bedane *et al*., (2010) because it incorporates seed damage and seed loss in quantifying the overall performance of a seed processing system. Figure 7 shows that the best thresher performance index of 92.55 % could be obtained from a combination of cylinder speed of 2100, fan speed of 1200, feed rate of 30 kg/h and moisture content of 16 % (wb). This threshing performance index is made up of 98.03 % threshing efficiency, 94.45 % cleaning efficiency, 2.36 % seed loss and 1.59 % mechanical damage index.

Therefore, based on the limitations of the machine geometry, the scope of the test procedure and the analysis above, the best combination of parameters for the *Prosopis africana* thresher are cylinder speed of 1200 rpm, fan speed of 1200 rpm, 30 kg/hr feed rate and 16 % wb moisture content wet basis of the crop.

3.6. Comparison with Earlier Prosopis Africana Thresher:

The maximum threshing and cleaning efficiencies of 95.8 % and 96.0 % respectively at cylinder speed and fan speed of 450 rpm were achieved for the *Prosopis africana* thresher earlier developed by Raji and Akaaimo (2005). Whereas the new *Prosopis africana* thresher developed in this research had a maximum threshing and cleaning efficiencies of 98.4 % and 99.82 % at cylinder speed of 1200 rpm and fan speed of 2100 rpm respectively. Likewise, the least seed loss and mechanical damage index recorded for this new thresher was 1.69 % and 1.02 % respectively while the earlier thresher had a least seed loss of 11%. Furthermore, there was no single unthreshed pod from the new thresher.

Cases of unthreshed whole pod and high seed loss reported for earlier thresher could be due to the fact that the cylinder and the fan were run at the same low speed and there was no dwell time provided for the seeds to be properly cleaned. Mechanical damage index was not evaluated for the earlier thresher. Therefore, threshing performance index which is an overall assessment index could not be computed and hence, the best combination of cylinder speed and fan speed could not be recommended.

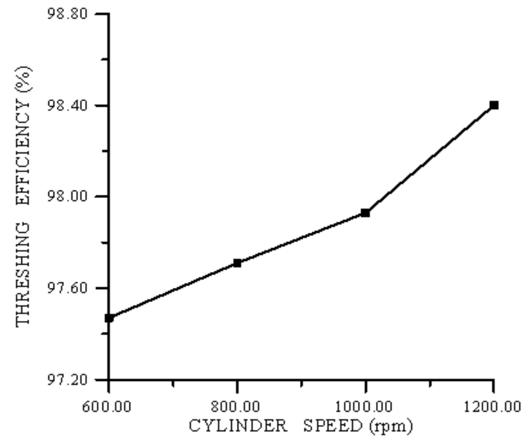

Fig. 3: Effect of cylinder speed on threshing efficiency.

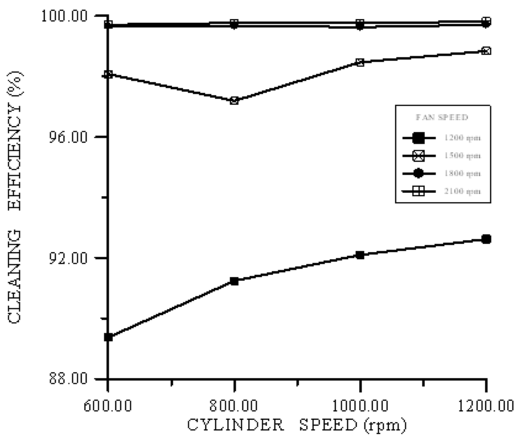

Fig. 4: Effect of cylinder speed and fan speed on cleaning efficiency.

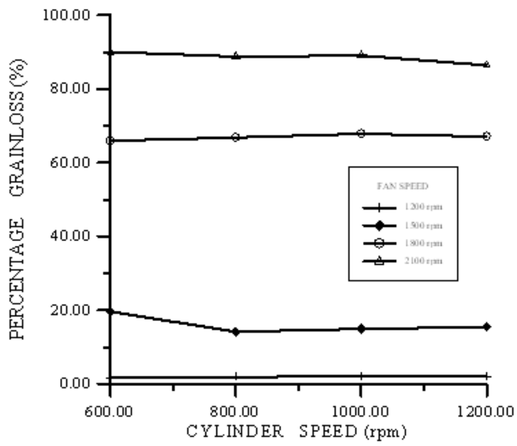

Fig. 5: Effect of cylinder speed and fan speed on percentage seed loss.

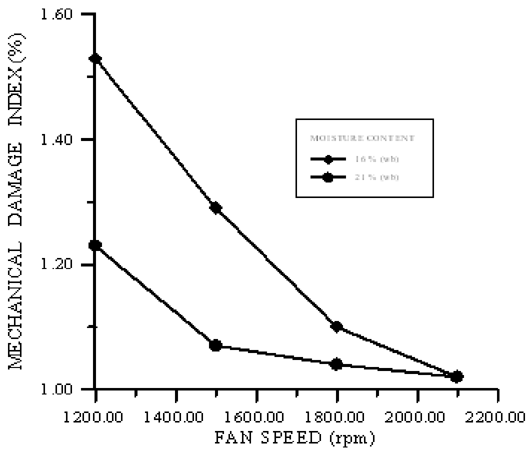

Fig. 6: Effect of fan speed and moisture content on mechanical damage index.

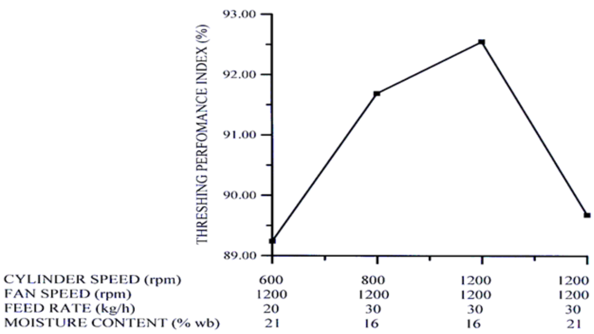

Fig. 7: Threshing performance index of the best combination of cylinder speed, fan speed, feed rate and moisture content.

Conclusions:

A Prosopis africana pod thresher was developed and tested. The results of the performance evaluation showed that threshing efficiency, cleaning efficiency and seed loss increased with increase in cylinder speed and fan speed. Hence to achieve high threshing and cleaning efficiencies with corresponding low seed loss and mechanical damage index, a cylinder speed of 1200 rpm, fan speed of 1200 rpm, feed rate of 30 kg/h and moisture content of 16 % wb are ideal. All the materials used for the fabrication were sourced locally. Hence, it is affordable by peasant farmers in a developing country like Nigeria.

ACKNOWLEDGEMENTS

We thank the authorities of University of Ilorin, Ilorin, Nigeria for providing the facilities and support to carry out this research work.

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