PERFORMANCE EVALUATION OF A BAMBARA GROUND NUT SHELLER

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Abstract
The shelling of pod to obtain clean seed is one of the most tedious operations in Bambara groundnut processing. As a result, it has constituted a bottle- neck to the large scale production and processing of this important proteinous crop. To overcome the problem, some physical properties of bambara groundnut pod relevant in bulk handling and processing, were investigated and a sheller using roller mechanism was designed for the crop, constructed and tested.

Measurements of the physical properties showed that at the moisture content of 5% (wb), the major, intermediate and minor diameters of Bambara groundnut pod averaged 1.89 cm, 1.57 cm and 1.44cm respectively. The true and bulk densities, porosity and one thousand-pod weight averaged 754.83 kg/m^3 and 432 kg/m^3, 42.77% and 1.24 kg, respectively and the angle of repose and static coefficient of friction of the pod on steel sheet averaged 30.4^o and 0.56.

Results of machine performance tests showed that the moisture content, material feed rate and the interaction between them had significant effect on the quantity of shelled, unshelled and partially shelled pods as well as that of damaged seeds and winnowed chaffs at 1% level of significance. Shelling and winnowing efficiencies decreased while percentage of partially shelled and unshelled pods increased with increase in moisture content and feed rate. The maximum shelling and winnowing efficiencies of 80% and 79.5% respectively, were obtained at the moisture content of 5% (wb) and feed rate of 93.6 kg/h. The percentage seed damage increased with increase in moisture content – between 5 and 10% (wb) - to a maximum value of about 38%, and decreased with further increase in moisture content. At low moisture levels, it increased with increase in feed rate but at higher moisture levels, it decreased with increase in feed rate.

Regression models that could be used to express the relationship existing between the sheller performance indices, pod moisture content and feed rate were established. Further work would be carried out to modify the sheller and optimize its performance.

Keywords: Bambara groundnut, Efficiency, Evaluation, Performance, Sheller, Shelling, Winnowing

Introduction

Bambara groundnut *(Vigna subterranea (L.) verdc.)* is an indigenous African crop that is now grown across the continent from Senegal to Kenya and from the Sahara to South Africa. It is a highly nutritious crop that plays an important role in the people's diet. The seed contains about 63% carbohydrate, 19% protein and 6.5% oil (Goli, 1997) and is consumed in different forms. For instance, it is usually fried or boiled with salt and eaten as snack or pounded into flour and used in the preparation of soup, porridge and various fried or steamed food products such as 'akara', 'moi-moi' and 'okpa' in Nigeria. It also finds a use in the preparation of the local food drink 'kunu' and such dish as 'tuwo' (Linnemann, 1988). Linnemann (1990) reported that bambara groundnut flour has been used in making bread in Zambia, and Brough et al. (1993) noted that the milk prepared from bambara groundnut gave a preferred flavour to that of milks from cowpea, pigeon pea and soybean. Atiku (2000) found that in North Eastern Nigeria, bambara groundnut is not only consumed as food, but also used for medicinal purposes. The haulm is used for livestock feed (Tanimu and Aliyu, 1997) and the leaves, which have been reported to be rich in nitrogen and phosphorus, are suitable for animal grazing. Mungate (1997) noted that bambara groundnut is not only to be used for relish and livestock fodder but also as a soil conditioner since it has the ability to fix much needed nitrogen in the soil. Inspite of the growing importance of bambara groundnut, research efforts have been concentrated on its agronomy and little attention has been paid to the technologies for its post harvest handling and processing operations.

Bambara groundnut seed is contained in pod, which usually developed underground (Figure 1). The pod is harvested by pulling or lifting the plant manually or by using a hoe. Sometimes, a single furrow ox-drawn plough is used. The pod is then washed, dried and shelled or stored in Rhumbus, Hessian bag or pot. Traditional technologies are still employed in the shelling of bambara groundnut. These include pounding in mortar with pestle, beating with stick on a flat surface and cracking with a stone on top of another stone or a hard flat surface. These techniques are not only laborious and time consuming, but also wasteful. As a result, the shelling of Bambara groundnut pod has constituted a bottleneck to the large-scale production and processing of the crop. To solve this problem and relief the processors of the tedium of the manual shelling operation, a mechanical device that is capable of shelling the pod to produce clean seed was designed and fabricated.
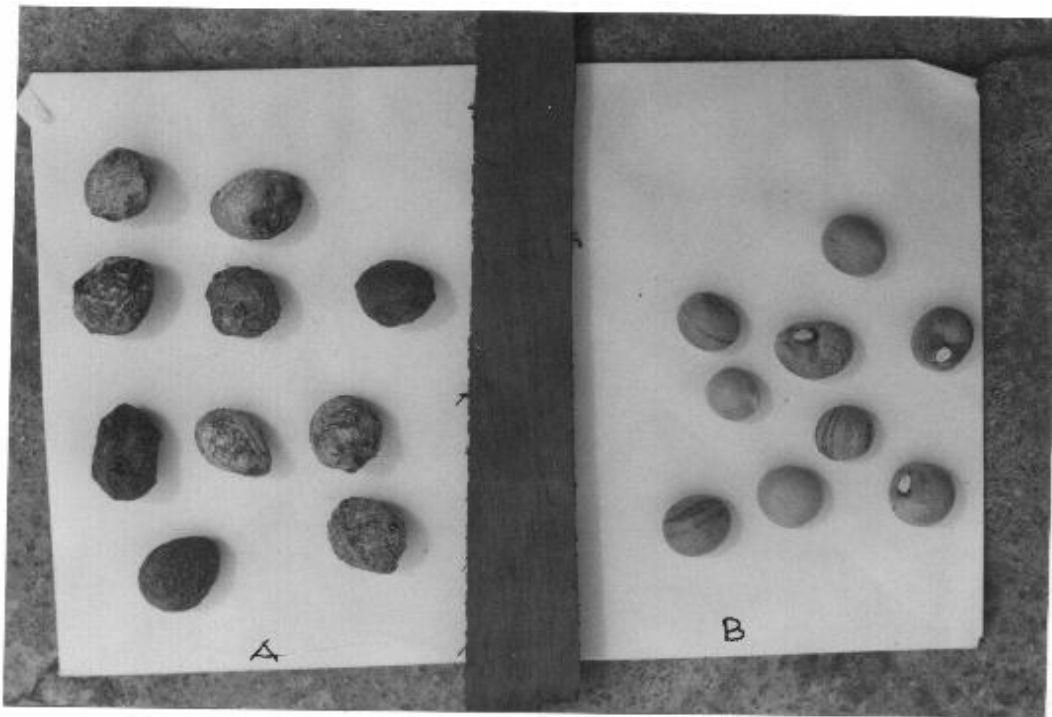
Figure 1: Bambara groundnut pods and seeds, A: pods; B: seeds

As part of the machine development efforts, this paper reports the performance evaluation of the Bambara groundnut sheller. The effect of moisture content and material feed rate on the sheller's performance indices was also investigated.

Materials and Methods
Physical Properties of Bambara Groundnut pod
Some physical properties of bambara groundnut pod relevant in bulk handling and processing were investigated. A bulk quantity of pods was purchased from local farmers in Mubi, Adamawa State, Nigeria. The variety was the common milk coloured one, which is mainly grown in North Eastern Nigeria (Atiku, 2000). The pods were cleaned and sampled for experiment using a multi-slot riffle box divider. The moisture content was determined using the ASAE (1983) recommended method for edible beans, and the initial content of the pods was found to be $5 \pm 0.38\%$ (wb). At this moisture content, the physical properties of the pods were determined.
Pod size was determined by measuring the axial dimensions of 100 randomly selected pods, using a vernier caliper reading to 0.05mm. Values of the axial dimensions would govern the clearance between the rollers of the sheller that would engender effective shelling of the pod. The true density was determined using the water displacement method as reported by Aviara et al. (1999). The bulk density was determined using the AOAC (1980) recommended method and the porosity of the pods was calculated from the relationship given by Mohsenin (1986) as follows:

$$P \approx \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{1}$$

where P = porosity, %; ρ_b = bulk density, kg/m^3; ρ_t = true density, kg/m^3.

The one thousand pod weight was obtained with an electronic balance reading to 0.001g. An open ended box with removable front panel was used to determine the pod angle of repose and the inclined plane method as described by Aviara et al. (2002) was used to determine the static coefficient of friction of the pod on metal sheet. All the experiments were replicated five times at the above moisture content and the average values are reported.

Bambara Groundnut Sheller Description and Operation

The Bambara groundnut sheller designed to operate by means of roller mechanism, consists of a feed hopper, shelling unit, winnowing unit and power system (Fig. 2).

The hopper, which is rectangular in shape, is mounted on the shelling unit at an inclination of the pod's angle of repose. It is held on to the tool frame by a hopper support mounting. A flow rate control device is located at the hopper base and used to obtain varying gate openings between the hopper and the shelling unit. By this device, the quantity of pods entering into the shelling chamber per unit time was regulated and varying feed rates were achieved.
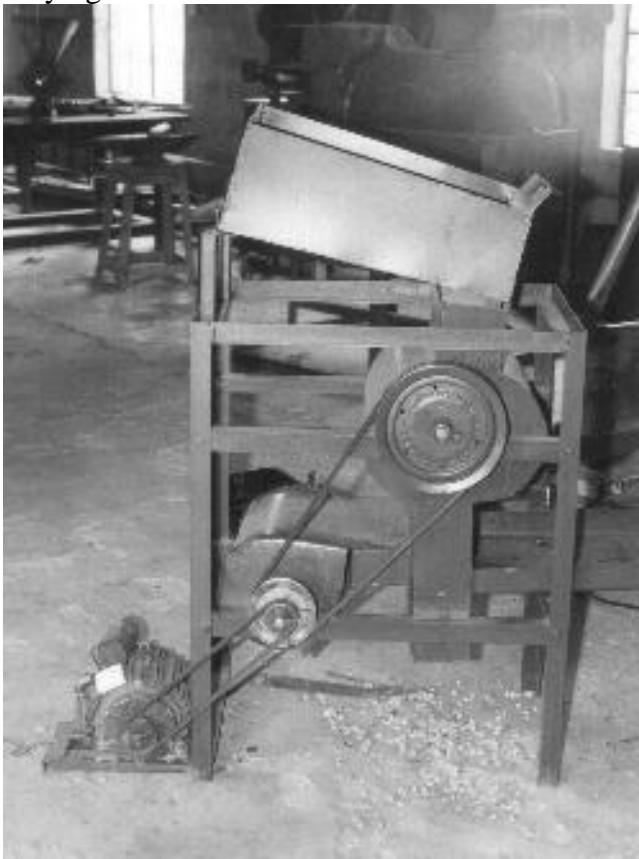

Figure 2: Photograph of the fabricated bambara groundnut sheller

The shelling system consists of two rollers in the shelling chamber. One of the rollers is driven by a belt and pulley arrangement, while the other is not driven. The rotary roller has three shelling bars welded at an angle to its surface and running through its length. It creates a clearance that is less than the pod size but greater than the seed size with the stationary roller. During machine operation, the pod from the hopper drops between the rollers. The shelling bar of the rotary roller collects and compresses it against the non-driven roller and by that action the pod is shelled. The mixture of seed and shell falls through a drop or opening at the base of the shelling unit into the winnowing chamber.

The winnowing unit comprises the winnowing chamber (where the seed and shell are separated by air current) and the blower, which is powered by a 3.5 hp, 1000 rpm electric motor. There is also a shell outlet and a seed collection chute. As the mixture of seed and shell falls through the winnowing chamber, the air current from the blower lifts the lighter shell and carries it out through the shell outlet. The denser seed falls through the air stream into the collection chute.

The power system consists of the electric motor and belt and pulley drives by which it runs the shelling roller and the blower. The above components were assembled and mounted on a rectangular tool frame. Figure 3 shows the assembly details of the sheller and its part list.

Performance Tests and Evaluation

Tests were conducted to evaluate the performance of the Bambara groundnut sheller. The flow rate control device was calibrated following the procedure outlined by Oluwole et al. (2004) in a work on sheanut cracking. The moisture content of the pods was varied using the method of Ezeike (1986) as reported by Aviara et al (2002). This involved the soaking of a bulk quantity of the pods at an initial moisture content of 5% (wb) in clean water for one, two and three hours respectively. At the end each period of soaking, the pods were spread out in thin layer to dry in natural air for about eight hours. The pods were then sealed in marked polyethylene bags and stored in that condition for a further twenty four hours. This enabled stable and uniform moisture content of the pods to be achieved in the bags. The polyethylene bags were transferred into a refrigerator and when needed for experiments, the pods were allowed to equilibrate in ambient condition for six hours. To conduct a performance test, the hopper base was completely closed using the flow rate control device. The hopper was filled with Bambara groundnut pods at specified moisture content and the total number of nuts (N_T) was determined by counting. The nuts were poured back into the hopper, the power supply was switched on to run the electric motor and set the working components of the sheller in motion. The flow rate control device was adjusted to select the gate opening that will deliver a particular feed rate of the pods into the shelling chamber. The pods were discharged into the machine and shelled until the hopper was emptied. The number of pods that were completely shelled and unbroken (N_1), completely shelled but broken (N_2), partially shelled and unbroken (N_3), partially shelled and broken (N_4) and the number of unshelled pods (N_5) were determined at the end of each run. The quantity of shells winnowed out and those collected with the seeds were noted. Preliminary tests showed that good results could be obtained with the roller clearance of 18mm. Therefore, this clearance was maintained throughout the performance tests.

The tests were conducted at the initial moisture content of 5% (wb) and the moisture contents of 8.5, 12.2 and 18% (wb) obtained after conditioning. The three feed rates used were 93.6, 187.2 and 374.4 kg/h. At a combination of each of the above conditions, the test was replicated three times and the performance of the sheller was evaluated on the basis of the following indices:

(a) Shelling efficiency, $E_s \approx \left(\dfrac{N_1 + N_2}{N_T} \right) \times 100\%$

(2)

(b) Percentage damage, $P_d \approx \left(\dfrac{N_2 + N_4}{N_T} \right) \times 100\%$

(3)

(c) Percentage partially shelled, $P_{ps} \approx \left(\dfrac{N_3 + N_4}{N_T} \right) \times 100\%$

(4)

(d) Percentage of unshelled pods, $P_u \approx \left(\dfrac{N_5}{N_T} \right) \times 100\%$

(5)

(e) Winnowing efficiency, $E_w \approx \left(\dfrac{m_{ws}}{m_{Ts}} \right) \times 100\%$

(6)

where m_{ws} = Mass of winnowed shells, and m_{Ts} = Total mass of shells.

Regression analyses were performed on the data obtained, to determine the relationship existing between the machine performance indicators, moisture content and material feed rate. Analysis of variance (ANOVA) was used to determine the extent to which moisture content and or feed rate affected the indices.
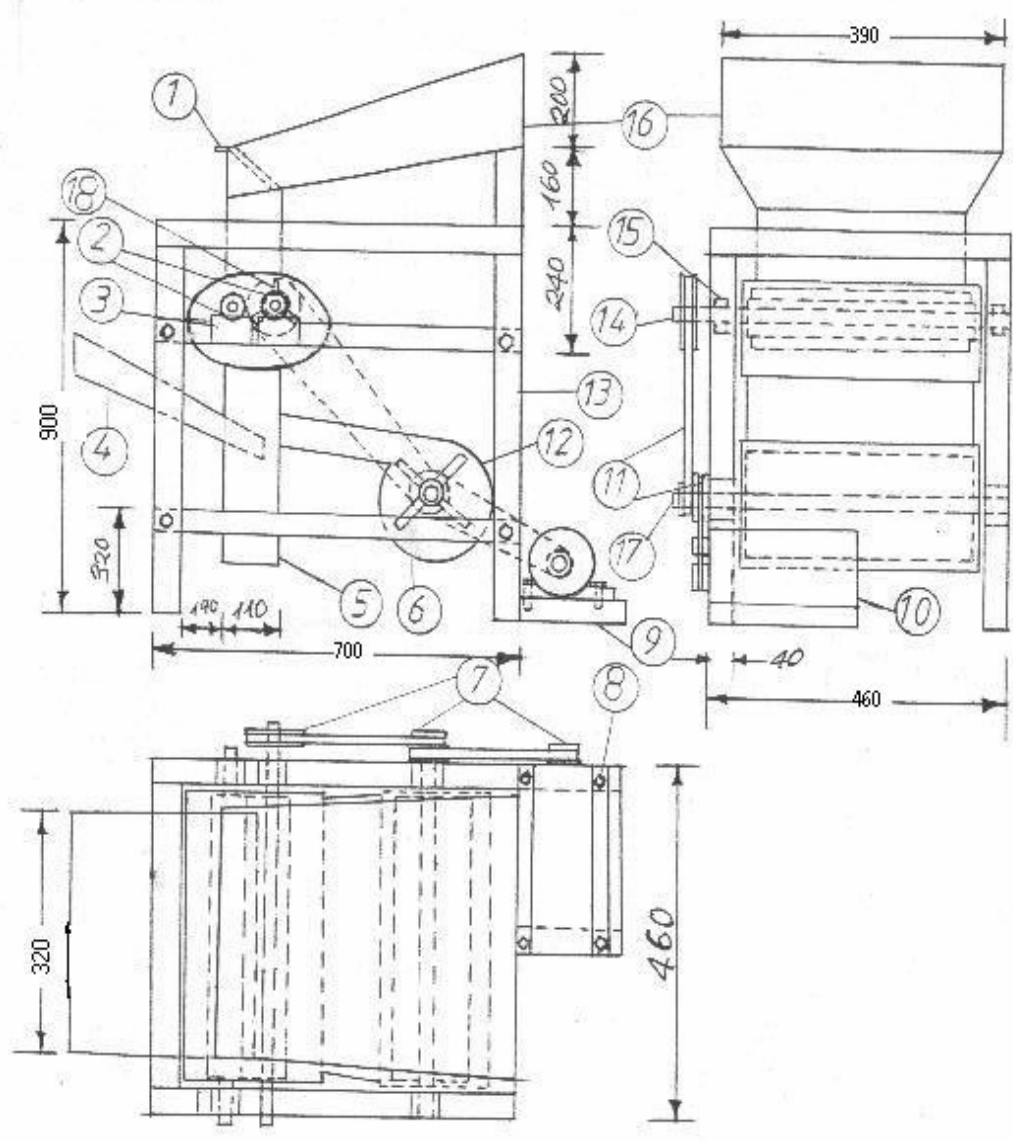
Figure 3: Detailed assembly and parts list of Bambara groundnut sheller

S/N	DESCRIPTION OF ITEM	MATERIAL	NO. OFF
18.	Shelling bar	Flat metal bar	3
17.	Blower shaft	Steel	1
16.	Hopper	Metal sheet	1
15.	Roller bearing	High carbon steel	2
14.	Roller shaft	Steel	2
13.	Tool frame	1.5 inch angle iron	1 assembly
12.	Blower housing	Metal sheet	1
11.	Drive belt		2
10.	Electric motor		1
9.	Electric motor mounting	1 inch angle iron	1 assembly
8.	Electric motor mounting bolt	Steel	4
7.	Drive pulley	Cast iron	4
6.	Blower blade	Metal sheet	4
5.	Seed collection chute	Metal sheet	1
4.	Chaff outlet	Metal sheet	1
3.	Roller shaft bearing housing and mounting	High carbon steel	4
2.	Roller	High carbon steel pipe	2
1.	Feed rate control device	Metal steel sheet	1
S/N	DESCRIPTION OF ITEM	MATERIAL	NO. OFF

Figure 3(Continued)--Parts list of Bambara groundnut sheller

Results and Discussion
Physical Properties of Bambara Groundnut Pod
The values of the physical properties of bambara groundnut determined are presented in Table 1. The maximum, minimum and average values at the moisture content of 5% (wb) are reported with the standard deviation. The properties play important role in the determination of the sheller features and performance characteristics. The pod size governs the clearance between rollers that would make for effective shelling operation. The true and bulk densities, porosity and coefficient of friction influence the pressures exerted on hopper walls and flow through the orifice. The one thousand pod weight could be used for the theoretical determination of the pod's effective diameter and the angle of repose was used to determine the hopper inclination.

Table 1: Some physical properties of Bambara groundnut pod at the moisture content of 5% (wb)

Properties	Values			
	Maximum	Minimum	Mean	Standard deviation
Axial dimensions: Major diameter (cm)	2.16	1.64	1.89	0.13
Intermediate diameter (cm)	1.74	1.35	1.57	0.11
Minor diameter (cm)	1.65	1.22	1.44	0.101
True density (kg/m^3)	1060	630	754.83	101.83
Bulk density (kg/m^3)	442	410	432	12.01
Porosity (%)	-	-	42.77	-
One thousand pod weight (kg)	1.36	1.08	1.238	0.10
Angle of repose	35	28	30.4	2.21
Static coefficient of friction on metal sheet	0.715	0.406	0.561	0.082

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Machine Performance

The results of the performance test analyses are presented in Table 2 and Figures 3, 4, 5, 6 and 7 respectively. Table 2 shows that moisture content significantly affected the quantity of shelled pods at 1% level of significance. The effect of moisture content on the shelling efficiency at various feed rates is shown in Figure 3. From this figure, it can be seen that the shelling efficiency decreased with increase in moisture content at each of the feed rates employed. It also decreased with increase in feed rate at any moisture level within the studied range. As a result of the above trend, the maximum shelling efficiency of 80% was obtained at the lowest moisture content and feed rate of 5% (wb) and 93.6kg/h respectively. The relationship existing between the shelling efficiency, moisture content and feed rates could be expressed by the following regression equation.

$$E_s = 137.892 - 8.994M - 1.954 \times 10^{-2}F - 3.04 \times 10^{-4}MF + 0.118M^2 + 1.492 \times 10^{-4}F^2$$
$$(R^2 = 0.89) \tag{7}$$

where M = Moisture content, % (wb) and F = Feed rate, kg/h.

The moisture content was found to make the strongest unique contribution to the shelling efficiency. The t-test of the coefficients showed that the F, MF, M^2 and F^2 terms did not make statistically significant unique contribution to the equation.
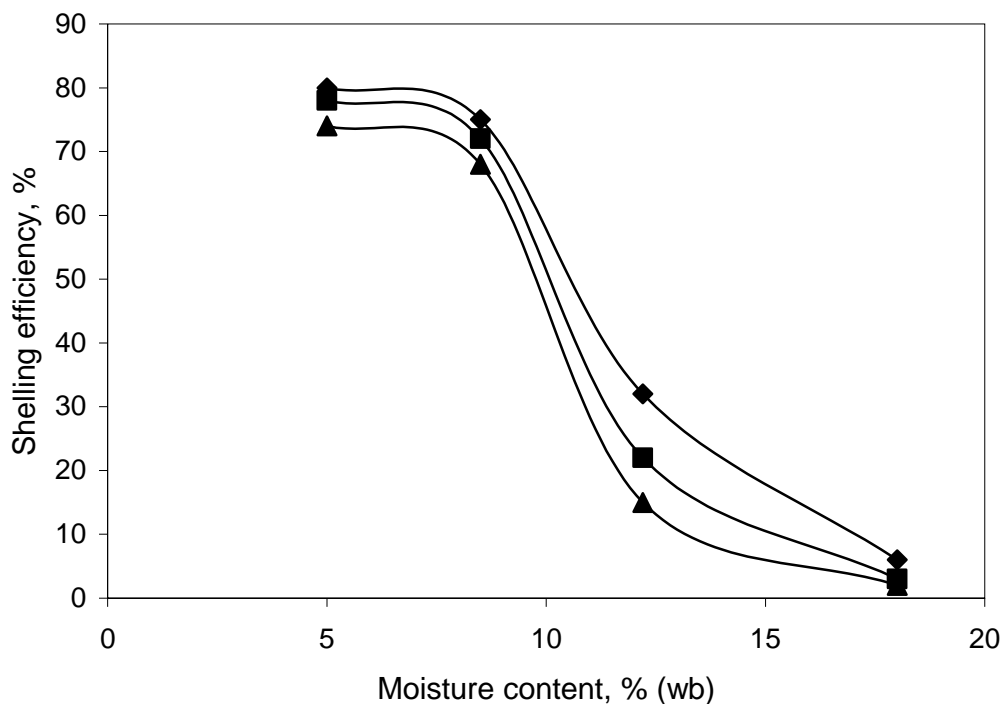
**Figure 4: Effect of moisture content on shelling
efficiency at various feed rates**

| ◆ 93.6 kg/h | ■ 187.2 kg/h | ▲ 374.4 kg/h |

The result of the ANOVA of shelled pods with unbroken seeds presented in Table 2 shows that moisture content; feed rate and the interaction between them all have significant effects on the quantity of shelled pods at 1% level. Although the effect of feed rate and its interaction with moisture content reached statistical significance, the actual size of their effect was found to be smaller than that of moisture content.

Table 2 also shows that moisture content, feed rate and the interaction between them had significant effects on the quantity of damaged seeds at 1% level of significance. The percentage seed damage increased with increase in moisture content to a maximum value and decreased with further increase in moisture content (Figure 5). Figure 5 also shows that at lower moisture levels, the percentage damage increased with increase in feed rate but at higher moisture levels, it decreased with increase in feed rate. Bambara groundnut seeds are likely to be brittle at low moisture contents and this may have caused them to be susceptible to mechanical damage. Also, the seed size may have increased with moisture content leading to increase in damage at constant roller clearance.

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Table 2: F – ratio for the results of performance tests

Source of variation	F - ratio				
	Shelled pods with unbroken seeds	Shelled pods but with broken seeds	Partially shelled pods	Unshelled pods	Winnowed chaff
Moisture content M	21957.61*	2926.1*	18930.1*	1181.78*	41068.3*
Feed rate F	363.85*	83.3*	518.11*	286.74*	2075.63*
Interaction M*F	93.59*	345.23*	18.53*	10.6*	165.64*

* significant at 1%
** significant at 5%

As the moisture content continued to increase, a moisture level must have been attained at which the effect of moisture content on the seed size was no longer significant with the seed becoming more visco-elastic. This could have been responsible for the decrease in seed damage recorded after certain moisture levels were exceeded. The relationship existing between percentage damage and moisture content and material feed rate could be expressed by the equation

$$P_d = 0.862 + 6.532M + 2.623 \times 10^{-2}F – 4.40 \times 10^{-3}MF – 0.322M^2 + 1.744 + 10^{-5}F^2$$

$$(R^2 = 0.802) \tag{8}$$

The moisture content made the strongest unique contribution to the percentage of seed damage, while the constant, F, MF and F2 terms did not make statistically significant unique contributions to the equation.
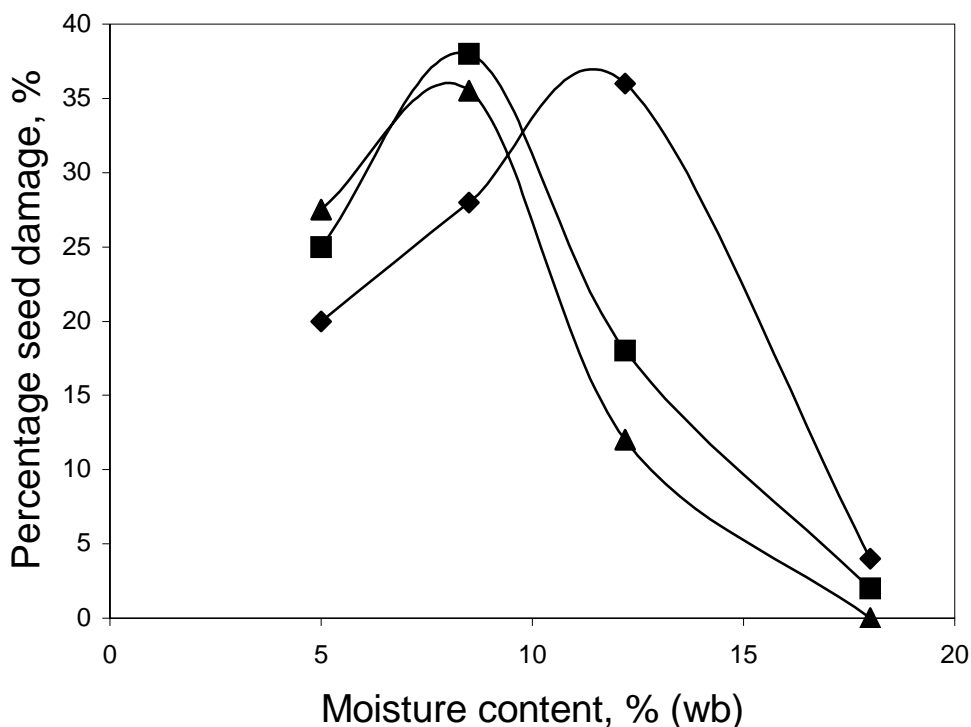
**Figure 5: Effect of moisture content on percentage
seed damage at various feed rates**

| ◆ 93.6 kg/h | ■ 187.2 kg/h | ▲ 374.4 kg/h |

The quantities of partially shelled and unshelled pods were both significantly affected by moisture content, feed rate and the interaction between them at 1% level of significance (Table 2). The results presented in Figures 6 and 7 respectively show that the percentage of partially shelled and unshelled pods increased with increase in both moisture content and feed rate. This is quite unexpected since bambara groundnut size is expected to increase with increase in moisture content, and the roller clearance was kept constant. The above results may be attributable to some extraneous factors. The clearance between the rollers may not have remained constant throughout the duration of the shelling operation and the shelling bars may have undergone some deformation with time. The speed of machine operation could be another factor that contributed to the above results. However, the relationship existing between the percentages partially shelled and unshelled pods, moisture content and material feed rate can be expressed with the following equations:

$$P_{ps} = -35.188 + 6.36M + 0.1F + 5.178 \times 10^{-4}MF - 5.63 \times 10^{-2}M^2 - 1.61 \times 10^{-4}F^2$$

$$(R^2 = 0.90) \tag{9}$$

$$P_u = -12.135 + 2.826M + 6.206 \times 10^{-2}F + 6.967 \times 10^{-4}MF - 8.43 \times 10^{-2}M^2 - 1.04 \times 10^{-4}F^2$$

$$(R^2 = 0.74) \tag{10}$$

The moisture content made the strongest unique contribution to equations 9 and 10, while the F, MF, M2 and F2 terms for equation 9 and the F, MF and F2 terms for equation 10 did not make statistically significant unique contributions.
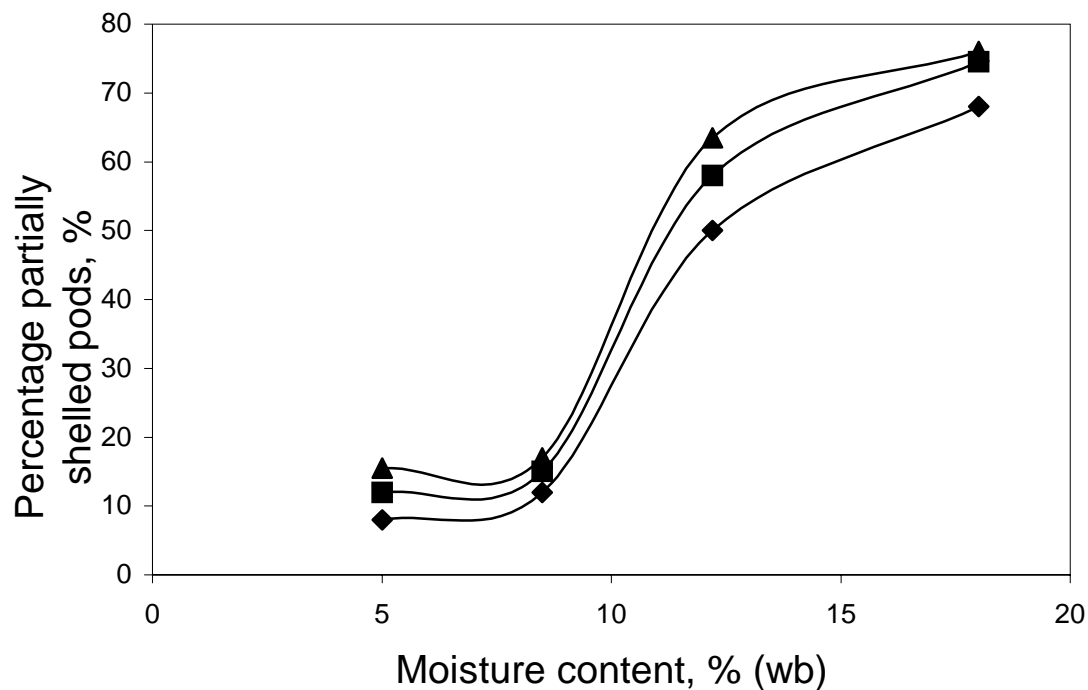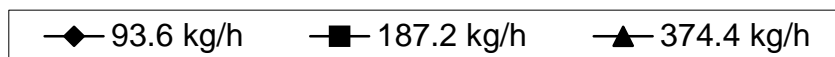

Figure 6: Effect of moisture content on percentage partially shelled pods at various feed rates
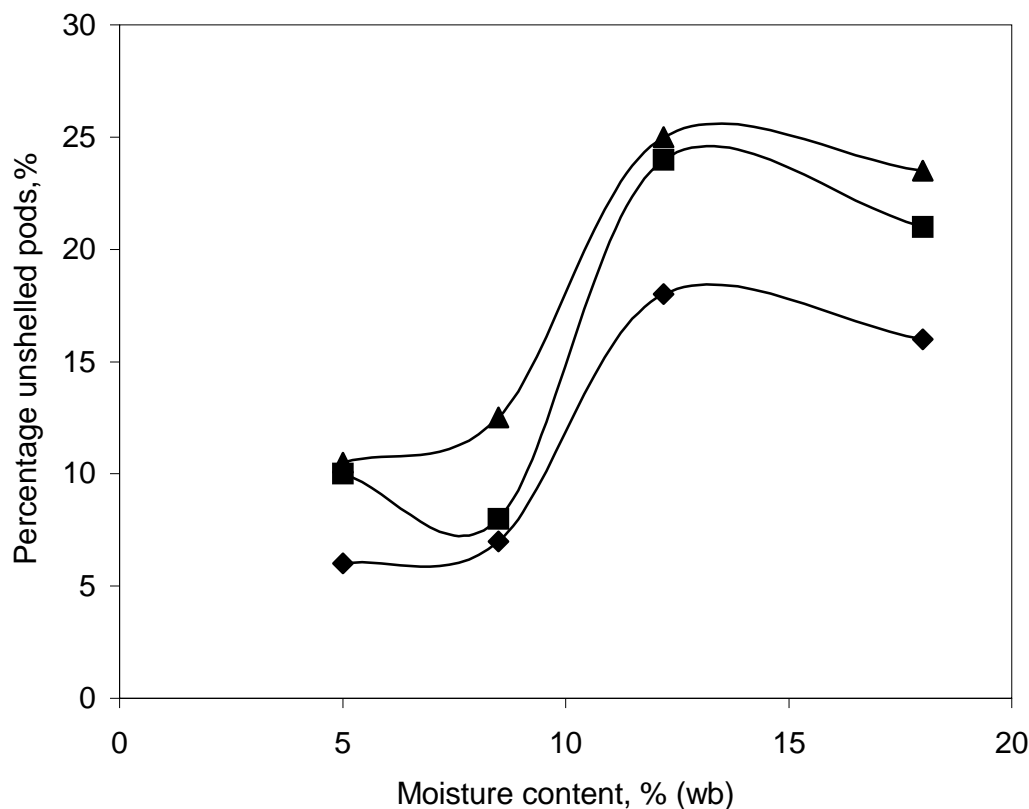
$\blacklozenge$ 93.6 kg/h $\blacksquare$ 187.2 kg/h $\blacktriangle$ 374.4 kg/h

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**Figure 7: Effect of moisture content on
percentage unshelled pods at various feed rates**

The pod moisture content, material feed rate and the interaction between them significantly affected the quantity of winnowed chaffs at 1% level of significance (Table 2). The winnowing efficiency presented in Figure 8 decreased with increase in moisture content and feed rate. Increase in moisture content may have resulted in increase in shell bulk density, which in turn could have increased its resistance to pneumatic transportation. Increase in feed rate must have increased the weight of the material being handled by the air stream and decrease in winnowing efficiency must have resulted from inadequacy of the air pressure supplied to convey the materials away. For the above reason, a blower of adjustable speed would be suitable for use in this type of shelling equipment. The relationship existing between the winnowing efficiency, moisture content and material feed rate can be expressed by the following equation:

$E_w = 143.509 - 10.112M - 0.188F - 1.79 \times 10^{-4} + 0.218M^2 + 3.206 \times 10^{-4}F^2$

$(R^2 = 0.89)$ (11)

Again, the moisture content made the strongest unique to the equation and the F, MF and F2 terms did not make statistically significant unique contributions.
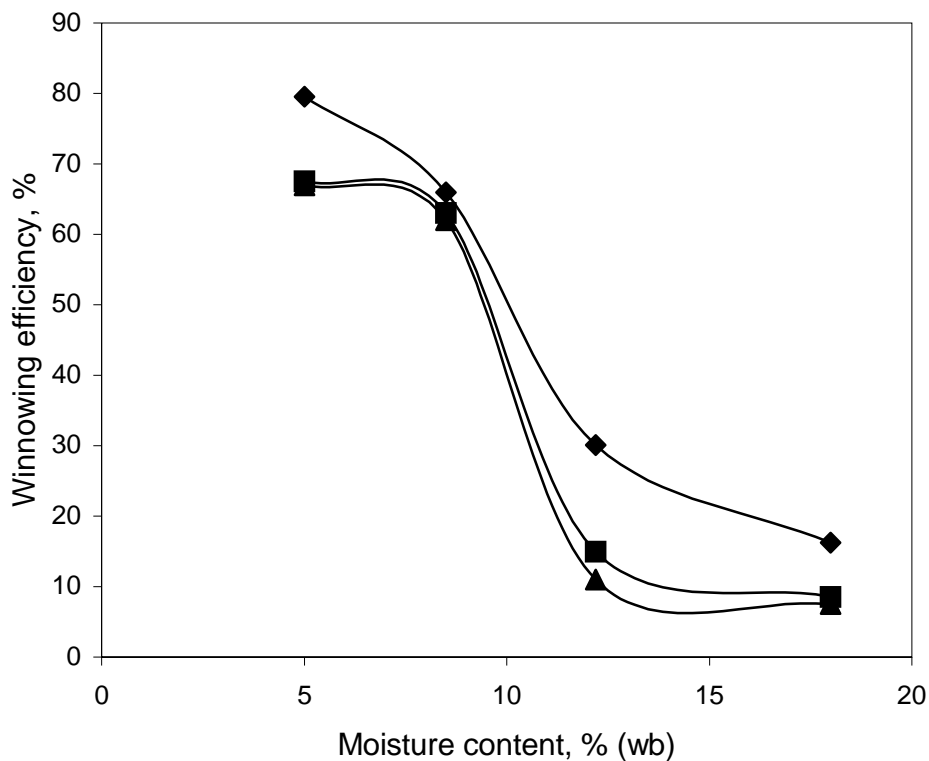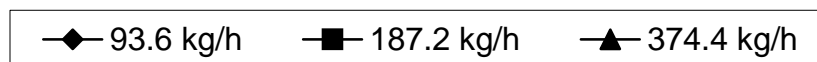

Figure 8: Effect of moisture content on the winnowing efficiency

--- 93.6 kg/h --- 187.2 kg/h --- 374.4 kg/h

Conclusions

The performance evaluation of bambara groundnut sheller operating by means of roller mechanism showed that moisture content, material feed rate and the interaction between them had significant effect on the performance indices. Shelling and winnowing efficiencies decreased with increase in moisture content, percentage damage increased to a maximum and decreased, and the percentages partially shelled and unshelled pods increased with increase in moisture content. The relationship existing between the performance indices and moisture content were found to be adequately expressed by regression equations. Maximum shelling and winnowing efficiencies of 80% and 79.5%

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were obtained. The machine has a compact design and robust building. It will contribute to the enhancement of Bambara groundnut processing as it could replace the present manual methods of shelling the pods, which are very tedious.

In order to improve the performance of the Bambara groundnut sheller, the working components would be modified and assembled to withstand the stresses of the shelling operation over time. A roller clearance adjustment device and blower with variable fan speed would be incorporated. Tests would be conducted at different roller clearances, operational speeds and winnowing air velocities with different Bambara groundnut varieties at different moisture contents and material feed rates. An optimization technique would be used to determine the parametric combinations that would yield the optimum machine performance. The machine would be subjected to varying length of operational time to test for endurance.

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