

Evaluation of Some Centrifugal Impaction Devices for Shelling Bambara Groundnut

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ABSTRACT

A bulk quantity of bambara groundnut pods (milk coloured) was purchased from a local farmer in Damboa, Borno State, Nigeria. The pods were prepared for experiment by cleaning and varying their moisture content to have three different moisture levels (5.3, 9.6 and 12.2% db). Three groups of impellers (forward facing, radially positioned and backward facing) each group with three different number of slots (eight slots, four slots and two slots) were used for the shelling of the pods. One hundred pods were randomly selected from each pod sample and introduced into the centrifugal cracker. This was replicated five times for each impeller at the three moisture levels. Results of the tests carried out were examined using 3x3x3 factorial design with moisture content, number of impeller slots and impeller slot angulations as variables. Results showed that the forward facing impeller with eight numbers of slots gave 96% effective shelling efficiency, 3.4% breakage and 0.6% partially shelled pods at an average feed rate of 215.8 kg/h, and impeller speed of 1900 rpm.

Keywords: Cracking, bambara groundnut, moisture content, sheller, impaction device, shelling efficiency, pods, Nigeria.

1. INTRODUCTION

Bambara groundnut (*Vigna subterranean (L) Verdc*) is an indigenous African crop grown across the continent from Senegal to Kenya and from the Sahara to South Africa (Atiku *et al.*, 2004). Bambara groundnut is the third most important grain after groundnut and cowpea (Ezeaku, 1994). In separate reports by Ezue (1977) and Atiku (2000) it was noted that in Nigeria bambara groundnut are widely produced in Borno, Anambra, Plateau, Taraba, Sokoto, Bauchi, Benue, Kano, Yobe, Adamawa and Gombe states.

Goli (1997) reported that bambara groundnut contains about 63% carbohydrate, 19% protein, and 6.5% oil and is consumed in different forms. In separate reports by Akani *et al.* (2000), Atiku (2004) and Linnemann (1988) the seed of bambara groundnut is used for baby food, human consumption, industrial products and for animal feed. 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. According to Atiku (2000) the fresh bambara groundnut

seed is cooked before eating. It is used as main food, snacks, relish and medicine and has high ceremonial value.

Kay (1979) recommended that bambara groundnut should be dried in the sun to about 8 to 12% moisture content (wb) after harvesting, the dried seed could be taken as snacks after roasting or milled to flour for the production of other food.

Despite the economic importances, no commercial production and no industrial use of the crop take place in Nigeria. According to Akani *et al.* (2000) research is concentrated only on the agronomic aspect, while the processing aspects have been neglected. The pod of bambara groundnut is very hard and the cracking methods are still traditional. These cracking methods vary from locality to locality depending on the quantity produced. Some communities use mortar and pestle to crush the dry pods, some beat with sticks on flat ground, while others use stones to crush on flat ground. These methods have the disadvantages of damaging the seeds, slow and tiresome.

Atiku *et al.* (2004) carried out a performance evaluation of a bambara groundnut sheller working on the principle of rollers and pneumatically separating the shells from the seeds. They got the maximum shelling and winnowing efficiencies of 60% and 79.5% respectively at pod moisture content of 5% (wb) and feed rate of 93.6 kg/h. The percentage of seed damage was about 20%, while the percentage of partially shelled (broken and unbroken seeds) and percentage of unshelled pods were 10% and 7% respectively, while machine lost accounted for 3%. Oluwole *et al.* (2007) evaluated the effect of moisture content on shelling ability of bambara groundnut using a centrifugal cracker at three moisture levels (5.3, 9.6 and 12.2% (db) and found that the most effective performance was obtained at moisture content of 5.3% (db).

Adigun and Oje (1993) reported that nuts whose shells/pods cannot be easily broken by the roller cracker are easily cracked using centrifugal cracker. Makanjuola (1975) evaluated some centrifugal impaction devices for shelling melon (egusi) seeds and found that a centrifugal impact method is a good technique for shelling melon seeds. He evaluated three types of impellers with four slots, eight slots and two parallel plates respectively. He concluded that the impeller with four slots is the most effective of all the three types tested. Odigboh (1979) developed and tested an impact egusi (melon) shelling machine that gave about 96% shelling efficiency and 100% winnowing efficiency. He also evaluated three types of impellers positioned at different vane angulations (radial vane impeller, impeller with vane positioned at 45° to the radius and impeller with vane positioned at 90° to the radius) with four vanes each. He concluded that impeller with vane positioned at 45° to the radius gave the best combination of higher shelling and low percentage of damage. Audu *et al.* (2004) developed a concentric cylinder locust bean dehuller.

Oluwole *et al.* (2004) developed and tested a sheanut cracker working on the principle of impaction and pneumatically separating the shells from the kernel. They evaluated three types of impeller similar to that of Odigboh but with slight different in the vanes angulations. Radial vanes impeller, impellers with vanes positioned at 45° and 30° to the radius respectively and concluded that the radially positioned vanes impeller gave 100% effective cracking efficiency

and winnowing efficiency of 97%. Akani *et al.* (2000) determined the optimum impact energy for shelling bambara groundnut at pod moisture content range of 5 – 8% (wb) and found that the impact energy ranged from 0.24 J to 0.59 J.

This paper presents the results of applying nine different types of impellers to evaluate the effect of moisture content, impeller vane angulations and number of impeller vanes on the shelling ability of a centrifugal sheller on bambara groundnut.

2. MATERIALS AND METHODS

A bulk quantity of bambara groundnut pods (milk coloured) were cleaned and sampled for experiment using a multi-slot riffle box divider. The moisture content of the pods was varied to have three moisture levels using the methods reported by Aviara *et al.* (2002), Oluwole *et al.* (2004) and Ajibola *et al.* (1990). This method involved the soaking of a bulk quantity of the pods in ordinary water at room temperature for different periods of time. 60 minutes for the first sample and 90 minutes for the second sample while the third sample was retained at the stable moisture content as a control sample. The soaked 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 24 hours. This enables stable and uniform moisture content of the pods to be achieved in the bags.

The moisture content of each sample was determined using the method described by ASAE (1983), Oje (1993) and Ajibola *et al.* (1990). The method involved oven drying of pod samples at 130°C with weight loss monitored on hourly basis to give an idea of the time at which the weight began to remain constant. After oven drying for 6 hours, the pods were weighed using an electronic balance weighing to 0.001 g to determine the final weight. The moisture content was determined using the formula (Oluwole *et al.* (2004):

$$Mc = [(W_i - W_f) / W_f] \times 100 \% \text{ (db)} \quad [1]$$

Where Mc = moisture content, %

W_i = initial mass of pods, g

W_f = final mass of pods, g

db = dry basis

This was replicated three times for each sample and the average values were determined.

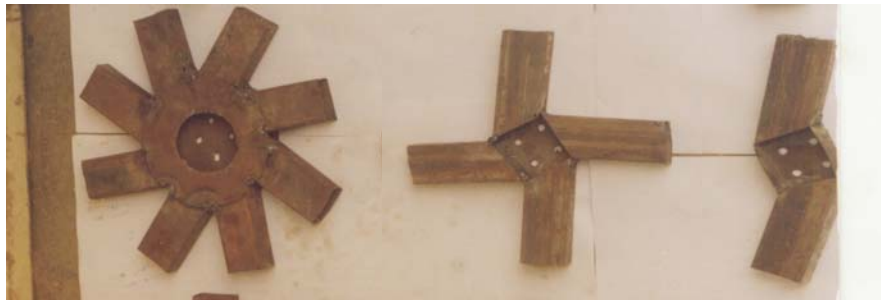
3. DESCRIPTION OF THE IMPACTION DEVICE

The device similar in principle to Odigboh's impact egusi Sheller (Fig. 1) consists of a feed hopper, pod shelling unit and power unit. The conical shaped hopper is mounted on the tool frame and held in place by a hopper support frame. The base is connected directly to the shelling unit. The shelling unit consists of a 410 mm diameter by 150 mm height cylindrical shell made from 5 mm steel sheet, whose inner surface serves as a cracking surface and an impeller made of 25 mm by 50 mm rectangular steel pipe similar to that described by Dicken (1961) as shown in Figure 2. Figure 3 shows the schematic diagram of the impellers. The cylindrical shell is covered with a transparent plastic cover 400 mm diameter of 4 mm thickness with a concentric opening (80 mm diameter) at the center that serves as pods inlet. The impeller is concentrically positioned

within the cylindrical shell and horizontally mounted on a vertical shaft to give a clearance that is greater than the size of the seed with cracking surface. Figure 4 shows the assembly details of the machine and its parts list. This impeller is driven by a vertical shaft powered by a 0.5 hp, 1920 rpm electric motor through a system of belt and pulley. The arrangement gave an impeller speed of 1900 rpm.



Figure 1: The impaction device



i

ii

iii

Figure 2a: Group F- Forward facing impellers i-8 slots ii-4 slots iii- 2 slots

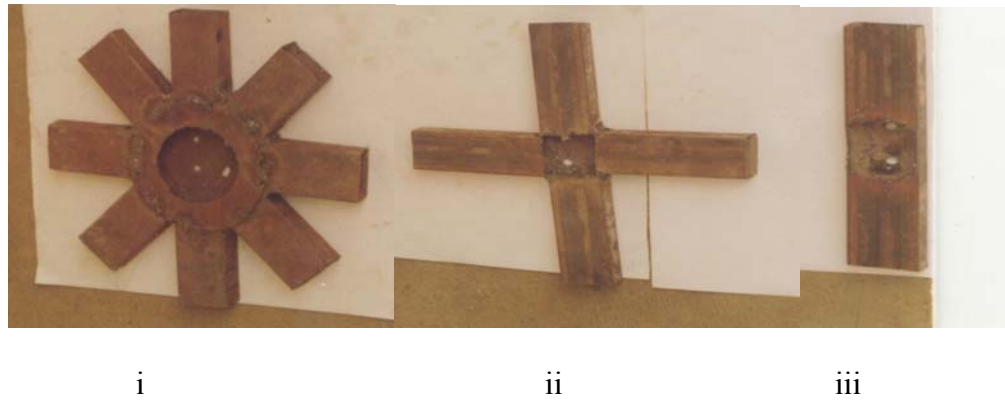


Figure 2b: Group R- Radially positioned impellers i-8 slots ii-4 slots iii- 2 slots

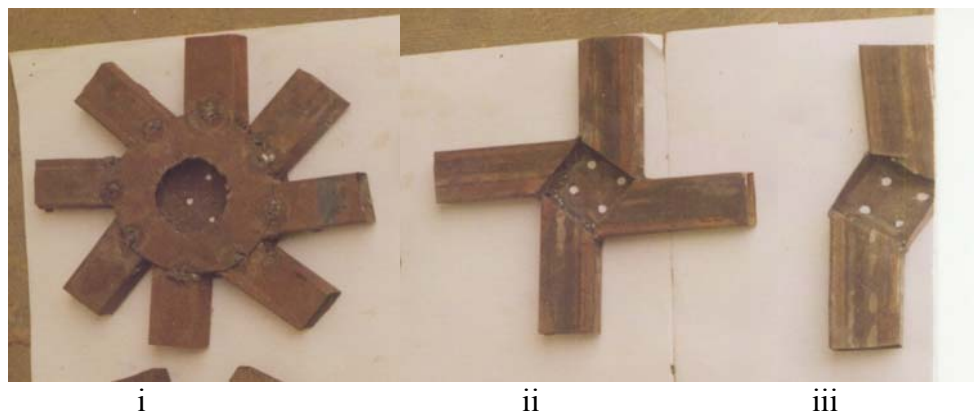


Figure 2c: Group B- Backward facing impellers i-8 slots ii-4 slots iii- 2 slots

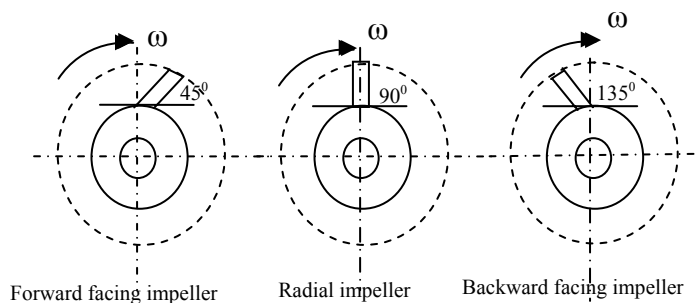


Figure 3. Schematic diagram of the impellers

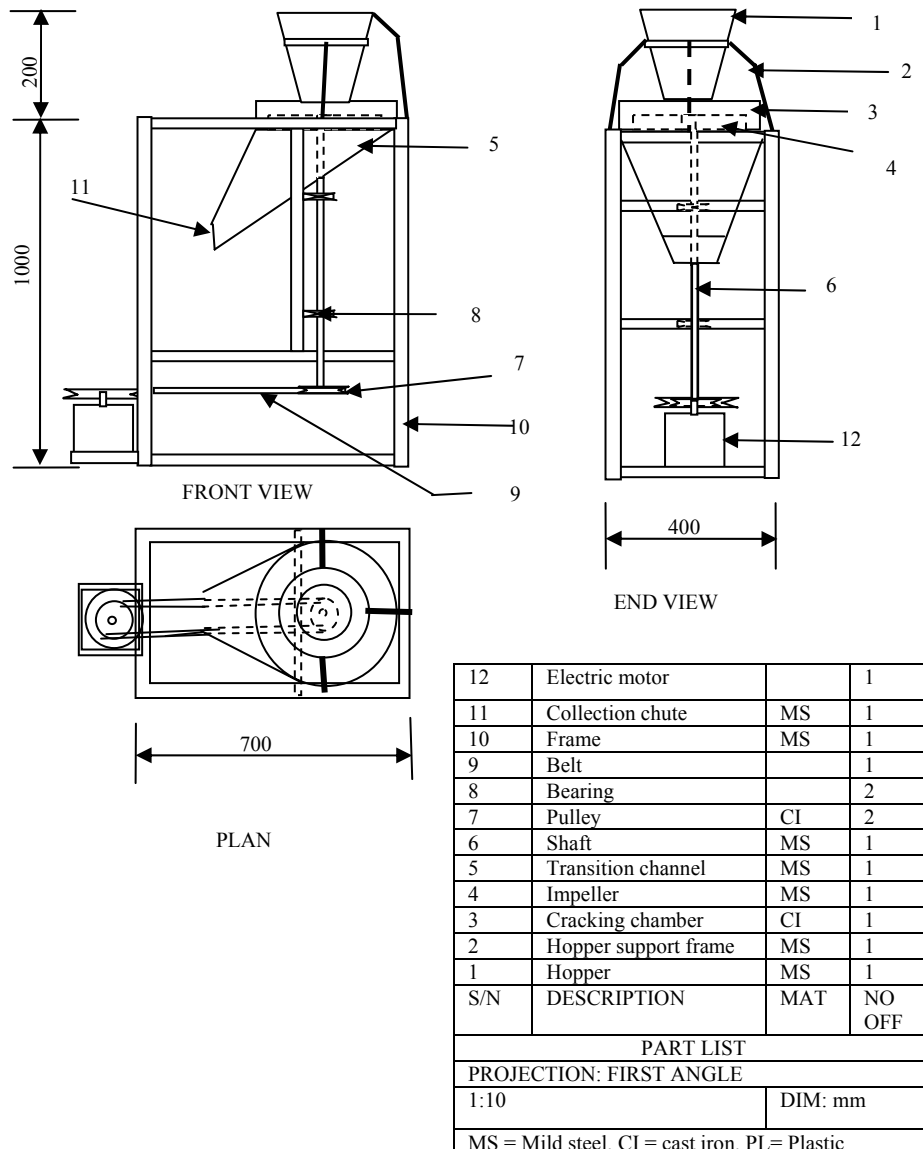


Figure 4. Centrifugal Impaction device and Part List

3.1 Principle of Operation

To operate the device, the nut flow control device is closed completely. The hopper is then filled with a known number and mass of nuts. The main switch is then switched on to actuate the electric motor, which runs the impeller in the cracking chamber. As the impeller reaches its operating speed, the nut flow control device is opened to allow nuts to flow into the impeller eye (pods inlet). The incoming nuts slide and roll on the inner surface of the rectangular pipe, the centrifugal force developed as a result of the rotation of the impeller throws the nuts against the

cracking surface and causes the nuts to crack. The seeds and the shelled pods flow down through the clearance between the impeller and the cylindrical shell and fall on an inclined transition channel that leads to the collection outlet. Figure 5 shows the impeller mounted in the operational position.



Figure 5 Impeller mounted in the operational position

4. EXPERIMENTATION

To carry out the experimentation, a preliminary test was conducted by varying the speed of the impeller to get the optimum speed that will give the best result. At the end of the test, impeller speed of 1900 rpm gave the best performance. Nine types of impellers were evaluated. These impellers were divided into three groups. Group F: forward facing impeller with slots positioned at 45° to the tangent; Group R: radially positioned impeller and Group B: backward facing impeller with slots positioned at 135° to the tangent. Each group has impellers with eight slots, four slots and two slots. Each of these impellers was used to shell Bambara groundnut at three different moisture levels (5.3, 9.6 and 12.2% db). 100 pods were randomly selected and weighed. These pods were poured into the hopper while the pods flow control was completely closed. The main control switch was switched on, as the impeller attains the operating speed, the pod flow control was opened to allow the pods to flow into the eye of the impeller at an average feed rate of 215.8 kg/h. These pods were carefully collected after going through the impeller and grouped into four as follows:

- a. pods fully shelled without broken kernels, N_1
- b. pods fully shelled with broken kernels, N_2
- c. pods partially shelled, N_3
- d. unshelled pods, N_4

Each of these tests was replicated five times at each moisture level. The performance was evaluated on the basis of the following indices:

- i. percentage of effective shelling, $\eta_s = (N_1/N_0) \times 100$ [2]
- ii. percentage of broken kernel, $\eta_b = (N_2/N_0) \times 100$ [3]

- iii. percentage of partially shelled pods, $\eta_p = (N_3/N_0) \times 100$ [4]
- iv. percentage of unshelled pods, $\eta_u = (N_4/N_0) \times 100$ [5]
- v. shelling efficiency, $\eta_{ST} = [(N_1 + N_2)/ N_0] \times 100$ [6]

where N_0 = number of pods fed into the impeller
 These results were statistically analysed using factorial design.

5. RESULTS AND DISCUSSION

Tables 1 and 2 show the results of the performance test. Table 3 shows the results of applying Duncan Multiple Range Test (DMRT) to the mean of effect of moisture content on the performance indicators. Table 2 shows that the three main effects: moisture content (M), number of slots (F) and impeller angulations (S) affected the shelling efficiency (η_s), percentage breakage (η_b), percentage partially shelled pods (η_p) and percentage of unshelled pods (η_u) at significant level of 5%. Also interaction between moisture content and number of slots, and interaction between moisture content and impeller angulations affected the shelling efficiency (η_s) and percentage partially shelled pods (η_p) at 5% level of significant. It can be seen from Table 3 that moisture content significantly affected all the performance indicators at 5% level with moisture content of 5.3% (db) having the highest percentage of fully shelled pods (77.96%) and the least percentages of partially shelled and unshelled pods (6.64% and 12.78% respectively). It was also observed that the percentage of fully shelled pods and percentage broken seeds decreased with increase in moisture content while the percentage of partially shelled pods and percentage of unshelled pods increased with increase in moisture content. This may be attributed to the earlier report by Atiku *et al.* (2004) that at low moisture content bambara groundnut pod is brittle and susceptible to mechanical damage.

Table 1: Results of the performance test

Impeller type	Shelling efficiency (η_s)	Percentage of breakage (η_b)	Percentage of partially shelled pods (η_p)	Percentage of unshelled pods (η_u)
MOISTURE CONTENT (5.3 (db))				
S _{F8}	96.0 (1.414)	3.4 (1.517)	0.6 (0.548)	0.0 (0.000)
S _{F4}	83.4 (4.219)	3.4 (1.140)	4.4 (2.510)	8.6 (1.517)
S _{F2}	74.6 (2.702)	2.8 (0.447)	8.6 (2.510)	14.0 (4.416)
S _{R8}	86.6 (1.140)	3.6 (1.673)	5.6 (1.949)	4.2 (1.304)
S _{R4}	74.4 (3.362)	2.4 (0.548)	6.0 (2.121)	17.2 (4.087)
S _{R2}	64.8 (3.493)	2.2 (0.837)	11.4 (1.95)	21.6 (2.074)
S _{B8}	85.0 (1.581)	2.4 (1.140)	5.4 (1.140)	7.2 (1.304)
S _{B4}	73.2 (1.924)	2.0 (1.225)	5.2 (1.095)	19.6 (2.302)
S _{B2}	63.6 (2.608)	2.0 (0.707)	12.4 (1.673)	22.0 (2.915)
MOISTURE CONTENT (9.6 (db))				
S _{F8}	77.8 (2.864)	2.4 (1.140)	7.8 (1.095)	12.0 (2.915)
S _{F4}	67.4 (2.408)	2.0 (0.707)	11.0 (6.00)	19.6 (1.140)
S _{F2}	62.2 (2.588)	1.6 (1.517)	14.0 (1.225)	22.2 (1.483)
S _{R8}	69.0 (0.707)	2.4 (1.517)	9.4 (1.140)	19.2 (1.304)
S _{R4}	60.2 (2.280)	1.0 (1.000)	11.8 (1.483)	27.0 (2.000)
S _{R2}	51.4 (2.702)	0.8 (0.447)	15.4 (2.881)	32.4 (1.517)
S _{B8}	66.0 (2.000)	1.8 (0.837)	8.4 (3.05)	23.8 (3.633)
S _{B4}	61.2 (4.266)	0.6 (0.548)	12.8 (1.924)	25.4 (3.647)
S _{B2}	51.0 (1.000)	0.6 (0.548)	17.4 (2.881)	31.0 (3.000)
MOISTURE CONTENT (12.2 (db))				
S _{F8}	62.0 (1.581)	1.2 (0.447)	13.8 (2.588)	23.0 (3.000)
S _{F4}	55.4 (2.702)	0.4 (0.548)	15.6 (1.517)	28.6 (3.715)
S _{F2}	49.4 (2.408)	0.4 (0.548)	17.2 (0.837)	33.0 (2.540)
S _{R8}	59.2 (0.837)	0.8 (0.447)	12.4 (1.817)	27.6 (1.673)
S _{R4}	52.6 (3.912)	0.6 (0.548)	12.2 (2.490)	34.6 (3.782)
S _{R2}	42.0 (2.739)	0.2 (0.447)	14.4 (2.074)	43.4 (4.506)
S _{B8}	56.8 (1.643)	0.6 (0.548)	13.0 (2.646)	29.6 (1.517)
S _{B4}	52.2 (2.683)	0.4 (0.548)	13.2 (2.588)	34.2 (2.588)
S _{B2}	40.4 (1.140)	0.2 (0.447)	13.6 (1.673)	45.8 (1.924)

S_{F8}=Forward facing with 8 slots; S_{F4}=Forward facing with 4 slots; S_{F2}=Forward facing with 2 slots; S_{R8}=radially positioned with 8 slots; S_{R4}=radially positioned with 4 slots; S_{R2}=radially positioned with 2 slots; S_{B8}=Backward facing with 8 slots; S_{B4}=Backward facing with 4 slots; S_{B2}=Backward facing with 2 slots

Values in parentheses represent standard deviations

Table 2: F-ratio for the performance tests

Source of variation	Shelling efficiency (η_s)	Percentage breakage (η_b)	Percentage partially shelled pods (η_p)	Percentage of unshelled pods (η_u)
<u>Main effects:</u>				
Moisture content (M)	1181.73*	69.55*	157.64*	50.90*
Number of Slots(F)	564.37*	13.01*	77.93*	20.22*
Impeller Angulation(S)	148.86*	7.98*	3.43*	11.32*
<u>Two-factor Interaction:</u>				
M*F	8.12*	0.814	9.06*	0.76
M*S	5.21*	0.869	10.64*	0.09
S*F	2.37	0.61	1.32	0.28
<u>Three-factor Interaction:</u>				
M*F*S	0.88	0.49	1.34	0.16

*significant at 5% level

Table 3: Effect of moisture content on performance Indicators

Moisture Content % (db)	Shelling efficiency (%) (η_s)	Percentage breakage (%) (η_b)	Percentage partially shelled pods (%) (η_p)	Percentage of unshelled pods (%) (η_u)
5.3	77.96 ^a	2.692 ^a	6.64 ^c	12.78 ^c
9.6	62.64 ^b	1.42 ^b	11.87 ^b	23.47 ^b
12.2	52.22 ^c	0.53 ^c	13.96 ^a	33.20 ^a

Values in the same vertical column with the same superscript letters are not significant at 5% level

Table 4 presents the results of applying DMRT to the mean of effect of number of slots on the performance indicators. It was observed that the effect is significant at 5% level on all the performance indicators. It can also be seen that the percentage of fully shelled pods and percentage of broken seeds decreased as the number of slots reduce while the percentage of partially shelled pods and percentage of unshelled pods increased as the number of slots reduce. This may be so because the impeller slots served as vanes, and the higher the number of slots the more the exit points, and the tendency for well distributed impaction force, allowing higher number of pods to hit the cracking surface with the required impact energy.

Table 4: Effect of number of slots on performance Indicators

Number of (%)	Shelling efficiency (%) (η_s)	percentage breakage shelled pods (%) (η_b)	Percentage partially shelled pods (%) (η_p)	Percentage of unshelled pods (%) (η_u)
S ₈	73.16 ^a	2.07 ^a	8.51 ^c	16.40 ^c
S ₄	64.40 ^b	1.42 ^b	10.24 ^b	23.82 ^b
S ₂	52.22 ^c	1.16 ^c	13.96 ^a	33.20 ^a

Values in the same vertical column with the same superscript letters are not significant at 5% level

Moreover, Table 5 shows the results of applying DMRT to the mean of effect of slot angulations on the performance indicators. This effect is significant at 5% level. This table indicates that the forward facing slots gave the highest shelling efficiency and highest percentage breakage, with lowest percentages of partially shelled and unshelled pods. This might be so because the impeller angulations influenced the impact velocity of pods emerging from the impeller.

Table 5: Effect of slots angulation on performance Indicators

Slot angulation	Shelling efficiency (%) (η_s)	Percentage breakage (%) (η_b)	Percentage partially shelled pods (%) (η_p)	Percentage of unshelled pods (%) (η_u)
F	69.53 ^a	1.919 ^a	10.20 ^b	17.62 ^b
R	62.24 ^b	1.56 ^b	11.00 ^{ab}	25.36 ^a
B	61.04 ^c	1.18 ^c	11.27 ^a	26.47 ^a

Values in the same vertical column with the same superscript letters are not significant at 5% level

Tables 6 and 7 show effects of two-factor interaction on the performance indicators. From Table 6 it can be seen that interaction between moisture content and number of slots affected the percentages of fully shelled and partially shelled pods at 5% level. Combination of moisture content of 5.3 % and impeller with eight slots gave the best performance, at this moisture content the pod is brittle and the number of slots is high allowing higher number of pods to hit the cracking surface. Table 7 shows that interaction between moisture content and slot angulations affected the percentages of fully shelled and partially shelled pods at 5% level. This may be so because the impeller angulations have influence on the impact velocity of pods emerging from the impeller and moisture content has effect on the physical properties of the pods. However these interactions did not have significant effect on the percentages of breakage and unshelled pods.

Table 6: Effect of interaction between moisture content and number of slots on performance indicators

Moisture content X number of	Shelling efficiency (%) (η_s)	Percentage breakage (%) (η_b)	Percentage partially shelled pods (%) (η_p)	Percentage of unshelled pods slots (%) (η_u)
M ₁ *S ₈	89.20 ^a	3.12	3.86 ^c	4.00
M ₁ *S ₄	77.02 ^b	2.61	5.21 ^f	15.16
M ₂ *S ₈	70.93 ^c	2.20	8.42 ^e	18.52
M ₁ *S ₂	67.67 ^d	2.33	10.87 ^d	19.20
M ₂ *S ₄	62.80 ^e	1.22	11.87 ^c	24.10
M ₃ *S ₈	59.33 ^f	0.87	13.13 ^b	26.53
M ₂ *S ₂	54.20 ^g	0.87	15.20 ^a	27.73
M ₃ *S ₄	53.40 ^g	0.47	13.67 ^b	32.33
M ₃ *S ₂	43.93 ^h	0.27	15.07 ^a	40.73

Values in the same vertical column with the same superscript letters are not significant at 5% level

Table 7: Effect of interaction between moisture content and slot angulation on performance indicators

Moisture content X impeller angulations	Shelling efficiency (%) (η_s)	Percentage breakage (%) (η_b)	Percentage partially shelled pods (%) (η_p)	Percentage of unshelled pods (%) (η_u)
M ₁ *F	84.67 ^a	3.20	4.53 ^e	7.53
M ₁ *R	75.27 ^b	2.73	7.73 ^d	14.53
M ₁ *B	73.93 ^c	2.13	7.67 ^d	16.27
M ₂ *F	68.33 ^d	1.87	10.53 ^c	17.13
M ₂ *R	60.20 ^e	1.40	12.20 ^b	26.53
M ₂ *B	59.40 ^e	1.00	12.87 ^b	26.73
M ₃ *F	55.60 ^f	0.67	15.53 ^a	28.20
M ₃ *R	51.27 ^f	0.53	13.07 ^b	35.00
M ₃ *B	49.80 ^g	0.40	13.27 ^b	36.40

Values in the same vertical column with the same superscript letters are not significant at 5% level

It was generally observed that the forward facing impeller with eight slots gave the best effective shelling efficiency of 96.0%, though the percentage of damage was 3.4% it was compensated for by the percentage of partially shelled pods amounting to 0.6% at the moisture content of 5.3% (db) and impeller speed of 1900 rpm.

6. CONCLUSION

The results of the study using the centrifugal impaction devices show that moisture content, number of impeller slots and impeller slot angulations significantly affected the performance indicators.

Shelling efficiency and percentage of damage decreased with increase in moisture content, while percentages of partially shelled and unshelled pods increased with increase in moisture content.

Generally impellers with eight slots gave the best performance at the three moisture contents for the three slot angulations employed.

In conclusion, a centrifugal impaction method can be used effectively to shell bambara groundnut at the pods stable moisture content of 5.3% (db). The development of a centrifugal impact bambara groundnut Sheller with winnower is suggested for further reduction in the drudgery of the manual processing of bambara groundnut.

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