Development of a Snake Gourd Seed Decorticating Machine

D. O. Idowu[1*] and O. K. Owolarafe[2]

[1]Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria.
[2]Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

Authors' contributions

This work was formulated and supervised by author OKO but all the experiment was carried out by author DOI. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Aims: A snake gourd seeds sheller which comprises of hopper, decorticating chamber, and the cleaning chamber was designed, fabricated and evaluated in this study.

Methodology: A 3-level factorial response surface methodology (RSM) of design expert version 6.0.8 of 2002 was used to identify the relationship between the response functions and the process variables of the device. The factors considered are shaft speed (300, 350, 400 rpm), soaking time (8, 15, and 20 minutes.), hammer diameter (115, 135 and 150 mm) and feed rate (90, 120, 150 kg/hr.) in the determination of shelling efficiency while air speed (2, 4, and 6 m/s) and angle of air injection (20, 40, 60^0) were used in the determination of cleaning efficiency.

Results: The shelling efficiency was observed to increase with increase in hammer speed, hammer diameter and soaking time but decreased with increase in machine feed rate. The maximum shelling efficiency of 97.61% was recorded when the soaking time is 20 minutes, hammer speed is 400 rpm, hammer diameter is 150 mm and feeding rate is 90 kg/hr. The cleaning efficiency increases with increase in air speed and angle of air injection. The cleaning efficiency of the machine was found to be 92.5 % when the angle of injection and air speed is 60^0 and 5.0 m/s respectively. The effect of the speed and the angle of injection was found to be significant ($p < 0.05$).

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*Corresponding author: Email: doidowu@lautech.edu.ng;

Conclusion: The study concluded that with the result of the performance evaluation of the machine, it is suitable for inclusion in the process line for the seed and hence its potential could be harnessed.

1. INTRODUCTION

Snake gourd (*Trichosanthes cucumenina* L.) commonly called snake tomato in Nigeria is a popular ornamental and food plant with medicinal compositions [1] which belongs to the botanical family *cucurbitaceae*. They are widely distributed all over the world with about 70 genera and over 700 species [2]. The fruit is long with deep green background [3]. The flowers are monoecions (individual flowers are either male or female, but both sexes can be found on the same plant) and are pollinated by insects.

Snake gourd fruit which contains oilseed is a valuable source of oil, protein, fat and vitamins [4]. It has been reported by [5] that the seed is a good source of nutrients containing crude protein (26.4 g/100 g), fat (50.9 g/100 g), phosphorous (79.75 g/100 g) and calcium (45.35 g/100 g) while the fruit pulp is a good source of ascorbic acid (23.2 mg/100 g). It is a biannual climber crop growing to 5 m at a fast rate. The plant could be planted twice in a year in an area with bimodal rainfall like the western Nigeria [6] early planting is April-July and late planting between August and November. It has been recorded that the early planting yielded better than the late planting. Studies by [6] recorded 1.0 m x 1.0 m seed spacing at planting and 2 plants per ridge with three times weeding between planting and harvesting.

The general demand for fats and oils increases with increasing population through discovery of new uses [7]. Vegetable oils which yield valuable product that are used in the manufacturing of many products, namely, building auxiliaries, candles, cleaning agents, cosmetics, detergents, fire-extinguishing agents, flotation agent, food emulsifiers, insecticides, lubricants, paints, paper production, pharmaceuticals etc. The global demand for vegetable oil has far exceeded production. It is becoming increasingly difficult to meet world demand for vegetable oil from traditional source of available oilseed. It has been confirmed that the seed contain about 57% oil [8] which is a good percentage compared to other oil seeds.

It is evident that acceptability of any oilseed for industrial use depends on the availability of appropriate technology for processing it. Shelling and cleaning has been identified as a major bottle neck in recommending snake gourd seed for large scale production. Currently, shelling of snake gourd seed as a preparatory step for oil extraction is done manually. Traditional (manual) method of shelling snake gourd seed is slow (time consuming), tedious, inefficient and energy consuming, thus debarring higher productivity. Therefore, to encourage mechanization of the crop and its industrial utilization, a shelling and cleaning machine is needed and this is addressed in this study.

2. MATERIALS AND METHODS

The material and the method used is as presented below

2.1 Sample Collection and Preparation

The snake gourd seeds were collected from Agricultural Engineering Demonstration Farm of the Ladoke Akintola University of Technology, Ogbomoso. Fully matured fruits (Plate 1) were harvested when ripe and soft. The seeds were separated from the pulp manually by washing it in clean water and later spread outside to dry for safe- keeping.

2.2 Physical Gravimetric and Frictional Properties of Snake Gourd Seed

Some physical, gravimetric and frictional properties of snake gourd seed that are required in the design of a functional snake gourd sheller which have been reported by [9] and [10] are seed mass, true density, bulk density, surface area, geometric diameter, sphericity, coefficient of friction, compressive energy etc. These were considered during the development of the machine.

2.3 Design of the Snake Gourd Sheller

The machine was designed to shell snake gourd seed, and also separate the kernel from the

chaff. The sheller was divided into six main parts which are hopper, decorticating unit, cleaning unit, discharge outlet, power unit and the frame. The machine was designed to use impact mechanism to separate the shell from the seed, and thereafter separate the broken shell and kernel based on size and aerodynamic properties of the kernel. The material flows from the hopper, where it is metered into the main shelling system. The mixture of shelled seeds and chaff are then dropped into the separating section where kernel and chaff are separated. The orthographic views and the assembly drawing of the snake gourd decorticator are as shown in Figs. 1 and 2, respectively.

2.3.1 Design of machine elements

The machine parts were designed and fabricated according to their performance and functions. The design of these parts is as discussed below.

esign of the hopper: The design of a hopper depends principally on the mechanical behavior and the physical properties of the material. The geometrical characteristics of hopper affect the rate of flow of the material out of the hopper.
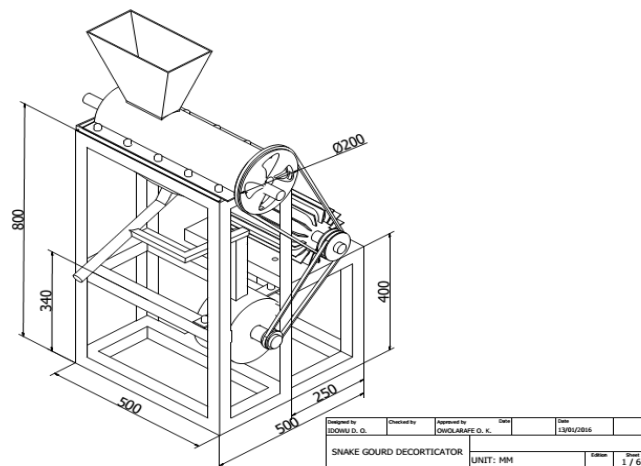
The machine was designed to shell 3.5 kg/min of snake gourd seed. Given that the bulk density of the seed is 0.743 g/cm^3 and the mass of a snake gourd seed is 0.24 g [9]. Then the volume of the seed will be 71.43 mm^3, therefore the bulk volume of 3.5 kg was calculated using the relationship below.

The volume of 3.5kg seed $= \frac{71.43 \times 3500 mm^3}{0.24} = 1041687.5\ mm^3$
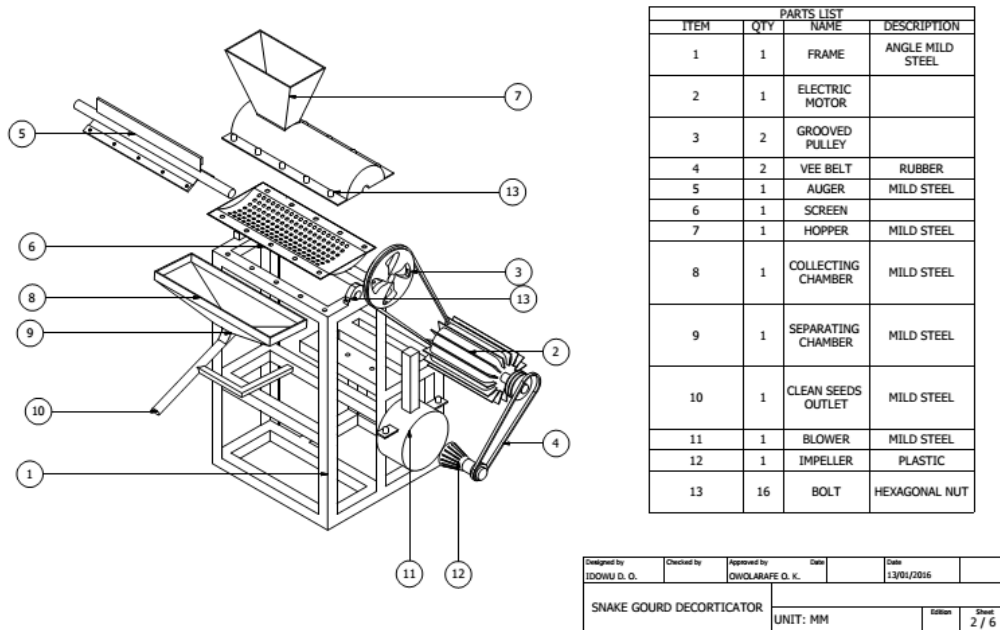
The hopper was designed to hold this volume of seeds for about 5 min, therefore the hopper volume is about 5.3 x 10^{-3} m^3.

Plate 1. Picture of a (fully matured) ripe snake gourd fruit

Fig. 1. The isometric views of the snake gourd decorticating machine

PARTS LIST			
ITEM	QTY	NAME	DESCRIPTION
1	1	FRAME	ANGLE MILD STEEL
2	1	ELECTRIC MOTOR	
3	2	GROOVED PULLEY	
4	2	VEE BELT	RUBBER
5	1	AUGER	MILD STEEL
6	1	SCREEN	
7	1	HOPPER	MILD STEEL
8	1	COLLECTING CHAMBER	MILD STEEL
9	1	SEPARATING CHAMBER	MILD STEEL
10	1	CLEAN SEEDS OUTLET	MILD STEEL
11	1	BLOWER	MILD STEEL
12	1	IMPELLER	PLASTIC
13	16	BOLT	HEXAGONAL NUT

Designed by	Checked by	Approved by	Date		Date	
IDOWU D. O.		OWOLARAFE O. K.			13/01/2016	
SNAKE GOURD DECORTICATOR					Edition	Sheet
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Fig. 2. The assembly drawing of the snake gourd decorticator

[11] Equation 1 for wedge hopper was used in the determination of the semi- included angle after the experimental determination of the angle of friction (δ).

$$\varPhi = 0.0023\delta^2 - 1.5646\delta + 43.343 \qquad (1)$$

Where $\varPhi$ is semi-included angle
δ is coefficient of friction

Design of the hopper outlet: In other to obtain a steady flow of snake gourd seed during shelling, Beverloo equation which was also reported by [12] was used for the determination of the outlet dimensions.

$$W = 0.58\rho_b g^{0.5}(B - Kd_p)^{2.5} \text{ [13]} \qquad (2)$$

Where, W is discharge rate (kg/sec), ρ_b is bulk density (kg/m³), g is gravitational constant

B is outlet size (m), K is constant (typically 1.4, d_p is particle size (m).

Design of the shelling shaft: The shaft was designed as a rotary hammer. This shaft rotates with fins on it that serve as the hammer as the machine rotates. These fins are inclined at an angle to achieve the desired impact, and are covered with dampening rubber in order not to shatter the whole piece.

2.3.2 Determination of power requirement for impact shelling mechanisms

The power required for the shelling
$P_{Total} = P_{shaft} + P_{shelling}$ (3)

Where P_{Total} is the total power required,

P_{shaft} is Power required to run the machine empty
$P_{shelling}$ is Power required for shelling to shell one seed the power required is 0.0745W [10].

2.3.3 Design of the shelling chamber

The shelling chamber was designed to hold the seed when the hammer rotates to shell the seed using impact force.

2.4 Performance Evaluation of the Machine

The performance evaluation of the machine was divided into two major categories viz: evaluation of the shelling efficiency and evaluation of the cleaning efficiency of the machine.

2.4.1 Sample preparation

Different samples of snake gourd seed were soaked in water for different soaking times of 8,

15 and 20 minutes in order to determine the best soaking time in combination with other shelling conditions for best shelling efficiency. The aim of this soaking is to vary the moisture content of the seed shell. These samples were dried at 70° C for uniform drying time of ten minutes and then shelled at different machine parameters. All these samples were then decorticated at 300, 350, and 400 rpm impeller speed and three hammer diameter of 115, 135 and 150 mm. The effect of all these parameters were then determined on the cleaning and shelling efficiency of the machine using Design Expert 2002 software.

2.4.2 Experimental design

The four factors identified are soaking time (which resulted in differential moisture content), hammer speed, hammer diameter and feed rate as shown in Table 1. These factors were used in investigating the optimal performance of the machine. The Design Expert version 6.0.8 of 2002 was used as statistical tools to evaluate main and the interaction effects of these factors on both the shelling and the cleaning efficiencies. The effect of angle of injection and the air speed was also investigated on the cleaning efficiency of the machine. Design expert version 6.0.8 of 2002 was also used to investigate the main and the interaction effects of all these factors on the cleaning efficiency and the cleaning losses of the machine.

Table 1. Factors and levels for experimental design

Factor	Levels		
Soaking time (min.)	8.0	15.0	20.0
Hammer speed (rpm)	300.0	350.0	400.0
Hammer diameter (mm)	115.0	135.0	150.0
Feed rate (kg/hr.)	90.0	120.0	150.0

2.4.3 Determination of evaluation parameters

The performance parameters were determined using the Equations below:

(i) Shelling efficiency (η_s)

The shelling efficiency is the ability of the machine to effectively shell the seed. It was calculated using Equation 4 as reported by [14].

$$\text{Shelling Efficiency} = \left[1 - \frac{Mass\ of\ unshelled\ seeds}{Total\ mass\ of\ sample}\right] \times 100 \quad (4)$$

(ii) Percentage of broken kerne

This was calculated from Equation 5.

$$T_B = \frac{M_C}{M_C + M_B} \times 100 \quad (5)$$

Where:
T_B is percentage shelled
M_B is mass of whole cotyledons
M_C is mass of broken cotyledons

(iii) Throughput

The throughput of the sheller was calculated as shown in Equation 6 as reported by [14].

$$Throughput = \frac{Total\ mass\ of\ sample\ (kg)}{Total\ time\ to\ feed\ in\ the\ mass\ (hr.)} \quad (6)$$

(iv) Cleaning Efficiency

The cleaning efficiency was determined using the formula adopted from [14].

$$\text{Cleaning Efficiency} = \left[1 - \frac{Mass\ of\ impurities}{Total\ s\ of\ clean\ kernels}\right] \times 100 \quad (7)$$

Where impurities revers to seed chaff found in kernel collecting points

(v) Blower losses

During separation of chaff from kernel by the blower after shelling, some of the kernels which were lighter or broken were blown with the husk through the husk delivery. The blower loss was calculated using Equation 8 as reported by [14].

$$Blower\ losses\ (\%) = \frac{Mass\ of\ kernel\ (broken + whole)\ in\ chaff}{Total\ mass\ of\ sample} \times 100 \quad (8)$$

(vi) Machine Efficiency

Machine efficiency is the ability of the machine to shell the seed and separate the kernel and chaff through the kernel delivery section. This was calculated from Equation 9 as reported by [14].

$$Machine\ Efficiency\ (\%) = \frac{Percentage\ of\ kernels\ recoveryred}{54.3\ \%} \times 100 \quad (9)$$

Where 54.3 % represents the mass of kernel in 100 g of seeds at the time of shelling.

3. RESULTS AND DISCUSSION

The results of the experiments performed on the snake gourd decorticator is as discussed below

3.1 Effect of some Operating Parameters on the Shelling Efficiency of the Machine

The results of the evaluation of the snake gourd decorticating machine are as presented below.

3.1.1 Effect of seed soaking time on the machine shelling efficiency

Seed soaking as a pretreatment before decortication was found to be effective in improving seed shelling efficiency of the machine (Figs 3 and 4). It was observed that soaking time influences the easy of detachment of the cotyledon from the shell. The preliminary observation from experimentation showed that the soaking time beyond 20 minutes produces high un-shelled broken seeds. It was observed that seed soaking time played a very important role in increasing shelling efficiency. As the soaking time increased from 8 to 20 minutes the shelling efficiency increased from 88.0 to 97.6 % when other conditions remain constant (Table 2). It was observed that the least shelling efficiency

(51.7%) was recorded at soaking time of 8 minutes. This observation of increase in shelling efficiency with increase in soaking time was in agreement with previous research reports by [15] on melon sheller; [16] on melon sheller; [17] on locust bean depulpping an [18] on melon sheller, [19] on Buchananian lanzan and [20] on Jatropha seed.

3.1.2 Effect of hammer speed on the machine shelling efficiency

The shelling efficiency increased with increase in hammer speed. The maximum shelling efficiency of 97.6 % was recorded when the hammer speed was 400 rpm while the least shelling efficiency of 51.7 % was recorded when the hammer speed was 300 rpm (Table 2). The surface plot of shelling efficiency at different hammer speed is as presented in Fig. 3. This result of increase in shelling efficiency with increase in hammer speed is in agreement with earlier report by [21] on millet dehuller; [22] on melon sheller; [23] on cowpea dehuller; [16] on melon sheller, and [24] on melon sheller [25] on Jatropha seed and [26] on melon seed. The increase in shelling efficiency may be due to an increase in speed which increases available impact shelling energy. The relationship between the hammer speed and the shelling efficiency was observed to be linear as shown in Fig 3.


Plate 2. Snake gourd sheller

### 3.1.3 Effect of feeding rate on the shelling efficiency of the machine

The shelling efficiency was observed to decrease with increase in feed rate (Figs 4 and 5). It was observed that at the same speed (400 rpm), soaking time (20 minutes) and hammer diameter (150 mm), the shelling efficiency decreased from 97.6 to 60.3% with increase in feed rate from 90 to 150 kg/hr. Similar findings were reported by [27] and [28] on peanut and melon sheller, respectively. This may be due to a reduction in available energy needed for shelling as the feed rate increased. The relationship between the feeding rate and the shelling efficiency was observed to be linear.

3.1.4 Effect of hammer diameter on the shelling efficiency of the machine

The relationship between the hammer diameter and the shelling efficiency of the machine was observed to be quadratic. It was observed that the higher the hammer diameter the higher the efficiency. The shelling efficiency of the machine was observed to increase from 84.8 to 97.6% when the hammer diameter increased from 115 to 150 mm as the other machine operating parameters (soaking time 20, hammer speed 400 rpm and feeding rate 90 kg/hr.) remain the same for the operations. This may be due to more robbing effect which increases with increase in hammer diameter.
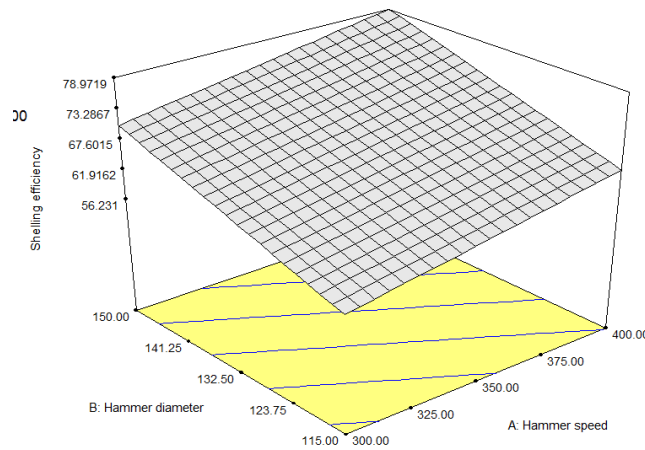
Fig. 3. Response surface plot of interaction of hammer speeds (rpm) and hammer diameter (mm) on shelling efficiency (%) when the soaking time was 8 minutes and the feed rate is 90 kg/hr
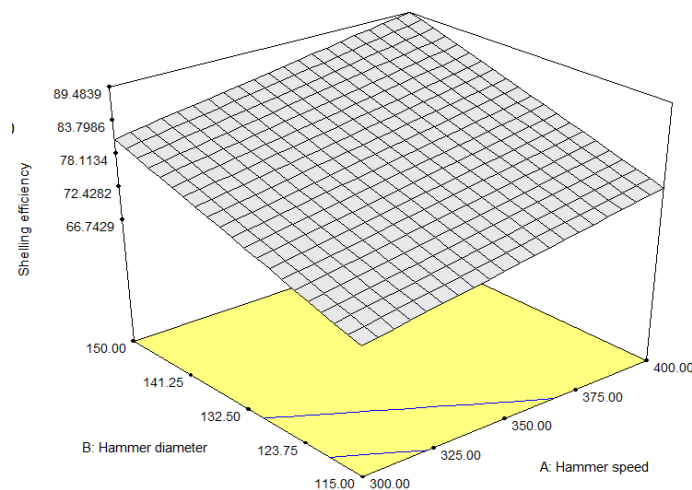
Fig. 4. Interaction of hammer speed (rpm) and hammer diameter (mm) on shelling efficiency (%) when the soaking time is 20 minutes and feed rate is 90 kg/hr
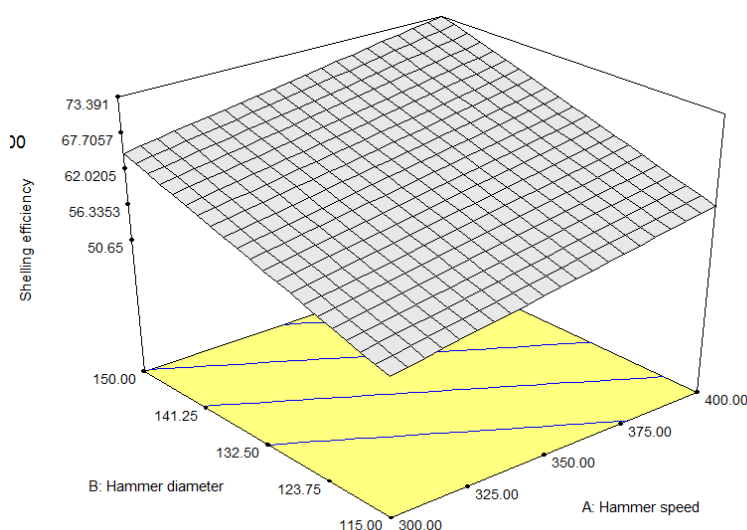
Fig. 5. Interaction of hammer speed (rpm) and hammer diameter (mm) on the shelling efficiency (%) when the soaking time is 20 minutes and feeding rate is 150 kg/hr

Table 2. Effect of soaking time on the shelling efficiency of the sheller

Soaking time (min.)	Hammer diameter (mm)	Hammer speed (rpm)	Feed rate (kg/hr)	Shelling efficiency (%)
8	115	300	90	66.5
20	115	300	90	76.2
8	115	400	90	75.2
20	115	400	90	84.9
8	115	400	150	60.3
20	115	400	150	69.0
8	115	300	150	51.7
20	115	300	150	61.3
8	150	300	90	79.4
20	150	300	90	90.0
8	150	400	90	88.0
20	150	400	90	97.6
8	150	300	150	64.5
20	150	300	150	74.4
8	150	400	150	73.1
20	150	400	150	82.0

The results of the experiments were analyzed Statistical analysis of the experimental data using Design Expert version 6.0.8 showed that all the factors investigated (hammer speed, hammer diameter, soaking time and machine feeding rate) on the machine efficiency were significant ($p < 0.05$).

3.1.5 Empirical model for predicting shelling efficiency

Design Expert model 6.0.8 was used to develop a linear empirical model for predicting shelling efficiency of the machine. The empirical model relating the shelling efficiency with the hammer speed, hammer diameter, soaking time and feeding rate is as presented in Equation 10.

$$SE = 14.37548 + 0.086356\,HS + 0.36648\,HD + 0.801\,ST - 0.24772\,F_{sr} \tag{10}$$

Where

SE is shelling Efficiency (%); HS is hammer speed (m/s); HD is hammer diameter (mm);

ST is seed soaking time (minutes); F_{sr} is machine feeding rate (kg/hr.)

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3.2 Effect of Some Operating Parameters on the Breakage Percentage of the Machine

As the hammer speed increases, breakage increases for the same hammer diameter, moisture content and feed rate (Fig.6). Shelled and unshelled snake gourd seeds were broken at higher shelling speed.

The increase in breakage may be due to higher impact force impacted to the seed during shelling process beyond their maximum stress limit, since higher speed imply higher force. This result is in agreement with the reports of other previous researchers i.e [29] on groundnut sheller; [30] on groundnut cracker; [31] on manual groundnut sheller and [14] on motorized groundnut cracker.

Shelling clearance reduces as shelling hammer diameter increases. With increase in the hammer diameter percentage breakage also increased at all the hammer speed, soaking time and feed rate. It was observed that an increase in the feed rate also increased the percentage breakage at all hammer speed, hammer diameter and soaking time. The higher percentage breakage at higher feeding rate may be due to clogging of the material in the shelling chamber.

Also, higher feed rate resulted in more kernel bruising by rubbing between the layers of unshelled and shelled seed in the shelling chamber thereby resulting in more breakage. This trend has been reported by [30] on groundnut cracker; [31] on manual groundnut sheller and [29] on groundnut sheller. The effect of soaking time on the percentage breakage was not significant ($p < 0.05$).

The experimental results from the effect of snake gourd seed shelling operating parameters on percentage breakage during seed shelling operation were analyzed using Design Expert software 6.0.8. The analysis of variance showed that only feed rate and hammer diameter were significant ($p < 0.05$) on the percentage breakage.

$$PB = -9.65533 + 0.012131\,HS + 0.027565\,HD + 0.012285\,ST - 0.051644\,\text{Fsr} \tag{11}$$

Where,
PB is percentage breakage (%)
HS *is* hammer speed (m/s)
HD is hammer diameter (m)
ST is seed moisture content (d.b %) F_{sr} is Machine feeding rate (kg/s)

3.3 Effect of some Operating Parameters on the Percentage Unshelled Seeds

The effect of the four operating parameters (soaking time, hammer diameter, hammer speed, and feeding rate) on the percentage unshelled increase with decreased in hammer diameter (Figs.7 and 8) indicates that the higher the hammer diameter, the higher the shelling efficiency therefore the lower the percentage unshelled. The reduction in the percentage of unshelled at higher speeds could be due to the fact that at higher speed, the machine had greater force to crack more of the seeds as compared to lower speeds. This trend was in agreement with earlier reporter on Jatropha seed decortication by [14]; [16] on melon and [32] on melon. The statistical result of the analysis of variance, showed that all the operating parameters were significant ($p < 0.01$) on percentage unshelled seeds.

3.4 Optimization of Shelling Efficiency

Optimization of technical performance of the sheller requires maximization of shelling efficiency and minimization of percentage damage [33-34]. The design Expert software version 6.0.8 was used to estimate the optimum operating condition of the sheller. The interactions and regression analysis by the software resulted in prediction of the optimum operating conditions of 400 rpm hammer speed, 149.5 mm hammer diameter, 16.8 minutes soaking time and 149.6 kg/s feeding rate produced shelling efficiency of 98.0% with desirability of 0.98.

The operating conditions identified by the Design Expert was verified experimentally. Although the exact value was not used for soaking time and hammer diameters, a close value of 17 minutes for soaking time and 150 mm for hammer diameter was used instead. The predicted and the actual shelling efficiency of 98.97 % and 96.8 %, respectively was close. Considering a variation of 2.19 %, the variation is still within the acceptable value for agricultural research results [35-36].

3.5 Effect of some Operating Parameters on the Cleaning Efficiency of the Machine
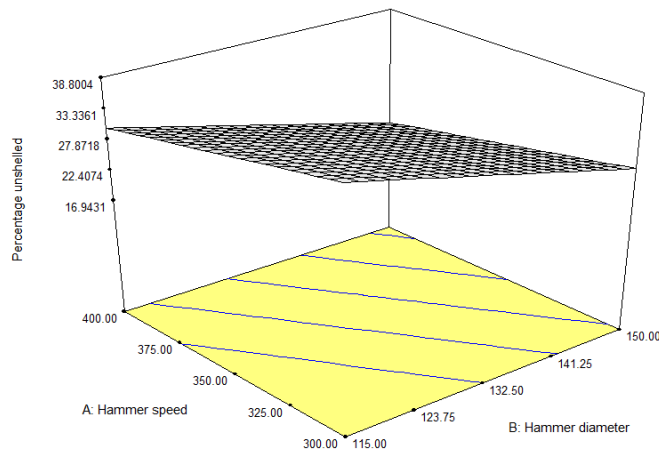
The effect of the angle of injection and the cleaning air speed on the cleanin efficiency of the machine is presented below.
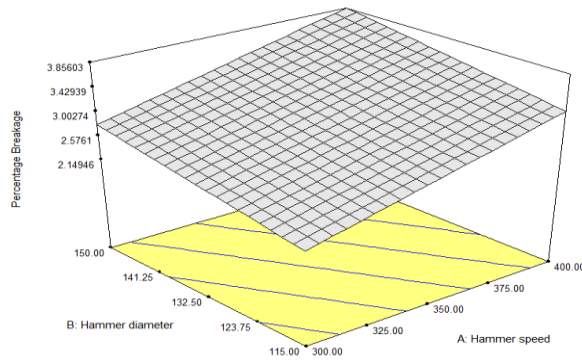
Fig. 6. Effect of increase in hammer speed (rpm) and hammer diameter (mm) on the percentage breakage (%) when the soaking time is 20 minutes and feed rate is 150 kg/hr. on the percentage breakage
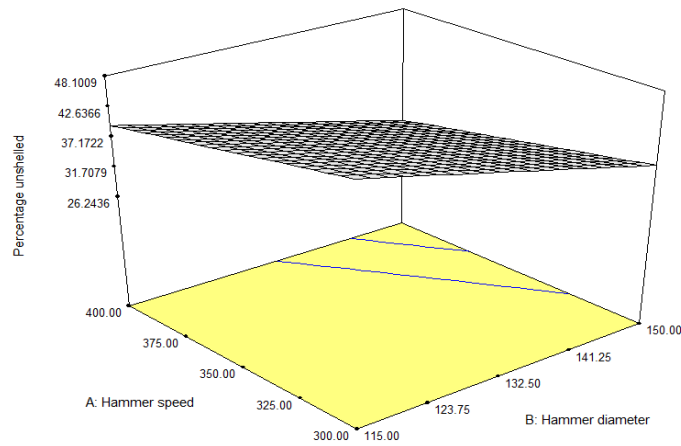
Fig. 7. Effect of increase in hammer speed (rpm) and hammer diameter (mm) on the percentage unshelled (%) when the Ssoaking time is 8 minutes and feeding rate is 150 kg/hr. on the percentage unshelled

Fig. 8. Effect of increase in hammer speed (rpm) and hammer diameter (mm) on the percentage unshelled (%)   when the soaking time is 20 minutes and feeding rate is 150 kg/hr. on the percentage unshelled

3.5.1 Effect of cleaning air speed on the cleaning efficiency of the machine

The surface plot (Fig. 9) shows the interaction effect of the cleaning air speed and the air angle of injection on the cleaning efficiency of the machine. It was observed that as the cleaning air speed increases, the cleaning efficiency also increased in the range examined. This may be due to the fact that at higher speed, the air speed has enough power to blow much of the shell out of the samples, hence higher cleaning efficiency. This result is in agreement with the report of [37-38] on pneumatic cleaning of cowpea, which reported an increase in pneumatic cleaning of cowpea with increase in cleaning air velocity. It was observed that as the angle of air injection increased the cleaning efficiency decreased.

The experimental results of the effect of kernel/chaff separating air speed and angle of air injection on the cleaning efficiency of the snake gourd shelling machine (Table 2) were analyzed using Design Expert software 6.0.8. The analysis of variance shows that the air speed and the interaction effect of separation air and angle of injection were significant ($p < 0.01$). Regression analysis of the data relating separating air speed and angle of injection to the cleaning efficiency was developed and represented with the empirical formula (Equation 12).

The predicted cleaning efficiency and the experimental were plotted (Fig.10), the result of the plotting show a high correlation ($R^2 = 0.9875$) shows that the empirical model can be used to predict the cleaning efficiency of the machine.

$$Cleaning\ efficiency = -18.99 + 0.977\ SA + 39.40\ AI - 0.026\ SA^2 - 5.229\ AI^2 + 0.275\ SA\ xAI \tag{12}$$

Where SA is separating air speed (m/s) and
   AI is angle of air injection (degree)

3.5.2 Effect of cleaning air speed on the cleaning loss of the machine

Fig. 11. Presents the interaction of air speed and angle of injection on cleaning loss. The graph shows an increase in cleaning loss as the separating air speed increases. At higher air speed, excessive air velocity fluidizes the kernel and deposited it with the chaff. This result is in agreement with the results of the earlier research reports by [39-40]. The angle of injection had significant effect ($p<0.001$) on cleaning loss. It

was observed that as the injection angle increases the cleaning loss is decreasing. The result of the analysis of variance on the data shows that the interaction of the angle of injection and cleaning air speed is significant ($P<0.01$).

Regression analysis of the data relating separating air speed and angle of injection to the cleaning loss was developed and represented with the empirical formula (Equation 13). The graph of correlation between the experimental and the predicted cleaning loss efficiency of the machine is as presented in Fig. 12. The correlation ($R^2 = 0.9765$) show that equation can correctly represent the cleaning loss of the machine.

$$Cl = + 11.35402 + 0.22764\ AJ - 4.24598AS + 1.24741\ AS^2 - 0.14\ AJ^* AS\ (R^2 = 0.9765) \tag{13}$$

Where;
Cl is cleaning losses,
AJ is air injection angle
AS is air speed

3.6 Optimization of Cleaning Efficiency and Minimization of Percentage blower loss

The main objective in determining the optimum working condition of the cleaning section of the machine is to obtain the highest cleaning efficiency. The cleaning efficiency was optimized using the design expert version 6.0.8 of 2002. The Design Expert software predicted 95.87 % cleaning efficiency when angle of injection is (60^0) and air speed is (5.34 m/s).

This optimization was verified by experimental work. It was not easy to get air speed of 5.34 m/s, but 5.0 m/s air speed was used. The cleaning efficiency of the machine achieved experimentally with the set condition was 92.5 %. This verification runs confirmed well the predicted values at optimum conditions with acceptable percentage (3.5 %) variations from predicted value.

3.7 Overall Machine Efficiency

The efficiency of the machine in shelling and separating the kernel from the chaff at different speeds is as presented in Table 3. The speed of operation of the machine had very significant effect on the machine efficiency. The machine efficiency increased from 76.3 to 88.9% as the

machine speed increased from 300 rpm to 400 rpm but decreased from 88.9 to 82.2% as the speed increased to 500 rpm. This may be as a result of higher air speed above the terminal velocity of the kernel thereby blowing the kernel with the chaff, leading to reduction in the kernel recovery at the kernel outlet which in turn leads to decrease in efficiency. The regression equation for the relationship between the machine efficiency and the machine speed is polynomial as shown in Equation 14.

$$ME = -2.56\,MS^2 + 16.78\,MS + 61.66 \quad (R^2 = 0.9717) \tag{14}$$

Where;
ME is machine efficiency,
MS is machine speed
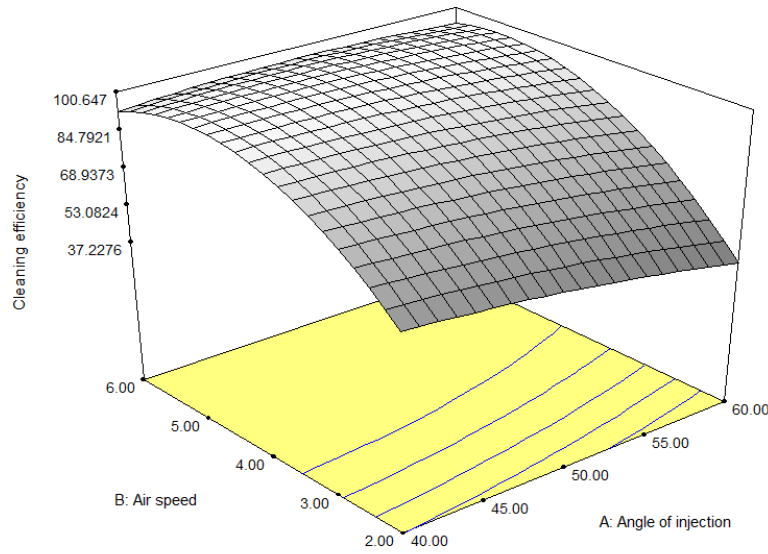
Fig. 9. Effect of increase in kernel/chaff separating air speed (rpm) and air angle of injection (%) on the cleaning efficiency of the machine
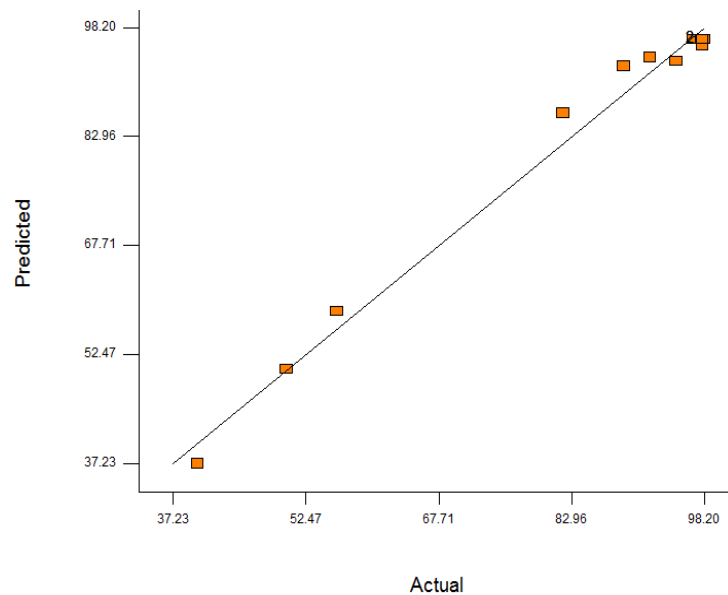
Fig. 10. Correlation between the experimental and the predicted cleaning efficiency of the machine

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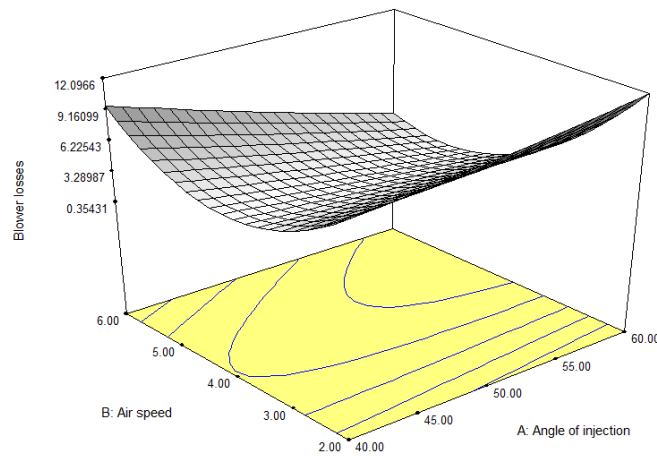**Table 3. Effect of angle of injection and air speed on cleaning efficiency and blower losses of the sheller**

Std.	Run	Angle of injection (degree)	Air speed (m/s)	Cleaning (%)	Blower losses (%)
6	1	60	4	82.0	2.0
11	2	40	4	98.0	4.0
3	3	50	6	98.0	5.0
5	4	50	4	92.0	3.5
10	5	40	4	96.2	4.3
9	6	40	4	97.0	4.4
8	7	40	6	89.0	10.0
7	8	40	2	56.0	9.5
1	9	50	2	50.2	10.0
2	10	60	2	40.0	12.0
13	11	40	4	98.0	4.0
4	12	60	6	95.0	1.3
12	13	40	4	97.9	4.0

Fig. 11. Effect of increase in kernel/chaff separating air speed and air angle of injection on the cleaning loss
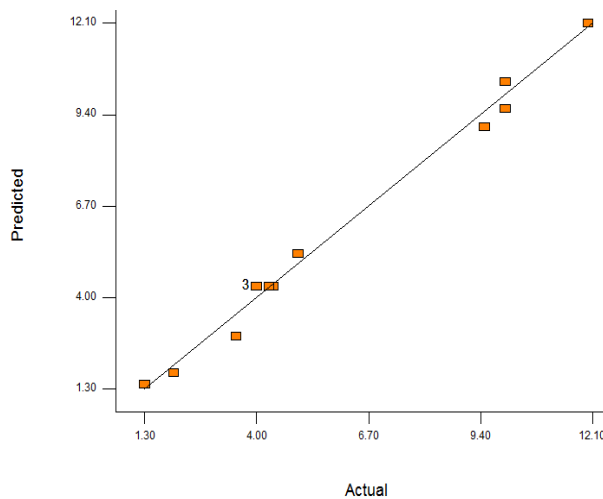
Fig. 12. Correlation between the experimental and the predicted cleaning loss of the machine

4. CONCLUSIONS

Snake gourd seed decorticating machine was designed, fabricated and evaluated for its performance in this study. The result of the evaluation exercise indicates a high decorticating efficiency of 97. % and cleaning efficiency of 98%. The breakage percentage and unshelled percentage of 2.3 and 2.7 %, respectively are low thus indicating good performance. With this performance the machine could be included in the process line for processing of snake gourd seed. This will hence increase snake gourd seed production and thereby contributing positively to the vegetable oil production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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