Development of a Guna Seed Extractor

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ABSTRACT

Guna seed extraction presents an onerous task and has been the labour and time consuming operation that militates against the large scale production and processing of this important oil crop. To overcome this problem, a guna seed extractor that works on the principle of impact from breaker arms and macerators was developed. The seed extractor consists of a hopper equipped with flow rate control device, a seed extraction unit, winnowing unit and power system. Performance tests were conducted on the seed extractor using the fruits of two varieties of guna crop namely *citrullus colocynthis* and *citrullus lanatus* in the moisture ranges of 87.21-92.45% (wb) and 85.07-89.74% (wb) respectively, obtained by varying the fruit storage duration.

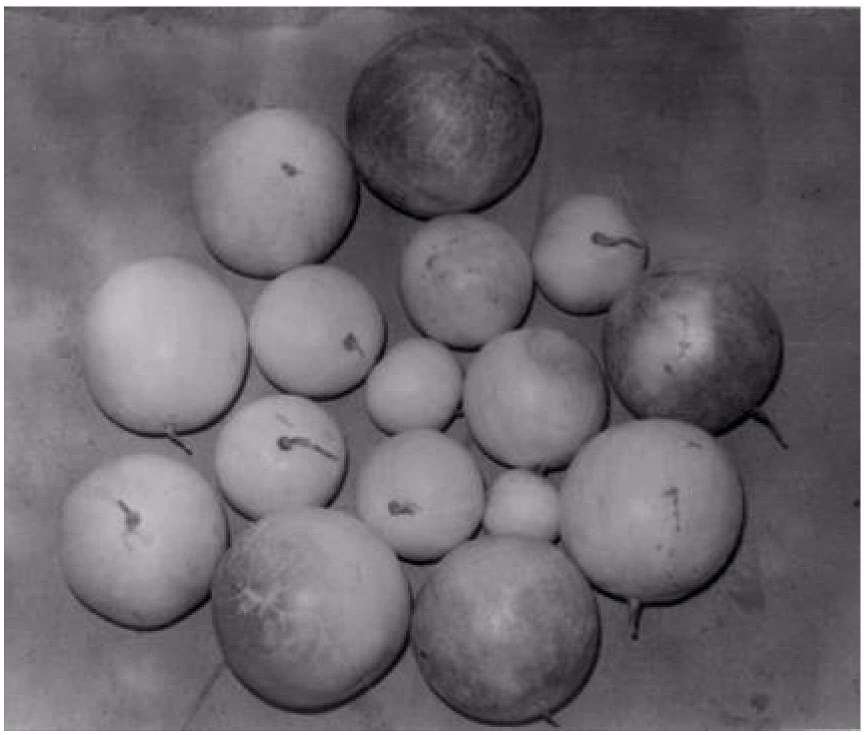
Result of tests and analyses showed that the performance indicators (percentage effective seed extraction, cleaning efficiency, cleaning loss, percentage seed loss at concave, material retention and percentage seed retention) were significantly affected by fruit moisture content (storage duration), material feed rate and machine speed at 1 and 5% levels. Percentage effective seed extraction and percentage seed loss at concave increased with increase in fruit moisture content, material feed rate and machine speed Maximum percentage effective seed extraction of 95.1% at the moisture content of 92.45% for the *colocynthis* fruit, and 96.0% at 89.74% moisture content for the *lanatus,* was obtained at the material feed rate of 375 kg/h and machine speed of 939 min $^{-1}$. Maximum percentage seed loss at concave was less than 5%. Cleaning efficiency, cleaning loss and material retention in the seed extraction chamber, decreased with the increase in the fruit moisture content for both varieties of guna fruits, but increased with increase in material feed rate and machine speed, while percentage seed retention decreased with increase in moisture content, material feed rate and machine speed. Maximum cleaning efficiency of 94.15% and 91.28% for the *colocynthis* and *lanatus* varieties respectively, was obtained at the material feed rate of 375 kg/h, machine speed of 939 min $^{-1}$, and fruit moisture contents of 87.21% and 85.07%. Maximum cleaning loss was less than 30% and percentage seed retention was high at low fruit moisture content, material feed rate and machine speed. Practically no seed damage was recorded.

Regression models that could be used to express the relationship existing between the seed extractor performance indices and fruit moisture content, material feed rate and machine speed were established for each variety of guna crop.

Keywords: Guna, variety, drudgery, extractor, seed extraction, extraction efficiency, moisture content, feed rate, machine speed, Nigeria

1. INTRODUCTION

Guna is a drought tolerant crop that belongs to the cucurbitaceace family of flowering plants. The crop is important mainly for its seeds that have an average protein and oil content of 27 and 50% respectively (Norton, 1993). The seed oil obtained from its kernel has been reported to have adequate content of essential amino acids and complete absence of α-linoleic acid that can cause stability problem in refined oil (Norton, 1993). Badifu and Ogunsua (1991) reported that guna seed oil can be used for cooking purposes, and the seed kernel ground into powder and used as soup thickening or flavouring agent. The plant leaves and fruit pods are used for medicinal purposes and as livestock feed (Aviara and Haque, 2002). Two varieties of the crop, namely *citrullus colocynthis* (Fig. 1A) and *citrullus lanatus* (Fig. 1B) are commonly grown in the Northeast Arid Region of Nigeria (Aviara *et al;* 2007).



A

B

Figure 1. Fruits of *citrullus colocynthis* (A) and *citrullus lanatus* (B) varieties of guna crop

The main indicator of fruit maturity is the change of the pedicle colour from green to brown, the drying of leaves and the change of fruit colour from green to milky. Harvesting of matured fruits is carried out by hand picking and gathering in heaps on the farm for post harvest processing (Aviara and Haque, 2002). Locally, farmers store guna fruits on bare ground in an open and well ventilated area or on mat under a 'zanah' shed. The storage duration is normally dependent on the ambient temperature of the area. In Northeastern Nigeria, the on farm storage of guna fruits does not normally exceed eight weeks. Traditional technologies are still employed in the extraction of seeds from guna fruit (Aviara and Haque, 2002). These include manual crushing of fruit with pestle and decaying of fruits in a heap or pit. These techniques are not only energy sapping and time consuming, they yield low quality products, while the rotten pods contribute to environmental pollution. The difficulties inherent in the extraction of guna seeds from the pod has made it to constitute a bottleneck to the large-scale production and processing of the crop. To solve this problem, there is the need to develop a mechanical device that is capable of digesting the guna fruit to extract the seeds.

Olusoji (1980) developed a cocoa bean extractor that works on the principle of impact from a hammer on the pod positioned on a centering table. Adewumi and Fatusin (2006) followed a similar approach in developing a manually operated cocoa pod breaker for seed extraction. Kushwaha *et al.* (2005) developed a motorized okra seed extractor that worked on the basis of the rubbing action of a rotary cylinder, while Kailappan *et al.* (2005) tested a tomato seed extractor that utilized the squeezing action of a screw auger, and obtained a seed extraction efficiency of up to 98.8%. Oloko and Agbetoye (2006) developed a melon depodding machine that operated on the principle of impact from spikes on a rotating drum and Balakrishnan *et al.* (2006) using a similar principle, developed a chilli seed extractor that gave a seed extraction efficiency of 94%. Gwandzang *et al.* (1994) reported the adaptation of an EMCOT thresher for guna seed extraction with results that were not satisfactory. This study was therefore carried out to develop a guna seed extractor to relieve the crop processors of the tedium of the traditional methods of the seed extraction.

2. SOME DESIGN, DEVELOPMENT AND PERFORMANCE CONSIDERATIONS

The engineering properties of guna fruits that are relevant in bulk handling and mechanical processing (Aviara *et al;* 2007), were considered in the design, development and performance analysis of the seed extractor. The properties included major and minor semi axial dimensions, thickness of the epicarp and mesocarp, pod-fruit, pulp-fruit and seed-fruit mass ratios, particle and bulk densities, fruit impact strength, bioyield, rupture and compressive strengths, modulus of stiffness and modulus of elasticity.

The fruits were considered spheroidal in shape in accordance with the findings of Aviara *et al.* (2007). The seeds were taken as being oval in shape and flat (Aviara *et al;* 1999), and as a result, they were considered to be able to pass through perforations that were made on a concave, when released from the fruit. The axial dimensions governed the openings of the feed hopper, the total mass of thick epicarp was estimated from the pod-fruit mass ratio and the total mass of seeds contained in fruit was determined from the seed-fruit mass ratio. The fruit impact and compressive strengths were used to determine the machine functional requirements and fundamental relationships including drive shaft and drum sizes, speeds and forces that the components should supply as well as the ones that they should withstand. Similar considerations have been successfully applied in the development of bambara groundnut sheller (Atiku *et al;* 2004) and sheanut cracker (Oluwole *et al;* 2004).

3. GUNA SEED EXTRACTOR DESCRIPTION AND OPERATION

The seed extractor was designed to work on the principle of impact from breaker arms and macerators. It is made up of five units, namely the feed hopper, seed extraction unit, cleaning unit, power system and the tool frame (Fig. 2).

The feed hopper, which is trapezoidal in shape, is mounted on the seed extraction unit at an inclination that enabled the fruits to flow uniformly into the extraction chamber. It is held in place by the top cover of the seed extraction unit which is hinged on to the tool frame. The hopper has rectangular upper and base openings of 30cm x 20cm and 20cm x 16cm respectively. A flow rate control device is located at the hopper base and used to obtain varying gate openings between the hopper and seed extraction unit. Using this device, the quantity of fruits entering into the extraction chamber per unit time could be regulated and varying feed rates achieved. Below the base opening of the hopper and enclosed in the cover is the extraction chamber, which forms a hollow cylindrical cavity where seed extraction takes place. Through this chamber runs a metal drum of 61cm length and 9cm diameter having a steel drive shaft of 4.5cm diameter and

116cm length that runs in two journal bearings that are mounted at each end of the machine on the tool frame.

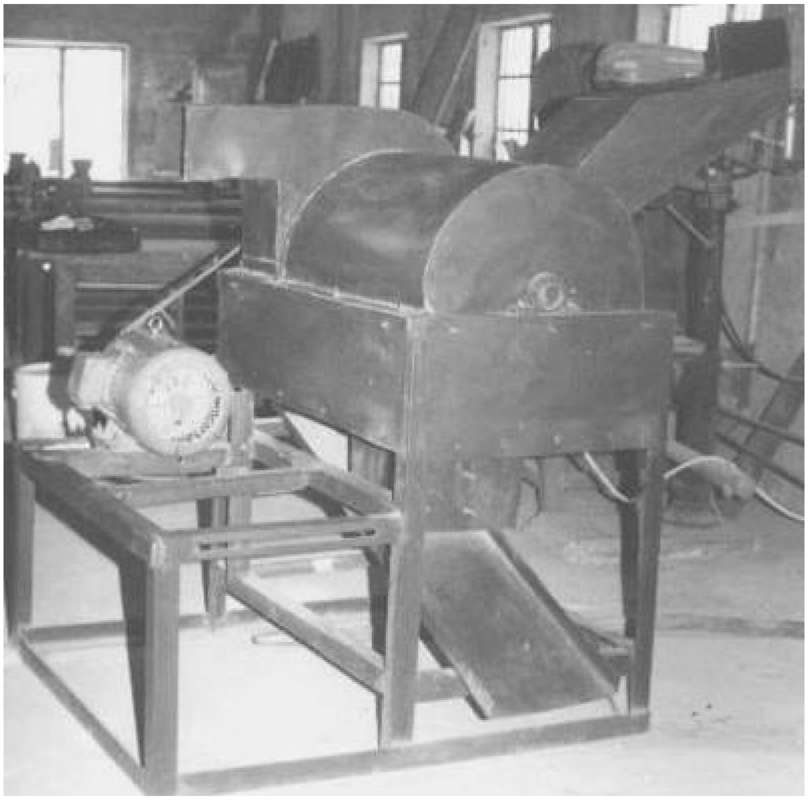


Figure 2. Photograph of the guna seed extractor

The machine components (Fig. 3) were assembled and mounted on a rectangular tool frame, which gives it a compact design and a sturdy outlook.

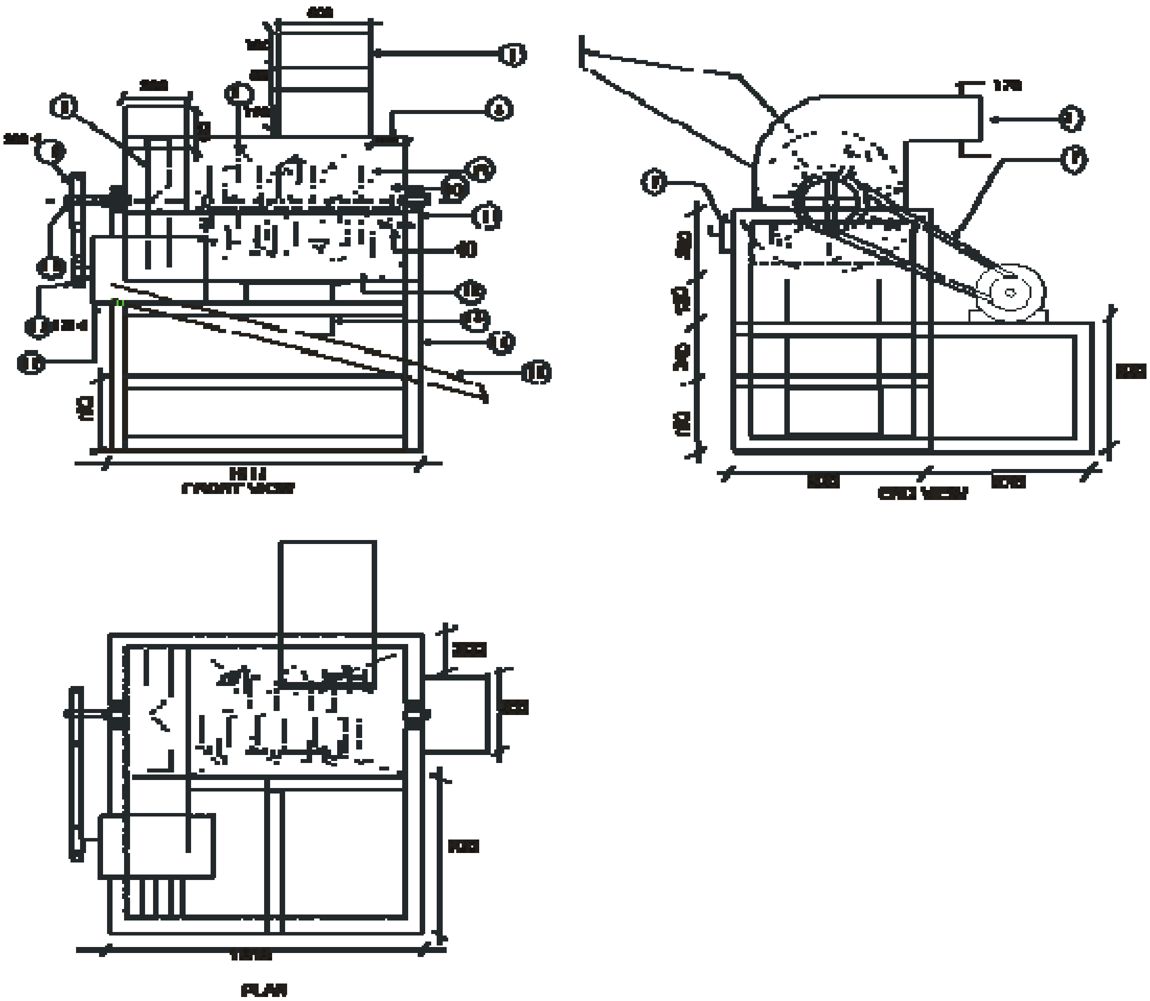
The drum carries the breaker arms and macerators (Fig. 3) that are spaced 1cm apart on its surface in such away that a clearance less than the fruit size (Aviara *et al;* 2007) is maintained between their edges and the perforated concave. The breaker arms and macerators are the working components that provide the impact, shear and compressive forces needed in breaking the fruits and releasing the seeds. They are arranged on the drum surface in a way that enables a churning and screw conveying movement of the crushed material containing the seeds, the broken epicarp and the mucilage in the extraction chamber, to be achieved and the separation of the extracted seeds enhanced. The perforated concave screen made from a thick gauge steel sheet is positioned below the drum. It enables the extracted seeds to be separated from the broken fruit epicarps. The perforations are of 1cm diameter and through them, the extracted seeds drop into a transition channel down to the delivery chute. The delivery chute fabricated from mild steel plate is mounted on the tool frame below the transition channel at an angle of 60^o to the horizontal. It forms the passage through which the extracted seeds flow into the collection chute.

Figure 3. Guna seed extractor showing the working components

The cleanining unit having a chamber formed by an extension of the seed extraction unit consists of a centrifugal fan mounted on the seed extractor drive shaft and a cleaner outlet. The fan is made of a disc plate of 44cm diameter with 14 rectangular fan blades of 17.5cm by 6cm welded on it. This unit supplies the air stream and pressure required to remove the broken fruit epicarps from the extraction chamber. The broken epicarp materials are pulled into the cleaning chamber by the suction action of the fan in addition to the screw conveying action of the fruit digestion components. They are then thrown out through the rectangular 20cm x 17cm cleaner outlet. The power system consists of a three-phase 5.5kW electric motor, which runs at 1440 min^{-1} and uses a belt and pulley drive arrangement to operate the machine. The motor is mounted on a seating that is a component of the tool frame and on its shaft is coupled a driving pulley of variable groove diameter.

The detailed assembly drawings and part list of the seed extractor are presented in Figure 4.The materials of construction are readily available and the technologies employed in it fabrication are not complicated.

To operate the seed extractor, the flow rate control flap is completely shut and the hopper filled with guna fruits. The main is then switched on and the motor start button is pushed in to actuate the electric motor and run the drum. As the machine attains the selected speed, the fruits are fed in through the flow rate control device by setting it to a desired flow rate opening. The fruits fall into the seed extraction chamber through the hopper base opening and are crushed by the impact of the rotating breaker arms and macerators. The extracted seeds fall through the perforated concave into the delivery chute, while the broken epicarps are sucked into the cleaning chamber and thrown out through the cleaner outlet.



(1) Hopper, (2) Macerator, (3) Cleaning fan, (4) Digestion unit cover, (5) Cleaner outlet, (6) Machine drive pulley, (7) V-belt, (8) Breaker arm, (9) Electric motor switch, (10) Digestion drum, (11) Journal bearing, (12) Machine drive shaft, (13) Perforated concave, (14) Transition channel, (15) Electric motor pulley, (16) Tool frame, (17) Electric motor, (18) Seed delivery chute

Figure 4. Assembly drawings and part list of the guna seed extractor

4. PERFORMANCE TESTS AND EVALUATION

4.1. Material Preparation

Bulk quantities of freshly harvested fruits of the *Citrullus colocynthis* and *Citrullus lanatus* guna crops were purchased from farmers at Ngamdu in Kaga Local Government Area of Borno state, Nigeria. The fruits were sorted and the damaged ones discarded. The undamaged ones were cleaned and divided into three lots from each variety. The first set was composed of freshly harvested fruits and the second and third sets were stored on a mat on the floor of sheds constructed with 'zanah' grass mats, for a duration of four and eight weeks respectively. The roofs of the sheds were also made of 'zanah' mats. The moisture content of the fresh fruits was determined using the method of ASAE (1983) as applied by Ajibola *et al.* (1990) and Oje (1993). This involved a random selection of samples from each variety, reduction of the size of the samples and oven drying at 130^{O}C to constant weight. This was replicated three times for each variety and the average fruit moisture content was determined. The same procedure was followed in determining the moisture contents of the fruits stored for four and eight weeks respectively. The above experiments yielded fruits at three moisture levels that were used in carrying out the machine performance tests.

4.2. Tests and Analyses

Performance tests were carried out on the seed extractor using the fruits of two varieties of the crop namely *citrullus colocynthis* and *citrullus lanatus*. Three samples of each variety at different three moisture content levels obtained. The wet basis moisture contents of the fruit samples freshly harvested, stored for four weeks and stored for eight weeks were respectively 87.21, 90.1 and 92.45% for *citrullus colocynthis* and 85.07, 87.58 and 89.74% for *citrullus lanatus*. For each fruit variety, the flow rate control device was calibrated to establish the hopper gate openings that will deliver various material feed rates into the seed extraction chamber, using the method described by Oluwole *et al.* (2004). This involved closing of the hopper base opening using the flow rate control flap pushed through a slot. A graduated stem was used to determine the size of gate opening indicated by a number that ranged from 0 to 8. The hopper was filled with fruits and the stem was adjusted to read gate opening number 1. The fruits were allowed to flow freely through the gate and the time taken to discharge a known mass was recorded. The process was repeated at higher gate opening numbers and replicated three times at each gate opening. The rate of flow of fruits through the gates obtained using Eqn (1) was taken as the material feed rate.

$$F \approx \frac{W_f}{t} \quad (1)$$

where F is the fruit flow rate (material feed rate) in kg/h; W_f is the mass of fruits in kg and t is the total time taken for the mass of fruits to be discharged through a gate in h.

To carry out a performance test, the hopper base opening was closed using the flow rate control device and a known mass of fruits was poured into the hopper. The main was switched on to run the electric motor and set the working components of the seed extractor into motion. The flow rate control device was adjusted to select the gate opening that will deliver a given feed rate, and the machine was allowed to run until the material was completely fed and digested. After that, the total mass of fruits fed into the machine, mass of seed collected at the delivery chute, mass of material retained in the extraction chamber, mass of seed retained, mass of seed collected at the cleaner outlet, mass of broken epicarp collected at the cleaner outlet, mass of seed damaged and mass of seed lost at the concave in kg were recorded. Four feed rates of 150, 225, 300 and 375 kg/h obtained from gate opening numbers 1 – 4 and three machine speeds of 689, 814 and 939 min^{-1} obtained by varying the size of the driving pulley were used in conducting the performance tests. Each experiment was replicated three times for each variety of guna fruit at different moisture contents.

The performance evaluation of the seed extractor was carried out on the basis of the following indices

i. Percentage effective seed extraction, $E_e \approx \frac{(W_{sc} + W_{so} + W_{cl} + W_{sd})}{W_{st}} \times 100$ (2)

ii. Cleaning efficiency, $E_c \approx \frac{W_{eb}}{W_{et}} \times 100$ (3)

iii. Cleaning loss, $L_c \approx \frac{W_{so}}{W_{st}} \times 100$ (4)

iv. Percentage seed loss at concave loss, $L_{cv} \approx \frac{W_{cl}}{W_{st}} \times 100$ (5)

v. Material retention, $m_r \approx \frac{W_{mr}}{W_f} \times 100$ (6)

vi. Percentage seed retention, $\eta_{sr} \approx \frac{W_{sr}}{W_{st}} \times 100$ (7)

vii. Percentage seed damage, $\eta_{sd} \approx \frac{W_{sd}}{W_{st}} \times 100$ (8)

where E_e is the percentage effective seed extraction in %; W_{sc} is the mass of seeds collected at the delivery chute in kg; W_{so} is the mass of seeds collected at the chaff outlet in kg; W_{cl} is the mass of seeds lost through the concave sides in kg; W_{sd} is the mass of seeds damaged in kg and W_{st} is the total mass of seeds contained in the fruits in kg; E_c is the cleaning efficiency in %; W_{eb} is the mass of broken fruit epicarp collected at the cleaner outlet in kg and W_{et} is the total mass of epicarp contained in the fruits in kg; L_c is the cleaning loss in %; L_{cv} is the percentage seed loss at concave; m_r is the material retention in %; W_{mr} is the mass of material retained in the seed extraction chamber at the end of each performance test in kg; W_{sr} is the mass of seeds retained in kg and η_{sr} and η_{sd} are the percentages seed retention and seed damage respectively in %.

Regression analysis was performed on the data obtained in order to determine the relationship existing between the machine performance indices, fruit moisture content, material feed rate and machine speed. Analysis of variance (ANOVA) was used to determine the extent to which the machine and crop parameters affected the performance indices.

5. RESULTS AND DISCUSSION

The F-ratios of the performance tests result are presented in Table 1, while the variation of the performance indices with fruit moisture content, material feed rate and machine speed are presented in Tables 2 - 7.

Table 1. F-ratio for the results of performance tests for *citrullus colocynthis* and *citrullus lanatus* guna fruits

Source of variation	*F*-ratio											
	Seed collected at chute		Seed collected at cleaner outlet		Epicarp collected at cleaner outlet		Concave loss		Material retention		Percentage seed retenrion	
	c.colo	c.lana	c.colo	c.lana	c.colo	c.lana	c.colo	c.lana	c.colo	c.lana	c.colo	C.lana
Moisture content (M)	10.591^{*}	11.944^{*}	5.431^{**}	6.650^{**}	0.136^{NS}	21.141^{**}	15.545^{*}	6.792^{NS}	3.979^{NS}	5.927^{**}	30.388^{*}	46.181^{*}
Material Feed rate (F)	113.104^{*}	79.435^{*}	11.505^{*}	15.208^{**}	107.732^{*}	437.221^{*}	93.568^{*}	22.005^{*}	72.209^{*}	226.988^{*}	1.273^{NS}	4.109^{**}
Machine Speed (S)	19.550^{*}	3.704^{NS}	9.446^{**}	6.318^{**}	5.742^{NS}	8.244^{**}	17.150^{**}	4.822^{NS}	10.013^{**}	10.242^{**}	18.659^{*}	41.124^{*}
Interactions												
M*F	13.490^{*}	24.245^{*}	18.692^{*}	48.960^{*}	2.677^{NS}	0.923^{NS}	6.371^{*}	1.650^{NS}	10.421^{*}	5.327^{*}	6.915^{*}	36.676^{*}
M*S	1.546^{NS}	2.670^{NS}	1.196^{NS}	5.852^{*}	7.409^{*}	1.518^{NS}	1.764^{NS}	0.757^{NS}	1.752^{NS}	2.521^{NS}	3.709^{**}	1.404^{NS}
F*S	1.987^{NS}	1.979^{NS}	3.271^{**}	7.148^{*}	1.786^{NS}	10.488^{*}	1.430^{NS}	1.013^{NS}	1.233^{NS}	1.609^{NS}	12.324^{*}	15.051^{*}
M*F*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* significant at 1% level; ** significant at 5% level; NS no significant difference; c.colo, citrullus colocynthis; c.lana, citrullus lanatus

From Table 1, it can be seen that fruit moisture content, material feed rate and interaction between moisture content and material feed rate on the two varieties and machine speed on *citrullus colocynthis,* significantly affected the quantity of seed collected at the delivery chute at 1% level. The effect of machine speed for *citrullus lanatus* and interaction between moisture content and machine speed, material feed rate and machine speed and moisture content, material feed rate and machine speed for both varieties on the quantity of seed collected from the chute was not significant. The variation of percentage effective seed extraction with fruit moisture content, material feed rate and machine speed for the *colocynthis* and *lanatus* guna fruits is shown in Table 2. From this table, it can be seen that percentage effective seed extraction increased with increase in fruit moisture content, material feed rate and machine speed for the two varieties of guna crop. The maximum percentage effective seed extraction of 95.10% and 96.00% for the *colocynthis* and *lanatus* varieties was obtained at the material feed rate of 375 kg/h, machine speed of 939 min^{-1} and fruit moisture contents of 87.21% and 85.07% respectively. The relationship existing between the percentage effective seed extraction and fruit moisture content, material feed rate, machine speed and their interactions could be expressed by the following regression equations:

$$\begin{aligned} E_{ec} \approx & -692.994 - 1.205M + 5.908F + 1.746S - 0.062MF - 0.017MS \\ & -0.008FS + 8.589\times10^{-5}MFS + 0.088M^2 - 2.001\times10^{-4}F^2 \\ & -8.819\times10^{-5}S^2 \end{aligned} \quad (9)$$

$$\begin{aligned} E_{el} \approx & \ 2907.85 - 68.722M + 0.116F - 0.089S + 8.318\times10^{-4}MF + \\ & 0.002MS + 1.921\times10^{-4}FS - 2.621\times10^{-6}MFS + 0.402M^2 - \\ & 5.511\times10^{-5}F^2 - 2.797\times10^{-5}S^2 \end{aligned} \quad (10)$$

with values for the coefficient of determination, R^2 of 0.90 and 0.99 respectively, where E_{ec} is the percentage effective seed extraction for *citrullus colocynthis* %; E_{el} is the percentage effective seed extraction for *citrullus lanatus* %; M is moisture content in % (w.b); F is the material feed rate in kg/h and S is machine operational speed in min^{-1}.

The interaction between material feed rate and machine speed was found to make the strongest unique contribution to percentage effective seed extraction for *citrullus colocynthis*, while the square of fruit moisture content is the main predictor for *citrullus lanatus* when compared with other variables.

Table 2. Variation of percentage effective seed extraction with guna fruit moisture content, material feed rate and machine speed

	cylinder speed:689 min^{-1}				cylinder speed:814min^{-1}				cylinder speed:939min^{-1}			
Feed rate (kg/h)	Variety				Variety				Variety			
	c. colo.		*c.lana*		*c. colo.*		*c.lana*		*c. colo.*		*c.lana.*	
	M	E_e	M	E_e	M	E_e	M	E_e	M	E_e	M	E_e
150	87.21	50.00	85.07	45.76	87.21	55.30	85.07	49.60	87.21	62.00	85.07	53.80
	90.10	54.00	87.58	49.89	90.10	59.60	87.58	56.00	90.10	67.30	87.58	61.50
	92.45	62.73	89.74	58.96	92.45	66.00	89.74	62.80	92.45	73.81	89.74	69.20
225	87.21	56.30	85.07	53.00	87.21	63.00	85.07	61.30	87.21	68.80	85.07	64.00
	90.10	60.30	87.58	58.10	90.10	68.10	87.58	65.93	90.10	77.20	87.58	72.60
	92.45	70.11	89.74	67.50	92.45	75.00	89.74	73.70	92.45	83.30	89.74	79.50
300	87.21	64.00	85.07	65.80	87.21	73.60	85.07	70.10	87.21	78.00	85.07	74.40
	90.10	68.00	87.58	70.10	90.10	78.40	87.58	75.20	90.10	86.36	87.58	80.00
	92.45	77.76	89.74	79.50	92.45	85.20	89.74	84.70	92.45	94.00	89.74	90.00
375	87.21	72.00	85.07	76.00	87.21	81.77	85.07	80.00	87.21	85.60	85.07	83.56
	90.10	76.00	87.58	78.60	90.10	84.40	87.58	84.00	90.10	93.20	87.58	88.00
	92.45	86.00	89.74	87.20	92.45	92.10	89.74	93.40	92.45	95.10	89.74	96.00

Table 1 also shows that material feed rate for both guna varieties, interaction between fruit moisture content and machine speed on the *citrullus colocynthis* and interaction between material feed rate and machine speed for *citrullus lanatus* significantly affected the quantity of broken epicarp collected at the cleaner outlet at 1% level. The effect of fruit moisture content and machine speed on the *citrullus lanatus* broken epicarp collected at the cleaner outlet was significant at 5% level. The fruit moisture content, machine speed and interaction between material feed rate and machine speed for *citrullus colocynthis* and interaction between fruit moisture content and machine speed for *citrullus lanatus*, interaction between fruit moisture content and material feed rate and between fruit moisture content, material feed rate and machine speed on both guna varieties did not have significant effect on the quantity of broken epicarp collected.

The variation of machine cleaning efficiency with fruit moisture content, material feed rate and machine speed is shown in Table 3. The table indicates that the cleaning efficiency of the seed extractor decreased with increase in fruit moisture content for both guna varieties, but increased with the increase in both material feed rate and machine speed. The relationship existing between the cleaning efficiency and fruit moisture content, material feed rate and machine speed could be expressed by the following equations:

$$E_{cc} \approx -1974.10 + 52.442M - 0.685F - 0.520S + 0.009MF + 0.006MS + 3.621\times10^{-4}FS - 4.764\times10^{-6}MFS - 0.337M^2 - 5.319\times10^{-5}F^2 + 9.60\times10^{-7}S^2 \qquad (11)$$

$$E_{cl} \approx 329.838 - 10.596\,M + 1.671\,F + 0.545\,S - 0.020\,MF - 0.006\,MS$$
$$-0.002\,FS + 2.136 \times 10^{-5}\,MFS + 0.084\,M^2 + 4.489 \times 10^{-5}\,F^2$$
$$-2.712 \times 10^{-5}\,S^2 \qquad (12)$$

with values for the coefficient of determination, R^2 of 0.95 and 0.97 respectively, where E_{cc} is the machine cleaning efficiency on *citrullus colocynthis* in % and E_{cl} is the machine cleaning efficiency on *citrullus lanatus* in % .

The t-test of coefficients showed that the square of moisture content for *citrullus colocynthis* and interaction between moisture content and material feed rate for *citrullus lanatus,* were found to make the strongest unique contribution to the respective equations as compared to other variables.

Table 3. Variation of cleaning efficiency with guna fruit moisture content, material feed rate and machine speed

	cylinder speed:689min^{-1}				cylinder speed:814min^{-1}				cylinder speed:939min^{-1}			
Feed rate (kg/h)	Variety				Variety				Variety			
	c. colo.		*c.lana.*		*c. colo.*		*c.lana.*		*c. colo.*		*c.lana.*	
	M	E_c	*M*	E_c	*M*	E_c	*M*	E_c	*M*	E_c	*M*	E_c
150	87.21	71.86	85.07	72.46	87.21	74.24	85.07	75.95	87.21	80.34	85.07	78.71
	90.10	71.40	87.58	70.13	90.10	72.47	87.58	73.39	90.10	77.46	87.58	75.08
	92.45	57.77	89.74	69.42	92.45	66.16	89.74	72.89	92.45	67.97	89.74	73.86
225	87.21	79.04	85.07	76.05	87.21	80.14	85.07	79.20	87.21	83.08	85.07	81.77
	90.10	77.62	87.58	73.39	90.10	78.17	87.58	75.19	90.10	81.05	87.58	78.36
	92.45	60.79	89.74	71.73	92.45	75.75	89.74	74.14	92.45	80.43	89.74	76.09
300	87.21	84.36	85.07	78.67	87.21	86.46	85.07	81.30	87.21	90.46	85.07	89.51
	90.10	81.06	87.58	75.14	90.10	84.34	87.58	80.17	90.10	89.14	87.58	83.08
	92.45	74.26	89.74	72.06	92.45	80.15	89.74	79.17	92.45	88.13	89.74	81.26
375	87.21	90.12	85.07	83.22	87.21	90.50	85.07	86.03	87.21	94.15	85.07	91.28
	90.10	88.98	87.58	78.21	90.10	89.10	87.58	84.97	90.10	90.36	87.58	88.23
	92.45	82.88	89.74	73.70	92.45	88.43	89.74	81.54	92.45	89.52	89.74	86.31

The result of the ANOVA presented in Table 1 for seeds collected at the cleaner outlet shows that material feed rate for the *colocynthis*, interaction between fruit moisture content and material feed rate for the two varieties and interactions between moisture content and machine speed and that between material feed rate and machine speed for the *lanatus*, significantly affected the quantity of seeds at 1% level. Moisture content and machine speed for both varieties, feed rate for *citrullus lanatus* and interaction between material feed rate and machine speed for *citrullus colocynthis* significantly affected the quantity of seeds at 5% level, while the interaction between moisture content and machine speed for *citrullus colocynthis* and the interaction between moisture content, material feed rate and machine speed for both varieties did not have significant effect.

Table 4 shows the variation of cleaning loss with fruit moisture content, material feed rate and machine speed. From this table, it can be seen that the cleaning loss decreased with increase in moisture content, but increased with increase in material feed rate and machine speed for the two varieties of guna crop. Eqns (13) and (14) show the relationship existing between the cleaning loss and fruit moisture content, material feed rate and machine speed for the *colocynthis* and *lanatus* varieties, respectively.

$$L_{cc} \approx -736.236 + 19.985M - 1.196F - 0.462S + 0.014MF + 0.005MS + 0.002FS - 2.542\times10^{-5}MFS - 0.133M^2 - 6.267\times10^{-5}F^2 - 4.614\times10^{-6}S^2 \quad (13)$$

$$L_{cl} \approx -3128.88 + 61.483M + 4.301F + 1.235S - 0.051MF - 0.015MS - 0.005FS + 5.978\times10^{-5}MFS - 0.290M^2 + 1.552\times10^{-4}F^2 + 2.093\times10^{-5}S^2 \quad (14)$$

with the values for the coefficient of determination, R^2 of 0.86 and 0.84 respectively, where L_{cc} is the cleaning loss for *citrullus colocynthis* in % and L_{cl} is the cleaning loss for *citrullus lanatus* in %.

The interaction between material feed rate and machine operation speed was found to be the main predictor for Eqn (13) and the interaction between fruit moisture content and material feed rate was the main predictor for Eqn (14) as compared to other variables.

Table 4. Variation of cleaning loss with guna fruit moisture content, material feed rate and machine speed

	cylinder speed:689min^{-1}				cylinder speed:814min^{-1}				Cylinder speed:939min^{-1}			
Feed rate (kg/h)	Variety				Variety				Variety			
	c. colo.		*c.lana.*		*c. colo.*		*c.lana.*		*c. colo.*		*c.lana.*	
	M	L_c	*M*	L_c	*M*	L_c	*M*	L_c	*M*	L_w	*M*	L_c
150	87.21	7.72	85.07	10.33	87.21	8.83	85.07	12.85	87.21	10.58	85.07	14.53
	90.10	5.77	87.58	8.48	90.10	8.24	87.58	11.21	90.10	8.51	87.58	13.58
	92.45	2.79	89.74	6.47	92.45	5.87	89.74	8.32	92.45	8.38	89.74	8.59
225	87.21	8.75	85.07	11.92	87.21	10.46	85.07	13.60	87.21	12.18	85.07	16.96
	90.10	7.69	87.58	9.30	90.10	8.48	87.58	11.12	90.10	9.94	87.58	14.76
	92.45	5.77	89.74	7.39	92.45	7.45	89.74	7.58	92.45	9.50	89.74	9.42
300	87.21	15.56	85.07	19.02	87.21	20.58	85.07	26.57	87.21	24.57	85.07	29.09
	90.10	11.12	87.58	13.81	90.10	17.84	87.58	20.64	90.10	22.10	87.58	23.38
	92.45	6.66	89.74	8.32	92.45	7.12	89.74	11.09	92.45	8.75	89.74	11.23
375	87.21	16.46	85.07	20.59	87.21	19.82	85.07	25.29	87.21	23.56	85.07	26.30
	90.10	12.08	87.58	20.89	90.10	14.61	87.58	22.97	90.10	16.69	87.58	27.45
	92.45	9.09	89.74	11.20	92.45	10.06	89.74	13.42	92.45	12.77	89.74	25.16

Table 1 also shows that fruit moisture content and interaction between moisture content and material feed rate for *citrullus colocynthis* and material feed rate for both *citrullus colocynthis* and *citrullus lanatus* significantly affected the quantity of seeds lost at the concave at 1% level. The machine speed for *citrullus colocynthis* also affected the quantity of seeds lost at the concave at 5% level significance, while moisture content, machine speed and the interactions between moisture content and material feed rate for *citrullus lanatus*, between moisture content and machine speed, material feed rate and machine speed and moisture content, material feed rate and machine speed for both varieties of guna fruit did not have significant effect. The variation of percentage seed loss at concave with fruit moisture content, material feed rate and machine speed is shown in Table 5. The table indicates that percentage seed loss at concave increased with increase in moisture content, material feed rate and machine speed for both varieties of guna. The relationship existing between the percentage seed loss at concave and fruit moisture content, material feed rate and machine speed could be expressed by the following equations:

$$L_{cvc} \approx 222.411 - 5.672M + 0.112F + 0.054S - 0.001MF - 5.639\times10^{-4}MS$$
$$-1.318\times10^{-4}FS + 1.359\times10^{-6}MFS + 0.035M^2 - 3.605\times10^{-6}F^2 +$$
$$7.773\times10^{-7}S^2 \qquad (15)$$

$$L_{cvl} \approx 40.541 - 1.892M + 0.172F + 0.072S - 0.002MF - 8.271\times10^{-4}MS$$
$$-2.004\times10^{-4}FS + 2.171\times10^{-6}MFS - 8.271\times10^{-4}M^2 -$$
$$1.437\times10^{-5}F^2 + 3.760\times10^{-6}S^2 \qquad (16)$$

with values for the coefficient of determination, R^2 of 0.93 and 0.90 respectively, where L_{cc} is the percentage seed loss at concave for *citrullus colocynthis* in % and L_{cl} is the percentage seed loss at concave for *citrullus lanatus* in %.

The square of moisture content was found to make the strongest unique contribution to the concave loss for *citrullus colocynthis,* while the square of material feed rate was the main predictor for *citrullus lanatus* when compared with other variables.

From Table 1, it can be seen that material feed rate and interaction between fruit moisture content and material feed rate for both guna varieties significantly affected the quantity of material retained in the seed extraction chamber at 1% level, while moisture content for *citrullus lanatus* and machine speed for the two varieties significantly affected the quantity of material retained at 5% level.

The interaction between moisture content and machine speed, material feed rate and machine speed and between moisture content, material feed rate and machine speed for both guna varieties had no significant effect on material retention.

Table 5. Variation of percentage seed loss at concave with guna fruit moisture content, material feed rate and machine speed

	cylinder speed:689min^{-1}				cylinder speed:814min^{-1}				cylinder speed:939min^{-1}			
Feed rate (kg/h)	Variety				Variety				Variety			
	c. colo.		*c.lana.*		*c. colo.*		*c.lana.*		*c. colo.*		*c.lana.*	
	M	L_{cv}	*M*	L_{cv}	*M*	L_{cv}	*M*	L_{cv}	*M*	L_{cv}	*M*	L_{cv}
150	87.21	0.92	85.07	1.07	87.21	1.61	85.07	1.65	87.21	1.85	85.07	2.08
	90.10	1.49	87.58	1.55	90.10	1.84	87.58	2.19	90.10	2.42	87.58	2.72
	92.45	2.15	89.74	2.44	92.45	2.43	89.74	2.71	92.45	2.67	89.74	2.93
225	87.21	1.18	85.07	1.34	87.21	1.28	85.07	1.38	87.21	2.39	85.07	2.57
	90.10	1.55	87.58	1.78	90.10	2.49	87.58	2.62	90.10	2.58	87.58	2.93
	92.45	2.59	89.74	2.68	92.45	2.67	89.74	2.81	92.45	3.16	89.74	3.44
300	87.21	2.05	85.07	2.17	87.21	2.16	85.07	2.53	87.21	2.33	85.07	2.83
	90.10	2.33	87.58	2.97	90.10	2.49	87.58	3.01	90.10	2.47	87.58	3.14
	92.45	3.16	89.74	3.88	92.45	3.35	89.74	4.22	92.45	3.60	89.74	4.22
375	87.21	2.23	85.07	2.44	87.21	2.40	85.07	2.61	87.21	2.78	85.07	2.82
	90.10	2.42	87.58	2.82	90.10	2.67	87.58	3.33	90.10	2.76	87.58	3.32
	92.45	3.31	89.74	3.64	92.45	3.49	89.74	3.81	92.45	3.66	89.74	4.11

Table 6 shows the variation of material retention with fruit moisture content, material feed rate and machine speed. The relationship between material retention and moisture content, material feed rate and machine speed can be expressed for *citrullus colocynthis* and *citrullus lanatus* guna fruits using the following equations:

$$m_{rc} \approx -42.233 + 0.756M + 0.045F + 0.023S - 3.665\times10^{-4}MF - 2.107\times10^{-4}MS - 2.357\times10^{-5}FS + 3.063\times10^{-7}MFS - 0.003M^2 - 1.382\times10^{-5}F^2 - 2.693\times10^{-6}S^2 \quad (17)$$

$$m_{rl} \approx -114.065 + 2.545M - 0.007F + 0.004S + 2.772\times10^{-4}MF + 1.240\times10^{-5}MS + 5.722\times10^{-5}FS - 6.370\times10^{-7}MFS - 0.015M^2 - 2.059\times10^{-5}F^2 - 2.587\times10^{-6}S^2 \quad (18)$$

with values for the coefficient of determination, R^2 of 0.95 and 0.99 respectively, where m_{rc} is the material retention for *citrullus colocynthis* in % and m_{rl} is the material retention for *citrullus lanatus* in %.

The t-test of coefficients showed that the square of material feed rate made the strongest unique contribution to material retention compared to other variables.

Table 6. Variation of material retention with guna fruit moisture content, material feed rate and machine speed

	cylinder speed:689min^{-1}				cylinder speed:814min^{-1}				cylinder speed:939min^{-1}			
Feed rate (kg/h)	Variety				Variety				Variety			
	c. colo.		*c.lana.*		*c. colo.*		*c.lana.*		*c. colo.*		*c.lana.*	
	M	m_r	M	m_r	M	m_r	M	m_r	M	m_r	M	m_r
150	87.21	1.60	85.07	1.65	87.21	1.69	85.07	1.71	87.21	1.75	85.07	1.78
	90.10	1.41	87.58	1.70	90.10	1.46	87.58	1.77	90.10	1.51	87.58	1.80
	92.45	1.55	89.74	1.61	92.45	1.58	89.74	1.61	92.45	1.58	89.74	1.77
225	87.21	2.54	85.07	2.60	87.21	2.79	85.07	2.81	87.21	2.83	85.07	2.93
	90.10	2.49	87.58	2.54	90.10	2.55	87.58	2.61	90.10	2.60	87.58	2.71
	92.45	2.13	89.74	2.41	92.45	2.14	89.74	2.49	92.45	2.20	89.74	2.51
300	87.21	2.55	85.07	2.82	87.21	3.06	85.07	3.23	87.21	3.08	85.07	3.31
	90.10	2.67	87.58	2.95	90.10	2.70	87.58	3.28	90.10	2.71	87.58	3.31
	92.45	2.64	89.74	2.95	92.45	2.76	89.74	2.99	92.45	2.82	89.74	3.01
375	87.21	3.38	85.07	3.61	87.21	3.52	85.07	3.71	87.21	3.63	85.07	3.81
	90.10	3.27	87.58	3.43	90.10	3.58	87.58	3.68	90.10	3.68	87.58	3.70
	92.45	2.96	89.74	3.25	92.45	3.08	89.74	3.35	92.45	3.23	89.74	3.35

Table 1 equally shows that material feed rate and interaction between fruit moisture content and material feed rate for both guna fruit varieties had significant effect on the quantity of seeds retained in the extraction digestion chamber at 1% level. The fruit moisture content on *citrullus lanatus* and machine speed on both varieties significantly affected it at 5% level, while moisture content on *citrullus colocynthis*, interaction between moisture content and machine speed and between moisture content, material feed rate and machine speed on both guna fruit varieties had no significance effect on the quantity of seeds retained in the seed extraction chamber. The variation of percentage seed retention with fruit moisture content, material feed rate and machine speed is shown in Table 7. The table shows that percentage seed retention decreased with increase in fruit moisture content, material feed rate and machine speed for the two guna varieties. The relationship existing between percentage seed retention and fruit moisture content, material feed rate and machine speed can be expressed by Eqns (19) and (20).

$$\eta_{src} \approx -1749.190 + 42.254M + 0.456F + 0.097S - 0.006MF - 0.002MS - 7.451\times10^{-4}FS + 7.964\times10^{-6}MFS - 0.241M^2 + 5.649\times10^{-5}F^2 + 7.893\times10^{-6}S^2 \quad (19)$$

$$\eta_{srl} \approx -2847.72 + 69.839M - 0.157F + 0.067S - 3.833\times10^{-4}MF - 0.002MS - 1.418\times10^{-8}FS + 2.026\times10^{-6}MFS - 0.409M^2 + 6.232\times10^{-5}F^2 + 3.128\times10^{-5}S^2 \quad (20)$$

with values for the coefficient of determination, R^2 of 0.99 and 0.99 respectively, where η_{src} is the percentage seed retention for citrullus colocynthis in % and η_{srl} is the percentage seed retention for citrullus lanatus in %.

The square of fruit moisture content made the strongest unique contribution to percentage seed retention for both *citrullus colocynthis* and *citrullus lanatus* guna fruits.

Table 7. Variation of percentage seed retention with guna fruit moisture content, material feed rate and machine speed

	cylinder speed:689min^{-1}				cylinder speed:814min^{-1}				cylinder speed:939min^{-1}			
Feed rate (kg/h)	Variety				Variety				Variety			
	c. colo.		*c.lana.*		*c. colo.*		*c.lana.*		*c. colo.*		*c.lana.*	
	M	η_{sr}	M	η_{sr}	M	η_{sr}	M	η_{sr}	M	η_{sr}	M	η_{sr}
150	87.21	40.8	85.07	44.16	87.21	44.51	85.07	40.51	87.21	37.91	85.07	41.21
	90.10	40.61	87.58	40.16	90.10	40.53	87.58	40.25	90.10	32.79	87.58	38.56
	92.45	37.35	89.74	40.07	92.45	34.08	89.74	37.22	92.45	26.32	89.74	30.88
225	87.21	43.74	85.07	46.95	87.21	36.93	85.07	38.62	87.21	31.22	85.07	35.91
	90.10	39.66	87.58	41.90	90.10	31.96	87.58	33.94	90.10	22.04	87.58	27.33
	92.45	29.91	89.74	32.42	92.45	24.93	89.74	26.28	92.45	16.71	89.74	20.58
300	87.21	35.97	85.07	34.17	87.21	26.38	85.07	29.89	87.21	21.94	85.07	25.54
	90.10	31.96	87.58	29.89	90.10	21.53	87.58	24.74	90.10	13.58	87.58	19.95
	92.45	22.33	89.74	20.44	92.45	14.80	89.74	14.68	92.45	6.09	89.74	9.88
375	87.21	28.03	85.07	23.90	87.21	18.22	85.07	19.97	87.21	14.39	85.07	16.39
	90.10	23.96	87.58	21.46	90.10	15.53	87.58	16.03	90.10	6.74	87.58	11.99
	92.45	14.00	89.74	12.81	92.45	7.88	89.74	6.54	92.45	4.89	89.74	4.02

6. CONCLUSIONS

A guna seed extractor was developed in this study. The performance evaluation of the extractor showed that fruit moisture content, material feed rate and machine speed had significant effect on its performance indices.

Percentage effective seed extraction and concave loss increased with increase in fruit moisture content, material feed rate and machine speed. Cleaning efficiency, cleaning loss and material retention decreased with increase in moisture content and increased with increase in material feed rate and machine speed. Percentage seed retention decreased with increase in fruit moisture content, material feed rate and machine speed and practically no seed damage was recorded.

It should however be noted, that the significant effect of fruit moisture content on the performance indices within the moisture ranges employed that appeared narrow, might have been influenced by the contribution of biochemical and physiological changes that must have taken place in the fruits during storage.

The seed extractor has a compact design and a robust outlook. It will contribute to the enhancement of guna crop processing as it could be used to eliminate the tediousness of the present traditional methods of extracting guna seeds from the fruits.

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7. REFERENCES

Adewumi, B.A. and Fatusin, A.B. (2006). Design, fabrication and testing of impact-type hand operated cocoa pod breaker. *Agricultural Engineering International: The CIGR EJournal,* Manuscript PM 06 022, vol. 8.

Ajibola, O. O; Eniyemo, S. E; Fasina, O. O; & Adeeko, K. A. (1990). Mechanical expression of oil from melon seeds. *Journal Agricultural Engineering Research,* 45: 45 – 53.

Atiku, A. A; Aviara, N. A. and Haque, M. A. (2004). Performance evaluation of a bambara groundnut sheller. *Agricultural Engineering International: The CIGR EJournal,* Manuscript PM 04 012, vol. 6.

ASAE (1983). ASAE Standards: ASAE 352.1, Moisture measurement-grain and seeds. American Society of Agricultural Engineers. St. Joseph, Michigan.

Aviara, N. A; Gwandzang, M. I. and Haque, M. A. (1999). Physical properties of guna seeds. *Journal of Agricultural Engineering Research,* 73: 105 –111.

Aviara, N. A. and Haque, M. A. (2002). Processing and storage of guna crop in the North east arid region of Nigeria. *Agricultural Mechanisation in Asia, Africa and Latin America,* 33(1): 49 – 54.

Aviara, N. A; Shittu, S. K. and Haque, M. A. (2007). Physical properties of guna fruits relevant in bulk handling and mechanical processing. *International Agrophysics,* 21: 7 - 16.

Badifu, G. I. O. and Ogunsua, A. O. (1991). Chemical composition of kernels from some species of curcubitaceace grown in Nigeria. *Plant Foods and Human Nutrition,* 41: 35 - 44.

Balakrishnan, M; Thirupathi, V. and Sree Narayanan, V. V. (2006). Development and testing of a chilli seed extractor. *Agricultural Mechanization in Asia, Africa and Latin America,* 37 (4): 46 – 48.

Gwandzang, M. I; Aviara, N. A; Yelwa, H. and Hassan, H. K. (1994). Guna crop production, processing and storage. Seminar paper, Department of Agricultural Sciences and Technology, Ramat Polytechnic, Maiduguri, Nigeria.

Kailappan, R; Baig, P. K; Varadharaju, N; Appavu, K. and Krishsamy, V. (2005). Fabrication and testing of a tomato seed extractor. *Agricultural Mechanization in Asia, Africa and Latin America,* 36(2): 62 – 66.

Kushwaha, H. L; Srivastava, A. P; & Singh, H. (2005). Development and performance evaluation of an okra seed extractor. *Agricultural Engineering International: The CIGR EJournal,* Manuscript PM 05 001, vol. 7.

Norton, G. (1993). *Guna seed analysis.* Department of Applied Biochemistry and Food Science, The University of Nottingham, UK.

Oje, K. (1993). Some engineering properties of thevetianut. *Journal of Agricultural Engineering and Technology*, 1: 38 – 45.

Oloko, S. A, and Agbetoye, L. A. S. (2006). Development and performance evaluation of a melon depodding machine. *Agricultural Engineering International: The CIGR EJournal,* Manuscript 06 018, vol. 8.

Olusoji, O. (1980). Development of a cocoa bean extractor. *Proceedings of the Nigerian Society of Agricultural Engineers*, 4: 65 – 84.

Oluwole, F. A; Aviara, N. A. and Haque, M. A. (2004). Development and performance tests of a sheanut cracker. *Journal of Food Engineering*, 65: 117 – 123.