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The effect of mechanized shelling and packaging on the quality of melon seeds

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ABSTRACT

A comparative study was carried out between mechanized shelling and manual shelling of Egusi-melon seeds and the effect of different packaging materials on some quality attributes of shelled Egusi-melon seeds(Bara and Serewe). Egusi-melon seeds were manually shelled and mechanically shelled using the National Centre for Agricultural Mechanization (NCAM) mechanical melon Sheller (2018 and 2020 models) and a Rice huller (SB-10D Rice mill). Shelled Egusi-melon seeds were packaged and stored in kraft paper, glass bottles, laminated pouches, and a low-density polypropylene bag for 10 weeks. The Shelling efficiency of different machines compared to manual shelling (control) was evaluated. Manual shelling (control) was the most efficient in terms of output quality. The 2020 NCAM mechanical melon Sheller was the most efficient of the mechanized processes, while the rice huller was the least efficient. The shelled seeds were evaluated for shelling, free fatty acid, and microbial analysis. Results showed that Bara was more efficiently shelled by machines while Serewe was more efficiently shelled manually. Kraft paper seems to reduce seed spoilage over the storage period compared to the other packaging materials, the seeds shelled using the 2020 NCAM mechanical melon Sheller consistently recorded a significantly lower percentage increase in free fatty acid and fungal load. This research has provided valuable insight that selecting a suitable variety, shelling machine, and packaging material is crucial for the overall efficiency and high-quality output of large-scale production of shelled Egusi-melon.

Keywords: Egusi-melon seed, shelling machine, free fatty acid, packaging material

INTRODUCTION

Egusi is a type of watermelon (*Citrullus lanatus, Citrullus vulgaris, or Colocynthis citrullus*) **[1]** that is mostly grown in West Africa for its seed, with Nigeria accounting for about 65% of the total production **[2]**, **[3]**. Egusi-melon seed is characterized by high moisture content (about 90%) and is an excellent source of dietary oil (49.05%-53.10%) and protein (27.60%-33.80%). Its amino acid profile compares favourably with soybean meal **[4]**, **[1]**, **[5]**. Given its rich nutritional profile, Egusi-melon seeds are used as a major ingredient to enrich soups especially, as a soup thickener. Egusi serves as a meat substitute in soups and snacks served on special occasions **[6]**, **[7]**. Its use as a meat substitute follows the formulation process with spices, moulding into different shapes, roasting, smoking, and drying. In addition, Egusi oil is high in unsaturated fatty acids which could be used for different applications (domestically and industrially) **[8]**.

The economic importance of Egusi-melon seed as a trading commodity is growing. Nigeria's export of Egusi-melon seed in 2021 to India, Guatemala, and Brazil was approximately 42,000 metric tons **[2]**, **[9]**, **[10]**. Notably, before the exportation of Egusi-melon seeds, they are processed after harvest into value-added products for easy marketability and acceptance. The unit operations involved in Egusi processing include fermenting the pod (10-

15 days) after harvest to soften the pulp, extracting the seeds from the soft pulp, washing and drying the seeds, followed by removing the shells (hulls) to obtain the cotyledon/kernel **[8]**.

Importantly, the decortication of Egusi-melon seed is a step in its processing that is crucial to produce cotyledons of acceptable quality before being processed for consumption. Currently, Egusi-melon seeds are manually peeled by local women. The process of manual decortication is a slow, tedious, time-consuming, and inefficient process, and increases the risk of contamination due to manual handling. This tends to create a scarcity of products with associated high pricing, especially during the off-season period in non-producing areas. To avert the limitations associated with manual handling, Egusi producers adopted the use of shelling machines which has significantly changed the dynamics of Egusi-melon seed production to meet the capacity for large-scale production. Most researchers have developed different Egusi shelling machines intending to automatically separate kernels from shells, thus saving time and labour requirements **[11]**, **[12]**. However, some of these machines have some identified setbacks as there have been reports of broken seeds and mechanical injuries on the cotyledon (kernels) inflicted by these shelling machines. For instance, Olusegun and Adekunle **[13]** recorded broken seeds that exceeded 20% of the number of seeds being shelled after testing Egusi-melon seed shelling by passing them through two wooden shelling discs, one fixed and the other made to rotate in the clockwise and anti-clockwise direction. Consequently, product quality is lost as spoilage can rapidly set in due to rancidity because of cell rupturing that liberates free fatty acids **[14]**, **[15]**, causing objectionable flavour, taste, and appearance **[16]** observed that when such injured/broken seeds are used as a soup ingredient, the soup quickly acquires a rancid off-flavour. Given these setbacks, the large-scale processing of Egusi-melon seed for export purposes is significantly limited, as consumers tend to prefer the manually shelled seeds to the mechanized shelled Egusi-melon seed. Therefore, it is very fitting to find ways of improving the shelling efficiency of Egusi-melon seed by studying how the types of machines and seed varieties affect the overall output.

Furthermore, following the shelling of Egusi-melon seed is the packaging of the cleaned melon seeds, as it adds value to the final product. Packaging is done to provide the food with an enclosure that protects it from contamination from physical, chemical, or biological sources in its environment **[17]**. The type of packaging material significantly affects the shelf-life and product quality. Glass bottles, paper bags, polyethylene/polypropylene, and laminated aluminium pouches are primarily used in packaging food products because they tend to be inert/unreactive to the food. However, these packaging materials have different barrier properties and would offer varying levels of protection to food **[18]**. Finding the right packaging material for Egusi-melon seed is also vital for large-scale production (especially for the export market) since moisture and gases (air) are responsible for hydrolytic rancidity and oxidative rancidity respectively. Therefore, this study aims to determine the effect of mechanized decortication and packaging on the quality attributes of different varieties of Egusi-melon seed. This work will guide the design of improved equipment for the mechanical shelling of Egusi-melon seeds, reduced cost of shelled Egusi-melon seeds and reduced spoilage of processed Egusi-melon seeds. It will also guide processors on variety selection for optimized efficiency with an increased volume for commercial purposes.

Scientific Hypothesis

Using an improved shelling machine, proper selection of Egusi-melon seed variety, and packaging material can improve the quality of stored shelled Egusi-melon seeds. We expect a higher efficiency for the improved Egusi-melon shelling machine than the old model machine. There would be a reduced percentage increase in free fatty acid and fungal colony count for the seeds shelled using the improved machine with suitable packaging.

MATERIAL AND METHODOLOGY

Samples

Two different unshelled Egusi-melon seed varieties (Serewe and Bara) used in this research were purchased from dealers at Kofar-Gwari market located at Kokona L.G.A in Nasarawa State, Nigeria. The study was done at Emery Research Laboratory (ERL) in Abia state, Nigeria.

Chemicals

All Chemicals used were provided by ERL, Nigeria. Phenolphthalein indicator solution for free fatty acid determination. Sterile peptone water was used in the CFU analysis. Freshly neutralized hot ethyl alcohol was used for acid test. Standard alkali solution for FFA determination. Sabouraud dextrose agar plates (SDA), produced by Dimante Scientific. Streptomycin for SDA medium modification. All solvents and reagents supplied by ERL, including water were of analytical grade quality.

Animals, Plants and Biological Materials

Animals - Animals were not used in this research.

Plants - *Colocynthis citrullus* L. referred to as Egusi-melon in this study.

Biological materials - Special biological materials were not used in this research.

Instruments

Electric blender (Itel-IBL80E1) for easy oil extraction. Soxhlet extractor SE- 6P was used to extract fat from Egusi-melon seed. Mechanical melon shellers (2018 and 2020 Models) sourced from National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria. Rice huller, SB-10D Rice Mill (Satake Company, China). An industrial violet sterilizer (model UV-2500, Rio, Italy) was used to sterilize the packaging materials. Mechanical sealing machine operated manually (Super master, Japan) was used to seal the packages hermetically. Stirer, conical flask, Petri dishes, ovens, and filter papers were also used in this research.

Laboratory Methods

The shelling efficiency of both manual and machine-shelled Egusi-melon seeds was determined by calculating the ratio of completely shelled melon seeds to the total weight of unshelled melon seeds fed into each machine type or shelled manually. The shelling efficiency of Egusi-melon seed expressed in percentage is given below.

$$\text{Shelling efficiency (\%)} = \frac{Weight\ of\ wholesome\ melon\ seeds}{Total\ weight\ of\ shelled\ melon\ seeds} \times 100 \quad (1)$$

Where the total weight of shelled melon seeds is given as melon shells + broken shelled melon seeds + unbroken shelled melon seeds + damaged melon seeds.

The free fatty acid of the samples were determined by the standard method as described by **[19]**, The packaged/stored samples were milled using an electric blender (Itel-IBL80E1) for easy oil extraction. Soxhlet extractor was used to extract fat from Egusi-melon seed by weighing 5 g of milled sample into a filter paper, wrapping, and placing in an extraction thimble. After extraction, the solvent was evaporated by drying in the oven. The extracted oil (5 g) was weighed and transferred accurately in a 250m conical flask and 50 ml of freshly neutralized hot ethyl alcohol and 0.5 ml of phenolphthalein indicator solution were added. The mixture was boiled for about five minutes and titrated while hot against a standard alkali solution until colour changed to pink. This was carried out periodically for 10 weeks. The free fatty acid, expressed in percentage is given as;

$$\text{FFA (\%)} = \frac{56.1 \times V \times N}{W} \quad (2)$$

Where:

V – Volume of the standard potassium hydroxide used (ml); N – Normality of the potassium hydroxide solution; W – Weight of the sample (g).

Given the nature of the material and susceptibility of Egusi-melon seeds to be prone to fungal infestation, the fungal colony counts of the samples were determined on Sabouraud dextrose agar plates (SDA) according to the standard as method described by **[20]**. The SDA media was modified with streptomycin to inhibit bacterial contamination. Each sample (1 g) was homogenized in 9 ml of sterile peptone water. Ten-fold serial dilution was done aseptically, and 0.1 ml of the diluted samples were inoculated into a petri dish containing solidified SDA and incubated for 3-5 days at 37 °C. Colonies were then counted and recorded after the incubation period. This was carried out bi-weekly for 10 weeks.

Description of the Experiment

Sample preparation: The Egusi-melon seeds were sorted to remove stones, dirt, and unhealthy seeds. Samples (5kg) were separately shelled using 4 different processing systems (Manual shelling, NCAM mechanical melon Sheller (2018 Model), NCAM mechanical melon Sheller (2020 Model), and SB-10D Rice milling machine (Figure 1). Notably, NCAM mechanical melon Sheller (2018 Model) is made of mild steel (prone to rust), while NCAM mechanical melon Sheller (2020 Model) is made of stainless steel. Each sample was pretreated by tempering with 200 ml of water per 5 kg of the sample at ambient temperature, mixed thoroughly, spread on a paper, and allowed to rest for 1 hour before the shelling operation. This makes the seed coat more pliable and reduces breakage making it more suited for shelling. The pretreated samples were divided into four equal parts, each for a different shelling approach.

Number of samples analyzed: We analyzed 80 samples.

Number of repeated analyses: All measurements of instrument readings were performed three times.

Number of experiment replication: Samples from the same population across the Egusi varieties were analyzed in triplicates.

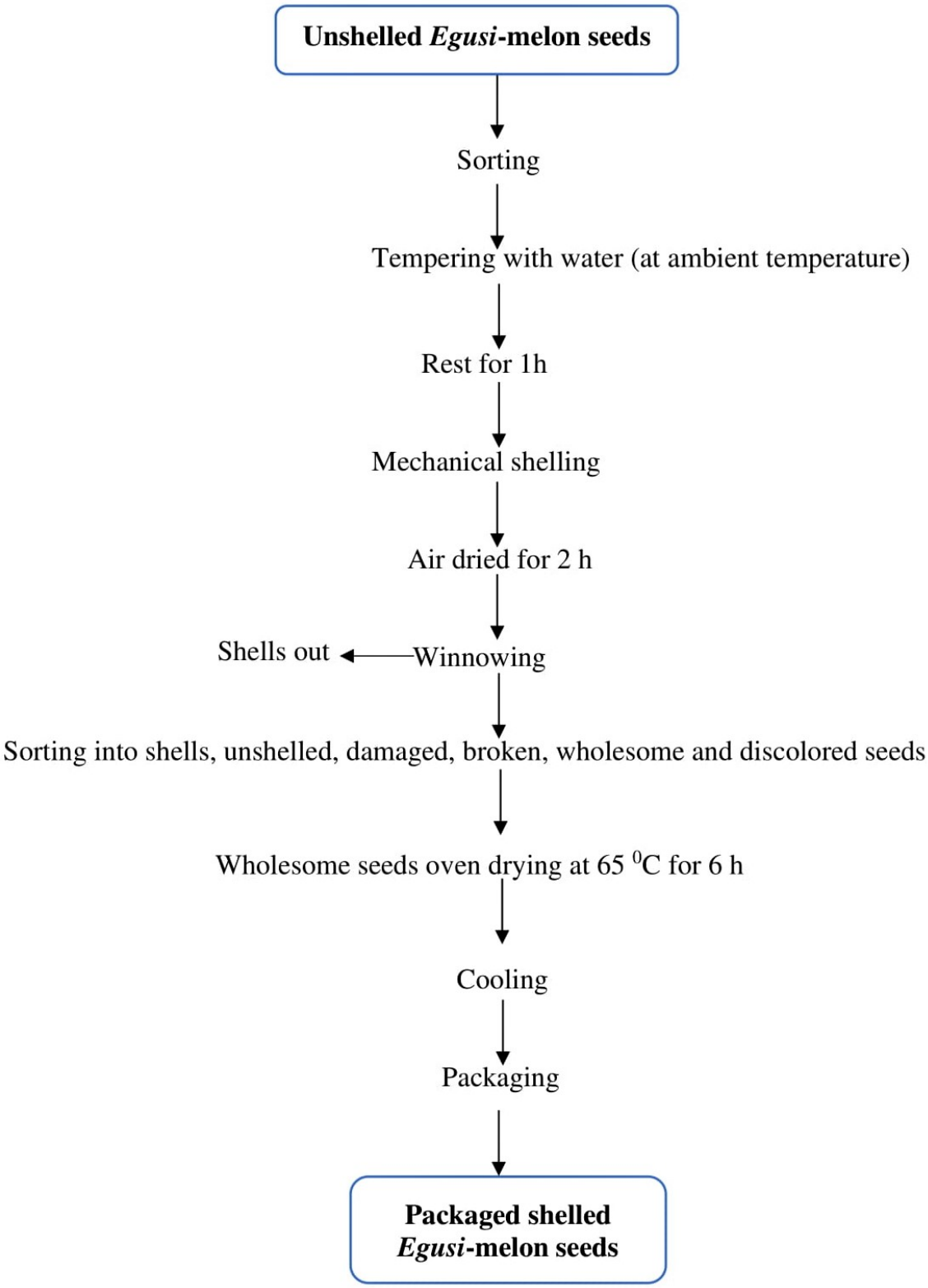

Figure 1 Flow chart for machine-shelled Egusi-melon seeds.

Design of the experiment: The experimental design, showing the various stages from procurement of Egusi samples to laboratory analyses is shown in Figure 2. Briefly, this research was designed to carry out a comparative study between mechanized shelling and manual shelling of Egusi-melon seeds and the effect of different packaging materials on some quality attributes of the shelled Egusi-melon seeds. This was done by shelling Egusi-melon seeds using different machines (Manual shelling, NCAM mechanical melon Sheller (2018 Model), NCAM mechanical melon Sheller (2020 Model), and SB-10D Rice milling machine (Figure 1). The NCAM mechanical melon shellers do shelling by impact and attrition principle and are driven by a 5.5 HP petrol engine prime mover at 650 RPM. The prime mover speed control lever was adjusted to achieve the desired speed.

On the other hand, the SB-10D Rice milling machine is a compact combined rubber roll mill that can rub off the Egusi-melon seed shell as they pass through the space between two counter-rotating rubber rollers driven at 1500 RPM by a 20 HP diesel engine prime mover. Five volunteers shelled a portion of the samples manually, and this served as the control. All shelled samples were dried, winnowed, and sorted into various categories (shells, shelled whole seeds, unshelled seeds, broken seeds, damaged seeds, and partially shelled seeds) followed by packaging as shown in Figure 1.

The packaging materials were sterilized using an industrial violet sterilizer (model UV-2500, Rio, Italy). Shelled Egusi samples (100 g) were placed in different packaging materials made of glass bottles, Kraft paper envelops (thickness 0.01 mm, density 1.4 g/cm^3, and porosity 3.21 g/cm^2), low-density polypropylene bags (thickness 0.02 mm and density 0.45 g/cm^3) and laminated (Aluminum/high-density polyethylene) pouches (thickness 0.5 mm and density 0.82 g/cm^3). All packages were properly corked/sealed hermetically and stored under ambient conditions of about 25-27 ºC in the laboratory for 10 weeks. Analysis (shelling efficiency, free fatty acids, and microbial load of shelled Egusi-melon seeds after being packaged in different packaging materials) was carried out bi-weekly by collecting samples from the packaged/stored samples. The multilevel factorial (2 × 4 × 4) experimental design is shown in Table 1.

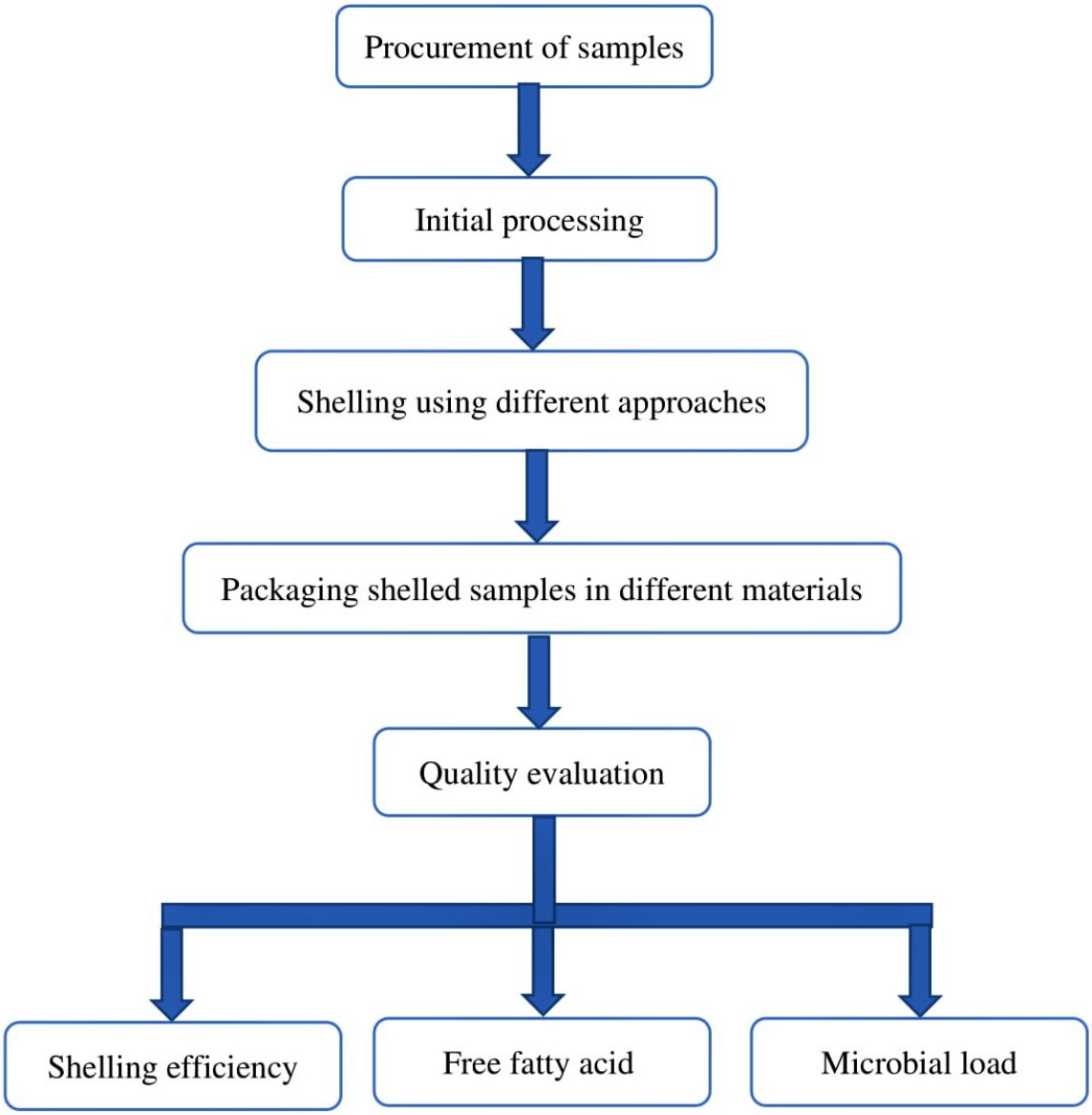

Figure 2 Schematic diagram of the experiment.

Table 1 Multilevel Factorial Experimental Design.

	Factor A	Factor B	Factor C
Name	Melon variety	Shelling equipment	Packaging material
Type	Nominal	Nominal	Nominal
Levels	2	4	4
1	Serewe	Manual	Paper
2	Bara	2018 NCAM Machine	Plastic
3	-	2020 NCAM Machine	Glass
4	-	Rice huller	Laminated pouch

Statistical Analysis

Using the boxplot, Levene's test, and skewness & kurtosis tests, the Analysis of Variance (ANOVA) assumptions of outliers, homogeneity of variances, and normality were examined, respectively **[21]**. As shown in Table 1, data from measurements of melon samples in triplicate were treated to a multilevel (2 × 4 × 4) factorial design. Using SPSS version 26, a three-way ANOVA was conducted, which considered the type of melons, the shelling apparatus, and the packaging material. Mean differences were reconciled using Fisher's least significant difference (LSD). The mean and standard deviation were used to express the results of the dependent variables (measured parameters) (SD). Simple correlation tests were also carried out to identify any connections between the measured shelling analyses. The level of statistical significance was set at 95% (p <0.05) confidence level. IBM SPSS software version 20 (IBM Corporation, New York, USA) was used to do the analysis **[22]**.

RESULTS AND DISCUSSION

The result of the shelling efficiency of two varieties of Egusi-melon seed for the different machines shows that all the mechanized shelling processes were less efficient in terms of output of shelled whole cotyledons than the manual shelled (Control) Egusi-melon seeds. The Bara variety was consistently more efficiently shelled than the Serewe variety for the mechanized shelling processes but less efficiently shelled for the control. The thicker shell of the Bara variety **[23]** may have naturally made it more suitable for mechanized shelling. From the result, the handling for the manually shelled Egusi-melon was more efficient for the smooth, thin-shelled Serewe variety than the thick black edge Bara variety. Therefore, the Bara variety is a preferably better-performing choice raw material for mechanized shelling than the Serewe variety. This result is similar to the findings by **[24]** who reported 55.8% shelling efficiency for mechanically shelled Bara seeds and 50.3% efficiency for mechanically shelled Serewe seeds.

The rice huller was the least efficient machine. This is probably because the rice huller is designed for a more energy-intensive and higher friction task of rice dehusking operation compared to the Egusi-melon shelling operation which may not require as much energy input and friction considering the more delicate cotyledon. This claim is supported by **[25]** who opined that rice processing and milling involve many unit operations that expose the grains to various forces such as impact, shearing, and friction mainly during husking and milling. The thicker shell of the Bara variety was able to resist the damaging effect of the rice dehusking rollers much more than the Serewe variety, and this agrees with **[26]**, who established that the magnitude of the damage caused during the processing depends on the physical and mechanical properties of the grains. Thus, its shelling efficiency was more than double that of the Serewe variety with the rice huller. The Egusi mechanical Sheller (2020 model) machine gave a higher efficiency than the Egusi mechanical Sheller (2018 model) machine for both varieties confirming the design upgrade's improvement.

The shelling analysis of the different varieties of Egusi-melon seeds by different shelling machines is shown in Tables 2 and 3. Manual shelling (control) produced the highest whole-shelled seed output compared to all other shelling (mechanized) processes. This result agrees with the previous research of **[12]** and **[24]** regarding the output of whole/intact shelled cotyledons. The whole-shelled seeds from the mechanized operations were about 50% of the output except for the rice huller, which had 18% (Serewe variety) and 30% (Bara variety). The whole seeds from the manual operation were significantly (p <0.05*)* higher for the Serewe variety (65%) compared to the Bara variety (60%). The Serewe variety produced a significantly (p <0.05) higher whole seed output than the Bara variety for the manual shelling, but the mechanized operations produced significantly (p <0.05*)* higher whole seed for the Bara variety (30%-50%) than the Serewe variety (18%-47%) **[27]**. The thicker shell of the Bara variety **[24]** may have naturally made it more suitable for mechanized shelling. The seed shell was significantly (p <0.05) higher for the Bara variety (7%-22%) compared to the Serewe variety (4%-16%) for all the machine types and control. This is a result of the thicker shell that occurs with the Bara variety, which

corroborates the report by **[28]**, who reported differences in the thickness of the shell between the two varieties of Egusi-melon seed. This thicker shell probably provided greater protection for the cotyledon from being broken. Thus, the Serewe variety suffered significantly (p <0.05) higher breakages in the mechanized operations and control. The lighter shell of the Serewe variety could also cause the occurrence of significantly (p <0.05) higher partially shelled seeds for the Serewe variety for the mechanized operation.

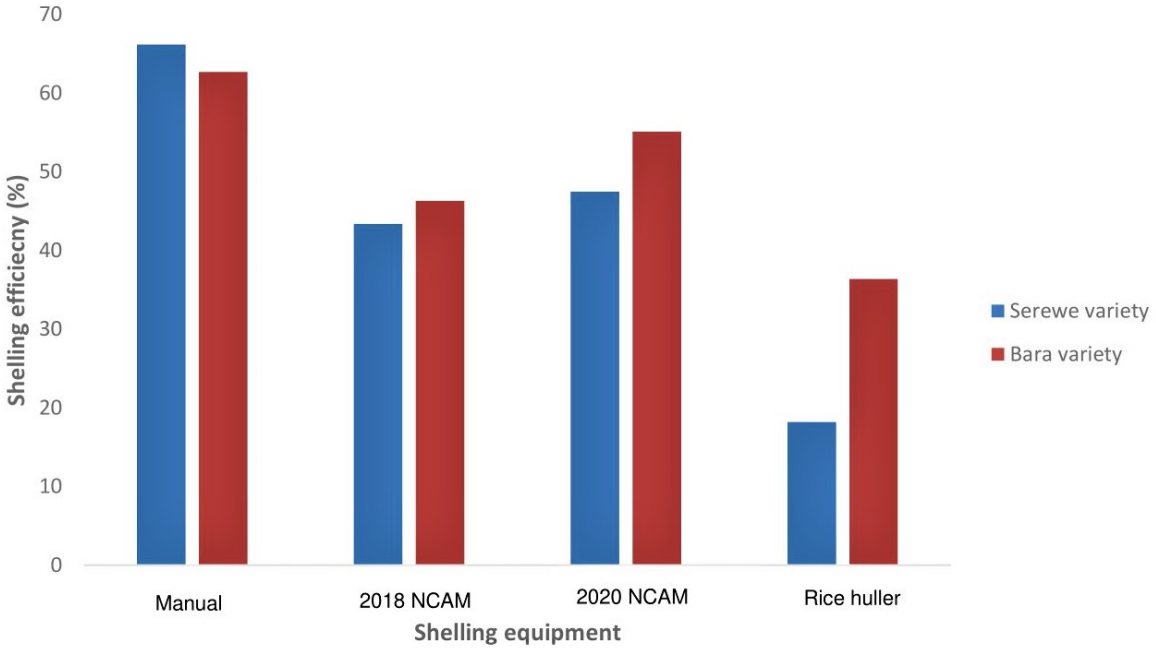

Figure 3 Shelling efficiency of different shelling equipment on Egusi-melon of two varieties.

Table 2 Whole seed, broken seed and seed shell of melon seed varieties as affected by shelling equipment.

Shelling equipment	Whole seed (%)		Broken seed (%)		Seed shell (%)	
	Serewe variety	Bara variety	Serewe variety	Bara variety	Serewe variety	Bara variety
Manual	*65.10^{a} ±0.14	59.90^{a} ±0.39	*13.00^{d} ±0.24	9.80^{d} ±0.29	16.00^{a} ±0.65	*21.57^{a} ±0.77
2020 NCAM	47.00^{b} ±0.21	*49.61^{b} ±0.28	*21.20^{b} ±0.86	16.67^{b} ±0.86	10.00^{b} ±0.53	*13.14^{b} ±0.31
2018 NCAM	40.60^{c} ±0.56	*44.02^{c} ±0.55	*16.20^{c} ±0.56	12.35^{c} ±0.64	8.00^{c} ±0.84	*14.22^{c} ±0.61
Rice huller	18.00^{d} ±0.84	*29.61^{d} ±0.67	*30.00^{a} ±0.75	20.59^{a} ±0.45	3.60^{d} ±0.14	*7.06^{d} ±0.21
LSD	**1.08**	**0.76**	**2.98**	**2.26**	**0.94**	**1.97**

Note: Values are means of duplicate determinations (N = 2). a,b…means with different superscripts along a column for each variety within a parameter is significantly different (p <0.05). *….means with an asterisk (*) within a row and the measured parameters of shelling analysis are significantly different (p<0.05).

The two-factor first-order analysis of variance that shows the interaction between the Egusi-melon variety and shelling equipment is presented in Table 4. There is a high level of interaction between the Egusi-melon variety and shelling equipment in the output of the whole, damaged, and partially shelled seed. This implies that a proper selection of Egusi-melon variety and equipment is important for overall efficiency and high-quality output, mainly to produce whole-shelled Egusi-melon and reduce the damaged seed.

Table 3 Damaged seed, partially shelled seed and density of melon seed varieties as affected by shelling equipment.

Shelling equipment	Damaged seed (%)		Partially shelled seed (%)		Density (g/cm^3)	
	Serewe variety	Bara variety	Serewe variety	Bara variety	Serewe variety	Bara variety
Manual	$0.20^{d} \pm 0.00$	$*0.49^{d} \pm 0.13$	$3.40^{d} \pm 0.28$	$*3.73^{c} \pm 0.09$	$*1.13^{a} \pm 0.00$	$1.11^{a} \pm 0.00$
2020 NCAM	$*10.00^{c} \pm 0.28$	$7.84^{a} \pm 0.45$	$*10.80^{c} \pm 0.14$	$2.75^{d} \pm 0.28$	$*1.13^{a} \pm 0.00$	$1.11^{a} \pm 0.00$
2018 NCAM	$*4.60^{b} \pm 0.53$	$2.84^{b} \pm 0.69$	$*24.10^{a} \pm 0.21$	$22.55^{a} \pm 0.30$	$*1.13^{a} \pm 0.00$	$1.11^{a} \pm 0.00$
Rice huller	$*30.00^{a} \pm 0.82$	$17.65^{c} \pm 0.56$	$*17.50^{b} \pm 0.11$	$8.82^{b} \pm 0.83$	$*1.13^{a} \pm 0.00$	$1.11^{a} \pm 0.00$
LSD	**2.84**	**0.73**	**1.12**	**1.00**	**NS**	**NS**

Note: Values are means of duplicate determinations (N = 2). a,b…means with different superscripts along a column for each variety within a parameter is significantly different (p <0.05). *….means with an asterisk (*) within a row and the measured parameters of shelling analysis are significantly different (p <0.05).

Table 4 Two-factor (first order) ANOVA of Egusi-melon variety and shelling equipment on the shelling parameters of melon samples.

Parameter	Variance ratios (F value)			Mean square error
	Main effect		Interaction	
	A	B	A × B	
Whole seed	85.769*	2279.785*	104.677*	0.451
Partial Eta Squared	*0.915*	*0.999*	*0.975*	-
Broken seed	30.284*	40.471*	2.202^{NS}	3.636
Partial Eta Squared	*0.791*	*0.938*	*0.452*	-
Seed shell	68.554*	98.635*	1.891^{NS}	1.232
Partial Eta Squared	*0.895*	*0.974*	*0.415*	-
Damaged seed	28.623*	192.789*	14.444*	2.229
Partial Eta Squared	*0.782*	*0.986*	*0.844*	-
Partially shelled seed	137.913*	519.543*	35.392*	0.585
Partial Eta Squared	*0.945*	*0.995*	*0.930*	-

Note: A – Melon variety; B – Shelling equipment; A × B – Variety × Shelling equipment; Analyses were done for two melon varieties, four shelling equipment, and four packaging materials. *F value is significant at p <0.05; NS implies not significant (p >0.05).

The percentage increase in free fatty acid and fungal colony count is shown in Table 5.

The largest increase in free fatty acid was observed with the samples packaged in the Laminate packaging materials (410%-3298%) while the least increase was observed for the paper-packaged samples (413%-2290%). This trend was corroborated by the increases in fungal growth, which followed a similar pattern. It is possible that the laminate allowed some level of oxygen transmission across the plastic inner lining that enabled profuse fungal growth and an increase in free fatty acid. Plastics are known to permit the transmission of oxygen **[29]** and aluminium is known to have an oxide layer on its surface **[30]**. The paper packaging on the other hand due to its absorbent nature may have reduced the occurrence of FFAs because it allowed for the drying of stored shelled Egusi-melon seed and because it must have absorbed some of the oil **[31]**. This is supported by **[32]**, who stated that volatile molecules evaporate at the packaging surface. This result makes paper the most suited packaging material for quality retention of shelled Egusi-melon seeds, at least, in the short term. There was appreciable free fatty acid in samples packaged in glass with corresponding fungal colony count. The oxygen in the headspace of

the bottle could have supported the increases. This corroborates the findings by **[33]** who reported an increase in free fatty acid from stored sunflower oil.

The highest free fatty acid increase (410%-3298%) occurred with the Bara variety while the least increase was observed for the Serewe variety (413%-2290%). The increase in fungal growth also followed the same pattern. There may be differences in the genetic disposition among the two varieties in terms of promotion or limitation of fat hydrolysis activity; there could be differences in their inherent antioxidant mechanisms **[34]**. This supports the findings of **[35]** who reported genetic diversity among Nigerian Egusi melon varieties. **[36]** Suggests that the presence of microorganisms is a possible cause of high free fatty acid in the stored seeds, therefore samples of the Bara variety, which recorded a significant (p <0.05) higher microbial load also recorded a higher percentage increase in free fatty acid. The bruises to the cotyledons leading to the exposure of the fat content and possibly lipases in the cotyledons would have promoted the build-up of free fatty acids **[37]**. Therefore, the Bara seeds which recorded a significantly (p <0.05) higher fat content than the Serewe variety, according to the findings by **[38]**, also had a significantly (p <0.05) higher percentage increase in free fatty acid.

The highest free fatty acid increase (3298%) occurred with the Egusi samples processed in the Egusi mechanical Sheller (2018 model) machine. The same sample also had the highest increase in fungal colony count (1636%). The least free fatty acid increase (410%) was recorded for the manually shelled Egusi-melon sample and the least fungal growth (255%) occurred with the manually de-hulled Egusi-melon samples. These results confirm that manual shelling still produced the least damaging effect on quality compared to mechanized shelling. It is also possible that the injuries on the Egusi-melon cotyledons, which exposed oil and othe nutirents, promoted the fungal growth. This corroborates the report by **[39]** which suggests that stored shelled oilseeds are prone to fungal growth. These breakages occurred more with the mechanized shelling. The use of mild steel (which rusts easily) for the Egusi mechanical Sheller (2018 model) compared to the stainless steel of the Egusi mechanical Sheller (2020 model) could have caused more pitting on the contact surfaces of the machine thereby making it a rough surface and could have impacted more injuries on the cotyledons **[40]**. The ANOVA table (Refer to Table 4) indicates a high level of interaction (0.627) between the Egusi-melon variety and packaging material. This implies that the variety and packaging material has a significant (p <0.05) effect on free fatty acid production. There was also a significantly (p <0.05) high level of interaction between the shelling equipment and packaging material for free fatty acid changes and the changes in fungal colony count.

Table 5 Percentage increase in free fatty acid (%) and fungal colony count (cfu/g) of melon of different varieties.

Shelling equipment	Packaging material	Percentage increase in FFA (%)		Percentage increase in fungal growth (%)	
		Bara variety	Serewe variety	Bara variety	Serewe variety
Manual	Glass	*1894^{f} ±2.15	1433^{e} ±7.09	*734^{g} ±6.80	460^{f} ±7.92
	Laminate	*2869^{b} ±3.23	1882^{b} ±9.80	*1207^{c} ±9.51	736^{c} ±9.75
	Paper	*410^{k} ±5.65	413^{l} ±5.77	*493^{j} ±8.70	255^{h} ±4.17
	Plastic	*1472^{h} ±7.03	1026^{j} ±7.16	*528^{i} ±5.09	357^{g} ±6.52
2020 NCAM	Glass	*2415^{c} ±7.44	1542^{d} ±5.24	*1219^{c} ±5.32	694^{c} ±4.91
	Laminate	*2888^{b} ±8.40	1896^{b} ±6.42	*1233^{c} ±6.43	739^{c} ±6.11
	Paper	*814^{i} ±3.83	518^{k} ±2.99	*637^{h} ±3.18	399^{f} ±8.56
	Plastic	*2100^{e} ±8.92	1193^{h} ±7.31	*705^{g} ±7.18	371^{g} ±3.46
2018 NCAM	Glass	*2926^{b} ±7.55	1385^{f} ±9.37	*1439^{b} ±8.22	844^{b} ±8.45
	Laminate	*3298^{a} ±9.14	2290^{a} ±9.88	*1636^{a} ±5.79	993^{a} ±8.12
	Paper	*1683^{g} ±5.49	1067^{i} ±7.89	*809^{f} ±6.57	472^{ef} ±7.73
	Plastic	*2523^{c} ±7.66	1788^{c} ±8.28	*985^{e} ±4.32	513^{e} ±8.10
Rice huller	Glass	*2299^{d} ±8.41	1513^{d} ±6.83	*947^{e} ±8.76	557^{e} ±9.15
	Laminate	*2991^{b} ±9.87	1903^{b} ±8.42	*1157^{d} ±4.32	758^{c} ±6.49
	Paper	*644^{j} ±4.95	538^{k} ±2.38	*566^{i} ±5.55	354^{g} ±5.73
	Plastic	*1963^{f} ±3.22	1275^{g} ±4.95	*636^{h} ±5.16	410^{fg} ±8.16
	LSD	**160**	**32**	**96**	**90**

Note: Values are means of duplicate determinations (N = 2). a,b,c means with the same superscript along a column for each variety within a parameter is not significantly different (p >0.05). *….means with an asterisk (*) within a row and the percentage increase in free fatty acid and fungal growth is significantly different (p <0.05).

The total fungal growth of the shelled Egusi-melon seed varieties during storage is shown in Figure 4. Fungal activity is the major cause of the problem of melon seeds deterioration **[41]**. The Serewe variety maintained a higher load of fungal colony-forming units throughout the storage period compared to the Bara variety, However, the rate of increase of the fungal colony count of the Bara variety was higher than that of the Serewe variety. This could be a result of the genetic makeup of the variety which enhances the suitability of Serewe as a fungi substrate. But the moisture content of the Bara variety, according to the findings by **[38]**, could have promoted the proliferation of fungi on the cotyledons. According to **[42]**, the storage deterioration of melon seed is significantly influenced by the moisture content, because the microorganisms require moisture for their activities. Also, the mechanical damage on the shelled seed could have facilitated the growth of microbes because nutrients will be available at the point of damage. The pattern of fungal growth followed the same trend of reduction in the rate of increase between the second and the fourth week. This reduction is consistent for both varieties and could be attributed to a systemic phenomenon, like a reduction in the headspace's available oxygen, which could have slowed mould growth. The curves also showed a high level of linearity (R^2 = 0.9952 for the Serewe variety and R^2 = 0.9945 for the Bara variety).

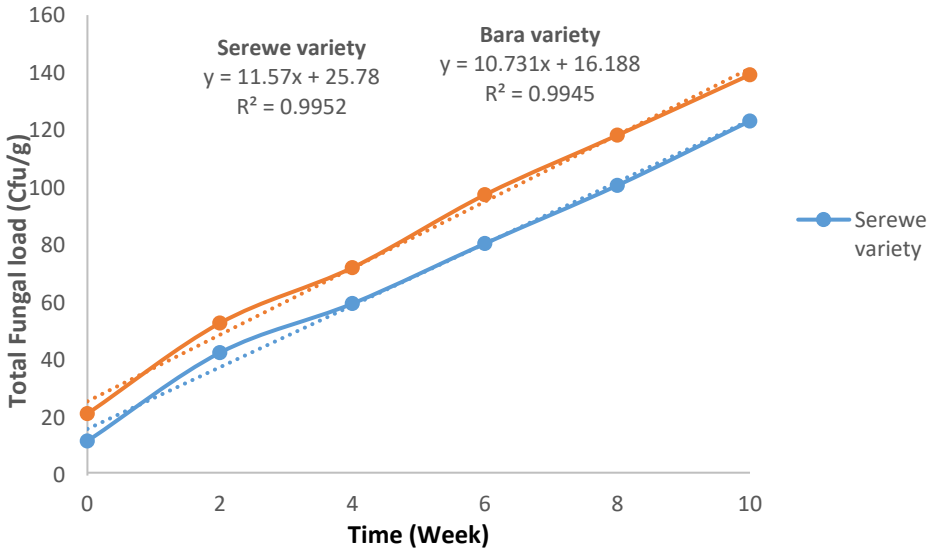

Figure 4 Total fungal load of processed *Egusi*-melon varieties over a period.

The effect of the different shelling equipment on the total fungal load is shown in Figure 5. The Egusi seed samples shelled using Egusi mechanical Sheller (2018 model) had the highest rate of fungal growth followed by the seeds shelled using the Egusi mechanical Sheller (2020 model) shelled samples and the rice huller shelled samples. The control exhibited the least rate of growth. The samples shelled using the Egusi mechanical Sheller (2020 model) had a lower rate of fungal growth than the samples shelled with the Egusi mechanical Sheller (2018 model) indicating that it could have bruised the cotyledon less than the Egusi mechanical Sheller (2018 model). A slight decrease in the proliferation rate of fungi between the second and the fourth week was observed in all samples except for the control. This could result from growth factor like available nutrients or a drop in the oxygen in the head space. It is possible that the oxygen drop occurred more in the samples that had more injuries because they sustained a greater proliferation of fungi. There would have been a greater oxygen requirement from both the exposed oil (for oxidation) **[43]** and the fungi growth **[44]**. The exposed oil will absorb oxygen from the air around it as it gets oxidized. This will be more intense if the oil is exposed from the interior of the cotyledon through an injury. The injured surface could also provide a more nutrient-rich substance than an intact cotyledon. But in the control sample, the injury on the Egusi-melon seed cotyledon was less,minimizing the oxidation oxygen requirement from exposed oil. This is also reflected in the linearity of the slope for the control sample which was the highest (R^2 = 0.9981).

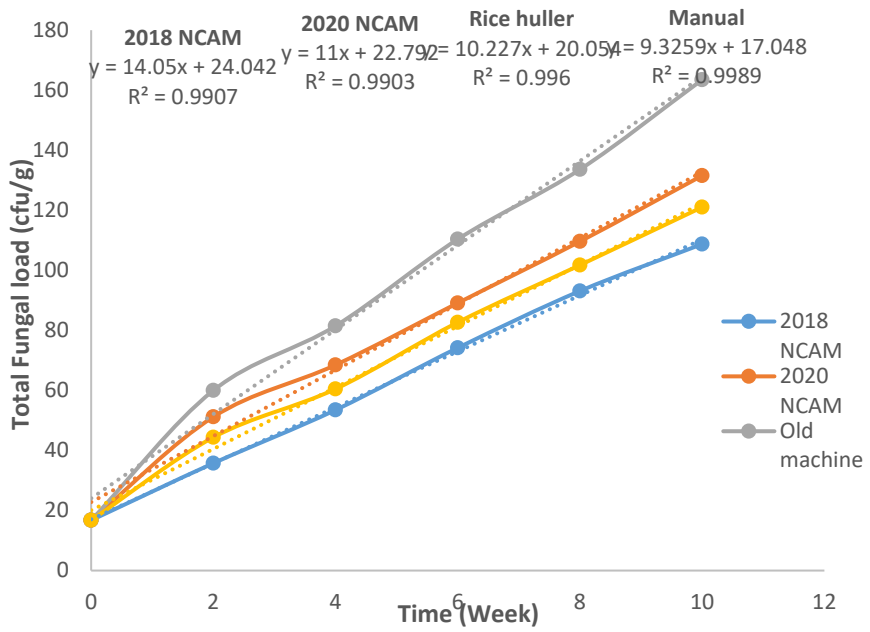

Figure 5 Effect of shelling equipment on the total fungal load over a period.

The effect of packaging materials on the total fungal load of the shelled Egusi-melon is shown in Figure 6. The highest fungal growth rate is observed in the samples packaged in a laminated pouch, followed by glass packaging and plastic packaging. The samples packaged in the paper had the least rate of fungal growth (33 CFU/g for week two and -93 CFU/g for week 10). Although factors such as the nature of the substrate **[45]** and moisture content of the sample **[46]**, are major contributors to the fungal deterioration of stored seeds, the use of improved storage structures/ packages, as mentioned by **[47]** significantly affects the product quality. This suggests that paper packaging material in this study could serve well in packaging shelled Egusi-melon seeds. The slowing of the rate of growth that occurred in the second to the fourth week was not apparent for the paper-packaged samples. The laminated pouch packaging exhibited a further slowing down of the rate of fungal growth beyond the 8th week. Both the plastic and paper-packaged samples exhibited a slight increase in fungal growth rate after eight weeks. The differences indicate the effect of different packaging materials on the quality of the product.

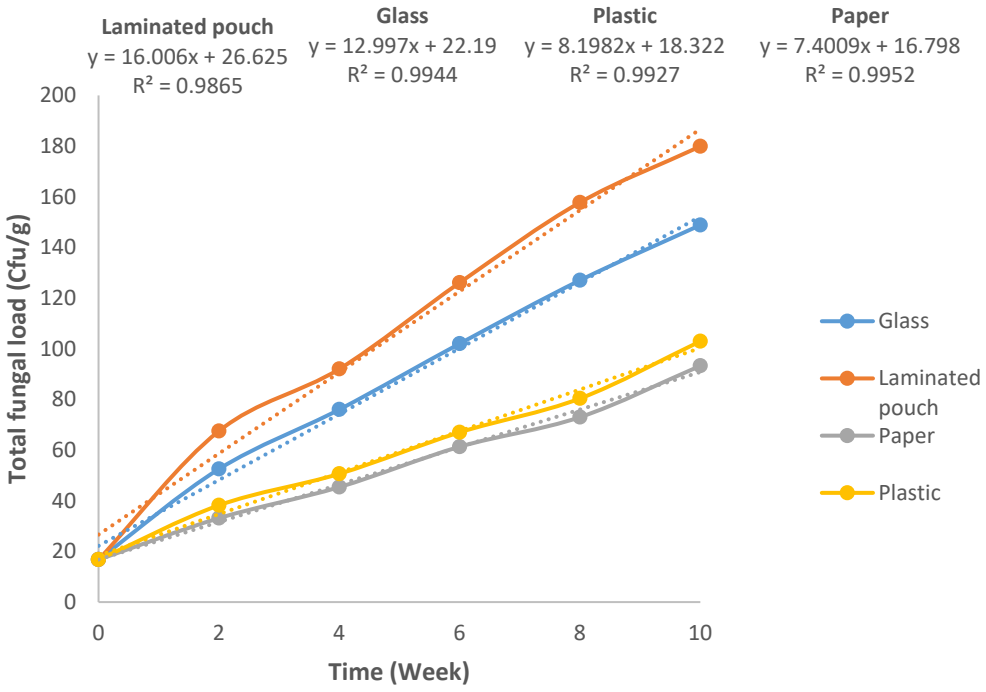

Figure 6 Effect of packaging on the total fungal load over a period.

2020 NCAM Mechanical melon sheller

2018 NCAM Mechanical melon sheller

SB-10D Rice mill

Manual (Hand) shelled seeds

NCAM shelled seeds

Rice huller shelled seeds

Figure 7 Mechanized shellers and shelled Egusi-melon seeds.

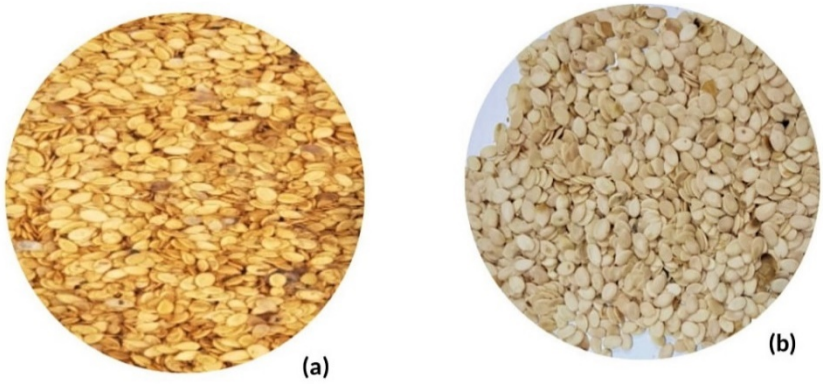

Figure 8 Unshelled (a) and Shelled (b) Egusi-melon seeds.

CONCLUSION

A comparative study was conducted between mechanized shelling and manual shelling of Egusi-melon seeds and the effect of different packaging materials on some quality attributes of the shelled Egusi-melon seeds. The Manual shelling of Egusi-melon produced more whole and fewer broken seeds than the Egusi-melon shelling machines used in this study. Serewe Egusi-melon seeds were more efficiently shelled manually (66% shelling efficiency) Bara variety was more efficiently shelled with machine processing (55% shelling efficiency). The manually shelled Egusi-melon seeds produced a less per cent increase in free fatty acids (410%-2869%) for 8 weeks of storage compared to the machine-processed seeds (518%-3298%). Material of machine construction affected the efficiency of shelling of Egusi-melon and the quality of cotyledons after shelling and during storage. Machines built with stainless steel produced more efficient shelling. Egusi-melon varieties with higher fat content

(Bara) produced more free fatty acids at a higher rate but with lower final free fatty acid content than those with lower fat content (Serewe). Packaging of shelled Egusi-melon seeds using sealed Kraft paper envelops (as given in this study) recorded a reduced per cent increase of free fatty acid (410%-1683%) on the seeds and exhibited lower microbial load. A proper selection of variety is necessary for the optimum performance of any machine design. Different Egusi-melon varieties have different microbial loads and exhibit different rates of microbial proliferation after shelling and during storage. Likely, the output of the shelled Egusi-melon from the rubber roll rice dehuller can still be improved if the manufacturer can make the necessary adaptations.

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