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Research Article

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Development and Testing of Indigenous Shea Butter Processing Plant in Nigeria

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Abstract

The increase demand of shea butter and its product globally has contributed immensely in its traditional household and small scale production in countries where it is present. This production method is laborious, time consuming and tedious. Also the shea butter obtained is of low grade and quality as result of contamination from either the type of equipment used or the processing method adopted. In other to address all these shortcomings a mechanised shea butter production plant was developed. The plant is made up of the following machines; sheller, crusher, steam roaster, miller and mixer. Fundamental design analysis and calculations were carried out in order to determine and select materials of appropriate strength and sizes for the machine component parts. Standard methods and procedures were used in the study and Response Surface Methodology was employed as the experimental tool. Five set of experiments were carried out to test the performance of the plant. The results of the experiment revealed that the shelling efficiency of the sheller increased with increase in both shelling speed and beaters. Crushing efficiency of the crusher increased with increase in both crushing speed and time. Yield of shea oil of the roaster decreased with increase in speed of stirring. Milling efficiency of the miller increased with increase in both speed and beaters. The oil extraction efficiency of the mixer decreased with increase in blades but increases with increase container diameter. The development of this plant have mechanized the major unit operations of shea butter production. It has make easier and faster processing of shea butter and thus, serves as a training center for local processors and a catalyst for the development of shea butter industry in Nigeria. It is capable of bringing improvement in the productivity of the shea butter to meet up with local and international demands. The developed plant produced 0.45 kg of shea butter from 1 kg of shea nut and processed 12.5 kg of shea paste in 10 min. It has input and throughput capacities of 600 kg of shea nut and 270 kg of shea butter respectively, in 8 hours operational time per day. The total cost of establishment of the plant is $2650.

Keywords

Crushing, Milling, Mixing, Shea butter, Shelling, Plant, Roasting

Introduction

Shea butter is obtained from processing shea nut, which is among the useful parts of Shea tree. Shea tree can be found growing naturally in the northern regions of the Guinea Zone and the southern region of the sahel. The major producing countries are West African countries [1]. According to, Adazabra et al. [2] and Gana et al. [3] the tree is found around the savannah region of Nigeria. Shea butter have been reported by many researchers to have numerous socio-

economic and health benefits. Gana et al. [3] and Karin [4] reported that shea butter is the most important source of fatty acids, glycerol in the diet. It is used in herbal medicine due to its antimicrobial properties. Maranz et al. [5] reported that shea nut oil obtained from the shea kernels is the main traditional medicine in many rural areas of developing countries. It is also used in pharmaceutical and cosmetic industries as important raw materials, a precursor for the manufacture of soaps, candles and cosmetics. According, to Aviara et al. [6] shea butter is used in the manufacture of soap, candles, cosmetics, pharmaceutical products and butter substitutes. In addition it is used as a sedative or anodyne for the treatment of sprains, dislocation and the relief of minor aches and pains. Shea butter contains reasonably high amounts of oleic acids. It also contains triglyceride with high amount of vitamin A, E, F and some other valuable nutrients required in manufacturing of cosmetics and pharmaceutical industries, as well as for domestic use in cooking, confectionery and frying [7].

The increase awareness of shea butter's socio-economic and health benefits, as well as its increase demand globally as an important ingredient in personal care and edible products [8] has contributed immensely in increasing the number of its processors both at household and small scale levels. In most of the developing countries like Nigeria shea butter is mostly processed using traditional manual method. This traditional method of extraction of shea butter from the kernel had been reported by Aviara et al. [6]to involve a series of unit operations. These operations include shelling or cracking of the shell using stone or by gently pounding the nuts with a mortar or pestle. According to, Gana et al. [3], in Nigeria, mostly shea nuts shelling is been done manually by rural women and children, which is time consuming and tedious. Also the locally available machines are not having a cleaning unit and this resulted to manual cleaning of the shelled nut. The shelled kernel is then broken into small pieces for roasting. This is done using either two stones or piston and mortal, it is also very tedious and time consuming [9]. Crushed shea nut pieces are roasted using cylindrical container made of mild steel with handle on open fire. This is where the slight smoky smell of traditional shea butter originates. According, to Shehu [10] most of the existing equipment for processing of shea butter especially the roasters is made of mild steel materials. The mild steel can easily become rusted and cause contaminant of the product. Metal particles form as a result of the rusting settlement at the bottom of the equipment, thus causing contamination of the product. Smoke from open fire can result in contamination of the Polycyclic Aromatic Hydrocarbon (PAHS), some of which are said to be highly carcinogenic [11]. In addition, open fire roasting has the disadvantage of producing burnt crushed kernels which in turn leads to black shea oil formation and loss of vital and essential nutrients [12]. After the roasting, the roasted shea kernel are allowed to cool down for at least 30 min or at most 1 hour, before being milled in a milling machine into a fine paste. The next stage is the mixing or oil extraction, this is the most complex operation in the production process. It involve the following stages; mixing the paste with water, beating the paste with a palm of the hand, adding further small quantities of water, and gathering the floating fat. The mixing process serve two main purposes that is to release the fat from the ground mass and remove as much of the brown colour as possible from the brown mass and produce a fairly clean fat [10]. Moreover, the manual method of mixing used by women in Nigeria is very tedious. Most often the container holding the paste is placed on the ground; women stand over the bucket and bend at the waist. Not only is mixing by hand tedious and time consuming, but the bending can cause strain on the back, making the process only suitable for younger women and also exposes product to further contamination. The few existing mixing machines are only available in large scale industries which are sophisticated to handle and maintain by the local processors [13, 14].The traditional method of shea butter production is shown in figure 1.



Figure 1: The traditional method of shea butter production.

Hence, there is every need to address all these shortcomings involve in shea butter production. The present presentation on establish and carry out performance evaluation of shea butter production plant.

Materials and Methods

Materials selection

Stainless steel (gauge 16) materials were used for construction of component parts of the machine that have direct contact with the shea kernel and oil because of its high resistance to corrosion. A 50 x 50 mm angular iron was used for the construction of the machine frame in order to give a rigid support and ensure stability of the machine when in operation [15].

Processing centre layout

The shea butter processing plant at the Federal Polytechnic

Bida has the following five main sections as shown in figure 2.

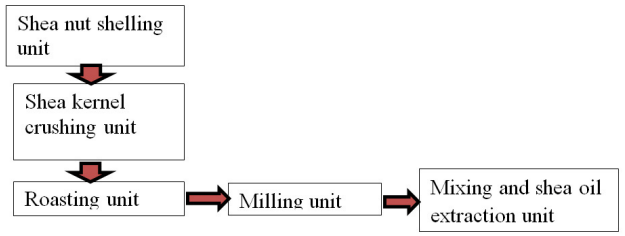


Figure 2: Shea butter processing plant layout.

1. Shea nut shelling and separation areas: this is the area where the shelling of the shea nut and separation of the broken shelled from the kernel takes place.

2. Shea kernel crushing area: this is the section were the shelled kernels are crushed into smaller sizes for further processing.

3. Steam roasting area: this is the section where the roasting of the crushed kernel takes place. The boiler generates steam and delivered it to the roasting chamber where the roasting takes place.

4. Milling unit: this is where the size reduction of the roasted kernel takes place. The size reduction is achieved using a hammer mill powered by a 15 hp electric motor.

5. Mixing or oil extraction area: this is where the fine kernel is mixed with water to form a paste. The paste is being fed into the mixer where the oil is being extracted.

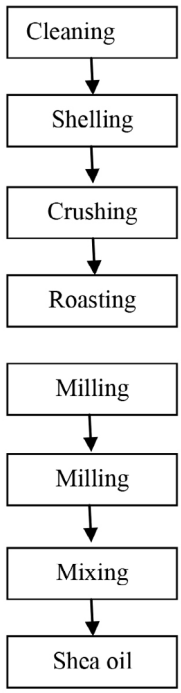


Figure 3: Processing process of the small scale shea butter processing plant at Federal Polytechnic Bida.

The plant's components

The following machines are developed and installed at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida.

Shelling and shell separating machine

The shea nut shelling machine (Figure 4) is made of hopper through which the shea nut is fed into the shelling unit. Its frame is made of angled bar of 0.05 m x 0.05 m x 0.05 m size which serves as a support for the machine. The transmission unit consists of a shaft, bearing, pulley and V-belt, which transmits power from the electric motor to the shelling and cleaning units. The shelling unit consists of rubber beaters attached to flat bars which are bent at one end at an angle of 900. The flat bars are attached to the cylinder which houses the central shaft. The cleaning unit facilitates separation of the shell from the nuts. Power is being supplied by a 5 hp electric motor to the shelling drum shaft through belt connection via the pulleys. The shelling drum shaft which rotates with the support of the bearings provides drive to the cleaning chamber shaft through belts and pulleys. As the sheanuts are being fed into the shelling unit through the hopper, the nuts are beaten resulting in cracking and separation from the kernels. This is achieved by a cylinder fitted with rubber spikes which rotates above a stationary perforated cylinder drum. The materials pass by the action of rubber spikes. As the materials move over the perforated cylinder, air is being blown from the fan to clean the kernels and lighter broken shells are conveyed out through the shell outlet [3].



Figure 4: Shea nut shelling machine.

Shea kernel crushing machine

The shea kernel crushing machine (Figure 5) comprises of the following functional components. The hopper; this is of a rectangular in shape with dimensions 0.4 m x 0.35 m x 0.31 m. It is inclined at angle of 45° in order to allow free flow of the materials into the crushing chamber. It is power by 4.5 kw electric motor. The crushing unit is made up of a shaft with dimensions 0.5 m x 0.04 m. Attached to the shaft are 14 rectangular beaters with dimensions 0.15 m x 0.03 m x 0.005 m.

A concave sieve with grids of 0.005 m was attached at the bottom of the crushing unit.



Figure 5: The Shea nut crushing machine

Steam roaster

The roasting machine (Figure 6) is made of stainless steel plate (1 mm). The roasting machine was made up of the following components; hopper which is cylindrical shape and through which the crushed kernel flow into the roasting chamber. Discharge unit through which the roasted crushed kernels is being discharge out of the machine. It is been inclined at an angle of 45° from the horizontal plane in order to allow free flow of the materials. The boiling unit consists of two pipes: water inlet pipe which allows water passage into the tank and a steam exit pipe which serves to transfer the steam generated at the upper part of the tank into the steam chamber of the roaster. The flow of steam is regulated by a gate valve. The water inlet and the steam outlet pipes are located close to the top of the tank. A charcoal fuelled burner is fixed to the bottom of the tank to serve as heat source. Kernel roasting chamber is cylindrical shaped vessel made of stainless steel plate with three separate compartments that include the roasting chamber, steam chamber, and insulator chamber. The roasting chamber houses the crushed kernels with stirring blades attached to the shaft and in turn to the gear motor. The blades aid in stirring the crushed kernels as the steam enters into the walls of the roasting chamber. This constant stirring and heat application bring about uniform roasting of kernels. Power transmission unit comprises of a gear motor which is connected to the stirring blade through a shaft linked together by two bearing. The gear motor receives power from human power.



Figure 6: The Shea kernel roaster

Shea kernel grinding machine

The hammer mill is made up stainless steel materials. It has 21 rectangular beaters and eight circular beaters. The rectangular and circular beaters have dimension of 0.11 m x 0.05 m x 0.006 m and 0.22 m x 0.006 m respectively. The milling chamber has concave sieve at the bottom. The machine is power by 15 hp electric motor and it is shown in figure 7.



Figure 7: Shea kernel grinding machine.

Shea paste mixer

The Machine was made up of the following components; mixer blades: these are interchangeable set of blades made up of stainless sheet of 5 mm each. These are blades attached to the shaft inside the mixing container. The blades have the same area of cutting edges but different orientation. The blades are: 2- blade assembly, 3 - blade assembly, 4 - blades assembly, 5 - blades assembly and 6 - blades assembly. The mixing tank made with dimensions 0.39 m x 0.30 m x 0.002 m and it was mounted on the machine frame made up of 0.50 m angle iron assembly. Boiling tank this is made with dimensions 0.35 m x 0.41 m x 0.002 m up of 2 mm and it was mounted on the machine frame made up of 0.50 m angle iron assembly. A shea butter delivery pipe was fitted to the bottom side of the drum in order to allow out flow of extracted shea oil. Stirring arm this is made up of 0.30 m diameter circular pipe, length of

0.24 m and arm length of 0.129 m. It was attached to the stirrer arm through a gear system. Burner this is fitted inside an enclosure which is square in shape with height and width of 0.40 m each. Between the burner and the enclosure insulating material was fitted in order to prevent heat loss.

The two most complex operations that influence the quantity and quality of shea butter production as shown in figure 1 are the roasting and mixing (oil extraction) operations. In the established processing plant these two unit operations are replaced with steam roaster and a mixer as shown in figure 9.



Figure 8: Shea paste mixer.

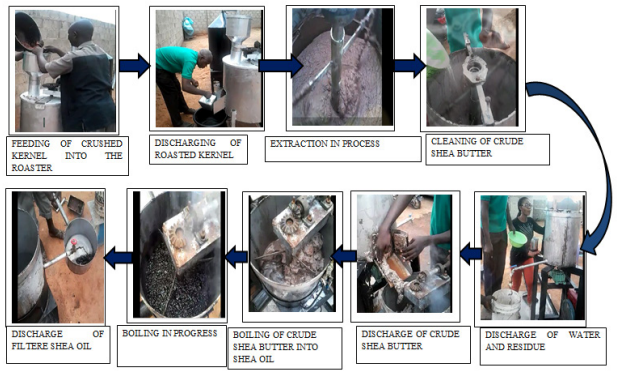


Figure 9: Crushed shea kernel roasting and shea oil extraction in the established processing plant.

Design analysis of the plant components

Fundamental design analysis and calculations were carried out in order to determine and select materials of appropriate strength and sizes for the machine component parts. Some of the major design analyses are presented in table 1.

Mode of operation of the production plant

The production process of the small scale shea butter processing plant at Federal Polytechnic Bida is explained in figure 3. The dried shea nut is cleaned by removing all foreign material. The nut is then fed into the shelling machine were the shell is broken and separated from the kernel. The kernel is being reduced to smaller sizes with the aid of the crusher. The crushed nuts are then roasted with steam inside the developed steam roaster. The kernel roaster is a cylindrically shaped vessel made of stainless steel plate with three separate compartments that include the roasting chamber, steam chamber, and insulator chamber. Crushed kernel is poured into the roasting chamber through the hopper or inlet. The steam chamber receives the heat from incoming steam and heat up the outer wall surface of the roasting chamber. After a few minutes, when the chamber has heated up, stirring of the crushed kernels begins by rotating the paddle carrying shaft through the rotating handle with the aid of gear arrangement. This constant stirring and heat application bring about uniform roasting of kernels. The roasted crushed kernels are then discharge into the collection pan through the roasted outlet. The roasted shea kernel is reduced into finer sizes by milling using the developed milling machine. The milled shea kernel was then mixed with water to form shea paste. The paste is fed into the mixing container; cold water was added intermittently to the paste. As the machine blade rotates, it mixes the paste with water. Mixing continued with addition of small amount of cold water from time to get a smoother texture. This process was continued until the fat begins to break away from the cake (this is indicated by the colour of the mixture from chocolate to milk chocolate). At this stage cold or warm water is added depending on the temperature of the environment. A more quantity of cold-water is then pours into the mixture and stirred continuously to cause a grey, oily scum to rise. The water draining tap was then open and water with lesser density than the oil was drain out of the mixer through the tap. Fat was also collected into the boiling/heating container. Fat collected is immediately boiled in the boiling/heating container to complete the separation of fat from the cake. Boiling is continued until separation occurs and then oil is drained through the tap into a container and allows settling down for 30 min. Heat supply from the combustion unit is temporary cut off to allow for clean-up of the cake residues that settled under the oil in the bottom of the heating tank in the form of a thick brown paste. The oil was retrieved into the clean heating tank where it was boiled to dehydrate the fat completely on a gentle heat and monitored closely to remove floating particles and dirty foam with ladle. The warm liquid fat or oil was then filtered through the tap using the ordinary thick cotton materials and finally collected on a plastic container and allowed to cool down and solidify. Wooden ladle was used to stirred Shea oil into a smooth and uniform texture when it begins to show signs of solidification or refrigerated immediately where it is available.

Sample preparation for the experiments

Shea nut (*Butyrospernum paradoxum*) was used for all the

Table 1: Summary of some the major design analysis.

S/N	Parameters	Formula	Type of machine & Value obtained				
			Sheller	Crusher	Roaster	Miller	Mixer
1	Mass of materials to be processed at a time (kg)	$M_b = \rho_g \left(\frac{V_d \, x \, T_b}{T_T} \right)$	18	15	15	14	14
2		$16 / \pi S_s \sqrt{(K_b M_B)^2 + (K_t M_t)^2}$	0.02	0.03	0.05	0.05	0.05
3		$M_t \omega^2 / 2\pi l$	23126	6417	14.58	6930.53	836.5
4	Gear motor reduction ration						1:30
5	Angular speed (rpm)	$2 \text{ x } \pi \text{ x } N / 60$	81.67	40.74	6.3	40.1	14.5
6	Total force (N)	$M \text{ x } r_d \text{ x } \omega^2$	2035	847	120	1524	1423
7	Torque generated (Nm)	$F \text{ x } r_d$	58.69	25.4	2.40	76.2	71.13
8	Power (kw)	$2 \text{ x } \pi \text{ x } N \text{ x } \tau / 60$	3.725	3.725	0.25	11.18	7.45
	Thickness of insulating material (m)	$\Delta r = r_5 - r_4, \; r_5 = r_4 \text{ x } \left(e \frac{2\pi K_4 (T_5 - T_4)}{q / l} \right)$			0.05		
9	Heat loss through pasteurizer (w/m)	$\frac{q}{l} = \left[\frac{T_1 - T_5}{\frac{1}{2\pi K_1 L} \ln \left(\frac{r_2}{r_1} \right)} + \frac{T_1 - T_5}{\frac{1}{2\pi K_2 L} \ln \left(\frac{r_3}{r_2} \right)} + \frac{T_1 - T_5}{\frac{1}{2\pi K_3 L} \ln \left(\frac{r_4}{r_3} \right)} \frac{T_1 - T_5}{\frac{1}{2\pi K_4 L} \ln \left(\frac{r_5}{r_4} \right)} \right]$			80.23		
10		$\pi d s^4 / 32$					
11	Deflection on the shaft (Degree)		1.9	3.92	2.73	1.95	2.24

experiments in this study. The dried kernels were procured from the local market in Bida, Niger State, Nigeria. The shea nut kernels were cleaned manually in order to remove the impurities such as dust, stone, sticks, immature and damaged kernels. The experiments were carried out at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida, Nigeria.

Sample preparation for the shelling experiment

Six thousand five hundred pieces of shea nuts were manually picked from the sample earlier sorted and cleaned. The sample was randomly selected for the experiment to ensure uniform sample size [16-18]. The shea kernel was divided into thirteen samples, each sample had 500 number of shea kernel. It was then processed using the developed sheller in accordance with the design matrix shown in table 2 [15].

Sample preparation for the crushing experiment

Sixty five kilograms of shelled shea kernel was used for this experiment. The shelled kernel was divided into thirteen samples of 5 kg each. It was then processed using the developed crusher in accordance with the design matrix shown in table 3 [15].

Sample preparation for the roasting experiment

The crushed shea kernel was divided into thirteen samples of 5 kg each. The samples were then processed using the developed roaster in accordance with the design matrix in table 4 [15].

Sample preparation for the milling experiment

One hundred kilograms of roasted shea kernel was used for this experiment. The roasted shea kernel was divided into twenty samples of 5 kg each. The samples were then processed using the developed miller in accordance with design matrix in table 5 [15]. The five moisture content levels of the sample were obtained following the procedure reported by AOAC [19]. The initial moisture content of the roasted kernels was determined by drying the samples in a hot air oven at 103 ± 1 °C for 24 hours [20]. The initial moisture content of the sample was 12.2% d.b., this was further dried to 9% d.b

to be able to obtain the required levels of moisture contents. The samples were moistened to increase the moisture content to the desired five different levels, by adding calculated quantity of water using the following equation reported by Zareiforoush et al. [21],

$$M_w = W_i\ (M_f\ -M_i)/100 \text{ x } M_f \text{ ------- (1)}$$

Where, is the mass of water to be added (kg), is initial weight of the sample (kg), is the initial moisture content of the sample (%, d.b), is the final moisture content of the sample (%, d.b).

Table 2: Result of effects of shelling speed and beaters on shelling efficiency.

Std.ord.	Run ord.	Shelling speed	No. of beaters	Shelling efficiency
4	1	1700	30	98.71
10	2	1500	23	61.36
7	3	1500	12	33.13
5	4	1217	23	23.08
6	5	1783	23	94.33
12	6	1500	23	61.08
8	7	1500	33	70.22
2	8	1700	15	60.54
13	9	1500	23	60.62
11	10	1500	23	61.23
9	11	1500	23	64.75
3	12	1300	30	55.43
1	13	1300	15	31.22

Sample preparation for the mixing experiment

Sixty five kilograms of shea paste was used for this experiment. The shea paste was divided into thirteen samples of 5 kg each. The samples were processed using the developed mixer in accordance with the design matrix in table 6 [15].

Testing of the plant

The performance of the shea butter production plant was evaluated in accordance with procedures reported by Shehu [10] and Gana et al. [3]. Some 600 kg of shea nut were purchased from Bida central market and the samples were cleaned to remove unwanted materials before processing using the developed machines. Five sets of experiment were carried out in order to determine the performance of the plant. The experiments were carried out at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida, Nigeria.

Experimental setup and procedure

A standard response surface methodology (RSM) design called central composite rotatable design (CCRD) was used in this study. It consists of three factors – five levels experiments and two factors – five levels experiments.

Testing of shelling machine

Two factors – five levels experiments were used based on some earlier findings by Gana et al. [3] to determine the effects of speed and beaters on the shelling efficiency of the machine. The experimental factors levels are; shelling speed of 1217 rpm, 1300 rpm, 1500 rpm, 1700 rpm, 1782 rpm, and number of beaters of 12, 15, 23, 30 and 33. The Design matrix of the experimental is shown in table 2.

Testing of crushing machine

Two factors – five levels experiments were used based on some earlier findings by Gana et al. [3] in other to determine the effects of speed and crushing time on the crushing efficiency of the machine. These are crushing speed and crushing time of 959 rpm, 1100 rpm, 1100 rpm, 1200 rpm, 1241 rpm, and 288 seconds, 300 seconds, 330 seconds, 360 seconds, 372 seconds respectively. The Design matrix of the experimental is shown in table 3.

Table 3: Results of effects of speed of crushing and crushing time on crushing efficiency.

Std.ord	Run order	Speed of Crushing (rpm)	Crushing Time (secs)	Crushing Efficiency (%)
10	1	1100	330	78.34
11	2	1100	330	71.11
4	3	1200	360	98.23
8	4	1100	372	90.12
2	5	1200	300	93.11
12	6	1100	330	77.45
3	7	1000	360	70.56
7	8	1100	288	67.33
5	9	959	330	56.24
13	10	1100	330	78
9	11	1100	330	78.05
6	12	1241	330	98.58
1	13	1000	300	62.23

Testing of the roaster

Two factors – five levels experiments were used based on some earlier findings by Orhevba et al. [12] and Shehu et al. [22] to determine the effects of blade angle and speed on yield of shea butter. These are blade angle and speed of 48°, 60°, 90°, 120°, 132° and 39 rpm, 45 rpm, 60 rpm, 75 rpm and 81.2 rpm respectively. The Design matrix of the experimental is shown in table 4. Sixty five kilograms of crushed shea kernel was used for this experiment.

Testing of the milling machine

Three factors – five levels experiments were used based on some earlier findings by Gana et al. [15], Nwagwe et al. [23] and Nasir [24]to determine the effects of hammer beaters, milling speed and kernel moisture content on the shea oil extraction efficiency. The factors levels are hammer beaters configuration of 33- heads, 30- heads, 25- heads, 20- heads and 17- heads assembly, milling speed of 1568 rpm, 1500 rpm,

Table 4: Result of effects of blade angle and speed of stirring on yield of shea butter oil of the roaster.

Std. ord	Run order	Blade angle (Degree)	Speed of stirring (rpm)	Yield of butter
13	1	90	60	45.23
1	2	60	45	35.48
5	3	48	60	28.21
12	4	90	60	43.02
6	5	132	60	27.41
2	6	120	45	32.33
9	7	90	60	45.66
10	8	90	60	45.82
11	9	90	60	45.55
3	10	60	75	30.4
7	11	90	38	40.47
4	12	120	75	31.52
8	13	90	81	33.43

Table 5: Result of effects of hammer head, moisture content and speed on milling efficiency.

Std. ord	Run order	Speed of Milling (%)	No. of Beaters	Shea kernel MC (%)	Milling Eff. (%)
6	1	1500	20	13	69.26
15	2	1400	25	12	81.23
19	3	1400	25	12	80.78
2	4	1500	20	11	78.43
5	5	1300	20	13	71.24
12	6	1400	33	12	99
18	7	1400	25	12	81.25
14	8	1400	25	13.68	67.03
10	9	1568	25	12	88.25
7	10	1300	30	13	79.78
20	11	1400	25	12	80.31
9	12	1232	25	12	79.34
13	13	1400	25	10.32	80.05
8	14	1500	30	13	87.85
11	15	1400	17	12	70.15
3	16	1300	30	11	92.06
17	17	1400	25	12	81.26
16	18	1400	25	12	80.01
4	19	1500	30	11	99.52
1	20	1300	20	11	74.81

1400 rpm, 1300 rpm and 1232 rpm, roasted kernel moisture content of 13.7%, 13%, 12% 11% and 10.3%. The Design matrix of the experimental is shown in table 5.

Testing of the mixer

Two factors – five levels experiments were used based on some earlier findings by Shehu [10] in other to determine the effects of mixing drum diameter and blades on oil extraction efficiency. These are mixing drum diameter of 0.31 m, 0.35 m, 0.45 m, 0.55 m and 0.59 m and blade number of 2, 3, 4, 5 and 6. The Design matrix of the experimental is shown in table 6.

Table 6: Effects of blade type and container diameter on shea oil extraction efficiency of the mixer.

Std. ord	Run order	Drum diameter (cm)	Blade type (No.)	Extraction efficiency (5)
9	1	0.45	4	75.66
4	2	0.55	5	61.93
8	3	0.45	5	58.61
11	4	0.45	4	75.44
12	5	0.45	4	75.69
10	6	0.45	4	74.63
1	7	0.35	3	65.09
6	8	0.59	4	84.19
5	9	0.31	4	61.67
7	10	0.45	3	90.21
3	11	0.35	5	55.3
13	12	0.45	4	75.78
2	13	0.55	3	99.24

Performance evaluation

Shelling efficiency

This is percentage of shelled nuts to the total number of the shea nuts feed into the sheller. It was determined using the expression reported by Gana et al. [3]and is given as

$$S_E = N_S / N_T \text{ x } 100 \text{ ----(2)}$$

Where, is the shelling efficiency (%), is the number of the shelled nut, is the total number of the shea nuts

Crushing efficiency

This is the ratio of the mass of crushed kernel that pass through the screen (10 mm) to the total mass of shea kernel feed into the crusher expressed in percentage. It was determined using the expression reported by Gana et al. [3] and given in the following equation.

$$C_E = M_S / M_T \text{ x } 100 \text{ -------(3)}$$

Where, is the crushing efficiency (%), is the mass of crushed kernel (kg), is the total mass of the shea kernel

Yield of the shea oil

This is the quantity of the shea oil produced by the machine and was determined from the relationship in equation 3 as reported by Alonge et al. [25].

$$Y_o = W_1 - W_2 / W_1 \times 100 \quad \text{----------(4)}$$

Where, is the Yield of the shea oil (%), is the initial weight of the shea paste (kg), is the weight of the residue (kg)

Machine milling efficiency

This is the measure of the degree by which the shea kernel are reduced in size and was determined as reported by Nwagwe et al. [23] and Nasir [24].

$$M_E = M_o / M_1 \times 100 \quad \text{---------(5)}$$

Where, is the milling efficiency (%), is the amount of the material passing through the sieve (kg), is the total weight of the material feed into the machine (kg)

Extraction efficiency

This is the measure of the ratio of refined or crude oil extracted to the total weight of shea paste and water feed into mixing container and was determined as reported by Alonge et al. [25] and Gana [26].

$$E_m = \frac{\text{A-W}}{\text{MT-W}} \times 100 \text{---------(6)}$$

Where, is the extraction efficiency (%), A is the amount of the unrefined shea butter (kg), MT is the total weight of the shea paste and water feed into the machine (kg), W is the amount of water used (kg).

Results

Result of effects of speed of shelling and beaters on shelling efficiency

The result of effects of speed of shelling and beaters on shelling efficiency is presented in table 2. The values of shelling efficiency ranged from 31.22 to 98.71%. The highest values of shelling efficiency of 98.71% was obtained from combination of speed and beaters of 1700 rpm and 30 respectively while the least value of crushing efficiency of 31.22% was obtained from combination of speed and of beaters of 1300 rpm and 15 respectively.

Result of effects of speed and crushing time on crushing efficiency

The result of effects of speed and crushing time on crushing efficiency is presented in table 3. The highest values of crushing efficiency of 98.23% was obtained from combination of speed and crushing time of 1200 rpm and 360 seconds respectively while the least value of crushing efficiency of 56.24% was obtained from combination of speed and crushing time of 959 rpm and 330 seconds respectively.

Result of effects of blade angle and speed of stirring on yield of shea butter oil of the roaster

The result of effects of Effects of blade angle and speed of stirring on yield of shea butter oil of the roaster is presented in table 4. The yield of butter is the degree by which the oil is been extracted from the paste it was evaluated using the formula reported by Gana [26]. The yield of shea oil ranged between 27.41% and 45.23%.

Result of effects of hammer head, moisture content and speed on milling efficiency

The milling efficiency is the degree by which the materials were reduced in size and it was evaluated using the formula reported by Gana et al. [15] and Nwaiegwu et al. [27]. The effects of independent variables; speed of rotation, hammer head and moisture content of the shea kernel on the milling efficiency is presented in table 5. The milling efficiency ranged between 67.03% and 99.52%.

Result of effects of blade type and container diameter on shea oil extraction efficiency of the mixer

The result of effects of blade type and container diameter on shea oil extraction efficiency of the mixer is presented in table 6. The extraction efficiency is obtained as reported by Gana [26]. The extraction efficiency of the oil ranged from 55.3% and 99.24%.

Discussion

From figure 10, it was observed that the shelling efficiency increases with increase in both speed and of beaters. The increase in shelling efficiency with increase in speed of shelling could be as result of increase in impact with increase in speed. This trend followed similar pattern on a study conducted on pistachio nuts by Khodabakhshian et al. [16]. Also the increase in shelling efficiency with increase in beater could be as result of more impact and rubbing actions associated with increase in beaters. This agreed with the results of an earlier study by Wangette et al. [28] were increased in speed and beaters of groundnut shelling machine resulted to increase in collision and rubbing actions that generate the forces that result in the shelling of the groundnut pods lead to an increase in shelling

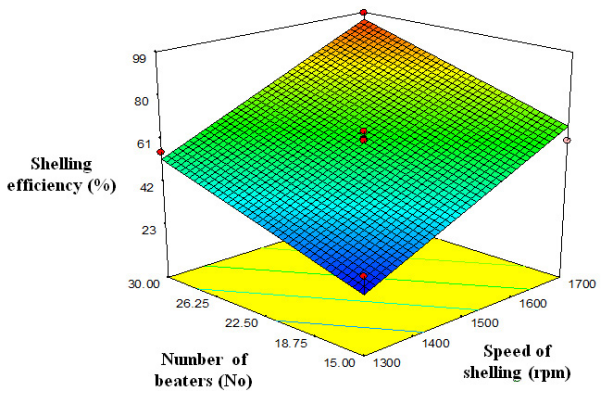


Figure 10: Results of effects of speed of crushing and number of beaters on shelling efficiency.

efficiency. From the analysis of variance (ANOVA) conducted speed of rotation of the shelling machine on shelling efficiency has more significant effects at the 1% probability level with high F value of 111.15 and P value of less than the number of beaters with F value of 48.93. The optimum values of shelling speed of 1700 rpm and 30 beaters produced shelling efficiency of 98.71% and desirability of 0.960.

The crushing speed of the crusher guides the crusher to break the materials according to the different particle size and different texture. Therefore, selecting the proper speed would avoid the phenomenon of over crushing and also reduce the power consumption. From table 3, it was observed that the crushing efficiency increases with increase in both speed and crushing time. The increase in crushing efficiency with increase in speed of crushing could be attributed to increase in hit probability between the crushing plate and shea kernel, enhancing the impacting and segregation effects impact with increase in speed. Therefore, the higher the crushing speed, the larger the striking force between the hammer plate and materials. LDHIST [29], also reported that with the increasement of rotor speed, the impacting force between materials and impacting plate become higher and the crushing effect becomes better. This trend followed similar pattern on a study conducted on influence of rotor speed on biomass pulverization by Luo et al. [30]. The increase in crushing efficiency with increase in crushing time could be as result of more impact action between the crusher heads and shea nut with increase in crushing time. This agreed with result reported by Gbabo et al. [31] were blending efficiency of drink was found to be affected by the degree of impact resulting from repeated effect of the hammers and volume of the material loaded into the blender.

The result of analysis of variance (ANOVA) conducted showed that speed of crushing has more significant effects at the 1% probability level with high F value of 133 and P value of less than the crushing time with F value of 19. The optimum values of the machine obtained are shelling speed of 1200 rpm and 360 seconds. This produced crushing efficiency of 98.58% and desirability of 0.999.

From table 4, the highest yield of butter of 45.23% was obtained from interaction between blade angle of 90° and speed of 60 rpm, while the least oil yield of 27.41% was obtained from interaction between blade angle of 132° and speed of 60 rpm.

The response surface of yield of shea butter oil was presented in figure 11. The yield of shea oil decreased from 36.5% to 29.5% as the speed of stirring increased from 45 rpm to 75 rpm. This agreed with result of an earlier study by Gana [26] were blade design was found to influence yield of soya milk slurry. Also the yield of the shea butter increase from 36.5% to 46% with increase in blade angle from 60° to 90° and then decreased 36.5% with further increase in the blade angle to 120°. This could be due to increase in agitating and mixing of the kernel with increased in blade diameter. This agreed with result of an earlier study by Gana [26] were blade design was found to influence the mixing of soya paste and water. The result of analysis of variance (ANOVA) conducted showed that speed of stirring has more significant effects at the 1% probability level with high F value of 29.13 and P value of less than the blade angle time with F value of 1.16. The optimum values of the machine obtained are shelling speed of 56.3 rpm and 88.86°. This produced yield of shea oil of 45.31% and desirability of 0.972.

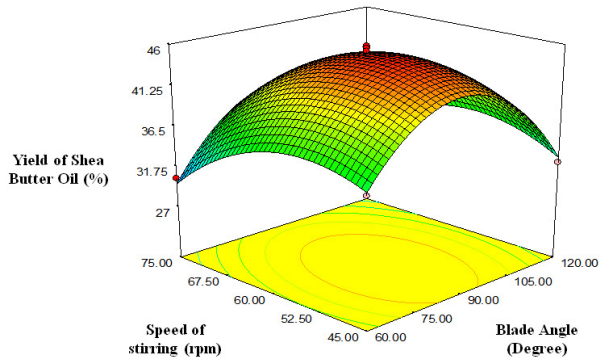


Figure 11: Response surface for yield of shea butter oil with respect to blade angle and speed of stirring.

From table 5, the highest milling efficiency of 99.52 was obtained from interaction between 30 hammer head assembly, shea kernel moisture content of 11% and speed of 1500rpm, while the least efficiency of blending of 67.03% was obtained from interaction between 25 hammer head assembly, shea kernel moisture content of 13.68% and speed of 1400 rpm.

The response surface of milling efficiency based on relationship between moisture content and speed of milling is presented in figure 12. The milling efficiency decreased from 80% to 73% as the shea kernel moisture content increase from 11% to 13%. This could be as result of increase in friction and resistance to segregation of the shea kernel as the moisture content increased. The speed of milling was also observed to increase from 80% to 87% as the speed increased from 1300 rpm to 1500 rpm. This could be as result of more segregation of the materials with increase in speed of milling.

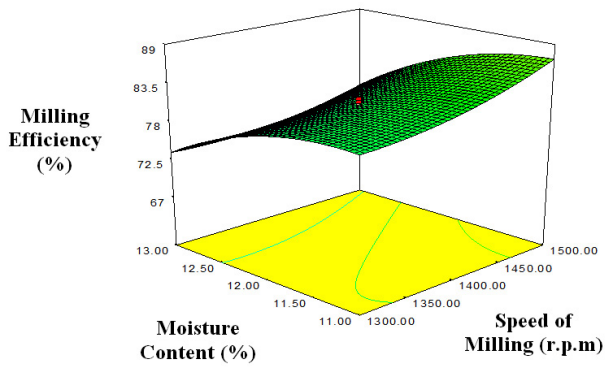


Figure 12: Response surface for milling efficiency with respect to moisture content and speed.

The response surface of milling efficiency based on relationship between moisture content and hammer heads is presented in figure 13. The milling efficiency was observed to decrease from 79% to 68.5% with increase in moisture content from 11% to 13%. This could be as result of increase in resistance of the shea kernel to segregation due its high water content. This is in lined with an earlier on study by El Shal [32] on effects of some operational factors on hammer mill, were the fineness of grain was increased with decrease in the grain moisture content. The milling efficiency was also observed to increase from 79% to 95% with increase in hammer heads from 20 to 30. This was as result of more contact between the kernel and the hammer head with increase in hammer heads. This conforms to the result of an earlier study by Helmy et al. [33] were increase in drum beaters from 4 to 8 increased the machine output.

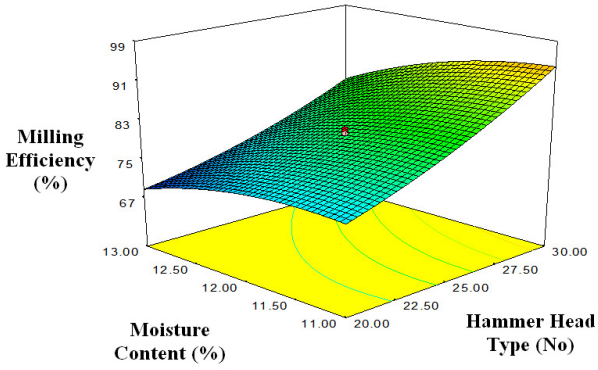


Figure 13: Response surface for milling efficiency with respect to moisture content and hammer head type.

From the analysis of variance (ANOVA) conducted both speed of milling and number of beaters have positive significant effects at 1% probability level and F values of 6.3 and 79.16 respectively, and P values of less than 1. On other hand the kernel moisture content has negative significant effects at 1% probability level and F value of 20.9. The optimum values of milling speed of 1497 rpm, number of beaters of 30 and M.C of 11.11% produced milling efficiency of 99.63%.

From table 6, the highest oil extraction efficiency of 99.24% was obtained from interaction between container diameter of 0.55 m and 3-blade type, while the least oil extraction efficiency of 50.66% was obtained from interaction between container diameter of 0.35 m and 5- blade types.

The response surface and contour plot for oil extraction efficiency with respect to blade type and container diameter is presented in figure 14. The extraction efficiency decreased from 67% to 56.5% as the blades increased from 3 to 5. This could be due to decreased in agitating and mixing of the paste slurry with increased in blades number. All the blades were designed with equal contact area, therefore the fewer the blades the more the contact area and the more the blades the less the contact area. This agreed with result of an earlier study by Racheal et al. [34] were blade design affect segregation of materials Gana [25] were blade design was found to affect rate of mixing. Also the extraction efficiency of the shea oil increase from 56.5% to 99.24 with increase in mixing container diameter from 0.35 m to 0.55 m.

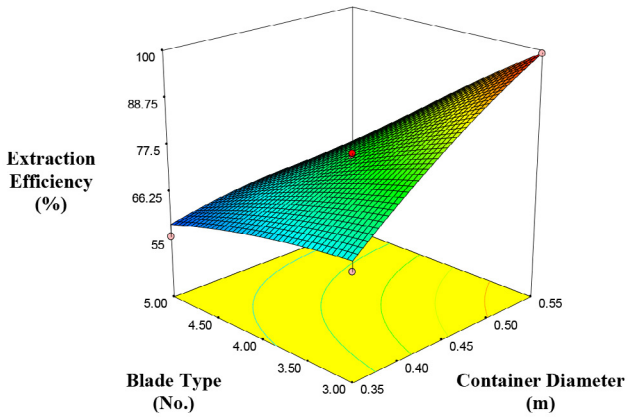


Figure 14: Response surface for oil extraction efficiency with respect to blade type and container diameter.

Conclusion

The Federal Polytechnic shea butter processing plant is the first complete indigenous processing plant that has been established in the Polytechnic after elaborate research work on the development of all components of the plant. The total cost of construction of the plant was $2650. The local processors can acquire this technology through their cooperative society, community groups or NGO's. The development and establishment of the plant overcome some of the major challenges associated with the traditional method of shea butter production in Nigeria. Also it will improved the quality and quantity of the butter produced. Therefore based on the findings of the study, the following conclusions were made;

The shelling and winnowing machine section of the plant addressed the problem of traditional method of shelling that employ the use of stones, mortar and pestle which are arduous and time consuming [35]. On the other hand, some of the existing shelling machine destroyed the nut during the shelling process [36]. This problem was addressed by the used of rubber beaters and optimizing the crusher's process parameters. Also manual winnowing requires a wind which is not always available to blow away the pieces of the broken shells [1]. This problem was addressed by incorporating a blower into the shelling machine.

The developed crusher reduces labor and energy wastage involved in crushing with mortar and pestle, which was reported by Onikoyi et al. [35] to be slow, tedious, energy sapping, arduous and grossly inefficient. The developed machine crushed 100 kg of shea kernel into grits in 28 min while crushing the same quantity of kernel using a mortar and pestle took approximately 3 hours [36].

The traditional method of roasting using container over an open fire generates smoke that can result in contamination of the Polycyclic Aromatic Hydrocarbon (PAHS), burnt the crushed kernels which in turn leads to black shea oil formation and loss of vital and essential nutrients[11]. On the other hand some of the existing roasters have problem of

insufficient heating of the nuts or too much heating of the nuts which affects the extraction process. This problem was addressed by lagging the developed roaster to prevent heat loss and also incorporating it with temperature gauge that aid in temperature control.

The grinding of the coarse paste into a finer paste on a grinding stone is a highly labour intensive activity [35]. This is replaced by the developed grinding mill made from stainless steel materials in other to avoid contamination of the product. Grinding of 100 kg of coarse paste into a finer paste using the developed grinding mill was accomplished in 30 min while it took four adult females 3½ hours to mill the same quantity of materials using grinding stones as reported by Godfred et al. [36].

The developed mixer substitutes the traditional kneading process that is been carried out inside large pot. The mixing is done by hand until the shea paste starts to cover itself with white emulsion of fat. This task is also arduous and time consuming. One major shortcoming of the traditional method is that the shea butter is been extracted at a temperature above the melting point, which might be too hot for bare hand [1]. This problem was address in the developed mixer by the introduction of stirrer. Kneading using the traditional method took an average of 2½ hours to knead 12.5 kg of shea paste (41 kg per day) [36]. But kneading the same quantity of shea paste using the developed mixer was accomplished in 10 min (600 kg per day). Therefore the developed plant has input capacity of 600 kg of shea nut and throughput capacity of 270 kg of shea butter.

The developed plant has higher output of 0.45 kg of shea butter from 1 kg of shea nut which is more than the value of 0.30 kg obtained from traditional methods. It reduces the fuel wood consumption to 7 kg per 100 kg of shea nut compared to 25 kg per 100 kg of shea nut used in the traditional method.

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