Journal of Information Engineering and Applications
ISSN 2224-5782 (print) ISSN 2225-0506 (online)
Vol.7, No.10, 2017
www.iiste.org

Design and Optimisation of Shea Butter Mixer

Shehu A. A.[1] Balami A. A.[2] Osunde Z. D.[2] Ademoh N.A.[3]
1.Department of Agricultural & Bio-environmental Engineering, Federal Polytechnic Bida, Niger State Nigeria
2.Department of Agricultural & Bioresources Engineering, Federal University of Technology Minna, Niger State Nigeria
3.Department of Mechanical Engineering, Federal University of Technology Minna, Niger State Nigeria

Abstract
A shea butter mixer was designed, fabricated and tested. The machine mixed milled shea paste with water and extract shea butter oil from the paste. Its major component parts included mixing blade, mixing tank, gear system, diesel engine and burner. The machine capacity was 56 kg per hour. The results of testing of the machine revealed that the yield of oil ranged between 26.52 % and 39.43 %. The highest oil yield of 39.43 % was obtained from interaction between container diameter of 50 cm, blade type 5 numbers and speed of 110 rpm, while the least oil yield of 26.52 % was obtained from interaction between container diameter of 33.2 cm, blade type of 3 numbers and speed of 110 rpm. The blade type, container diameter and speed of mixing were found to have significant effects on yield of the shea butter. The development of this mixer would have a positive economic impact on the local processors. The mixer would improve oil extraction and increase the product throughput for the local investors
Keywords: shea butter, mixer, blade, yield

1.0 Introduction

Shea nut contains reasonably high amounts of oleic acids from which the shea butter is obtained. Shea butter is one of the basic materials for most food, cosmetics, soap and pharmaceutical industries. It is sometimes used as a substitute for cocoa butter. Shea nut serves as a main source of livelihood for the rural women and children in Northern Ghana who are engaged in its gathering (Warra, 2011). The kernel is obtained from the nut locally by cracking with stones or mortar and pestle. Traditional methods of extraction of shea butter from the kernel involve a series of operations which includes steeping, roasting, pounding or grinding and boiling (Aviara *et al.,* 2005). Shea butter is marketed as being effective in treating the following conditions; burns, rashes, severe dry skin, dark spots, skin discoloration, chapped lips, stretch marks and wrinkles. It provides natural protection against ultra violet rays.

The tree can be found growing naturally in the Southern parts of the Sahel in Northern regions of the Guinea Zone. It thrives in Savanna areas where oil palm cannot grow due to low rainfall (Rose-monde and Se'bastian, 2013). The major producing countries are West African countries including Nigeria, Burkina Fasso, Benin, Ghana, Ivory Coast, Senegal and Cameroon. In Nigeria about 45 percent of the land area is suitable for the growth of shea tree. It currently grows in the wild in many states of the country; including Niger, Benue, Plateau, Nassarawa, Kogi, Bauchi, Jigawa, Kano, Kaduna, Yobe, Taraba, Kebbi, Sokoto, Borno, Zamfara, Edo, Oyo, Ekiti, and FCT (Onwualu, 2010; Eneh, 2010). *Butyrospermum paradoxum* (shea butter tree) is abundant in the middle belt areas of Nigeria (Benue, Kwara, Niger states and Abuja) where it is found growing wild. According to Nigerian Institute for Oil Palm Research report Niger state has the largest concentration of shea tree in Nigeria followed by Kwara state (USAID, 2010).

In Nigeria rural women use shea butter for daily applications as well as product to earn income. The current manual method of production of shea butter processes is physically demanding. Moreover it results into product of poor quality (Olaoye, 2012). The method of mixing used by women in Nigeria is to mix mainly using hand. Most often the container holding the paste is placed on the ground, and 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 through sweat and exposing from the mixer. The few existing mixing machines are only available in large scale which is costly, requires skill to operate and maintain by small and medium scale operators (Olaoye, 2012 and Balami *et al.,* 2013 and Olaoye, 2012).

The problems enumerated above calls for developments to improve the traditional methods of production by reducing the intensive labour and time consumed so as to increase the process efficiency, yield and quality of product. A mixer will improve oil extraction and increase the product throughput for local investors. A modernised approach to solving part of this problem is the main objective of this work. That is, to develop and carryout performance test of the shea paste mixer; so as to improve the overall production process an d economics.

2.0 Materials and Methods

Materials Selection

Stainless steel materials were used for construction of component parts of the machine that have direct contact with the shea butter because of its high resistance to corrosion (Gana *et al*., 2017).

Design Consideration

The design consideration was carried out with a view to evaluate the necessary design parameters such as strength and size of materials of the various machine components in order to avoid failure by excessive yielding and fatigue during the required working life of the machine.

2.1 Machine Description

The Machine was made up of the following components; the construction and the functions of which are described below.

Mixer Blades: These are set of blades made up of stainless sheet of 5 mm each. They consist of 1 set of blade attached to the blade housing at an angle of 90^0. 2-set of blades attached to the housing at 180^o. 3-sets of blades each attached to the housing at angle of 120^0 each. 4-set of blades each attached to the housing at 90^0 and 5-set of blades attached to the housing at angle of 72^0 each. The blade is shown in figure 1.

Mixing Tank: This is made up of 2 mm of stainless sheet with diameter of 0.304 m, height of 0.50 m and it was mounted on the machine frame made up of 5mm angle iron assembly as shown in figures 1 and 2. A paste discharge chute was fitted to the bottom side of the drum in order to allow out flow of mixed paste to the mixing tank.

Boiling Tank: This is made up of 2 mm of stainless sheet with diameter of 0.406 m, height of 0.350 m and it was mounted on the burner frame made up 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 butter.

Stirring Handle: This is made up of 0.030m diameter circular pipe, length of 0.24 m and arm length of 0.129m. It was attached to the stirrer arm via a gear system as shown in figures 1 and 2.

Burner: This is fitted inside an enclosure which is square in shape with height and width of 0.40m each. Between the burner and the enclosure insulating material was fitted in order to prevent heat loss as shown in figures 1 and 2.

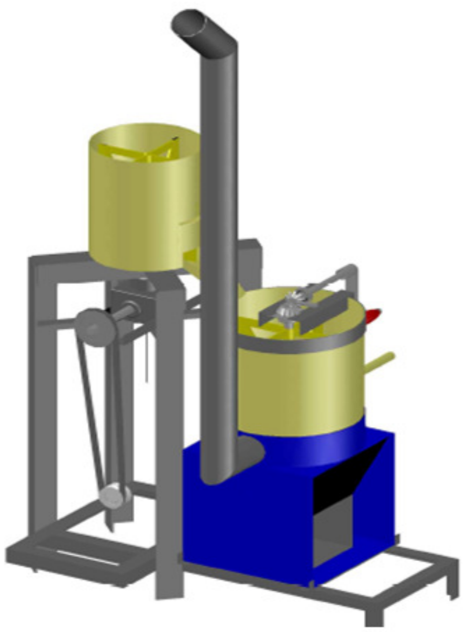

Figure 1: The Pictorial View of Shea Butter Mixer

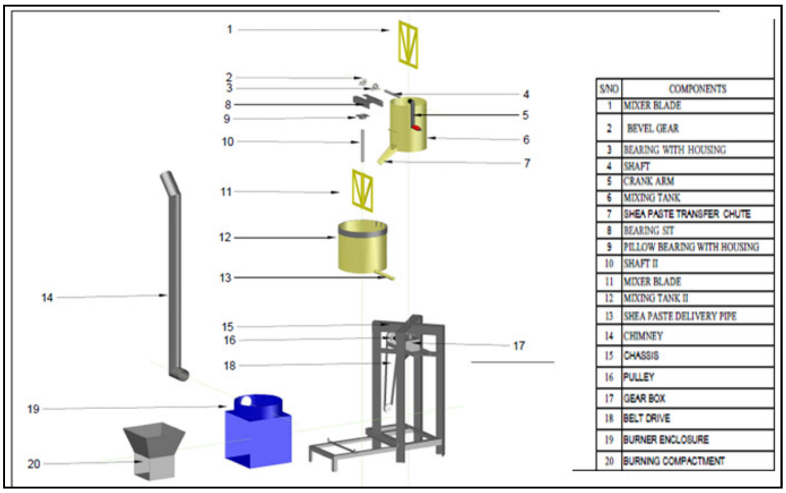

Figure 2: Exploded view of Shea Butter Mixer

2.2 Design Analysis of Machine Components

The detailed design of the shea paste mixer include the power requirement for mixing operation, assessment of the mass of material required for achieving homogeneous mixing operation, quantity of water to be added to form paste, power requirement for machine operation, size of central shaft.

Determination of Power Requirement

The power requirements of the machine depend on force in the material to be processed, mixing blade, shaft, machine pulley and the bearings. This was computed from the equation given by Khurmi and Gupta (2005)

$$P = 2 \times \pi \times N \times \tau /60 \quad (1)$$

$$\tau = F \times r_d \quad (2)$$

$$F = M \times r_d \times \omega^2 \quad (3)$$

$$\omega = 2 \times \pi \times N /60 \quad (4)$$

$$M = (M_{sp} + M_w + M_s + M_H + M_B + M_{MB} + M_{Be} + M_s) \quad (5)$$

where, P is power required by the machine (watts), F = the total force (N), τ = the torque generated (Nm), M = total mass of the container (kg), ω = angular speed (rpm), M_{sp} is the mass of the shea paste (kg), M_w is the mass of the water (kg), M_s is the mass of the shaft (kg), M_H is the mass of the handle (kg), M_B is the mass of the bearing (kg), M_{MB} is the mass of the mixing blade (kg), $M_{Be}$is mass of the bearing (kg), g is the acceleration due to gravity, π is a constant, N is the speed of revolutions per minute (rpm)

Mass of the Material (Shea paste)

The mass of the shea paste to be processed is very essential in determination of power requirement of the machine. Considering the volumetric capacity of the machine to be 0.7808 m^3/day and since each batch is assumed to take 25 minutes, the mass of material to be processed per batch is given in equation (Gana *et al*, 2017)

$$M_{Nb} = \rho_P \left(\frac{V_d \times T_b}{T_T}\right) \quad (6)$$

where, M_{Nb} is the mass of shea paste to be processed per batch (kg), ρ_P is the density of the shea paste, V_d is the volume of the paste to be processed per day (m^3), T_T is the total time required to process the expected quantity of material in a day (8 hrs), T_b is the expected time to process one batch (25 minutes).

Mass of Water

Mass of water to be used is assumed to be three times the mass of the paste in order to have proper extraction of the oil and is given as

$$M_w = 3 \text{ x } M_P \quad (7)$$

Where M_w is mass water (kg), M_P= mass of paste (kg),

Mass of Mixing Blade

The mass of the mixing blade is vital in computation of the power requirement of the machine. The mass of mixing blade was computed using the following equation reported by Gana *et al.* (2017) as

$$M_B = \rho_B \text{ x } V_B \quad (8)$$

$$M_B = \rho_B \begin{bmatrix} N_{HB}(L_{HB} \text{ x } B_{HB} \text{ x } T_{HB}) + (L_{VB} \text{ x } B_{VB} \text{ x } T_{VB}) + \\ + \pi h_{hB}(r_{HBE}^2 - r_{HBI}^2) \end{bmatrix} \quad (9)$$

where, M_B = the mass of the blade assembly (kg), V_B = the volume of blade assembly (m^3), ρ_B = the density of blade (stainless steel) (kg/ m^3), N_{HB} = the number of horizontal blades (m), L_{HB} = the length of horizontal blade (m), B_{HB} = the breadth of horizontal blade (m), T_{HB} =the thickness of horizontal blade component (m), N_{VB} =

the number of vertical blades component (m), L_{VB} = the length of vertical blade component (m), B_{VB} = the breadth of vertical blade component (m), T_{VB} = the thickness of vertical blade component (m), h_{hB} = the height of blade housing (m), r_{HBE} = the total radius of blade housing (m), r_{HBI} = the internal radius of blade housing (m), π = constant

Mass of the Shaft

The mass of the shaft is essential in the determination of the power requirement, as reported by Khurmi and Gupta (2005)

$$M_s = \rho_s V_s \quad (10)$$

$$M_s = \rho_s (\pi \frac{d_s^2}{4}) L_s \quad (11)$$

Where, M_s is mass of the shaft, ρ_s is the density of the shaft, V_s is volume of the shaft, D_s is the diameter of the shaft, L_s is the length of the shaft.

But the diameter of the shaft was determined from the relationship in equations 12

$$d_s = \left(\frac{16M_c}{\pi S_s}\right)^{0.33} \quad (12)$$

Substituting $M_t = Mgd_b/2$

$$d_s = \left(\frac{16Mgd_b}{2\pi S_s}\right)^{0.33} \quad (13)$$

where d_s is the diameter of the shaft (m), M_t is the total mass (kg), M is the mass of the shea paste (kg), g is the acceleration due to gravity, M_B is the mass of the bearing, d_b is the diameter of the blade (m), S_S is the permissible Shear stress of the shaft (N/m^2).

Second Polar Moment of Area of the Shaft

Determination of the second polar moment of area of the shaft is essential in determination of the resistance of the shaft to bending and deflection, and it was determined as reported by Khurmi and Gupta (2005)

$$J = \pi \frac{d_b^4}{32} \quad (14)$$

Where, J is the second polar moment of the shaft (m^4), d_b is the diameter of the shaft

Torsional Stress on Shaft

Determination the torsional stress was computed as a function of twisting moment, diameter of the shaft and second moment of area as expressed by Gbabo and Igbeka (2003)

$$\tau = \frac{M_t d_s}{2J} \quad (15)$$

But, $M_t = \frac{Mg}{2}$

$$\tau = \frac{Mgd_s}{4J} \quad (16)$$

Where, τ is the torsional shear stress in N/m^2, Mt is the twisting moment (Nm)

$$\frac{Mgd_s}{4J} = \frac{\rho_s L_s g d_s}{8}$$

Where, L_S is length of the shaft (m), d_S is the diameter of the shaft (m),
J is second polar moment of area (m^4), ρ_S is density of shaft material (kg/m^3)

Radial Deformation in the Shaft

Determination of radial deformation in the shaft that transmits power to the mixing chamber was expected to experience deformation due to the torsional shear stress. The extent of distortion (deformation) depends on the torsional shear stress, length, modulus of rigidity and radius of the shaft, Gbabo, and Igbeka, (2003)

$$\omega = \frac{\tau L}{Gr} \quad (17)$$

Where ω is the radial deformation or angle of twist in radians, τ is the maximum torsional shear stress of the shaft (N/m^2), G is modulus of rigidity of the shaft, r is radius of shaft

Design of the Mixing Cylinder

The volume of the mixing cylinder was assumed to be 2 times the volume of its content in order to avoid spilling of the material (Olaoye and Babatunde, 2001)

$$V_{MC} = 2(V_c) \quad (18)$$

Where, V_{MC} is volume of the mixing cylinder, V_C is total volume of cylinder content.

Therefore,

$$V_C = (V_{sn} + V_w + V_b + V_{sh}) \quad (19)$$

where, V_{sn} is volume of the shea paste (m^3), V_w is volume of the water, V_b is volume of the blade, V_{sh} is volume of the shaft

Working Procedure of the Machine

The mixing blade was fixed on the shaft inside the mixing tank or container. The milled shea paste were feed into the machine mixing tank, cold water was added intermittently to the paste. As the machine blade rotates it mixes the paste with water. This process was continued until fat begins to form and float on surface of the solution, the fats were skimmed off into another pot. The water draining valve was then open and water with lesser density than the oil was drain out of the machine. After draining the water the oil valve was opened and oil flow out into the heating unit. The oil is heated to remove particles and mucilage, the melted oil was filtered and then left to cool and solidify to shea butter.

2.3 Materials Preparation

Shea butter mixer was designed and fabricated using stainless steel materials. All parts of the plants that will get in direct contact with the product were made up of stainless steel materials in order to avoid contamination (Gana *et al*. 2017). The shea kernels used in the study were obtained from Assanyin village in Katcha Local Government Area of Niger State, Nigeria. The kernels were cleaned manually by hand to remove all foreign matter such as dirt, stone pieces and broken seed. The cleaned shea nut were then crushed, roasted and milled using crusher, roaster and the developed mixer. The experiments were carried out at the Agricultural and Bioenvironmental Engineering Departmental workshop of Federal Polytechnic, Bida, Nigeria.

2.4 Testing of the mixer

In the testing of the mixer, effects of mixing container diameter, blade type and speed of mixing on yield of the shea butter was examined. The experiments were carried out at the Agricultural and Bioenvironmental Engineering Department of Federal Polytechnic Bida, Nigeria.

Experimental Setup and Procedure for Developing the Design Matrix

In this study, Central composite rotational design (CCRD) of response surface method (RSM) was tested at five levels with three independent variables; mixing tank diameter, blade type and speed of mixing in order to investigate the yield of shea butter of the machine. The experiment consists of 20 experimental runs involving eight factorial points, six axial point and six replicated centre points at zero level (Gana *et al*, 2017; Aworanti *et al*., 2013). . The matrix transformation of the design is shown in table 1.

Determination of Yield of the Shea Butter

This is the measure of the degree by which the grains are reduced oil size and was determined as reported by Gana (2011)

$$Y_{oil} = \frac{\mathrm{A}}{\mathrm{M}} \mathrm{x}\ 100 \qquad (21)$$

Where Y_{oil} is the yield of the shea butter (%), A is the amount of shea butter oil obtained (kg), M is the total weight of the shea paste feed into the mixing drum (kg)

3.0 Results and Discussions

Yield of the Shea Butter (%)

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 (2011). The effects of independent variables; container diameter, blade type and speed of mixing on the yield of butter is presented in Table 1. The yield of oil ranged between 26.52 % and 39.43 %. The highest yield of oil of 39.43 % was obtained from interaction between container diameter of 50 cm, blade type 5 numbers and speed of 110 rpm, while the least oil yield of 26.52 % was obtained from interaction between container diameter of 33.2 cm, blade type of 3 numbers and speed of 110 rpm.

Table 1: Effects of container diameter, blade type and speed on yield of the shea butter

Std. Ord	Run Ord	Container Diameter (cm)	Blade Type (No)	Speed of Mixing	Yield of Butter
7	1	40	4	120	29.82
17	2	50	3	110	35.05
4	3	60	4	100	33.23
5	4	40	2	120	28.32
1	5	40	2	100	23.73
2	6	60	2	100	30.23
16	7	50	3	110	38.32
14	8	50	3	127	28.04
20	9	50	3	110	37.77
13	10	50	3	93	27.44
6	11	60	2	120	31.18
3	12	40	4	100	28.44
18	13	50	3	110	37.98
19	14	50	3	110	37.05
11	15	50	1	110	33.16
10	16	66.82	3	110	32.18
9	17	33.18	3	110	26.52
8	18	60	4	120	31.98
12	19	50	5	110	39.43
15	20	50	3	110	37.98

The Response Surface and Contour Plot for Yield of Shea Butter with Respect to Blade Type and Container Diameter

The response surface and contour plot for yield of shea butter oil were presented in Figures 3 and 4 respectively. The yield of butter increased from 29.5 % to 33.5 % as the blade number increased from 2 to 4 numbers. This could be due to increase in agitating and mixing of the paste slurry with increased in blade number. This agreed with result of an earlier study by Gana (2011) where blade design was found to effect mixing of milk slurry, the more the contact between the blade and the paste the more the rate of mixing. Also the yield of the shea butter increase from 29.5% to 37.7 % with increase in mixing container diameter from 40 cm to 50 cm and then remain constant with further increase in the containers diameter.

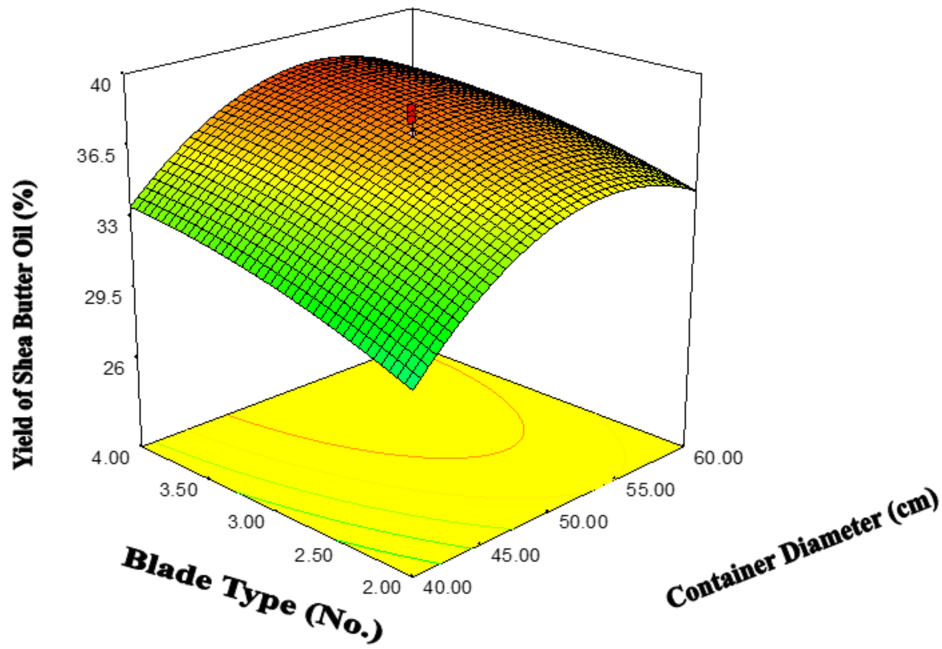

Figure 3: Response Surface for Yield of Shea Butter with Respect to Blade Type and Container Diameter

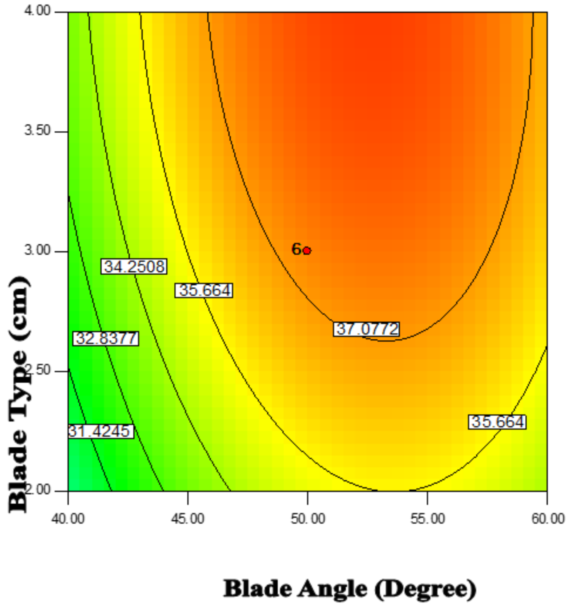

Figure 4: Contour Plot for Response Surface of Yield of Shea Butter with Respect to Blade Type and Container Diameter

Relationship between Speed of Mixing and Blade Type

The relationship between speed of mixing and blade type is presented in Figures 5 and 6. The Yield of butter oil increased from 30.25 % to 33 % as the blade number increased from 2 to 4 numbers. Also the yield increased from 30 % to 35 % as the speed of mixing increased from 100 rpm to 110 rpm and then decreased to 32.90 with further increased in speed of mixing. The higher yield of butter observed with initial increased in speed of mixing could be as result more agitation of the paste with more speed. But as the speed of mixing exceeded 110 rpm the paste slurry became hotter due to more heat generated with the higher speed.

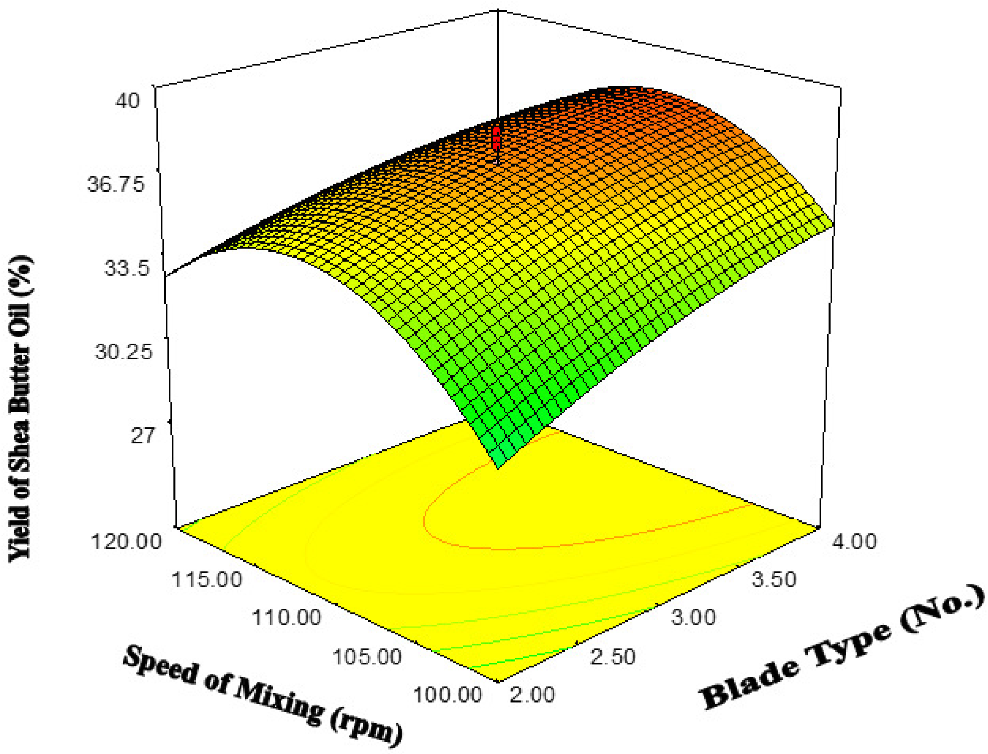

Figure 5: Response Surface for Yield of Shea Butter with Respect to Speed of Mixing and Blade Type

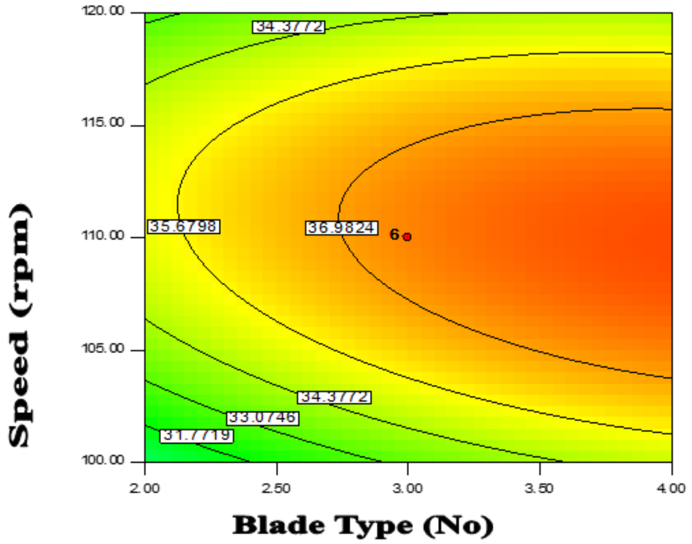

Figure 6: Contour Plot for Response Surface of Yield of Shea Butter with Respect to Speed of Mixing and Blade Type

4 Conclusions

The developed machine is capable of increase in production of shea butter and it product, reduce production cost, saved operation time. It also has the advantage of producing hygienic and quality shea butter, higher output capacity, its mode of operation is simple and its cost of production is reasonable.

The yield of oil ranged between 26.52 % and 39.43 %. The highest yield of oil of 39.43 % was obtained from interaction between container diameter of 50 cm, blade type 5 numbers and speed of 110 rpm, while the least oil yield of 26.52 % was obtained from interaction between container diameter of 33.2 cm, blade type of 3 numbers and speed of 110 rpm.

The yield of butter increased from 29.5 % to 33.5 % as the blade number increased from 2 to 4 numbers. Also the yield of the shea butter increase from 29.5% to 37.7 % with increase in mixing container diameter from 40 cm to 50 cm and then remain constant with further increase in the container diameter. Also the yield increased from 30 % to 35 % as the speed of mixing increased from 100 rpm to 110 rpm and then decreased to 32.90 with further increased in speed of mixing.

References

Aworanti, O. A., Agarry, A. O. and Ajani, A. O. 2013. Statistical Optimization of Process Variables for Biodiesel Production from Waste Cooking Oil Using Heterogeneous Base Catalyst.*British Biotechnology Journal Vol*.3 (2) pp 116-132.

Balami, A. A**.,** Adgidzi, D., and Mua'zu, A., (2013): Development and Testing of an Animal Feed Mixing Machine, International Journal of Basic and Applied Science, Vol.01, No. 03, Jan 2013, pp.491-503.

Eneh, M.C.C. (2010). An overview of Shea Nut & Shea Butter industry in Nigeria being paper presented at the National Seminar organized by CBN in collaboration with Federal Ministry of Agricultural & Rural Development & Nigeria Export Production Council (NEPC). Hydro Hotels Ltd, Minna Niger State, Nigeria 2 – 4 august 2010.

Gbabo, A. and Igbeka, J. C. 2003. Development and Performance of a Sugar Centrifuge *Journal of Sugar Tech.,*5 (3), 131-136.

Gana, I. M. (2011). Development and Performance Evaluation of Grain Drinks Processing Machine, Unpublished M. Engineering Thesis, Federal University of Technology Minna

Gana I. M, Shehu A.A Dauda S. M. and Ahmad, D. (2016) Design, Fabrication and testing of shea nut shelling machine *International Food Research Journal* 23(suppl):871-879 www.ifrj.upm.edu.my

Gana I. M, Agidi G. Idah, A. I. and Anuonye J.C. (2017) Development and testing of an automated grain drinks processing machine Journal of Food and Bioproducts Processing, Elsevier 1 0 4 (2 0 1 7) 19–31 www.elsevier.com/locate/fbp

GtZ, (2009). Report on Training of trainers in shea Quality Improvement training programme (SQITP) for Bida/ Gbangbara community in Niger State, Nigeria 13 – 17th, 2009

Khurmi, R. S., and Gupta J. K. (2005). Machine Design.First Multicolour Edition.Enrasia Publishing House (PVT) Ltd. Ram Nagar, New Delhi-110 055

Olaoye, J. O., and Babatunde, O. O. (2001). Development and Testing of a Milled Shea Nut Mixer.
Journal of Food Science and Technology. Vol. 38 (5): 471 – 475

Olaoye, J.O (2012). Development Status of production & processing machinery of Shea Oil from a woody oil plant in Nigeria. International Journal of Science & Engineering Technology: 3(5). 107 – 115

Onwualu, A.P (2010). Role of Raw material Research & Development Council in the development & utilization of Shea nut in Nigeria. Being paper presented at the Shea Seminar organized by the Central Bank of Nigeria (CBN),

USAID, (2010). Investing in Shea in West Africa. A U.S. Investor's Perspective. West Technical Report

Rose-monde me'gnanou and Se'bastian N (2013). Effect of Nut Treatments on SB physicoxcal criteria & wrapper Hygienic. Quality influence on microbiological properties in Journal of Food Research 2(5) 2013 online Publication.

Warra, A. A. (2011). The cosmetic Potentials of African Shea Nut (*Vitellaria paradoxa*) Butter. *Current Researchin Chemistry, 3*, 80-86.