Development and Testing of a Milled Shea Nut Mixer

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A manually powered beater type mixer was designed, constructed and tested. The mixer was constructed to effectively mix milled shea nut with little effort and at minimal initial capital. It has a conical shape located located inside a hemispherical mixing bowl. It has an output capacity of 120 kg/h and the capacity of the mixing bowl at full load is 20 kg. The product obtained from the mixer was compared with the product from the traditional method. The results of the comparative economics of milled shea mixer indicated that the cost of mixing one tonne of milled shea nuts using the mechanical mixer costs about $ 2.2 (₦ 220) as compared to $ 6.5 (N 650) for manual mixing. Hence, the high cost requirement of mixing milled shea nut through traditional method and the high labour requirement were considerably reduced.

Keywords : Mixing machine, Manual operation, Milled shea nut, Oil extraction, Beater mixer.

Shea butter oil is one of the important derivatives from Shea butter tree (*Vitellaria paradoxia*). The plant grows in the wild and widely distributed around the Svannah region of Nigeria. Shea butter oil is obtained from the nut of the plant. The extraction of shea butter oil is on small-scale production level. The oil is processed by traditional method with little mechanical assistance. Shea butter oil is considered as a close substitute for oil palm in some part of Northern Nigeria (Olaoye 1990). It is used for soap making, pomade, medicinal purpose and as a raw material for industries (Hampton and Fellows 1992). According to Patterson (1989) shea nut contains about 34-45 % fat; fibre products, carbohydrates and proteins constitute the other components of shea nut. Chemical analyses of shea butter oil also revealed that the oil contained FFA, saponification value, Iodine value, unsaponifiable matter, peroxide value and ash content value corresponding to 2.16, 177.0, 59, 6.5 %, 2.6 and 0.16, respectively (Fernando and Akajobi 1987). It is more saturated than cocoa butter and it is used as cocoa substitute. Shea butter has dual characteristics, a fat at ambient temperature (25-30°C) and oil at temperature above this value (UNIFEM 1993).

According to UNIFEM (1993), shea butter nut processing provides approximately 60 % of the income for women in the Sahel and is a vital source of fat for the community. Niess (1983) developed a dry extraction method for shea butter. This method reduced the arduous task involved in traditional procedure and improved the oil output. But this method could bring about a change in the traditional division of labour, affecting the earnings of the women. In Nigeria, application of mechanical devices such as hydraulic or screw press for removal of oil are rarely used. The steps involved in the traditional processing of shea butter oil are presented in Fig. 1.

Traditional mixing takes place in a large pot, strong enough to withstand the applied force through trampling that causes mixing or stirring of the milled shea nut. According to Olaoye (1994) mixing of milled shea nut with water caused the colour of the milled shea nut to change from brownish to

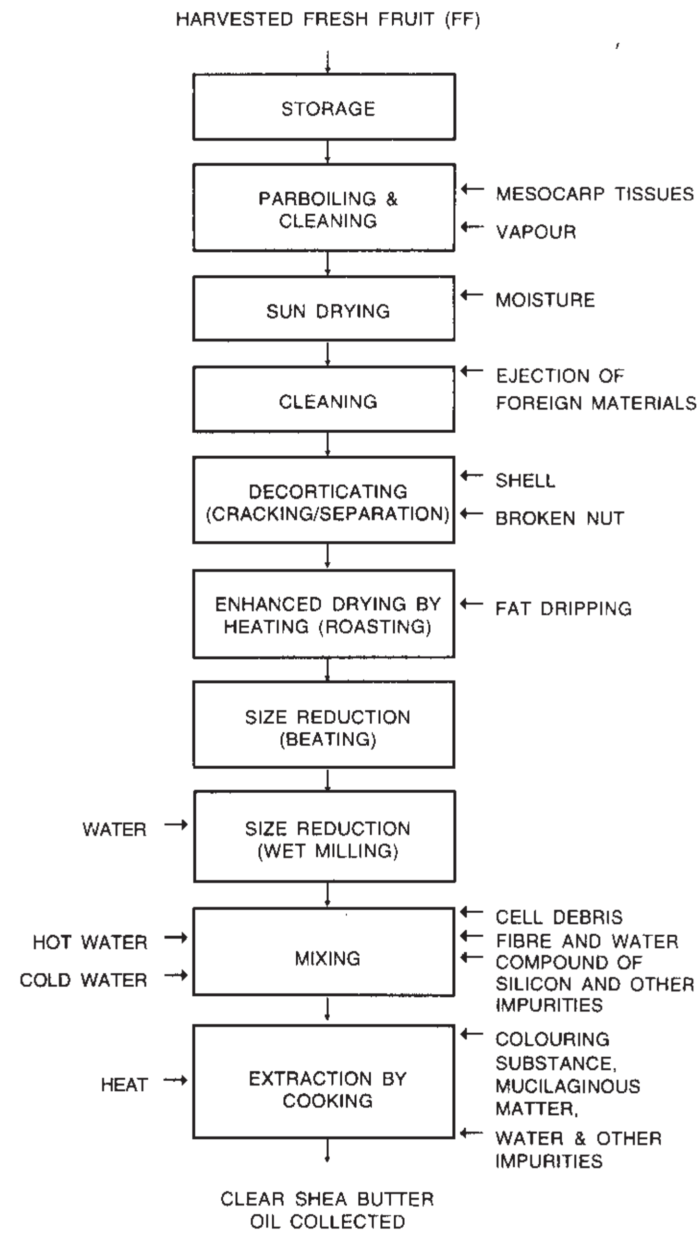

Fig. 1. Flow chart for the local processing of shea butter oil

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greyish colour and the resulting dillution enhanced easy separation of oil and precipitation of the impurity and fibres during cooking. There are mechanical devices for drying and size reduction operations, but mixing of milled shea nut is yet to be mechanized. Olaoye (1994) found that the quantity of oil obtained through the traditional method was low, the procedure was time consuming and the mixing operation was a difficult task. Mainly, women carry out the processing of shea butter with the assistance of children.

This study was aimed at mechanizing the indigenous method of mixing of milled shea butter during traditional processing of shea butter oil. For this purpose, a mechanical mixer was designed, tested and compared with the traditional trampling of mixing procedure.

Materials and Methods

Design of the mixer : McCabe et al (1985) described two methods of operation of Change Can mixers as pony mixer and beater mixer. The milled shea nut is a viscous material. A Change Can mixer mixes viscous liquid or light pastes. It consists of a small removable can, which holds the material to be mixed. The motion of the beater or agitator causes the redistribution of material components. The beater or agitator covers the entire portion of the mixing bowl. The milled shea nut mixer under consideration is the beater type.

The requirement for effective mixing of viscous material is to ensure that all materials must be brought to the agitator/ beater or the agitator must visit all parts of the mix. As the beater rotates, it compresses the mass of the material, so that it repeatedly visits all parts of the vessel (McCabe et al. 1985). The beater creates a flow pattern in the system, causing the liquid to circulate through the vessel and return eventually to the beater.

Fig. 2 shows the general design of the mixer. A close clearance was provided between the sides and bottom of the mixing bowl and the beater during operation. The operation of the beater was to generate both rotary and translatory motion for effective mixing of the milled shea nut. A planetary gear assembly was used to generate a planetary motion of the beater from the effort applied to the handle. The whole arrangement was mounted on a wooden support. The basic design considerations for the milled shea nut mixer are summarized as follows.

(i) Capacity of the mixing bowl is fixed to ensure a mixing time of 10 min for 20 kg of Milled Shea Nut (MSN). (ii). Low labour requirement and an expected input power that can be supplied by children or women is assumed to be 0.25 kW and an average man can supply 0.25-0.30 kW continuously for 6-8 h, including rest time for relaxation and refreshment (Gosh 1978; Inns 1992). (iii.) A hemispherical mixing bowl is given. The tank bottom is rounded to eliminate sharp corners or region into which the fluid materials would be locked. (iv.) A conical shape beater is chosen. The beater is shaped to pass with close clearance over the side and bottom of the mixing vessel (McCabe et al. 1985; Lindley 1991), (Fig. 2). (v.) A shaft driven by a handle connects a planetary gear assembly to the beater thus allowing two motions of the beater rotating around the bowl and on the axis. A planetary motion of beater is desired for effective mixing of viscous material (Novak and Rieger 1969), (Fig. 2) and (vi.) The basic parameters of the milled shea nut (MSN) mixer are velocity of the beater, time of mixing, and diameter of the beater. The power delivered to the fluid during mixing depends on these parameters. The mixing time and the power requirement are functions of the speed; physical properties of the fluid and its characteristic properties related to power and Reynolds numbers. These variables are : density of the MSN is 1.082 g/cm^3 and for standard, 6- bladed beater, power number, Np is 5.2 (McCabe et al. 1985 ; Hall and Godfery 1968).

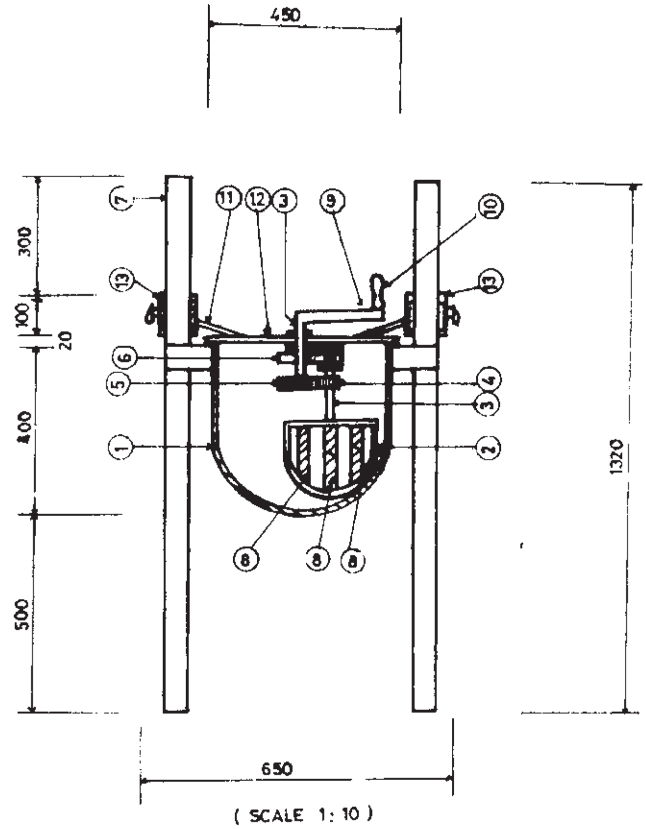

Fig. 2. Sectional view of the milled shea nut mixer
1. mixing bowl 2. beater 3. shaft 4. planet gear 5. sun gear 6. arm 7. main frame 8. paddle 9. cranke 10. handle 11. beater holder 12. corner plate 13. sliding guide

Development : The milled shea nut-mixing machine developed is a vertical feed, manually operated unit. The various components of the mixer are frame assembly, conical shaped anchored beater with three blades, mixing beater shaft, planetary gear assembly, shaft handle and the hemispherical mixing bowl that is supported with a wooden stand.

Geometry of mixing bowl : A hemispherical vessel was considered to accommodate the beater. The capacity of the vessel, V_b is calculated using equation 1 as

$$V_b = \frac{M_{sn}}{\rho} \qquad \text{...... (1)}$$

18500 cm^3 with Mass of Milled shea nut, M_{sn} = 20000g and density of milled shea nut, ρ= 1.082 g/cm^3. The capacity of the mixing machine, M_{ca} was expressed in equation 2 as the capacity of the mixing bowl per time taken for mixing. It is obtained as 110.8 1/h, where V_b is obtained from equation 1 and time taken for mixing, t_m = 0.167 h.

$$M_{ca} = \frac{V_b}{t_m} \qquad ...... (2)$$

The diameter of the mixing bowl, d_m was obtained from equation 3 (McCabe et al. 1985)

$$d_m = \left(\frac{24V_b}{2\pi}\right)^{1/3} \qquad ...... (3)$$

as 41.0 using V_b as obtained from equation 1. All parameters in equations 1—3 are as defined in the notation.

Mixing velocity of beater : The beater created flow pattern in the system causing the fluid to circulate through the vessel and return evenly to the beater. The power requirement, P was assumed to be 0.25 kW, diameter of the beater, and d_b to cause mixing were 0.195 m and 0.92 m/s, as the speed of mixing, V_s for hand operation of the beater. The mixing velocity of the beater and the gear ratio of the planetary assembly was obtained from the expression for the mixing speed, power input, P_o and speed of rotation, N of the beater using equations 4 and 5 (McCabe et al. 1985; Faires 1965). Factor of safety of 1.2 was used in equation 4. Therefore, speed of beater, N is calculated as 115 rpm and the speed of mixing, V_s 1.00 m/s.

$$V_s = \frac{\pi d_b N}{60} \qquad ...... (4)$$

$$P = \frac{N\rho N^3 D^5_b \rho}{g_c} \qquad ...... (5)$$

The input speed, N of the revolution of handle at 115 rpm gave the angular speed, ω of the planet gear from equation 6 as 5.1 rad/s. About 90 % of the input speed was assumed to be transmitted to the beater and the number of teeth of the sun was 30.

$$V = \omega r \qquad ...... (6)$$

Therefore, it was assumed that gear 1: the sun was fixed with the same angular velocity of gear 2, the planet and arm 3 relative to ground. The number of teeth of the planet gear were obtained as 18 teeth from Marbie and Reinholtz (1987) as shown in equation 7 since, the sun and the planet moved in opposite direction. All parameters in equations 4-6 are as defined in the notation.

$$\omega_{21} = \omega_{31}\left(1 - \frac{N_1}{N_2}\right) \qquad ...... (7)$$

Beater mounting shaft : In the mixing machine, when the beater and shaft were loaded with the milled shea nut, the shaft was subjected torque and bending moment is neglected as the shaft was mounted vertically. The torsional Equations 8, 9 and 10 (Faires 1965) were used to calculate the size of the shaft. Torque, T was calculated as 140 kgcm using equation 9, where power input, P_o = 0.25 kW, mechanical efficiency of transmission of power, η =90 % and speed of beater, N = 115 rpm (from equation 5).

$$\frac{T}{J} = \frac{F_s}{r} \qquad ...... (8)$$

$$P_o = \frac{2\pi NT}{4500\eta} \qquad ...... (9)$$

Equation 10 was obtained by re expressing polar moment of inertial, J and radius of the shaft, r in equation 8 in term of the diameter of the shaft, d_s. From equation 10 d_s was calculated as 12.3 mm, where, T= 140 kg cm (from equation 9) and torsional shear stress of mild steel, F_s = 375 kg/cm^2 (Marbie and Reinholts 1987).

$$d_s = \left(\frac{16T}{\pi F_s}\right)^{1/3} \qquad ...... (10)$$

All parameters in equations 7-10 are as defined in the notation. Based on the available material, a shaft of 20 mm diamter was selected.

Construction of the mixer

Frame : The frame was made of square mahogany wood of size 50 x 50 mm. The overall dimensions of frame were 595 mm x 595 mm x 900 mm high. The mixing vessel was positioned on top of the frame, through a circular hole of 450 mm diamter. In this frame, the support for adjustment of beater was located above the surface of mixing vessel, 400 mm high. This was essential for the sliding and adjustment of the beater in the mixing bowl and for the loading and discharging of the shea nut.

Mixing beater shaft : A mild steel shaft of 25 mm diameter of length 250 mm was used to connect the beater to the planet gear. The crank was made of a mild steel hollow pipe of 45 mm diameter of length 200 mm. It was connected to the fixed axis of rotation arm and the planet gear. The arm connected the plant gear to the sun gear at moving axis of rotation of the sun. The arrangement of the planetary gear assembly is shown in Fig. 2. The handles transmitted the input power through the gear assembly to the anchored beater that rotated inside the hemispherical mixing bowl.

Three blades of a pair of length 150 mm and a length 200 mm, each of width 35 mm and thickness 3 mm, made of stainless steel were placed in a hemispherical anchor of diameter 195 mm. The blades were rigidly welded in place at equidistant. Two mild steel shafts each of 250 mm x 20 mm diameter were fixed to the sliding guide of the frame as a support for adjustment of the beater. These members were used to support the beater inside the mixing bowl.

Mixing vessel : A hemispherical mixing bowl of diameter 400 mm was used. A flat mild steel of thickness 3.5 mm was used. The vessel accommodates the milled shea nut and the

TABLE 1. THE RESULT OF THE PERFORMANCE TEST OF THE MIXER

Input speed	Time of operation, h				Capacity, 1/h				Oil recovery, %				Average oil recovery efficiency, %
(Rpm)	R_1	R_2	R_3	Avg	R_1	R_2	R_3	Avg	R_1	R_2	R_3	Avg	
85	0.185	0.180	0.190	0.185	100	103	96	100	34	32	35	34	85
100	0.168	0.172	0.165	0.168	114	108	112	111	32	30	30	31	77
115	0.150	0.160	0.160	0.157	116	116	116	118	28	30	29	29	72

beater, which freely rotated and compressed so as to be able to visit all parts of the mixing vessel.

Evaluation : The performance of the milled shea nut mixer was evaluated for the mixing period, capacity and oil recovery with respect to the speed of the beater. The unit was run at different speeds by considering the operating speed of the machine when three different people; a boy, a woman and a man operated the machine. The boy, woman and man operated the machine at 85 rpm, 100 rpm and 115 rpm, respectively. To ensure steady speed an operator's mate helped by counting the number of revolutions within a minute of stopwatch. Sample of milled shea nut was collected after passing through the processing stages as indicated in Fig. 1 for the purpose of the testing. The mixing period was established as the time taken, when mixed milled shea nut was assessed to have attained the necessary textural and colour requirements. The capacity of the mixer for various speeds of the beater was determined using equation 2. The oil recovery was estimated as the percentage of the oil recovered from the mixed milled shea nut after extraction.

Results and Discussion

Effect of beater speed on mixing period, capacity and oil recovery : The effect of the beater speed on the mixing period of milled shea nut, the capacity of mixer and the oil recovery of the mixer are presented in Table 1. In the speed range of 85 and 115 rpm of the beater of diameter 19.5 cm, the mixing time decreased between the average time of 0.185 h and 0.160 h as the speed increased. This might be due to the fact that at higher speed the rate at which energy expanded was higher (equation 2). Between the speeds 85 and 115 rpm, the decrease in the mixing time was in the range of 1.5 %. The capacity increased with increase in speed in the speed range of 85 to 115 rpm. The capacity was greater for higher speed.

The percentage oil recovery was greater for lower speed. Increased speed leads to decrease in oil recovery. The increment in the oil yield as speed decreases may be due to the longer time taken for the beater to act on the cell wall of the milled shea nut that entrapped the oil droplet. The effect of longer time enhanced the settling of the heavier particles, hence improved oil yield during cooking. The oil recovery ranged from 34 to 29 % as the speed changed between 85 and 115 rpm.

The oil recovery efficiency of the manual procedure and the mechanical mixer was compared. The average oil content of shea nut was about 40 % (UNIFEM 1993; TPI 1971). The average oil recovery efficiency for the mechanical mixer operated at different speeds is presented in Table 1. The comparative economics of the milled she nut mixer indicated that the mechanical mixer had higher average oil recovery efficiency as compared to manual mixer (Table 2).

Economics of the mixer : The economics of the mixer was worked out and compared with the traditional mixing method and cost of mixing per tonne of milled shea nut (Table 2). The following assumptions were made while calculating the economics of the mixer.

Interest rate on investment, 21 %

Annual repairs and maintenance, 10 % on the investment cost.

No. of working hours/year, 1040 h/y for the mixer and 2080 h/y for traditional method.

Capacity, 120 kg/h for mixer and 40 kg/h for traditional method

Labour cost $ 0.25/ h (₦ 25/h).

The cost of mixing was much less for the developed mixer compared to traditional methods.

Conclusion

A hand operated milled shea nut mixer was developed from the available local materials and it was sufficiently rugged for local production, operation and maintenance. The capacity of the machine was 120 kg/h. The performance of the machine

TABLE 2. COMPARATIVE ECONOMICS OF MILLED SHEA MIXER*

Description	Mechanical mixer, $	Manual mixing, $
Cost of machine	35	1
Annual fixed cost		
1. Interest on investment	7.35	-
2. Depreciation (life period of 10 years)	3.15	-
3. Repair and maintenance	3.50	-
Total annual fixed cost	14.00	-
Fixed cost/h	0.014	
Operating cost/h (wages to labour/h)	0.25	0.25
Total operating cost/h	0.25	0.25
Total mixing cost/h	0.26	0.25
(Fixed cost + operating cost)		
Hence cost of mixing for one tonne of milled shea nut.	2.20	6.25
Oil recovery efficiency	76 %	72 %

*₦ 100 = US $ 1

was evaluated at beater speed between 85 and 115 rpm. The oil recovery ranged from 29 to 34 %, necessitating selection of a suitable mixing speed in order to optimize the performance of the machine. The cost of mixing is less than the conventional method of mixing.

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Notations

d_b - diameter of beater, mm

d_m - diameter of mixing bowl, mm

d_s - diameter of shaft, mm

F_s - Torsional shear stress of mild steel, 375 kg/cm^2 (Marbie and Reinholtz 1987)

g_c - gravitational contant (9.80 m/s^2)

J - Polar moment of intertia cm^4

M_{ca} - Capacity of mixer (kg/h, 1/h)

M_{sn} - Mass of milled shea nut (kg)

N - Speed of beater (rpm)

N_1 - Number of teeth of sun gear

N_2 - Number of teeth of planet gear

N_p - Power number of beater, 5.2 (MaCable et al. 1985)

P, P_o - Power input (kW)

r - radius of shaft (mm)

T - Torque applied (kg m)

t_m - mixing time (h)

V_b - Volume of mixing bowl (cm^2)

V_s - Speed of mixing (m/s)

ρ - density of milled shea nut (g/cm^3)

η - mechanical efficiency

ω - angular speed (rad s^{-1})

ω_{21} - angular speed of planet relative to sun (rad s^{-1})

ω_{31} - angular speed of arm relative to sun (rad s^{-1})

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