DEVELOPMENT OF A SMALL SCALE MACHINE FOR ROASTING SHEA KERNEL PRIOR TO SHEA BUTTER EXTRACTION

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ABSTRACT

Shea kernel roasting prior to shea butter extraction is done to prepare the kernel in a good condition for the extraction of the fat (shea butter). Besides, roasting reduces the viscosity of oil to be extracted, ruptures the oil cells, adjusts the moisture content of the kernel to the optimum level for oil extraction and destroys or deactivates enzymes which inhibit the release of oil from the kernel. All these facilitate the extraction process. A small scale machine for roasting shea kernels prior to shea butter extraction was designed, constructed and tested The machine consists of a hopper, top cover, roasting chamber, chamber support, an auger or screw conveyor, temperature-controlled heating device, a discharge outlet, a 2 hp electric motor and a speed-reduction gear box. The machine derives its power from the electric motor through a gear reduction box to the shaft of the screw conveyor. Shea kernel is fed through the hopper into the roasting chamber and then conveyed to the discharge end after being roasted. Heat is supplied to the kernel inside the roasting chamber form two 750 W ring-type heaters placed at both ends of the chamber. The roasting temperature is regulated by a thermostat connected to the electric heaters. The machine has a capacity of 20 kg/h and the production cost was USD100. Test results revealed weight losses of 12.1, 27.6, 31.8 and 32.8 % in the kernels at roasting temperatures of 50, 70, 90 and 110 ^{0}C respectively. The kernels were of uniform deep-brown colour with clear film of oil on the surface after roasting indicating that they experienced uniform roasting.

Keywords: development, roasting machine, roasting temperature, shea butter, shea kernel

1. INTRODUCTION

Oilseed materials with high protein content are usually roasted before pressing in order to coagulate the protein and free the oil for extraction. Shea kernel (SK) roasting prior to shea butter (SB) extraction is a common practice among SB processors in the Nigerian rural communities because it facilitates oil extraction process. Besides, roasting reduces the viscosity of oil to be extracted, rupture the oil cells, adjusts the moisture content of the kernel to the optimum level for oil extraction and destroys or deactivates enzymes which inhibit the release of oil from the kernel. SB is the fat content of SK which is used in food, soap, cosmetics, pharmaceutical, medical and engineering industries for the production of cooking oils, toilet soaps, pomade, drugs, ointments and metal cutting fluids respectively. The residual cake from which the oil is extracted – shea cake (SC) – can be an excellent ingredient for livestock feed production and a substitute for cocoa butter in the chocolate and confectionary industries. These products, in Nigeria, have high potential for export and as foreign exchange earners.

Olopade and Akinoso (2004) designed and fabricated 2 kg capacity roaster for roasting cassia sieberiana seeds. Visual observation while testing the roaster revealed that physical changes on the seeds were time dependent; 200 ^{0}C roasting temperature and 15 min roasting time gave the best samples of cassia sieberiana during the testing. Mahama, Mburidiba, Mensah, and Seidu (2004) developed a machine for roasting crushed SK in Northern Ghana. The roaster consists of an enclosed cylindrical drum with a lid welded to the opening to prevent the material from falling out during operation. Inside the drum are agitators which transfer the material into different positions in order to prevent burning, mixes the material in the drum for uniform roasting and sweeps the roasted materials properly in the drum in order to receive fresh one. However, the machine is very slow in operation and operates with much heat loss and too much heat to body contact with possibility of fire disaster during roasting (Mahama, Mburidiba, Mensah, and Seidu 2004).

Akinoso, Asiru, and Awoliyi (2004) developed a 300 kg/h manual cashew nut roasting machine which uses charcoal as a source of heat energy. Performance evaluation showed that the roaster could roast 15 kg of raw cashew nut having a moisture content of 12 %

wet basis for 3 minutes using 130 ^{0}C as a roasting temperature. Davids (2003) stated that roasting machines basically operate at temperatures between 240-275 ^{0}C for a period of time ranging from 3 to 30 minutes. Raemy and Lambelet (1982) explained that coffee roasting process is initially endothermic (absorbing heat) but becomes exothermic (giving off heat) at a temperature of about 175 ^{0}C. It implies that, at this temperature, the beans are heating themselves; thus, roaster design engineers should know that roaster's heat source should be adjustable and controllable. Basically, there are two common types of roasting machines which include drum roasters and hot-air roasters (Anonymous, 2012). Others that are less common include packed bed roasters, tangential roasters and centrifugal roasters (Anonymous, 2012). In hot air coffee roasters, heated air is forced through a perforated plate under the coffee beans with a force sufficient enough to lift the beans while tumbling and circulation of the beans within the fluidized bed aid the process of heat transfer to the beans (Anonymous, 2012).

In the traditional method of SB extraction, SK is roasted over fire for a certain period of time using some local devices. One of such devices is made of a perforated clay pot inside which the kernels are placed and then heated from the bottom using firewood. Another one consists of an empty drum with a perforated bottom while the kernels are fired underneath using firewood. This traditional method is crude, tedious, labour intensive, has no provision for ergonomic factors and also exposes the operators to excessive smoking and heat radiation. SB extracted from SK treated using this method has been found to be poor quality. A SB processor in the rural communities needs a SK roasting device that can easily be operated, used and maintained. Therefore, the objectives of this work are to design, construct and test a simple small scale machine for roasting SK prior to SB extraction in the rural communities. Such a machine would remove the hazards involved in the traditional roasting of SK and eventually improve the efficiency of SB extraction.

2. THE MACHINE

3.1. Description and Working Principles

The roaster consists of a hopper, top cover, roasting chamber, chamber support, an auger or screw conveyor, temperature-controlled heating device, a discharge outlet, a 2 hp electric motor and a speed-reduction gear box. The machine derives its power from the electric motor through a gear reduction box to the shaft of the screw conveyor. SK is fed through the hopper into the roasting chamber and then conveyed to the discharged end after being roasted. Heat is supplied to the kernel inside the roasting chamber form two 750 W ring-type heaters placed at both ends of the chamber. The roasting temperature is regulated by a thermostat connected to the electric heaters. The isometric view of the machine is shown in Figure 1.

3.2. Design Considerations

Design considerations included machine capacity of 20 kg/h; roasting chamber adequately insulated to prevent heat loss during roasting operation; a speed-reduction mechanism to step down the motor to the desired shaft speed; temperature-control device to regulate the roasting temperature; a screw auger to serve the dual purposes of conveying and stirring the kernels in the roasting chamber thereby preventing burning of the kernels; roasting chamber designed to accommodate the required quantity of SK; roasting chamber designed to ensure maximum contact of individual kernel with the heat output in order to increase efficiency and reduce heating time; and a strong main frame to serve as structural support for the machine.

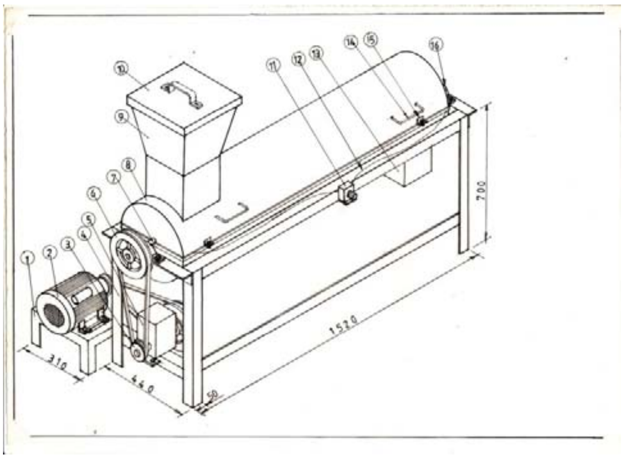

Figure 1: Isometric View of the Roasting Machine: 1-Electric motor stand, 2-Electric motor, 3-Speed reduction pulley, 4-Machine stand, 5-Speed reduction box, Machine pulley, 7-Conveyor shaft, 8-Roasting drum, 9-Feeding hopper, 10-Hopper lid, 11-Thermostat, 12-Thermocouple wire, 13-Kernel outlet, 14-Drum handle, 15-Drum flange, 16-Bearing housing

2.3. Design Theorems

2.3.1 Transmission Shaft

The main shaft that makes the screw conveyor in the roasting chamber is subjected to bending moment and shear stress during rotation. The permissible diameter of the shaft, according to American Society of Mechanical Engineers (ASME) Code was determined as:

$$d^3 = \frac{16}{\delta_o \pi} \sqrt{M^2 + T^2} \tag{1}$$

where d is the permissible shaft diameter in m, M is the bending moment in Nm, T is the maximum torque in Nm, δ_o is the yield stress in N/m^2 and π is a constant. With M = 13.13 Nm, T = 60 Nm, and δ_o = 72 x 10^6 N/m^2, hence d = 15.11mm. Therefore, a solid mild steel rod of diameter of 20 mm was used for the transmission shaft.

2.3.2. Auger Capacity

The theoretical capacity of the auger was calculated from the equation developed Onwualu, Akubuo, and Ahneku (2006) as:

$$Q = 60 x \frac{\pi}{4} (D^2 - d^2) pN\phi \tag{2}$$

where Q is the theoretical capacity in m^3/h, D is the screw diameter in m, d is the shaft diameter in m, p is the screw pitch in m, N is the shaft speed in rpm and ϕ is the filling factor. Substituting D = 30 cm, d = 20 mm, p = 30 cm, N = 30 rpm and ϕ =.8, hence, Q = 30.401 m^3/h.

2.3.3. Power Requirement

The power required to rotate the auger was determined using an adapted form of Onwualu, Akubuo, and Ahneku (2006)'s equation as:

$$P = \frac{QL\rho g F}{3600} \tag{3}$$

where P is the power required in W, L is the length of the conveyor in m, ρ is the density of shea kernel in kg/m^3, g is the acceleration due to gravity in m/s^2 and F is the material factor. Substituting Q = 30.401 m^3/h, L = 150 cm, ρ = 754.18 kg/m^3, g = 9.81 m/s^2 and F = 0.4 into Equation 2.3 and taking into consideration the speed-reduction ratio of 15:1, hence, P = 562.298 W. To give allowance to power used in driving the pulley and other losses, the rated power was 570 W. The power of the electric motor to drive the system was estimated as:

$$P_m = \frac{P}{\eta} \tag{4}$$

where P_m is the power of electric motor in W and η is the efficiency of the motor in decimal. Given that η = 0.8, therefore, P_m = 712.5 W or 0.96 hp. The machine can be driven by a 1 hp electric motor. However, a 2 hp single-phase electric motor was selected.

2.3.4. Operating Capacity

The operating capacity of the machine was calculated from the energy equations used by Akinoso, Asiru, and Awoliyi (2004) and Olopade and Akinoso (2004) as:

$$Q_o = mc\theta \tag{5}$$

and

$$t = \frac{Q_o}{P_h} \tag{6}$$

where Q_c is the quantity of heat required in kJ, m is the mass of shea kernel in kg, c is the specific heat capacity of shea kernel in kJ/kg ^{0}C, θ is the change in temperature in ^{0}C, t is the roasting time in s and P_h is the rated power of the heaters in kW. With m = 7 kg, c = 1.507 kJ/kg ^{0}C, θ = 120 ^{0}C and P_h = 1.5 kW substituted into Equation 2.4, hence, Q_c = 1265.88 kJ and t = 14.07 min. Therefore, the machine can roast 7 kg of SK in about 15 min.

3. MATERIALS SELECTION AND CONSTRUCTION

The feeding hopper was fabricated from a standard length of 1.5 mm thick metal sheet. Four pieces of dimension 300 x 450 mm were cut from the metal sheet to make the four sides of the hopper. A 50 mm length was cut from both sides of the width to a height 200 mm to form a base of dimension 200 x 200 mm for the hopper. The four pieces of metal sheet were welded together to form the required shape of the feeding hopper. The roasting chamber is essentially a double wall cylindrical container made from mild steel sheet of 1.5 mm and 1.2 mm for the outer and inner walls respectively. The outer cylinder was of dimension 1000 x 1500 mm while the inner one was 950 x 14500 mm and the clearance was filled with insulation materials. The metal sheet was cut by a treadle-operated guillotine while a rolling machine was used to fold the sheet into a cylindrical shape.

The main frame was fabricated using a 40 x 40 mm angle iron. The procedures involved measurement with steel tape, marking out with scriber and cutting using power hacksaw. After cutting each component to the required dimensions, they were welded together to serve as support and stand for the roasting chamber and prime mover thereby enhancing the stability of the whole machine. The screw conveyor (auger) was made from a mild steel shaft (Φ 20 mm) on which a 1.2 mm metal sheet was welded spirally to form a screw. The turning and facing of the shaft were carried out on the lathe. The specification of construction materials is shown in Table1. Fabrication was carried out at the Central Engineering Workshop, University of Ilorin. Figures 2 and 3 show the exploded and orthographic front views of the roasting machine respectively.

Table 1: Materials of Construction of the Shea Kernel Roasting Machine and their Specifications

Material of Construction	Specifications	Quantity
Metal sheet	1.5 mm thickness, standard size	1
Metal sheet	1.2 mm thickness, standard size	1
Mild steel rod	Φ 25 mm, $\frac{1}{2}$ standard size	1
Angle iron	40 X 40 mm, standard length	3
Electric heater	750 W	2
TDC*	0-150 ^{0}C	1
Electric wire	3 m length	1
Welding electrode	Gauge 12	18
Electric plug	15 A	2
Bolts and nuts	M12	10
Bolts and nuts	M13	10
V - belt	A 42, 12.5 X 1125 mm	1
V - belt	A 35, 12.5 X 925 mm	1
Insulating materials	25 kg	1

*TDC: Temperature Control Device

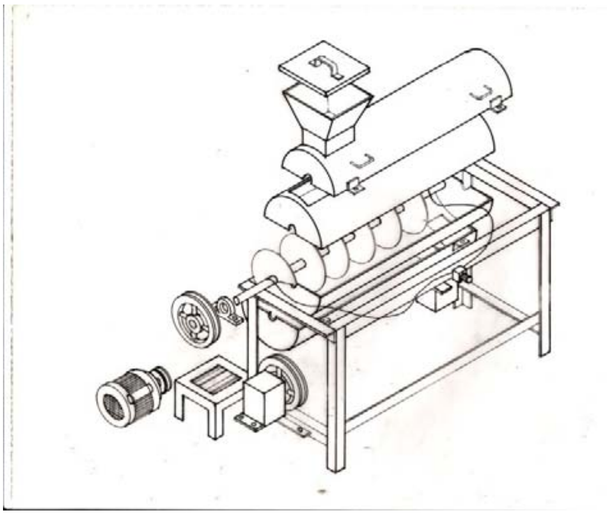

Figure 2: Exploded View of the Roasting Machine

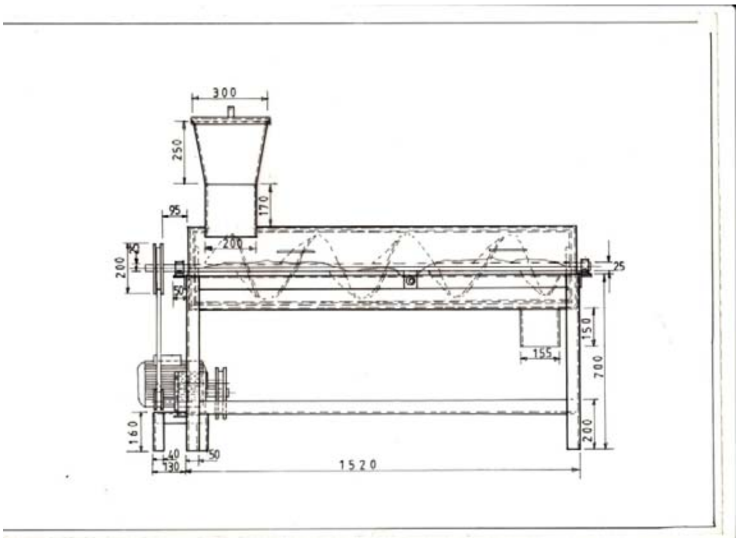

Figure 3: Front View of the Roasting Machine

4. MATERIALS AND METHODS USED FOR PERFORMANCE EVALUATION

In order to test for the performance of the machine, 2 bags (100 kg) of shea nuts (SN) were obtained from a produce merchant in Ilorin. The nuts were cracked, winnowed, dried, packaged in moisture-proof bags and stored in the laboratory at room conditions. The moisture content of the kernels was determined according to Adeeko and Ajibola (1989). After the assembly of the machine, the heater was switched on and the roasting chamber was allowed to attain a desired temperature (50 ^{0}C) using the thermostat. The machine was then set into operation and a known quantity of SK was introduced through the hopper. The rotary motion of the auger (screw conveyor) provided stirring and tumbling of the kernels in the roasting chamber. In this way, burning was prevented while even roasting of the kernels was ensured. The kernels were discharged after 20 min of roasting and reweighed. Weight loss, W_{LS} in %, was then determined as follows:

$$W_{LS} = \frac{100\left(W_{BR} - W_{AR}\right)}{W_{BR}}\% \qquad (7)$$

where W_{BR} and W_{AR} are weight before roasting and weight after roasting respectively in g. The same procedure was repeated for 70, 90 and 110 ^{0}C with each test being replicated thrice. Samples of SK roasted by the machine were processed by two screw press expellers and a model cage press for SB extraction. Oil yield, extraction efficiency and process loss were determined from standard formulae (Adeeko and Ajibola 1989; Olaniyan and Oje 2007) as follows:

$$O_Y = \frac{100 W_{OE}}{W_{US}} \% \tag{8}$$

$$E_E = \frac{100 W_{OE}}{x W_{US}} \% \tag{9}$$

$$P_L = \frac{100 \{W_{US} - (W_{OE} + W_{RC})\}}{W_{US}} \% \tag{10}$$

where O_Y, E_E and P_L are oil yield, extraction efficiency and process loss respectively in %; W_{OE}, W_{RC} and W_{US} are weights of oil extracted, residual cake and shea kernel sample respectively in g and x is the oil content of shea kernel in decimal. Each trial was carried out in triplicates.

5. RESULTS AND DISCUSSION OF PERFORMANCE EVALUATION

The results of weight loss in kernel after roasting and that of the extraction experiments are shown in Tables 2 and 3 respectively. The average percentage weight loss increased from 12.1 % to 32.8 % when the roasting temperature was increased from 50 ^{0}C to 110 ^{0}C. From visual observation, it was revealed that the kernels were of uniform deep-brown colour with clear film of oil on the surface after roasting indicating that the kernels experienced uniform roasting. During roasting operation, the flavour and aroma peculiar with roasting of SK were perceived. As shown in Table 3, the roasted SK gave appreciable yield of SB and high extraction efficiency during extraction experiments with a model ram press and the screw expellers. Process losses were very small using the three oil extraction equipment. These results showed that the SK roaster performed efficiently and effectively with a high degree of satisfaction.

Table 2: Results of Investigation of Weight Loss of the Roasted Shea Kernels*

Roasting Temperature (^{0}C)	Weight Loss (%)
50	12.1
70	27.6
90	31.8
110	32.8

* Each value is the mean of triplicates ± standard deviation

Table 3: Results of Investigation of Shea Butter Extraction from the Roasted Shea Kernels*

Measured Parameters	20 kg/h Screw Press Expeller	250 kg/h Screw Press Expeller	Model Cage Press
Oil Yield (%)	28.6	40.56	35.1
Extraction Efficiency (%)	47.6	67.6	58.5
Process Loss (%)	18.9	5.0	2.8

* Each value is the mean of triplicates ± standard deviation

6. CONCLUSION

A small scale machine for roasting SK prior to SB extraction was designed, constructed and tested. The construction materials were readily available locally and at affordable costs. With a production cost of USD100, the machine has an output capacity of 20 kg/h and was operated by a 2 hp single-phase electric motor. While testing the machine, the flavour and aroma peculiar with roasting of SK were perceived. Visual observation revealed that the kernels were of uniform deep-brown colour with clear film of oil on the surface after roasting indicating that the kernels experienced uniform roasting.

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NOMENCLATURE

c	Specific heat capacity	kJ/kg ^{0}C
d	Shaft diameter	m
D	Screw Diameter	m
E_E	Extraction efficiency	%
F	Filling factor	-
g	Acceleration due to gravity	m/s^2
L	Length of conveyor	m
M	Mass	kg
N	Rotational speed	rpm
N_1	Rated speed of electric motor	rpm
N_2	Speed of the shaft	rpm
O_Y	Oil yield	%
P	Power	W
p	Screw pitch	m
P_m	Power of electric motor	W
P_h	Rated power of the heater	W
P_L	Process loss	%
Q	Auger capacity	m^3/h
Q_o	Operating capacity	kJ
T	Torque	N/m^2
t	Roasting time	s
W_{AR}	Weight after roasting	kg
W_{BR}	Weight before roasting	kg
W_{US}	Weight of shea kernel sample	kg
W_{OE}	Weight of oil extracted	kg
W_{LS}	Weight loss	%
W_{RC}	Weight of residual cake	kg
δ_o	Yield stress	N/m^2
ρ	Density	kg/m^3
θ	Change in temperature	^{0}C
ϕ	Filling factor	-
η	Efficiency	%

BIOGRAPHY OF THE MAIN AUTHOR

Dr. Adesoji Matthew Olaniyan graduated with B.Eng, M.Eng and PhD in Agricultural Engineering from University of Ilorin, Nigeria in 1991, 1998 and 2006 respectively. Since 1998, he has been working on techniques, processes and equipment for processing agricultural and bioresources materials to food, fibre and industrial raw materials. Dr. Olaniyan's principal area of research is on Bioproduct Processing and Food Process Engineering, where he has carried out a number of projects and published a number of papers in local and international journals. He joined the service of the University of Ilorin in 1998 as an Assistant Lecturer in the Department of Agricultural and Biosystems Engineering and rose to the position of a Senior Lecturer in 2009. Currently, he is an Associate Professor at the Department of Agricultural and Bio-resources Engineering, Federal University Oye-Ekiti, Nigeria. Dr. Olaniyan has bagged several awards including the Award for the Best Paper (2007) in the Journal of Food Science and Technology, Mysore, India; Chinese Government Sponsorship (2008) for International Training Programme in Protected Agriculture at International Exchange Centre, Yangling, China; Netherlands Fellowship Programme (2009) for International Training programme in Milk Processing at Practical Training Centre, Onkerk, the Netherlands; and Postdoctoral Fellowship (2011) of the Academy of Sciences of Developing Countries.