https://doi.org/10.17221/83/2020-RAE

Development and evaluation of a combined roaster expeller for castor oil seeds for biodiesel production

Rasheed Amao Busari[1], Joshau Olarnrewaju Olaoye[2], Emmanuel Segun Adebayo[3], Adeshina Fadeyibi[1]*

[1]*Food and Agricultural Engineering Department, Kwara State University Malete, Malete, Nigeria*
[2]*Agricultural and Biosystems Engineering, Faculty of Engineering, University of Ilorin, Ilorin, Nigeria*
[3]*Department of Agricultural and Bioresources Engineering, Federal University of Technology Minna, Minna, Nigeria*

**Corresponding author: rasheed.busari@kwasu.edu.ng*

Citation: Busari R.A., Olaoye J.O., Adebayo E.S., Fadeyibi A. (2022): Development and evaluation of a combined roaster expeller for castor seeds for biodiesel production. Res. Agr. Eng., 68: 169–179.

Abstract: A combined roaster and oil expeller was developed with locally available and accessible materials and the efficiency of the machine was evaluated. The obtained result shows that the efficiency of the machine is a function of the roasting temperature, the roasting duration, the moisture contents of the processed seeds and the machine feeding rate. The expeller is movable, simple in design for local fabrication, is easy to operate, requires few repairs and little maintenance and is cost effective. It is powered using a gear reduction electric motor of 5.5 Hp, the expeller has an average oil yield of 25.77% and an extraction efficiency of 70.26% and is designed to work for 8 hours per day of operation. The shaft diameter was designed to be 30 mm, while the roaster heater capacity was 2.8 kW. The designed machine is good for castor oil expression for both small- and medium-scale processing among rural and urban communities.

Keywords: design and oil yield; extraction efficiency; extractor; process parameters

Castor plants normally grow over a wide scope of geographical areas and may survive under severe physical and climatic conditions. The plant is, however, essentially a tropical crop, although it can grow in temperate regions. It has an oilseed which has numerous uses. It would be of great advantage if these waste seeds, that contain about between 35% to 55% of the oil, are used for biodiesel production that runs on a compression ignition engine (single cylinder engine) to test the performance and emission characteristics (Weiss 2000).

Increases in the demand for fossil fuels with the increasing world population coupled with environmental implications are the major factors for the increasing pressure on renewable energy. According to the information available in the open literature, over 80% of the global energy consumption is derived from fossil fuels, while the remaining is derived from alternative sources of energy (Ezugwu 2015). The law of demand and supply on fossil fuels has resulted in its cost skyrocketing over the year as the population in Nigeria keeps increasing. However, alternative energy sources are either at the developmental stage or come at a higher cost. Hence, there is the need to expedite actions on scaling up the use of biofuels and their blends in thermal engines to make the availability of energy affordable and accessible. There is no gainsaying that energy is the driving force behind any nation's economical, technological, and social prospects. Presently, the sources of energy in Nigeria are mostly non-sustainable and non-renewable because of the overdependence on dwindling petroleum-based fuels which are the chief contributor to environmental pollution (Ezugwu 2015). Renewable energy offers a chance to reduce the emission levels of exhaust gases and

https://doi.org/10.17221/83/2020-RAE

to create a better sustainable environment. The use of biofuels and their blends in thermal engines helps to reduce the dependence on importing petroleum products, thereby providing a reliable market for agricultural produce especially for energy crops (Murugesan et al. 2008)

Vegetable oil from castor bean seeds is one of the best substances that can be used for biodiesel production, due to its unique characteristics, such as it is soluble in alcohol and does not require energy and heat in transforming it into fuel, as required by other vegetable oils (Sreenivas et al. 2011). Castor oil can be used as a food additive, flavouring, a candy, and a mould inhibitor (Wilson et al. 1998). The oil from the seed can also be used to prevent wheat, rice, and pulses from rotting and is an important raw material in the paint and nylon industries (Ogunniyi 2006; Mutlu and Meier 2010). Biodiesel produced from castor feedstock has a remarkable merit regarding its lubricity due to its high energy value and positive fuel properties (Berman et al. 2011). The oil expressed from the castor bean seed *(Ricinus communis)* is already known in the international market, with uses ranging from cosmetics, medicines, replacing petroleum in the manufacturing of biodiesel, plastics, lubricants and so on (Weiss 2000).

Vegetable oil extraction in most developing countries is traditionally undertaken by hand, which makes the process labour intensive, unhygienic, and time-consuming with a very low expression efficiency. The potential of castor bean seeds in producing oil and fat is far from being fully exploited, especially in Nigeria, due to the lack of appropriate processing equipment. Some of the conditions that can promote technology innovation in the oil extraction industry, which includes safety, cost savings, environmental considerations, are easily achievable by the development of an appropriate oil expeller (Fakayode and Ajav 2018).

The conventional techniques of roasting the seeds produces uneven roasted seeds due to the absence of correct temperature regulatory appliances, besides exposing the seeds to unhygienic conditions. Hand stirring and human exposure to excessive heat are tedious processes involved in the local or village ways of roasting seeds. Lawal et al. (1990) constructed a manual groundnut roaster with a stirrer, where the roaster was powered by means of wood or charcoal, but a temperature regulator was not included.

Hence, the objective of this research work was to modify a combined roaster and expeller in order to eliminate the drudgery associated with oil processing for castor oil processors. Consequently, controlled roasters exist (Olatunde et al. 2014), yet none of them are combined with an extractor.

MATERIAL AND METHODS

Operational process flow chart for the oil expression

The operational flow charts were developed for the expression of castor bean seeds. The charts simplified the process involved in the oil expression from the harvesting of the seeds to the oil extraction stage. The standard procedure as enumerated by the American Oil Chemists' Society (AOCS 1998) was adopted. Also, the charts served as a guide for this research work, and it will assist other processors for the oil expression from the seeds. The other usefulness or benefits of the developed operational flowcharts include the following:

– it helps in the communication flow process,
– it improves the consistency and process control,
– the process can manage exceptions faster and in the best manner,
– it increases operational efficiency,
– it helps spot any required improvements and reduces the process duration,
– it improves the productivity of the existing resources and labour; hence, it permits the group to accomplish more work with less assets, and
– it includes better asset utilisation.

The developed operational flow charts are presented in Figure 1. The objective of this research paper is to develop, modify and evaluate the machine performance in pursuit of knowing the optimum conditions for the oil extraction from castor seeds.

Design consideration

The knowledge of engineering properties of castor seeds is very important in the design and development of agricultural machines for cleaning, harvesting, conveying, material handling, sorting, separating, packaging, storing, drying and oil expressing. In this method of oil extraction (mechanical), the physical properties of the seeds must be known. Olaoye (2000) reported the physical properties of three different varieties of the castor nut at the moisture contents of 5.11, 5.62 and 4.94% (wet basis, wb) for the Ojji, Evahura and Asbowu varieties, respectively.

Also, to ensure the maximum oil expression in the oil-bearing seeds, it is necessary to consider the following, as reported by Poku (2002):

https://doi.org/10.17221/83/2020-RAE

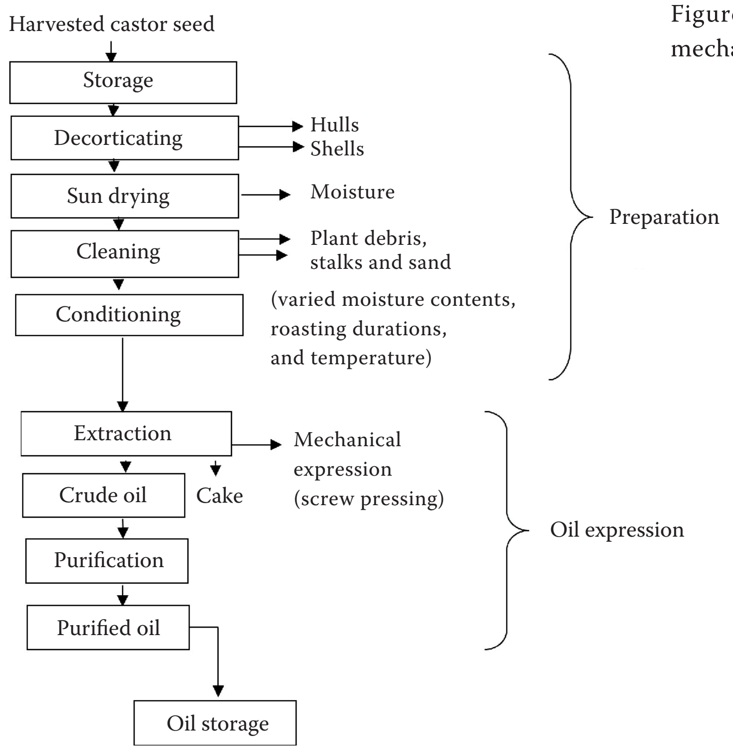


Figure 1. Block diagram showing the steps of the mechanical oil expression

– the best maturity time of the seeds/fruits/crops,
– the optimum period to keep the fresh (harvested) seeds/fruits before further processing,
– the optimum temperature for the oil expression,
– the appropriate selection of the material for the machine fabrication.
– the appropriate lagging of the barrel or extraction chamber to avoid heat loss.
– the adequate power selection to ensure the optimum performance of the designed machine.
– Should the roasting chamber be incorporated to the expeller when considering the heat loss while transferring the roaster seeds or nuts from the external roasting compartment? Also, extra costs will be involved. So, will the combined roaster expeller (new design) guarantee better efficiency?

For the design of the roaster compartment, the heat conducted through the materials is dependent on the following:
– the duration of the heat transfer,
– the type of material used for the construction,
– the material thickness,
– the temperature difference, and

Other criteria considered in the design of the roaster and oil expeller include:
– the ease of operation,
– the crushing capacity and oil output,
– the cost of operation /power consumption,
– the ergonomics of the machine operation,
– the availability of the materials,
– the ease of transportation

Description of the combined roaster and oil expeller

The screw expeller is comprised of a screw in a cylindrical drainage cage with the main shaft which carries a worm assembly and acts as an oil press which is mounted on a bearing. The roaster is incorporated into the screw press via an outlet opened to the hopper of the expeller. The roasting chamber has a provision for the heating element and a thermostat for the temperature regulation. A shaft was designed to run through the centre of the roaster compartment and metal bars are attached to the shaft to serve as a stirrer to create uniform heat distribution to prevent the roasting effect and burning of the castor seeds. An outlet was created at the base of the roaster and placed directly above the hopper of the screw press in order to maintain the seed temperature. The screw expeller was powered by a reduction gear motor. The power was transmitted from the electric motor via a v-belt to the expeller. A screw worm was welded to the shaft with an incrementally decreasing pitch along the shaft, where gradual pressure is built-up and presses and squeezes out the oil from the seed or nuts. The main components of the designed roaster expeller are: thermo-

https://doi.org/10.17221/83/2020-RAE

stat, bevel and pinion gear, feeder gate, roasting compartment, electric gear motor (5.5 Hp), screw press, pulley and V-belt connection of the bevel and pinion gear to the reduction gear, and hopper (0.006 m^3).

Design of the machine components

Hopper capacity. The hopper of the expeller was designed based on the criteria from the engineering properties (angle of repose), which is the maximum slope which a heap of any loose or bulk material will stand without sliding (Ojolo et al. 2012; Fadeyibi et al. 2014). While Avallone at al. (1996) refer to the angle of repose as the rest angle of agricultural materials. A gravity discharge mechanism was adopted for the hopper as recommended by Ojolo et al. (2012), in which they reported that, for agricultural materials whose angle ranged from 8° to 10°, is even lower than the angle of repose of castor seeds. The average angle of repose of the castor bean seed was taken to be 28° (Olaoye 2000). The design hopper was based on the volume of a frustum of a pyramid. The volume of the pyramid was obtained using Equation (1) as reported by Ogundipe et al. (2011):

$$V = \frac{1}{3}\left(A_1 + A_2 + \sqrt{A_1 + A_2}\right)h \tag{1}$$

where: V – volume of the pyramid (m^3); A_1, A_2 – areas of the top and bottom base of the hopper (m^2), respectively; h – the hopper height (m).

Shaft design. The shaft design for the oil expeller uses a worm. Applying the maximum shear equation, the shaft was designed using American Society of Mechanical Engineers (ASME) code equation of a solid shaft relationship, as seen in Equation (2):

$$d^3 = \frac{16}{\eth S_s}\sqrt{\left(k_b M_b\right)^2 + \left(K_t M_t\right)^2} \tag{2}$$

where: d – shaft diameter (m); S_s – shaft allowable shear stress (MPa); k_b – combined shock and fatigue factor applied to the bending moment (dimensionless); M_b – bending moment (N·m); K_t – combined shock and fatigue factor applied to the torsional moment (dimensionless); M_t – torsional moment (N·m).

Determination of the belt length and belt speed. The belt length – L (m) and the speed – V (m·s^{-1}) were calculated using Equations (3) and (4) as reported by Khurmi and Gupta (2004):

$$L = 2C + \frac{\pi}{2}\left(D_1 + D_2\right) + \frac{D_2 - D_1}{4C} \tag{3}$$

$$V_s = \frac{\pi D_1 N_1}{60} \tag{4}$$

where: L – the total length of the belt (1.1 m); C – the pulley centre distance (m); N_1 – the driving motor speed (rev·min^{-1}); D_1 – the driving pulley diameter (m); D_2 – the driven pulley diameter (m); V_s – the belt speed (14.2 m·s^{-1}).

Forces acting on the barrel. The screw worm also serves as a seed conveyor and is encased by a barrel which is cylindrical in shape. The gap between the worm and the barrel was just 1.5 millimetre. The length of the barrel and screw thread are the same. The circumferential or hoop stress and longitudinal stress are given in Equations (5) and (6) (Lasisi 1997):

$$\sigma_h = \frac{f}{tl} = \frac{Prl}{tl} = \frac{Pr}{t} \tag{5}$$

$$\sigma_l = \frac{\pi r^2 P}{2\pi rt} = \frac{Pr}{2t} \tag{6}$$

where: P – the internal pressure intensity (N·m^{-2}); r – the cylinder radius (m); l – the cylinder length (m); t – the cylinder thickness (m); f – the hoop stress (N).

Pitch of the thread is given as Equation (7):

$$D_{co} - D_{ci} = P \tag{7}$$

The thickness of the thread is calculated using Equation (8):

$$t = \frac{P}{2} \tag{8}$$

However, t can also be expressed as:

$$t = \frac{D_{co} - D_{ci}}{2} \tag{9}$$

where: D_{ci} – the inner diameter of the cylinder (m); D_{co} – the outer diameter of the cylinder (m).

Bending stress determination. The bending stress acting directly on the shaft could either be tension or compression.

$$S_b = \frac{M_b r}{I} \tag{10}$$

However, $I = \pi d^4/64$ for a cylindrical shaft (Olatunde et al. 2014).

where: I – the moment of inertia (m); d – the diameter of the shaft (m); M_b – the bending moment (N·m); S_b – the bending stress (72.2 MN·m^{-2}).

https://doi.org/10.17221/83/2020-RAE

Torsional stress. The torsional stress was determined using Equation (11):

$$\tau = \frac{M_T r}{J} \quad (11)$$

where: M_T – the torsional moment (N·m); r – the shaft radius (m); d – the shaft diameter (m); J – the area of the polar moment (m^2); τ_{xy} – the torsional stress (38.5 MN·m^{-2}); $J = \pi d^4/32$

Electric motor selection. The choice of the electric gear reduction motor for the designed expeller was based on the load the machine will be subjected to; therefore, a three-phase industrial electric motor (5.5 Hp, 50 Hz) was selected from the designed relationships. The selected electric motor was inculcated with a gear box for speed reduction. According to the work of Keyll et al. (2010), low speeds produce greater torque efficiency in the oil expression process and the machine power is equivalent to the power required for the conveyor, crushing, squeezing and roasting of the seeds and multiplied by the service factor that takes care of the loss during transmission. Using the power requirement given in Equation (12) (Singh 2005):

$$P = \frac{TN}{9\,550} \quad (12)$$

where: P – the developed power (kW); N – the speed of the machine (rpm); T – the machine torque (N·m).

$$T = \frac{JG\theta}{L}$$

where: L – the shaft length (mm); J – the polar moment (mm^4); θ – the angle of twist (θ°); G – the modulus of rigidity (N·mm^{-2}).

The polar moment of a solid shaft is given by Singh (2005). The diameter (d), of the shaft was assumed to be 30 mm. Thus,

$$J = \pi d^4/32 \quad (13)$$

$$J = 251\,360.00 \text{ mm}^4$$

$$G = 80\,000 \text{ N·mm}^{-2}$$

$$\theta = \frac{\pi}{180}$$

Also assuming the length of shaft to be 800 mm, the torque was found to be T = 438 705.96 N·mm.

Substituting the obtained torque into Equation (13), the power required was P = 2 756.26, W = 2.76 kW (3.69 Hp).

For design purposes, the service factor was considered in order to take care of any losses during operation. The service factor (K_s) value was obtained from the standard table, which is 1.5 as reported by Ajav and Busari (2011) and Fadeyibi and Ajao (2020). Therefore, the maximum power was calculated from relationship in Equation (14) as stated by Singh (2005).

$$K_S = \frac{\text{Maximum rated power } (P_M)}{\text{Actual power requirement } (P_A)} \quad (14)$$

The actual power requirement is the calculated power, Equation (15):

$$K_S = \frac{P_M}{3.69} \quad (15)$$

where: K_s = 1.5; P_M = 3.69 × 1.5 = 5.5 Hp

A 5.5 Hp electric motor was required to power the designed machine.

Determination of the heater capacity. The minimum required temperature for the seed or nut roasting is 80 °C for the easy and efficient extraction of the oil using the screw expeller according to Olatunde et al. (2014). Going by Fourier's law of conduction, Equation (16):

$$Q = \frac{-KA(t_2 - t_1)}{x} \quad (16)$$

where: Q – the rate of the heat flow through the cylinder (W or J·s^{-1}); K – the material thermal conductivity (W·m^{-1}·k^{-1}); A – the area (m^2); t_2–t_1 – the temperatures difference at the contact surface of the walls (°C); x – the thickness of the wall (m).

Heat flow by conduction in a cylinder is calculated by Equation (17):

$$Q = -KA\frac{dt}{dr} \quad (17)$$

where: K – the thermal conductivity of the material used (W·m^{-1}·k^{-1}); A – the area (m^2); Q – the rate of the heat flow through the cylinder (W or J·s^{-1}); dr – the radius of the cylinder (m); dt – the change in temperature (°C).

A 2.8 kW capacity heater was used for the roasting of the castor seed in the roasting compartment.

Design of the temperature control capacity.

$$Q = I \times V$$

https://doi.org/10.17221/83/2020-RAE

$$I = \frac{Q}{V} = \frac{2.8KW}{240} = 12 \tag{18}$$

where: Q – the heating element capacity (kW); V – the voltage entering the control (V); I – the current (A).

Working principles of the combined roaster expeller

The machine was designed for continuous operation. The roasting of the seeds was conducted in the roasting chamber with the help of a heating element. The screw press received the roasted castor bean seeds from the roaster via an outlet opened to the hopper and gradually moved them forward by the aid of the screw threads. The decreasing screw pitch along the shaft and screw height provided the compressing force needed to squeeze out the entrapped oil from the castor bean seeds. The residue (cake) from which the oil is expressed was forced out of the cake outlet as flakes and the oil was collected at the bottom. Figures (2–4) show the fabricated experimental rig, orthographic views of the designed roaster expeller and exploded view of the designed machine, respectively.

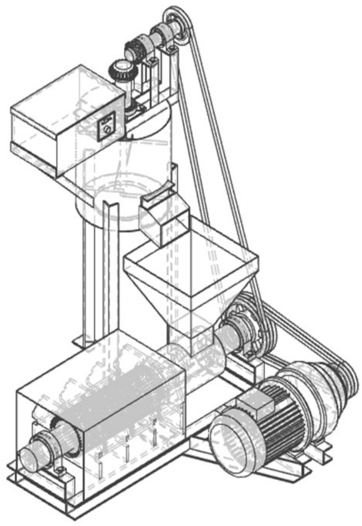


Figure 2. Schematic diagram of the designed experimental rig

Machine maintenance

Before the machine starts to operate, the power source, belt arrangement, the roasting compartment, expelling unit and temperature regulator were

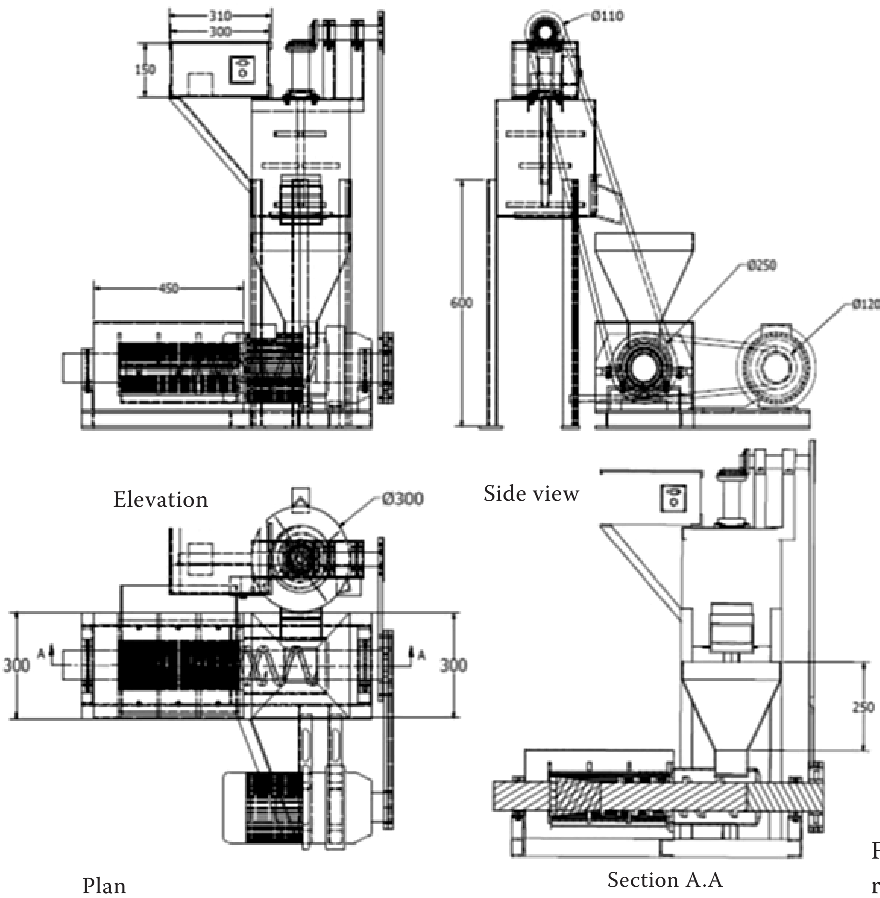


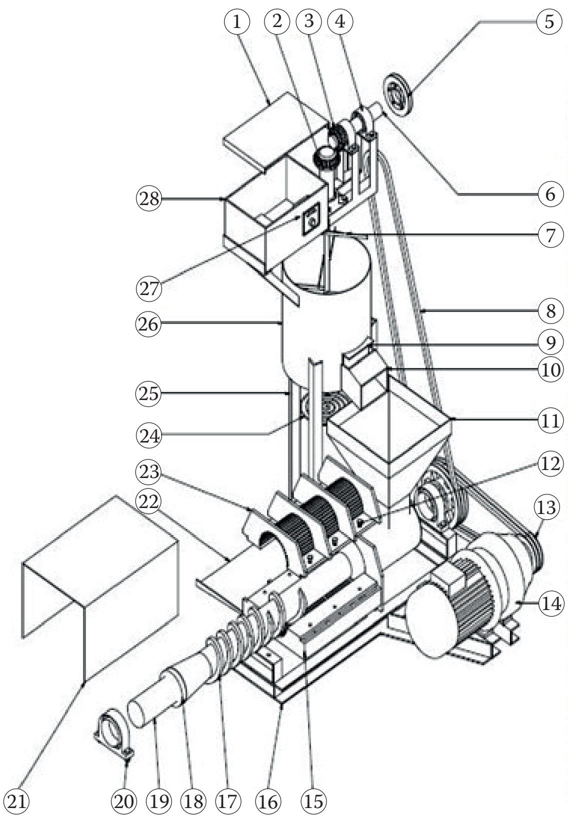
Figure 3. Orthographic views of the roaster expeller

https://doi.org/10.17221/83/2020-RAE

checked to ensure for their optimal performance. During operation, the stirrer in the roasting compartment was constantly checked to ensure that the castor seeds were effectively mixed and the heat distribution was evenly distributed. If there is any blockage in the mixing chamber, it slows down the expelling operation and a baffle may be needed to improve the mixing performance. After operation, both the roasting compartment and the expelling unit were properly cleaned using a soft iron brush to remove any residual particles and cake formed during operation. All the components and materials used for the designed machine were locally available at affordable prices in the market, thus, worn-out parts can be bought and replaced.

Performance evaluation of the designed machine

Castor seeds were harvested from the wild in the Ilorin metropolis of Kwara State, Nigeria. The seeds were thereafter crushed, dehulled and cleaned of any foreign materials and dirt by handpicking (Fadeyibi and Osunde 2012). The seeds were consequently dried in an electric oven at 65 °C for 6 h to a constant weight to remove the moisture content to a bone dry weight. The moisture content simulation for the conditioning of castor oil seeds by Olaoye (2000) was adopted. The Design Expert (Ver. 6.0.6) software was employed for the analysis and the model equation was developed for the dependent variables. The linear and quadratic models were used and fitted to the experimental data using the software package. An analysis of variance (ANOVA) was performed to check the effect of the significant individual terms and their interactions on the response. The variables and levels were fixed based on information from the literature and trial experiments (Ajala et al. 2016; Olaoye and Busari 2017). Three variables at five selected moisture content levels (6.32, 7.00, 8.00, 9.00 and 9.68 % wb) and a heating duration (6.59, 10.00, 15.00, 20.00 and 23.41 min) were used for the evaluation at five temperature settings (83.18, 90.00, 100.00, 110.00 and 116.82 °C) with the oil yield as a dependent variable. The variables and levels were fixed based on information



Parts list	
Part number	Description
1	cover
2	21-teeth gear
3	14 teeth gear
4	pillow bearing
5	pulley
6	shaft
7	stirrer
8	belt
9	lock gate
10	discharge channel
11	hopper
12	bolt
13	driven pulley
14	gear reduction motor
15	crushing block (lower part)
16	frame
17	auger
18	conical shaft
19	shaft
20	bolt
21	crushing chamber cover
22	oil discharge tray
23	crushing block (upper part)
24	heating element
25	toaster rigid support
26	toaster
27	thermocouple
28	thermocouple housing

Figure 4. Exploded view of the roaster expeller

https://doi.org/10.17221/83/2020-RAE

from the literature and trial experiments (Ajala et al. 2016). The oil expression was optimised by varying the independent variables. A central composite design (CCD) and ANOVA were used to determine the extent to which the roasting temperatures, roasting durations and moisture content affected the performance indices. The roasting of the castor bean seeds was undertaken in the roasting chamber attached to the designed machine. A shaft was design and pivoted through the centre of the roasting compartment. Four stirrers were attached to the shaft to turn the products, distribute the heat and prevent the seeds burning during the roasting operation. A gate located at the base of the roasting compartment helped to maintain the castor seeds temperature and allow for the easy flow of the roasted castor seeds into the extraction unit.

Oil extraction

The oil extraction from the processed castor bean seeds was undertaken using the mechanical expeller. The clean transparent liquid obtained was collected and poured into a separate container, weighed and the yield was calculated. The percentage oil yield was calculated using Equation (19):

$$Y = \frac{W_1 - W_2}{W} \times 100 \quad (19)$$

where: Y – the oil yield (%); W_1 – the weight of the unmilled castor seeds (g); W_2 – the weight of the cake sample (after milling) (g).

Efficiency of the machine

The machine efficiency was calculated using the relationship in Equation (20):

$$E = \frac{Y}{C_o} \times 100 \quad (20)$$

where: E – the machine efficiency (%); Y – the oil yield in percentage (%); C_o – the oil content of the nut (35–55% for castor bean seeds) (Busari and Olaoye 2017).

RESULTS AND DISCUSSION

Designed machine components

The designed machine specifications for the combined roaster expeller are presented in Table 1.

The expeller capacity and heater capacity were 4 kg per batch of each operation and 2.8 kW (12 A), respectively, while the power requirement was calculated to be 5.5 Hp (electric reduction gear motor), the shaft diameter was 30 mm and the volume of the hopper was 0.006 m^2. The length of the belt for the designed machine was determined to be 1.1 m while the belt velocity was 14 m per second, designed bending stress, torsional stress and maximum tensile stress were 72.2, 38.5 and 71.0 MN·m^{-2}, respectively. The experimental barrel pressure was calculated to be 70.0 MN·m^{-2} as presented in Table 1. The obtained results are slightly differ from the work of Fakayode and Ajav (2018) who reported a power requirement to be 2.0 Hp and a shaft diameter of 39.7 mm, this could be as result of the differences in the size of the designed machine and expeller capacity. Even though the obtained results were similar to the work of Olatunde et al. (2014) who had a belt length of 1.2 m and a belt velocity of 11.78 m·s^{-1}. They also obtained designed a bending stress, torsional stress, and maximum tensile stress of 76.2, 39.4 and 70.0 MN·m^{-2}, respectively. The machine gave the optimum oil yield of 26.77%, an equivalent of 59.48% and an oil expression efficiency of approximately 85% when compared to the 45% average oil content of the castor bean seeds at the optimum conditions of the variables under consideration.

Model equation for the oil expression

The desirability function was applied using the Design Expert software (Ver. 6.0.6) in order to compromise the response. In the optimisation analysis, the target criteria were set, in ranges and the response was set to be the maximum as reported by Olaoye

Table 1. Designed machine specifications

S/N	Parameter	Formulae	Value
1	expeller capacity		4 kg·batch^{-1}
2	temperature control capacity	$I = \frac{Q}{V}$	12 A
3	heater capacity	$Q = \frac{-KA(t_2 - t_1)}{x}$	2.8 kW
4	power requirement	$P = \frac{TN}{9\,550}$	5.5 Hp
5	shaft diameter	$d^3 = \frac{16}{\pi S_s} T_c$	0.03 m
6	experimental barrel	$\sigma_h = \frac{f}{tl} = \frac{Prl}{tl} = \frac{Pr}{t}$	70.0 MN·m^{-2}

S/N – specification/No.

https://doi.org/10.17221/83/2020-RAE

and Busari (2017). The regression model equation was developed for the oil yield with respect to the moisture content (*A*), roasting temperature (*B*) and roasting duration (*C*), and their respective interactions. The single and quadratic effects of the model revealed that *B*, *C*, and A^2 are directly proportional to the oil yield. A negative effect was observed between *A*, B^2, C^2, *AB*, *AC*, and BC on the oil yield. The optimum oil yield was validated using the data generated from the laboratory experiment. To confirm the accuracy of the developed model, the oil expression was carried out under the optimum conditions. The experimental oil yield was found to be 26.77% while the predicted oil yield from the model was 27.50%. The percentage error was calculated to be 0.97 which confirmed the validity of the model equation. The coefficient of the response of the surface model equation for the yield of the castor oil is given in Equation (21), which describes the relationship between the percentage oil yield and actual values of the independent operating parameters.

$$Y_1 = 12.68804 - 1.14776A + 0.34141B + 0.45270C + 0.11051A^2 - 1.0626E - 003B^2 - 6.89348E - 003C^2 - 0.015000AB - 0.015000AC - 1.0000E - 003BC \quad (21)$$

where: Y_1 – the response variable in terms of the castor oil yield (%); *A* – the moisture content over a range (6% ≤ M ≤ 10%); *B* – the heat temperature over a range (80 °C ≤ T ≤ 120 °C); *C* – the heat duration over a range (5 min ≤ *t* ≤ 25 min).

The shaft diameter was designed for 30 mm and the roaster heater capacity was 2.8 kilowatts. While the machine was powered using a 5.5 Hp reduction gear electric motor, with an extraction capacity of 115 kg·h^{-1}, designed to be operated for 8 working hours per day. The roaster expeller was designed for local construction, operation, repair/maintenance, and its cost-effectiveness. The roasting compartment was included in the design to help remove the drudgery and reduce the time involved in roasting the castor bean seeds separately. This is an improvement over the existing machines and appropriate technology for vegetable oil extraction processes where the operation is performed separately. The positive terms in Equation (21) signify the direct relationship between the independent variables and their interactions with the dependent variable, while the negative terms in the equation signify an inverse relationship between the variables. The maximum oil yield was achieved at 27.36% when the heating temperature was 80.96 °C with a 6.02% wb moisture content, while the minimum oil yield was at 26.23% when the heating temperature was 80.00 °C and the moisture content was 7.53% wb. This implies that as the roasting temperature increased, more cell wall/membranes were broken as result of the heating which allowed the oil to move out from trapped cell walls as reported by Aniket and Singh (2016). Acheheb et al. (2012) reported an increase in the moisture content with a decrease in the oil yield due to the decrease in friction and less crushing force applied on the seeds squeezed out of the oil. Olayanju et al. (2006) and Pradhan et al. (2011) reported that, for sesame seeds and jatropha, the presence of the optimum oil yield is a function of the moisture content and roasting temperature.

The optimum conditions of the variables were determined to be a moisture content of 9.96%, the heat temperature of 119.15 °C and heat duration of 10.60 min at a corresponding oil yield of 26.77%. The machine gave the optimum oil yield of 26.77%, which is the equivalent of 59.48% when compared to the 45% average oil content of the castor bean seeds at the optimum conditions of the considered variables. It was observed that all the variables have a direct influence on the oil yield. This implies that the oil yields increase with the increasing independent variables. The roasting temperature and moisture content were found to be the most significant factors affecting the castor oil yield. This agreed with the findings of other researchers on oil extraction, viz: Olajide's (2000) work on groundnut and shea nut oil expression, Akinoso's (2006) research on sesame seeds while Fakayode et al. (2016) investigated moringa seeds.

CONCLUSION

The development of any machine requires the critical design of its various components based on different operating conditions. This will help the designer eliminate, to the barest minimum, any possible causes of machine component failure. The designed expeller was simple enough for the local fabrication, ease of operation, low repair and maintenance costs and cost effectiveness. The roaster compartment that was incorporated in the design removed the drudgery and time consumed during the roasting of castor bean seeds before the oil expression. This is an improvement over the available machines and, thus, provides

https://doi.org/10.17221/83/2020-RAE

appropriate technology for vegetable oil extraction. The choice of materials and the overall cost of the machine would encourage mass production for local consumption. The machine can be used for both small- and large-scale castor oil extraction among rural and urban communities. An individual can establish a cottage oil processing plant based on this available technology in order to be self-employed or employer of labourers. The machine gave an optimum oil yield of 26.77%, an equivalent of 59.48%, and an oil expression efficiency of approximately 70.26% when compared to the 45 % average oil content of the castor bean seeds at the optimum conditions of the variables under consideration.

REFERENCES

Acheheb H., Aliouane R., Ferradji A. (2012): Optimization of oil extraction from pistacia atlantica desf. seeds using hydraulic press. Asian Journal of Agricultural Research, 6: 73–82.

Ajala E.O., Aberuagba F., Olaniyan A.M., Onifade. K.R. (2016): Optimization of solvent extraction of shea butter (*Vitellaria paradoxa*) using response surface methodology and its characterization. Journal of Food Science Technology, 53: 730–738.

Ajav E.A., Busari R.A. (2011): Modification and performance evaluation of African bush mango (*irvingia gabomensis*) cracker. Journal of Agricultural Engineering and Technology (JAET), 19: 60–70.

Akinoso R. (2006): Effects of moisture content, roasting duration and temperature on yield and quality of palm kernel (*Elaeis guineensis*) and sesame (*Sesamum indicum*) oils [Ph.D. Thesis]. Ibadan, University of Ibadan.

Aniket P., Singh A.K. (2016): Optimization of microwave assisted mechanical extraction of oil from canola seeds by using response surface methodology. Agricultural Engineering International, 18: 297–308.

AOCS (1998): Official Methods and Recommended Practices of the AOCS. Champaign, American Oil Chemists' Society.

Avallone E.A., Baumeister T., Sadegh A.M. (1996): Standard Handbook for Mechanical Engineering. New York, McGraw-Hill Publishers.

Berman P., Nisri S., Wiesman Z. (2011): Castoroil biodiesel and its blends as alternative fuel. Biomass Bioenergy, 35: 2861–2866.

Busari R.A., Olaoye J.O. (2017): Biodiesel production from castor bean seed: An optimization processing using response surface methodology. Annals Food Science and Technology, 2: 110–116.

Ezugwu C.N. (2015): Renewable energy resources in Nigeria: Sources, problems and prospects. Journal of Clean Energy Technologies, 3: 68–71.

Fadeyibi A., Osunde Z.D. (2012): Mechanical behaviour of rubber seed under compressive loading. Current Trent in Technology and Science, 1: 59–61.

Fadeyibi A., Ajao F.O. (2020): Design and performance evaluation of a multi-tuber peeling machine. AgriEngineering, 2: 55–71.

Fadeyibi A., Osunde Z.D., Agidi G., Evans E.C. (2014): Flow and strength properties of cassava and yam starch-glycerol composites essential in the design of handling equipment for granular solids. Journal of Food Engineering, 129: 38–46.

Fakayode O.A., Ajav E.A. (2018): Development, testing and optimization of a screw press oil expeller for moringa (*Moringa oleifera*) seeds. Agricultural Research, 8: 102–115.

Fakayode O.A, Ajav E.A, Akinoso R. (2016): Effects of processing factors on the quality of mechanically expressed moringa (*Moringa oleifera*) oil: A response surface approach. Journal of Food Process Engineering, 40: 1–12.

Keyll C.R.M., Pires H.C.S., Viana L.G., Lídia S.P.M., Silva L.E.M., Rodrigues J.R.P. (2010): Development of a prototype of screw press for the collection of oil from seeds of castor and jatropha. In: 13th Brazilian Congress of Thermal Sciences and Engineering, Uberlandia, Dec 5–10, 2010: 1–8.

Khurmi R.S., Gupta J.K. (2004): Machine Design. New Delhi, Eurasia Publishing House (Pvt), Ltd.

Lasisi M.A. (1997): Design, construction, and testing of a groundnut oil expeller for use in a rural community. [Unpublished B.Sc. Project.] Ibadan, Faculty of Technology. University of Ibadan: 32–35.

Lawal A.O., Yiljep Y.D., Abubakar S.Z. (1990): Construction of Multi-purpose Roaster. National Agricultural Extension and Research Liaison Services, Ahmadu Bello University, Zaria, Bulletin Series, 88: 1–10.

Murugesan, A., Umarani C., Subramanian R., Nedunchezhian N. (2008): Biodiesel as an alternative fuel for diesel engines – A review. Renewable and Sustainable Energy Reviews, 13: 653–662.

Mutlu H., Meier M.A.R. (2010): Castor oil as a renewable resource for the chemical industry. European Journal of Lipid Science and Technology, 112: 10–30.

Ogundipe O.S., Obiakor S.I., Olotu F.B., Oyelade O.A., Aransiola J.A. (2011): Design of a low-cost cocoa oil expeller. Journal of Agricultural Engineering and Technology, 19: 17–26.

Ogunniyi D.S. (2006): Castor oil: A vital industrial raw material. Bioresoure Technology, 97: 1086–1091.

Ojolo S.J., Orisaleye J.I., Ismail S.O. (2012): Design of a jathropha oil expelling machine. Journal of Emerging Trends in Engineering and Applied Sciences, 3: 412–419.

https://doi.org/10.17221/83/2020-RAE

Olajide J.O. (2000): Process optimization and modelling of oil expression from groundnut and sheanut kernels [Ph.D. Thesis]. Ibadan, University of Ibadan.

Olaoye J.O. (2000): Some physical properties of castor nut relevant to the design of processing equipment. Journal of Agricultural Engineering Research, 77: 113–118.

Olaoye J.O., Busari R.A. (2017): Optimization of mechanical expression of castor seeds oil (*Ricinus communis*) using response surface methodology. Arid Zone Journal of Engineering, Technology and Environment, 13: 878–887.

Olatunde O.B., Ajav E.A., Fatukasi S.O. (2014): Design and fabrication of groundnut (*Arachis hypogaea*) roaster cum expeller. International Journal of Science and Technology, 3: 177–184.

Olayanju T.M.A., Akinoso R., Oresanya M.O. (2006): Effect of worm shaft speed, moisture content and variety on oil recovery from expelled beni seed, Agricultural Engineering International, 7: 1–7.

Poku K. (2002): Small scale palm oil processing. Available at https://agris.fao.org/agris-search/search.do?recordID=XF2016059994

Pradhan R.C., Mishra S., Naik S.N., Bhatnagar N., Vijay V.K. (2011): Oil expression from jatropha seeds using a screw press expeller. Biosystems Engineering, 109: 158–166.

Singh K.K. (2005): Physical and frictional properties of orange and sweet lemon. Applied Engineering in Agriculture, 20: 821–825.

Sreenivas P., Mamilla V.R., Sekhar K.C. (2011): Development of biodiesel from castor oil. International Journal of Energy Science, 1: 192–197.

Weiss E.A. (2000): Castor. Oilseed Crops. 2nd Ed., Oxford, Blackwell Scientific, Ltd.: 13–52.

Wilson R., Van Schie B.J., Howes D. (1998): Overview of the preparation, use and biological studies on polyglycerol-polyrecinoleate (PGPR). Food and Chemical Toxicology, 36: 711–718.

Received: October 13, 2020
Accepted: March 8, 2022
Published online: November 11, 2022