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Development and Performance Evaluation of a Castor Oil Extractor

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Abstract: *This paper presents the development and performance evaluation of a castor seed oil expeller. The machine's various components were designed using standard engineering equations and fabricated with locally available materials. The oil expeller was powered by a 3 phase, 4.0 kW electric motor and a 1:20 speed reduction gear. The study was carried out using physical properties such as screw speed, roasting time and roasting temperature. 500 g per run (27 runs in total) of castor seeds were subjected to different temperatures, (80, 100 and 120 °C) and at different roasting times, (10, 20 and 30 minutes). The screw speed was varied at 27, 39 and 51 rpm. The effect of the roasting temperature was seen to increase the efficiency of the oil expeller from 42% to 63% as it increases from 80 °C to 105 °C and then reduces the efficiency to 47% as it further increases to 120 °C. Also, the increase in roasting time from 10 minutes to 30 minutes gave an overall increase in the efficiency of the machine from 42% to 62% and the increase in screw speed from 27 rpm to 39 rpm reduces the efficiency of the expeller from 62% to 60% and further increase in the speed of the expeller increased the efficiency back to 67%. The efficiency was highest at the roasting temperature of 100 °C, roasting time of 20 minutes and screw speed of 51 rpm. The highest efficiency of the expeller is 69.4% and it has a capacity of 6.74 kg/hour. The castor seed oil expeller is recommended for use in small scale production of castor seed oil.*

Keywords: *Expeller, machine efficiency, roasting temperature, roasting time, screw speed.*

1. INTRODUCTION

The human diet has known vegetable oil to be an essential part of it and the demand for fats and oils is increasing with increase in population and as new sources are discovered. With the advancement of technology, there are various oil recovery methods that have been gotten to be capable of removing oil and fats from oil bearing seeds [1]. In Nigeria, castor seed is obtained abundantly in every part of the country and it contains 40 to 60 % oil [2]. The seed is known as castor seed and it is referred to differently depending on the locality where it is found. The Yoruba's call it 'Lara', the Hausas refer to it as 'Zurma', the Kanuris call it 'Kwolakwola', while the Igbos refers to it as Kpikpi [3].

There are various processes of oil recovery, which are undertaken in many countries. The traditional methods as its name implies makes use of locally fabricated equipment or highly labor-intensive set-up which are highly time consuming with low power output [4]. The modern methods are the use of screw press, hydraulic press and solvent extraction. Considering the hydraulic press, it extracts the oil by the process of squeezing the oil seed in a confinement and it is mostly used for seeds with high oil content [1].

Oleaginous products industry manufactures edible and non-edible oils. Edible oils (which is about 2/3 of the total volume of the oil products) are used directly in food or used in the industry of margarine, mayonnaise, cooking fats, bakery products, confectionery, canned food, confectionery and others, and the non-edible oils (representing one third of the total volume of oil produced) are used in production of detergents, paint, varnish, fatty acids, pharmaceuticals and cosmetics. They are divided onto three groups, the nuts, the seeds and the mesocarp. The nuts are coconuts, groundnuts, palm kernel nuts and shea-nut. The seeds are castor cotton seed, linseed, neem, sunflower, sesame and Jatropha. The mesocarp is palm fruit [5].

Castor plant (*Ricinus communist L.*) is a member of the *Euphorbiaceae* and it contains many plants mostly native to the tropics [6]. Although it is commonly known as the castor bean plant, the seed is really not a true bean and it is not related to the Bean or Legume Family (*Fabaceae*). The seeds with hulls removed contain 35 to 55% oil. The seeds, leaves, and stems of the plant contain ricin and ricinine, which are poisonous to humans and animals. Eating a castor bean causes nausea, and eating several may cause death. These toxic compounds are not present in the oil. The castor bean plant grows well in soil of medium texture [7].

From previous research in the field of oil seed processing, there have been found two major ways of obtaining oil from oil seeds and they are solvent extraction and mechanical expression; before new and upcoming technologies in oil extraction were developed, oil was extracted from oil seeds using the traditional method. It is a process by which oil can be obtained from oil seeds. Mechanical expression happens to be the most widely used method for oil expression in the world. It involves the use of either hydraulic or screw press. Oil can be extracted mechanically with the use of a ram press, an expeller or even a wooden mortar and pestle, a traditional method that originated in India. Presses range from small, hand-driven models that an individual can build to power-driven commercial presses. The ram press uses a piston inside a cage to crush the seed and force out the oil [8]. The aim of this research work is to design, fabricate and evaluate a castor oil extractor.

2. MATERIALS AND METHODS

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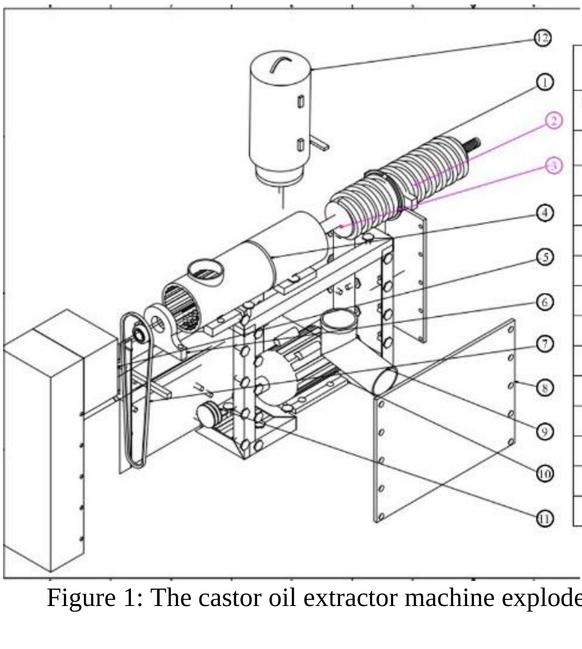
2.1 Material Selection and Production Planning

Table 1 shows the summary of the design prerequisites and materials used in the fabrication of the machine components. All materials were sourced locally after which examination was conducted on each of the component, to locate the point and position they will occupy. The below information was used to carry out production plane and later assembly plane. Electrodes, hammer and block, sniper, welding machine, cutting machine, grinding machine, drilling machine, hack saw, vise and lathe machine, are the machine tools and equipment used in fabrication and construction of this machine. The exploded view of the conceptual design of the machine is also shown in figure 1.

Table 1: List of component parts of the machine and material selection

Components	Material Selection	Selection Criteria	Value of Property
Expeller Screw	Medium carbon steel	Conventional and stronger than mild steel and its locally available	Yield strength: Sy = 248 N/m^2 Tensile strength: Su=399 MN/m^2
Pressure cone	Medium carbon case hardened steel	Hard water resistance material and it is locally available	Yield strength: Sy = 289 N/m^2 Tensile strength: Su=413 MN/m^2
Bearing supporting bar	Mild Steel	Easily machined	Yield strength: Sy=230 N/m^2 Tensile strength: Su=205 MN/m^2
Hopper	Mild steel plate	Easily machined	Yield strength: Sy=230 N/m^2 Tensile strength: Su=205 N/m^2
Speed reduction system	Electric motor, belt, pulley and speed reduction gear	Three phase electric motor of 5hp, A shaped belts and 1:20 speed reduction gear	Good serviceability and relatively cheap to maintain
Angle iron	Mild steel	Mild steel	Locally available



TABLE

Column 1	Column 2	Column 3	Column 4
S/N	Component Parts	Number	Description
1	Auger	1	Metal
2	Barel Head	1	Metal
3	Auger Shaft	1	Metal
4	Barrel	1	Metal
5	Power Unit Cover	1	Metal
6	Bearing Block	1	Metal
7	Belt	1	Rubber
8	Side Cover	4	Metal
9	Collecting Trough	1	Metal
10	Motor	1	
11	Driver Pulley	1	Metal
12	Hopper	1	Metal

Figure 1: The castor oil extractor machine exploded view of the concept design

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2.2 Machine Design

The design analysis of the machine are as follows:

2.2.1 Hopper design

The hopper design is based on the volume of a cylinder as shown:

Figure 2: Schematic diagram of a cylindrical hopper

To obtain the height of the hopper, we will obtain the expected volume of the hopper as shown in equation 1 below

$\rho = \frac{m}{v}$ [9] (1)

v =0.00178 m^3

To know the height of the cylindrical hopper, we use equation 3 below:

$V = \pi r^2 h$ [9] (2)

where: v is the volume of the hopper, r is the radius of the cylinder and h is the cylinder height.

$h = 0.0883$ m

thickness of the hopper T is as shown in equation 3 below:

$T = r_1 - r_2$ [10] (3)

$T = 0.006$ m

2.2.2 Cylindrical Barrel Design

The extracting chamber is design based on internal pressure in the chamber, the extracting chamber is treated as thin-walled cylinder or vessel as shown in Figure 3 by [11]

$\sigma = \frac{\rho d}{2t}$ Kpa (4)

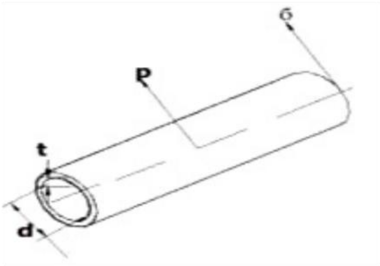

Figure 3: Schematic diagram of a cylindrical barrel

Where: σ is the perpendicular or hoop stress, d is the internal diameter, t is the thickness and ρ is the internal pressure = force/area of cylinder= F/A.,

Area of cylinder, $A = \pi R^2$

$A = 0.0177\ m^2$

Force, $F = \frac{\text{Torque,T}}{\text{length of the chamber,l}}$ (5)

Torque, $T = HP\frac{5252}{N} = 524.79$ Nm (6)

Force, $F = 699.72$ N

$\rho = 39.5$Kpa

Therefore, the expected internal pressure is $\sigma = 74.06$ Kpa

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2.2.3 Power Requirements

The total power required by the expeller; P is given as:

$P = P_N + P_C + P_M + P_E$ [10] (7)

Where P_N = Power required to operate the expeller screw at no loading (kW)
P_C = Power required to crush the castor seed by the expeller (kW)
P_M = Power required to move the crushed seed horizontally (kW)
P_E = Power required to compress and expel the oil from crushed seeds (kW)

$P_N = \frac{DL\,(kW)}{20}$ [10] (8)

Where D is the expeller screw diameter (m), L is the screw length (m)

$P_N = \frac{0.1 \times 0.68}{20} = 0.0034$ kW

$P_C = FV$ [10] (9)

Where F is the crushing force which is Yield stress of Castor seeds x Surface Area of seeds

$F = P \times A$ [10] (10)

$F = 6 \times 117.5 = 705$ N

V is peripheral speed of screw = wr.
Where w is the screw rotating speed, r is the screw radius

$V = 2.55$ m/s

$P_C = 1.7978$ kW

$P_M = \frac{C_O QLg}{3600}$ [11] (11)

$P_M = \frac{C_O QL}{367}$

Where C_O is material coefficient for coal and rocks
Using C_O is 4 for castor seeds

$Q = 3600.S.V.\gamma.K$ (Tons/hr) [11] (12)

Where Q is material flux or screw throughput, S is conveyor house filled area (m^2)

$S = \frac{\eta\pi d^2}{4}$ [11] (13)

Where d is diameter of housing of screw, η = 0.125 for heavy materials such as castor seeds

$S = 0.00166$ m^2

V is the travelling speed of screw

$V = \frac{t.n}{60}$ [11] (14)

Where t is the screw pitch
$t = 0.05$ m
$V = 0.0425$ m/s
$\gamma = 450.42$ Kg/m^3 which is the castor seed bulk density
K = 1 for horizontal conveyor
$Q = 114.398$ tons/hr
$P_M = 0.8479$ Kw
P_E = Power required to expel oil from crushed seeds
= pressure applied × surface area of compression × 9.81 × screw travelling speed

Oil extraction pressure for small-scale expeller and medium-scale expeller ranges from 170 kg/cm^2 to 540 kg/cm^2 (Sirisomboon et. al., 2007)

Assuming pressure of 170 kg/cm^2

$P_E = F \times V$ [10] (15)

Pressure, $P = \frac{F}{A}$ [9] (16)

$F = P \times A$

A is the conveyor house filled area, S = 0.00221 m^2 =22.1 cm^2

Therefore, F = 36856 kg

Therefore, $P_E = F \times V$ [10] (17)

Where V = 0.0425 m/s which is the screw travelling speed

$P_E = 36856.17 \times 0.0425 = 1566.387$ W $= 1.5664$ kW

Therefore, total power required is

$P = 0.0034 + 1.7978 + 0.8479 + 1.5664$

$P = 4.2155$ kW ≈ 4 kW

2.2.4 Torque Requirement

Total Torque requirement, $T = T_{sc} + T_{sh} + T_c$ [9] (18)

Where T_{sc} = screw torque, T_{sh} = Shaft torque, T_c = Crushing torque

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$T_{sc} = \frac{2L\Delta F_{RA} R \tan(\alpha_e + \alpha_s)}{3P}$ [9] (19)

Where ΔF_{RA} = Axial force on screw = weight of bulk material on each screw pitch = W

$W = n(R_0 - R_i)\rho.P.g.n_f$ [11] (20)

Where R_O is screw radius, let R_i is shaft radius, P is Pitch

use $\eta_f = 0.7$ which is fill radius

α_e = Helix angle

$\alpha_e = \frac{\text{lead of screw}}{\text{circumference}} = 28.6°$

$\alpha_s = 23°$ which is friction angle between castor seed and screw surface

$n = 0.0425$ m/s which is travelling speed

$W = 0.021326$ N

$T_{sc} = 0.012198$ Nm

$T_{sh} = \frac{2nR_i\sigma_n L}{P}$ [11] (21)

Where σ_n = normal pressure due to bulk solid

$\sigma_n = K.P.g.\rho.n_f$ [11] (22)

$\sigma_n = 154.6517$ N/m

$T_{sh} = 8.7636$ Nm

Crushing Torque, $T_c = Fr$ [11] (23)

Where F = crushing force, r is radius of rotation which is also the radius of screw

$T_c = 1386.8561$ Nm

$T = T_{sc} + T_{sh} + T_c$

$T = 1395.6319$ Nm

2.2.5 Shaft Design

To calculate the vertical loading on shaft, the following factors must be considered: screw weight (uniform load), rotational at the bearings, vertical component of crushing force, weight of the pulley

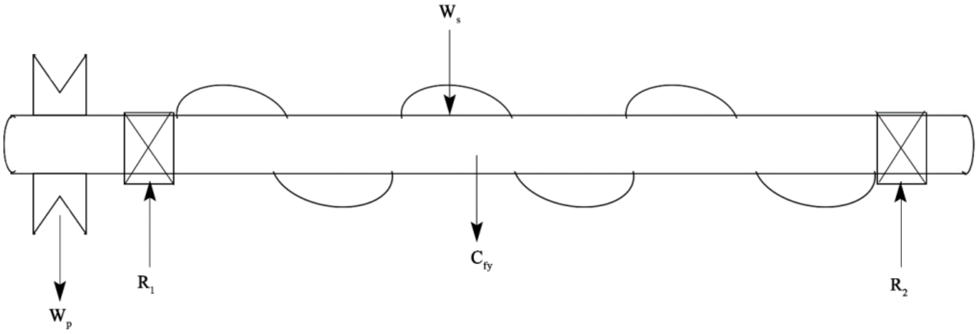

Figure 4: Vertical loading diagram

where Ws is the screw weight, Wp is the weight of pulley, C_{fy} is the vertical component of crushing force, R_2 and R_1 = reactions at bearings

$C_{fy} = C_f \text{Sin}45^o = 7.07$ N [9] (24)

To find weight of screw

L = 0.77 m, d = 0.13 m, P = 0.065 m

For 0.77 m, number of turns $= \frac{L}{P}$ [9]

$n = 11.85 \cong 12$ turns

For a turn, surface area $= \frac{\pi D^2}{4}$ [9] (25)

$= \frac{\pi 0.13^2}{4} = 0.013273\ m^2$

Volume of a turn = area x thickness

Choosing a plate of 9 mm thickness

Volume $= 0.013273 \times 0.009$

$= 0.00011945\ m^3$

Volume of 12 turns $= 0.00011945 \times 12$

$= 0.001434\ m^3$

Density of mild steel plate = 7870 kg/m^3

Therefore, mass of screw = 11.2817 kg

weight of screw = 110.639 N

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$R_1 + R_2 = 9.81 + 117.709 = 127.519$ N

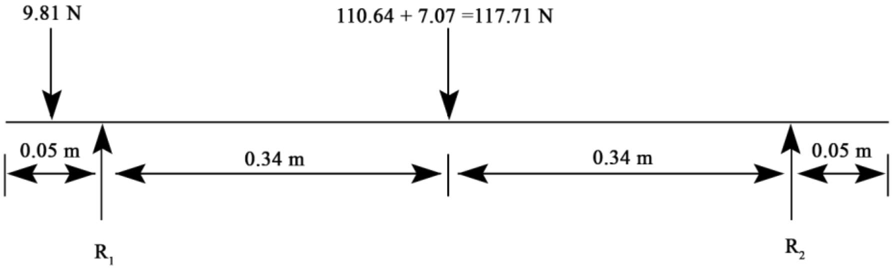

Figure 5: Vertical loading diagram

Taking moment at R_2

$9.81 \times 0.72 = 11.709 \times 0.335 = R_1 \times 0.67$

$R_1 = 69.396590$ N

$R_2 = 117.709 - 69.39658955 = 48.312410$ N

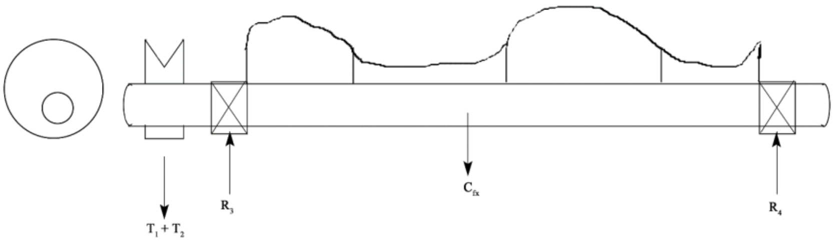

Figure 6: Horizontal loading on shaft

T_1 = Belt tension on tight side, T_2 = Belt tension on slack side, C_{fx} = Horizontal component of crushing force, R_3, R_4 = Bearing reactions, $C_{fx} = 7.01$ N

$\frac{T_1}{T_2} = 3$ (Assumed belt tension ratio = 3) [9] (26)

$T_1 = 3T_2$

Torque, T = Torque transmitted by electric motor to belt

$T = \frac{60P}{2\pi N}$ [9] (27)

$$T = \frac{60 \times 750}{2 \times \pi \times 1400} = 5.1157 \text{ Nm}$$

$T = (T_1 - T_2)r$ [9] (28)

Where r = radius of electric motor pulley $= \frac{95 \text{ mm}}{2} = 47.5 \text{ mm} = 0.0475$ m

$5.1157 = (T_1 - T_2)0.0475$

$(3T_2 - T_2) = 107.69895$ N

$T_2 = 53.849474$ N

$T_1 = 3T_2$

$T_1 = 161.5484211$ N

$T_2 + T_1 = 215.3978948$ N

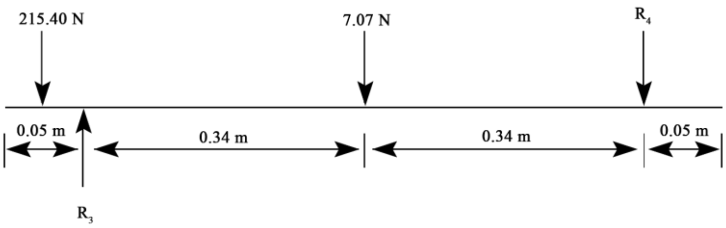

Figure 7: Horizontal loading diagram

$R_3 + R_4 = 215.3978948 + 7.07$

$R_3 + R_4 = 222.468$ N

Taking Moment about R_4

$R_3 = 235.0074776$ N

$R_4 = -12.53947761$ N

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2.2.6 Bending Moment Calculation

For vertical loading
At A, B. M. = 0 Nm
At B, B. M. = 0.49 Nm
At C, B. M. = 16.184658 Nm
At D, B. M. = 0 Nm
For horizontal loading
At A, B. M. = 0 Nm
At B, B. M. = 11.1234 Nm
At C, B. M. = 4.200725 Nm
At D, B. M. = 0 Nm
Resultant B.M.
R.B.M. at B = 11.134187 Nm
R.B.M. at C = 16.716414 Nm

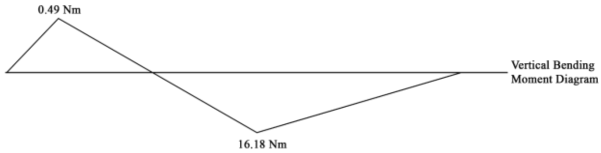

Figure 8: Vertical bending moment diagram

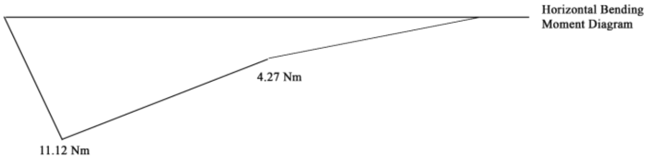

Figure 9: Horizontal bending moment diagram

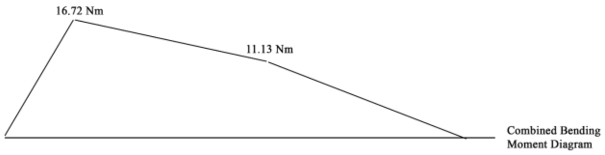

Figure 10: Combined bending moment diagram

2.2.6 Design of Drive Chain

The schematic diagram of the pulley and belt is shown in the figure 11.

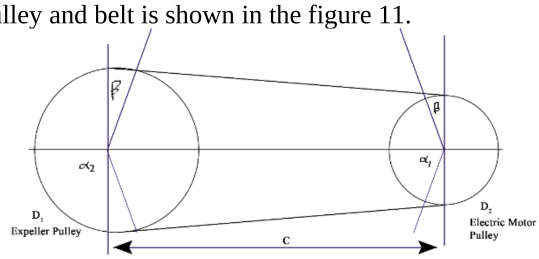

Figure 11: Schematic diagram of pulley and belt

C = center to center distance (m)

$$C = \frac{1}{2}(D_1 + D_2) + D_1 \quad [10] \tag{29}$$

Where D_2 = motor pulley, D_1 = motor pulley
C = 0.4225 m
Determination of length of belt, L

$$L = \frac{\pi(D+d)}{2} + (2C) + \frac{(D+d)^2}{(4C)} \quad [9] \tag{30}$$

where D = diameter of large pulley, d = diameter of small pulley
Belt for pulley 1 (diameter = 0.25 m) = 1.457353727 m = 57.376 in
Belt for pulley 2 (diameter = 0.167 m) = 1.302166389 m = 51.266 in
Belt for pulley 3 (diameter = 0.125 m) = 1.224214245 m = 48.197 in

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2.3 Evaluation Parameters

The evaluation of the machine was performed in a face centred – central composite design using$3 \times 3 \times 3!$ Factorial experimental design which consists of roasting time, roasting temperature and screw speed each at three different level. The different levels of moisture content are 10, 20 and 30 minutes, while the different levels of roasting temperature are 80, 100, and 120 ºC and that of screw speed are 27, 39, and 51rpm. This is the experimental procedure that was used to determine the effect of these oil extraction factors on these extraction variables that are considered, extraction loss, extraction rate and extraction efficiency.

2.3.1 Oil extraction efficiency

The machine is built in order to effectively remove the oil content of castor seed from the cake at the barest loss possible. Hence it is important to determine the efficiency of the machine by taking the percentage of the ratio of the expelled oil to the actual expected expelled oil as show in equation 31

$$\text{Extraction Efficiency} = \frac{\text{weight of expelled oil}}{\text{weight of expected oil}} \times 100\% \qquad (31)$$

2.3.2 Extraction loss

Oil extracted is used to determine the efficiency of the machine, the difference between the expected oil yield and the actual oil yield then becomes the loss incurred during the extraction process and this loss is calculated as show in equation 32

$$\text{Extraction Loss} = 100 - \left(\frac{\text{expected cake yield}}{\text{actual cake yield}} \times 100\%\right) \qquad (32)$$

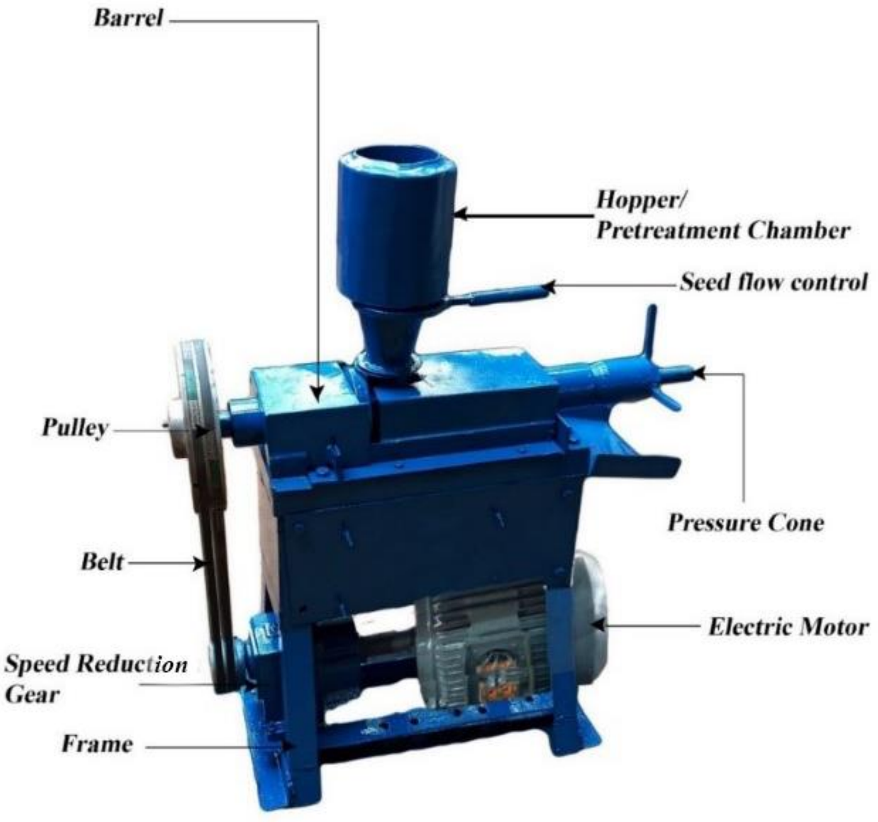
2.3.3 Extraction rate

The quantity of oil the machine is able to produce per time from the quantity of seed fed into it is used to determine the extraction rate of the machine and the rate is calculated mathematically as show in equation 33

$$\text{Extraction Rate} = \frac{\text{weight of expelled oil}}{\text{time taken to extract oil}} \qquad (33)$$

3. RESULTS AND DISCUSSION

The developed mechanical castor oil extractor is as shown in Plate 1 below. The machine consists of a hopper which houses a 5w band heater which serves as a pre-treatment chamber, a barrel made from mild steel, a seed flow control, a pressure cone for varying the barrel internal pressure, a screw shaft, a pulley and a type A belt. All these are mounted and fastened to a 3x3 angle bar frame.



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3.1 Extraction Efficiency

Figure 12 shows the graphical representation (contour and 3D Surface plot) of extraction efficiency of the developed oil expeller at different roasting temperature, roasting time and machine speed. According to the figure, the extraction efficiency for the castor seed ranges from 32.0% - 69.4%. The maximum value (69.4%) for the extraction efficiency of the oil expeller was recorded at roasting temperature, roasting time and machine speed of 100 °C, 20 min and 51 rpm respectively, meanwhile, the minimum value (32%) for the extraction efficiency of the oil expeller was recorded at roasting temperature, roasting time and machine speed of 80 °C, 10 min and 27 rpm. The efficiency obtained in this study is in close range to the value (27.85% - 65.17%) reported by [12] during the development of an oil extraction machine for *jatropha cucas* seed and [13] reported 64% extraction efficiency from palm kernel oil using hydraulic press. Also, the value obtained in this study was found higher than the value (39.4%) reported by [14] during the development of a motorized kneader for groundnut oil extractor, [15] who obtained 47.0% oil yield from palm kernel using mechanical extraction process and [16] who obtain oil yield values of between 15-17.18% and 31-34.37% from Moringa oleifera seeds with manual and Soxhlet extraction methods respectively. The variation in the performance of this study compare to this study might be due to the introduction of heating system for roasting of the seed prior to the extraction process. However, the increase in the roasting temperature, roasting time, and machine speed by 1 ºC, 1 min and 1 rpm respectively, resulted in an average increase in the extraction efficiency of the oil expeller by 0.352%, 0.542% and 0.255% respectively.

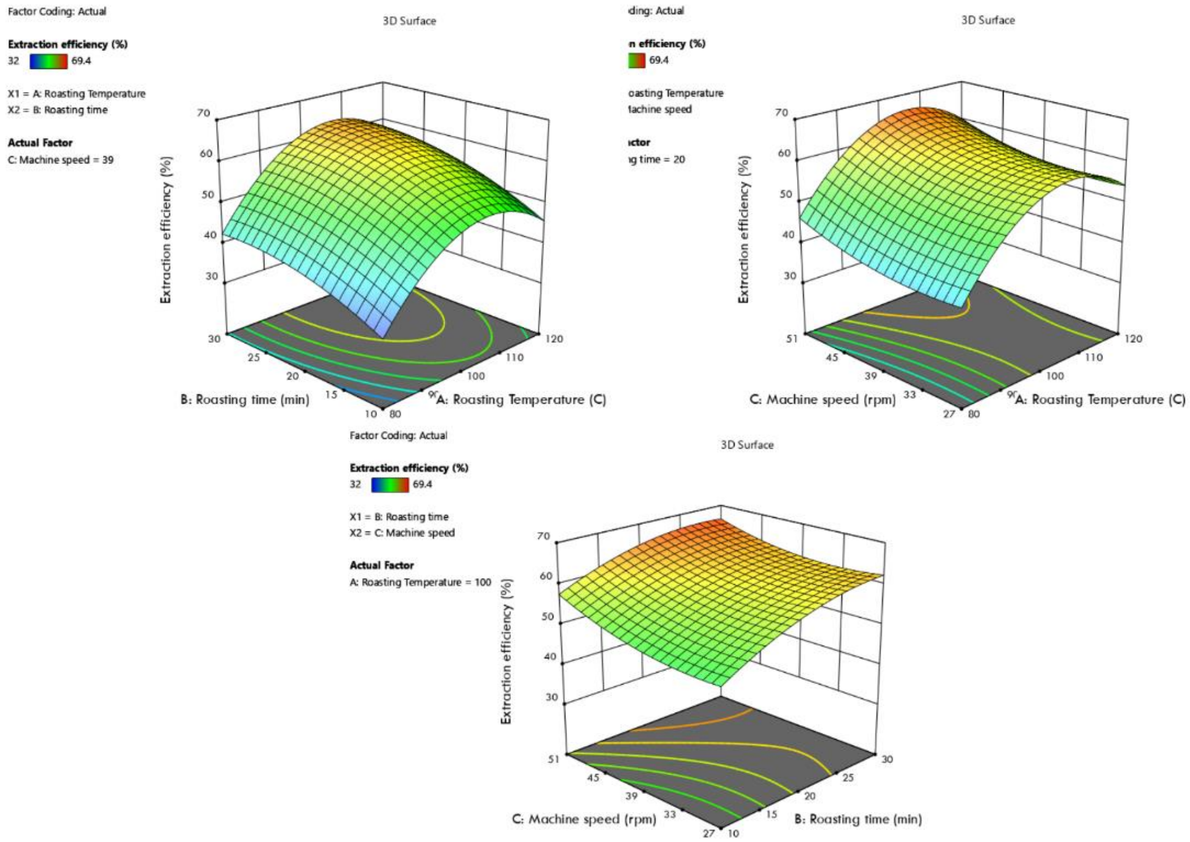

Figure 12: 3D surface of the extraction efficiency of the oil expeller as affected by the roasting time, roasting temperature and machine speed

The mathematical relationship between the extraction efficiency and the input parameters (roasting temperature, roasting time, and machine speed is shown in Equation 34 with a determination coefficient of roasting time and this shows that the equation can significantly (P<0.05) predict the 91.72% change in the extraction efficiency as a function of roasting temperature, roasting time and machine speed.

$$E = -276.55 + 6.16T + 1.72t - 0.89S + 3.45x10^{-3}Tt - 3.41x10^{-4}TS - 8.29x10^{-3}tS - 0.03T^2 - 0.03t^2 + 0.02S^2 \quad (34)$$

where E is the extraction efficiency, T is roasting temperature (°C), t is roasting time (min) and S is machine speed (rpm) Table 2 shows the result of the analysis of variance (ANOVA) of the extraction efficiency. Based on the table, the change in the extraction efficiency significantly (P<0.05) depends on the roasting temperature followed by roasting time and machine speed has the least significant effect on the extraction efficiency of the castor oil expeller.

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Table 2: Analysis of variance for the extraction efficiency (%) of the oil expeller

Source	Sum of	Df	Mean	F-value	p-value	
Model	2375.663	9	263.963	18.462	0.000	significant
A-Roasting Temperature	893.658	1	893.658	62.504	0.000	
B-Roasting time	528.233	1	528.233	36.946	0.000	
C-Machine speed	169.035	1	169.035	11.823	0.004	
AB	7.604	1	7.604	0.532	0.477	
AC	0.107	1	0.107	0.008	0.932	
BC	15.821	1	15.821	1.107	0.309	
A^2	378.891	1	378.891	26.500	0.000	
B^2	24.651	1	24.651	1.724	0.209	
C^2	16.961	1	16.961	1.186	0.293	
Residual	214.464	15	14.298			
Lack of Fit	61.930	5	12.386	0.812	0.567	not significant
Pure Error	152.533	10	15.253			
Cor Total	2590.126	24				

3.2 Extraction loss

Figure 13 shows the graphical representation (contour and 3d Surface plot) of extraction loss of the developed oil expeller at different roasting temperature, roasting time and machine speed. According to the figure, the extraction loss for the castor seed ranges from 11.55% - 18.21%. The maximum value (18.21%) for the extraction loss of the oil expeller was recorded at roasting temperature, roasting time and machine speed of 80 °C, 10 min and 27 rpm respectively, meanwhile, the minimum value (11.55%) for the extraction loss of the oil expeller was recorded at roasting temperature, roasting time and machine speed of 120 °C, 30 min and 51 rpm respectively. The action loss in this study is in a close range to the values (15%) reported by [17] during the development of development of u-channel screw jack for vegetable oil extraction from groundnut seed. Also, [18] got extraction loss in the range of 2.495% - 16.122% from oil extraction from fluted pumpkin seed using n-hexane as the solvent. A unit increase in the roasting temperature, roasting time, and machine speed resulted in an average decrease in the extraction loss of the oil expeller by 0.08%, 0.098%, and 0.031% respectively.

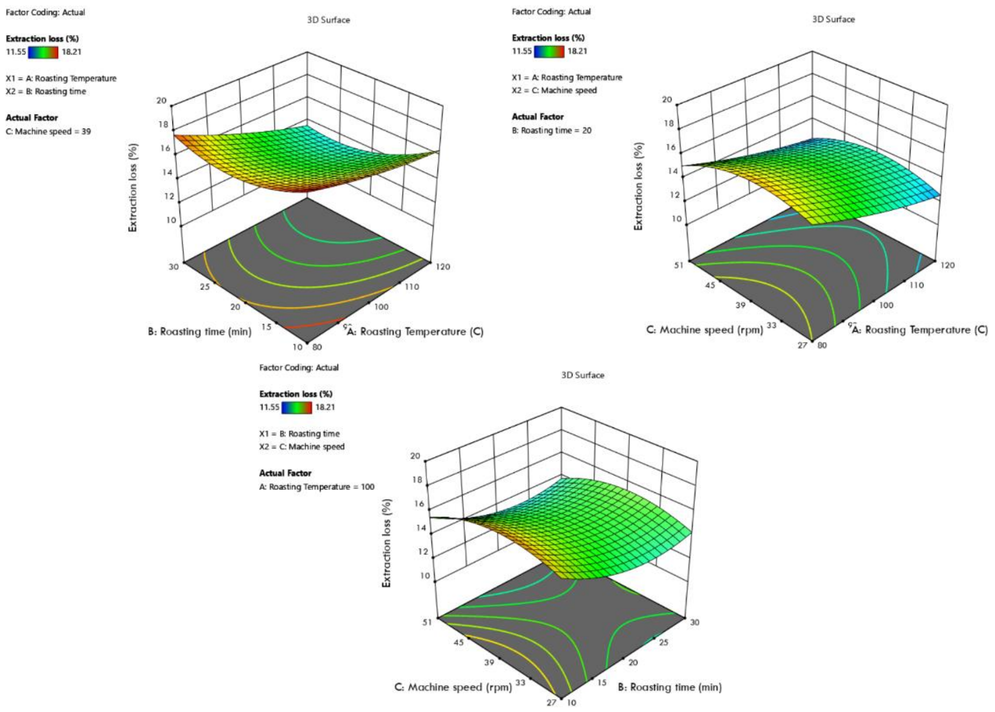

Figure 13: 3D surface of the extraction efficiency of the oil expeller as affected by the roasting time, roasting temperature and machine speed

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The mathematical relationship between the extraction loss and the input parameters (roasting temperature, roasting time, and machine speed is shown in Equation 35 with a determination coefficient (R^2) of 0.9174 and adjusted R^2 of 0.8679 which was in reasonable agreement with the predicted R^2 of 0.8109; i.e., the difference is less than 0.2. However, this shows that the equation can significantly ($P<0.05$) predict the 91.75% change in the extraction loss as a function of roasting temperature, roasting time and machine speed

$$L = 24.43 - 0.22T - 0.41t + 0.57S - 2.36x10^{-3}Tt + 8.23x10^{-4}TS + 9.37x10^{-4}tS + 7.64x10^{-4}T^2 + 0.01t^2 - 9.06x10^{-3}S^2 \quad (35)$$

where L is the extraction loss, T is roasting temperature (°C), t is roasting time (min) and S is machine speed (rpm)
Table 3 shows the result of the analysis of variance (ANOVA) of the extraction loss. Based on the table, the change in the extraction loss significantly ($P<0.05$) depends on the roasting temperature followed by the roasting temperature followed by roasting time and machine speed has the least significant effect on the extraction loss of the oil expeller

Table 3: Analysis of variance for the extraction loss (%) of the oil expeller

Source	Sum of	Df	Mean	F-value	p-value	
Model	2375.663	9	263.963	18.462	0.000	significant
A-Roasting Temperature	893.658	1	893.658	62.504	0.000	
B-Roasting time	528.233	1	528.233	36.946	0.000	
C-Machine speed	169.035	1	169.035	11.823	0.004	
AB	7.604	1	7.604	0.532	0.477	
AC	0.107	1	0.107	0.008	0.932	
BC	15.821	1	15.821	1.107	0.309	
A^2	378.891	1	378.891	26.500	0.000	
B^2	24.651	1	24.651	1.724	0.209	
C^2	16.961	1	16.961	1.186	0.293	
Residual	214.464	15	14.298			
Lack of Fit	61.930	5	12.386	0.812	0.567	not significant
Pure Error	152.533	10	15.253			
Cor Total	2590.126	24				

3.3 Extraction rate

Figure 14 shows the graphical representation (contour and 3d Surface plot) of extraction rate of the developed oil expeller at different roasting temperature, roasting time and machine speed. According to the figure, the extraction rate for the castor seed ranges from 0.06 g/s - 0.13 g/s. The maximum value (0.13 g/s) for the extraction rate of the oil expeller was recorded at roasting temperature, roasting time and machine speed of 100 °C, 20 min and 51 rpm respectively, meanwhile, the minimum value (0.06 g/s) for the extraction rate of the oil expeller was recorded at roasting temperature, roasting time and machine speed of 80 °C, 10 min and 27 rpm. A unit increase in the roasting temperature, roasting time and machine speed resulted in an average increase in the extraction rate of the oil expeller by 0.0007 %, 0.001 %, 0.0005 % respectively. [19] reported the increase in extraction rate with speed as might to the fact that, as the speed increases, the rate at which the seeds are transported into the press barrel per unit time increases. At high speed, the retention time of feed-stock in the press barrel is shortened, therefore the amount of feed-stock processed per unit time increased, and similar result was observed in this study. Also, the plasticity of the paste could have reduced at high temperature thereby improves the compressibility which resulted in good extraction rate. At low temperature also, the moisture in the seeds might be higher and act as a hindrance to the separation of oil from the cell of seed during pressing [20].

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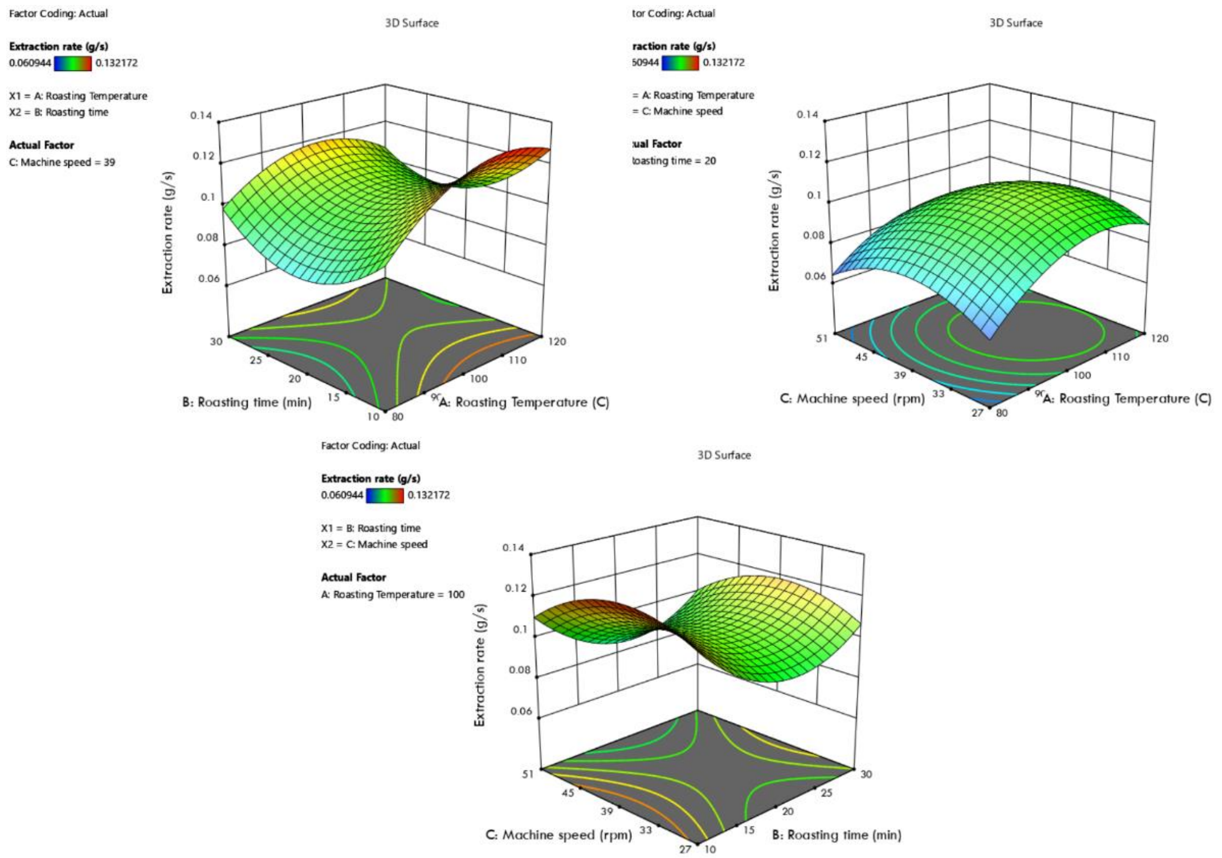

Figure 14: 3D surface of the extraction of the oil expeller as affected by the roasting time, roasting temperature and machine speed

The mathematical relationship between the extraction rate and the input parameters (roasting temperature, roasting time, machine speed and) is shown in Equation 36 with a determination coefficient of roasting time and this shows that the equation can significantly (P<0.05) predict the 52.01% change in the extraction rate as a function of roasting temperature, roasting time and machine speed.

$$ER = -0.48 + 9.42x10^{-3}T - 6.51x10^{-3}t + 8.71x10^{-3}S - 2.43x10^{-5}Tt - 1.39x10^{-5}TS + 8.08x10^{-6}tS - 3.97x10^{-5}T^2 + 2.02x10^{-4}t^2 - 1.00x10^{-4}S^2 \quad (36)$$

where ER is the extraction rate, T is roasting temperature (°C), t is roasting time (min) and S is machine speed (rpm)
Table 4 shows the result of the analysis of variance (ANOVA) of the extraction rate. Based on the table, the combination of roasting temperature, roasting time, machine speed and cannot significantly explain the variation in the extraction rate at 95% probability level. The F-value of 1.81 implies the model is not significant relative to the noise. There is a 14.96% chance that an F-value this large could occur due to noise. However, the change in the extraction rate significantly (P<0.05) depends on the roasting temperature followed by the roasting temperature followed by roasting time and machine speed has the least effect on the extraction rate of the oil expeller. The lack of fit F-value of 1.20 implies the lack of fit is not significant relative to the pure error and there was a 37.58% chance that a lack of fit F-value this large could occur due to noise.

Table 4: Analysis of variance for the extraction rate (g/s) of the oil expeller

Source	Sum of	Df	Mean	F-value	p-value	
Model	0.0049	9	0.0005	1.8100	0.1496	not significant
A-Roasting Temperature	0.0014	1	0.0014	4.7300	0.0460	
B-Roasting time	0.0006	1	0.0006	1.8400	0.1947	
C-Machine speed	0.0003	1	0.0003	0.9610	0.3425	
AB	0.0004	1	0.0004	1.2600	0.2798	
AC	0.0002	1	0.0002	0.5951	0.4524	
BC	0.0000	1	0.0000	0.0501	0.8259	

A^2	0.0007	1	0.0007	2.3100	0.1490	
B^2	0.0011	1	0.0011	3.7200	0.0728	
C^2	0.0006	1	0.0006	1.9100	0.1875	
Residual	0.0045	15	0.0003			
Lack of Fit	0.0017	5	0.0003	1.2000	0.3758	not significant
Pure Error	0.0028	10	0.0003			
Cor Total	0.0094	24				

3.4 Optimal machine performance

The numerical optimization of the castor oil extraction was carried out by super-positioning of the different responses (extraction efficiency, extraction loss and extraction rate). the optimum solution was obtained by minimizing the extraction loss and maximizing the extraction efficiency and the extraction rate, the experimentally obtained result was taking as the range of optimality, the responses optimally range from 32 - 69.4%, 11.55 - 18.21% and 0.06 g/s - 0.13 g/s for the extraction efficiency, extraction loss and extraction rate respectively (Table 5). The obtained optimal machine and operation parameter for the castor oil expeller are roasting temperature of 110.95 C, roasting time of 30.0 min and machine speed of 27.0 rpm. The obtained optimum machine performance values for the oil expeller are 63.04%, 13.15% and 0.106 g/s for the extraction efficiency, extraction loss and extraction rate respectively, with the highest desirability of 73.9% as shown in Table 6.

Table 5: The range optimality and goal for the optimization process

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Roasting Temperature	is in range	80	120	1	1	3
B: Roasting time	is in range	10	30	1	1	3
C: Machine speed	is in range	27	51	1	1	3
Extraction efficiency	maximize	32	69.4	1	1	3
Extraction loss	minimize	11.55	18.21	1	1	3
Extraction rate	maximize	0.06	0.13	1	1	3

Table 6: Optimal performance of the castor oil extractor

SN	Roasting temperature	Roasting time	Machine speed	Extraction efficiency	Extraction loss	Extraction rate	Desirability
1	110.948	30.000	27.000	63.040	13.126	0.106	0.739
2	111.073	29.864	27.000	62.997	13.098	0.106	0.737
3	108.790	30.000	27.001	63.446	13.339	0.107	0.736
4	110.726	29.759	27.002	63.074	13.120	0.106	0.736
5	110.242	30.000	28.724	62.833	13.520	0.110	0.735
6	111.385	30.000	29.063	62.493	13.468	0.110	0.735
7	108.383	30.000	49.074	66.504	13.444	0.103	0.733
8	108.406	30.000	48.716	66.319	13.511	0.104	0.732
9	109.840	30.000	47.304	65.424	13.643	0.106	0.731
10	109.770	30.000	46.567	65.111	13.764	0.108	0.730
11	111.939	30.000	31.468	62.011	13.769	0.113	0.729
12	109.342	30.000	45.162	64.616	13.994	0.111	0.727
13	107.831	30.000	45.382	64.881	14.095	0.111	0.726
14	108.960	30.000	31.583	62.667	14.063	0.114	0.726
15	109.679	30.000	43.366	63.928	14.161	0.113	0.724
16	109.943	30.000	43.268	63.846	14.147	0.113	0.724
17	107.939	30.000	31.431	62.789	14.144	0.114	0.723

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18	111.967	30.000	35.331	61.907	14.113	0.115	0.721
19	111.360	30.000	40.107	62.681	14.220	0.115	0.720
20	111.236	30.000	38.864	62.485	14.257	0.116	0.719

4. CONCLUSION

The castor oil extractor was developed and evaluated for optimal performance characteristics. The fabricated machine which consists of various components such as hopper, screw, cylindrical barrel, collecting tray, frame, cake outlet, expeller house, auger, pulley and shaft was evaluated by varying machine and seed parameters which are roasting temperature, roasting time and machine speed. The extraction efficiency increases as the roasting temperature increases from 20 ºC to 30 ºC, as the roasting time increases from 10 minutes to 30 minutes and the machine speed increases from 27 rpm to 49 rpm. The extraction loss is reduced as the machine speed is reduced to 27 rpm while roasting temperature and roasting time increases to 111 ºC and 29.8 minutes respectively. The extraction rate increases as the roasting time and roasting temperature increase to 30 minutes and 111 ºC respectively and the machine speed increases to 38.8 rpm. The optimal and desirable operational parameters for the developed castor seed oil extraction machine are 63.04%, 13.15% and 0.106 g/s for the extraction efficiency, extraction loss and extraction rate respectively, with a desirability level of 73.9%.

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