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Design, Fabrication, and Optimization Studies of a Groundnut Kneader

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ABSTRACT

Nigeria's small-scale oil extraction remains a significant bottleneck. In this study, an improved groundnut kneader was designed, fabricated, and evaluated based on groundnut oil extraction. Also, some pertinent parameters of the developed kneading machine including machine speed, finger numbers, and water temperature were successfully optimized. The result of the study revealed that the highest number of fingers (F_3) produced the highest machine efficiency of 78.39% and maximum output capacity of 17.97 kg/h while the lowest efficiency of 69.74% and the lowest output capacity of 10.79 kg/h were recorded at the lowest number of fingers (F_1). The highest oil yield of 38.84% was obtained at the water temperature of 60°C, while the lowest groundnut oil yield of 33.7% was recorded at 40°C. The optimum machine efficiency, output capacity, and yield of 80.9%, 19.98 kg/h, and 19.73% were obtained when the machine speed, water temperature, and the number of fingers were 400 rpm, 60°C, F_3 for speed, water temperature, and the number of fingers respectively. The results indicated that as the speed (rpm), water temperature (°C) and fingers were increased the responses such as efficiency (%), oil yield (%), and output capacity (kg/h) were increased. From the performance evaluation of the kneader, it was observed that all the evaluated factors are significant at $p \leq 0.05$. Finger number, water temperature, and speed significantly impact kneader oil yield, efficiency, and output capacity; modelling equations were valid and show no significant difference between the statistical and experimental values.

Keywords: design, fabricate, groundnut kneader, oil yield, machine speed, groundnut oil

INTRODUCTION

Groundnut (*Arachis hypogaea* Linnaeus), which is generally known as peanut, though locally called Gyeda in the Hausa language, Epa in the Yoruba language, and Guzhia in the Nupe language, is nowadays an essential oilseed and food crop (Hassan & Osunde, 2022). It is an important oilseed crop with an excellent protein source for the production of oil, fuel, and food (Varshney *et al.*, 2017). Due to its abundant oil content, groundnut is ranked fourth globally in terms of oil-producing seeds (Worldwide Oilseed Production, 2022/2023). During the production of oil, a considerable amount of over 50% by-product is produced in comparison with starting material being groundnut cake. Groundnuts have important qualities such as oil, protein, fatty acid, and amino acid composition (Ajao *et al.*, 2010; Nguyen *et al.*, 2022) Due to its high smoke point, the oil is ideal for high-temperature cooking with no burning. It is recognized for having a pleasant flavour and a subtle nutty scent (Olatunde *et al.*, 2014).

Groundnut kneading is an essential step in the process of groundnut oil extraction, which is a significant industry in many developing countries (Akerele & Ejiko, 2016). The traditional method of kneading groundnuts involves manual labour, which is time-consuming and labour-intensive. As a result, there has been a growing interest in the development of mechanized groundnut kneaders (Mikailu *et al.*, 2018).

Groundnut oil extraction is a vital industry in many developing countries, with groundnut kneading being an essential step in the process. Traditionally, the process involves manual labour, which is time-consuming and labour-intensive (Olajide & Igbeka, 2003; Odewole *et al.*, 2016). As a result, there has been an increasing interest in the development of mechanized groundnut kneaders to improve efficiency and reduce labour costs.

The design and fabrication of groundnut oil kneaders have been the subject of numerous studies. For instance, Maduako *et al.* (2004) designed and fabricated a motorised groundnut kneading machine. Further addressing the laboriousness of the manual process, test findings showed considerable and significant kneading time savings. The amount of time needed to knead was reduced by 80%, and the machine's throughput capacity was found to be 46.3 kg/hr. Shu'aibu (2013) also modified an existing kneader at the Department of Agricultural Engineering Bayero University, Kano and results revealed that the efficiency of the machine was in the range of 66.38% to 71.40%. Ibrahim (2015) redesigned a Kneader at the Department of Agricultural Engineering at Bayero University, Kano, and reported the highest extraction efficiency of 78.59% with the *Manipintar* groundnut seed variety. A study by Ravi *et al.* (2017) developed a motorized groundnut kneading machine that reduced the time required for kneading by 70%. The authors reported that the machine's throughput was approximately 10 kg/hr. Lawan *et al.* (2019) developed an integrated groundnut oil extraction machine that was capable of producing a higher-quality of groundnut paste. Similarly, Adeyanju *et al.* (2021) developed a semi-automatic groundnut kneading machine that uses a mechanical system to reduce the time and effort required for kneading. The machine was designed with a variable speed control and a mixing drum that ensures even mixing of the groundnut paste. Moreover, the machine's output capacity was approximately 15 kg/hr of groundnut paste.

Several studies have reported the development of the screw method of extraction (Olajide *et al.*, 2007; Olajide *et al.*, 2014; Alonge & Olaniyan, 2006; Raphaelle *et al.*, 2012; Alonge *et al.*, 2004; Olaniyan & Oje, 2007) but it was discovered that screw oil extraction had not been adopted by women processors since the by-product from screw extraction cannot be processed into a kind of a snack called '*Kulikuli*' in Nigeria which is usually the main product and the processing of the groundnut oil only as part of the process. Hence, necessitating the development of an improved kneading machine. Similarly, several studies reported on the kneading method of oil extraction machines (Maduako *et al.*, 2004; Bashir, 2014; Ibrahim, 2015). However, there are still reported limitations as regards groundnut oil kneading machines which includes the issue of the collection of extracted oil which can only be done after the batch operation in the existing designs. This increases the downtime and hence reduces the overall efficiency of the process. Also, the power transmission shaft and bevel arrangement in the existing designs involve longer link elements.

Other studies have also investigated the use of different materials and design features to improve the efficiency and effectiveness of groundnut kneaders. In a study by Abdulkadir *et al.* (2020), a groundnut roaster was designed and fabricated, which could roast up to 50 kg of groundnuts at a time. The roaster's design included a fan, a heater, and a rotating drum, which allowed for even roasting of the groundnuts. The researchers reported that the roaster's efficiency was approximately 85%, and it significantly reduced the time required for roasting.

Several studies have also emphasized the importance of designing groundnut kneaders that are user-friendly, cost-effective, and accessible to small-scale farmers and entrepreneurs. In a study by Ajiboye *et al.* (2017), a manually operated groundnut shelling machine was developed, which could shell up to 12 kg/hr of groundnuts. In a study by Zewdu *et al.* (2020), the researchers developed a groundnut sheller and kneading machine that could shell and knead 25 kg/hr groundnuts. The machine's design consisted of a hopper, a shelling unit, and a kneading unit, which were driven by a single electric motor. The authors reported that the machine's shelling efficiency was approximately 90%, and its kneading time was 20 minutes.

The above reviewed studies have highlighted the potential of mechanized groundnut kneaders to advance the efficiency of groundnut oil extraction. Various design features and materials to improve the efficiency of the existing kneading machines have also been explored. However, more research is highly desirable to further optimize these designs and evaluate their feasibility for commercial production. The development of affordable and user-friendly groundnut kneaders using locally available materials and manufacturing techniques for small-scale farmers and entrepreneurs in developing countries is highly requisite.

The development of an optimized and improved groundnut kneader that addresses some of the drawbacks of the existing kneading machines is yet to be reported. Hence, the present study tends to address the above-stated drawbacks in the existing designs by designing and fabricating an improved groundnut kneader by incorporating of new features and modifications that could enhance the performance and efficiency of the machine. The developed machine will provide for continuous collection of oil during operation with reduced linkages to minimize overall costs and power requirements. It will also incorporate several design improvements, such as the use of a more powerful motor, a better sealing mechanism to prevent oil leakage, and an ergonomic design that reduces operator fatigue.

This aimed to design, fabricate, and optimize an enhanced groundnut kneader that can improve traditional groundnut processing techniques, increase productivity, and enhance the livelihoods of small-scale farmers and food processors in Nigeria and other developing countries.

MATERIALS AND METHODS

Material Selection

The knowledge of the properties of the available materials for a design is indispensable. Hence, materials selection is based on the type and severity of stress on machine components. Also, during material selection, materials availability, suitability of the materials for the working conditions, and cost of materials were adequately considered. A stainless metal sheet was chosen for kneading cylinder construction because of its resistance to corrosion even under damp conditions. The angle iron that was used for the frame was selected because of its durability, availability, thermal conductivity, low cost, and strength to hold other components. The v- belts were selected together to produce a tight fit for the transmission of power from the drive to the driven side. The choice of materials used for shafts and stirrer fingers was based on thermal conductivity, availability, low costs, and strengths. Mild steel was employed for the construction of the rotating shaft based on the strength required for a ductile material. Other materials such as bearings and grinding plates were both selected due to their durability, availability, low cost, low corrosion, and resistance to wear.

Design of the Kneader Components

Major components of the machine such as container capacity, thickness of the container, stirrer fingers, power requirement and shaft diameter were designed.

Design of the hopper

The container, which is a tapered cylindrical shape in form of a frustum houses the iron bars attached to a rotating shaft and the groundnut paste stock from which oil is extracted. The design of the kneading chamber was derived from (Babatunde, 1995):

$$V = \frac{M}{\rho} \tag{1}$$

Where V = volume of the chamber in m^3
M = mass of the paste in kg
ρ = density of the groundnut paste in kg/m^3

To provide for clearance, avoid choking, avoid splashing, and effective mixing of the groundnut paste in the container during the extraction process, the volume of the container was made 2 times the volume of the groundnut paste.

$$V = 2 \times 0.023$$

$$V = 0.046 m^3$$

The diameter and length of the container were calculated from the equation for calculating the frustum of a cone as given in equation 2 (John, 2007):

$$V = \frac{\pi h}{3}\left(R^2 + Rr + r^2\right) \tag{2}$$

Thus, the height of the container was obtained from the volume of a frustum.
Where; V = Volume of the container (m^3); h = Container height (m); R = Radius of the upper side of the Container (m); r = Radius of the lower side of the Container (m)

Based on existing kneader designs, R = 0.17 m; and r = 0.11 m were selected

$$0.046 = \frac{\pi h}{3}\left(0.17^2 + (0.17 \times 0.11) + 0.11^2\right)$$

$$h = \frac{0.138}{0.188}$$

$$h = 0.73$$

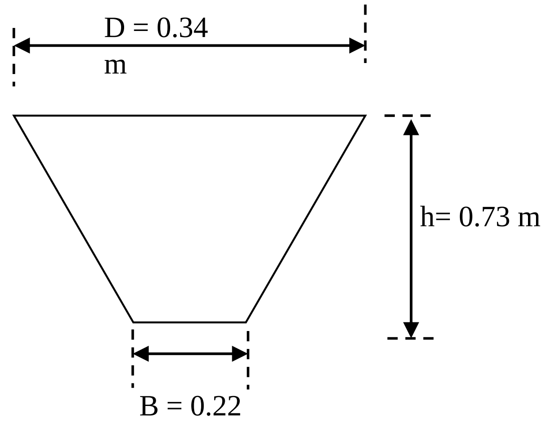

Figure 1. Hopper free body diagram

Design of plate thickness for the hopper

The container was assumed to be formed of a thin section in order to estimate the thickness of the container wall. The groundnut paste it contains and the agitation of the paste during the extraction process will cause pressure to build up inside the container.

The container cover is opened intermittently during operation to the atmosphere, the cylinder's maximum interior pressure is indicated as (Aperebo, 2007):

$$\text{Maximum Pressure, } P_{max} = P_{atm} + \rho g(h_1 - h_2) \tag{3}$$

where P_{atm}= atmospheric pressure=101325 N/m^2

ρ =1043.3 kg/m^3 (Idrisa, 2009)

g = acceleration due to gravity=9.81 m/s^2

h_1-h_2 = height of the container=0.1829 m

In order to account for the forces created by the iron bars' (fingers') squeezing action and the pressure produced by the paste's collision with the container's internal wall during oil extraction, a factor of safety of n = 4 will be chosen for the design. Thus, the working stress of the hopper made of mild steel is given in equation 3.4 (Collins & Sitar, 2011):

$$\text{Working stress, } \sigma_{ws} = \frac{\sigma_{yp}}{n} \quad (4)$$

where σ_{yp}=yield stress of mild steel=250 MPa

σ_{ws}=working stress N/m^2

For a thin-walled cylindrical vessel, the tangential stress (working stress) is given as (Collins & Sitar, 2011)

$$\text{Tangential stress, } \sigma_{ws} = \frac{P_{max} \times d}{2t} \quad (5)$$

Where σ_{ws} = working stress N/m^2

P_{max} = maximum built-up pressure inside cylinder N/m^2

d = diameter of the base of the container (m)

t = thickness of the wall of container (mm)

Hence, a mild steel plate of 2 mm thickness was considered adequate for the fabrication of the container.

Design of vertical scrappers

Three vertical scrappers were made with 50 mm angle iron of 4 mm thickness and mounted inside around the hopper's wall, spaced uniformly apart. They function as scrapers. The relationship between a circle's circumference and the distance between the scrappers was used to calculate this distance:

$$\text{Circumference, } C = \pi D \quad (6)$$

Where D = diameter of the top of the container

If D = 410mm (from existing groundnut kneader)

i. e $C = \pi \times 410 \approx 1288$mm

Number of vertical scrappers, N_b=3

∴ Position of the vertical scrappers from one another $= \frac{C}{N_b}$

Vertical scrappers position from one another $= \frac{1288}{3} = 429.33$mm

As a result, the vertical scrappers were positioned circumferentially around the inner wall of the container at a distance of about 430 mm from one another. Hence, this is meant to help in breaking of groundnut paste lumps during operation.

Determination of total power requirement for the kneader

The power requirement was calculated using equation 3.7 (Khurmi & Gupta, 2005):

$$P = \frac{2\pi NT}{60} \quad (7)$$

Where P = Power required to drive the shaft (W)

N = Operating speed (rpm)

T = Torque (Nm)

Determination of power required to rotate the shaft without load

There are four number of fingers (maximum number of fingers) always acting on the shaft even without load, hence;

$$F_f = mg = v \times \partial \times g \quad (8)$$

Where F_f = is the weight of the finger

V_f = volume of the finger

∂_s = density of mild steel

g = acceleration due to gravity

Length, breadth and thickness of the fingers were selected based on the existing kneader designs available to the smallholder women processors which are 0.225 m, 0.029 m and 0.005 m respectively.

$$V_f = l \times b \times t \tag{9}$$

Where: V_f = volume in m^3
l = length in m
b = breadth in m, and
t = thickness in m.

Note: F_o is the total weight exerted by the fingers on the shaft (No load).

From (Idris, 2011);

$$T_o = F_o \times r_f \tag{10}$$

Determination of power required to rotate the shaft with load:

From;

$$F_l = w \tag{11}$$

Where F_l = the total load on the shaft

w = maximum load of groundnut paste that can be processed at a time. This is given as 24kg (Ibrahim, 2010; Idris, 2011; Ibrahim, 2015).

Power required to rotate the shaft with load is;

$$P_L = \frac{2\pi NT}{60}$$

Determination of horizontal shaft power requirement

The vertical shaft connected with horizontal shaft through bevel gear, and the relationship between power acting on both vertical shaft and horizontal shaft is given by the relationship below (Davis *et al.*, 2012):

$$P_H = \frac{P_V}{Cos\theta} \tag{12}$$

Where P_H = the power required to power horizontal shaft (watt)
P_V = the power required to power vertical shaft (watt)
θ = the pressure angle of bevel gears

According to Davis *et al.* (2012), θ is 20° for bevel gears.

Determination of power due to belt tension P_b

The power due to belt tension was calculated from (Davis *et al.*, 2012):

$$\text{Required power } (P_b) = P_b = b_p \times b_s \tag{13}$$

Where b_p = belt pull (*N*)
b_s = belt speed (*rpm*)

Determination of shaft diameter

The American Society of Mechanical Engineers (ASME) design code for ductile material (mild steel) was used to design the rotating shaft based on strength. The equation contains the general relation 3.14.

Since the shaft was subjected to bending and torsional stress, the diameter was determined using the expression given by Khurmi and Gupta (2005):

$$D^3 = \frac{16\sqrt{(K_b M_b)^2 + (K_t M_t)^2}}{\pi S_s} \tag{14}$$

Where: D = shaft diameter (m); M_b = resultant bending moment; M_t = twisting/torsional moment, K_t = combined shock and fatigue factor applied to bending moment; K_b = combined shock and fatigue factor applied to torsional moment; S_s = allowable shear stress in shaft. From

ASME design shafting code, K_b and K_t for rotating shaft experiencing minor shock equals 1.5 to 2.0 and 1.0 to 1.5 respectively.

Determination of shaft torsional moment

$$\text{Torsional moment, } M_t = \frac{60P}{2\pi N} \text{ (Khurmi \& Gupta, 2005)} \tag{15}$$

Where M_t = torsional moment (Nm)
N = Speed (rpm)

Determination of belt speed

Belt speed was estimated using the expression given by Khurmi and Gupta (2005) as:

$$V = \frac{\pi \times D_1 \times n_1}{60} \tag{16}$$

Where: V = Belt speed (m/s),
n_1 = operating speed = 450 rev/min, selected based on literature
D_1 = Diameter of driven pulley (m) = 0.257m (from existing pulley)

To determine the value of T_1, T_2 and W, the following expressions were used (Khurmi & Gupta, 2005) as:

$$\frac{T_1}{T_2} = e^{\mu\theta} \tag{17}$$

Where T_1 = Carrying side of belt tension (N)
T_2 = Return side of belt tension (N)
θ = Angle of contact between the pulley and belt (°) = 101.45°
μ = Coefficient of friction between drive pulley and belt = 0.25

$$\frac{T_1}{T_2} = e^{0.25 \times 101.45}$$

$$T_1 = 1.035 T_2 \text{(Khurmi \& Gupta, 2005)} \tag{18}$$

Similarly belt tension can also be calculated using power transmission as given by Khurmi and Gupta (2005)

$$P = (T_1 - T_2) \times V \tag{19}$$

Where P = Conveying power = 3kW; V = Belt speed = 6.06m/s putting the values in the equation above:

$$3 = (T_1 - T_2) \times 6.06$$

$$\frac{3}{6.06} = (T_1 - T_2)$$

$$T_1 = T_2 + 0.5 \tag{20}$$

Weight of the pulley was obtained using the relation given by Khurmi and Gupta (2005):

$$W = mg \tag{21}$$

Where: m (mass (kg) of pulley – existing pulley (cast aluminium)) = 1.6 kg
g = acceleration due to gravity (9.81 m/s)

Resultant bending moment M_b will be obtained using equation given by Khurmi and Gupta (2005) as:

$$M_b = \sqrt{(M_V)^2 + (M_H)^2} \tag{22}$$

Where M_V = Maximum vertical bending moment = 73.64 Nm
M_H = Maximum horizontal bending moment = 73.64 Nm

Determination of shaft diameter

Shaft diameter was determined using the expression given by Khurmi and Gupta (2005) as:

$$d = \sqrt[3]{\frac{16}{\pi\tau}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}} \tag{23}$$

Where, τ = Allowable shear stress = (0.60 τ_{ut}), K_b = 1.5; (Fatigue factor as applied to Bending moment), K_t =1; (Combine shock factor as applied to Torsional Moment), Ultimate tensile strength (τ_{ut}) = 700 N/mm).

Bearing selection

SKF (2012) bearing catalogue was used to select standard bearings base on their load carrying capacity, life expectancy and reliability. The relationships between the basic rating life, the basic dynamic load rating, C and bearing load, P that are as given below was used (Karwa, 2010):

$$C = (L_{10})^{\frac{1}{k}} \times P \tag{24}$$

$$L_{10} = \frac{60\,n}{10^6} \times L_H \tag{25}$$

Where: L_{10} = rating life of bearing for 90% survival at one million revolutions,

L_H = required life of bearing in million revolutions,
k = exponential for life equation of bearing (k = 3 for ball bearing),
n = bearing rotational speed (rpm); n = 450 rpm
L_H = 8000 hrs (Khurmi & Gupta, 2005)

Description of the Groundnut Oil Extraction Machine

The groundnut kneading machine was constructed using readily available and appropriate materials including mild steel sheet, medium carbon grade steel, stainless steel sheet, stainless steel flat bar and angle iron. The main features of an engine-powered groundnut kneading machine include the power unit, the supporting frame, the kneading cylinder, and the transmission unit as shown in Figure 2. It shows the exploded and orthographic views of the motorised groundnut paste kneading machine, the kneading head, the power unit, the transmission unit and the seating. With an oil drainpipe inserted at the bottom to drain the extracted oil into the oil container both during and after the operation, the kneader has an internal diameter at the top of 340 mm and an internal depth of 730 mm. The stirrer shaft, two pulleys and one V-belt make up the transmission unit. The petrol engine provides the V-belt with its drive, which it then transfers to the stirrer shaft via the connecting shaft and pulleys. Three separate detachable fingers on the shaft allow for efficient stirring of the paste inside the container. The kneading head, which takes the role of the conventional pestle, is made up of the shaft, shaft bushing, shaft fingers, and oil seal. The 3.0 kW (4.0 hp) petrol engine and its tiny pulley, from which the V-belt receives its drive, make up the power unit. The petrol engine provides the necessary power for the shaft's rotation and is bolted to the section that is sitting close to the container.

Mode of Operation of Motorized Groundnut Paste Kneading Machine

For the machine to begin operating, a known weight of paste is poured into the container, and it is then set up as illustrated in Figure 2. Once the engine is running, the V-belt and connecting shaft provide rotary power to the kneading shaft.

The centrifugal force of the rotating fingers acts on the oil molecules in the paste to knead it, and warm, clean water is gradually added as the process goes along until it is finished.

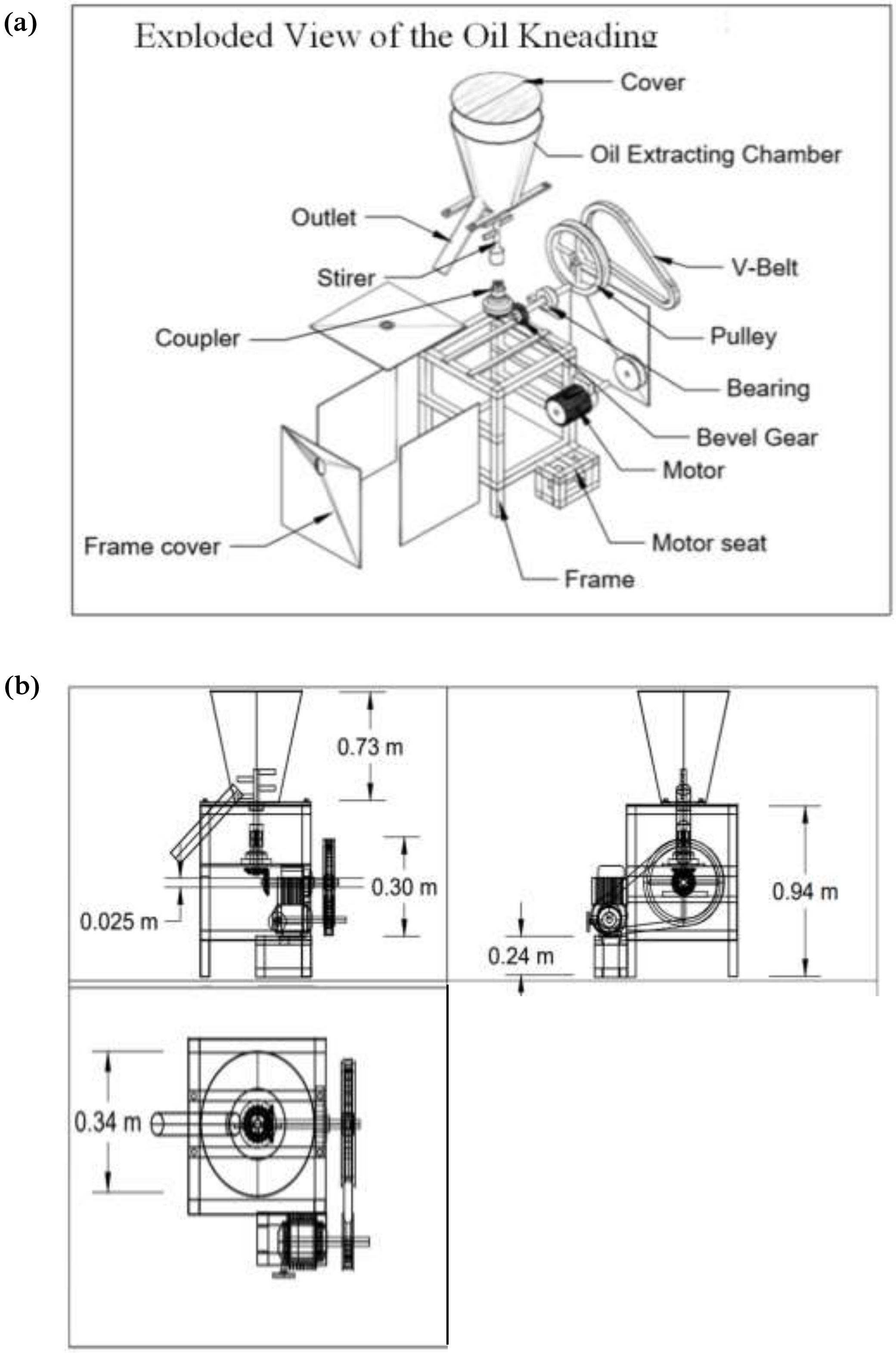

Figure 2. Orthographic view (a); Exploded view of motorized groundnut paste kneading machine

Performance Evaluation of Motorized Groundnut Paste Kneading Machine

The designed kneading machine was fabricated and tested to evaluate its performance. Maibargo variety of groundnut was used to evaluate the machine and it was collected from the open market Dawanau grain market, Kano State. The performance of the groundnut kneading machine was evaluated based on oil extraction efficiency, Output capacity, and oil yield efficiency. The equations used to determine the oil extraction efficiency, output capacity, and oil yield as expressed by Mikailu *et al.* (2018) are given;

$$OEE = \frac{OY}{AEO} \times 100\% \tag{26}$$

Where; OEE = oil extraction efficiency
OY = oil yield (%)
AEO = amount of oil expected (%) (% Oil content x Mass of seeds processed (kg).

$$OC = \frac{M_P}{T_E} \text{ (Adetola \textit{et al.}, 2014)} \tag{27}$$

Where; OC = output capacity (kg/h)
M_P = mass of oil produced (kg)
T_E = effective time taken (h)

$$OY = \frac{W_O}{W_{PK}} \times 100\% \tag{28}$$

Where; OY = oil yield (%)
W_O = weight of oil obtained (kg)
W_{PK} = weight of groundnut paste kneaded (kg)

Experimental Factors

Since the speed of the machine, finger numbers and water temperature of the groundnut paste are the major variables that could influence the overall performance oil kneading machine (Maduako *et al.,* 2004; Olajide *et al.*, 2014; Joelle *et al.*, 2015; Ibrahim, 2015). Hence these variables were considered in this study to investigate the performance of the developed kneading machine.

Optimization and Modelling of the Kneader

Experimental Design

Machine speed, number of fingers, and water temperature were considered as the variables, to determine the optimized conditions for oil yield, oil extraction efficiency, and machine output capacity using Design Expert – User-Defined Design (UDD). A total number of 45 experimental runs were generated according to the UDD experimental design and were replicated three times.

Optimization and Modelling of the Kneader

The parameters were modelled using the user-defined design method of Design-Expert software (Design-Expert 13.0.13.0, Stat-Ease Inc., Minneapolis, USA). For the speed (rpm), fingers and water temperature (°C) as factors (5 × 3 × 3 factorial design), a total of 45 trial formulations were generated as independent variables. Efficiency (%), oil yield (%), and output capacity (kg/hr) were evaluated as dependent variables (responses). The experimental layout of the composition variables (factors) and their corresponding response values (quality parameters) are reported in Appendix II. The mean values of the investigated responses measured for all trial formulations in the 5 × 3 × 3 factorial designs were fitted to get model equations. Best- fitting mathematical models were determined based on the comparison of the adjusted multiple correlation coefficient (adjusted- R^2) and predicted multiple correlation coefficient (predicted- R^2). Optimization of the kneader was carried out based on the criteria of output capacity, efficiency, and oil yield. The fingers, speed, and water temperature were set in the range of the lower and upper limits. The output capacity, efficiency, and oil yield were maximized in relation to their goal and the weighting was done based on the importance of each characteristic of the responses.

Validation of the Performance Responses at Optimum Conditions of the Kneader

The most likely predicted optimum condition of the water temperature (°C), fingers, and speed (rpm) was validated by five (5) verification experiments. Verification entails comparing the mean values obtained from the verification runs to the predicted values of the generated models. After running the values with the kneader, a t-test was used to check the significant level between the model-predicted values and experimental values generated from optimum values.

RESULTS AND DISCUSSION

Optimization and Modelling of the Groundnut Kneading Machine

The percentage of extraction efficiency, oil yield, and output capacity of the machine at varying speeds of 200, 250, 300, 350, and 400 rpm, and the water temperature of 40, 50, and 60°C were evaluated. Also, the finger numbers ranged between (2-4). Table 1 shows the result of the performance evaluation of the developed oil expeller. Based on the result of the optimization result as presented in Table 1, the optimum conditions of speed (400 rpm, water temperature (60°C), and the number of 4 Fingers (F_3) recorded the highest percentage of oil yield (40.60%), oil extraction efficiency (82.82%), as well as superior output capacity of 19.38 kg/hr, respectively. The results obtained in this study is consistent with previous studies. For instance, Oriaku *et al*. (2014) obtained 78.1% efficiency, and Ezeoha *et al*. (2017) reported an optimum oil extraction efficiency of 73%, while Davies (2014) obtained 79.5% extraction efficiency from a continuous screw press for soybean oil extraction while Srikanth *et al.* (2020) achieved optimum machine efficiency of 96.78% for cocoa beans extractor.

Since the optimization of the output capacity process showed the optimum values of 400rpm, 60°C, and F_3 for speed, water temperature, and fingers respectively while the machine output capacity which is the response has an optimum value of 19.29 kg/h and desirability of 0.968. The output capacity obtained in this study is consistent with previous studies (Ezeoha *et al*,. 2017; Perone *et al.*, 2022). The output capacity recorded in the present study is higher than the optimum output capacity of 16 kg/h and 15.57 kg/h reported by Okoye *et al.* (2008) and Ojolo *et al*. (2010) for palm kernel nut vegetable oil expeller and cashew nut shelling machine.

The optimization of the groundnut oil extracting process for oil yield showed the optimum design values of 400rpm, 60% and 4 Fingers (F_3) for speed, water temperature, and fingers respectively while the oil yield which is the response has an optimum value of 40.28% for the output with the desirability of 0.97. The desirability values indicated the nearness of the response value to the adjusted goal or desired design value and the adequacy of models established in describing the observed data. Akinoso and Adeyanju (2012) reported 14.45% as the optimum oil yield from Ofada rice bran; Liu *et al.* (2009) obtained 25.83% as the optimum oil yield for extraction of passion fruit seed oil; Olajide *et al.* (2014) reported 32.36 % as the optimum mechanical extraction of oil from groundnut kernel.

Table 1. Performance evaluation of the groundnut kneading machine

Runs	Speed (rpm)	W. Temp (°C)	Fingers	Oil Yield (%)	Efficiency (%)	Output Capacity (kg/hr)
1	300	40	4	34.54	75.15	16.90
2	250	60	3	38.77	77.71	12.70
3	300	50	3	36.52	75.15	14.13
4	400	50	2	36.05	72.60	11.68
5	400	50	4	37.25	79.24	19.98
6	350	50	2	35.78	71.06	11.88

7	350	50	4	37.15	80.78	19.98
8	300	60	3	38.85	77.71	12.92
9	300	40	2	32.55	69.02	11.40
10	400	40	4	35.00	79.24	19.54
11	400	60	3	39.10	79.24	14.13
12	300	50	4	37.54	78.73	19.08
13	250	40	4	34.28	74.64	16.61
14	300	40	3	34.01	70.55	13.22
15	350	40	3	34.06	71.57	14.12
16	400	40	2	33.85	69.53	11.91
17	350	50	3	36.74	75.66	14.36
18	200	60	4	39.24	79.75	16.68
19	250	60	2	37.60	70.04	9.16
20	350	60	4	40.03	81.80	19.09
21	350	60	2	38.04	73.11	11.68
22	200	40	4	34.27	73.62	14.97
23	200	50	2	35.52	66.46	9.64
24	250	50	3	36.45	74.64	14.13
25	350	40	4	34.76	76.69	19.23
26	200	40	2	30.55	62.37	9.09
27	400	60	2	38.50	76.18	11.73
28	350	60	3	38.79	79.24	12.97
29	250	50	4	37.10	76.69	16.25
30	200	40	3	33.81	69.53	12.80
31	200	60	3	38.77	76.69	12.64
32	400	40	3	34.03	72.60	14.30
33	400	60	4	40.60	82.82	19.38
34	250	50	2	35.52	68.51	9.83
35	200	60	2	37.52	69.53	8.93
36	250	60	4	39.55	80.27	16.33
37	250	40	3	34.01	70.04	12.97
38	250	40	2	32.54	66.46	9.26
39	200	50	3	36.35	74.13	13.19
40	400	50	3	36.77	75.66	14.93
41	300	60	2	38.01	72.60	10.87
42	300	50	2	35.55	69.02	12.98
43	200	50	4	37.08	75.66	16.92
44	300	60	4	39.90	80.78	18.67
45	350	40	2	33.52	69.53	11.88

Modelling of Oil Extraction Machine Efficiency

The 3D-surface diagram in Figure 3-5 shows the relationship between the machine efficiency and water temperature with speed at different fingers level (stirrers). The machine efficiency increased with an increase in speed and water temperature as shown in Figures 3-5. The machine efficiency was significantly affected by speed, water temperature and fingers.

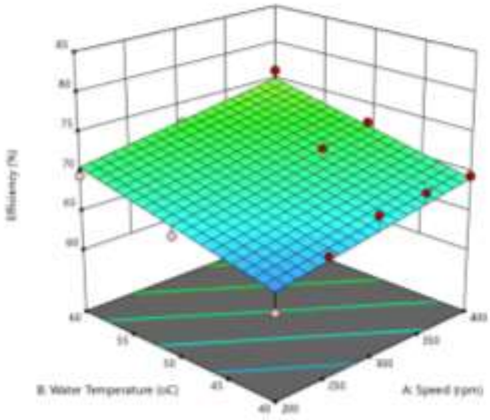

Figure 3. Machine efficiency against water temperature and speed for 2 fingers

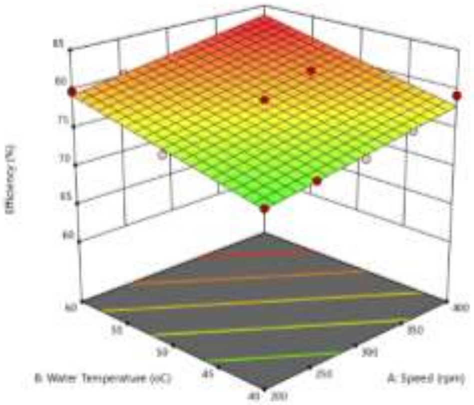

Figure 4. Machine efficiency against water temperature and speed for 4 fingers

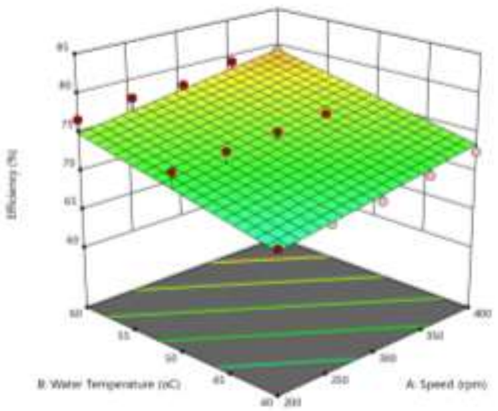

Figure 5. Machine efficiency against water temperature and speed for 4 fingers

ANOVA shows the significance of the response surface models as linear, 2FI, quadratic, and cubic terms. In addition, the results indicate the sequential p-value, adjusted R^2, and predicted R^2 of the results for each response (Table 2). Responses have shown linear model equations at a 95% level of significance. Table 2 shows the results for the Analysis of variance which established the statistical significance of the regression model relating the machine efficiency to the speed, water temperature and fingers at 95% confidence level ($p < 0.05$). From the Table, the model F-value is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

Table 2. Fit summary for efficiency

Source	Sequential p-value	Adjusted R²	Predicted R²	
Linear	**< 0.0001**	**0.9472**	**0.9400**	**Suggested**
2FI	0.1894	0.9496	0.9370	
Quadratic	0.3112	0.9506	0.9316	
Cubic	0.0021	0.9717	0.9326	**Aliased**

Table 3. ANOVA for the linear model of the efficiency of the groundnut oil kneader

Source	**Sum of squares**	**Df**	**Mean square**	**F-value**	**Sig. level**
Model	923.14	3	307.71	263.93	< 0.000541
A-Speed	109.30	1	109.30	93.74	< 0.000766
B-Water Temperature	251.89	1	251.89	216.05	< 0.001344
C-Fingers	561.95	1	561.95	481.99	< 0.002321
Residual	47.80	41	1.17		
Cor Total	970.94	44			

The model developed was significant as depicted by F-value; this implies that at least one of the independent variables contributed to the response observed in machine efficiency. The F-values and the corresponding p-values obtained for speed, water temperature, and fingers were 93.74, 216.05, and 481.99 respectively. These values indicated that there were 0.01, 0.01, and 0.01% chances that the F-values for speed, water temperature, and fingers could occur due to noise. The machine efficiency was significantly influenced by the independent variables (i.e. speed, water temperature, and fingers) as indicated in Table 3. This showed that the effect of variation of the independent parameters on the machine efficiency was significant.

Furthermore, the coefficient of determination (R^2) obtained was found to be 0.95. The predicted R^2 and adjusted R^2 values were found to be 0.94 and 0.95 respectively. The predicted R^2 is in reasonable agreement with the adjusted R^2 values i.e. the difference between them is less than 0.2. The adequate precision (signal to noise ratio) of 58.583 was obtained, which is greater than 4; this shows that the model has a signal which is strong enough for optimization and can be used to navigate the design space. The regression model was reduced with respect to the significance level of the independent parameters for its improvement as expressed in equations 29.

$$\text{Efficiency}=40.18233+0.022040\text{speed}+0.289767\text{w. temp}+4.32800\text{fingers} \tag{29}$$

$$(R^2 = 0.95,\ \text{Pred.}R^2 = 0.94,\ \text{Adj.}R^2 = 0.95,\ \text{Adeq. Precision} = 58.58)$$

Modelling of Machine Output Capacity

The surface diagram in Figures 6-8 shows the relationship between the machine output capacity and water temperature with speed. The output capacity for all the three different fingers used (i.e. 2, 3 and 4 fingers) was significantly affected by speed and fingers while the effect of water temperature on the oil yield was minimal.

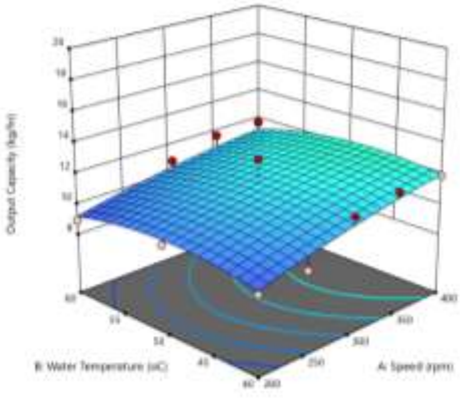

Figure 6. Machine output capacity against water temperature and speed for 2 fingers

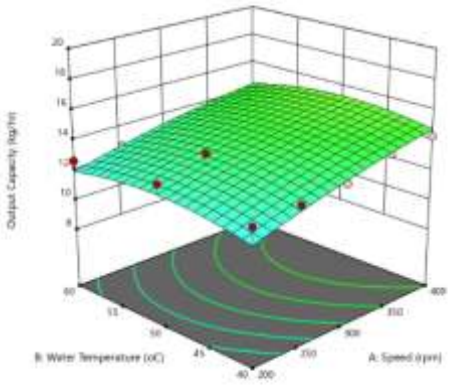

Figure 7. Machine output capacity against water temperature and speed for 3 fingers

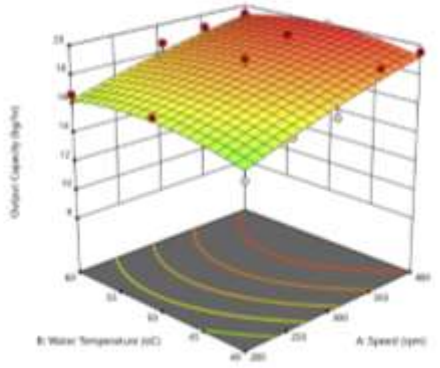

Figure 8. Machine output capacity against water temperature and speed for 4 fingers

ANOVA shows the significance of the response surface models as linear, 2FI, quadratic, and cubic terms. In addition, the results indicate the sequential p-value, adjusted R^2, and predicted R^2 of the results for each response (Table 4). Responses have shown quadratic model equations at a 95% level of significance. The results for the Analysis of variance of regression model relating the output capacity to the independent variables are presented in Table 5. The information obtained for the ANOVA test showed the statistical significance of the regression model in equations 4.2 at 95% confidence level ($p < 0.05$).

Table 4. Fit summary for the output capacity

Source	Sequential p-value	Adjusted R²	Predicted R²	
Linear	< 0.0001	0.9254	0.9182	
2FI	0.4650	0.9247	0.9165	
Quadratic	**0.0003**	**0.9520**	**0.9401**	**Suggested**
Cubic	0.0132	0.9675	0.9535	Aliased

Table 5. ANOVA for quadratic model of the output capacity of the groundnut oil kneader

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	445.85	9	49.54	97.93	< 0.0001
A-Speed	44.70	1	44.70	88.37	< 0.0001
B-Water Temperature	0.0038	1	0.0038	0.0076	0.9310
C-Fingers	386.62	1	386.62	764.27	< 0.0001
AB	0.3634	1	0.3634	0.7185	0.4024
AC	0.8800	1	0.8800	1.74	0.1957
BC	0.8282	1	0.8282	1.64	0.2091
A^2	0.4949	1	0.4949	0.9783	0.3294
B^2	5.29	1	5.29	10.46	0.0027
C^2	6.66	1	6.66	13.17	0.0009
Residual	17.71	35	0.5059		
Cor Total	463.55	44			

The model F-value of 97.93 indicates that the regression model gotten is significant. There is only a 0.01% chance that an F-value this large could occur due to noise; this implies that at least one of the independent variables contributed to responses observed in output capacity. The F-values obtained for speed, water temperature and fingers were 88.37, 0.0076 and 764.27 respectively. These values suggested that there are 0.01, 93.1 and 0.01% chances that the F-values for speed, water temperature and fingers could occur due to noise. This implied that output capacity was significantly influenced by speed, and fingers. This showed that the effect of variation of the independent parameters on the capacity was not by chances.

Moreover, the coefficient of determination (R^2) obtained was found to be 0.96 as shown in the regression model in below. This shows that the variation in the independent variables accounts for 97% of the total variability in the capacity. The predicted R^2 and adjusted R^2 values were 0.94 and 0.95 which is close; i.e. the difference is less than 0.2 thus indicating that the predicted R^2 is in reasonable agreement with the adjusted R^2. The adequate precision (signal to noise ratio) of 32.168 was obtained, which is greater than 4; this shows that the model has a signal which is strong enough for optimization. The regression model was reduced with respect to the significance level ($p<0.05$) of the decision factors for model improvement as shown in equation 30.

$$O.C = -10.95866 + 0.029653\, s + 0.711850\, w.t - 3.05229\, f - 0.000156\, s * w.t + 0.002422\, s * f + 0.020350\, w.t * f - 0.000025\, s^2 - 0.007273\, w.t^2 + 0.816339\, f^2 \quad (30)$$

Where; O.C = output capacity (kg/h),
s = speed (rpm),
w.t = water temperature (^oC),
f = fingers
(R^2 = 0.96, Adj. R^2 = 0.95, Pred. R^2 = 0.94, Adeq. Precision = 32.2)

Modelling of Oil Yield

The surface diagram in Figures 9-11 shows the relationship between the oil yield and water temperature with speed. The oil yield for all three different fingers used (2, 3 and 4 Fingers) was significantly affected by speed and water temperature while their interaction effects on oil yield were minimal. The oil yield increase with an increase in speed and water temperature as shown in Figures 9-11.

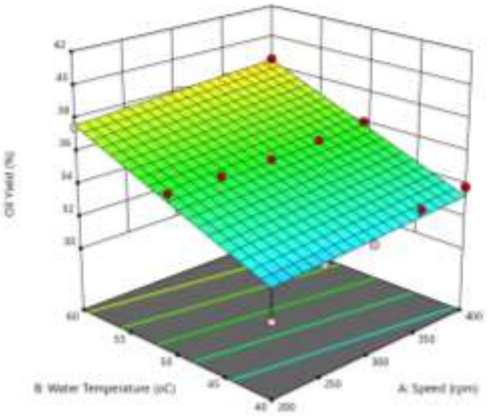

Figure 9. Oil yield against water temperature and speed for 2 fingers

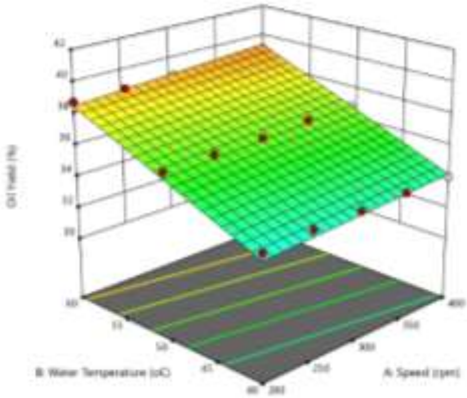

Figure 10. Oil yield against water temperature and speed for 3 fingers

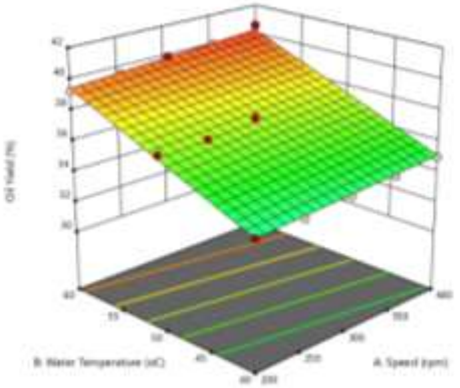

Figure 11. Oil yield against water temperature and speed for 4 fingers

ANOVA shows the importance of the response surface models as linear, 2FI, quadratic, and cubic terms. Further, the effects suggest the sequential p-value, adjusted R^2, and predicted R^2 of the results for each response and the generated best-predicted model that define the correlation between the experimental variables and the responses for oil yield is a linear model as indicated in Table 6. At a 95% level of confidence (p 0.05), the results of the analysis of variance for the regression model linking the oil yield to the speed, water temperature, and fingers are shown in the table. According to the ANOVA results, there is a statistically significant correlation between oil yield and independent variables including speed, water temperature, fingers, and their interactions. The model is believed to be significant given its F-value of 484.80. An F-value this large might happen owing to noise only 0.01% of the time. F-value demonstrated that the model developed was significant, indicating that at least one of the independent variables contributed to the response discovered during the oil extraction process. The F-values obtained for speed, water temperature, and fingers were 25.84, 1271.95, and 156.60 respectively. These values indicated that there were 0.01, 0.01, and 0.01% chances that the F-values for speed, water temperature, and fingers could occur due to noise. The oil yield was significantly influenced by speed, water temperature and fingers as shown in Table 7. This showed that the effect of variation of the independent parameters on oil yield was not by chance.

Moreover, the determination coefficient (R^2) was discovered to be 0.97. This indicates that 98% of the overall variability in the oil yield can be attributed to variations among the independent variables. The calculated values of the predicted R^2 and adjusted R^2 were 0.96 and 0.97, respectively. This is close and shows that the predicted and adjusted R^2 have a good degree of agreement. Equation 31 illustrates how the regression model was reduced based on the independent parameters' significance levels.

Table 6. ANOVA for regression model for the oil yield

Source	Sequential p-value	Adjusted R²	Predicted R²	
Linear	**< 0.0001**	**0.9706**	**0.9649**	**Suggested**
2FI	0.1705	0.9721	0.9569	
Quadratic	0.2553	0.9730	0.9538	
Cubic	0.0001	0.9879	0.9704	Aliased

Table 7. ANOVA for the linear model of the oil yield of the groundnut oil kneader

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	228.87	3	76.29	484.80	< 0.0001
A-Speed	4.07	1	4.07	25.84	< 0.0001
B-Water Temperature	200.16	1	200.16	1271.95	< 0.0001
C-Fingers	24.64	1	24.64	156.60	< 0.0001
Residual	6.45	41	0.1574		
Cor Total	235.32	44			

The adequate precision (signal to noise ratio) of 66.195 was gotten, which is greater than 4; this shows that the model has a signal which is strong enough for optimization. This model can be used to pilot the design space.

$$O.Y = 19.45556 + 0.004251\, s + 0.258300\, w.t + 0.906333\, f \qquad (31)$$

Where: O.Y = oil yield, s = speed, w. t = water temperature, f = finger.

Validation of the Performance Responses at Optimum Conditions of the Kneader

The optimum predicted results are as presented in Table 8. Five (5) verification runs validated the optimum condition of water temperature at 60 ^{o}C, finger at 4 and speed at 400 rpm. There were no significant differences between the statistical values and experimental runs as shown in Table 8. Hence, verification runs confirmed the predicted values at optimum conditions with an acceptable significant level

Table 8. Predicted results and verification run results

Responses Variables	Statistical Values	Experimental Values	Sig. (0.05)
Output capacity (kg/hr)	40.28	40.496±0.1527	0.386
Efficiency (%)	83.70	83.506±0.1372	0.191
Oil yield (%)	19.29	19.056±0.1655	0.063

CONCLUSION

An improved kneader was successfully designed, fabricated and evaluated. From the performance evaluation of the kneader, it was observed that all the evaluated factors are significant at $p \leq 0.05$. The result of optimization of the machine performance, output capacity revealed that the optimum conditions of 60°C, 400 rpm, and F_3 for water temperature, speed, and fingers respectively recorded an optimum machine efficiency of 83.7%, output capacity of 19.29 kg/h with desirability of 0.968, while the oil yield has an optimum value of 40.28% for the output with the desirability of 0.97. The results of 3D modelling revealed that fingers, water temperature and speed significantly affect the oil yield, efficiency and output capacity of the kneader. The generated modelling equations were observed to be valid since there was no significant difference between the statistical values and the experimental values.

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