Modification and Optimization of Groundnut (*Arachis hypogaea*) Roasting Machine

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Authors' contributions

This work was carried out in collaboration among all authors. Authors OJO, OAA and AM designed the study, wrote the protocol, performed the statistical analysis, managed the analyses of the study and managed the literature searches. Authors OAA, AM and AMA wrote the first draft of the manuscript. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Roasting of groundnut is essential to ensure quality improvement, easy handling, safe storage, further processing, and value addition of the product. Therefore, the aim of the study was modified and optimized a groundnut roasting machine. Standard design parameters were used for the design modification. The design of the experiment had 27 runs. Machine speed (6.60, 12.80 and 19 rpm), roasting temperature (120, 160 and 200℃), and feed rate (120, 180 and 240 kg/h) were used as independent parameters, and the response variables include the moisture content of the groundnut, roasting efficiency, mechanical damage, throughput and quality efficiency of the machine. Response Surface Methodology (RSM) of the Design Expert Version 11 was adopted for the optimization process by applying the central composite design method for the Analysis of Variance (ANOVA) and optimized responses within the limit of the independent factors tested. Roasting temperature (200℃), machine speed (19 rpm) and feed rate (240 kg/h) were found as the optimum operational conditions which will optimally result in the optimal machine performance of 8.76% moisture content ($r2 = 0.94$), 76.99% roasting efficiency ($r2 = 0.90$), 2.46% mechanical damage ($r2 = 0.86$), 62.32 kg/h machine throughput ($r2 = 0.98$), 74.3% quality performance efficiency ($r2 = 0.86$) with the high desirability of 88%. An increase in machine speed increased the

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moisture content of the groundnut, roasting efficiency, mechanical damage, throughput, and quality efficiency of the machine. The study showed the optimal machine parameters for a groundnut roasting machine.

1. INTRODUCTION

The groundnut, *Arachis hypogaea*, is an annual legume grown in the tropics and temperate regions around the world [1]. Groundnuts were regarded as feed for livestock and food for the poor and were considered to time and labor-consuming to grow and harvest to be economically feasible. Groundnuts are also used in a wide variety of other areas, such as cosmetics, nitroglycerin, plastics, dyes, and paints [2]. Groundnuts are rich in nutrients, providing over 30 essential nutrients and phytonutrients. Groundnuts are usually harvested at high moisture content and then artificially dried to a safe storage moisture level of 7 - 8% w.b. Generally, groundnut contains 35 – 55% moisture, without reducing the moisture content to about 10%, the product is quite susceptible to contamination by molds [3,4]. Many of the agricultural products are dried at the farm level to prevent decay and improve storage properties [5]. Roasting of groundnut is another way of drying groundnuts, but it is done at a higher temperature than simply drying them [6]. Many Agricultural, horticultural and industrial products including chemicals and pharmaceuticals are roasted for various purposes like safe storage, easy handling, value addition, further processing, and quality improvement [7].

Chavda and Naveen [7] defined roasting as the process of generating characteristics aroma, flavor, and colour required by consumers for acceptance of such roasted food. The perfect roast depends on visual examination, colour, appearance, hardness, and flavour of seeds. Visual examination is one of the techniques to judge the roasting stage and it is widely adopted even in the industry [7,8]. Roasting of groundnut in Nigeria, and generally in Africa is mostly traditionally, done using different pots such as clay pots, on an open fire until they are brown [9]. Groundnut seeds are roasted traditionally by constant stirring in an open mild steel pan over an open wood fire [8]. Woods et al. [3] reported that roasting of groundnut and extraction of groundnut oil in West Africa has been a serious issue especially where the roasting and the extraction of the oil are achieved by traditional methods. This is also done mechanically by placing groundnut in mechanical roaster at a high temperature [10]. For the preparation of groundnut, the end products obtain from roasting operation is most important for nutritive and market point of view. The existing local methods and roasting machines are ineffective, cumbersome, time-consuming, and labour-intensive [3]. Apart from overcoming the above problems, the successful modification and evaluation of the existing machine will not only promote its usage as a preheating machine to a roasting machine but will provide the best and appropriate operating condition that will be recommended for usage in groundnut roasting.

Olaniyan et al. [10] developed a combined groundnut roaster and oil expeller with a roasting efficiency of 66.9% and mechanical damage of 11.88%, they stressed the need for improvement on their result. Other similar designs have been developed [3,11]. Recently, Akintade and Bratte [12] also carried out the performance evaluation of a groundnut Blanching machine with a roasting capacity of 0.2 kg/min, 9.90% mechanical damage, and roasting efficiency of 89.46%, and there is need for improvement. More so, [13] worked on a locally fabricated multipurpose pre-heat dryer to develop and evaluate an integrated pneumatic drying system that will reduce the drying time for High-Quality Cassava Flour (HQCF) using band heaters, belt and pulley as a heat source and power transmission respectively while an improvement on the heat lost was recommended. The heat loss is an indication of the necessity for modification to improve the utilization of the loss heat for roasting. The successful modification (source of energy and drive mechanism) and evaluation of this machine will not only improve the utilization of the loss heat for drying, it will promote the usage of the machine as a pre-heat dryer to a high capacity multipurpose dryer and roaster. It will completely eradicate the norms associated with traditional roasters which will also increase production rate, improve roasting efficiency and provide the best and appropriate operating condition(s) that would be recommended for usage in groundnut roasting. The objective of this research was to modify and optimize a groundnut roasting machine.

2. MATERIALS AND METHODS

The major material used for the modification and performance evaluation of the groundnut roasting machine was fresh groundnut, which was obtained from the local market in Akure, Ondo State, Nigeria. The instruments used to measure the processing parameters were thermocouple wire, thermometer (digital k-type), tachometer, weighing balance, stopwatch, and grain moisture meter.

2.1 Description of the Existing Machine

The existing machine (Fig. 1) consists of two cylindrical troughs (drying troughs) made of stainless steel. The troughs house the screw conveyors. The machine was supported by metal frames that carry the drying chambers and provide a seat for the electric motors. Heating element (band heaters) was used as the heat source and was positioned right below the drying chambers for heating the troughs. Belt conveyor mechanism was used for power transmission from the electric motors to the rotating shafts of the screw conveyors.

2.2 Limitations of Existing Machine

2.2.1 Screw augers and conveyor troughs

There was friction between the screw augers and conveyor troughs as a result of heavy load on the shaft, poor alignment, inadequate and inaccurate number, and size of angle iron bars used in holding the entire unit.

2.2.2 Belt and Pulley

Stiffness of pulley, tensed, and slippery of belt was due to load, poor alignment of machine parts, and improper choice of power transmitting devices. This can be replaced with a chain and sprocket mechanism.

2.2.3 Band heaters

This Consists of 5 pieces of electric band heaters with a rated capacity of 1.5 kW. Installed band heaters promote the burning of the flour as a result of inadequate choice of heat source.

2.2.4 Crevices, cracks, bolts, and nuts

Crevices and cracks between joined and welded parts; promotes heat loss, bacterial growth, and wastage which can be controlled by proper welding and finishing without leaving any crevice and cracks. Arc welding can be introduced to hold material together. The use of bolts tension provides more confidence at the bolted joint. Bolts and nuts can be properly used to couple components together.

2.3 Design Calculation

2.3.1 Design of troughs hopper

Fig. 2 provides the schematic diagram of the trough hopper. Equation 1 was used to design the hopper to enable the easy flow of groundnut into the machine according to Khurmi and Gupta [14].

$$V_h = \frac{1}{3}\left(l_{hd}W_{hd}\left(h_{hd} + h_p\right) - l_{ht}W_{ht}h_p\right) \qquad (1)$$

Where,

V_h is the volume of the hopper, l_{hd} is the length of the hopper head, W_{hd} is the width of the hopper head, h_{hd} is the height of the hopper head, h_p is the height of the hopper, l_{ht} is the length of the hopper tail, W_{ht} is the width of the hopper tail and h_p is the height of the resulting pyramid.

$V_h = 0.026m^3$ The maximum capacity of the hopper is 0.026 m^3.

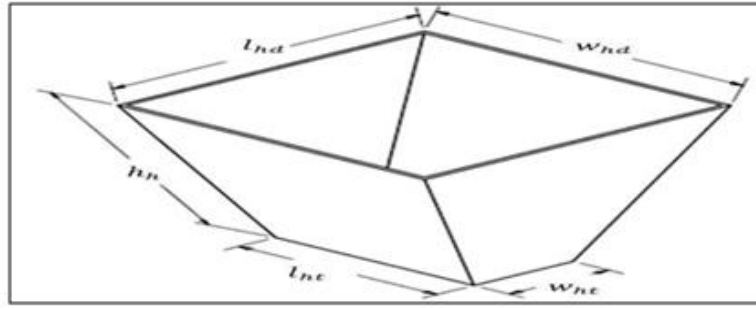**Fig. 1. Isometric view of the existing machine**
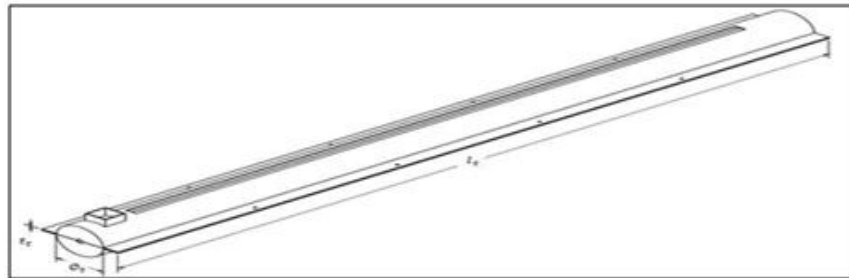
Fig. 2. The trough hoppe

Fig. 3. The conveyor trough

2.3.2 Design of conveyor trough

Fig. 3 presents the diagram for the conveyor trough. Trough capacity and material volume for the trough were calculated using equations 2 and 3 respectively. Conveyor trough was designed as recommended by Khurmi and Gupta [14]. The design of the inclined trough enhanced easy designed of other parameters (material volume and capacity of the trough). Two troughs of the same dimension and capacity were used.

$$V_{ot} = \frac{\pi}{4}\emptyset_t^2 l_t \quad (2)$$

Where,

V_{ot} the capacity of the trough is, $\emptyset_t$ is the internal diameter of the trough and l_t is the length of the trough.

V_{ot} = 0.28 m³; and $W_t = \rho_t V_t g$

$$V_t = \frac{\pi}{4}l_t((\emptyset_t + 2t_t)^2 - \emptyset_t^2) \quad (3)$$

V_t = 0.0038 m³; and $W_t = 291.28$ N

Where,

W_t the weight of the trough (N), ρ_t the density of the trough (k gm⁻³), V_t the material volume of the trough (m³) and g the acceleration due to gravity (9.81 ms⁻²).

2.3.3 Design of the conveyor auger and capacity of the trough

The auger was designed by determining using equations 4 and 5 as recommended by Khurmi and Gupta [14].

$$P_a = \frac{4v_a \emptyset_{xa} X_a}{\frac{\pi}{4}\omega_a(\emptyset_{xa}^2 - \emptyset_{ia}^2)} \quad (4)$$

The external diameter of the auger is a function of the trough diameter. $\emptyset_{xa}$ = f($\emptyset_t$)

$$\emptyset_{xa} = \emptyset_t - 2c \quad (5)$$

The capacity of the trough was determined using equation 6 according to Khurmi and Gupta [14].

$$Q_m = \frac{\pi(\emptyset_{xa}^2 - \emptyset_{ia}^2)}{4}P_a \omega_a si60 \quad (6)$$

Q_m (capacity of the trough) = 2075.83 kg/hr.

Where,

$\emptyset_{ia}$ is the internal diameter of the auger (m), $\emptyset_{xa}$ is the external diameter of the auger (m), V_a is the downward flow velocity of material flow into the

auger (m/s), X_a is the distance along the length of the auger (m) ω_a = angular velocity of the auger (rpm) and P_a = pitch of the auger (m), c is the clearance between the trough and the conveying auger, the pitch of the conveying auger P_a is 310 mm, Q_m is the capacity of the trough (kg/hr), s is the specific mass of the materials (N/m^3) and i is the degree of trough filling (%).

2.3.4 Selection of conveying auger sprockets

The speed ratio of the conveyor auger sprockets was determined using equation 7 as recommended by Khurmi and Gupta [14].

$$N_1 t_1 = N_2 t_2 \qquad (7)$$

Where,

N_1 is the speed of the electric motor (rpm), t_1 is the number of teeth driver (mm), N_2 is the speed of the auger (rpm) and t_2 is the number of teeth driving the auger shaft (mm). $t_2 = \omega_a$, $N_1 = 75$ rpm. W_2 and $W_1 = 5.88$ N and 1.764 N.

2.3.5 Power rating of the dryer

Equation 8 was used to determine the total power needed to drive the machine as recommended by Khurmi and Gupta [14].

$$P_T = P_m + P_h \qquad (8)$$

Where,

P_T is total power required to drive the machine (kW), P_m is the power capacity of the first auger (kW) and P_h is the power capacity to drive the second auger (kW).

2.3.6 The power capacity of the auger

The power capacity of the auger according to Adegbite et al. [13] was determined using equation 9

$$P_m = \frac{Q_m l_a\, k}{3600\, X\, 102} \qquad (9)$$

Where,

k is the frictional coefficient of maize grain

P_m = 3.58 kw
Since the augers are two, for higher efficiency, P_{Tm} = 3.58 x 2 = 7.17 kW.

Taking into consideration the factor of safety of 1.1. Therefore, the total power required to drive augers will be 7.17 x 1.2 = 7.89 kW = 10.34 hp.

Hence, a gear electric motor of 10 hp was used to power the augers.

2.3.7 Design of the conveyor auger shaft

The conveyor auger shaft was determined using equation 10 as recommended by Khurmi and Gupta [14].

$$d_s^3 = \frac{16}{\pi S_s} \sqrt{(K_b M_{b1})^2 + (K_t M_{t1})^2} \qquad (10)$$

d_s = 39 mm. Taking into consideration the factor of safety of 1.1. Therefore, d_s = 42.9 mm. Hence, 45 mm was used as the shaft diameter.

Where S_s is the shaft constant, K_b is the combined shock and fatigue factor applied to bending moment, K_t is the combined shock and fatigue factor applied to torsional moment, M_{b1} is the resultant bending moment of the auger shaft (Nm) and M_{t1} is the resultant torsional moment of the auger shaft (Nm).

2.3.8 Boiler (steam drum) power rating

Equation 11 was used to determine the boiler (steam drum) power rating as recommended by [15].

$$W = (h_g - h_f)m \qquad (11)$$

Where W is the boiler capacity (kW), h_g is the enthalpy steam (kg), h_f is the enthalpy condensate (kg) and m is the steam evaporated (kg/s).

2.3.9 Dimension of the boiler (steam drum)

Length (height, h) = 1778 mm, Diameter (D) = 500mm and Thickness = 7.0 mm.

2.3.10 Boiler efficiency

At any point boiler design is overall boiler efficiency. Boiler efficiency varies with different types of fuels, it is important to determine the efficiency to know what is expected from the boiler. The boiler efficiency was calculated using equation 12 as recommended by Rajput [15].

$$\eta = \frac{m_s(h_s - h_{fw})}{LCV} \, X\, 100\% \qquad (12)$$

Where,

η is the efficiency of the boiler (71.8%), hs is the enthalpy of saturated steam at operating pressure (kJ/kg), hfw is the enthalpy of feed water (kJ/kg) and ms is the mass of steam formed kilogram per hour (kg/hr).

2.4 Modification Process

The machine was tested at no load; corrections and modifications were then carried out. The finished groundnut roasting machine is shown in Fig. 4.
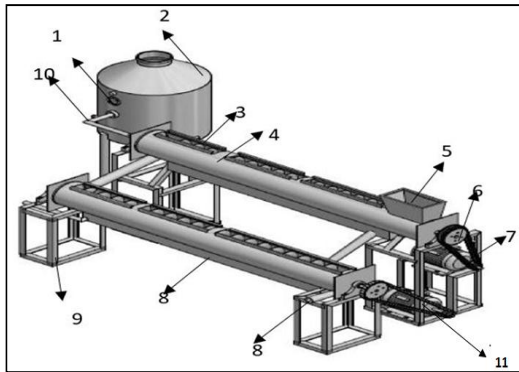
Fig. 4. Isometric view of the modified machine
Where 1 is the pressure, 2 is the steam boiler, 3 is the conveyor, 4 is the trough, 5 is the hopper, 6 is the sprocket, 7 is the chain, 8 is the outlet, 9 is the heat exchanger, 10 is the steam pipe, and 11 is the frame

2.5 Experimental Design and Data Analysis

The design of the experiment had 27 runs. Machine speed (6.60, 12.80 and 19 rpm), roasting temperature (120, 160 and 200°C), and feed rate (120, 180 and 240 kg/h) were used as independent parameters, and the response variables include the moisture content of the groundnut, roasting efficiency, mechanical damage, throughput and quality efficiency of the machine. Response Surface Methodology (RSM) of the Design Expert Version 11 was adopted for the optimization process by applying the central composite design method for the Analysis of Variance (ANOVA) and optimized responses within the limit of the independent factors tested. Equation 1 presents the general formulae for a multiple linear and a quadratic regression model respectively.

$$Y = a + a_1 Sp + a_2 T + a_3 Fr + a_{11} Sp^2 + a_{12} SpT + a_{13} SpFr + a_{21} T^2 + \cdots a_p X_{p1} \qquad (1)$$

Where,

a, a_1, a_2, a_3, a_{11}, a_{12}, a_{13}, a_{21}, a_p are the coefficients) for testing the effect of the independent variables (machine speed [Sp], roasting temperature [T] and feed rate [Fr] on the responses/dependents variables, Y (moisture content, roasting efficiency, mechanical damage, machine throughput, and quality performance efficiency), a is a constant (shows the value of Y when the of X=0), a, a_1, a_2, a_3, a_{11}, a_{12}, a_{13}, a_{21}, a_p are the model coefficients (shows how much Y changes for each unit change in X).

3. RESULTS AND DISCUSSION

3.1 Groundnut Moisture Content (%)

Fig. 5a and 5b represent the effect of the roasting temperature, machine speed and feed rate on the moisture content of the groundnut. According to Fig. 5a and 5b, it was observed that the moisture content of the groundnut increases with an increase in the machine speed from 6.60-19.00 rpm.

The moisture content of the groundnut was in the range of 8.21– 11.93% while the highest moisture content value was observed at a feed rate of 180 kg/h, the roasting temperature of 120°C and machine speed of 19 rpm meanwhile the lowest moisture content was observed at a feed rate of 120 kg/h, the roasting temperature of 200°C and machine speed of 6.60 rpm. The increase in the roasting temperature from 120 – 200°C led to a decrease in the moisture content of the groundnut while the moisture content of the groundnut increased as the feed rate increases from 120– 240 kg/h. This shows that reduction in machine speed increase the retention time and moisture content of the groundnut in the drying chamber, increase in the retention time of groundnut in a heating section of groundnut oil expeller was reported by Odewole et al. [16] during the study of the effect of process condition on the physicochemical properties of the groundnut oil extracted with a vertical screw jack.

Equation 13 shows the mathematical model for effective prediction of the groundnut moisture content as a function of the operational parameter: roasting temperature, machine speed, and feed rate. The model shows that the moisture content exhibits a factorial relationship with the roasting temperature, machine speed and feed rate with a high value of the coefficient

of determination (r^2 = 0.94) and this depicts that the roasting temperature, machine speed, and feed rate can significantly explain about 94.09% variation in the moisture content of the groundnut. The machine speed and feed rate with small coefficients had a little impact on the moisture content of the groundnut while the roasting temperature with a negative coefficient means the magnitude was the exact opposite of the moisture content of the groundnut.

$$MC = 9.26 + 0.262Sp - 0.011T + 0.012Fr - 0.001SpT \qquad (13)$$

Where,

MC is the moisture content Sp is the machine speed (rpm), T is the roasting temperature (℃) and Fr is the feed rate (kg/h).

3.2 Roasting Efficiency (%) of Groundnut Roasting Machine

The roasting efficiency of the machine was in the range of 55.15 – 76.50% where the highest roasting efficiency value for the machine was observed at a feed rate of 240 kg/h, the roasting temperature of 120°℃ and machine speed of 19 rpm whereas the lowest value of the roasting efficiency was observed at a feed rate of 120 kg/h, the roasting temperature of 120°℃ and machine speed of 6.6 rpm. The maximum roasting efficiency obtained in this study was in a close range with the value reported by Olaniyan et al. [10] and Akintade et al. [17].

Fig. 6a and 6b depict the effect of the roasting temperature, machine speed and feed rate on the roasting efficiency of the machine. It was observed that the roasting efficiency of the roasting machine increased with the increase in machine speed from 6.60- 19.00 rpm. The roasting efficiency of the roasting machine also increased with an increase in roasting temperature from 120- 200 ℃ respectively while an increase in the feed rate from 120– 240kg/h resulted in a significant decreased in roasting efficiency of the groundnut. A similar result was reported by [8,18,11].

Equation 14 shows the mathematical model for the machine roasting efficiency as a function of the operational parameters: roasting temperature, machine speed, and feed rate. The increasing influence of temperature on the roasting efficiency of the machine shows that more roasted will be obtained when operating the machine at a higher temperature and this will favour the oil extraction process as, during groundnut oil production, this finding is in agreement with the findings of Kabri et al. [19].

The model shows that the roasting efficiency exhibit a quadratic relationship with the roasting temperature, machine speed and feed rate with a high coefficient of determination value of 0.8994 and this depict that the variation in the roasting temperature, machine speed, and feed rate can significantly explain about 89.94% variation in the roasting efficiency of the machine. The machine speed and the temperature with small coefficients had little impact on the roasting efficiency of the machine while the feed rate with a negative coefficient means the magnitude was the exact opposite of the roasting efficiency.

$$RE = 54.57 + 1.056Sp + 0.26T - 0.40Fr \quad (14)$$

Where,

RE is the roasting efficiency (kg/h), Sp is the machine speed (rpm), T is the roasting temperature (℃) and Fr is the feed rate (kg/h).
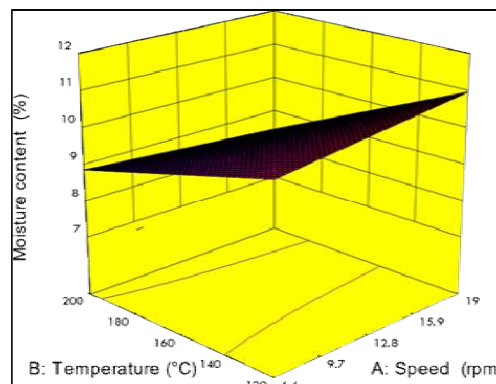

Fig. 5a. Contour plot of moisture content as a function of screw speed and temperature
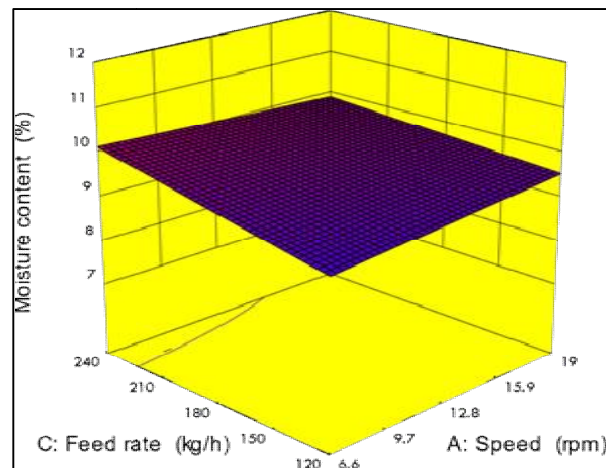
Fig. 5(b). Contour plot of moisture content as a function of screw speed and feed rate

3.3 Mechanical Damage (%) of Groundnut Roasting machine

The mechanical damage of the groundnut was in the range of 1.68 – 3.60% where the highest value was observed at a feed rate of 120 kg/h, the roasting temperature of 120°C and machine speed of 19 rpm meanwhile the lowest was observed at a feed rate of 240 kg/h, the roasting temperature of 200°C and machine speed of 6.6 rpm. Figs. 7a and 7b represent the effect of the roasting temperature, machine speed and feed rate on the mechanical damage of the groundnut. The maximum mechanical damage obtained in this study was in a close range with a value of 1.20%; 2.00% and 4.1% reported by Abubakar et al. [20] respectively. Whilst, all the values obtained under different operational condition in this study is lower compared to the mechanical damage of 11.8% reported by the Olaniyan et al. [10] during a study on the combined groundnut roaster and oil expeller and 9.9% mechanical damage that was reported by Okegbile et al. [5] and Olatunde et al. [8] during evaluation of groundnut roasting and blanching machine and testing of a developed small scale peanut roaster respectively and this variation might be due to the difference in the configuration of the machine or other parameter that was not considered in their studies.
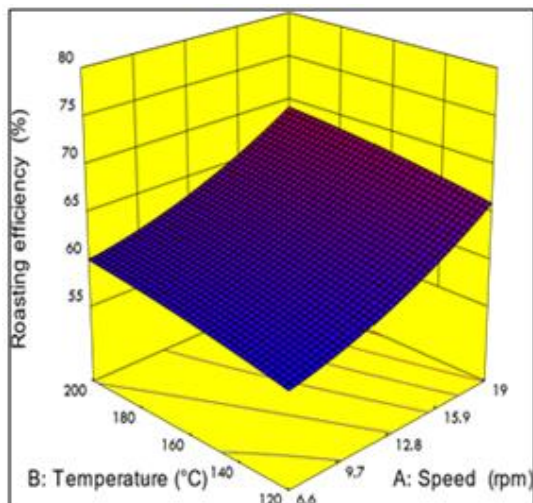

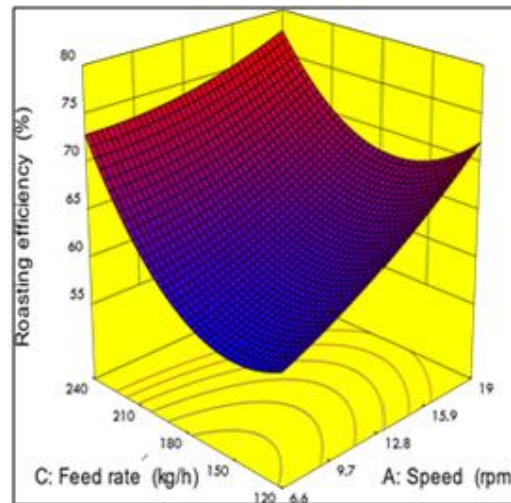**Fig. 6(a). Contour plot of roasting efficiency as a function of screw speed and temperature**

Fig. 6(b). Contour plot of roasting efficiency as a function of screw speed and temperature

According to Fig. 7a and 7b, it was observed that the mechanical damage caused by the roasting machine increased with an increase in the machine speed from 6.6- 19.0 rpm. The increase in the roasting temperature from 120- 200°C leads to a decreased in the mechanical damage of the groundnut while the mechanical damage of the groundnut decreased as the feed rate increases from 120– 240 kg/h. The increase in the mechanical damage with the machine speed might be due to the continuous collision of the groundnut with the wall of the machine and one another which might result in more broken kernel at higher machine speed [20].

Equation 15 shows the mathematical expression of the mechanical damage as a function of the operational parameter: roasting temperature, machine speed, and feed rate. The model shows that the mechanical damage exhibit a quadratic relationship with the roasting temperature, machine speed and feed rate with a high coefficient of determination value of 0.860 and this depict the that the variation in the roasting temperature, machine speed, and feed rate can significantly explain about 85.98% variation in the mechanical damage of the groundnut. The machine speed with a small coefficient had a little impact on the mechanical damage of the machine while the temperature and the feed rate with negative coefficients mean the magnitudes

were the exact opposite of the mechanical damage of the machine.

$$MD = 5.8 + 0.014Sp - 0.009T - 0.026Fr \quad (15)$$

Where,

MD is the mechanical damage, Sp is the machine speed (rpm), T is the roasting temperature (°C) and Fr is the feed rate (kg/h).

3.4 Machine Throughput (kg/h) of Groundnut Roasting machine

Figs. 8a and 8b represent the effect of the roasting temperature, machine speed and feed rate on the throughput of the machine. The throughput of the machine was in the range of 23.00 – 65.45 kg/h where the highest value of the machine throughput was observed at a feed rate of 240 kg/h, the roasting temperature of 200°C and machine speed of 19 rpm whereas the lowest value of the throughput was observed at a feed rate of 240 kg/h, roasting temperature of 200°C and machine speed of 6.6 rpm. The magnitude of the minimum quantity of roasted groundnut produced by the machine under a specific operation in this study was in a close range to the throughput value of .0.5 kg/min, 0.51 kg/min, and 0.5 kg/min reported by the (10 and (20) respectively.
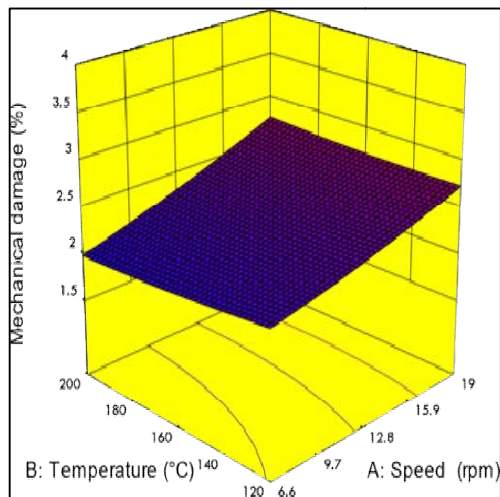
Fig. 7(a). Contour plot of mechanical damage as a function of screw speed and temperature
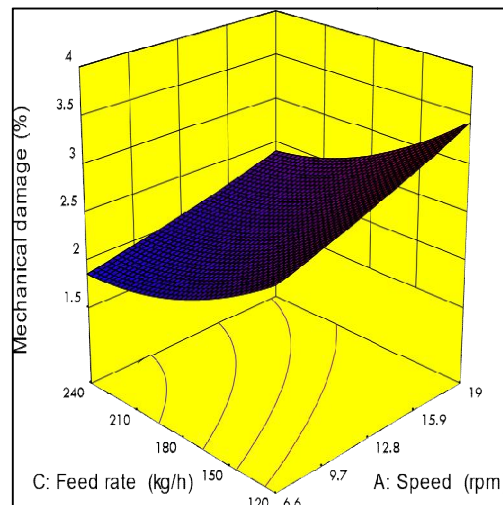
Fig. 7(b). Contour plot of mechanical damage as a function of screw speed and feed rate

According to the figures, it was observed that the throughput of the throughput increased with increase in the machine speed from 6.60- 19.00 rpm while an increase in the roasting temperature from 120- 200℃ and increase in the feed rate from 120– 240 kg/h lead to the decrease in the throughput of the machine.

Equation 4.4 shows the mathematical model for the machine throughput as a function of the operational parameters: roasting temperature, machine speed, and feed rate. The model shows that the throughput exhibit a factorial relationship with the roasting temperature, machine speed and feed rate with a high coefficient of determination value of 0.9799 and this depict the

variation in the roasting temperature, machine speed, and feed rate can significantly explain about 97.99% variation in the throughput of the machine. The machine speed with a small coefficient had a little impact on the throughput of the machine while the temperature and the feed rate with negative coefficients mean the magnitudes were the exact opposite of the throughput.
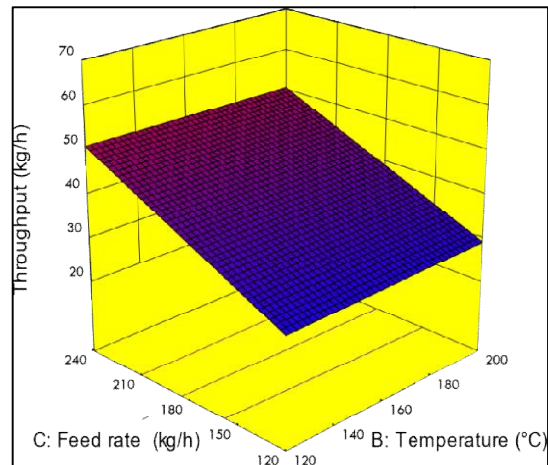
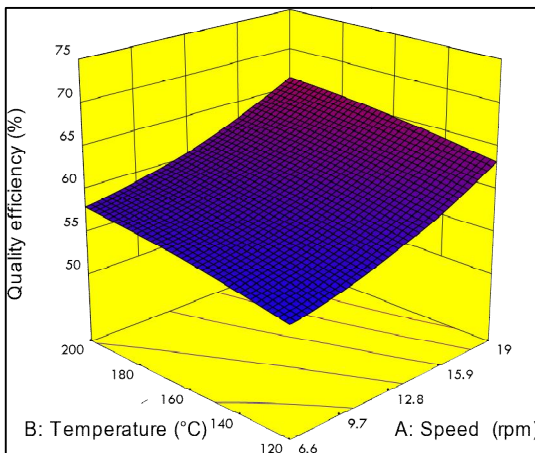$$MT = 10.08 + 0.593Sp - 0.008T - 0.102Fr \quad (16)$$

Where,

MT is the throughput (kg/h), Sp is the machine speed (rpm), T is the roasting temperature (℃) and Fr is the feed rate (kg/h).
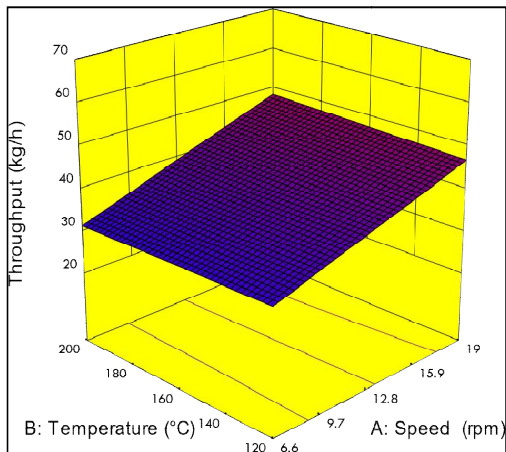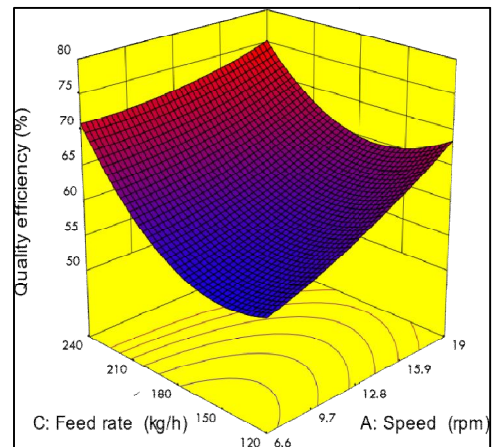

Fig. 8(a). Contour plot of throughput as a function of screw speed and temperature

Fig. 8(b). Contour plot of throughput as a function of screw speed and temperature

Fig. 9(a). Contour plot of quality efficiency as a function of screw speed and temperature

Fig. 9(b). Contour plot of quality efficiency as a function of screw speed and temperature

3.5 Quality Efficiency of Groundnut Roasting machine

Fig. 9a and 9b represent the effect of the roasting temperature, machine speed and feed rate on the quality performance efficiency of the machine. The quality performance efficiency of the machine was in the range of 52.50 – 73.95 kg/h where the highest value of the quality performance efficiency of the machine was observed when the machine was operated at a feed rate of 240 kg/h, the roasting temperature of 120°C and machine speed of 19.0 rpm and the lowest value of the quality efficiency of the machine was observed when the machine was operated at a feed rate of 120 kg/h, the roasting temperature of 120°C and machine speed of 6.6 rpm.

It was observed that the quality performance efficiency of the machine increases with increase in the machine speed (6.60 - 19.0 rpm) and the increase in the roasting temperature (120 – 200°C) lead to increase in the quality efficiency of the machine while the increase in the feed rate from 120– 240 kg/h resulted in a significant decrease in the quality performance efficiency of the groundnut.

Equation 17 shows the mathematical model for the quality efficiency of the machine as a function of the operational parameters: roasting temperature, machine speed, and feed rate. The model shows that the quality performance efficiency shows a quadratic relationship with the roasting temperature, machine speed and feed rate with a high coefficient of determination value of 0.860 and this shows that the variation in the roasting temperature, machine speed, and feed rate can significantly explain about 85.97% variation in the quality performance efficiency of the machine. The machine speed and the temperature with small coefficients had little impact on the quality efficiency of the machine while the feed rate with negative coefficient means the magnitude was the exact opposite of the quality efficiency of the machine.

$$QE = 48.77 + 1.042Sp + 0.269T - 0.372Fr \quad (17)$$

Where,

QE is the quality efficiency (kg/h), Sp is the machine speed (rpm), T is the roasting temperature (°C) and Fr is the feed rate (kg/h).

3.6 Optimal Solutions for the Roasting System Performance

Optimum conditions were determined by maximizing roasting efficiency, throughput, and quality performance efficiency of the roasting machine, while minimizing moisture content and mechanical damage of the product. While optimizing, the independent parameters: roasting temperature, machine speed, and feed rate were kept within the range of optimality (6.60 - 19.00 rpm, 120 – 200°C and 120 – 240 kg/h for machine speed, roasting temperature and feed rate respectively). The range of experimental data were taken as the range of optimality for the responses where moisture content ranges from 8.21 to 11.43%, roasting efficiency ranges from 55.15 to 76.50%, mechanical damage ranges 1.68 to 3.6%, moisture content ranges from 23.00 to 65.45 kg/h and the quality performance efficiency ranges from 52.5 – 73.95%. Based on the statistical analysis (optimization via Response Surface Methodology); 200 °C roasting temperature, 19 rpm machine speed and 240 kg/h feed rate was found as the optimum operational conditions which will optimally result in the optimal machine performance of 8.76% moisture content, 76.99% roasting efficiency, 2.46% mechanical damage, 62.32 kg/h machine throughput, 74.3% quality performance efficiency with the high desirability of 88%.

4. CONCLUSIONS

The moisture content of the groundnut, roasting efficiency, mechanical damage, throughput, and quality efficiency of the machine was in the range of 8.21– 11.93%, 55.15 – 76.50%, 1.68 – 3.60%, 23.00 – 65.45 kg/h and 52.50 – 73.95% respectively. An increase in machine speed increased the moisture content of the groundnut, roasting efficiency, mechanical damage, throughput, and quality efficiency of the machine. An increase in the roasting temperature increased the roasting efficiency and the quality efficiency of the machine, and decreased the moisture content of the groundnut, mechanical damage, and throughput respectively. An increase in feed rate increased the moisture content of the groundnut and decreased the roasting efficiency, mechanical damage, throughput, and quality efficiency of the machine. The quality performance efficiency of the machine increases with increase in the machine speed (6.60 - 19.0 rpm) and the increase in the roasting temperature (120 – 200°C) lead to increase in the quality efficiency of the machine

while the increase in the feed rate from 120–240kg/h resulted in a significant decrease in the quality performance efficiency of the groundnut. The roasting temperature, machine speed, and feed rate can significantly explain about 94.09% 89.94% 85.98% 97.99% 85.97% variation in the moisture content of the groundnut, roasting efficiency, mechanical damage, throughput and quality performance efficiency of the machine. Roasting temperature (200℃), machine speed (19 rpm) and feed rate (240 kg/h) were found as the optimum operational conditions which will optimally result in the optimal machine performance of 8.76% moisture content, 76.99% roasting efficiency, 2.46% mechanical damage, 62.32 kg/h machine throughput, 74.3% quality performance efficiency with the high desirability of 88%.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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