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DESIGN AND MANUFACTURE OF A MANUAL VERTICAL GROUNDNUT ROASTING MACHINE

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ABSTRACT
Purpose: The study aimed to develop a roasting machine to meet the demand of small-scale groundnut processing industries.
Design/Methodology/Approach: Three conceptual designs were considered for the drive system. The conceptual designs were assessed using a comprehensive evaluation criterion. AutoCAD was used to design the roaster parts. After the design, the parts were manufactured and assembled to form the roaster. Two experiments were conducted with different fuel sources, and a 4 kg groundnut mass was used to test the roaster. The fuel sources used were firewood and LPG, with an average seed loss of 1.8%.
Research Limitation: The roaster was manufactured based on existing designs in Northern Ghana.
Findings: The roaster's throughput capacity and efficiency were 15 kg/h and 98%, respectively. Unlike previous roasters, whose cylinders were positioned horizontally, this roasting machine's cylinder was placed vertically, with the upper part of the roaster opened, making it possible to monitor the groundnut while roasting.
Social Implications: Groundnut roasting is essential to ensure quality improvement, easy handling, safe storage, further processing, and value addition of the product.
Practical Implications: The roaster's design allows it to use charcoal as fuel. It employs a bevel gear system, which requires less operator effort. This implies that larger volumes of groundnut can be roasted within the shortest possible time.
Originality/Value: This work uniquely manufactures a vertical groundnut roasting machine for local industries. This machine enables easy monitoring of the groundnut during roasting. The design differs from the horizontal ones that already exist. This knowledge adds to our understanding of existing roasters in the local areas.

Keywords: *Groundnut. firewood. industries. liquified petroleum gas. roasting machine*

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INTRODUCTION

The groundnut (Arachis hypogea) is a significant leguminous crop grown mainly in Ghana's northern regions. Almost no peanut plant or fruit component is used for human benefit. The plant's roots improve the soil, while the nuts are beneficial in various ways and are the most important source of edible oil (Scheme et al., 2017). Defatted groundnut meal is produced by powdering the cake and extracting its insolvent (Scheme et al., 2017; Ansar *et al*., 2020). Groundnut is the world's fourth most important oilseed crop, the third most important source of vegetable protein after soyabean and cottonseed, and the thirteenth most important food crop (Ado, 2016). Roasting produces the distinctive fragrance, flavour, and colour consumers expect from fried foods. At a reasonably high temperature, roasting food causes thermal changes in the chemical components (Kabri et al,. 2010).

Roasting nuts requires excellent care and attention to avoid losing many nutrients. As a result, throughout the roasting process, selecting optimal roasting parameters for the best product quality is crucial (Gonzales et al,. 2018, Akintade et al,. 2014). Local farmers and low-income earners who use groundnut frying for a living generally roast the nuts in the customary method. This is achieved by heating the material with hot air or a tiny metal surface to the appropriate temperature at which the substance changes colour (Abubakar et al,. 2017). Groundnut butter, confectionery, and pastry items may all be made using dry roasted groundnuts. Roasting lowers moisture content, gives the product a nice flavour, and makes it more palatable for ingestion. Mold is prevented, and staling and rancidity are reduced by reducing moisture during roasting (Ravishankar, 2015). Groundnuts are historically roasted in Africa in various pots, including clay and aluminium pots, over an open fire until golden brown or ready to be consumed (Olatunde et al., 2014). Firewood, charcoal, and other types of fuel are commonly used. Sand is usually added to the groundnut in the pot to prevent it from burning, and it is turned constantly with a spatula until it is well-cooked. This approach is unproductive, time-consuming, and challenging (Ahanmisi et al., 2019). It is a tedious process involving hand stirring and exposure to heat and a time-consuming procedure that requires hand churning and exposure to heat (Olaniyan et al., 2017).

Several studies have been undertaken to mechanise the roasting process to relieve the burden of groundnut processors. However, horizontal groundnut roasting machines have limited capacity, uneven roasting, longer roasting time, and lower efficiency. This project will go a long way toward addressing the aforementioned issues.

Kabri et al. (2010) developed a manual groundnut roasting machine. The system utilised charcoal as the heat source and incorporated a blower to supply constant air to maintain the roasting temperature. The mixer was manufactured with a mild steel shaft with stirring paddles attached and manually stirred. The machine could roast 33 kg/h of groundnut with an efficiency of 98.9 %.

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Ahanmisi et al. (2019) and Unguwanrimi et al. (2020) manufactured similar manually operated machines and were able to achieve a 98 % and (up to) 100 % roasting efficiency. Unguwanrimi et al. (2020) investigated the variables affecting roasting efficiency and listed them as heat from charcoal, crop moisture content and crop variety. On the other hand, Alao et al. (2020) fabricated an electrically operated groundnut roasting machine. The machine was able to generate a 94 % efficiency. A 3 kg mass of groundnut was roasted, and the temperature was set to 60 °C using the temperature regulator to avoid burning the groundnut. A reduction of 19 minutes was recorded when roasting mechanically compared to the traditional. A 120 °C roasting temperature was employed by Adesoji et al. (2017). The roasting chamber designed for the system is a double-wall cylindrical drum enfolded by four 250 W heating rods connected to the thermocouple and an electronic temperature controller to regulate the heat supply. The highest efficiency achieved was 73.54 % in 10 minutes of roasting time.

Heat transfer in conventional ovens occurs by radiation from oven walls to the product surface, by convection from heating media, and by conduction from the surface of the carrier/plate to the product (Marcotte, 2007). The equation governs the net heat transfer by radiation,

$$Q_R = \sigma\varepsilon A\ (T_1^4 - T_2^4). \quad (1)$$

where Q_R is heat transfer by radiation (W/m^2), ε is the emissivity of the grey body (since radiant heaters are not perfect), σ is Stefan–Boltzmann constant (5.67 × 10− 8 W/m^2 K4), A is an area (m^2), $T_1$is the temperature of the emitting body surface (K), and T_2 is the temperature of the food sample (K).

Chhanwal, Anishaparvin, Indrani, Raghavarao, and Anandharamakrishnan (2010) employed discrete transfer, surface to surface and discrete ordinates radiation models for simulation of bread-baking (similar to roasting) in an oven with the following equations,

$$dI/ds + \alpha I = \alpha\sigma T_s^4/\pi \quad (2)$$

$$q_{out.k} = \varepsilon K\ \sigma T^4 + \rho K\ q_{in.k} \quad (3)$$

where I is radiation intensity (kJ m^2/ rad), α is gas absorption coefficient (m^{-1}), T is the temperature of food surface (K), and $q_{out.k}$ and $q_{in.k}$ are energy fluxes (W/m^2) leaving and incident on surface K, respectively.

For natural convection, heat transfer is calculated by,

$$Q_{CV} = hA\ (T_S - T_a) \quad (4)$$

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where Q_{CV} is heat transfer by convection (W/m^2), h is convective heat transfer coefficient (W/m^2K), and T_a is the temperature of air (◦C).

For efficient roasting, air is forcefully circulated utilising fans to create turbulence, allowing for faster heat exchange. As the evaporated water migrates within the product during roasting, saturated vapour comes into contact with colder surfaces, and either film condensation or drop-wise condensation occurs, the former being predominant.

Feyissa, Gernaey, Ashokkumar, and Adler-Nissen (2011) employed a formulation that represents transient heat conduction with a phase change to characterise the contact baking process (similar to roasting), which is as described below:

$$\rho_p Cp\, \partial Ts/\partial t = \partial/\partial z\, (kp\, \partial T/\partial z) - \rho_s\, R_{evp} H_{evp} \quad (5)$$

where t is time (s), kp is thermal conductivity (W/m^2K), Cp is the specific heat capacity of the product (J/kgK), H_{evp} is the latent heat of evaporation (J/kg), R_{evp} is the rate of evaporation (kg of water/kg of solids), and ρ_p and ρ_s are the density of the product and dry solids (kg/m^3), respectively.

Musa et al. (2020), Oladeji (2013), and Vanessa et al. (2019) modified and optimised a peanut roasting machine and showed that an increase in the machine speed and roasting temperature increases the machine's performance efficiency. In contrast, an increase in feed rate would result in a major decrease in the machine's performance efficiency.

In the study carried out by Musa et al. (2020), Oluwo and Idowu (2021) and Vanessa et al. (2019), which involved a focus on the auger-barrel clearance as a means of improving the efficiency of a 1.04 kg/batch peanut roasting machine, a minute amount of groundnut roasted were recorded burnt as a result of uneven distribution of heat over the heating surface due to heat controller malfunction. Oluwo and Idowu (2021) suggested that some work should be done on uniform heat distribution to reduce groundnut loss to burns and a better appearance (colour) after roasting.

MATERIALS AND METHODS

Manufacturing a vertical groundnut roaster falls under the applied research category, explicitly focusing on the roasting equipment's design, fabrication, and performance evaluation. Materials that are available locally and strong enough to stand the workload were used for the manufacture of the vertical roaster (Akpakpavi et al., 2023; Okaiyeto et al., 2020; Musa et al., 2020; Ahanmisi et al., 2019). They include mild steel (mild steel plate, mild steel shaft and other parts), flat bar, and angle iron. Others are pillow block bearings, bevel gear, and assorted bolts and nuts. The

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principal material, mild steel, has been selected for the design due to its nature. Mild steel has high tensile strength, is highly malleable, has high impact strength, higher melting point, and is easy to work with. AutoCAD was employed to design the parts. The assembly was done based on the design models. The experimental parameters to be investigated include the roasting temperature, roasting time, groundnut batch size and the heat sources.

Conceptual design

Three conceptual designs were considered for the drive system based on key parameters to choose the best out of the three designs. They are belt drive (concept 1), gear drive (concept 2) and chain drive (concept 3). The conceptual designs were evaluated using evaluation criteria (Table 1) based on general parameters (i.e. cost of production, portability, operational life, ease of maintenance), in addition to a parameter related to the drive system (shaft orientation). The parameters were given equal weight. Through the decision matrix (Table 2), the gear drive system (concept 2) had the highest and was selected for further analysis.

Table 1: Evaluation Criteria for Conceptual Designs

	Magnitudes		
Parameters			
Cost of production	Expensive	Moderate	Cheap
Score	1	3	5
Portability	Difficult	Moderate	Easy
Score	1	3	5
Ease of maintenance	Difficult	Moderate	Easy
Score	1	3	5
Shaft Orientation	Single	Few	Many
Score	1	3	5
Operational Life	Short	Long	Very long
Score	1	3	5

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Table 2: Design Matrix for the System

Parameter		Design A	Design B	Design C
Cost of Production	Magnitude	Easy	Easy	Easy
	Score	5	5	5
Ease of Maintenance	Magnitude	Easy	Moderate	Moderate
	Score	5	3	3
Portability	Magnitude	Difficult	Easy	Difficult
	Score	1	5	1
Shaft Orientation	Magnitude	Single	Many	Single
	Score	1	5	1
Operational life	Magnitude	Long	Very long	Long
	Score	3	5	3
Score (%)	Magnitude	(15/25) × 100	(23/25) × 100	(15/25) × 100
	Score	60%	92%	60%

Components of the groundnut roasting machine

The machine's major components are the roasting chamber, the heating unit, the discharge outlet, the handle and the stirring system, including bevel gears and bearings.

Manufacture of Parts

Stirring System: The stirring system comprises the drive and the driven system. The drive system consists of a handle, a drive shaft, and a bevel gear, which is found outside the roaster. The main function of the external part is to transmit motion to the driven part to move the stirring blades. The second part of the stirring system is inside the drum, which is made of bevel gear, a driven shaft, and a stirring blade. The driven part is positioned 90° vertically in the middle of the drum and supported by the flat bars. The function of the driven part is to convert the rotational motion from the drive system into a circular motion to cause

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the stirrer to move in a circular path.

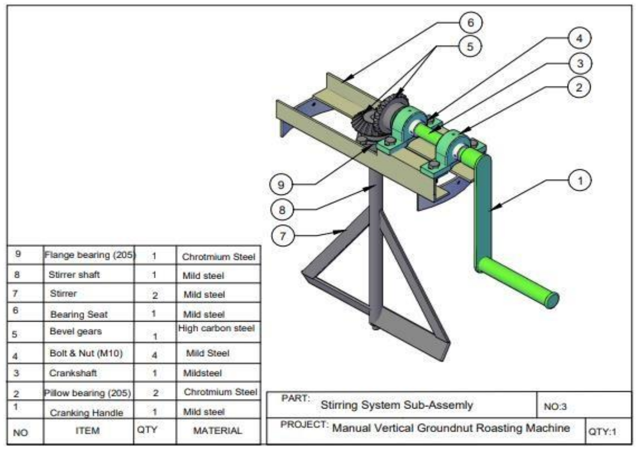

Figure 1: A Drawing Showing the Stirring System of the Roasting Machine

Roasting Chamber: The drum comprises a mild steel plate with dimensions 2 mm x 1200 mm x 2400 mm. It is directly situated on the heating chamber, separated by a circular mild steel plate. With the same circumference as the heating chamber, the drum is coiled into a cylindrical shape, forming a cylinder with a sealed base and an open top. Inside the roasting chambers are the stirring shaft and blades for stirring the groundnut during roasting. The drum's main function is to house the groundnut during roasting.

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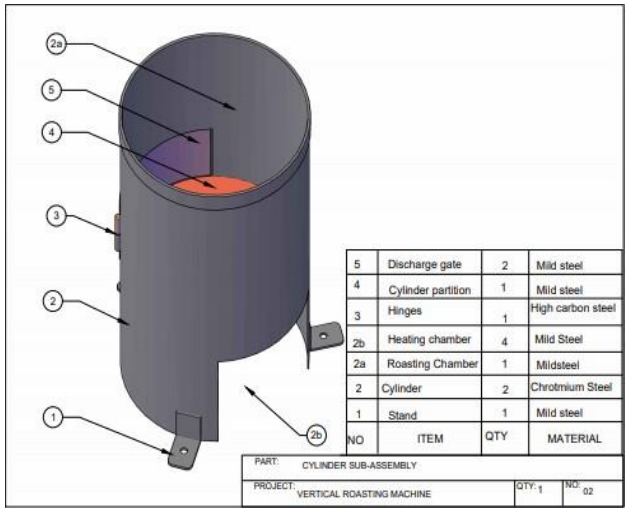

Figure 2: A Drawing Showing the Roasting Chamber of the Machine

The Base/heating chamber: The base is the main support for the whole machine. The base comprises a mild steel plate coiled into a cylindrical shape with an open cut-out. The base is constructed with a 3 mm x 1200 mm x 2400 mm mild steel plate. The lower part of the heating chamber has been attached with fixed supports to stabilise the entire machine. Inside the heating chamber is where the source of heat would be supplied. The base has been designed in such a way that different sources of heat can be used for the roasting process. The upper part of the base is covered with a circular mild steel plate that separates the bottom from the roasting chamber.

Burner: The burner is made of cast iron coiled into a circular shape. Three mild steel stands support it. The burner is connected to a valve that regulates the quantity of gas leaving it.

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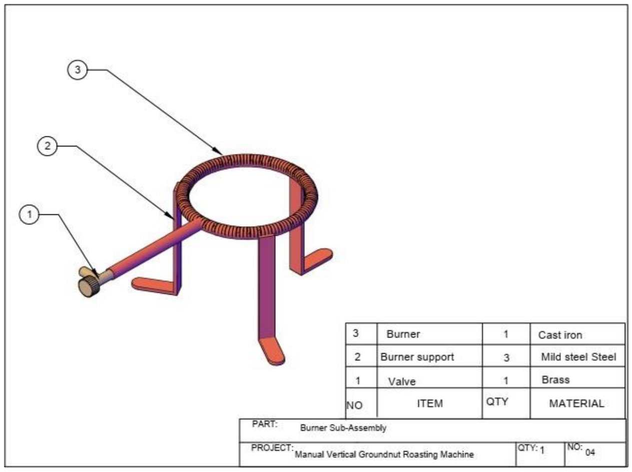

Figure 3: A Drawing Showing the Burner of the Roasting Machine

Mode of Operation

The roasting machine works on the concept of heat absorption by the groundnut seeds, resulting in consistent roasting owing to heat from the heating element and the action of the paddles housed by the shaft, which force the seeds to turn with the help of an attached handle. The groundnut seeds with the desired moisture content are fed into the roasting chamber. The cranking handle is rotated either counterclockwise or clockwise. The motion of the drive shaft is transferred to the driven shaft with the aid of the bevel gears. The paddles attached to the driven shaft turn the seeds at a given temperature to ensure even roasting. When the discharge unit of the roasting chamber is opened, the seeds move out into the collector.

Design Analysis of the Groundnut Roasting Machine

Roasting Volume

Finding the radius of the circular base with a circumference (C) of 2.5 m. The radius, r and the circumference, C are related by the formulae:

$$C = 2\pi r \quad (6)$$

$$r = C/2\pi \quad (7)$$

$r = 2.5/2\pi$. $\quad r = 0.4$ m

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$V = \pi r^2 h$ (8)

h is the height of the cylinder. $V = \pi \times 0.4^2 \times 2.4$

$= 1.2064\ m^3$

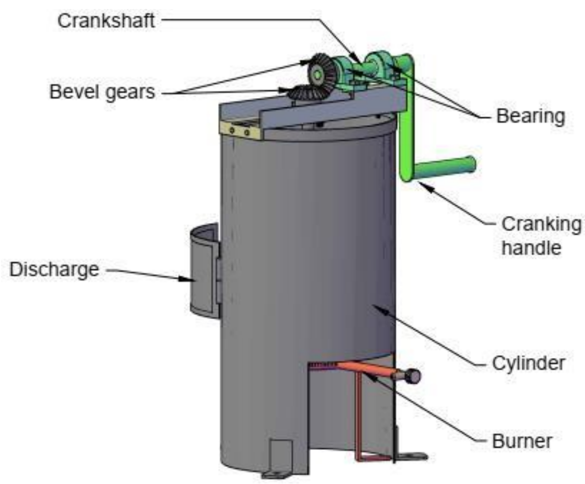

Figure 4: A Drawing of the Groundnut Roasting Machine

Roasting capacity

Volume to be occupied by groundnut

$Vg = ⅓ \times \pi r^2 h$ (9)

$⅓ \times 1.2 = 0.4\ m^3$ is the expected volume to be occupied by the groundnut

Shaft Analysis

The relation that characterises the torque of the driven shaft is given by;

$$T_s = \frac{\pi P s d^3}{8} \quad (10)$$

Ts refers to the torque developed by the shaft (Nm), Ps is the pressure induced by the shaft (MPa), and d is the diameter of the roasting cylinder (m).

If the stirring/internal pressure of the roasting cylinder is 0.0017 MPa, with an internal diameter of 0.5 m, the torque developed by the shaft would be 83.45 Nm.

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Power required by the shaft

The relation calculates the power required by the driven shaft connected to the stirring blades**:**

$$P_s = \omega Ts \quad (11)$$

Where P_s is the power required by the driven shaft, ω is the angular velocity, and Ts is the torque the shaft develops. To determine the angular velocity, we use the relation;

$$\omega = \sqrt{\frac{4Ts}{Md^2}} \quad (12)$$

M in the relation refers to the weight of the groundnut roasted per batch and the weight of the roasting cylinder. The measured weight of the groundnut roasted per batch and the roasting cylinder is 24 kg. Given a diameter of 0.5 m and a torque of 83.45 Nm, the angular velocity was calculated as 7.46 rad/s. Therefore, the power required by the driven shaft would become 0.622 kW.

RESULTS AND DISCUSSION

The roasting unit was positioned vertically to allow for easy monitoring of the groundnut during roasting. In this case, groundnut damage is reduced compared to the horizontal roasting machines, where the roasting unit is horizontal. Efficiency is also improved by utilising different energy sources (firewood and LPG) and comparing the roasting time. The lower the roasting time, the higher the efficiency, and vice versa. The outcome of our design and manufacturing process is shown in Figure 5.

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Figure 5: A Photograph Showing the Manufactured Groundnut Roasting Machine

The results of the experiments conducted to evaluate the performance of the roaster is illustrated in Table 3.

The roaster efficiency for the roaster was analysed with the relation:

$$R_E = \frac{M_g}{M_T} X\ 100\% \quad (13)$$

The percentage of Nuts lost was calculated with the relation:

$$G_L = \frac{M_d}{M_T} X\ 100\% \quad (14)$$

The throughput capacity was evaluated with the relation:

$$T_c = \frac{T_r}{60\ mins} X\ M_T \quad (15)$$

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Table 3: Performance characteristics of the roaster

Parameters	Firewood	LPG
Mass of nut not damaged $\boldsymbol{M_g}$ (kg)	3.89	3.95
Mass of nut damaged $\boldsymbol{M_d}$ (kg)	0.11	0.05
Time used for roasting $\boldsymbol{Tr}$ (min)	18.2	22.3
Roasting efficiency $\boldsymbol{RE}$ (%)	97.2	98.8
Percentage of nut lost $\boldsymbol{Gl}$ (%)	2.75	1.3
Throughput capacity $\boldsymbol{Tc}$ (kg/h)	13.2	10.76

The efficiency of the roaster for the set of experiments differs due to several factors. One distinct factor that affected the efficiency of the roaster was temperature. A similar result was also reported by Bello et al. (2024), Musa et al. (2020), Vanessa et al. (2019) and Oladeji (2013). The difficulty in varying the temperature for a heat source depended on the heat source used for roasting. Restricting the temperature of LPG was very easy since it had a regulator. The regulator is calibrated to allow for the specific temperature one wants to select. The ease with which the temperature was regulated when using LPG ensured that the groundnut was not over-roasted and, as such, fewer nuts were damaged. The use of firewood in the experiment produced low efficiency compared to the other heat sources due to the difficulty in regulating the temperature of heat produced. The only way to reduce or increase the temperature was by manually adding or removing some of the firewood. This method can either cause the groundnut to burn or take longer to roast successfully. However, the use of firewood is more economical than that of LPG. Aside from temperature, other neglected factors, such as the stirring rate and friction, could affect the machine's efficiency. Figure 6 shows a graph of efficiencies against heat sources.

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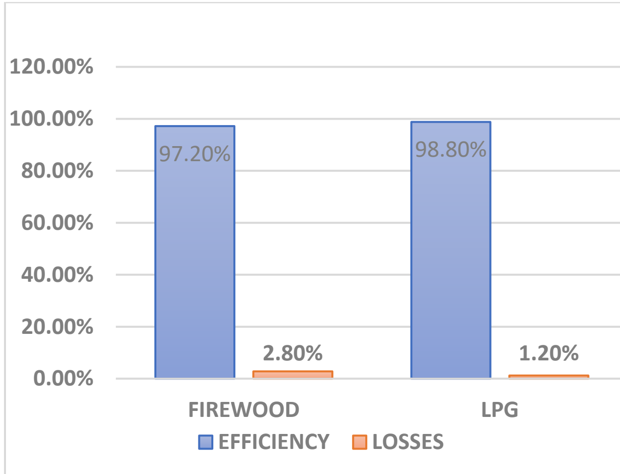

Figure 6: A Graph of Efficiencies Against Heat Sources

CONCLUSION

In this research work, the design, manufacture and evaluation of a vertical manual roasting machine were carried out with a throughput capacity of 15 kg/h and a roasting efficiency of 98%. The machine's performance was evaluated using two different fuel sources (firewood and LPG). The machine employs a bevel gear system for the stirring system and allows the state of the groundnut to be seen during roasting. Three sub-assemblies come together to form the entire machine: the vertical cylinder, the string system and the heating chamber. Even though the groundnut was used as the case study, the machine can roast nuts such as maize and shear nuts. The primary material used to manufacture the machine was mild steel with other durable selected materials. Compared to the existing horizontal roasters, the machine is economical, simple to operate, and efficient.

Social Implications

As the groundnut is roasted, its quality improves. It is also easy to handle, safe to store, and further processed, and the product adds value.

Practical Implications

Based on its design, the roaster can also use charcoal as fuel. It employs a bevel gear system that requires less effort from the operator. This implies that larger volumes of groundnut can be roasted within the shortest possible time.

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The novelty of this work is manufacturing a vertical groundnut roasting machine for local industries. This machine enables easy monitoring of the groundnut during roasting. The design differs from the horizontal ones already existing. This knowledge adds to our understanding of existing roasters in the local areas.

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