UNIZIK JOURNAL OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

Journal homepage: https://journals.unizik.edu.ng/ujabe/

UJABE

April (2026), 1(2): 42-57

ISSN: 3141-2912

DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A GROUNDNUT CAKE EXTRUDER WITH VARIABLE DIE GEOMETRY

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Received: 30th January 2026; **Accepted:** 6th February 2026; **Available Online:** 30th April 2026

ABSTRACT

Groundnut cake (*kulikuli*) is a protein-rich snack widely consumed in Nigeria, but its traditional production methods are labor-intensive, unhygienic and unsuitable for large-scale processing. This study presents the design, fabrication and performance evaluation of a locally developed groundnut cake extruder equipped with variable die geometry. A single-screw extruder was designed and fabricated using locally available materials and fitted with three interchangeable die shapes: circular, square and inverted (which is a die whose opening is shaped in a reversed orientation influencing the shape and physical properties of the extruded groundnut cake). A randomized experimental design was employed to evaluate the effects of screw speed (7rpm, 9rpm and 11rpm), moisture content (5.04%, 7.04% and 10.65%) and die shape on extrusion performance and product quality. Statistical analysis was carried out using Response Surface Methodology (RSM) and Analysis of Variance (ANOVA). Results indicated that screw speed, moisture content and die shape significantly influenced extrusion capacity, bulk density, expansion ratio and specific length of the extrudates ($P < 0.05$). Model adequacy and predictive capability were confirmed using coefficients of determination ($R^2 \geq 0.60$), Adjusted and Predicted R^2, adequate precision ratios and error analysis parameters. The extruder recorded an average extrusion capacity of 12.30Kg/h with high extruding and cutting efficiencies. Optimum performance was achieved at a screw speed of 9 rpm, moisture content of 7.04%, and circular die shape, which produced groundnut cake with relatively low bulk density, improved expansion ratio, uniform shape and stable extrusion flow. The results demonstrate that the designed and fabricated machine is suitable for hygienic, efficient and small-to-medium scale production of groundnut cake.

Keywords: Groundnut cake, Single screw extruder, Die geometry, Machine performance, Food processing

1.0 INTRODUCTION

Groundnut (*Arachis hypogaea*) is an important oilseed crop cultivated extensively in the arid and semi-arid regions of Nigeria. It serves as a major source of edible oil, protein and income for rural households. Recently, the use of groundnut meal is becoming more renowned not only as a dietary supplement for children on protein poor cereals-based diets but also as effective treatment for children with protein related malnutrition. It is the 13th most important food crop in the world and the 4th most important source of edible oil. Its seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%) (Food and Agriculture Organization (FAO), 2006). The groundnut oil is used in making diverse types of medicated ointments, plasters, syrups and medicated emulsion (Vyas et al., 2023). It is also employed in the preparation of various food like butter, milk, candy and chocolate, chutney, groundnut pack etc. One of the common food products derived from groundnut is groundnut cake, locally known as *kulikuli*, which is widely consumed as a snack across Nigeria. Despite its nutritional value and economic importance, the processing of groundnut cake in developing countries remains largely traditional. Manual operations such as shaping and molding of the cake are labor-intensive, time-consuming and unhygienic, leading to inconsistent product quality and low consumer acceptance. These limitations hinder large-scale production and commercialization. Extrusion technology offers an effective solution to these challenges. It is a high-temperature, short-time process widely used in the food industry to produce uniform, hygienic and shelf-stable products. Owing to the processing flexibility offered by extrusion cooking technology, it has found abundant uses in the cereal and pet food industries as well as in dairy, bakery, and confections industries. Over-all, the final extrudate has low moisture content and seen as a shelf-stable food product (Pasqualone et al., 2020).

Consumers' find expanded, ready-to-eat extruded snack products very attractive because of suitability, textural attributes, shelf stability and enhanced flavor. As a result of consumer interest for food manufacturers to produce an extensive range of high-protein foods and food products, the industrial fabrication of snack foods, using different sources of plant protein as main ingredients, has grown rapidly during the last decade. However, the application of extrusion technology to groundnut cake production is still limited. The beneficial appeal of high-protein, high-nutritional, low-calorie snacks would be additional attribute of extruded products from legume seeds such as groundnut. Die geometry and screw speed are critical parameters that influence material flow, pressure build-up, product shape and overall machine performance. This paper focuses on the design and fabrication of a groundnut cake extruder with variable die geometry and evaluates its performance under different operating conditions. The aim is to develop a cost-effective and efficient machine capable of producing groundnut cake with improved hygiene, uniformity and productivity.

2.0 MATERIALS AND METHODS

2.1 Materials

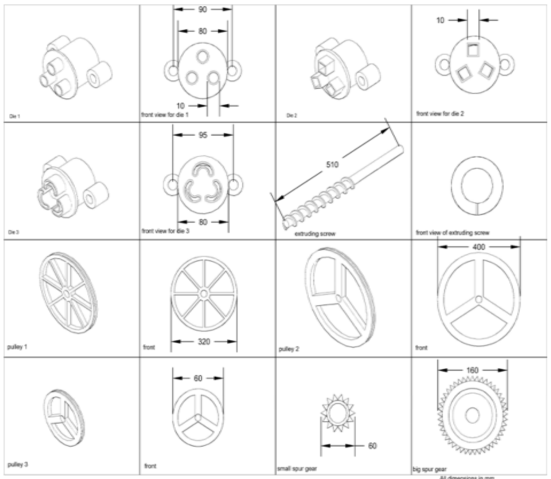
Groundnut seeds were purchased from Kure Market, Minna, Niger State, Nigeria. The groundnut paste obtained after traditional oil extraction was used as the feed material. The paste was prepared at varying moisture contents by adding measured quantities of water. All machine components were fabricated using locally sourced mild steel, bearings, pulleys, gears and a 1hp single phase electric motor. Isometric drawing of the machine and parts drawing of the extruder is as shown in Fig. 1a and 1b.

2.2 Methods

This section outlines the approach employed in the design, fabrication and performance evaluation of the groundnut cake extruder.

2.2.1 Description and Working Principles of the Extruder

A groundnut cake extruder was designed and fabricated using locally sourced materials. The machine consisted of a hopper, screw conveyor, barrel, die plate, cutter, transmission system and frame. The screw conveyor and barrel were designed based on material density, capacity requirement and standard mechanical design equations. Three interchangeable die shapes (square, inverted and circular) were fabricated to assess their influence on extrudate characteristics. Power transmission from the 1hp motor to the screw and cutter was achieved through a belt-pulley and gear arrangement.

(1a) 

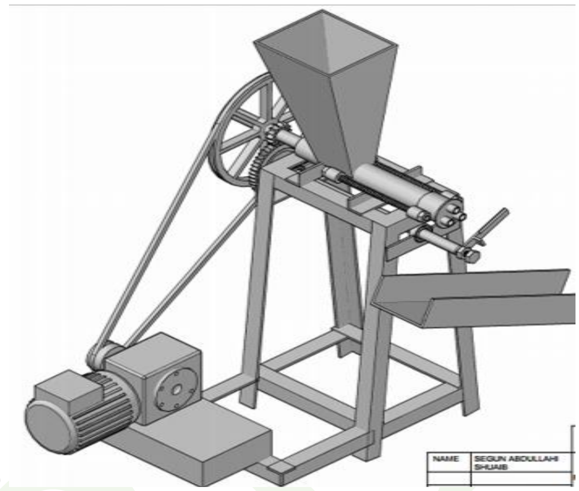
(1b) 

Fig.1a and 1b: Isometric View and Part Drawing of the Extruder Machine

2.2.2 Design Consideration

The density of groundnut paste was identified as a critical factor influencing the performance of the extruder and it guided the design of the hopper, screw and cutter to ensure efficient material flow, prevent blockages and maintain consistent extrusion**.** Some of the basic factors considered for this extruder machine are the availability of materials, selection of materials and the cost of the materials for its design and fabrication. The materials selection for the design depends on the following:

- The availability of its materials in our local markets.
- The cost of these materials such that it will be affordable to low-income processors.
- The ability of the material to resist mechanical forces and load.
- The simplicity and ease in construction so as to facilitate easy maintenance.
- The suitability of these materials to serve the purpose for which the project was intended (versatility).

2.2.3 Design Calculations and Components Selection

Assumed capacity of the machine is 120 Kg and the machine is to be operated for 8 hrs. Therefore, the theoretical capacity C_{th} of the machine using the formula (Rabbani et al., 2016) in Equation 1;

$$C_{th} = \frac{\text{Assumed mass of Groundnut Paste Q}}{\text{Time t}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$\mathbf{C_{th} = \frac{120}{8} = 15\ Kg/h}$$

2.2.3.1 Hopper Design

The shape of the hopper is in the form of a truncated pyramid with an inclination angle of 60° to enable free flowing and conveying. This is calculated using the formula as cited by Shuaib (2021) in equation 2.

$$\text{Volume of hopper} = \frac{(a^2 + b^2 + ab)h}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

2.2.3.2 Power Requirement

The design for motor output power enables appropriate selection of a motor with enough power to start and run the machine at full load. The power required by extruder screw conveyor is given by the mathematical expression cited by Fadebiyi *et al.* (2016)

$$P = 0.7355CIQ \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

Where,

P=Power required by the extruder kW
C=Coefficient constant for conveyed material, 0.3
l=Length of the screw conveyor m
Q = Theoretical capacity of the machine kg/h

2.2.3.3 Determination Of Screw Conveyor Diameter

The diameter of the screw conveyor required for conveying material at a rate of 20 kg/h for the capacity of a continuous screw conveyor were calculated from the expression given by Olasusi et al. (2022) in equation 4.

$$D^3 = \frac{4Q}{60\pi(Sn\emptyset PC)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4$$

2.2.3.4 Length of Screw

This was determined from the length to diameter (L: D) of the screw. It is the ratio of the flight length of the screw to the original diameter. A ratio of 13:1 was selected for portability. This means that the flight of the screw is 13D (where D= original diameter of the screw). The feed section, transition section and the metering section are in the ratios of 5D: 4D: 4D respectively.

2.2.3.5 Design of Drive System (Belt and Pulley Design)

The machine runs with a 1430 rpm motor which will produce a speed reduction of 70 rpm using reduction gear of ratio 1:20. This reduces the speed of the motor via a V ⁻belt before it enters the shaft. The smaller pulley is adapted at the motor and connected to the bigger pulley on the shaft of the screw via a belt drive. The bigger pulley is connected to a gear system that controls the screw and the cutter. V-belt and pulley arrangement were adopted in this work to transmit power from the electric motor to the shaft of the extruding unit. The main reasons for adopting the v-belt drive are its flexibility, simplicity and low maintenance cost. Additionally, according to Jekayinfa (2025) the V-belt has the ability to absorb shocks thereby mitigating the effect of vibratory forces.

a. Pulley diameter

The diameter of the pulley for the shaft of the extruding screw is computed using the formula as cited by Khurmi and Gupta (2005) as shown in equation 5.

$$D_2 = \frac{N_1 D_1}{N_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5$$

b. Belt speed

The belt speed for the extruder is calculated using the formula expressed by Idris et al. (2018) as shown in equation 6.

$$\mathrm{v} = \frac{\pi \mathrm{DN}}{60000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 6$$

2.2.3.6 Belt Length

The Belt length for the extruder drive can be determined using the formula as expressed by Idris et al. (2018) in equation 7.

$$\mathrm{X} = 2\mathrm{C} + 1.57(\mathrm{D}_1 + \mathrm{D}_2) + \frac{(\mathrm{D}_1 - \mathrm{D}_2)^2}{4\mathrm{C}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

2.2.3.7 Volume of Extruder Barrel

The volume of the extrusion barrel (V_{EX}) is computed using formular of a frustum as given by Hussein (2022) in equation 8 as:

$$V_f = \frac{\pi}{3} h_f (R^2 + Rr + r^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 8$$

2.2.3.8 Determination of Extrusion Pressure of the Barrel

The pressure in the extruder is very important to obtain the barrel thickness. The equation as cited in Nielsen et al. (2025) is as shown in equation 9:

$$\mathrm{P}\left(\frac{\mathrm{N}}{\mathrm{m2}}\right) = \frac{\mathrm{L}}{\mathrm{V_f}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 9$$

2.2.3.9 Determination of Thrust Force (W)

The thrust force moving the material inside the extrusion barrel of cross-sectional area (A) is computed by using expression by Khurmi and Gupta (2005) as shown in equation 10. W = PA Where, P = the pressure in the barrel kPa, A = Area of the extruder barrel m^2

$$A = \pi(R + r)\sqrt{(R - r)^2 + h^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 10$$

2.2.3.10 Determination of Die Extrusion Pressure

For a constant feed rate, speed of extrusion, feed formulation and material density, the extrusion pressure only varies with die size, the pressure of extrusion in respect to die size is computed using the formula given by Singh (2016) as expressed in equation 11.

$$P = \frac{W}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 11$$

Where; P = Extrusion pressure N/m^2, W = Thrust force N and A= Area of extrusion holes, m^2
The die plate is made from a circular plate of stainless steel of thickness of 5mm with effective diameter of 80mm.This design is considering three dies with three-hole sizes drilled into the plate, the area of the dies is thus:

Die 1 (Square): L and Width = 10.0 mm. $A = L \times B$ …………………. 12

$$A = 10 \times 10 = 100 \text{ mm}^2$$

Area covered by die hole = Area of 1 hole × number of holes (3)

Area covered by die holes = $\frac{\pi \times 10^2 \times 3}{4}$

Die 2 (Inverted): D_2 = 12.0 mm

$$A = \frac{1}{2} \times \frac{\pi D^2}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 13$$

$$\text{Area covered by die holes} = \frac{\pi \times 12^2 \times 3}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 14$$

Die 3 (Circular): D_3 = 10.0mm

$$A = \frac{\pi D^2}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 15$$

$$\text{Area covered by die holes} = \frac{\pi \times 10^2 \times 3}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 16$$

Therefore, the corresponding ressures are:

For Die 1,2 and 3 $P = \frac{\text{Thrust Force,W}}{\text{A,Area}}$ …………………. 17

2.2.4 Experimental Procedure

Dried groundnut seed was purchased from Kure market, Minna, Niger State. The groundnut was divided into three samples and milled to paste by mixing 20Kg of each sample with 10,12 and 14 litres of water respectively. The amount of water added chosen was as a result of the amount of water used by traditional processors in preparing their groundnut paste which was 11 litres. The samples were weighed using a digital measuring balance in the Crop Processing and Storage Laboratory of the Agricultural and Bioresources Engineering Department FUTMinna. The moisture contents of the groundnut sample were then determined by oven drying method. About 250g of each sample were dried in the oven till a constant weight was achieved after three consecutive time of weighing to determine the loss in weight which also represents moisture loss. The moisture content of the paste was determined as expressed by Nirmaan et al. (2022) in equation 19.

$$\text{Moisture content (\%)}=\frac{Weight\ of\ paste\ before\ drying-Weight\ of\ paste\ after\ drying}{Weight\ of\ paste\ before\ drying}\ X\ 100\% \quad \ldots\ldots\ 18$$

2kg weight of each of the samples were fed into the extruder machine at three different screw speeds of 7, 9 and 11 rpm as shown in Table 1. These reduced speeds were attained with the aid of a reduction gear motor. Three detachable dies (Square, Inverted and Circular) were fabricated to give room for the production of different shapes of groundnut cake. The maximum and minimum level of the factors considered in the performance evaluation of the groundnut cake extruding machine is presented in Table 1 to show the minimum level of speed at 7rpm and maximum speed at 11rpm, the moisture content in percentage at minimum of 5.04 and 10.65 and finally the categoric value of the square die shape at minimum and circular shape at maximum. Table 2 indicates the experimental layout of the groundnut cake extruder.

Table 1: Experimental design used to evaluate the groundnut cake extruding machine.

Factor	Name	Units	Type	Minimum	Maximum
A	A: Speed	RPM	Numeric	7.00	11.00
B	B: Moisture Content	%	Numeric	5.04	10.65
C	C: Die Shape		Categoric	Square	Circular

Table 2: Experimental layout for the groundnut cake extruder

S/N	Run	Factor 1: Speed (RPM)	Factor 2: Moisture Content (%)	Factor 3: Die Shape
1	4	7	10.65	Square
2	3	7	7.04	Square
3	10	7	7.04	Circular
4	12	7	7.04	Circular
5	1	7	5.04	Square
6	5	7	5.04	Inverted
7	6	7	5.04	Inverted
8	7	7	5.04	Inverted
9	9	9	10.65	Circular
10	17	9	10.65	Inverted
11	22	9	10.65	Circular
12	16	9	7.04	Square
13	14	9	5.04	Square
14	20	9	5.04	Circular
15	21	9	5.04	Circular
16	8	11	10.65	Inverted
17	2	11	7.04	Inverted
18	11	11	7.04	Circular
19	15	11	7.04	Circular
20	18	11	7.04	Square
21	13	11	5.04	Square
22	19	11	5.04	Inverted

2.2.5 Performance Evaluation of the Groundnut Cake Extruder

The Groundnut cake extruder was fabricated using the designed and selected materials. The performance evaluation of the extruder was carried out at the Mechanical Central Laboratory at Federal University of Technology Minna. The extruder was evaluated for performance in terms of some machine parameters as they affect the product quality parameters. The fabricated groundnut cake extruder is as shown in Plate 1.

Plate 1: Fabricated Groundnut Cake Extruder

2.3 Machine Parameter

2.3.1 Specific Mechanical Energy (SME)

This is a measure of the work done by the extruder on the feed materials and the energy that is transformed into the thermal energy which is an important index in terms of the cost of manufacturing extruded products. SME as reported by Satimehin (2022) was calculated using equation 20:

$$SME = \frac{2\pi \times T \times Ss/60}{Fr} \times 3.6 \left(\frac{Kj}{Kg}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 19$$

Where;

T is the corrected torque (Nm),
Ss is the screw speed (rpm),
Fr is the feed rate (Kg/h).

The torque T required to drive the screw was calculated using equation 21 according to Mittal et al. (2024):

$$T = \frac{60P}{2\pi N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 20$$

Where,

P is the input power,
N is the machine speed in rpm and
T is the torque required.

2.3.2 Extruder Capacity

The extruder efficiency was evaluated by determining parameters like the extrusion capacity and functional/extrusion efficiency of the machine from the observed data. Extrusion capacity was calculated according to Ibrahim et al. (2025) using equation 21.

$$EC = \frac{Me}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 21$$

Where;

EC is the extrusion capacity (Kg/min),
Me is the mean mass of the extrudates for each treatment (Kg),
T is the mean time taken for the extrusion (min).
Extrusion efficiency was calculated as the ratios in percentage of the extrudates to the initial mass of materials fed into the machine.

This is represented mathematically as: $RE = \frac{Me}{Mi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 22$

Where;

RE is the extrusion efficiency (%),
Me is the mean mass of extrudates (kg),
Mi is the mean initial mass of ingredients (kg)

$$\text{Extruding Efficiency } R_e = \frac{Me}{Mi} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 23$$

Where,

R_e= Extruding Efficiency (%)
Me = Average quantity extruded 1.87 kg
Mi = Quantity fed into the machine 2 kg
Re= $\frac{1.87}{2} \times 100 = 93.5\ \%$

And

$$\text{Cutting Efficiency Ce} = \frac{Mc}{Mi} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 24$$

Where,

Ce= Cutting Efficiency (%)
Mc = Average quantity cut by blade 390.06 g
Mi = Quantity fed into the machine 2000 g
Ce= $\frac{390.06}{2000} \times 100 = 19.5\ \%$

The overall operational efficiency of the machine was estimated as the average of the extruding efficiency and cutting efficiency in order to evaluate the combined performance of the extrusion and cutting mechanisms.

Therefore, the average operational efficiency = $\frac{93.5 + 19.5}{2} = 56.5\ \%$

The Extruding Capacity (feed rate) is the quantity extruded in kilogram per hour.

$$Fr = \frac{Me}{T} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 25$$

Fr= Extruding capacity (kg/h)
T= Average time taken, 548.18 s (0.152 h)
Me= Average quantity extruded, 1.87 kg

Therefore,

Feed rate $Fr = \frac{1.87}{0.152}$
Fr= 12.30 kg/h

2.4 Product Parameters

2.4.1 Expansion Ratio

This was determined according to (Choudhury *et al.*, 2022) where extrudates are measured using Vernier caliper and the radial expansion ratio calculated from the formula in equation 26.

$$Er = \frac{D^2}{d^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 26$$

Where;

Er is the expansion ratio,
D is the extrudates diameter while d is the diameter of the die.
Specific length of the extrudates could be measured also with the help of Vernier caliper. The specific length is calculated as extrudate length divided by extrudate mass.

$$\text{Specific length} = \frac{\text{Le}}{\text{Me}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 27$$

2.4.2 Bulk Density

Bulk Density (BD) is expressed in g/cm^3. It was measured using the method described by Leonard et al. (2020) for bulk pieces of extrudates by taking it in a defined volume jar or cylinder.

$$\text{Density}(\rho) = \frac{\text{mass}}{\text{volume}} \ (\text{g/cm}^3) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 28$$

where ρ is the bulk density of extrudate (g/cm^3). The samples were randomly selected and replicated 3 times and the average value taken.

2.5 Experimental Design and Statistical Analysis

The Study was conducted using a randomized block design to evaluate the effect of three parameters; screw speeds (7, 9, and 11rpm), moisture content (5.04%, 7.04% and 10.65%) and die shape (square, inverted and circular) on the physical properties of the extrudate. These were the independent variables. Bulk density, length, weight, diameter, extruding time, extrusion capacity, expansion ratio and specific length of the extrudates were measured as the response/dependent variables. A layout was obtained by the process of randomization showing the different combination of moisture content, screw speeds, and die shape. The layout obtained was as shown in Table 1. The experiment was conducted in three replicates for all the extruded physical properties. All collected data were analyzed with response surface methodology (D-optimal design) using Design Expert 11.1.2.0 which consisted of 3 numerical independent variables of moisture content and screw speeds, each at three levels and one categorical variable of die shape at three levels. The fitness of the model was evaluated and the interactions between the independent variables and its effect on the dependent variables were identified by using an analysis of variance (ANOVA). The goodness of fit of the second order equation was expressed by the coefficient of determination (R^2) and its statistical significance was determined by F-test. Significant terms were accepted at $P < 0.05$. The R^2 of 0.6 was accepted for predictive purposes (Schmid *et al.*, 2022).

3.0 RESULTS AND DISCUSSION

3.1 Results

The result of the experiment carried out on the groundnut cake extruder is shown in Table 3.

Table 3: Experimental Result on the Groundnut Cake Extruder

	Fac 1	**Fac 2**	**Fac 3**	**Res 1**	**Res 2**	**Res3**	**Res 4**	**Res5**	**Res 6**	**Res7**	**Res 8**
Run	**Spe**	**MC**	**DS**	**Length**	**Weight**	**Dia**	**BD**	**ET**	**EC**	**ER**	**SL**
	RPM	%		mm	g	mm	g/ml	Sec	kg/min		Mm
4	7	10.7	Square	60	12.2	11.4	0.98	606	0.184	1.3	4.91
3	7	7.04	Square	57.2	23.79	11.7	0.98	625	0.18	1.36	2.4
10	7	7.04	Circle	54.0	25.54	12.4	0.998	640	0.17	1.54	2.11
12	7	7.04	Circle	129.8	16.85	14.4	1.07	598	0.189	1.45	7.7
1	7	5.04	Square	129.8	16.85	14.4	1.07	598	0.189	1.45	7.7
5	7	5.04	Inverted	129.8	16.85	14.4	1.07	598	0.189	1.45	7.7
6	7	5.04	Inverted	68.5	13.35	11.7	1.13	620	0.176	1.37	5.13
7	7	5.04	Inverted	68.5	13.35	11.7	1.13	620	0.176	1.37	5.13
9	9	10.7	Circle	71.3	10.9	11.5	1.1	541	0.217	1.33	6.53
17	9	10.7	Inverted	133.5	11.44	12.3	1.1	561	0.199	1.51	11.66
4	7	10.7	Square	60	12.2	11.4	0.98	606	0.184	1.3	4.91
3	7	7.04	Square	57.25	23.79	11.7	0.98	625	0.18	1.36	2.4
10	7	7.04	Circle	54	25.54	12.4	0.998	640	0.17	1.54	2.11
12	7	7.04	Circle	129.75	16.85	14.4	1.07	598	0.189	1.45	7.7
1	7	5.04	Square	129.75	16.85	14.4	1.07	598	0.189	1.45	7.7
8	11	10.65	Inverted	79.25	11.11	11.6	1.15	474	0.235	1.35	7.13
2	11	7.04	Inverted	74.75	11.74	12.2	1.158	493	0.231	1.49	6.36
11	11	7.04	Circle	164.25	17.3	14.63	1.18	445	0.248	1.49	9.49
15	11	7.04	Circle	160	17.28	14.97	1.18	452	0.257	1.56	9.26
18	11	7.04	Square	156.5	19.47	15.3	1.18	464	0.225	1.63	8.03
13	11	5.04	Square	89	14.02	12.7	1.2	481	0.237	1.61	6.34
19	11	5.04	Inverted	89	14.02	12.7	1.2	481	0.237	1.61	6.34

Fac – Factor, Res - Response, Spe – Speed, MC – Moisture Content, DS – Die Shape, Dia – Diameter, BD – Bulk Density, ET – Extruding Time, EC – Extrusion Capacity, ER - Expansion Ratio, SL – Specific Length

3.2 Discussion

3.2.1 Effect of Screw Speed and Moisture Content on Extrudate Length

The extrudate length varied from 54.0 to 164.25 mm (Table 3), indicating strong dependence on processing conditions. Statistical analysis showed that screw speed and die shape had significant effects ($p < 0.05$) on extrudate length, while moisture content had no significant effect. The

ANOVA model for length was highly significant with an F-value of 25.63 ($p < 0.0001$) and a coefficient of determination $R^2 = 0.8578$, indicating good model fit and predictive reliability. Increased screw speed led to longer extrudates due to higher shear and temperature, reducing binding at the die exit. This agrees with findings by lazou (2024) and Basediya et al. (2013), who reported similar effects of screw speed on extrudate length.

3.2.2 Effect On Extrudate Weight

Variations in extrudate weight observed in Table 3 reflect differences in flow stability and material conveyance at different screw speeds and moisture levels. Although weight increased slightly with improved flow conditions, statistical results showed that weight was less sensitive to individual processing variables compared to length and extrusion capacity. This suggests that weight changes were largely influenced by combined effects of screw speed and die geometry rather than a single dominant factor as supported by Chen et al (2025).

3.2.3 Effect On Extrudate Diameter

The diameter of the extruded groundnut cake ranged from 11.4 to 15.3 mm (Table 3). ANOVA results showed that the diameter model was not statistically significant ($p > 0.05$), with an R^2 value of 0.6627, indicating moderate correlation between factors and response. Screw speed, moisture content, and die shape did not individually exert significant influence on diameter. However, circular dies produced more uniform diameters due to symmetrical flow. This agrees with Yadav et al (2025), who noted that die geometry primarily governs extrudate diameter rather than processing variables.

3.2.4 Effect On Bulk Density

Bulk density values ranged from 0.98 to 1.20 g/cm³ (Table 3). Statistical analysis indicated that screw speed and moisture content significantly influenced bulk density ($p < 0.05$). Higher moisture contents produced denser products due to reduced expansion at the die exit. Increased screw speed also contributed to higher bulk density through increased barrel pressure. These results are consistent with the observations of Umoh and Iwe (2023) who reported similar trends in extruded food materials.

3.2.5 Effect On Extruding Time

Extruding time decreased with increasing screw speed, as observed in Table 3. An increase in screw speed generally resulted in a reduction in extruding time due to enhanced material conveying and pressure buildup along the screw channel which conforms with a study by Sofi et al. (2023). Statistical results confirmed that screw speed had a significant effect ($p < 0.05$) on extruding time. Higher screw speeds improved material conveyance and reduced residence time inside the barrel, enhancing overall machine efficiency. The predictive equations generated in terms of actual factors for extruding time under the different die shapes are presented in Equations (27-29).

For Square Die shape:

$$\text{Extruding time} = 865.73 - 35.76A - 0.53B \quad \ldots\ldots\ldots\ldots\ldots\ldots \; 29$$

For Inverted Die shape:

$$\text{Extruding time} = 875.07 - 35.7A - 0.53B \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 30$$

For Circular Die shape:

$$\text{Extruding time} = 871.64 - 35.76A - 0.53B \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 31$$

Where;

A = Factor 1: Screw speed (rpm)
B = Factor 2: Moisture Content (%)

The developed models therefore provide reliable predictive relationships for estimating extruding time within the experimental range of screw speed and moisture content investigated.

3.2.6 Effect On Extrusion Capacity

Extrusion capacity ranged from 0.17 to 0.257 kg/min, with the highest values recorded at 11 rpm. ANOVA results showed that screw speed had a highly significant effect on extrusion capacity ($F = 142.90$, $p < 0.0001$), while moisture content and die shape were not statistically significant. The quadratic model was significant with an F-value of 18.03 ($p < 0.0001$) and non-significant lack of fit, indicating good model adequacy. This confirms screw speed as the dominant factor controlling throughput, in agreement with Gao et al. (2014).

3.2.7 Effect On Expansion Ratio

The expansion ratio ranged from 1.30 to 1.63 (Table 3). Statistical analysis revealed that moisture content significantly affected expansion ratio ($p<0.05$), with lower moisture contents promoting higher expansion due to better elastic recovery at the die exit. Increased moisture reduced expansion by suppressing starch gelatinization. This behavior is typical of extrusion processes and aligns with established extrusion studies.

3.2.8 Effect On Specific Length

Specific length varied across treatments and was significantly influenced by the interaction of screw speed and moisture content ($p < 0.05$). The observed influence of extruding length can be rationalized through its control over material residence and energy transfer, aligning with broader extrusion findings that link barrel geometry to process performance. Moderate screw speed and moisture content produced higher specific length values, indicating improved structural uniformity of the extrudate. The statistical model showed acceptable predictive strength ($R^2 \geq 0.60$), confirming the suitability of the developed response surface models for optimization purposes.

4.0 CONCLUSION

An electric gear motor operated groundnut cake extruder machine was developed from locally sourced materials. The concept of its fabrication allows easily detachable dies for production of different sizes of groundnut cake. The machine was tested and found efficient for the production of groundnut cake recording an extruding efficiency of 93.5 %. The machine has extrusion capacity of 12.30 kg/h which means the machine can produce groundnut cake of 98.4 kg (approximately 100 Kg) for an 8- hour operation against the traditional means of production which was found to be at 26 Kg for the same duration. This machine will help increase production, maximize profit and reduce drudgery among the producers of the cake which are largely women. Surface response methodology predicted that for the machine to operate at its optimum, the best process condition is at screw speed of 10.98 rpm, moisture content of 9.345 %, circular die shape and desirability at 0.512.

4.2 RECOMMENDATIONS

a. Circular die geometry should be used for maximum throughput and efficiency.
b. Extruder operation should be maintained at moderate screw speeds. operators are advised to maintain screw speed within the range of 10–12 rpm and moisture content between 9–10%, as this range ensures stable material flow, adequate shear development, and consistent extrudate formation
c. Further work should investigate product quality attributes such as texture and shelf life.
d. Temperature control and automation could enhance machine performance.

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To cite this article:
Shuaib A. S., Salaudeen O. H., Idah P. A., Usman Mohammed, 2026. Design, Fabrication and Performance Evaluation of a Groundnut Cake Extruder with Variable Die Geometry. 1(2): 42-57. https://journals.unizik.edu.ng/ujabe/