DEVELOPMENT AND PERFORMANCE EVALUATION OF A GROUNDNUT CAKE (*KULIKULI*) MOULDING MACHINE.

BY

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(M.ENG. SIPET/2018/8285)

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN AGRICULTURAL AND BIORESOURCES ENGINEERING

AUGUST, 2023

DECLARATION

I hereby declare that this thesis titled: "**Development and Performance Evaluation of a Groundnut Cake (*Kulikuli*) Moulding Machine**" is a collection of my research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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CERTIFICATION

The thesis titled: **"Development and Performance Evaluation of a Groundnut Cake (Kulikuli) Moulding Machine"** by: (**UWAEZUOKE, Uchechukwu Emmanuel**) (MEng. SIPET/2018/8285) meets the regulations governing the award of the degree of M.Eng. of the Federal University of Technology, Minna and it is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Moulding of groundnut cake (*Kulikuli*) is predominantly done using the traditional method, which involves using bare hands to mould the groundnut paste. It takes approximately five hours for a single individual to mould a 10 kg of groundnut paste into various forms. This process is laborious, inefficient for mass production, and consumes a significant amount of time. The traditional method of producing *Kulikuli* faces several issues such as lack of standardized equipment, processes, and raw materials. Additionally, there is insufficient attention given to hygiene during and after production, and minimal or no packaging, leading to inadequate preservation and a high presence of contaminants. A *Kulikuli* moulding machine having actual capacity of 62.5 kg/h, which consist majorly of hopper, screw, mould, barrel and cutter was designed, fabricated and evaluated. Experimental design was carried out. The study was conducted using a D-optima design to evaluate the effect of the dependent variable such as speed, feed rate, and die shape, and independent variable such as actual capacity, efficiency, bulk density and moisture content. The machine was found to have a moulding efficiency of 90 % and feed rate of 7.5 kg/min, a moisture content of 10 %, a speed of 60 rpm and a cylindrical die shape. Out of the three shapes(circle, square and cylindrical) that were used in the evaluation, the cylindrical die produced the highest actual capacity of 15.42 kg/h and bulk density of 1.14 kg/m^3, while the circular die produced the lowest actual capacity of 11.22 kg/h The *Kulikuli* moulding machine was found to be capable of producing groundnut cake with desirable physical properties, such as thickness, bulk density and actual capacity.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The leguminous crop known as Groundnut (*Arachis hypogaea* L.) has different names across various cultures. Among the Hausa people, it is referred to as *'Gyadda,'* while the Ibos call it *'Opapa.'* In Yoruba, it is known as *'Epa,'* while in American English, it is commonly referred to as peanuts, and in French, it is called *arachides.* Groundnut is widely cultivated as an important oilseed crop and is native to South America. It is grown extensively in various regions around the world. Recently, there has been an increasing acknowledgment of groundnut meal's significance, not only as a dietary supplement for children who consume protein-deficient cereal-based diets but also as an efficient remedy for children experiencing protein-related malnutrition.

Groundnut, commonly known as peanuts, holds the 13th position among the most important food crops globally and stands as the 4th most critical source of edible oil. The seeds of groundnuts consist of high-quality edible oil approximately 50 %, easily digestible protein about 25 %, and carbohydrates around 20 % (Girei *et al.*, 2013). The cultivation of groundnuts is primarily concentrated in the northern region of Nigeria, with a significant portion of the country's groundnut production attributed to states such as Kano, Kaduna, Taraba, Bauchi, Borno, and Adamawa. These states collectively account for over 85 % of the groundnuts produced in Nigeria (Abdussalam, 2023).

Groundnut cake is considered a valuable feed source due to its high protein content. Typically, it contains around 50-55 % protein in terms of dry matter (dm), but this can vary depending on factors such as oil content, presence of skins, and hulls. Peanut cake produced on-farm, which includes shells and residual oil, may have a lower protein content of less than 40 % of dm. The protein content of peanut meal can range from 42 % to more than 60 %, depending on the specific processing method and composition of the peanuts. Peanut meal is known to have deficiencies in essential amino acids such as lysine, and it is relatively low in methionine and tryptophan. Additionally, compared to soybean meal, peanut meal tends to have higher fiber content. In particular, when the meal contains a significant amount of skins and shell fragments, the crude fiber content can reach around 10 % of dm. These factors should be taken into consideration when formulating animal feeds or evaluating the nutritional profile of peanut meal (Dean, 2021).

In Nigeria, peanut meal is commonly used to produce a popular snack known as *Kulikuli.* The traditional methods of processing *Kulikuli* prevail in the country, and it is typically prepared using a mortar and pestle or a grinding machine for larger quantities. The process involves removing the husk from the roasted groundnuts and separating the chaff through winnowing. This traditional method allows for the production of *Kulikuli*, a crunchy and flavourful snack enjoyed by many in Nigeria. To prepare *Kulikuli*, the groundnut is combined with spices such as salt, dry pepper, and ginger, and ground into a paste. To prevent the paste from becoming too crispy when fried, oil is extracted from the groundnut paste. The paste is then shaped into various shapes using hands, and finally, it is fried in groundnut oil obtained from the groundnut cake. This process ensures that *Kulikuli* achieves its desired texture and flavour (Patel *et al.,* 2019).

The primary objective of this study is to design and construct a Groundnut cake (*Kulikuli*) moulding machine and develop various moulds capable of producing regular shapes such as circular, rectangular, and square shapes. These moulds will enable the production of uniformly shaped groundnut cakes, enhancing their aesthetic appeal and ease of consumption. The development of this moulding machine and the corresponding moulds aims to improve the efficiency and standardization of groundnut cake production processes.

1.2 Statement of the Research Problem

In Nigeria, groundnut cake is predominantly made using the traditional method, which involves manual production by hand. However, this method lacks hygiene as it can introduce dirt from the hands, posing potential health risks (Awoke, 2003).

As stated by Bordewijk and Schifferstein (2020), it takes approximately five hours for a single individual to shape 10 kg of groundnut paste into various forms. This process is laborious, inefficient for mass production, and consumes a significant amount of time.

The traditional method yields a low output that fails to meet market demands due to its time-consuming nature. Furthermore, the use of hands in the process leads to inconsistencies and irregular shapes in the moulded groundnut cake, often resulting in frequent breakages. Consequently, this leads to a decrease in both the quantity and potentially the quality of the final product (Awoke, 2003).

To address the aforementioned challenges, it is essential to develop an efficient and cost-effective *Kulikuli moulding* machine that can streamline the process of shaping groundnut paste. This machine would significantly reduce the effort required and considerably minimize the time involved in the moulding process. By introducing such a technology, it would be possible to achieve greater efficiency, increased productivity, and improved consistency in shaping the groundnut cake. Moreover, making the machine affordable would ensure wider accessibility and adoption within the industry.

1.3 Aim and Objectives of the Study

The aim of the project is to develop and carryout performance evaluation of groundnut (*Kulikuli*) moulding machine.

The objectives of the study are;

i. To design groundnut cake (*Kulikuli*) moulding machine

ii. To fabricate *Kulikuli* moulding machine

iii. To conduct the performance evaluation of the machine.

1.4 Justification of the Study

There are several reasons why the fabrication of a *Kulikuli* moulding machine is necessary.

Firstly, the traditional method of moulding *Kulikuli* is time-consuming and not very efficient. With a moulding machine, the process becomes simpler and more reliable, thus increasing efficiency and productivity.

Secondly, the use of a moulding machine ensures that the moulded groundnut cake has uniform shapes and sizes, which improves the quality of the product and increases marketability.

Thirdly, the use of a machine reduces the risk of contamination and improves hygiene, as it eliminates the need for hand-moulding which may introduce dirt and bacteria.

Finally, the fabrication of a *Kulikuli* moulding machine will create employment opportunities and enhance the economic growth of the country.

The design of this machine addresses the complexity of moulding *Kulikuli* into various desired shapes such as squares, rectangles, and circles. By automating the moulding process, it eliminates the need for conventional hand moulding, resulting in increased efficiency and productivity. The machine allows for consistent and precise shaping of *Kulikuli*, enabling a higher quantity of production within a limited timeframe. This advancement not only streamlines the manufacturing process but also ensures uniformity in the shapes of the moulded *Kulikuli*, enhancing the overall quality and appeal of the final product.

1.5 Scope of the Study

The project's scope is focused on the design and fabrication of a *Kulikuli* moulding machine capable of producing moulded *Kulikuli* in various shapes such as circular, cylindrical and square.

CHAPTER TWO

2.0 LITERATURE REVIEW

Groundnut cake is a widely consumed local food in Nigeria, enjoyed by both urban and rural populations. However, despite the significant role of groundnut oil and cake processing in creating employment opportunities and reducing poverty among the rural population in Nigeria State, there is a lack of information regarding the specific impact on the poverty level of the processors in the states. To address this knowledge gap, the research conducted in this study aimed to investigate the processing of groundnut into groundnut cake (Oyewole and Isah, 2012).

2.1 Nutritional composition of Groundnut

Groundnut, also known as peanut, has various uses and all parts of the plant are valuable. The kernel is particularly notable as it is a high-quality source of edible oil. The kernel contains a significant amount of oil, ranging from 36 % to 54 %, and also possesses protein content ranging from 25 % to 32 % (Variath and Janila, 2017). Approximately two-thirds of the global production of groundnut is crushed to extract oil, highlighting its significance as an oilseed crop (Chang *et al.*, 2013). The extracted oil plays a vital role in various applications, primarily in cooking and the production of margarine, shortening, and soaps.

Groundnut seeds have versatile uses and can be consumed in various ways. They can be eaten raw or roasted as a snack, chopped and included in confectioneries, or ground into peanut butter. Additionally, the young pods of the groundnut plant can be consumed as a vegetable, and the young leaves and tips are commonly cooked and enjoyed as a green vegetable (Shabangu, 2021).

Groundnut offers a range of non-food applications as well. Its oil finds diverse applications in the production of non-food items, including soaps, medicines, cosmetics, pharmaceuticals, insect control emulsions, and lubricants. Additionally, the oil cake, which is a by-product of oil extraction, is a high protein feed that can be used as livestock feed and may also have potential for human consumption (Variath and Janila, 2017).

Groundnut plants offer additional benefits beyond their seeds. The haulms, or stems and leaves, are rich in protein and can be used as high-quality hay for horses and ruminant livestock. Groundnut shells also have various applications, such as being used as fuel in the form of fireplace "logs," as a soil conditioner, as a component of sweeping compounds, as a filler in cattle feed, as a raw material for organic chemicals, as an extender of resin, as a substitute for cork, and in the building industry for making blocks or hardboard (Adazebra, 2019). The pictures of a groundnut plant with pods, unshelled, shelled seeds and roasted kernel are shown in Plates I-IV.

Plate I: Picture of Groundnut Plant with Pods
(Source: Adazebra, 2019)

Plate II: Picture of In-Shell Groundnut
(Source: Adazebra, 2019)

Plate III: Picture of Kernel (Coat/Hulled Kernel)
(Source: Adazebra, 2019)

Plate IV: Picture of a Roasted Groundnut

(Source: Adazebra, 2019)

2.2 Health Benefits of Groundnuts

According to Gibbons *et al.* (2021) the following are the health benefits of groundnuts.

(i) Groundnuts are a valuable protein source, playing a crucial role in our diet, given that our bodies contain over 10,000 different types of proteins. Peanuts are particularly recognized for their excellent contribution of plant-based protein, making them a popular choice in the diets of vegetarians and individuals with protein deficiencies.

(ii) Groundnuts are rich in heart-healthy fats. Elevated cholesterol levels can lead to the build-up of fatty deposits in arteries, increasing the risk of heart disease. However, groundnuts contain a combination of monounsaturated and polyunsaturated fats, which have been shown to promote heart health by helping to lower blood cholesterol levels.

(iii) Groundnuts are notably rich in minerals, offering a plentiful supply of essential elements like magnesium, phosphorus, potassium, zinc, calcium, sodium, and others. These minerals play vital roles in various physiological processes, and maintaining appropriate levels of these minerals helps mitigate the risk of mineral deficiency disorders.

(iv) Groundnuts are notably rich in foliate. The elevated levels of foliate present in groundnuts make them particularly beneficial during pregnancy. Studies have indicated that foliate intake can help reduce the occurrence of birth defects and conditions associated with anaemia. Therefore, including groundnuts in the diet can be advantageous for pregnant women.

(v) Groundnuts can be beneficial for weight loss endeavours. Despite being calorie-dense, their high fibre and protein content contribute to enhanced and prolonged satiety, helping individuals feel full and satisfied. As a result, having a small serving of peanuts as a snack can lead to reduced overall food intake compared to consuming the same number of calories from a chocolate bar. Groundnuts' fibre and protein content make them a more fulfilling and nutritious option for individuals seeking to manage their weight.

(vi) Groundnuts exhibit anti-aging effects. They are rich in vitamin E, an antioxidant that has the potential to slow down the aging process. Antioxidants function by safeguarding cells against the detrimental impact of free radicals. Table 2.1-2.4 illustrate the food value of groundnuts, their nutritional characteristics, chemical composition, and nutritional value.

Table 2.1: Food Value of Groundnut

S/N	Content	Percentage (%)
1	Protein	25.2
2	Oil	48.2
3	Starch	11.5
4	Soluble Sugar	4.5
5	Crude Fibre	2.1
6	Moisture	6

Source: (Ayoola *et al.*, 2012)

Table 2.2: Nutritional Characteristics of Groundnut

S/N	Characteristics	Raw	Roasted
1	Calories(g)	564	582
2	Protein(g)	26	26
3	Fat(g)	47.5	48.7
4	Carbohydrate(g)	18.6	20.6
5	Calcium(mg)	69	72
6	Phosphorus(g)	401	401
7	Iron(mg)	2.1	2.2
8	Thiamine(mg)	1.14	0.32
9	Riboflavin(mg)	0.13	0.13
10	Niacin(mg)	17.2	17.2

Source: (Ayoola *et al.*, 2012)

Table 2.3: Chemical Composition of Groundnut Shell, Haulm and Oil cake (%)

S/N	Characteristics	Shell	Haulm	Oil cake
1	Cellulose	65.7	22.11 - 35.35	
2	Carbohydrates	21.2	38.06 - 46.95	22 - 30
3	Proteins	7.3	8.30 - 15.00	45 - 60
4	Minerals	4.5	1.39 - 2.88	4 – 5.7

5	Crude Fibre	22.11 – 35.55	3.8 – 7.5
6	Moisture	7.13 – 10.00	8 – 10

Source: (Ayoola *et al.*, 2012)

Table 2.4: Analysis of Groundnut Nutrients (Nutritional Value per 100 g.)

Principle	Nutrient Value	% of RDA
Energy	567 Kcal	29 %
Carbohydrates	16.13 g	12 %
Protein	25.80 g	46 %
Total Fat	49.24 g	165 %
Cholesterol	0 mg	0 %
Dietary Fiber	8.5 g	22 %
	Vitamins	
Folates	240 µg	60 %
Niacin	12.066 mg	75 %
Pantothenic acid	1.767 mg	35 %
Pyridoxine	0.348 mg	27 %
Riboflavin	0.135 mg	10 %
Thiamin	0.640 mg	53 %
Vitamin E	8.33 mg	55.5 %
	Minerals	
Calcium	92mg	9 %
Copper	1.144mg	127 %
Iron	4.58mg	57 %
Magnesium	168mg	42 %
Manganese	1.934mg	84 %
Phosphorus	76mg	54 %
Selenium	7.2 µg	13 %
Zinc	3.27mg	30 %

Source: (Ayoola *et al.,* 2012)

2.3 Economic Importance of Groundnut

Numerous studies have been conducted to examine the relationship between groundnut processing, poverty reduction, and economic growth. However, there exist differing perspectives on this topic. It is important to note that the relationship between the groundnut processing sector and other sectors should not be viewed as a competition but rather as interdependent. Strengthening linkages between these sectors can facilitate the accommodation of supply and demand, fostering a mutually beneficial relationship (Odetola and Etumnu, 2013).

One crucial sector that plays a significant role in the development of an economy is the industrial sector. It is widely recognized that any economy aiming for growth and progress must focus on enhancing its industries. Strengthening the industrial sector is imperative for fostering economic development and achieving long-term sustainability

However, it is important to acknowledge the significant role of the groundnut processing sector in Nigeria's quest for industrialization. Unfortunately, this sector has often been overlooked and its potential underestimated. Advocates of Agriculture-led Growth (ALG) emphasize that the development of the processing sector is a critical prerequisite for attaining industrialization. Recognizing the importance of the groundnut processing sector and integrating it into the broader industrialization agenda can contribute significantly to Nigeria's economic growth and development. The groundnut processing sector plays a vital role in various aspects such as boosting rural income, providing raw materials for industries, establishing a domestic market for the industry, and reallocating resources to support industrial activities. Acknowledging the significance of the groundnut processing sector can have a profound impact on driving overall efforts towards industrialization (Okoh *et al.,* 2019).

If the agricultural processing sector is neglected in favour of the industrial sector, it can result in sluggish economic growth and income inequality. While it is true that agricultural processing alone may not completely transform an economy, it is considered a vital and essential factor in initiating the process of industrialization during the early stages of development (Odetola and Etumnu, 2013). By recognizing the importance of agricultural processing, a foundation can be laid for kick-starting industrialization and achieving sustainable economic growth.

2.4 Traditional and Modern Methods of Groundnut Cake Production

Traditional and modern methods of groundnut cake production differ in terms of techniques, equipment used, and efficiency. Here's an overview of both approaches:

2.4.1 Traditional method

i Decorticating: The first step involves removing the hulled from the groundnuts manually, typically using the hands or simple tools like mortars and pestles.

ii Winnowing: The dehulled groundnuts are then subjected to winnowing, where the chaff or outer skin is separated from the seeds by tossing them in the air and allowing the wind to carry away the lighter chaff.

iii Roasting: The cleaned groundnuts kernels are roasted either over an open fire or in a frying pan until they turn golden brown. This step enhances the flavor and texture of the groundnuts.

iv Grinding: The roasted groundnuts kernels are ground into a paste using a mortar and pestle or grinding stone. This process requires significant physical effort and time.

v. Moulding: The groundnut paste is manually shaped into desired forms, typically by hand-rolling or pressing them into round or rectangular shapes.

vi. Drying: The moulded groundnut cakes are sun-dried or air-dried for a period of time to remove moisture and increase shelf life (Aboki, 2015).

2.4.2 Modern method:

i. Mechanical groundnut decorticator: The groundnuts are passed through a mechanical decorticating machine that removes the shells efficiently and at a faster rate.

ii. Mechanical Roasting: Roasting is done using modern equipment like roasting ovens or hot air dryers, which ensures uniform heating and reduces the risk of unevenly matted groundnuts.

iii. Mechanical Grinding: Groundnuts are processed using mechanical grinding machines or mills, which are more efficient and faster compared to manual methods.

iv. Automated Moulding: Specialized machines are used to mould the groundnut paste into various shapes automatically, providing consistent and standardized products.

v. Drying and Packaging: After moulding, the groundnut cakes are dried using drying chambers or ovens with controlled temperature and humidity. Once dried, they are packaged in suitable containers.

The modern methods of groundnut cake production offer advantages such as increased productivity, better quality control, and reduced labor requirements. They are characterized by the use of advanced machinery and technologies, resulting in higher efficiency, consistent product quality, and improved food safety. However, traditional methods still persist in certain regions, often due to cultural practices, limited access to modern equipment, or small-scale production (Aboki, 2015). The picture of Groundnut cake (*Kulikuli*) is shown in Plate V.

Plate V: Picture of a Groundnut Cake

Source: (Aboki, 2015)

The modern methods used are the extrusion moulding process. For this process, the already oil extracted groundnut paste is fed into the hopper, consisting of a screw which rotates within a sturdily built cylinder. As the screw turns, pressure is applied, pushing the mass towards the discharge end, which is the mould. The combination of friction and pressure generates heat within the mass, facilitating the moulding process. Groundnut cake passes through the mould and a cutter which cuts the paste is placed directly opposite the mould with a distance of 0.5 cm. The resulting press cake contains 5 % oil and can now be fried into '*Kulikuli*' (Aboki, 2015).

2.5 Review of Relevant Literature

This groundnut cake moulding machine has not being in existence. Therefore, the comparison in the relevant literature review from research cannot be achieve. The literature review adopted in this chapter will based on the various types of extruding machines.

Extruders have broad applications across various industries, including plastics, metals, and food processing. In particular, the extrusion process is extensively used in manufacturing products that rely on polymers as their main raw material. Some common examples of products produced through polymer extrusion include pipes, hoses, insulated wires, cables, sheets, films, and tiles (Chokshi and Zia, 2004). In general, extruders can be divided into two main types: single-screw and twin-screw extruders. Single-screw extruders are commonly employed in general polymer processing, whereas twin-screw extruders are favoured for compounding different fibres, fillers, and polymer blends before the final moulding stage (Sakai, 2013). Twin-screw extruders can be further categorized based on the interaction of the two screws: intermeshing and non-intermeshing twin-screw extruders. Among the various twin-screw extruder variants, fully intermeshing counter-rotating twin-screw extruders are particularly recognized for their excellent pumping capabilities, attributed to their positive displacement characteristics.

Introducing intermeshing counter-rotating twin-screw extruders as an evolution of continuous kneaders, their development can be traced back to 1939, where they were initially designed for compounding purposes. Over time, numerous extruder variations have emerged, aiming to enhance manufacturing performance across various sectors such as food, metal, pharmaceuticals, and composites (Cope, 1998). In the realm of polymer-based production, extruders found their initial use in profile extrusion, specifically for polyvinyl chloride pipes. Notably, modular extruders, particularly those designed for closely intermeshing counter-rotating twin-screw extrusion, have undergone extensive experimental investigation to improve their functionality (Lewandowski *et al.*, 2015).

The initial in-depth analyses of the extrusion process primarily focused on classical flood-fed single-screw extrusion, specifically examining the melt conveying process and later the solid conveying process. One of the earliest fundamental models for melting in a single-screw extruder was proposed by Tadmor (1966). These melting models and various comprehensive computer models served as the foundation for the development of flood-fed single-screw extruders, which will be discussed later in this paper. However, research on starve-fed single-screw extrusion has only recently commenced and has primarily centred on studying mixing and melting capacity. Comparatively little attention has been given to modelling the starve-fed extrusion process (Wilczyński *et al.*, 2013).

In modern industrial applications, twin-screw extruders are widely employed. These extruders can be categorized into two types based on the relative rotational direction of their screws: co-rotating and counter-rotating twin-screw extruders. In co-rotating twin-screw extruders, the maximum velocity occurs at the screw tips, whereas in counter-rotating twin-screw extruders, the maximum velocity is achieved in the intermeshing region (Lewandowski, 2011).

It can be argued that the co-rotating mechanism offers improved mixing capabilities as the material is transferred between the lobes. On the other hand, the counter-rotating mechanism generates higher pressure build-up, making it more efficient for profile extrusion (Shah and Gupta, 2004).

Numerous studies have been conducted to investigate the material flow within different types of extruders. In a design research aimed at developing a simplified extruder for extrusion cooking and processing local food materials in less developed countries (Senanayake and Clarke, 1999) compared single-screw and twin-screw extruders. It was found that single-screw extruders are relatively straightforward to construct. However, they are more prone to material clogging compared to twin-screw extruders.

The single-screw extruder is the predominant type of extruder and is known for its relatively lower investment cost. On the other hand, twin-screw extruders are utilized for higher output applications. In extrusion processes, the die plays a crucial role in determining both the output rate and the quality of the final product. One of the simplest ways to increase the throughput of an extruder is by raising the screw speed. However, this straightforward solution often leads to poor melt quality due to exceeding the melting capacity of the screw design and can also result in degradation caused by the high melt temperature. Therefore, increasing screw speed alone may not be the optimal approach for achieving higher output while maintaining product quality.

The utilization of a smaller diameter screw in extrusion can bring about several advantages when aiming for a higher throughput at higher screw speeds. Notably, one significant advantage of employing a smaller diameter extruder is its improved heat transfer characteristics. The use of a smaller diameter extruder enables the achievement of higher throughputs at elevated screw speeds, thereby enhancing the overall heat transfer efficiency of the process (Christiano *et al.*, 2012).

The objective of an extrusion die is to ensure the uniform distribution of the polymer melt within the flow channel, resulting in a consistent velocity and minimal pressure drop as the material exits the die. However, creating a single flow channel geometry that caters to a wide range of polymers and operating conditions, except for circular dies, is exceedingly challenging.

In the context of an extrusion die, the distribution of exit velocities is influenced by various factors such as shear rate, temperature, and the heat dissipation characteristics of the polymer melt. These factors collectively contribute to the velocity distribution of the exiting material from the die (Lebaal, 2019).

In both single-screw and twin-screw extrusion processes, it is crucial for all dies to be adequately and uniformly heated without any dead spaces in the flow channels. This is essential to avoid the formation of hot or cold spots in the polymer flow, which can adversely affect the melt viscosity or result in resin degradation (Giles *et al.,* 2004).

The performance of an extrusion die relies on the design of the manifold geometry as well as the specific operating conditions implemented during the extrusion process. Proper design and optimization of these factors contribute to achieving optimal die performance and ensuring consistent product quality (Lebaal, 2019).

Designing an extrusion die is a complex undertaking due to the interdependencies between the die design, polymer properties, and extrusion process parameters, which collectively determine the dimensions of the final extrudate product. Enhancements in the die design process can be achieved through the integration of computational simulation with empirical data and by advancing the extrusion monitoring instrumentation. By incorporating computational simulation and empirical data, the die design process can be refined, leading to improved product quality and reduced time required for designing and optimizing the extrusion process (Kostic and Reifschneider, 2006).

In twin-screw extruders, the intermeshing nature of the screws prevents blockages and promotes improved mixing of materials within the screw channels. The engagement of one screw's flight with the channel of the other contributes to the efficient flow and mixing of materials. In contrast, single-screw extruders tend to retain the material for a longer duration compared to twin-screw extruders. This is primarily attributed to the presence of stagnant layers on the screw surface, which hinders the flow and mixing of materials. Due to these factors, twin-screw extruders have approximately three times higher material output compared to single-screw extruders of similar size and screw speed (Sakai, 2013).

The material flow process in extrusion can be conceptually divided into four main sections: (a) feeding of the extruder, (b) mass transport, (c) flow through the die, and (d) exit from the die and subsequent downstream processing. Throughout these stages, the mass of the material undergoes transformation primarily through shear forces, pressure, cooling rates, shaping, and the duration of residence within the extruder.

Traditionally, the extrusion channel is divided into three distinct parts: (a) the feed zone, where the material is introduced into the extruder, (b) the transition zone, where the material undergoes changes in temperature and viscosity, and (c) the metering zone, where the material is further compressed and forced through the die.

The duration of material processing within the extruder is commonly referred to as the residence or distribution time, which reflects the time the material spends within the extruder before being extruded (Padmanabhan, 2008).

Many commercially available extruders offer the flexibility of using different types of screws or interchangeable sections that allow for modifications to the configuration of the feed, transition, and metering zones. This modular design approach enables extrusion processes to be adapted and customized to meet specific requirements, such as enhancing mixing capabilities. By utilizing this modular design feature, operators can optimize the extrusion process by selecting the appropriate screw or sections that best suit the desired outcome, thereby achieving improved mixing performance or other specific objectives (Chokshi and Zia, 2004).

Starve-fed screws are commonly found in twin-screw extruders. In such configurations, the extruder's throughput does not solely depend on the screw speed when operating at a steady state. Unlike the extensive research on melting in single-screw extruders, studies specifically focusing on melting in twin-screw extruders have only emerged in recent years (Lewandowski *et al.*, 2015).

To analyse the melting process in twin-screw extruders, various models have been developed. These models provide insights into the melting behaviour and enable a better understanding of the process. Additionally, several comprehensive computer models have been created based on these melting models, primarily focusing on co-rotating twin-screw extruders (Wilczyński *et al.*, 2013). These models contribute to the advancement of understanding and optimizing the melting process in twin-screw extruders.

2.5.1 Extrusion process in the barrel

The feed throat of an extruder serves the purpose of introducing the material into the screw channel. Typically, the throat is designed to fit around the initial few flights of the extruder screws. In order to prevent excessive temperature rise in the feed throat area, it is common for the casing to be water-cooled. This cooling helps maintain a controlled temperature during the material feeding process. If the temperature becomes extremely high, there is a risk of the polymer adhering to the surface of the feed opening. This can lead to flow restrictions, hindering the material from entering the extruder smoothly and causing difficulties in solid conveyance.

To ensure a consistent and uninterrupted flow of material through the hopper, it is important to consider the gradual compression in the converging region. Additionally, the cross section of the hopper is often designed to be circular, as it helps facilitate a steady and uniform material flow (Rauwendaal, 2014).

In modern extruders, a commonly adopted approach is the use of a modular screw design, which aims to improve the efficiency of mixing within the barrel. The modular design permits various screw configurations, such as thick flight designs, thin flight designs, and combinations of thick/thin flight designs. Effective control of shear conditions within the extruder can be achieved by modifying the flight geometry and adjusting the rotational speed. These design variations enable optimized mixing performance and improved processing of plastics (Senanayake, 1999).

Wilczynski *et al. (*2013) introduced a cutting-edge technique for comprehensive modelling of screw processing in plastics. This technique encompasses a detailed analysis of various parameters and factors involved in the screw processing, providing a valuable tool for understanding and optimizing the extrusion process. The combination of modular screw design and advanced modelling techniques contributes to advancements in extrusion technology and plastic processing. The study employed a versatile computer system to investigate the material's transport, melting, and mixing processes, as well as the pressure generation needed to extrude materials through the die of the extruder. The research primarily focused on model optimization using genetic algorithms, which emulate the natural evolution process, along with response surface methodologies based on mathematical models of the extrusion process. A key emphasis of the study was placed on accurately predicting the behaviour of the material, including melting properties and thermo-mechanical history of the material during the screw processing stage. By enhancing the comprehension and prediction of material behaviour, the research sought to improve the overall efficiency and effectiveness of the extrusion process. The structure of the die has been examined and enhanced through the utilization of finite element methods. This type of research has predominantly concentrated on metal extrusion dies due to the elevated levels of pressure and temperature they experience (Gonçalves *et al.,* 2015). The rate at which material is processed increases proportionally with the speed at which the screw rotates. Furthermore, the specific output appears to be unaffected by changes in pressure across a broad spectrum of melt temperatures and screw speeds.

The incorporation of advanced applications in the plastic industry has led to the use of more complex die profiles during production, resulting in imbalanced flow patterns (Crowther, 1998). There is a rapidly expanding field of study that centers on multilayer films, extensively used in packaging to meet specific performance criteria. The advancement of polymers and processing technologies has significantly contributed to the progress of multilayer film production (Mount III, 2010).

2.6 Summary of Review of Literature

Extensive research has been conducted on extrusion in previous years, as it is a widely utilized manufacturing process. However, with the advancement of materials, new requirements have emerged, prompting further investigation. Numerous authors have studied the mechanisms involved in polymer melting, mixing, and metering. Nevertheless, there is a paucity of literature focusing on these functions specifically in the context of multi-phase materials. In the case of mechanical product extrusion, the ultimate goal is to optimize the structural properties of the product. Achieving this requires determining the optimal process parameters through an iterative approach.

However, establishing the relationships between product properties and process parameters solely through experimental data can be complex, expensive, and limited in scope. This is where modelling and simulation play a crucial role by enabling rapid and cost-effective development through successful prediction and analysis.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for the development of groundnut cake moulding machine are;

i. Biomaterial: Shelled Groundnnut

ii. Construction materials: Stainless steel for parts in contact with the groundnut paste, angle iron, auger screw, welding machine, cutting disc, electrode, bearing, drilling machine, bolt and nut, gear measuring tape.

iii. Other units: Groundnut roaster (Hottop B Model), Grinding machine (Local design), oil extracting machine (Local design).

3.2 Methods

The Groundnut cake extruder was fabricated at the Hamstring Nigeria limited, Tunga, Niger State. It was transported to Mechanical Central Laboratory at Federal University of Technology Minna, where the performance evaluation of the extruder was carried out. The extruder was evaluated for performance in terms of some system and product parameters.

3.2.1 Design considerations

In designing the groundnut cake *(Kulikuli*) moulding machine, the following factors were considered;

i. Capacity: The capacity of the machine was designed to meet the specific needs of the user, taking into consideration factors such as the size of the production line and the target market.

ii. Material Selection: The choice of materials used in the construction of the machine is important. Materials that was used are durable and resistant to wear and tear, and also a food-grade.

iii. Hygiene: The machine was designed to be easy to clean and sanitize to ensure that the final product is safe for consumption.

iv. Automation: The level of automation required was considered when designing the machine. Automation can help improve productivity, reduce labour costs, and improve product consistency.

v. Safety: The machine was designed with safety in mind, including emergency stop buttons and guards to prevent accidental injury.

vii. Maintenance: The machine was designed to be easy to maintain and repair, with easy access to all components.

viii. Cost: The cost of the machine was reasonable and affordable for the target market, taking into account factors such as production capacity, level of automation, and material costs.

3.3 Design Calculations

The machine was designed and calculated using assumptions and theories with detailed consideration of the parts.

3.3.1 Determination of throughput capacity

To effectively determine the sizes of the screw, the throughput capacity is important to ensure that the material pressure exerted on the screw is within the design. The throughput capacity is calculated using equation 3.1 given by (Kurmi and Gupta, 2005).

$$Q_t = \frac{\mathrm{m}}{\mathrm{t}} \tag{3.1}$$

Where;

Q_t = Throughput capacity (kg/h)

m = Assumed mass of the groundnut paste to be processed per day is 500 kg, for an hour the machine can process 62.5 kg. Therefore the theoretical capacity is 62.5 kg/h

t= time taken (h).

3.3.2 Design of screw

The screw conveyor in Figure 3.1 is the integral part of the extruder; it is a conveyor that is made up of worm wound round a cylindrical shaft (Khurmi and Gupta, 2005).

Figure 3.1: Screw conveyor

3.3.3 Determination of volumetric flow rate

The volumetric flow rate is the volume conveyed by the screw per unit time. It is also an important parameter of screw design. It can be calculated using the equation 3.2 given by Saha *et al.* (2023).

$$\mathrm{V} = \frac{Q_t}{\rho} \tag{3.2}$$

Where;

ρ = is the density of the paste (1200 kg/m³)

V = is the volumetric flow rate (m^3/s)

Q_t = is the throughput capacity (kg/h).

3.3.4 Determination of moisture content

The moisture contents of the groundnut sample were determined by oven drying method. 250 g of each sample were dried till a constant weight was achieved after three consecutive time of weighing (Nielsen, 2010). A digital measuring scale with accuracy of 0.5x to 1.5x in the Crop Processing and Storage Laboratory of the Agricultural and Bioresources Engineering Department Futminna was used in weighing the sample before and after the drying to determine the loss in weight which also represents moisture loss. Moisture content can be calculated using equation 3.3 given by Ayanoglu *et al.* (2023).

$$\mathrm{MC} = \frac{\mathrm{w-d}}{\mathrm{w}} \times 100 \tag{3.3}$$

Where;

MC = Moisture content (%)

w = weight when wet

d = weight when dry

3.3.5 Determination of bulk density

Bulk Density (BD), represented in g/cm3, serves as an inverse measure of expansion. The measurement of BD is conducted using the approach described in Equation 3.4 by Tadesse *et al.* (2019) for bulk pieces of extrudates, by taking them in a specified volume jar or cylinder. This method allows for the determination of the extrudates' density, indicating how closely packed or expanded the material is.

$$\text{Density}=\frac{\text{Mass}}{\text{volume}} \quad (\text{g/cm}^3) \tag{3.4}$$

Where;

ρ = density of the groundnut paste = 1200 kg/m^3

m = mass of groundnut paste = 62.5 kg

v = volume of the paste (m^3)

3.3.6 Determination of screw speed

The quantity of the paste that will be extruded by the machine depend the speed of the screw, which determine free flow of materials inside the barrel without sticking to the barrel and without burning the material. Equation 3.5 and 3.6 given by Mishra *et al.* (2022) can be used to calculate the screw speed.

$$Q_t = \frac{\pi(\mathrm{D}^2 \times \mathrm{N})}{4} \tag{3.5}$$

Making speed of the screw subject;

$$\mathrm{N} = \frac{4 \times Q_\mathrm{t}}{[\pi \times \mathrm{D}^2 \times \mathrm{V}]} \tag{3.6}$$

Where;

Q_t = Throughput capacity (kg/h)

D = The diameter of the screw (mm)

V = The volumetric flow rate of the materials (m^3/s)

N = Screw speed

3.3.7 Determination of screw diameter

Due to the significance of screw threads in machine elements, the measurement and inspection of screw diameter have been extensively discussed. This measurement serves as a critical factor for the successful conveyance of groundnut paste and ensures the provision of the necessary pressure for a mechanically acceptable design. Equation 3.7 given by (Feuerbach and Thommes, 2021) can be used to calculate the screw diameter.

$$D = \sqrt{\frac{(4Q_t)}{(\pi \rho N)}} \tag{3.7}$$

Where;

Q_t= Throughput rate (kg/h)

ρ = Density of the paste (kg/m^3)

N = Screw speed (rpm).

3.3.8 Determination of screw pitch

The pitch of the screw is to serve the function of providing adequate clearance and shearing of the material conveyed between the screw and the wall of the barrel. The pitch of the screw can be calculated using the Equation 3.8 as cited by Hou *et al.* (2022).

$$P = \pi \times \frac{D}{N_t} \tag{3.8}$$

Where;

P = pitch of the screw (mm)

D = screw diameter (mm)

N_t = number of threads

3.3.9 Determination of barrel length

The barrel length is also important factors that affect the extrusion process. The barrel diameter should be slightly larger than the screw diameter to allow for material flow (Khurmi and Gupta, 2005). The barrel length can be calculated using Equation 3.9.

$$L_b = Ls + 4 \times D \tag{3.9}$$

Where;

L_b = barrel length (mm)

Ls = screw length (mm)

D = screw diameter (mm)

3.3.10 Determination of barrel shear rate

Estimate the shear rate: The shear rate is the rate at which the material is sheared or deformed in the barrel. Assuming a shear rate of 1000 kg/s, the shear stress can be estimated using the power law model for non-Newtonian fluids (Hammer *et al.,* 2022) as stated in Equation 3.10.

$$\tau = K \times \gamma^N \tag{3.10}$$

Where;

τ is the shear stress (N/m^2)

γ is the shear rate (m/s)

K is the consistency index, (s^{-1})

N is the flow behaviour index.

3.3.11 Determination of extrusion pressure

This is the pressure required to press the material out of the barrel through the mould patterns in order to produce the desired shapes. The extrusion pressure can be estimated using the given formula in Equation 3.11 (Fadeyibi *et al.*, 2016).

$$P_e = \tau \times \left(\frac{D}{2}\right) \tag{3.11}$$

Where;

P_e =extrusion pressure (Pa)

D = the screw diameter (mm)

τ = shear, (N/m^2)

3.3.12 Determination of compression ratio

The compression ratio has to be established not just to feed enough solid polymers to fill the screw, but also to introduce enough shear heating in the screw to complete melting. The compression ratio of the extruder is calculated using Equation 3.12 (Fadeyibi *et al.*, 2016).

$$Cr = \left(\frac{D_f}{D_c}\right)^2 \tag{3.12}$$

Where;

D_f = Diameter of the Feed Zone is the diameter of the screw at the beginning of the Feed zone (usually the hopper).

Dc = Diameter of the Compression Zone is the diameter of the screw at the end of the Feed zone and the beginning of the compression zone.

A screw diameter of 0,053 m was assumed, and an extruder with a feed zone of length 3 times the diameter was designed. Assuming that the diameter of the feed zone is equal to the diameter of the screw at the hopper, which is 0.053 m.

To determine the diameter of the compression zone, the empirical rule of thumb that the diameter of the compression zone should be 75-85 % of the screw diameter was used. a value of 80 % was used for the compression zone diameter.

3.3.13 Power requirement for motor selection

The design for motor output power facilitates the appropriate selection of a motor with sufficient power to start and run the machine at its full load capacity. The power required by the extruder screw conveyor can be determined using a Equation 3.13 as provided by Olalusi *et al.* (2022). This calculation allows for the proper sizing and selection of the motor, ensuring it can handle the required workload and operate the machine effectively.

$$\mathrm{P = 0.7355CIQ} \tag{3.13}$$

Where,

P = Power required by the extruder kW

C = Coefficient constant for conveyed material, 0.3

l = Length of the shaft m

Q_t = Theoretical capacity of the machine kg/h

3.3.14 Determination of volume of hopper

To determine the hopper dimensions, the trapezoidal hopper is characterized by its top and bottom widths (b1 and b2, respectively), the height of the trapezoid (h), and the length of the hopper (L). The dimensions of the hopper can be determined based on the desired capacity and material flow rate. Assuming a hopper angle of repose of 35 degrees, a top width of 200 mm, a bottom width of 150 mm, and a height of 300 mm are recommended. Figure 3.2 shows the hopper.

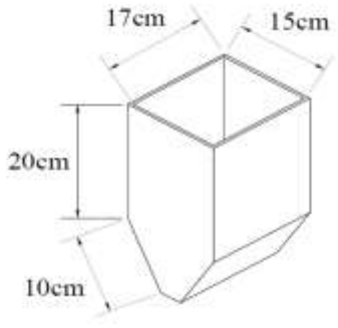


Figure 3.2: Hopper of the machine

3.3.15 Hopper opening

The hopper can be calculated using Equation 3.14, 3.15 and 3.16 given by Khurmi and Gupta (2005).

$$H_o = \frac{(b1+b2)}{2} \times h \times L \tag{3.14}$$

Where;

H_o = hopper opening

b1 = 200 mm

b2 = 150 mm

h = 300 mm

L = ?

Secondly, Area of the trapezoidal section of the hopper

$$A = W_a \times h \tag{3.15}$$

Lastly, Determination of Volume of hopper;

$$V = A \times L \quad (3.16)$$

3.3.16 Frame

The iron frame of the machine was fabricated in an L shape to ensure it possesses the necessary strength and rigidity. For this purpose, an iron steel section measuring 130×30×30 mm was used in constructing the frame. This design choice enhances the structural integrity of the machine, providing stability and support during its operation. Figure 3.3 shows the frame.

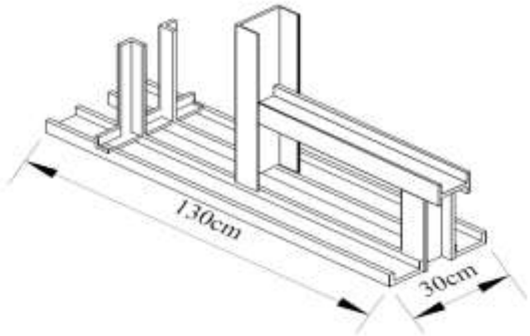


Figure 3.3: Frame of the machine.

3.3.17 Cutter

The cutter is a shaft that has its own gear that is connected to the gear driving the auger screw with the aid of an electric motor. And it is made of copper wire. It is for cutting the moulded groundnut cake. Figure 3.4 shows the cutter.

Figure 3.4: Cutter

3.3.18 Die plate

The extruder has a conical shape with a straight distance that exerts pressure and forms the material as it passes through the hole, resulting in the production of the final product (pellets). The dimensions of the entry and effective hole thickness can be adjusted to accommodate experimental treatment ratios and control specifications for the obtained extrudates. Figure 3.5 shows the Die plate

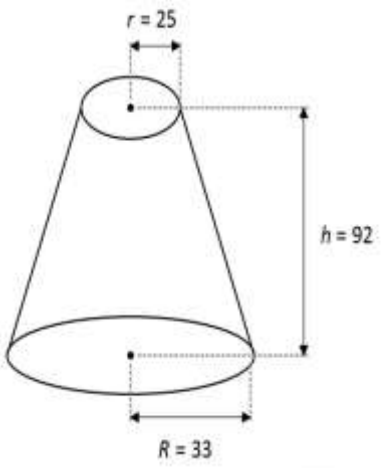


Figure 3.5: Die plate

To calculate the volume of paste that will pass through the small radius the Equation 3.17 was used:

$$V = \frac{1}{3}\pi(R_1^2 + R_1 r_2 + r_2^2)h \tag{3.17}$$

3.3.19 Design of gear drive

The machine gear is driven by a 1430 rpm motor, which is connected to a reduction gear with a ratio of 1:20. This reduction gear reduces the motor's speed by 70 rpm, resulting in an effective output speed of 1360 rpm (1430 rpm - 70 rpm) for the machine's operation. This reduction in speed occurs via a gear box before it is transmitted to the shaft, allowing the machine to operate at the desired speed for its intended function. In this setup, the smaller gear is attached to the motor and engages with the larger gear on the shaft. The larger gear, in turn, is linked to a gear system responsible for controlling the screw and the cutter. The primary motivations behind utilizing the gear drive are its cost-effectiveness in terms of maintenance. Furthermore, the gear transmission is adept at absorbing shocks and mitigating the impact of vibratory forces, ensuring smooth and stable operation of the machine (Olalusi *et al.*, 2022).

3.3.20 Determination of gear drive

In figure 3.6, the gear was designed to transfer mechanical power between rotating shafts. In the context of this machine, a spur gear is deemed appropriate due to its cost-effectiveness. The pitch line velocity, as defined by Khurmi and Gupta (2005), is used in this context to analyze the gear's performance and characteristics. Equation 3.18 and 3.19 was used to determining the relationship between the speed and the gear teeth.

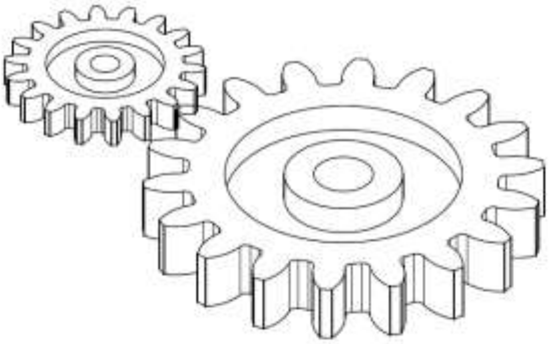


Figure 3.6: Machine Spur Gear

$$V = N_1\omega_1 = N_2\omega_2 \quad (3.18)$$

$$\omega_2 = \frac{N_1\omega_1}{N_2} \quad (3.19)$$

Where;

N_1 = Number of teeth of driving gear,

ω_1= Speed of motor and the extruder shaft, (rpm)

ω_2 = Diameter of extruding Screw, (mm)

N_2 = Number of teeth of driven gear

3.3.21 Bearing selection

The selection of bearing for the extruder was bored depend on various factors such as load, speed, temperature, and operating conditions. The bearing used in the construction of the machine is ball bearing.

3.3.22 Determination of load on the bearing

To determine the load on the bearings, the load on the bearings is a function of the force required to extrude the groundnut material and the speed at which the extruder operates. Assuming a maximum extrusion pressure of 25 MPa, a screw diameter of 53 mm, and a rotational speed of 70 rpm, the load on the bearings can be calculated using the Equation 3.20 (Bekaert *et al.*, 2021).

$$\mathrm{L} = \frac{\mathrm{E}}{(2 \times \pi \ \mathrm{S})} \tag{3.20}$$

Where;

L = the load bearing on the bearing (N)

E = extrusion pressure (MPa)

S = speed of the screw shaft (rpm)

3.3.23 Determination of feed rate

Feed rate is the mass of paste fed into the machine. Feed rate can be calculated using equation 3.21 given by (Kurmi and Gupta, 2005).

$$F_r = Q_t = \frac{m}{t} \tag{3.21}$$

Where;

F_r = Feed rate (kg/min)

Q_t = Throughput capacity (kg/h)

m = mass (g)

t = time

3.4 Fabrication and Assembly of Machine

The fabrication process involves several steps, including metal cutting, welding of the parts, and assembly. The hopper, a vital component of the machine, is constructed from four stainless steel plates that are welded together, slanting towards the opening to create a trapezoidal cross-section. The hopper is designed with two openings to facilitate the input and flow of materials during the operation of the machine. The larger opening of the hopper is used for introducing the groundnut paste into the machine, while the smaller hopper opening serves to connect the hopper to the barrel. This design allows for a controlled and efficient flow of the groundnut paste through the machine during the processing and moulding stages. The fabrication process begins by marking the plates with dimensions of 17 cm by 15 cm for the larger hopper opening and 10 cm by 10 cm for the smaller lower opening, with a height of 30 cm. After marking, the sheets are cut accordingly, and the plates are then welded together to form a trapezoidal shape. Following the welding, the surface is smoothed using an electric grinding machine.

Barrel that houses the screw shaft is welded to the hopper and the shaft has a spur gear of 36 teeth that is driving the cutter shaft gear of 44 teeth, an electric motor of 1 hp was used to transmit the motion to the gear. Bearing were used to join the frame, cutter, shaft and the screw shaft together. The bearing is welded to the frame with the aid of welding machine. The support frame is made of mild steel and has length of 130 cm, height of 30 cm and width of 30 cm.

The isometric, orthographic and the exploded views of the develop *Kulikuli* machine with the aid of AutoCad were presented in Figures 3.7, 3.8 and 3.9 respectively.

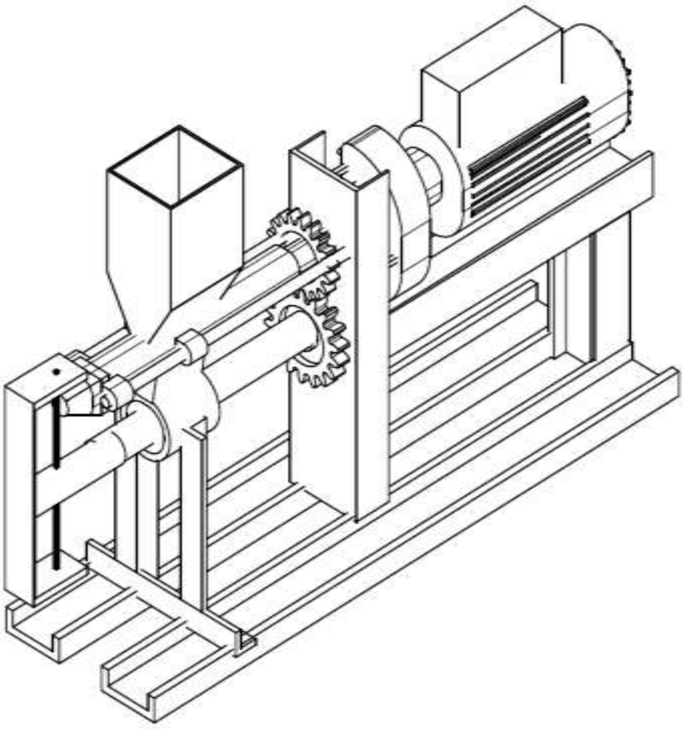
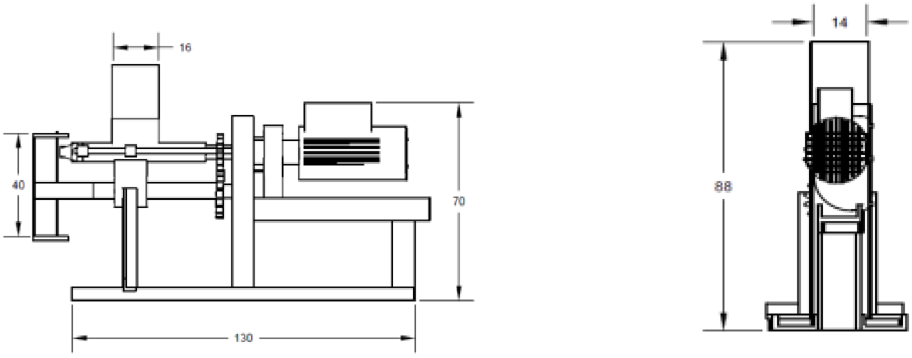
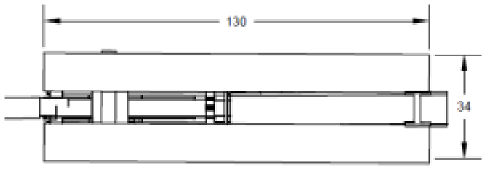


Figure 3.7: Isometric View of Groundnut Cake Moulding Machine.



Side view **Elevation**



Plan view

Figure 3.8: Orthographic Views of the Groundnut Cake Moulding Machine.

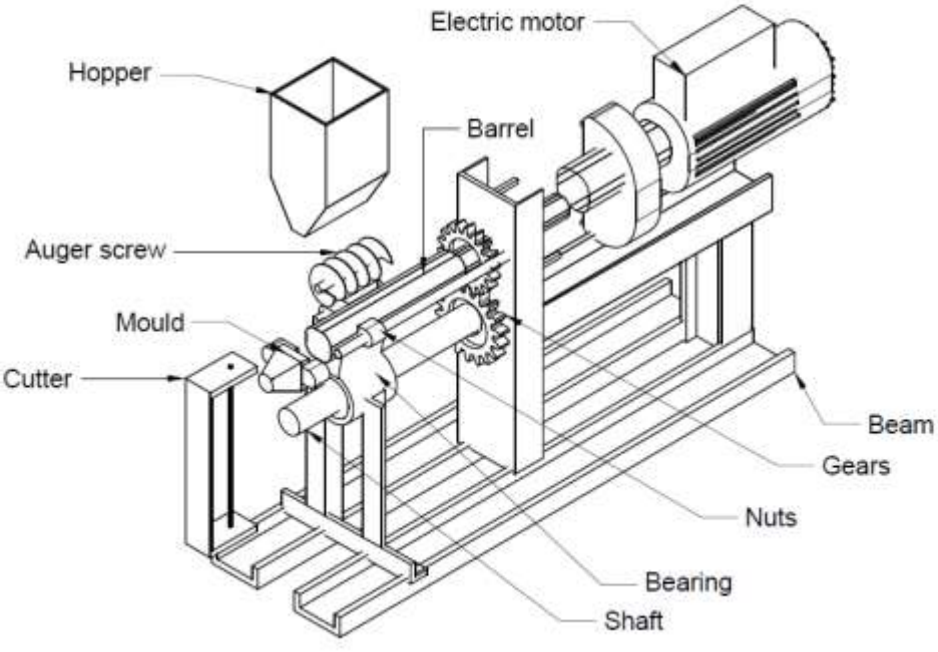


Figure 3.9: Exploded View of Groundnut Cake Moulding Machine

3.5 Description and Principles of Operation of the Developed *Kulikuli* Moulding Machine

Components were welded and bolt together for the fabrication of the machine. These parts include frame, hopper, electric motor, bearing, auger screw, cutter, barrel, assembly and the mould. The moulding machine is designed for small scale industrial purpose with main consideration of being: inexpensive, portable, capable of accommodating medium sized specimen and has standard operational procedure.

The principles of the operation The machine starts with feeding the groundnut paste through the hopper into the machine. The hopper functions as the inlet point and the temporary holder of the paste. Paste is then fed from the hopper to the barrel through gravity. The barrel is a medium housing that gives support to the screw auger. The screw also known as auger conveys the paste, the screw consists of two zones, the feeding zone and the discharge zone. In the feeding zone, the orientation of the paste remains unchanged as it is transferred to the subsequent zone known as the metering zone. Here, the paste is ready for injection. Also, after injection, the cutter cuts the moulded paste as it Ejected out of the mould. Finally, the moulded product is ready for frying.

3.6 Bill of Engineering Measurement and Evaluation (BEME)

Table 3.1 shows the BEME for the developed *Kulikuli* moulding machine. The total production cost was estimated from the addition of the materials costs, all the parts used either purchased or fabricated, labour costs (workers or manufacturer used to assemble and operate the machine and transportation) and manufacturing overhead (utility) costs. The cost of workmanship, ingredients used for test running and standardization of the fabricated single screw extruder were estimated for two hundred and twenty thousand naira (₦220,000).

Table 3.1: Bill of Engineering Measurement and Evaluation (BEME)

S/N	Materials	Quantity	Rate	(N)Amount
1.	4″ H-section beam	1 length	28,000	28,000
2.	2″ Angle bar	1 length	7,000	7,000
3.	Stainless steel pipe	0.6m	10,000	10,000
4.	Stainless steel 4mm plate	$\frac{1}{4}$ sheet	40,000	40,000
5.	Stainless steel 25mm diameter shaft	0.3m	6,000	6,000
6.	Mild steel 30mm diameter shaft	0.6m	2,000	2,000
7.	Meshing Gears	2	3,000	6,000
8.	Bearing	4	1,500	6,000
9.	Gear motor 750 watts	1	65,000	65,000
10.	Bolt and Nuts	1 dozen	1,200	1,200
11.	Paint	1 litre	3,000	3,000
12.	Thinner	1 litre	3,000	3,000
13.	Threaded shaft	1m	4,000	4,000
14.	6mm Diameter rod	2m	4,000	4,000
15.	Workmanship			34,000
	Total			**220,000**

3.7 Performance Evaluation of the *Kulikuli* Moulding Machine

The machine was first run under no load condition using an electric motor of 1.5hp to ascertain the smoothness of operation for the machine rotating parts. Three different feed rates were used to get the moulding capacity of the machine. Testing of the machine was targeted at evaluating its moulding efficiency, actual capacity and percentage recovery rate. The results obtained were analysed using analysis of variance (ANOVA).

3.7.1 Determination of actual capacity

This is the quantity in kilogram (kg) of the material that was fed and processed by the machine in a given time. Equation 3.22 given by Khurmi and Gupta (2005) is used to calculate the actual capacity of the machine.

$$Q_a = \frac{\mathrm{m}}{\mathrm{t}} \tag{3.22}$$

Where;

Q_a = Actual capacity (kg/h)

m = mass of the groundnut paste (g)

t = Time taken (h)

3.7.2 Percentage recovery (%)

The percentage recovery was determined using the Equation 3.23 (Chikwado, 2013).

$$\%\ \text{Recovery} = \frac{\text{Total mass of paste output from the Machine}}{\text{Total mass of paste Input}} \times 100 \tag{3.23}$$

3.7.3 Efficiency of the machine (η %)

The efficiency of the machine was determined according to (Chikwado, 2013). The efficiency is calculated using Equation 3.23.

$$\eta\ \% = \frac{\text{Total mass of extruded } \mathit{Kulikuli} \text{ produced}}{\mathit{Total\ mass\ of\ paste\ input}} \times 100 \tag{3.24}$$

3.8 Experimental Design

The Study was conducted using a D-optimal design to evaluate the effect of three parameters; screw speeds (60-80 rpm), moisture content (5-15 %) and die shape (square, circular, and cylindrical) on the dependent variable of the moulded groundnut cake. The independent variables, machine efficiency, throughput capacity, cake thichness of the groundnut cake moulding machine were measured as the response. A layout was obtained by the process of randomization showing the different combination of dependent and independent variables. The collected data were analyzed using response surface methodology with a D-optimal design in Design Expert 11.1.2.0 software. The design consisted of 2 numerical independent variables: moisture content and screw speeds, each at three levels, and one categorical variable representing the mould shape, also at three levels. The fitness of the model was assessed by conducting an analysis of variance (ANOVA), which helped evaluate how well the model represents the relationships between the independent and dependent variables. Through ANOVA, interactions between the various independent variables and their impact on the dependent variable were identified, providing valuable insights into the significance and influence of each factor on the outcome. In assessing the goodness of fit for the second-order equation, the coefficient of determination (R^2) was utilized. The statistical significance of the model was determined through an F-test, where terms with a significance level of $P \leq 0.05$ were considered significant. An R^2 value of 0.6 was accepted for predictive purposes, indicating an acceptable level of accuracy for the model's predictions (Asfaram *et al.,* 2015).

To visualize the interactive effects of the independent variables, 3-D response surfaces were employed. These surfaces allowed for a better understanding of how the variables interacted with each other and how they influenced the dependent variable.

Table 3.3 and Table 3.4 provide the experimental design details, indicating the levels of the independent variables used in the study. This table outlines the specific conditions under which the experiments were conducted, enabling researchers to systematically investigate the effects of different factors on the response variable.

Table 3.3: Experimental Design Details Indicating the Levels

Factor	Name	Units	Type	Mini	Max	Coded Low	Coded High	Mean	Std. Dev.
A	A:Speed	RPM	Numeric	60	10	-1 ↔ 7.00	+1 ↔ 10	8.91	1.69
B	B: MC	%	Numeric	80	15	-1 ↔ 5.04	+1 ↔ 15	7.04	2.19
C	C: Shape		Categoric	Square	Circular			**Levels:**	3

Table 3.4: Specific conditions under which the experiments were conducted.

Std	Run	Block	Factor 1 A: speed rpm	Factor 2 B:MC %	Factor 3 C:Shape	Response 1 Capacity Kg/h	Response 2 Bulk Density mm^3	Response 3 Cake Thickness	Response 4 Cutter Speed rpm
8	1	Block 1	6.59	13.00	Square				
18	2	Block 1	10.00	10.00	Circular				
13	3	Block 1	8.87	12.50	Square				
7	4	Block 1	6.43	10.00	Circular				
15	5	Block 1	10.00	15.00	Square				
17	6	Block 1	5.08	15.00	Square				
1	7	Block 1	10.00	15.00	Circular				
5	8	Block 1	5.00	15.00	Circular				
19	9	Block 1	5.00	15.00	Circular				
14	10	Block 1	10.00	13.13	Circular				
11	11	Block 1	5.08	15.00	Square				
10	12	Block 1	8.33	12.50	Circular				
4	13	Block 1	8.76	10.00	Square				
2	14	Block 1	10.00	15.00	Square				
6	15	Block 1	5.00	10.00	Square				
16	16	Block 1	5.00	10.00	Square				
9	17	Block 1	5.00	11.55	Circular				
3	18	Block 1	10.00	10.00	Circular				
12	19	Block 1	7.50	15.00	Circular				

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

A *Kulikuli* moulding machine was designed and fabricated with readily available and cheap materials. The components part of the machine were designed, fabricated and tested. From the design and calculations of the machine components, the design parameters are given in table 4.1.

Table 4.1 Technical Characteristics of the *Kulikuli* Machine

S/N	Parameters	Values
1	Actual Capacity	62.5 kg
2	Throughput flow rate	0.0173 kg/sec
3	Screw Diameter	53 mm
4	Screw Speed	17.36 rpm
5	Screw Pitch	56 mm
6	Barrel Length	312 mm
	thread	6 (assumed)
7	Extrusion Pressure	7.9 Kpa
8	Volumetric capacities	2.649×10^{-3} m^3 s-1
9	Compression ratio	1.8
10	Power requirement	1.021 kW
11	Hopper length	99 mm
12	Gear	52 teeth

The fabrication process include metal cutting, welding of the parts and assembling

After fabricating all the required components, they were assembled into an integral machine through welding and bolting. The picture of the developed machine is presented in Plate vi.

Plate VI: Picture of a *Kulikuli* moulding machine

The output gotten after testing of the machine with groundnut paste is shown in Plate vii

Plate VII: Picture of a moulded *Kulikuli*

4.1 Effect of Feed Rate on the Actual Capacity of the Machine

The result of the test conducted on the effect of feed rate on the actual capacity of the groundnut cake moulding machine at three different moisture levels is shown in Figure 4.1. The result indicates that at a moisture level of 5 %, the actual capacity of the machine increases with increasing feed rate, with the highest actual capacity recorded at a feed rate of 10 kg/min. However, at higher moisture levels of 10 % and 15 %, the actual capacity of the machine is more variable and does not follow a clear trend with increasing feed rate. At 15 % moisture content increase in feed rate increases the capacity but the capacity is less than that at 5 % moisture content. However, at moisture content of 10 %, there was a decrease in capacity when the feed rate increases from 5 to 7.5 kg/min. Overall it seems that the feed rate for maximizing the actual capacity of the machine may depend on the moisture level of the groundnut paste. It may be necessary to conduct further experiments to identify the most effective combination of feed rate and moisture level for achieving the desired capacity (Kishore *et al*., 2023). The tolerable maximum feed rate is calculated in real-time during operation to prevent mechanical shock and reduction in machining accuracy (Singh and Krishnaswamy, 2022). The moving distance of the working tool at each working block is obtained, and the actual feed rate is set to the allowable maximum rate when the commanded feed rate is faster.

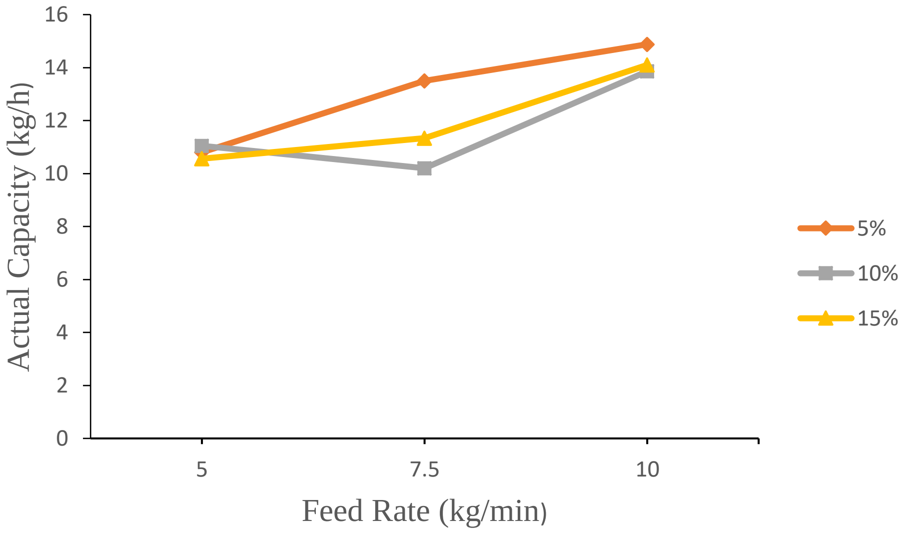


Figure 4.1: Effect of Feed Rate on Actual Capacity of Varying Moisture Content

4.2 Effect of Feed Rate on the Bulk Density of the Groundnut Cake

The result of the test conducted on the effect of feed rate on the bulk density of the moulded groundnut cake for moulding machine at three different moisture levels is shown in Figure 4.2. The result shows that the bulk density of the groundnut cake is affected by both the feed rate and the moisture level. At moisture content 5 %, the bulk density of the groundnut cake decreases slightly with increasing feed rate, with

1.08 kg/m^3 bulk density recorded at a feed rate of 5 kg/min. However, at higher moisture levels of 10 % and 15 %, the relationship between feed rate and bulk density is less clear and may even be reversed, with some feed rates leading to higher bulk densities than others. Furthermore, it seems that the optimal feed rate for minimizing the bulk density of the groundnut cake may depend on the moisture level of the groundnut paste. It may be necessary to conduct further experiments to identify the most effective combination of feed rate and moisture level for achieving the desired bulk density (Ajayi and Lateef, 2023).

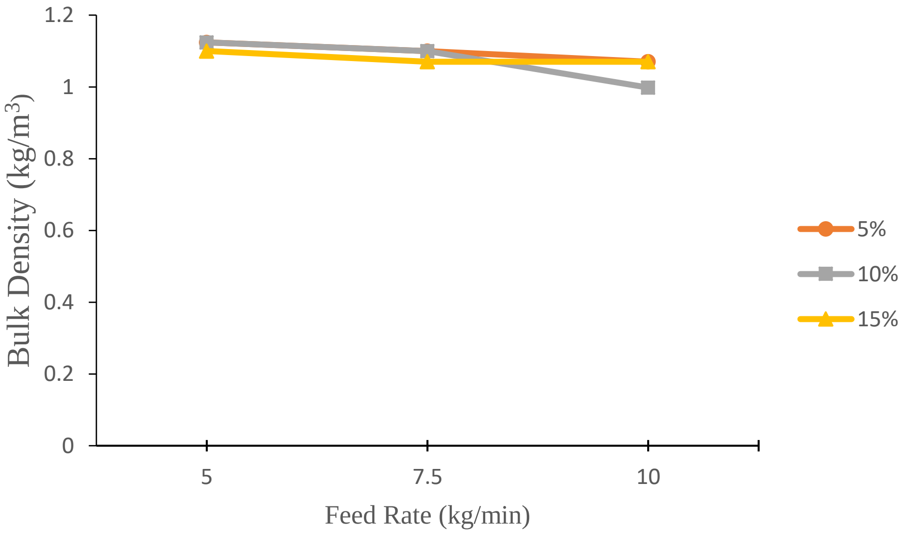


Figure 4.2: Effect of Bulk Density against Feed Rate of the Groundnut cake and Varying Moisture Content.

4.3 Effect of Feed Rate on the Cake Thickness

From the result of the effect of feed rate on the cake thickness shown in Figure 4.3, it can be observed that the relationship between the feed rate and the corresponding cake thickness at different moisture levels (5 %, 10 %, and 15 %) decrease in the cake thickness as the feed rate increases. At 5 % moisture level for instance, and feed rate of 5 kg/min, the cake thickness is 6.52 mm, while at 10 kg/min, the cake thickness reduces to 5.01 mm. This trend may be due to the fact that at higher feed rates, there is less time for the groundnut paste to solidify and form a thick cake. At 10 % moisture level, the trend is less clear, as there is some variation in the cake thickness across the different feed rates. For example, at a feed rate of 5 kg/min, the cake thickness is 5.003 mm, while at 10 kg/min, the cake thickness is 6.35 mm. This variation may be due to the complex interplay between the feed rate, moisture content, and other factors like the die shape and screw speed (Movahedi and Jamshidi, 2022).

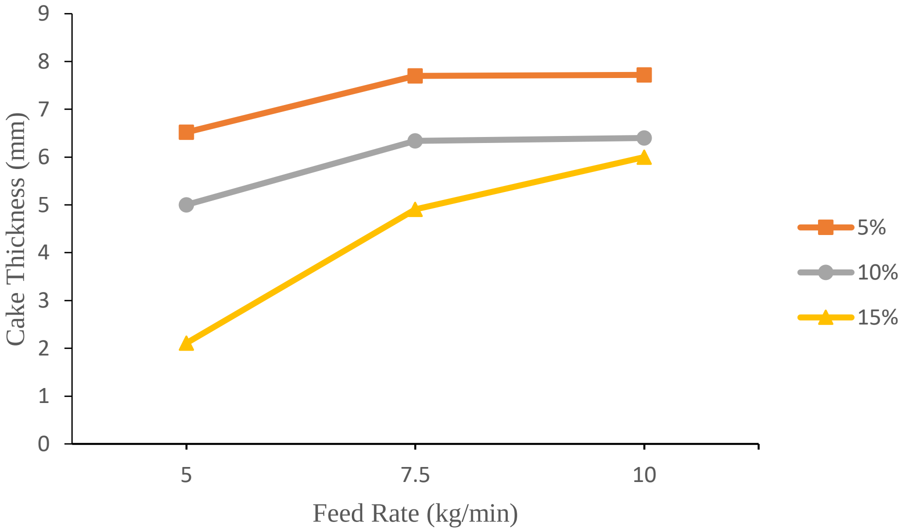


Figure 4.3: Relationships between Cake Thicknesses against Feed Rate and Varying Moisture Contents.

4.4 Effect of Speed on the Thickness of Groundnut Cake

Based on the results obtained for the effect of speed on the moulded cake thickness as shown in Figure 4.4, it can be observed that the speed has a significant effect on the cake thickness at different moisture levels. At 5 % moisture level, increasing the speed from 60 rpm to 70 rpm resulted in an increase in cake thickness from 3.0 mm to 5.0 mm, but a further increase in speed to 80 rpm caused a slight reduction in thickness to 7.7 mm. At 10 % moisture level, increasing the speed from 60 rpm to 70 rpm resulted in a slight increase in thickness from 2.4 mm to 2.8 mm, but a further increase in speed to 80 rpm resulted in a significant increase in thickness to 3 mm. At 15 % moisture level, increasing the speed from 60 rpm to 70 rpm resulted in a slight decrease in thickness from 2.23 mm to 2.01 mm, but a further increase in speed to 80 rpm resulted in a slight increase in thickness to 1.97 mm. Movahedi *et al.* (2022) assert that the thickness of the cake produced has strong correlation with the speed of the cake barter moulding machine.

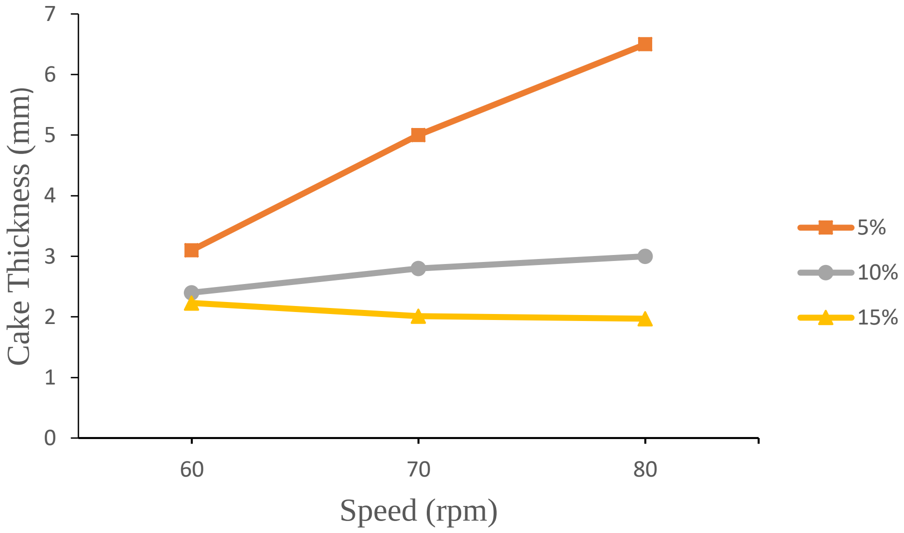


Figure 4.4: Effect of Speed on the Thickness of Groundnut Cake

4.5 Effect of Speed on the Bulk Density of the Groundnut Cake Paste

The results shown in Figure 4.5 depict that the effect of speed on bulk density is not consistent across different moisture levels. At 5 % moisture level, increasing speed leads to a decrease in bulk density, as seen in the decreasing values from 0.98 kg/m^3 to 1.0kg/m^3 as speed increases from 60 to 80 rpm. However, at 10 % moisture level, the bulk density remains relatively constant as the speed increases from 60 rpm to 80 rpm, with values ranging from 0.99 kg/m^3 to 1.124 kg/m^3. At 15 % moisture level, there is a slight increase in bulk density as the speed increases, with values ranging from 1.08 kg/m^3 to 1.14 kg/m^3 Consequently, the results suggest that the effect of speed on bulk density is dependent on the moisture content of the groundnut paste, with the highest moisture content of 10 % showing a slight increase in bulk density as speed increases to 80 rpm. This could be due to the fact that higher speeds may lead to more efficient extrusion and consolidation of the paste at higher moisture levels, resulting in higher bulk density. However, this trend is not comparably observed at lower moisture levels as obtained by Olalusi *et al.* (2022).

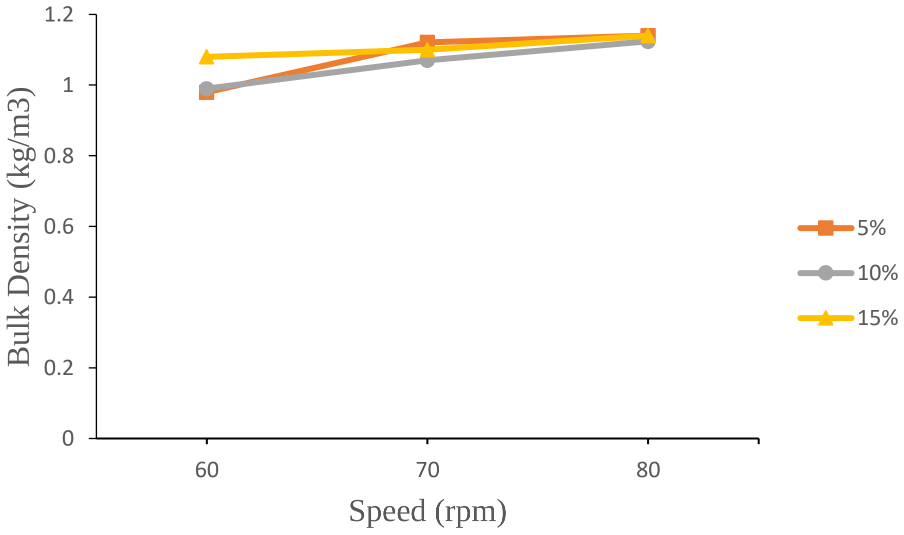


Figure 4.5: Effect of Speed on Bulk Density at Varying Moisture Content.

4.6 Effect of Speed on the Actual Capacity of the Machine

The results shown in Figure 4.6 on the effect of machine speed on the actual capacity of the machine indicates that the actual capacity of the machine increases with increasing speed and moisture content. For instance, at 5 % moisture level, increasing the speed from 60 rpm to 80 rpm resulted in an increase in actual capacity from 11.34 kg/h to 14.22 kg/h. Similarly, at 15 % moisture level, increasing the speed from 60 rpm to 80 rpm resulted in an increase in actual capacity from 10.56 kg/h to 15.42 kg/h. However, the effect of moisture content on actual capacity is not consistent. At 80 rpm, the actual capacity increased from 11.04 kg/h at 10 % moisture level to 13.86 kg/h at 15 % moisture level. But at 60 rpm, the actual capacity decreased from 10.2 kg/h at 10 % moisture level to 11.34 kg/h at 15 % moisture level. These results indicate that the machine's performance is affected by both speed and moisture content. The highest actual capacity was achieved at 80 rpm and 15 % moisture level.

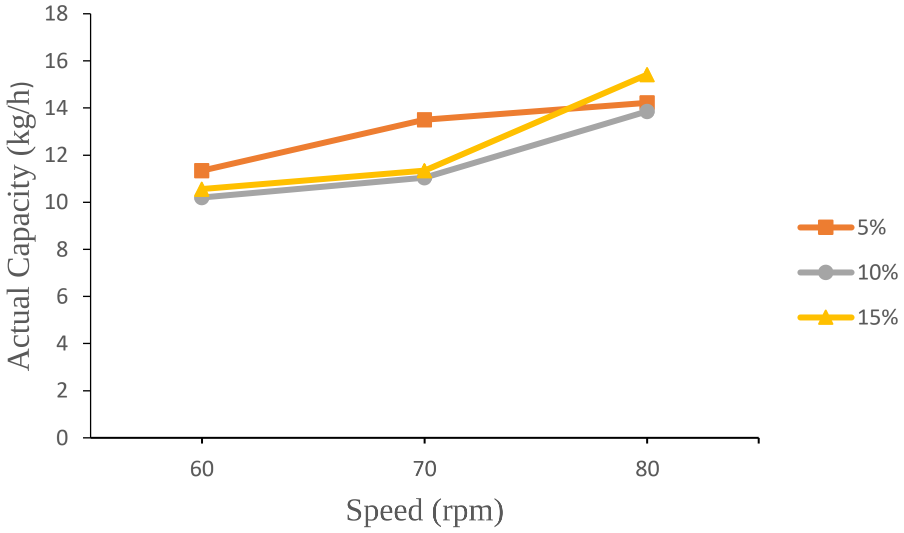


Figure 4.6: Effect of Machine Speed on Actual Capacity at Varying Moisture Content

4.7 Effect of Die Shapes on the Actual Capacity of the Machine

Based on the result shown in Figure 4.7, the different die shapes appear to have a significant effect on the machine capacity at different moisture levels. At 5 % moisture level, the circular die shape has the lowest capacity (10.8 kg/h), while the cylindrical die shape has the highest capacity (14.88 kg/h). The rectangular die shape has an intermediate capacity of 13.5 kg/h. At 10 % moisture level, the circular die shape has the lowest capacity (11.1 kg/h), while the rectangular die shape has the highest capacity (10.2 kg/h). The cylindrical die shape has an intermediate capacity of 10.8 kg/h. At 15 % moisture level, the circular die shape has the lowest capacity (11.22 kg/h), while the cylindrical die shape has the highest capacity (15.42 kg/h). The rectangular die shape has an intermediate capacity of 14.1 kg/h. The observed pattern suggests that the cylindrical die shape generally has the highest capacity, followed by the rectangular shape, and then the circular shape. The difference in capacity between the different die shapes could be due to variations in the surface area of the die shapes, which could affect the rate at which the groundnut paste is extruded. Additionally, the shape of the die may influence the flow of the groundnut paste through the die, which could affect the density and consistency of the extruded cake (Olalusi *et al.*, 2022).

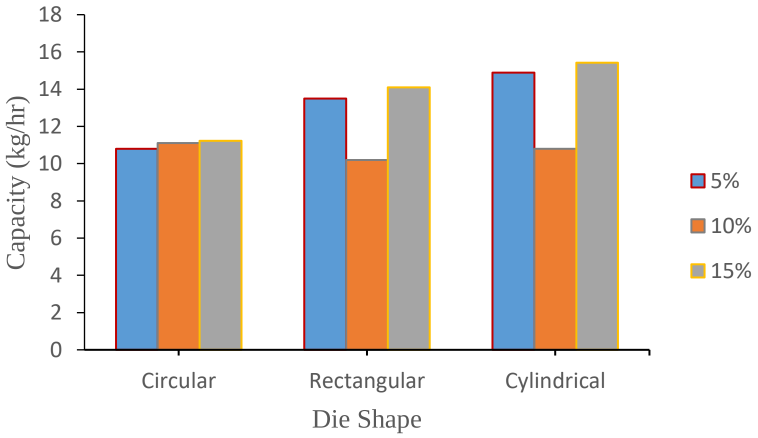


Figure 4.7: Relationship between Actual Capacity against Moisture Content, with varying Die Shapes.

4.8 Effect of Die Shapes on the Bulk Density of the Groundnut Paste

The result in Figure 4.8 represents the effect of die shapes on the bulk density of the cake paste at three different moisture levels (5 %, 10 %, and 15 %). The results show that there is a variation in bulk density of the cake paste based on the shape of the die used. At 5 % moisture level, the circular die produced the lowest bulk density of 0.98 kg/m^3, while the cylindrical die produced the highest bulk density of 1.14 kg/m^3. The rectangular die produced an intermediate value of 1.124 kg/m^3. At 10 % moisture level, the cylindrical die produced the highest bulk density of 1.124 kg/m^3, while the rectangular die produced the lowest bulk density of 0.998 kg/m^3. The circular die produced an intermediate value of 1.1 kg/m^3. At 15 % moisture level, the cylindrical die produced the highest bulk density of 1.14 kg/m^3, while the rectangular die produced the lowest bulk density of 1.07 kg/m^3. The circular die produced an intermediate value of 1.14 kg/m^3. These results suggest that the shape of the die used has a significant effect on the bulk density of the cake paste, and choosing the appropriate die shape based on the desired bulk density is important. It is also worth noting that the effect of the die shape on bulk density is dependent on the moisture level, as different moisture levels may require different die shapes to achieve the desired bulk density. The die shape can have an impact on the bulk density of the extrudate (Shelar and Gaikwad, 2019), although it is not the primary factor influencing bulk density in extrusion processes. Other process parameters, material properties, and operating conditions also play important roles (Nagaraju *et al.*, 2020).

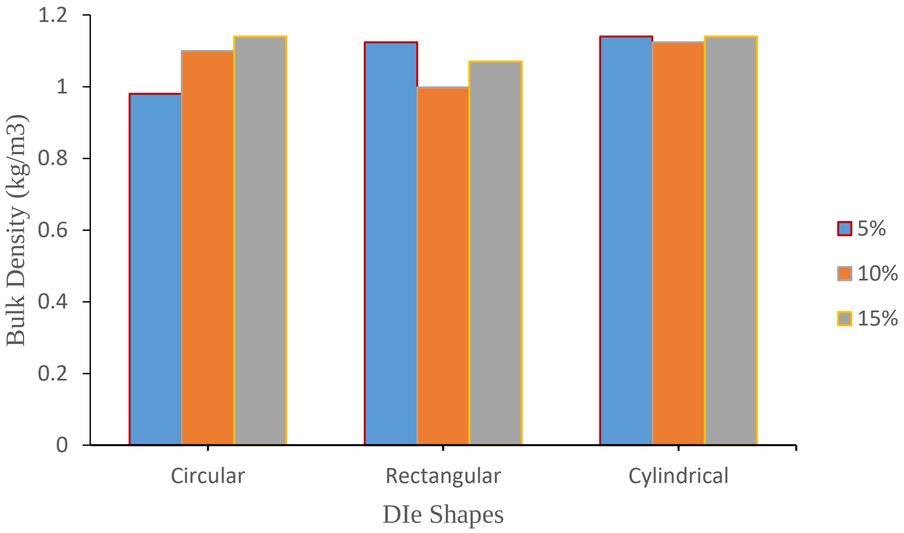


Figure 4.8: Relationships between Bulk Density and Moisture Content with varying Die Shape of the Groundnut Paste.

4.9 Effect of Die Shapes and Thickness of the Groundnut Cake Paste

From the result shown in Figure 4.9, it is observed that the die shape has a significant effect on the thickness of the groundnut cake paste at different moisture levels. The cylindrical die produced the thickest cake paste at all moisture levels, followed by the rectangular die and then the circular die. This may be due to the fact that the cylindrical die has a larger surface area, which allows for more paste to be extruded, resulting in a thicker cake. At 5 % moisture level, the circular die produced the thinnest cake paste with a thickness of 2.4 mm, while the cylindrical die produced the highest thickness of 7.7 mm. At 10 % moisture level, the rectangular die produced the thinnest cake paste with a thickness of 5.03 mm, while the cylindrical die produced the thickest cake paste with a thickness of 7.7 mm. At 15 % moisture level, the circular die produced the thinnest cake paste with a thickness of 2.4 mm, while the cylindrical die produced the thickest cake paste with a thickness of 7.13 mm. The result implies that the choice of die shape can be used to control the thickness of the groundnut cake paste produced. The cylindrical die may be suitable for producing thicker cakes, while the circular die may be suitable for producing thinner cakes. In the production of breakfast cereals, the die shape can determine the thickness and shape of the cereal flakes or puffs, which affects their crispness and mouth feel (Cork *et al.*, 2022).

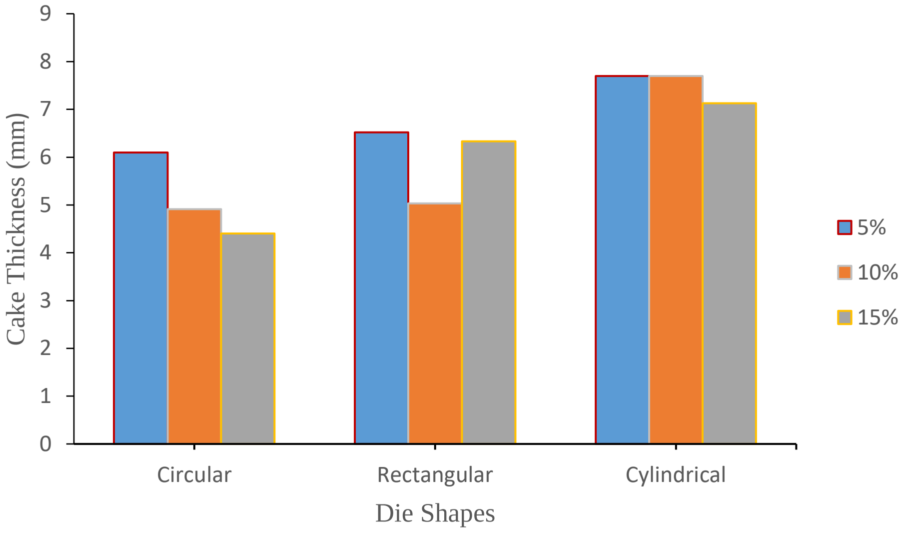


Figure 4.9: Effect of Die Shapes and Cake Thickness at Varying Moisture Contents

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Due to the time consuming nature of using traditional method to mould *Kulikuli*, a *Kulikuli* moulding machine which consist majorly of hopper, screw, mould, barrel and cutter was successfully designed, fabricated and evaluated. The groundnut paste moulding machine was found to be capable of producing groundnut cake with desirable physical properties, such as thickness, bulk density, and actual capacity.

2. The machine was found to have a moulding efficiency of 90 %, feed rate of 7.5kg/min, a moisture content of 10 %, a speed of 60 rpm and a cylindrical die shape.

3. Out of the three shapes that were used in the evaluation, the cylindrical die produced the highest actual capacity of 15.42 kg/h and bulk density of 1.14 kg/m^3, while the circular die produced the lowest capacity of 11.22 kg/h.

5.2 Recommendations

Manufacturers of groundnut cake processing machines should take into consideration the effect of the die shape on the cake thickness, bulk density, and actual capacity of the machine in the design and fabrication of the machines.

Additional research should be undertaken to explore the impact of other factors, such as temperature and pressure, on the quality of the groundnut cake paste.

Additional investigations should be carried out to examine the influence of various parameters on the properties of the groundnut cake. These parameters include the moisture content and particle size of the groundnut seeds, as well as the type and quantity of binder used in the cake formulation.

5.3 Contribution to Knowledge

A *Kulikuli* moulding machine having a capacity of 62.5 kg/h was designed, fabricated and evaluated. The machine was found to have a moulding efficiency of 90 % at optimal operating condition at feed rate of 7.5 kg/min, a moisture content of 10 %, a speed of 60 rpm and a cylindrical die shape.

REFERENCES

Abdussalam, M. S. (2023). Productivity of groundnut (Arachis hypogaea l.) As influenced by variety and spacing in Ningi LGA, Bauchi State, Nigeria. *Journal of Agripreneurship and Sustainable Development*, 6(1), 65-72.

Aboki, P. M. (2015). Traditional and modern groundnut processing and marketing in North Central Nigeria. *A P.hd Thesis, University of Nigeria, Nsukka*, 1-145.

Adazebra, I. A. (2019). Evaluation of mutant genotypes of groundnut (*arachis hypogaea* l) for improved agronomic traits and stability (Doctoral dissertation). *Journal of Composite Materials*, 50(2), 325-336

Ajayi, V. A., & Lateef, A. (2023). Biotechnological valorization of agrowastes for circular bioeconomy: melon seed shell, groundnut shell and groundnut peel. *Cleaner and Circular Bioeconomy*, 100039.

Ayanoglu, M. O., Carlsson, L. A., & Du, E. (2023). Effects of void content on the moisture uptake and mechanical strength of a glass/epoxy composite. *Journal of Composite Materials*, 57(2), 325-336.

Ayoola, P. B., Adeyeye, A., & Onawumi, O. O. (2012). Chemical evaluation of food value of groundnut (Arachi hypogaea) seeds. *American journal of food and nutrition*, *2*(3), 55-57.

Awoke, M. U. (2003). Production analysis of groundnut, (*arachis hypogaea*) in Ezeagu local government area of Enugu state, Nigeria. *Global Journal of Agricultural Sciences*, 2(2), 138-142.

Asfaram, A., Ghaedi, M., Goudarzi, A., Soylak, M., & Langroodi, S. M. (2015). Magnetic nanoparticle based dispersive micro-solid-phase extraction for the determination of malachite green in water samples: optimized experimental design. *New Journal of Chemistry*, *39*(12), 9813-9823.

Bekaert, B., Penne, L., Grymonpré, W., Van Snick, B., Dhondt, J., Boeckx, J., and Vanhoorne, V. (2021). Determination of a quantitative relationship between material properties, process settings and screw feeding behavior via multivariate data-analysis. *International Journal of Pharmaceutics*, *602*, 120603.

Bordewijk, M., & Schifferstein, H. N. (2020). The specifics of food design: Insights from professional design practice. *International Journal of Food Design*, *4*(2), 101-138.

Chang, A. S., Sreedharan, A., & Schneider, K. R. (2013). Peanut and peanut products: A food safety perspective. *Food Control*, *32*(1), 296-303.

Chikwado, U. K. (2013). Development and performance test of poultry feed mixing and pelleting machine. *International Journal of Scientific Research*, *4*(6), 1161-1166.

Chokshi, R., & Zia, H. (2004). Hot-melt extrusion technique: a review. *Iranian journal of pharmaceutical research*, *3*(1), 3-16.

Christiano, J. P., Davis Standard, L., & Pawcatuck, C. (2012). Examination of the performance of a high speed single screw extruder for several different extrusion applications. In *Proceedings of the Annual Technical Conference—ANTEC, Orlando, FL, USA* (pp. 2-4).

Cope, C. W. (1998). *U.S. Patent No. 5,847,016*. Washington, DC: U.S. Patent and Trademark Office.

Cork, S. D., Blanchard, C., Mawson, A. J., & Farahnaky, A. (2022). Pulse flaking: Opportunities and challenges, a review. *Comprehensive Reviews in Food Science and Food Safety*, *21*(3), 2873-2897.

Crowther, B. G. (1998). *Rubber Extrusion: Theory and Development* (Vol. 105). iSmithers Rapra Publishing.

Dean, L. L. (2021). Peanut protein-processes and applications. A Review. *Journal of Nutritional Food Science*, *4*(2), 10-31.

Fadeyibi, A., Z. D. Osunde, G. Agidi, & E. C. Egwim. (2016). Design of single screw extruder for homogenizingbulk solids. *Agricultural Engineering International: CIGR Journal*, 18(4):222-231.

Feuerbach, T., & Thommes, M. (2021). Design and characterization of a screw extrusion hot-end for fused deposition modeling. *Molecules*, *26*(3), 590.

Gibbons, J., Ahnan-Winarno, A. D., Cordeiro, L., Winarno, F. G., & Xiao, H. (2021). Tempeh: A semicentennial review on its health benefits, fermentation, safety, processing, sustainability, and affordability. Comprehensive Reviews in Food Science and Food Safety, 20(2), 1717-1767.

Giles Jr, H. F., Mount III, E. M., & Wagner Jr, J. R. (2004). *Extrusion: the definitive processing guide and handbook*. William Andrew.

Girei, A. A., Dauna, Y., & Dire, B. (2013). An economic analysis of groundnut (Arachis hypogea) production in Hong local government area of Adamawa State, Nigeria. *Journal of Agricultural and crop Research*, *1*(6), 84-89.

Gonçalves, N. D., Teixeira, P., Ferrás, L. L., Afonso, A. M., Nóbrega, J. M., & Carneiro, O. S. (2015). Design and optimization of an extrusion die for the production of wood–plastic composite profiles. *Polymer Engineering and Science*, *55*(8), 1849 1855.

Hammer, A., Roland, W., Zacher, M., Kohl, S., & Berger-Weber, G. (2022). Experimental validation of non-Newtonian stratified co-extrusion prediction models using a digital process twin. *Polymer Engineering and Science*, *62*(12), 3902-3922.

Hou, H. L., Zhang, G. P., & Xin, C. (2022). Research on the bottom hole size of internal thread extrusion. *The International Journal of Advanced Manufacturing Technology*, *120* (1-2), 707-717.

Kishore, S. G., Rajkumar, P., Sudha, P., Deepa, J., & Pandiselvam, R. (2023). Optimization of process conditions of the neem fruit depulping machine for the production of premium quality seeds and oil. *Biomass Conversion and Biorefinery*, 1 13.

Kostic, M. M., & Reifschneider, L. G. (2006). Design of extrusion dies. *Encyclopedia of chemical processing*, *10*, 633-649.

Kurmi & Gupta, 2005, Fadeyibi, A. O. Z. A. G. E. C., Osunde, Z. D., Gbabo, A., and Egwim, E. C. (2016). Design of single screw extruder for homogenizing bulk solids.

Lebaal, N. (2019). Robust low cost meta-modeling optimization algorithm based on meta-heuristic and knowledge databases approach: Application to polymer extrusion die design. *Finite Elements in Analysis and Design*, *162*, 51-66.

Lewandowski, A., Wilczyński, K. J., Nastaj, A., & Wilczyński, K. (2015). A composite model for an intermeshing counter-rotating twin-screw extruder and its experimental verification. *Polymer Engineering and Science*, *55*(12), 2838-2848.

Lewandowski, A. (2011). Closely Intermeshing Counter-Rotating Twin Screw Extrusion of Polymers. *Challenges of Modern Technology*, *2*(1), 36-40.

Mishra, R., Aamiri, O. B., Satyavolu, J., & Kate, K. (2022). Effect of process conditions on the filament diameter in single screw extrusion of natural fiber composite. *Manufacturing Letters*, *32*, 15-18.

Mount III, E. (2010). Coextrusion equipment for multilayer flat films and sheets. In *Multilayer Flexible Packaging* (pp. 75-95). William Andrew Publishing.

Movahedi, H., & Jamshidi, S. (2022). New insight into hydrodynamic and cake erosion mechanism during rotating-disk dynamic microfiltration of concentrated bentonite suspensions at different salinity conditions. *Separation and Purification Technology*, *300*, 121844.

Nagaraju, M., Tiwari, V. K., & Sharma, A. (2020). Effect of extrusion on physical and functional properties of millet based extrudates: A review. *Journal of Pharmacognosy and Phytochemistry*, *9*(6), 1850-1854.

Nielsen, S. S. (2010). Determination of moisture content. *Food analysis laboratory manual*, 17-27.

Odetola, T., & Etumnu, C. (2013, July). Contribution of agriculture to economic growth in Nigeria. In *Proceeding: the 18th Annual Conference of the African Econometric Society (AES), Accra, Ghana 22nd and* (pp. 1-28).

Okoh, S. A., Amadi, U., Ojiya, E. A., & Ani, E. C. (2019). Impact of fiscal policy on agricultural productivity in Nigeria: An empirical analysis. *Journal of Business School*, *2*(3), 7-27.

Olalusi, A. P., Olaoye, S. A., Isa, J., Oyerinde, A. S., Ayo-Olalusi, C., & Adesuyi, D. O. (2022). Development and Performance Evaluation of a Single Screw Extruder for the Production of Floating Fish Feed. *Journal of Engineering Research and Reports*, *23*(12), 48-58.

Oyewole, O. A., & Isah, P. (2012). Locally fermented foods in Nigeria and their significance to national economy: a review. *Journal of Engineering Research and Reports*, *23*(12), 48-58

Padmanabhan, B. (2008). Understanding the Extruder Processing Zone: the heart of a twin screw extruder. *Plastics, Additives and Compounding*, *10*(2), 30-35.

Patel, A., Devraja, H. C., Sharma, P., & Singh, R. R. B. (2019). Food Technology II.

Rauwendaal, C. (2014). *Polymer extrusion*. Carl Hanser Verlag GmbH Co KG.

Saha, N., Klinger, J., Rowland, S. M., Dunning, T., Carpenter, D., Mills, Z., & Parks, J. (2023). Influence of feedstock variability on thermal decomposition of forest residue in a screw feeder for high temperature conversion. *Fuel Processing Technology*, *245*, 107725.

Sakai, T. (2013). Screw extrusion technology-past, present and future. *Polimery*, *58*(11 12), 847-857.

Senanayake, S. A. M. A. N. S., & Clarke, B. (1999). A simplified twin screw co- rotating food extruder: design, fabrication and testing. *Journal of food engineering*, *40*(1-2), 129-137.

Shabangu, T. P. (2021). A Comparative Study of Swazi and Zulu Traditional Plant Use at Mkhondo and Edumbe, *South Africa. University of Johannesburg* (South Africa).

Shah, A., & Gupta, M. (2004). Comparison of the flow in co-rotating and counter-rotating twin-screw extruders. In *Antec-Conference Proceedings-* (Vol. 1, pp. 443-447). Unknown.

Shelar, G. A., & Gaikwad, S. T. (2019). Extrusion in food processing: An overview. *The Pharma Innovation Journal*, *8*(2), 562-568.

Singh, P., Bilyeu, L., & Krishnaswamy, K. (2022). Improving process sustainability by optimizing spray drying parameters: High oleic soymilk using response surface methodology. *Food and Bioprocess Technology*, *15*(4), 833-851.

Tadesse, S. A., Bultosa, G., & Abera, S. (2019). Functional and physical properties of sorghum-based extruded product supplemented with soy meal flour. *Cogent Food and Agriculture*, *5*(1), 1707608.

Tadmor, Z. (1966). Fundamentals of plasticating extrusion. I. A theoretical model for melting. *Polymer Engineering and Science*, *6*(3), 185-190.

Variath, M. T., & Janila, P. (2017). Economic and academic importance of peanut. *The peanut genome*, 7-26.

Wilczyński, K., Nastaj, A., & Wilczyński, K. J. (2013). Melting model for starve fed single screw extrusion of thermoplastics. *International Polymer Processing*, *28*(1), 34 42.

APPENDIX A

Determination of capacity

$\mathrm{C}_{th}=\frac{\mathrm{m}}{\mathrm{t}}$

(1)

$\mathrm{C}_{th}=\frac{62.5}{60\times60}=0.0173\mathrm{kg/sec}$

Determination of volumetric flow rate

$\mathrm{V}\ =\frac{\mathrm{C}_{th}}{\rho}$

(2)

$\mathrm{V}\ =\frac{0.0173}{1200}\ =\ 1.42\ \times 10^{-5}\mathrm{m}^3/s$

Determination of bulk density

Density (ρ) = $\frac{\mathrm{mass}}{\mathrm{volume}}$ (g/cm^3)

(3) $1200=\frac{62.5}{\mathrm{v}}\ \mathrm{v}=0.052\mathrm{m}^3$

Determination of Screw Speed

$\mathrm{C}_{\mathrm{th}}=\frac{\pi(\mathrm{D}^2\times\mathrm{N})}{4}$

(4)

$\mathrm{N}=\frac{4\times62.5}{(\pi\times53^2\times0.0173)}$

$\mathrm{N}=17.36\mathrm{rpm}$

Determination of Screw Diameter

$$\mathrm{D}\ =\sqrt{\frac{(4\mathrm{C}_{th})}{(\pi\rho\mathrm{N})}} \qquad (6)$$

In this case, the capacity is 62.5 kg/hr., which is equal to 0.017 kg/s. The density of paste is 1200 kg/m³, and we have already calculated the screw speed to be 13.56 rpm.

Substituting these values into the formula, we get:

$$\mathrm{D}\ =\frac{(4\ \mathrm{x}\ 0.017)}{(\pi\ \mathrm{x}\ 1200\ \mathrm{x}\ 13.56)}$$

$$D\ \approx\ 0.053\ m$$

So the calculated screw diameter is approximately 0.053m = 53mm

Determination of Screw Pitch

$$P = \pi \times \frac{D}{N_t}$$
(7)

Assuming a triple-flight screw (N_t =3), the pitch of the screw can be calculated as:
$$P = \pi \times \frac{0.053}{3} = 0.056\text{m}$$

$$P = 56\text{mm}$$

Determination of barrel length

$$L_b = Ls + 4 \times D$$
(8)

Assuming a screw length of 100 mm, the barrel length can be calculated as:

$$L_b = 100 + 4 \times 53 = 312 \text{ mm}$$

Determination of Barrel Shear Rate

$$\tau = K \times \gamma^N$$
(9)

Assuming a flow behaviour index of 0.5 and a consistency index of 5 Pa·s^n, the shear stress can be estimated as follows:

$$\tau = 5 \times (1000 \text{ s}^{-1})^{0.5} \tau = 158.1 \text{ Pa}$$

Determination of Extrusion Pressure

$$P_e = \tau \times \left(\frac{D}{2}\right)$$
(10)

$$P_e = 158.1 \times \left(\frac{0.1}{2}\right)$$

$$P_e = 7.9 \text{ kPa}$$

Determination of Compression ratio

$$Cr = \left(\frac{D_f}{D_c}\right)^2$$
(11)

$\mathrm{Dc} = 0.8 \times 0.053$

$\mathrm{D_c} = 0.0424$

Using this information, we can now calculate the compression ratio:

$\mathrm{Cr} = \frac{(0.053)^2}{(0.0424)^2} = 1.8$

So the compression ratio of the extruder is approximately 1.8

Power Requirement for Motor Selection

$\mathrm{P} = 0.7355\mathrm{CIQ}$
(12)

Assuming an efficiency of 90 %, the motor power required can be calculated as:

$\mathrm{P} = 0.80 \times 0.733 \times 0.3 \times 0.312 \times 62.5$

$\mathrm{P} = 1.021\mathrm{Kw}$

$\mathrm{P} = 1.36\mathrm{hp}$

Hopper Opening

$\mathrm{H_o} = \frac{(\mathrm{b1}+\mathrm{b2})}{2} \times \mathrm{h} \times \mathrm{L}$
(13)

Firstly, calculate average width of the hopper

$\mathrm{W_a} = \frac{(\mathrm{b_1}+\mathrm{b_2})}{2}$

$\mathrm{W_a} = \frac{(200+150)}{2}$

$\mathrm{W_a} = 175\mathrm{mm}$

Secondly, Area of the trapezoidal section of the hopper

$\mathrm{A} = \mathrm{W_a} \times \mathrm{h}$
(14)

$\mathrm{A} = 175 \times 300$

$\mathrm{A} = 5250\mathrm{mm}^2$

Lastly, Determination of Volume of hopper;

$\mathrm{V} = \mathrm{A} \times \mathrm{L}$
(15)

$0.052 = 0.00525 \times \mathrm{L}$

$\mathrm{L} = 0.099\mathrm{m} = 99.0\mathrm{mm}$

Determination of gear

$N_2 = \frac{30 \times 30}{17} = 52$

Determination of load on the Bearing

$\mathrm{L} = \frac{\mathrm{E}}{(2 \times \pi\ \mathrm{S})}$
(19)

$\mathrm{E} = \mathrm{P} \times \frac{\pi}{4} \times \mathrm{D}^2$
(20)

$\mathrm{E} = 25\ \mathrm{MPa} \times \frac{\pi}{4} \times (0.1)^2$

$\mathrm{E} = 1962.5\ \mathrm{N}$

Therefore;

$\mathrm{L} = 1962.5\ \mathrm{N} / (2 * \pi * 150\ / 60\ \mathrm{s/min})$

$\mathrm{L} = 261.7\ \mathrm{N}$

APPENDIX B

Table 1: Effect of Feed rate on Capacity of the Machine

	Capacity (kg/hr)		
Feed Rate	5 %	10 %	15 %
5	10.8	1 1.04	10.56
7.5	13.5	10.2	11.34
10	14.88	13.86	14.1

Table 2: Effect of Feed rate on Bulk Density

	Bulk density(g/m3)		
Feed Rate	5 %	10 %	15 %
5	1.124	1.124	1.1
7.5	1.1	1.1	1.07
10	1.07	0.998	1.07

Table 3: Effect of Feed rate on Cake Thickness

	Cake Thickness		
Feed Rate	5 %	10 %	15 %
5	6.52	5.003	2.11
7.5	7.7	6.34	4.91
10	7.72	6.4	6

Table 4: Effect of Speed on Cake Thickness

	Cake Thickness		
Speed(rpm)	5 %	10 %	15 %
5	3.1	2.4	2.23
7.5	5.003	2.8	2.01
10	6.5	3	1.97

Table 5: Effect of Speed on Bulk Density

	Bulk Density		
Speed(rpm)	5 %	10 %	15 %
5	0.98	0.99	1.08
7.5	1.121	1.07	1.1
10	1.14	1.124	1.14

Table 6: Effect of Speed on Machine Capacity

	Capacity		
Speed(rpm)	5 %	10 %	15 %
5	11.34	10.2	10.56
7.5	13.5	11.04	11.34
10	14.22	13.86	15.42

Table 7: Effect of Speed on Bulk Density

	Capacity(kg/hr)		
Shapes	5 %	10 %	15 %
Circular	10.8	11.1	11.22
Rectangular	13.5	10.2	14.1
Cylindrical	14.88	10.8	15.42

Table 8: Effect of Speed on Bulk Desnity

	Bulk Density		
Shapes	5 %	10 %	15 %
Circular	0.98	1.1	1.14
Rectangular	1.124	0.998	1.07
Cylindrical	1.14	1.124	1.14

Table 8: ANOVA for Moulding Capacity

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	0.013	17	7.49E-04	0.37	0.8818	not significant
A-speed	1.86E-04	1	1.86E-04	0.092	0.8126	
B-MC	5.99E-04	1	5.99E-04	0.3	0.683	
C-Feed Rate	1.06E-03	1	1.06E-03	0.52	0.6018	
D-Shape of Mould/Die	2.00E-04	2	1.00E-04	0.049	0.954	
AB	2.85E-05	1	2.85E-05	0.014	0.9249	
AC	2.71E-03	1	2.71E-03	1.34	0.4541	
AD	2.21E-03	2	1.10E-03	0.54	0.6919	
BC	1.29E-03	1	1.29E-03	0.63	0.5718	
BD	1.88E-03	2	9.42E-04	0.46	0.72	
CD	2.05E-03	2	1.02E-03	0.5	0.7055	
A^2	2.13E-04	1	2.13E-04	0.1	0.8006	
B^2	9.15E-04	1	9.15E-04	0.45	0.6234	
C^2	1.05E-03	1	1.05E-03	0.52	0.6035	
Residual	2.03E-03	1	2.03E-03			
Cor Total	0.015	18				

Table 8: ANOVA for Bulk Density

Source	Squares	df	Square	Value	Prob > F	
Model	0.048	17	2.85E-03	0.66	0.7634	not significant
A-speed	2.78E-03	1	2.78E-03	0.65	0.5685	
B-MC	3.63E-03	1	3.63E-03	0.85	0.5268	
C-Feed Rate	9.00E-03	1	9.00E-03	2.1	0.3849	
D-Shape of Mould/Die	5.71E-03	2	2.85E-03	0.66	0.6552	
AB	3.24E-03	1	3.24E-03	0.75	0.5447	
AC	8.04E-03	1	8.04E-03	1.87	0.4018	
AD	9.44E-04	2	4.72E-04	0.11	0.9054	
BC	3.59E-03	1	3.59E-03	0.84	0.5285	
BD	5.96E-03	2	2.98E-03	0.69	0.647	
CD	9.96E-03	2	4.98E-03	1.16	0.5489	
A^2	2.65E-04	1	2.65E-04	0.062	0.845	
B^2	8.13E-03	1	8.13E-03	1.89	0.4	
C^2	5.23E-03	1	5.23E-03	1.22	0.4687	
Residual	4.29E-03	1	4.29E-03			
Cor Total	0.053	18				

Response **3**

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Classical sum of squares - Type II]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	81.48	17	4.79	78.09	**0.00888**	significant
A-speed	4.73	1	4.73	77.01	**0.0221**	
B-MC	0.047	1	0.047	0.77	0.5422	
C-Feed Rate	2.43	1	2.43	39.61	0.1003	
D-Shape of Mould/Die	8.59	2	4.3	69.99	**0.0482**	
AB	3.25	1	3.25	53.02	0.0869	
AC	5.54	1	5.54	90.25	0.0668	
AD	4.8	2	2.4	39.12	0.1123	
BC	11.18	1	11.18	182.12	0.0471	
BD	11.46	2	5.73	93.38	0.073	
CD	9.82	2	4.91	80.04	0.0788	
A^2	33.27	1	33.27	542.15	0.0273	
B^2	7.73	1	7.73	125.94	0.0566	
C^2	10.9	1	10.9	177.6	0.0477	
Residual	0.061	1	0.061			
Cor Total	81.54	18				