DEVELOPMENT AND PERFORMANCE EVALUATION OF A GROUNDNUT CAKE EXTRUDING MACHINE

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SHUAIB, Abdullahi Segun
MEng/SEET/2017/6957

DEPARTMENT OF AGRICULTURAL AND BIORESOURCES ENGINEERING
FEDERAL UNIVERSITY OF TECHNOLOGY,
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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

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ABSTRACT

Manual production of groundnut cake involves a great deal of drudgery and time consumption in addition to the low consumer acceptance as a snack due to its unhygienic mode of production. In this study, a groundnut cake extruding machine was developed to mechanize the process and its extrudate properties evaluated. The effect of extrusion and process variables: feed moisture content, screw speed and die shape on the system parameters (extruder efficiency and specific mechanical energy) and the extrudate properties of the groundnut cake (expansion ratio, bulk density and specific length) were determined. The factors were varied at screw speeds (7, 9 and 11 rpm), moisture content (5.04 %, 7.04 % and 10.65 %) and die shape (square, inverted and circular). Data obtained were analyzed statistically using Design expert 11.1.2.0 statistical package to determine the response model and analysis of variance (ANOVA). It was observed that varying the screw speed and moisture content affected the length, bulk density, extruding time, extrusion capacity and expansion ratio but did not significantly affect the specific length, weight and diameter of the groundnut cake. Response variables predicted with model equations under optimum conditions were in general agreement with experimental data. Optimization of the independent factors produced the best response of 98.511 mm Length, 16.8 g weight, 12.867 mm Diameter, 1.161 g/ml Bulk density, 473.791s Extruding time, 0.257 Kg/min Extrusion Capacity, 1.537 mm Expansion ratio and 8.821 mm Specific length of dependent factors respectively. The developed groundnut cake extruder has an extruding efficiency of 93.5 % and extrusion capacity of 12.30 Kg/h.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Groundnut seed (*Arachis hypogea*), also referred to as peanut is a major crop grown in the arid and semi-arid zone of Nigeria. It is either planted for its nut, oil or its vegetative residue (haulms). Recently, the use of groundnut meal is becoming more renowned not only as a dietary supplement for children on protein poor cereals-based diets but also as effective treatment for children with protein related malnutrition. It is the 13th most important food crop in the world and the 4th most important source of edible oil. Its seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%) (Food and Agriculture Organization (FAO), 2006).

Nigeria is a major producer of groundnut accounting for 25 percent of world exports (International Food Policy Research Institute (IFPRI), 2012). In 2004, Nigeria had 3500 hectares cultivated and production of 2750 tonnes (National Bureau of Statistics (NBS), 2013). Groundnut accounted for 70% of total Nigeria export prior to petroleum oil boom (World Geography of Peanut, 2013) and is widely consumed in Nigeria as roasted or boiled nuts in the Western and Southern parts of the country (Adebesin *et al.*, 2011). Groundnut has therefore contributed immeasurably to the growth of the Nigerian economy through the sales of seeds, cakes, oil and haulms (Olorunju *et al.,* 1999; Mustapha *et al.*, 2015).

Groundnuts are produced in the tropical and subtropical regions of the world, on sandy soils. The production practices differ from highly refined commercial schemes in the western world to more traditional cropping practices in developing countries. Yields vary from about 400 kilograms to several tonnes per hectare depending on production system and production area (Abady *et al.,* 2019).

The groundnut sector provided the premise for the agro-industrial development and contributed considerably to the commercialization, monetization and integration of the natural rural sector. Previously, Nigerian groundnut cake was exported however presently, the cake is consumed domestically and employed in the preparation of feed rations for poultry and different animals (Oyedele *et al.,* 2017).

Groundnut is often called the 'king' of oilseeds and despite being a valuable source of all the nutrients, almost every part of it is of commercial value. The groundnut oil has many uses but it is principally used as cooking oil. It is used in many preparations, like soap making, fuel, cosmetics, shaving cream, leather dressings, furniture cream, lubricants, etc. It is also used as a means of conservation for preparation of pickles, chutney, etc. The groundnut oil is used in making diverse types of medicated ointments, plasters, syrups and medicated emulsion. It is also employed in the preparation of various food like butter, milk, candy and chocolate, chutney, groundnut pack etc. Groundnut cake is a good feed for animals and poultry due to its nutritious value and tastiness while groundnut shell has nice potential for business use. Traditional process of producing groundnut cake, locally called '*kulikuli*' is laborious, time consuming, prone to contamination and less attractive as a snack for human consumption, these underscores the need to mechanize the processes. Paramawati *et al.,* (2006) observed that using machines in postharvest handling and processing could lessen the contamination of aflatoxin on groundnut. Some improved production process of groundnut include; dryer, sheller, cleaning machine, roaster, grinder, oil expeller and fryer.

Extrusion technology was utilized in the production of groundnut cake in this research. Extrusion cooking technology is a high temperature-short-time, versatile and modern food operation that converts agricultural commodities, usually in a granular or milled form, into fully cooked food products. Owing to the processing flexibility offered by extrusion cooking technology, it has found abundant uses in the cereal and pet food industries as well as in dairy, bakery, and confections industries. Over-all, the final extrudate has low moisture content and seen as a shelf-stable food product (Pasqualone *et al*., 2020). Consumers' find expanded, ready-to-eat extruded snack products very attractive because of suitability, textural attributes, shelf stability and enhanced flavor. As a result of consumer interest for food manufacturers to produce an extensive range of high-protein foods and food products, the industrial fabrication of snack foods, using different sources of plant protein as main ingredients, has grown rapidly during the last decade. Extrusion is employed commercially to produce great value breakfast and snack foods based on cereals such as wheat or corn. However, this process technique is not being commercially used for legumes seeds because of the perception that legumes don't expand well in extrusion (Berrios *et al.,* 2013). The beneficial appeal of high-protein, high-nutritional, low-calorie snacks would be additional attribute of extruded products from legume seeds such as groundnut.

1.2 Statement of the Problem

Processing of groundnut into groundnut cake is largely done manually in developing countries which is time and energy consuming. Despite its nutritional benefits, its general acceptance as a snack is low which is as result of its poor hygienic and tedious production process, unappealing packaging, low shelf life and unacceptable standards. In particular, the molding of the cake to the various shapes are done using bare hands which is generally unhygienic and more so time consuming, hence the need to mechanize the process.

Groundnut processors are facing daily challenges especially when it comes to large scale production and wide ranging supply and demand operation. This is due to increasing cost of labour which has created a steady shifts towards labour reduction and the demand for development of machineries to bridge the gap. This trend has therefore necessitated the implementation of innovative technologies like the use of extrusion technology in the production of groundnut cake which can ensure guaranteed and improved productivity over time due to its versatility and acceptance in the food industry.

According to a report by the International Nut and Dried Fruit Council (INDFC) 2019), global growth of the middle class has led to a rise in consumption of perceivably more refined and healthier food items. On the other hand, groundnut cake production which still employs crude means of production creates negative effect to its acceptability as a result of concerns about its product quality.

1.3 Aim and Objectives of the Research

The aim of this study is to mechanize the processing of cake production from groundnut.

The Objectives of the research are to:

i. Fabricate an extruder with different die geometry of square, inverted and circular shape for producing groundnut cake.

ii. Carry out performance evaluation on the developed extruder.

1.4 Justification of the Study

The project when fully developed will accord '*kulikuli*' sellers the opportunity to prepare various shapes of attractive snacks safe for human consumption and appealing to the international market. The machine will be affordable and cake of various shapes in larger amount in very little or no time with reduced labor are going to be produced.

The fabrication of the extruder machine is a drive towards the indigenous production of machines which will in turns increase the technical knowledge and also create an opportunity towards industrialization that will create jobs especially for women who are mostly involved in the production of *kulikuli* as such this extruder machine will guarantee the profit on investment with time to processors and stakeholders. This will ultimately boost the economy and living standard of the people.

Mechanizing the process will improve the hygienic condition of the production process with the elimination of the use of hands for shaping the cake. Some mitigating factors that limits production which includes accessibility to improved processing techniques and technical know-how will be curtailed with the development of an easy to operate and maintain machinery to increase production at a lesser time. Increasing awareness of groundnut cake has shown that it is imperative to broaden production and create additional value through mechanized processing thereby opening new local and export markets.

Extrusion technology offers different benefits over the customary methods of food and feed processing such as improved digestibility, less water usage, high production rate and insignificant effluents. Unique constituents, innovative extrusion technology and state-of-the-art packaging methods need to be combined to produce new and improve already available snacks like *KuliKuli* so as to have better outlook, texture and mouth-feel, nutrition and shelf-life.

1.5 Scope and Limitation of the Study

The research work apart from designing and developing of an extruder machine is limited to performance evaluation with respect to the extruding section in the production process of groundnut cake in terms of only three parameters (moisture content, screw speed and die shape) and its effects on the product and machine capacity.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Groundnut Production

Groundnut is one of the most essential cash crops in Nigeria. It is a low priced commodity however a valuable source of all the nutrients. Groundnut is the sixth most important oilseed crop in the world (Soumya and Nair, 2012). It has 48-50% of oil and 26-28% of protein and is a rich source of minerals, dietary fiber and vitamins. Groundnut is grown globally in 26.4 million hectares with a total production of 37.1 million metric tonnes and an average productivity of 1.4 metric t/ha (Vaghasia *et al.*, 2016).

Globally, ground nut is grown in over 100 countries. Developing countries constitute 97% of the total area and 94% of the global production of this crop. The production of groundnut is concentrated in Asia and Africa with 56% and 40% of the global area and 68% and 25% of the global production, respectively (Engin *et al.*, 2018). Nigeria produces 41% of the overall groundnut production in West Africa (Echekwu and Emeka, 2005). Groundnuts are milled and used for the groundnut oil or basically consumed as a confectionary snack, roasted, salted or eaten as groundnut cake. In many parts of the world groundnut is cooked, either in the shell or unshelled state (Cilliers, 2017). Groundnuts are important constituent of Nigerian diet and about 5 percent of the projected 58.9g of crude protein available per head per day is contributed by groundnut. In most of developing countries, kernels are used for oil extraction, food and as a component in confectionery products and following extraction, the residual cake is processed largely for animal feed, but is also used for human consumption (Mubaiwa *et al.*, 2017).

Groundnut oil is largely used as a cooking medium and it may be processed into various products. After oil extraction, groundnut cake is obtained as a by-product. In general, the resultant cake contains about 43 to 65 percent protein and 6 to 20 percent fat plus some B-group vitamins depending upon the method of extraction (Nautiyal, 2012). The quality features that are essential for end uses of groundnut differ among the developed and developing countries. Groundnuts are mainly processed for oil in several developing countries and even as it is a good protein source, the cake obtained after oil extraction is not employed to the best advantage. In the collected works, groundnut as a cash crop is found to completely dictate its role as subsistent food crop and in spite of its importance to diets in many developing countries and the growing emphasis on food self-sufficiency, studies on local groundnut consumption are basically non-existent (Sangada *et al.,* 2016).

Countries like South Africa, India, Egypt and Nigeria have great prospective to exploit the opportunity to export groundnuts or groundnut products to the developed countries thus earning valuable foreign exchange to increase its economic conditions. In the international market, demand for groundnut products is determined by several factors. The primary cause in Africa has been population growth while in Asia, demand has grown due to a combination of population growth, increase in per capita income and urbanization (Ntare *et al.,* 2008). This realization underscores the need to mechanize the process of groundnut cake production to reduce drudgery, production time and ensure hygienic production of varieties of the cake with different shapes and sizes.

2.2 Traditional Production of Groundnut

It has been well established that groundnut is a very popular and well cultivated crop across the nation. It is well known to native people and put into series of uses by various indigenous inhabitants. Generally, rural women have conventionally played and continue to play an important part in agricultural production and postharvest activities (Ugbajah and Ugwumba, 2013). In Nigeria as well, the processing of groundnut just like other agricultural labour activities is typically done by women either for home consumption or for commercial purposes (Ibrahim, 2005). Women perform various roles in the production and marketing of groundnut as well as processing of the product. The processing of groundnut is both a source of income and employment to a large population of rural women. About 40% of the world yield of groundnut is processed into oil which has a horde of domestic and industrial applications. The high rise in demand for groundnut oil arose from its attributes such as palatability, inability to absorb odors easily like other cooking oils and it does not smoke (British Broadcasting Station (BBC) 2005).

Hence, the oil is used for cooking, making margarines, for pharmaceutical and cosmetic products as well as lubricants and emulsions for insecticides (Fekria *et al.*, 2012). Many agro-processing enterprises are at micro/subsistence level of development due to inadequate access to capital, seasonality of the product as well as other limitations such a drudgery, hazardous and unhygienic conditions and use of traditional processing techniques (Adisa and Okonade, 2011). In Nigeria, groundnut is put to numerous finished products for human consumption and this call for diverse methods of indigenous preparations as it is done in some localities or ethnic groups. The method of extracting oil locally as shown in plate 1 from groundnut kernel is mostly the same. Dried nuts are marginally roasted on a big earthen pot for 10 – 15 minutes subject to the quantity until it turns light brown. The bran is detached by blowing it off on a tray. A little quantity of pepper is added to the slightly roasted kernel and milled with a grinding machine to attain a white paste. To the paste, two spoonful of salt and small amount of water is added as ingredients. The ingredients are then thoroughly mixed with the paste. As mixing continues a small quantity of water is added at regular interval 3-4 times and the resultant combination begin to change color into light brown. In this state, the oil begins to be released and the resulting paste becomes hardened or solidified.

Plate I: Traditional production of groundnut oil (Zhigila *et al.,* 2014).

The liquid oil extracted is poured in a container and further addition of small quantity of salt and water to the solidified paste and mixing continues as usual with extra force to extract the remaining oil. Also the addition of salt at regular interval is to ensure the resulting cake that will be obtained had a desired taste as well as to facilitate easy extraction of oil. Once desired taste had been achieved only ordinary water or hot water are added as the case may be for the extraction oil. The oil extracted can be used as cooking oil, frying of bean cake, groundnut cake, fresh beef, fish and chicken, as lubricant in local bakery etc. The byproduct obtained after oil is extracted from groundnut paste is called groundnut cake as shown in plate 11. The groundnut cake is prepared by adding water intermittently to soften the thick groundnut paste for easy molding into desired shapes such as the ring type, irregular type, straight or circular type. These are then fried in a small frying pan containing hot oil extracted from the groundnut paste. The resultant cake obtained can be eaten directly as snacks or used to drink garri or pap. The cake can also be used as livestock feed to improve the palatability of the feed. The cake contains 45-60 protein, 22-30% carbohydrate, 3.8-7.5% crude fiber and 4-6% minerals (Desai *et al.,* 1999).

Plate II: Traditional production of groundnut cake (KuliKuli) (Zhigila *et al.*, 2014).

2.3 Improved Groundnut Production Process

Improved groundnut production involves machines that are developed to carryout sub-processing operations involved in traditional groundnut oil extraction and cake production. These machines are; shelling, roasting, de-skinning/winnowing, milling and kneading machines (Desai *et al.,* 1999).

2.3.1 Groundnut shelling machine

Groundnut shelling machine is a machine used to remove the shell of groundnut so as to obtain the groundnut seeds. The processing starts with the precleaning technique to separate foreign materials. The cleaned groundnuts are then sized so that the pods can be crushed without damaging the kernels. The shells are then crushed by passing between rollers. The groundnut pod is then crushed, pushing the shells and groundnut seeds through the perforations. Shells are aspirated. The crushed shells and groundnut kernels are then separated with oscillating shaker screens and aspirators. Groundnut kernels are then sized using screens, bagged and shipped (Achaya, 1993). Figure 2.1 shows a diagram of a developed groundnut shelling machine.

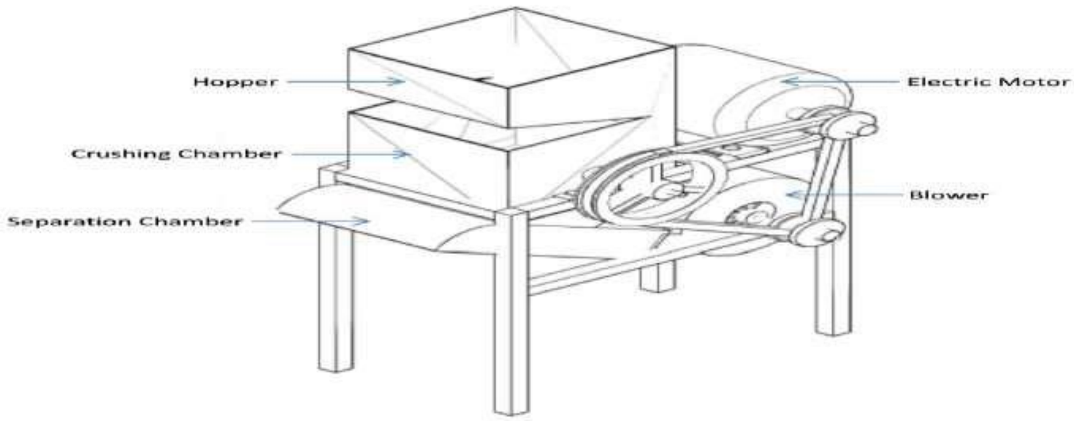

Figure 2.1: Developed Shelling machine (Ikechukwu *et al.*, 2014)

2.3.2 Groundnut roasting machine

Groundnut roasting is still achieved in many parts of the country by traditional method. This process is quite slow, tedious and time consuming considering the present level of demand for its production. Roasting reduces moisture content and develops a pleasant flavor which makes the products more acceptable for consumption (Musa *et al.,* 2020). Roasting also enhances better extraction as it reduces the oil’s viscosity and releases oil from intact cells. The amount of oil produced will be much if it is properly roasted (Okegbile *et al.,* 2014). However, excess heating during roasting results in low nutritional quality of protein. It also reduces the quantity of oil as well as makes the colour of oil extracted to be dark (Gerald, 2009). Some of the roasting machines in use include a manually operated rotating drum that is heated externally. The drum is housed in a brick and clay construction, similar to a scale bakery oven. For uniform roasting, the drum is rotated continuously throughout the process. The drum roaster consists of two drums and the outer drum is fitted to the brick work. The inner drum is made in form of a drawer that is detachable for loading and unloading.

Plate III: Groundnut seed roaster **(**Abdulrahman, 2011).

There are basically two types; batch roasters and continuous roasters. Batch roasters are typically natural gas-fired revolving oven (drum-shaped) and has the advantage of being able to accommodate the loss of moisture content from groundnut due to storage. The continuous roaster move groundnut through oven on a conveyor tray by gravity feed. In this system, the groundnut is agitated to ensure that air passes around the individual kernels to promote an even roast (Shankarappa *et al.*, 2003). It varies considerably in type and ensure a steady flow of groundnut. Plate III above shows a developed groundnut seed roaster.

2.3.3 Groundnut kneading machine

Kneading has been identified as one of the most tasking and energy consuming process in groundnut processing, which underscores the need to develop a motorized machine.

A motorized kneading machine is shown in plate IV. The main features of the oil extractor include the kneading head, the conventional mortar, the transmission unit and the supporting frame.

Plate IV: Motorized kneading machine (Shu'aibu, 2013)

The intended quantity of paste is poured into the mortar and the machine is set up for kneading. Once the electric motor is switched on, rotary power is transmitted to the kneading shaft through the intermediate shaft to the input shaft on which the kneading shaft is hooked. Kneading is accomplished by the centrifugal effect of the rotating fingers on the oil molecules in the paste, with water added gradually as the process progresses until the end.

2.4 Food Extrusion

Extrusion is a processing system that utilizes a single screw or a set of screws to force food through an opening in a perforated die with a design specific to the food and is then cut to a specified size by a blade fixed at the end. The machine which forces the mix through the die is called an extruder and the mix is known as the extrudate. The extruder consists of a large, rotating screw tightly fitted with a stationary barrel, at the end of which is the die (Singh *et al.*, 2007). The sole function of extrusion is to impart to the product a certain shape or form, without otherwise affecting the property of the material. The extruder is very versatile such that same equipment with slight modifications may be used for achieving different objectives or for processing many different products (Lazou and Krokida, 2010). It represents one of the most significant achievements in food process engineering in the last 50 years (Korus *et al.*, 2006). Extrusion cooking is a high temperature- short time process and retention time in the extruder is relatively short. The extruded product usually puffs and changes texture as it is extruded because of the reduction of forces and release of moisture and heat (Asare *et al.*, 2004). The extent to which it does is known as the expansion ratio. The extrudate is cut to the desired length by blades at the output of the extruder, which rotate about the die openings at a specific speed. Important factors of the extrusion process are the composition of the extrudate, screw length and rotating speed, barrel temperature and moisture, die shape and rotating speed of the blades. These are controlled based on the desired product to ensure uniformity of the product (Brennan *et al.*, 2008).

A broad chart of what a food extrusion processing production line encompasses is presented in Figure 2.2. The process begins with characterizing and receiving the raw ingredients. The raw ingredients used are crucial to the product consistency at the end of the processing line. The raw ingredients mixing or preconditioning, are done with the equipment such as ribbon blenders and preconditioners to ensure uniformity as it enter the extruder. However, mixing and preconditioning is optional for certain products (Fellows, 2009).

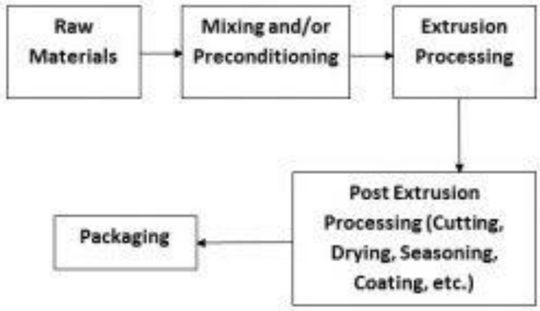

Figure 2.2: Flow chart of a typical extrusion processing line (Riaz, 2000)

In extrusion applications, two different extruder designs are mainly used: the single screw extruder and the twin screw extruder. Within each design, there are various further process design options, including screw size, screw geometry, screw speed, screw rotation (corotating, counterrotating), extruder length, die geometry, barrel geometry, throughput etc. Depending on the processing requirements, extruders can have throughputs ranging from several grams per hour to several tons per hour (Bordolloi and Ganguly, 2014). For most food extrusion applications, corotating twin screw extruders are well-suited and preferred, as it allow extensive variation in thermal and mechanical energy inputs, control of the residence time, and the application of efficient mixing. This uniquely versatile processing nature of extrusion has allowed the technology to develop into widespread industrial applications (Bouvier and Campanella, 2014).

In the case of breakfast cereals and snacks, high temperature and pressure during cooking of starch-based dough and high pressure drop in the extruder die lead to an evaporation of water at the die exit (Studer *et al.*, 2004). This evaporation leads to bubble formation (nucleation) and growth inside the dough and is responsible for significant expansion of the product resulting in its specific sensorial properties, i.e., taste, crunchiness, crispiness, and ‘mouth feel’ (Horvat *et al.*, 2013).

2.4.1 Advantages of extrusion

A wide range of products, many of which cannot be produced easily by any other process, is possible by changing the ingredients, extruder operating conditions and dies. The advantage of extrusion as described by Ganjyal and Hanna (2004) includes the following:

1) **Adaptability:** Ample varieties of products are feasible by changing the minor ingredients and the operation conditions of the extruder. The extrusion process is remarkably adaptable in being able to accommodate the demand by consumers for new product.
2) **Product characteristics:** A variety of sizes, shapes, textures, colors and appearance can be produced, which is not easily formed using other production methods.
3) **High product quality:** Since extrusion is a high temperature short time (HTST) heating process, a high quality and consistency of products can be gotten. It improves the digestibility of proteins, starches and destroys the anti-nutritional factors in food.
4) **Low cost:** Extrusion has lower processing cost and saves raw materials, labor cost and capital investment. 19 per cent raw material, 14 per cent labour and 44 per cent capital investment can be saved.
5) **Energy efficient:** Extruders operate at relatively low moisture while cooking food products, so less re-drying is required.
6) **No waste and effluent generation**: Extrusion does not produce waste matter and effluents and no disposal problems.
7) **New foods**: Extrusion can modify animal and vegetable proteins and starches and produce unique snack foods.

8) **Therapeutic foods and fabricated foods**: Foods such as low calorie, high fibre, high protein and nutritious food supplements can be produced.

2.4.2 Extruder

Food extruder is equipment used for the shaping and restructuring process for food ingredients. Extrusion processing equipment has become popular in many food industries throughout the world (Riaz, 2006). Figure 2.3 shows a schematic representation of an extruder.

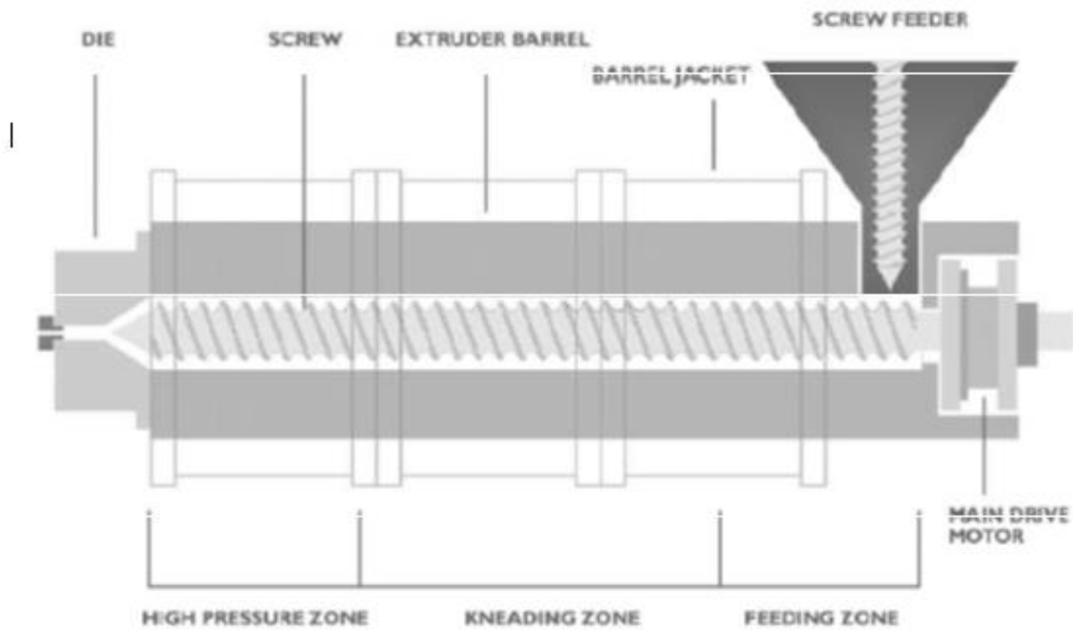

Figure 2.3: Schematic Representation of an extruder including its main parts and zones (Riaz, 2006)

The screw is the heart of the extrusion process and its design and speed of rotation greatly influence the extrusion operation. The screw has three functions: conveying, shearing and mixing. The feeder section accepts moistened granular feed materials and conveys it down the length of the screw to the exit. As the feed materials move along the screw, it encounter great friction, restriction or compression, causing it to completely fill the channel or the space existing between the screw flights. The energy necessary to make the viscous materials flow is supplied by a large drive motor turning the screw. Dies are provided at the exit to attain desired shape of the material and is cut into desired length using a cutter fitted at the end of the discharge.

2.4.3 Classification of extruders

There are mainly two types of extruders; single screw extruder and twin screw extruder. Both single-screw and twin-screw extruders are used for commercial production of a wide variety of food products, ranging from snack half-products, textured vegetable protein, animal feed (including pet foods), expanded ready-to-eat cereals, and flat breads (Dennis *et al.,* 2009). In all extruders, the premixed ingredients are conveyed through the barrel by a conveying screw.

2.4.3.1 *Single screw extruders*

Single screw extruders consist of a single rotating screw in a metal barrel which comes in varying patterns. The most commonly used single-screws have a constant pitch. Single-screws as discussed by Ainsworth (2011) usually consist of three sections: feeding section, compression section and the metering section.

1. Feed section: This is the portion of the screw which accepts the food materials at the feed port. Usually the feed section is characterized by deep flights so that the product can easily fall in to the flights. The function of the feed section is to ensure that sufficient material moved or conveyed down the screw and the screw is completely filled.
2. Compression section: The portion of the screw between the feed section and the metering section is called as compression section. The food ingredients are normally heated and worked into a continuous dough mass during passage through the transition section. This is the shearing/compression section in which

the materials are thoroughly worked into viscous dough, partially cooked and elevated in temperature and pressure.

3. Metering section: This is the portion of the section nearest to the discharge of the extruder which is normally characterized by having very shallow flights. The shallow flights increase the shear rate in the channel to the maximum level within the screw. The metering section in which dough is further cooked and starch granules may be broken down due to higher shear forces. The metering section continuously feeds the die with materials at uniform pressure; the raw materials are fed in a granular form at the hopper located in the feed section. The rotating action of the screw conveys the material to the transition section and in the transition section, the screw channel becomes shallower and the material is compacted. A major portion of mechanical energy is dissipated in this section, which results in a rise in temperature of the material. Starch becomes gelatinized, and the material becomes more cohesive. It is transported further by the metering section and pushed through the die opening. The barrels of single-screw extruders usually have helical or axial grooves on the inner surfaces. This helps to convey and mix the material more effectively. Single-screw extruders are usually characterized by its length to diameter (L/D) ratio and its compression ratio. The throughput (mass flow rate) capacity of a single-screw extruder is linked to screw speed, screw geometries, and material characteristics. Figure 2.4 shows a schematic representation of a single screw extruder.

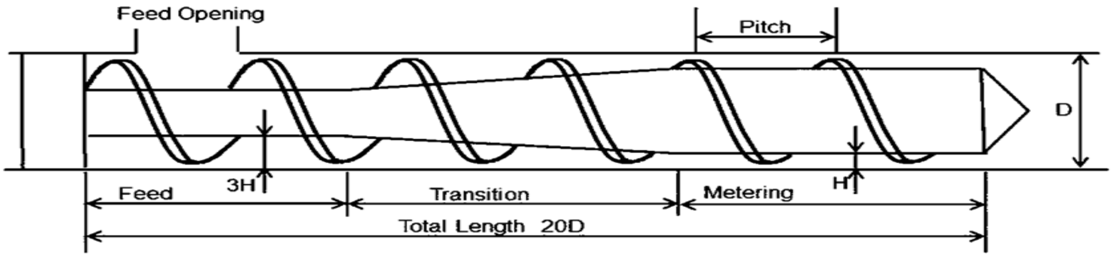

Figure 2.4: Schematic representation of screw in a single screw extruder (Harper, 1992)

Single-screw cooking extruders have compressive screws with decreasing channel depth turning at high speeds to increase shear and mechanical energy input for heating. The resulting friction induces heating of a product. In some cases, the barrel is jacketed for steam to allow additional contact heating in the metering section (Alam *et al.,* 2015).

2.4.3.2 *Categories of single-screw extruders include*

The various categories of single screw extruders according to Harper (1981) include:

1) Cold Forming (Pasta-Type) Extruder: deep flight, smooth barrel, low shear speed. Little or no cooking. Used for pasta, pastry dough, cookies, egg-rolls, ravioli, processed meat and certain candy.
2) High-Pressure Forming Extruder: grooved barrels to prevent slip at the wall and greater compression in the screw design. Commonly used for pre-gelatinised cereal and fried snack foods.
3) Low-Shear Cooking Extruders: moderates shear machines with high compression machines and grooved barrels to enhance mixing. Used for Soft-moist foods and meat like snacks.
4) Collet Extruders: high shear machines with grooved-barrels and screw with multiple shallow flights. Used for puffed snacks and expanded curls or collets.

2.4.3.3 *Advantages of single-screw extruders*

The advantages of single screw extruders are:

1) It is a short time process

2) No waste products

3) Versatility in application

2.4.3.4 *Twin-screw extruders*

Twin screw extruders consists of two parallel screws in a barrel with a figure-eight cross section. The use of twin-screw extruders for food processing started in the 1970s, with an expanding number of applications in the 1980s. Twin-screw extruders are generally one and a half times or more expensive than a single screw machine for the same capacity (Riaz, 2016). The degree of quality control and processing flexibility it offers make it attractive to food industries. Twin screws produce a more uniform flow of the product through the barrel due to the positive pumping action of the screw flights. The term ‘twin-screw’ applies to extruders with two screws of equal length placed inside the same barrel. It consists of two parallel screws in a barrel. It is more complicated than single screw extruders and provides much more flexibility and better control. Twin screws produce a more uniform flow of the product through the barrel due to the positive pumping action of the screw flights (Harper, 1992). A schematic representation of a twin screw extruder as shown in Figure 2.5.

Figure 2.5: Twin Screw Extruder (Riaz, 2016)

Some other advantages of twin screw according to Chakraborty *et al.* (2009) are:

1) Can handle viscous, oily, sticky or very wet material and some other products, which will slip in single screw extruders (it is possible to add up to 25 per cent fat in a twin-screw extruder).
2) Less wear in smaller part of the machine than in single screw extruder.
3) Wide range of particle size (from fine powder to grains) may be used, whereas single screw is limited to a specific range of particle size.
4) Clean-up is very easy due to its self-wiping characteristics.

2.4.3.5 *Types of twin-screw extruders*

There are four types of twin-screw extruders namely;

1. Non-intermeshed, co-rotating
2. Non-intermeshed, counter rotating
3. Intermeshed, co-rotating
4. Intermeshed, counter rotating

From these four types of twin screw extruders, co-rotating, intermeshed screw type has found the widest acceptance in the food industry (Koksel *et al.,* 2004).

2.5 Comparison of Single and Twin Screw Extruders

The main difference between single and twin screw extruder is the conveying mechanism (Sahay and Singh, 1994). In a single screw extruder, the conveying action is the result of the friction effects; the friction between screw and the product and the friction between barrel and product. The single screw extruder needs the barrel wall for the good conveying action. The product may co-rotate along with the screw. Whereas, in a twin screw extruder, the product is enclosed between the intermeshing screws and barrel and is conveyed positively towards the die. Due to such positive displacement action, the product is prevented from co-rotating with the screw. In twin screw extruder the friction at the barrel is of less importance. A single-screw extruder is the simplest food manufacturing device and is very economical to operate. Jianshe and Andrew (2009) suggested that single-screw extruders are only suitable for manufacturing of foods that contain less than 4% fat, 10% sugar and 30% water. The presence of high contents of fat, sugar and moisture will significantly reduce the friction between food material and the inner barrel surface and, therefore, impair the mixing and flow of food. Twin-screw extruders consist of two intermeshing screws either co-rotating or counter-rotating against each other. It have much higher mixing capability than single-screw extruders. One significant advantage of twin-screw extruders is the much extended product range. Food that contain 20% fat, 40% sugar and 65% moisture and can be handled by a twin-screw extruder (Jianshe and Andrew, 2009).

2.5.1 Extruder parts and components

The various component parts of an extruder as described by Fellows (2009) are:

1. **Extrusion drive:** The Power supply in food extruder is done by electric motors. The size of the motor depends on the capacity of the extruder and may be as large as 300 kW. The screw speed on extruder is a valuable control parameter. The speed of food extruders is normally less than 500 rpm. Thrust bearing must be able to sustain the load produced under normal extrusion conditions giving an expected life of 20,000 to 50,000 hr. (Fellows, 2009).
2. **Feeder:** A device providing a uniform delivery of food ingredients which are often sticky, non-free- flowing substances. It will regulate rate/pressure of flow. Some types of feeders commonly used are vibratory feeders, variable speed auger and weigh belts. (Fellows, 2009).

3. **Barrel or sleeves:** The barrel is divided into feeding, kneading and the sleeves surrounding the screw can be solid. These are often jacketed to permit circulating of steam or superheated oil for heating and water or air for cooling. (Fellows, 2009).

4. **Screw:** The screw of the extruder is certainly its most important component. It is the screw which conveys the materials. Diameter of the screw of a single screw extruder normally varies between 2-15 cm, Length to diameter ratio varies between 8- 20 and helix angle between $20^0 – 30^0$. (Fellows, 2009).

5. **Die or nozzle:** The die presents two main functions:

   1. It gives shape to the final product.

   2. Promote resistance. It increases in internal pressure. The die can present various designs and number of orifices. Dies may be designed to be highly restrictive, giving increased barrel fill, residence time and energy input. Die design has effects on functional properties and quality of a final product. (Fellows, 2009).

   Figure 2.6 shows different types of extruder dies and its extrudates.

Figure 2.6: Diagram of different types of extruder dies (Berk, 2009).

6. **Cutting mechanism:** The cutting mechanism must permit obtaining final products with uniform Size. Product size is determined by the rotation speed of the cutting blades. This mechanism can be horizontal or vertical (Fellows, 2009).

2.5.2 Characteristics of extruded products

The extrusion technology has become an important technique in food processing industries as it is one of the cost effective method. The characteristics of extruded products as reported by Huber, 2001 are:

i. **Degree of expansion on exit from the extruder:** For many products, the sudden release of pressure when exiting the die of the extruder causes water to flash off and the product to expand. The extent of expansion depends on the composition of the product, its internal microstructure as it exits the die, and the conditions (pressure and temperature) in the extruder. Degree of expansion may be calculated as either the ratio of the diameters or areas of the extruded product to the die (L/D) (Huber, 2001).

ii. **Bulk density:** The density of the final product depends on the nature of the solid material as well as on the amount of air space within the product. A highly expanded product, with plenty of air spaces, has significantly lower bulk density than a product with little air inclusion. (Huber, 2001).

iii. **Mechanical properties:** Physical and rheological properties determine the characteristics of the extruded product. These may be expressed as fundamental parameters, like elastic modulus, or may be characterized by empirical measures, such as hardness or crispness. Instruments that measure fundamental properties (rheometers) or empirical techniques (Instron or penetrometer) may be used to quantify characteristics of extruded products. (Huber, 2001).

iv. **Internal microstructure**: The arrangement of the components of the extruded product leads to the physical properties described above. The state of starch, whether partially or completely gelatinized, in the final product strongly influences physical characteristics. Typically, internal microstructure is evaluated using microscopy (scanning electron microscopy). (Huber, 2001).

v. **Protein quality:** The nature of extruded proteins depends on the extruder operating conditions, especially temperature profile as the extruded product is formed. High-heat treatment causes denaturation of many proteins, which influences physical characteristics such as viscosity. (Huber, 2001).

vi. **Starch characteristics:** Properties of starch in an extruded product that influence quality characteristics include such measures as water absorption index, water solubility index, and enzyme susceptibility. These depend on the operating parameters within the extruder as well as the type of raw materials used for extrusion. (Huber, 2001).

2.5.3 Operating characteristics of an extruder

The most important operating parameters in an extruder according to Riaz (2007) are:

1) Temperature; Increase in extrusion temperature results in higher degree of gelatinization.

2) Pressure.

3) Diameter of the die apertures; Increase in diameter reduces gelatinization of starch.

4) Shear rate.

5) Moisture; If moisture increases, viscosity decrease, torque decrease, product temperature decrease and bulk density increase (expansions die pressure decreases). (Riaz, 2007)

2.5.4 Factors to consider in selection of an extruder

The choice of an extruder type according to Riaz (2016) should depend on;

1) Type of product(s) to be made.
2) Size of plant sustainable by market.
3) Capital availability and recovery period.
4) Relative energy requirements; electricity, other energy forms.
5) Hardened wearing parts for sustained usage (screw tips, barrel sleeves, die inserts).
6) Local back up expectations and capabilities of manufacturer. (Riaz, 2016)

2.6 Factors Affecting Extrusion Cooking

The factors affecting extrusion cooking according to Riaz (2000) are the rheological properties of the food which have an important influence on the texture and colour of the product. Other factors are:

1) The type of feed materials

2) Moisture content

3) The physical state of the materials

4) The chemical composition, particularly the amounts and types of starches, proteins, fats and sugars

5) The pH of the moistened material.

6) Feed rate

7) Screw speed

8) Barrel temperature

9) Die characteristics

10) Screw design (Riaz , 2000)

2.6.1 Examples of extruded foods

1) **Pasta**: Ready-to-eat (RTE) cereals Puffed cereals, shredded cereals, etc.
2) **Snack products:** Corn curls, puffed snacks, crisp breads etc.
3) **Pet foods**: Dry, semi moist.
4) **Confectionery products:** Licorice, toffee, caramel, peanut brittle.
5) **Texturized proteins:** Meat analogs, fish paste. (Riaz, 2000)

2.7 Use of Extrusion Technology for Food Materials

Extrusion technology is widely used in the agro-food processing industry, where it is referred to as extrusion-cooking (Moscicki and Zuilichem , 2011). The extrusion cooking, especially used in the production of precooked and modified starches, ready to eat cereals, infant formulae and snack foods has increased recently (Shraddha and Singh, 2017). The benefits of extrusion cooking technology are its low cost, variability of product shape and high quality product. The most used raw materials in the extrusion process are starch and protein based materials. Natural biopolymers of raw materials such as cereals or tuber flours are rich in starch or oilseed legumes and other protein rich sources. A ready to eat food sample was successfully developed using the low amylose rice flour incorporated with banana powder in a single-screw extruder (Borah *et al.,* 2015) while Dhumel *et al.,* (2014) developed cold extrudate, microwave puffed and oven toasted low fat ready to eat food successfully using potato and barnyard millet. Table 2.1 shows some other raw materials used by various researchers for extrusion cooking.

Table 2.1: Raw material used by different researchers for extrusion cooking. **(**Shraddha and Singh, 2017)

S/No	Raw Material	Researcher (s)
1	Kodo, defatted soy flour and water chestnut	Azam (2016)
2	Cassava, maize and wheat flour	Fayose and Huan (2014)
3	Wheat, mungbean and groundnut	Pathania *et al.* (2013)
4	Water yam starches	Oke *et al.* (2013)
5	Rice-Sweet potato and rice-yam	Hazarika *et al.* (2013)
6	Broken rice flour, pineapple waste pulp powder and red gram powder	Kothakota *et al.* (2013)
7	African yam bean and cassava flour	Omeire (2012)
8	Pearl millet	Singh and Devi (2011)
9	Tef, corn and soy protein isolated blends	Forsido and Ramaswamy (2011)

2.8 Statistical Analysis

The statistical analysis was accomplished using Design Expert Software which offers test matrices for screening of all factors thereby determining the best lines or points of fit for the purpose of final optimization using a Response Surface Methodology (RSM). This is a technique that develops a suitable experimental design that integrates all of the independent variables and uses the data input from the experiment to finally come up with a set of equations that can give theoretical value of an input. The outputs are obtained from a well-designed regression analysis that is based on the controlled values of independent variables. Thereafter, the dependent variable can be predicted based on the new values of independent (Resurreccion, 1998).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Design Considerations

This study was conducted by purchasing prepared groundnut paste from local groundnut cake producers in Tunga area of Minna, Niger State. Each sample was packaged in a polythene bag to preserve its quality. Groundnut paste is the residue gotten after extracting oil from the groundnut kernels (Atanda and Akano, 1990).

Density of groundnut paste was recognized as an impediment to the operation of the machine and was used as a guide in the design of the hopper, the screw and the cutter. Some of the basic factors considered for this extruder machine are the availability of materials, selection of materials and the cost of the materials for its design and fabrication. The materials selection for the design depends on the following;

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

3.2 Design Calculations

Assumed capacity of the machine is 120 Kg and the machine is to be operated for 8 hrs. Therefore the theoretical capacity C_{th} of the machine is thus;

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

$$C_{th} = \frac{120}{8} = 15 \text{ Kg/h} \qquad (3.1)$$

3.2.1 Hopper design

The shape of the hopper is in the form of a truncated pyramid as represented in the free body diagram in Figure 3.1 with an inclination angle of 60° to enable free flowing and conveying Tuttuh *et al.*, (1998).

$$\text{Volume of hopper} = \frac{(a^2 + b^2 + ab)h}{3} \tag{3.2}$$

Where parameters of the hoppers are assumed to be;

Where b= outlet width of the hopper = 100 mm,

a= inlet width of the hopper = 200 mm,

h= Slant height = 370 mm.

Therefore;

$$V = \frac{(200^2 + 100^2 + (100 * 200))370}{3} = 8633333.33 \text{ mm}^3 = 0.0086 \text{ m}^3$$

It implies that the mass of the groundnut paste (*kulikuli*) the hopper will hold in Kg is given by;

$$M = \rho \times v \tag{3.3}$$

Where,

M is the mass of the groundnut paste inside the hopper

ρ is the density of the stainless steel, Kg/m^3 which is

$$M = 0.0086 \times 7850 = 67.51\ kg$$

The mass flow through the hopper using Johanson equation is calculated thus;

$$\text{Mass Flow} = \rho^\circ A \sqrt{\frac{Bg}{2(1+m)\tan\theta}} \tag{3.4}$$

Where,

ρ° = Bulk density of groundnut paste = 800 kg/m^3. This bulk density was reported by (Burubai *et al.*, 2007).

A = surface area of hopper (2(100+200) × 300) = 0.18 m^2

θ = Hopper Angle

g = acceleration due to gravity (9:807 m/s^2)

m= 0 (symmetric slot hopper)

B = W= 0.37 m

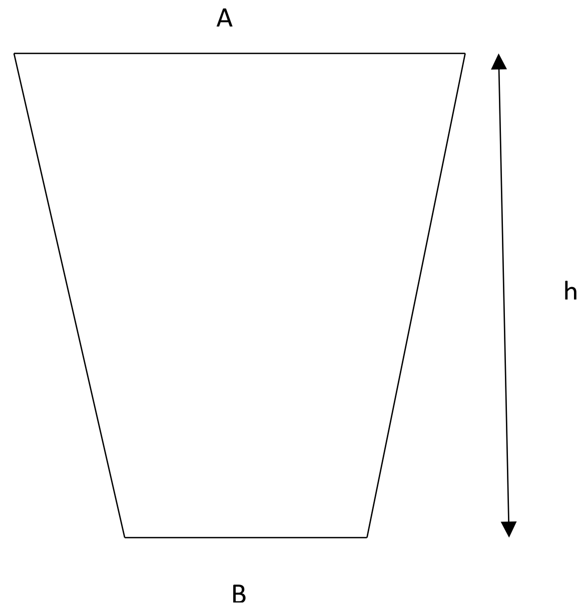

Figure 3.1: Free body diagram of the hopper

$$m_h = \frac{800 \ \times 0.18\sqrt{0.37 \times 9.807}}{2tan45} = 137\ Kg$$

3.2.2 Power requirement

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

$$P = 0.7355CIQ \tag{3.5}$$

Where,

P=Power required by the extruder kW

C=Coefficient constant for conveyed material, 0.3

l=Length of the screw conveyor m

Q = Theoretical capacity of the machine kg/h

$$P = 0.7355 \times 0.3 \times 0.5 \times 15$$

$$P = 1.65\ W$$

3.2.3 Determination of screw conveyor diameter

The diameter of the screw conveyor required for conveying material at a rate of 20 kg/h for the capacity of a continuous screw conveyor were calculated from the expression given by Spivakovsky and Dyachkov (1967),

$$D^3 = \frac{4Q}{60\pi(Sn\emptyset PC)} \tag{3.6}$$

Where,

D= Screw Diameter, mm

Q= capacity of screw conveyor = 20 kg/h,

S = screw pitch ,

$n =$ speed of conveyor =70 rpm,

$\emptyset =$ loading efficiency,

$P =$ free bulk density of the material = 800 kg/m^3,

$C =$ loading factor depending on the inclined angle to the horizontal.

The recommended values by Spivakovsky and Dyachkov (1967) for slow flowing abrasive material are;

S= 0.8D, $\emptyset = 0.125$ and C= 1 for inclination angle.

$$D = \sqrt[3]{\frac{4 \times 20}{60 \times 3.142 \times 0.8 \times 70 \times 0.125 \times 800 \times 1}}$$

D= 0.0423 m = 42.3 mm

3.2.4 Length of Screw

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

Feed section length (FL) = 5D = 5 × 42.3 = 211.5 mm

Feed section depth (Fd) = 0.2D = 0.2 × 42.3 = 8.46 mm

Transition section length (TL) = 4D= 4 × 42.3 = 169.2 mm

Metering section length (ML) = 4D = 4 × 42.3 = 169.2 mm

Metering section depth (Md) = 0.33Fd = 0.33 × 8.46 = 2.80 mm

Screw barrel clearance = 0.17D = 0.17 × 42.3 = 7.19 mm

3.2.5 Design of drive system (belt and pulley design)

The machine runs with a 1430 rpm motor which will produce a speed reduction of 70 rpm using reduction gear of ratio 1:20. This reduces the speed of the motor via a V – belt before it enters the shaft. The smaller pulley is adapted at the motor and connected to the bigger pulley on the shaft of the screw via a belt drive. The bigger pulley is connected to a gear system that controls the screw and the cutter. V-belt and pulley arrangement were adopted in this work to transmit power from the electric motor to the shaft of the extruding unit. The main reasons for adopting the v-belt drive are its flexibility, simplicity and low maintenance cost. Additionally, according to balami *et al.* (2013) as reported in Adebukola (2019) the V-belt has the ability to absorb shocks thereby mitigating the effect of vibratory forces.

a. Pulley Diameter

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

$$D_2 = \frac{N_1 D_1}{N_2} \tag{3.7}$$

Where,

D_1 = Diameter of electric motor pulley, 60 mm

N_1 = Speed of motor, 1430 rpm

D_2 = Diameter of extruding Screw pulley, mm

N_2 = Speed of extruding screw, 500 rpm

$$D_2 = \frac{1430 \times 60}{500}$$

$$D_2 = 171.6\, mm$$

b. Belt Speed

The belt speed for the extruder is calculated using the formula expressed by Shigley and Mischike (2001).

$$\mathrm{v} = \frac{\pi \mathrm{DN}}{60000} \tag{3.8}$$

Where

v = belt speed, m/s

D = diameter of motor pulley, 60 mm

N = speed of motor, 1430 rpm

$$v = \frac{\pi \times 60 \times 1430}{60000}$$

$$v = 6.03\, m/s$$

3.2.6 Belt length

The Belt length for the extruder drive can be determined using the formula as expressed by Shigley and Mischike (2001).

$$\mathrm{X} = 2\mathrm{C} + 1.57(\mathrm{D}_1 + \mathrm{D}_2) + \frac{(\mathrm{D}_1 - \mathrm{D}_2)^2}{4\mathrm{C}} \tag{3.9}$$

Where,

X = belt length, m

C = Center distance between pulleys, 350 mm

D_1 = Pitch diameter of driver pulley, 60 mm

D_2 = Pitch diameter of driven pulleys, 240 mm, 320 mm and 400 mm.

$$\mathrm{X}_1 = 2 \times 350 + 1.57(60 + 240) + \frac{(60 - 240)^2}{4 \times 350}$$

$$\mathrm{X}_1 = 1194.14 \text{ mm}$$

$$\mathrm{X}_2 = 2 \times 350 + 1.57(60 + 320) + \frac{(60 - 320)^2}{4 \times 350}$$

$$\mathrm{X}_2 = 1344.88 \text{ mm}$$

$$\mathrm{X}_3 = 2 \times 350 + 1.57(60 + 400) + \frac{(60 - 400)^2}{4 \times 350}$$

$$\mathrm{X}_3 = 1504.77 \text{ mm}$$

3.2.7 Volume of extruder barrel

The extrusion barrel is represented in figure 3.2, the volume of this barrel (V_{EX}) is computed using formular of a frustum as given by Khurmi and Gupta (2005) as:

$$V_f = \frac{\pi}{3} h_f (R^2 + Rr + r^2) \qquad (3.10)$$

Where;

V_f = Volume of frustum in m^3

R = radius of bigger end of cylinder, m

r = radius of the smaller end of cylinder, m

h_f = Height of frustum, m

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

$$V_f = 1.0471 \times 420(150^2 + 150 \times 100 + 100^2)$$

$$V_f = 20.89\ m^3$$

A = Area of frustum, m^2

$$A = \pi(R + r)\sqrt{(R - r)^2 + h^2} \tag{3.11}$$

$$A = \pi(150 - 100)\sqrt{(150 - 100)^2 + 420^2}$$

$$A = 66439.3\ mm^2$$

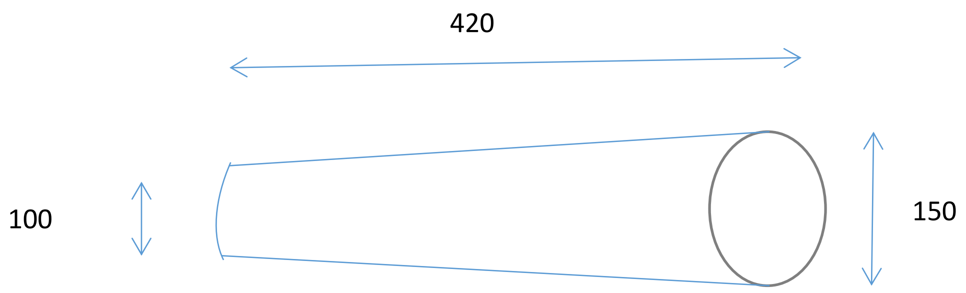

Figure 3.2: Extrusion Barrel

3.2.8 Determination of extrusion pressure of the barrel

The pressure in the extruder is very important to obtain the barrel thickness. The equation as cited in Balami *et al.* (2013) according to Kubota (1995) is;

$$P = \frac{L}{V_f} \tag{3.12}$$

Where:

P = Pressure inside the extrusion barrel**,** N/m^2

L = Power available to the conveyor, W.

V = volumetric flow rate of material, m^3/s

Since $V = \frac{Q}{\rho}$ (3.13)

Where,

V= Volumetric Flow rate m^3/s

Q = 15kg/h which is equivalent to 0.0042 kg/s

ρ = density of paste, 800 kg/m^3

$$V_f = \frac{0.0042}{800}$$

$$V_f = 0.00000525\ m^3/s$$

$$= 525 \times 10^5\ mm^3/s$$

The pressure in the extrusion barrel is therefore;

$$P_f = \frac{1.65}{0.00000525}$$

$$P_f = 314285.7\ Pa$$

$$P_f = 31.4\ KPa$$

3.2.9 Determination of thrust force (W)

The thrust force moving the material inside the extrusion barrel of cross sectional area (A) is computed by using expression by Khurmi and Gupta (2005).

$$\mathrm{W = PA} \tag{3.14}$$

Where,

P = the pressure in the barrel kPa

A = Area of the extruder barrel m^2

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

$$A = \pi(150 - 100)\sqrt{(150 - 100)^2 + 420^2}$$

$$A = 66439.3\ mm^2$$

Therefore,

$$W = 31.8 \times 6.644$$

$$W = 0.211\ kN$$

3.2.10 Determination of die extrusion pressure

For a constant feed rate, speed of extrusion, feed formulation and material density, the extrusion pressure only varies with die size, the pressure of extrusion in respect to die size is computed using the formula given by walker (1981)

$$P = \frac{W}{A} \tag{3.15}$$

Where;

P = Extrusion pressure, N/m^2

W = Thrust force, N

A= Area of extrusion holes, m^2

The die plate is made from a circular plate of stainless steel of thickness of 5mm with effective diameter of 80mm.This design is considering three dies with three hole sizes drilled into the plate, the area of the dies are thus;

Die 1 (Square)

L and Width = 10.0 mm

$$A = L \times B \tag{3.16}$$

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

Area covered by die hole = Area of 1 hole × number of holes

Number of holes is 3

Area covered by die holes = $\frac{\pi \times 10^2 \times 3}{4} = 235.65 \text{ mm}^2$

Die 2 (Inverted)

D_2 = 12.0 mm

$$A = \frac{1}{2} \times \frac{\pi D^2}{4} \tag{3.17}$$

$$A = \frac{\pi \times 12^2}{8} = 56.55 \text{ mm}^2$$

Area covered by die holes = $\frac{\pi \times 12^2 \times 3}{4} = 339.336 \text{ mm}^2$

Die 3 (Circular)

$D_3 = 10.0$

$$A = \frac{\pi D^2}{4} \tag{3.18}$$

$$A = \frac{\pi \times 10^2}{4} = 78.55 \text{ mm}^2$$

Area covered by die holes = $\frac{\pi \times 10^2 \times 3}{4} = 235.65 \text{ mm}^2$

Therefore, the corresponding pressure are;

For Die 1 $P = \frac{0.312}{235.65} = 0.0013 \text{ MPa}$

For Die 2 $P = \frac{0.312}{339.336} = 0.000919 \text{ MPa}$

For Die 3 $P = \frac{0.312}{235.65} = 0.00095 \text{ MPa}$

3.2.11 Determination of Shaft

Two shafts are designed for the machine, that is, shaft for the cutter and the screw extruder shaft. The design is as follows;

a. Design for extruder shaft

Kurmi and Gupta (2005) defined the expression for determining the centrifugal tension (T_c) of the belt as;

$$T_c = mv^2 \tag{3.19}$$

Where;

m= weight per meter of the selected belt, 1.89N

Belt speed was determined using the equation

$$v_b = \frac{\pi dN}{12} \tag{3.20}$$

Where; d is the diameter motor pulley, mm

N is the speed of motor, rpm

$$v_b = \frac{\pi \times 60 \times 500}{12}$$

$$v_b = 7853.98\, mm/s = 7.8\, m/s$$

Therefore,

$$\mathrm{T_c} = 1.89 \times 7.8^2$$

$$\mathrm{T_c} = 111.33\ \mathrm{N}$$

Kurmi and Gupta (2005) gave the following equations in respect of power, velocity and tension on the slack and tight side of v-belt drive

$$2.3log\frac{T_1}{T_2} = \mu\theta cosec\beta \qquad (3.21)$$

$$\mathrm{L} = (\mathrm{T_1} - \mathrm{T_2})\mathrm{v}$$

$$\mathrm{T} = (\mathrm{T_1} - \mathrm{T_2})\mathrm{r}$$

Where

T_1=Tension on the tight side, N

T_2=Tension on the slack side, N

T_c=centrifugal tension, N

μ=coefficient of friction, 0.25

T= maximum torque, Nm

L=Power, W

v=Velocity of pulley, m/s

r=radius of pulley, 0.12 m

$$\beta = \text{semi angle of groove of pulley, } 16^0$$

$$\theta = \text{Angle of wrap} = 180 - 2\sin\alpha$$

and

$$\alpha = \frac{\mathrm{d}_2 - \mathrm{d}_1}{2\mathrm{C}}$$

$$\theta = 180 - 2\sin^{-1}\left(\frac{240 - 60}{2 \times 350}\right)$$

$$\theta = 168.46^0$$

Therefore,

$$2.3log\frac{T_1}{T_2} = 0.25 \times 168.46 \times cosec16$$

$$2.3log\frac{T_1}{T_2} = 152.79$$

$$2.3logT_1 = 152.79\,T_2$$

Knowing that the maximum torque is expressed according to Kurmi and Gupta (2005) as;

$$\mathrm{T} = \frac{60\mathrm{P}}{2\pi\mathrm{N}} \tag{3.22}$$

Where P $= 1.65$

$$\mathrm{T} = \frac{60 \times 1.65}{2 \times \pi \times 800} \qquad \mathrm{T} = 0.019\ \mathrm{Nm}$$

Similarly, given that maximum torque is related with the tension with expression by Kurmi and Gupta (2005) as;

$$\mathrm{T} = (\mathrm{T}_1 - \mathrm{T}_2)\mathrm{r} \tag{3.23}$$

$$\mathrm{T}_1 = \frac{0.24}{0.12} + \mathrm{T}_2$$

$$\mathrm{T}_1 = 2 + \mathrm{T}_2 \tag{3.24}$$

And substituting equation 3.15 for T_2

$$2.3\log(2 - T_2) = 152.79T_2$$

$\therefore \mathrm{T}_2 = 12.98\mathrm{N}$

Substituting in equation

$$T_1 = 2 + 12.98$$

$$T_1 = 14.98 \text{ N}$$

Weight of the auger on shaft is computed using $\text{Wa} = \text{mg}$

Where;

$\text{m} = \text{mass of steel auger} = \text{density of stainless steel} \times \text{total volume of screw}$

$\text{density of steel} = 7800 \text{ Kg/m}^3$

$$\text{volume of screw} = \frac{\pi D^2 l}{4} \quad (3.25)$$

$$= \frac{3.142 \times 0.030^2 \times 0.550}{4}$$

$$\text{volume of screw} = 3.89 \times 10^{-4} \text{ m}^3$$

Therefore, mass of the auger is

$$\text{m} = \text{v} \times \rho \quad (3.26)$$

v=volume of the auger, m^3

ρ = density of mild steel, kg/m^3

$$m = 7800 \times 3.89 \times 10^{-4}$$

$$\text{m} = 3.034 \text{ kg}$$

The corresponding weight of the auger from Kurmi and Gupta, (2005)

$$W_a = \text{mg} \quad (3.27)$$

Where,

m = mass of the auger, kg

g = acceleration due to gravity, kg/ms^{-2}

$$W_a = 3.034 \times 9.81$$

$$W_a = 29.74N$$

b. Weight of the Pulley

The weight of the pulley on the shaft can also be computed using the expression by Kurmi and Gupta (2005)

$$W_p = \rho v g \tag{3.28}$$

Where

v= Volume of the pulley, kg

g=Acceleration due to gravity, 9.81 N/ms^{-2}

ρ=density of stainless steel, 7800 kg/m^3

But

$$\text{volume of pulley} = \frac{\pi D^2 l}{4} = \frac{\pi \times 0.24^2 \times 0.005}{4}$$

$$\text{volume of pulley} = 0.000226 \text{ m}^3$$

Therefore;

$$W_p = 7800 \times 0.000226 \times 9.81$$

$$W_p = 17.3 \text{ N}$$

3.2.12 Tangential tooth load of gear

The tangential tooth load of the gear is obtained from the power transmitted and the pitch line velocity using the expression stated by Khurmi and Gupta (2005)

$$W_g = \frac{P}{v} \times C_s \tag{3.29}$$

Where;

W_g = Permissible tangential tooth load, N

P= Power transmitted, W

v= pitch line velocity

C_s = Service factor, 1.25 for light shock load type that operate 8-10h/day

$$W_g = \frac{1.65}{6.03} \times 1.25$$

$$W_g = 0.34\ N$$

3.2.13 Number of teeth of the gear

The number of teeth of spur gear is calculated using the expression

$$T = \frac{D_p}{m} \tag{3.30}$$

where

D_p= diameter of the gear, mm

m = required module factor

$$T = \frac{60}{3.68}$$

$$T = 19.032$$

$$T \approx 20$$

The number of teeth on the gear reduction configuration is calculated using the expression by Khurmin and Gupta (2005)

$$N_1D_1 = N_2D_2 \tag{3.31}$$

Where;

N_1=number of revolution of the drive gear, rpm

D_1= Diameter of the drive gear, mm

N_2= number of revolution of the driven gear, rpm

D_2= Diameter of the driven gear, mm

$$N_2 = \frac{N_1D_1}{D_2}$$

$$N_2 = \frac{800 \times 0.070}{15} = 4.7333$$

$$N_2 = 5 \text{ rpm}$$

3.2.14 Weight of gear on the extruder shaft

The weight of the gear on the shaft can be calculated using the expression given by Khurmi and Gupta (2005).

$$W_g = \rho v g \tag{3.32}$$

Where;

v=volume of the gear, m^3

ρ =density of mild steel, kg/m^3

But;

$$\text{volume of gear} = \frac{\pi t(D^2 - d^2)}{4} \tag{3.33}$$

$$\text{volume of gear} = \frac{\pi \times 0.010(70^2 - 25^2)}{4}$$

$$\text{volume of gear} = 33.58\ m^3$$

Therefore,

$$W_g = 1440 \times 33.58 \times 9.81$$

$$W_g = 54.8\ kN$$

3.2.15 Calculating the reactions at the bearing due to the extruder shaft

The shaft assembly and the reactions (R_a and R_b) at the bearing is shown in the figure 3.3 below, considering the center of mass of the shaft as $\frac{3}{4}l$ and taking moment about one of the reactions says R_a

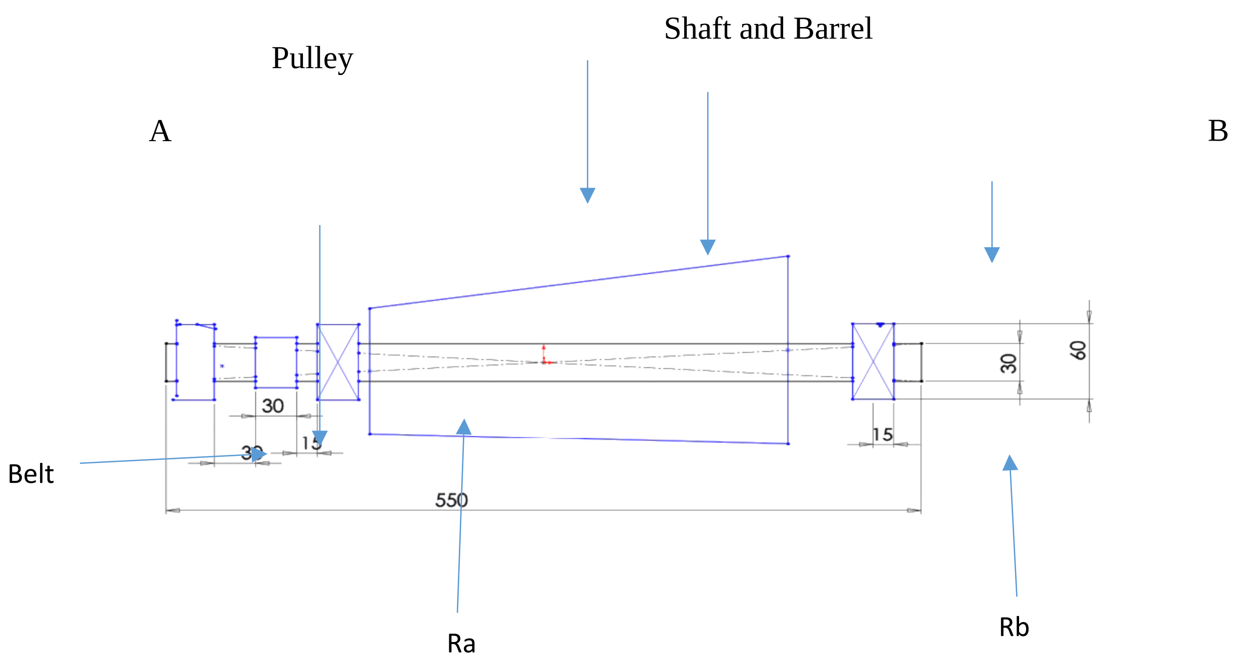

Figure 3.3: Free body Diagram of Forces acting on the Machine

Total weight acting on the machine are weight of the gear, weight of the pulley, weight of shaft, weight of hopper and the barrel

$$\mathrm{Ra} + \mathrm{Rb} = 29.74 + 67.5 + 54.8 + 14.7 = 166.74\ kg$$

Taking moment about on the reactions, R_a

$$\mathrm{Rb} \times 0.550 + 29.74 \times 0.49 + 166.74 \times 0.053 + 54.8 \times 0.030 = 14.7 \times 0.355$$

$$\mathrm{R_b} = -36.06\ N$$

$$\downarrow R_b = 36.06\ N$$

$$\mathrm{R_a} = 166.7 - 36.06$$

$$\mathrm{R_a} = 130.64\ \mathrm{N}$$

Bending Moment at A (M_{AV})

$$\mathrm{M_{AV}} = \mathrm{Ra} \times 0.10$$

$$\mathrm{M_{AV}} = 13.06\ \mathrm{Nm}$$

Bending Moment at B (M_{BV})

$$M_{BV} = Rb \times 0.275$$

$$M_{BV} = 9.9\ Nm$$

From the horizontal load as shown in fig 3.3

$R_{AH} + R_{BH} = 54.8$, Taking moment about A yield

$$R_{BH} \times 0.55 = 54.8 \times 0.275$$

$$R_{BH} = 27.4\ N$$

$$R_{AH} = 54.8 - 27.4$$

$$R_{AH} = 27.2\ N$$

Horizontal bending moment at M_{AH}

$$M_{AH} = R_{AH} \times 0.275 = 7.53$$

Horizontal bending moment at M_{BH}

$$M_{BH} = R_{BH} \times 0.275 = 7.53$$

The resultant bending moment at A (M_A)

$$M_A = \sqrt{(M_{AV})^2 - (M_{AH})^2} = 30.35Nm \tag{3.34}$$

The resultant bending moment at B (M_B)

$$M_B = \sqrt{(M_{BV})^2 - (M_{BH})^2} = 12.4Nm \tag{3.35}$$

Therefore, the maximum bending moment is at A is equivalent to 10.38Nm

Calculating the twisting moment of shaft

The expression for computing twisting moment of a shaft is given by Khurmi and Gupta (2005) as;

$$\mathrm{T_e} = \sqrt{(\mathrm{MK_b})^2 + (\mathrm{TK_t})^2} \tag{3.36}$$

$$\mathrm{d}^3 = \frac{16\mathrm{T}}{\pi\tau} \tag{3.37}$$

Where;

T_e = equivalent twisting moment, Nm

M= Maximum bending moment, Nm

T=Torsional Moment, Nm

K_b= Fatigue and shock factor due to bending, 2.0

K_t= Fatigue and shock Factor due to torsion. 1.5

d= diameter of shaft, m

τ=Maximum allowable shear stress, N/mm^2

$$T_e = \sqrt{(10.38 \times 2.0)^2 + (0.24 \times 1.5)^2}$$

$$T_e = 20.76\text{Nm}$$

Since the actual working stress is always less than maximum allowable stress, therefore the diameter is computed using the values of τ = 1.17 MPa and T= 0.24 Nm

$$d^3 = \frac{16 \times 0.24}{\pi \times 1.17}$$

$$d = 0.03001 \text{ m} \approx 30 \text{ mm}$$

3.3 Mode of Operation of the Machine

The groundnut cake extruder is a machine operated by an electric motor. The power from the electric motor is transmitted through the V- grooved belt to the shaft with the aid of pulleys. The shaft is attached to the pulley by means of a gear system which also connects to the cutter shaft. The shaft is held in place by two bearings for proper rotation. The rotary force is transmitted to the screw auger which develops friction force between the groundnut paste and the die. This force through the screw conveys the paste through the holes in the die to produce the extrudate. The formed extrudate is then cut to desired length by the cutter as it comes out of the die.

3.4 Description of Various Parts of the Machine

The components of the designed groundnut cake extruder were fabricated using locally available materials. The fabricated parts which include the frame, hopper, screw conveyor, gear etc are discussed below.

3.4.1 The frame

The iron frame of the machine was fabricated in the L shape to provide strength and firmness to the machine. The frame was made of iron steel section of 40×40×4 mm. The frame was constructed with the following dimensions: 703 mm height, 570 mm length and 325 mm width.

3.4.2 Hopper

The hopper was fabricated in trapezoidal shape, using stainless steel sheet of 20 gauge thickness to prevent sticking of feeds to the feed hopper and to allow easy cleaning. It has a dimension of 370 mm in length, 220 mm in width and base length of 100 mm.

3.4.3 Barrel

The barrel is a cylinder with internal diameter of 80 mm and thickness of 5 mm. It has a length of 300 mm. A flange was welded to the end of the barrel to support the die plate.

3.4.4 The die plate

The die is required to restrict the flow of feed material and provide the shape of the extrudate. The die plate had a thickness of 5 mm. The effective diameter of the die plate was 80 mm. Three die inserts of 8 mm were drilled into the plate. Three different dies of inverted, square and circular shapes were fabricated.

3.4.5 Screw conveyor

The screw conveyor was a worm wound round a cylindrical shaft. The maximum outer diameter of the worm was 78 mm to give clearance between screw and barrel. The screw conveyor was carried on a solid shaft of 25 mm which is driven by a pulley.

3.4.6 Electric gear motor

This was responsible in driving the die plate to an appropriate speed that led to the conversion of the groundnut paste into pellets. A single phase 1 Hp electric motor was used in order to drive the needed speed for operation of 1430 rpm and at the same time being able to bear overload should it happen.

3.5 Cost of Construction of the Machine

The cost of constructing the machine covers cost of materials used for the construction and those paid for labour. A summary of the list of materials used in constructing the machine along with its associated costs is given in Table 3.1. Various views and parts drawing of the machine are presented in Figures 3.4, 3.5, 3.6 and 3.7.

Table 3.1: Material Cost Estimate

S/No	MATERIAL	QTY	UNIT PRICE	AMOUNT
1	Mild Steel Angle Iron ($40 \times 40 \times 4\ mm$)	3	5000	15000
2	Mild Steel Plate 2mm	$\frac{1}{4}\ sheet$	28000	7000
3	Stainless Steel Pipe 0.6	1.2m	3500	7000
4	Stainless Steel Shaft 25mm Ø	0.5m	28000	14000
5	Stainless Steel Rod 6mm Ø	3m	3500	9500
6	Bearing (Ball Bearing)	4 pieces	1000	4000
7	Mild Steel Shaft 25mm Ø	0.6m	5000	5000
8	Set of Pinion gear	1	2500	2500
9	Pulley	3	2500	7500
10	Electric Gear Motor	1	44000	44000
11	Bolts & Nuts	2 dozen	600	1200
12	V-Belt	3	1000	3000
13	Paint	2 litres	800	1600
14	Thinner	2 litres	400	800
15	Electrode	1 tin	3000	3000
16	Labour			30000
	TOTAL			N155,100

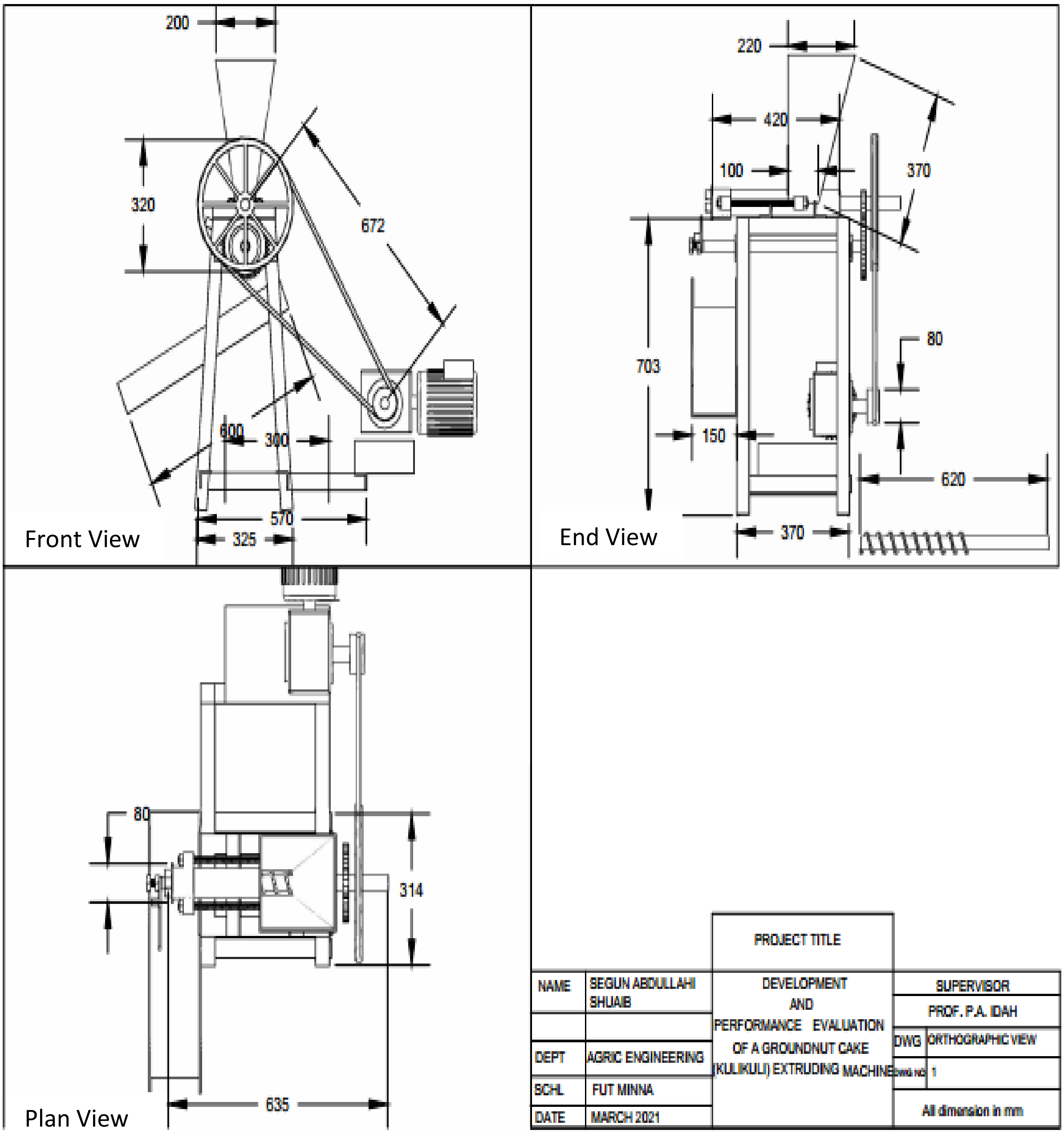

Figure 3.4: Orthographic Drawing of Extruder Machine

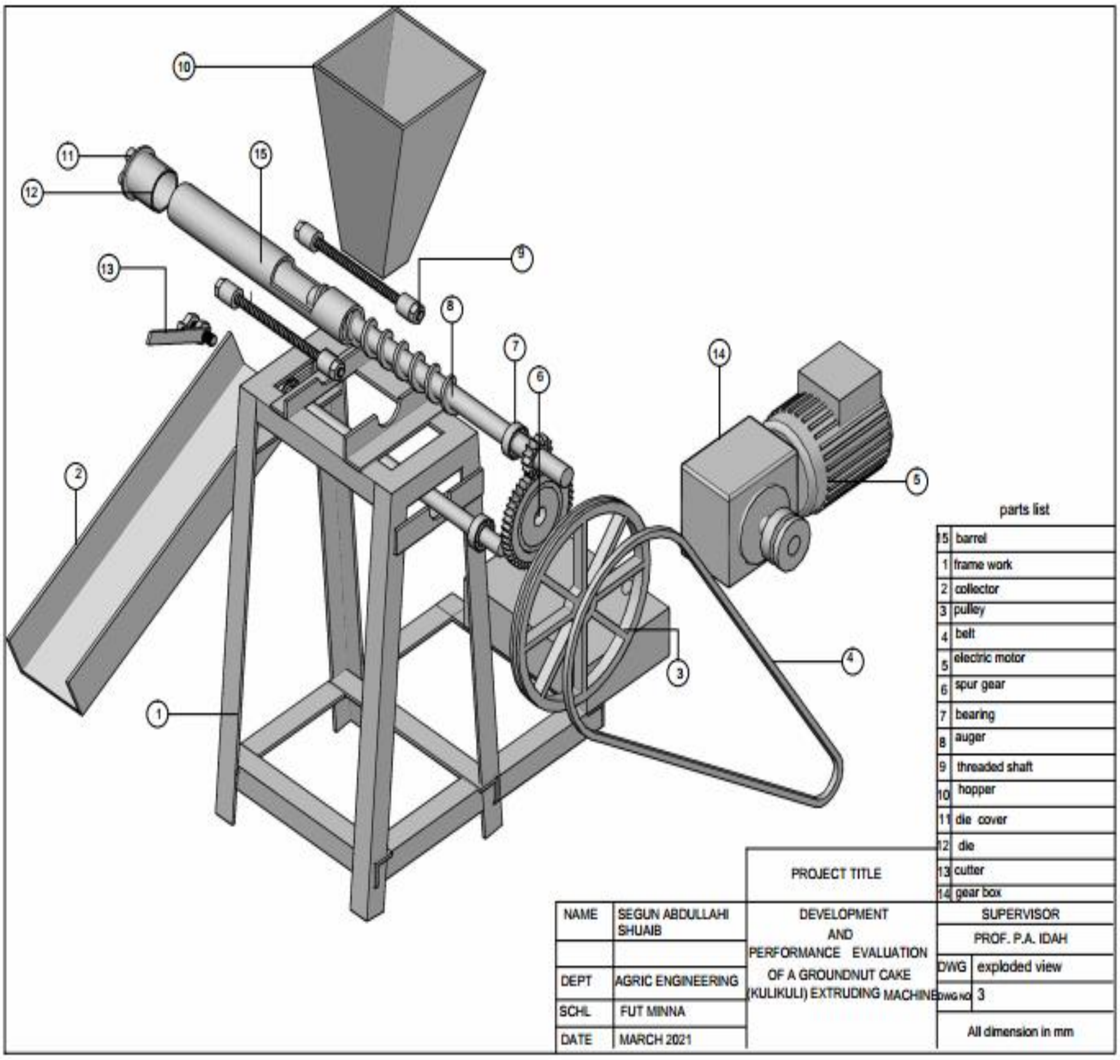

Figure 3.5: Exploded view of the extruder machine

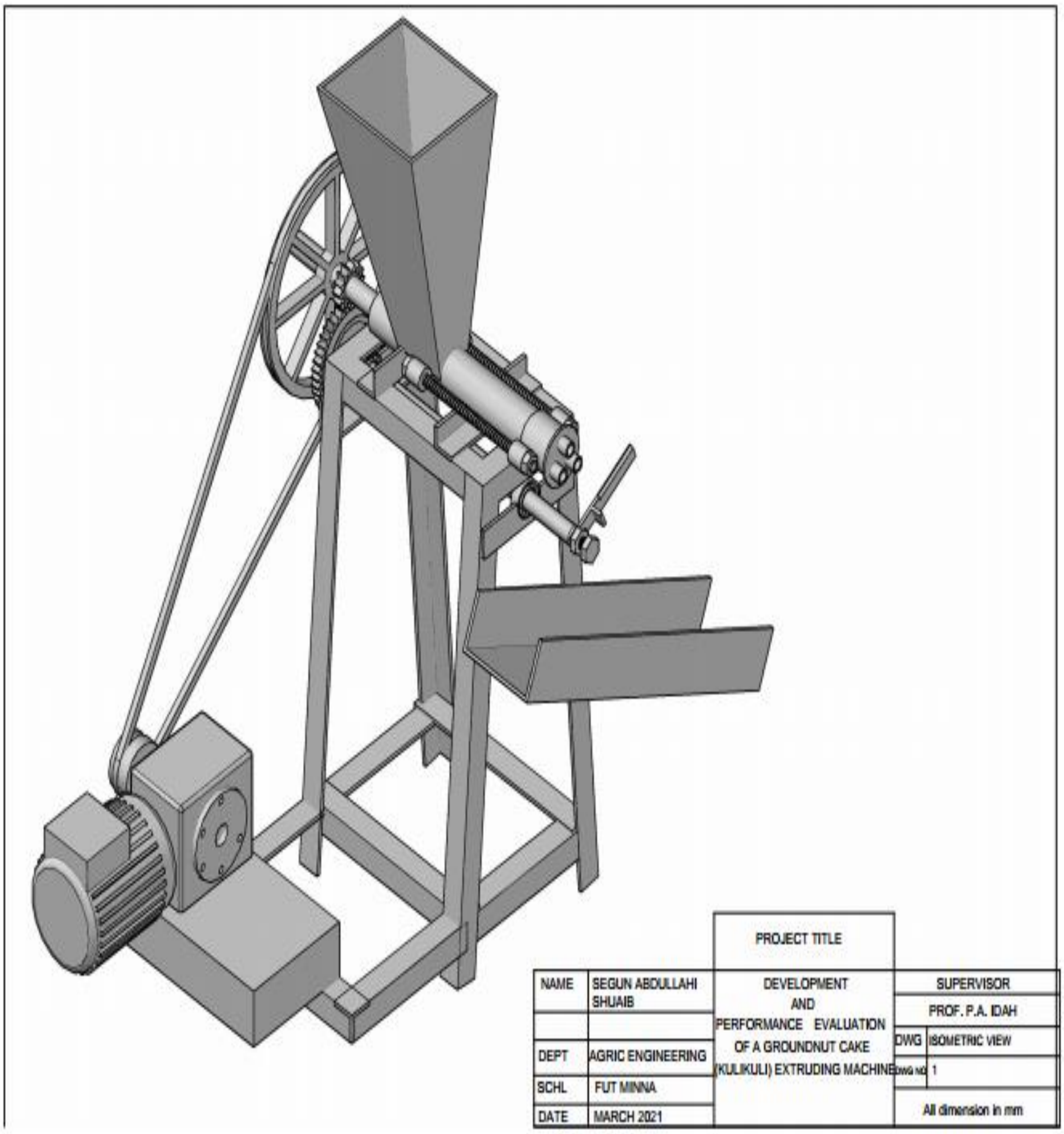

Figure 3.6: Isometric View of the Extruder Machine

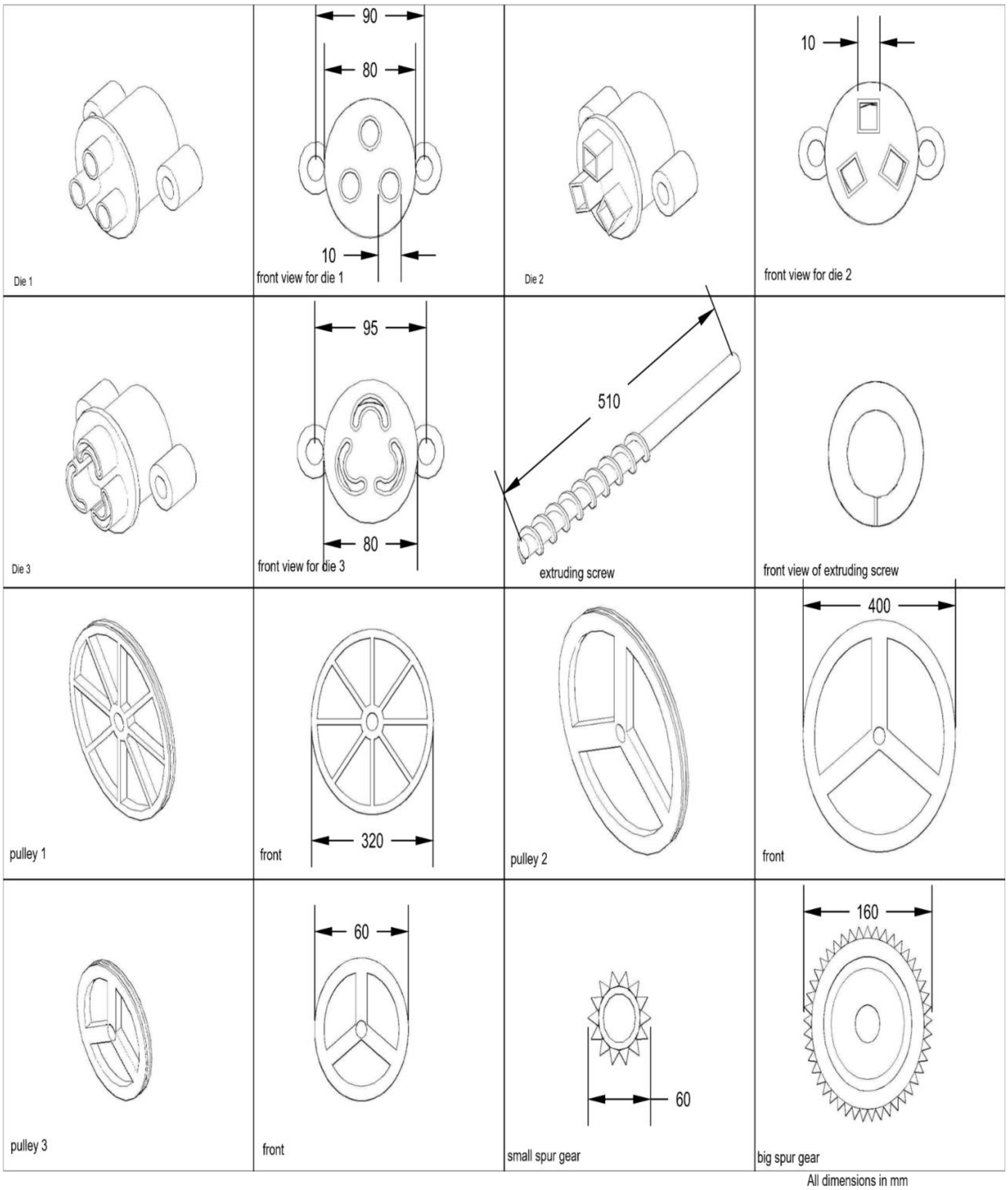

Figure 3.7: Part Drawing of the Extruder Machine

Plate V: Fabricated Groundnut Cake Extruder

3.6 Performance Evaluation of the Groundnut Cake Extruder

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

3.6.1 Machine parameter

3.6.1.1 Specific mechanical energy (SME)

This is a measure of the work done by the extruder on the feed materials and the energy that is transformed into the thermal energy which is an important index in terms of the cost of manufacturing extruded products. SME as reported by Fayose (2009) was calculated using equation 3.38:

$$\mathrm{SME} = \frac{2\pi \times \mathrm{T} \times \mathrm{Ss}/60}{\mathrm{Fr}} \times 3.6 \left(\frac{\mathrm{Kj}}{\mathrm{Kg}}\right) \quad (3.38)$$

Where;

T is the corrected torque (Nm),

Ss is the screw speed (rpm),

Fr is the feed rate (Kg/h).

The torque T required to drive the screw was calculated using equation 3.39 according to (Khurmi and Gupta, 2005); $T = \frac{60\mathrm{P}}{2\pi\mathrm{N}}$ (3.39)

Where,

P is the input power,

N is the machine speed in rpm and

T is the torque required.

3.6.1.2 Extruder capacity

The extruder efficiency was evaluated by determining parameters like the extrusion capacity and functional/extrusion efficiency of the machine from the observed data. Extrusion capacity was calculated according to Kabri *et al.* (2006) using equation 3.40

$$\mathrm{EC} = \frac{\mathrm{Me}}{\mathrm{T}} \quad (3.40)$$

Where;

EC is the extrusion capacity (Kg/min),

Me is the mean mass of the extrudates for each treatment (Kg),

T is the mean time taken for the extrusion (min).

Extrusion efficiency were calculated as the ratios in percentage of the extrudates to the initial mass of materials fed into the machine.

This is represented mathematically as: $\mathrm{RE} = \frac{\mathrm{Me}}{\mathrm{Mi}}$ (3.41)

Where;

RE is the extrusion efficiency (%),

Me is the mean mass of extrudates (kg),

Mi is the mean initial mass of ingredients (kg)

Extruding Efficiency $R_\mathrm{e} = \frac{Me}{Mi} \times 100$

Where,

R_e= Extruding Efficiency (%)

Me = Average quantity extruded 1.87 kg

Mi = Quantity fed into the machine 2 kg

Re= $\frac{1.87}{2} \times 100 = 93.5$ %

And

Cutting Efficiency Ce =$\frac{Mc}{Mi} \times 100$

Where,

Ce= Cutting Efficiency (%)

Mc = Average quantity cut by blade 390.06 g

Mi = Quantity fed into the machine 2000 g

Ce= $\frac{390.06}{2000} \times 100 = 19.5$ %

Therefore Efficiency = $\frac{93.5 + 19.5}{2} = 56.5$ %

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

$Fr= \frac{Me}{T}$

Fr= Extruding capacity (kg/h)

T= Average time taken, 548.18 s (0.152 h)

Me= Average quantity extruded, 1.87 kg

Therefore,

Feed rate $Fr = \frac{1.87}{0.152}$

Fr= 12.30 kg/h

3.6.2 Product parameters

3.6.2.1 Expansion ratio

This was determined according to (Choudhury *et al.*, 1998) where extrudates are measured using Vernier caliper and the radial expansion ratio calculated from the formula in equation 3.42:

$$Er = \frac{D^2}{d^2} \qquad (3.42)$$

Where;

Er is the expansion ratio,

D is the extrudates diameter while d is the diameter of the die.

Specific length of the extrudates could be measured also with the help of Vernier caliper. The specific length is calculated as extrudate length divided by extrudate mass.

Specific length $= \frac{Le}{Me}$

3.6.2.2 Bulk density

Bulk Density (BD) is expressed in g/cm^3. It was measured using the method described by Ding *et al.* (2005) for bulk pieces of extrudates by taking it in a defined volume jar or cylinder.

$$\text{Density}(\rho) = \frac{\text{mass}}{\text{volume}} \ (\text{g/cm}^3) \quad (3.43)$$

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

3.7 Experimental Design and Statistical Analysis

The Study was conducted using a randomized block design to evaluate the effect of three parameters; screw speeds (7, 9, and 11rpm), moisture content (5.04%, 7.04% and 10.65%) and die shape (square, inverted and circular) on the physical properties of the extrudate. These were the independent variables. Bulk density, length, weight, diameter, extruding time, extrusion capacity, expansion ratio and specific length of the extrudates were measured as the response/dependent variables. A layout was obtained by the process of randomization showing the different combination of moisture content, screw speeds, and die shape. The layout obtained is shown in Table 3.2. The experiment was conducted in three replicates for all the extruded physical properties. All collected data were analyzed with response surface methodology (D-optimal design) using Design Expert 11.1.2.0 which consisted of 3 numerical independent variables of moisture content and screw speeds, each at three levels and one categorical variable of die shape at three levels. The fitness of the model was evaluated and the interactions between the independent and dependent variables were identified by using an analysis of variance (ANOVA). The goodness of fit of the second order equation was expressed by the coefficient of determination (R^2) and its statistical significance was determined by F-test. Significant terms were accepted at $P < 0.05$. The R^2 of 0.6 was accepted for predictive purposes (Anuonye *et al.*, 2007). 3-D response surface model were used to visualize interactive effects of the independent variables.

3.7.1 Experimental procedure

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

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

2kg weight of each of the samples were fed into the extruder machine at three different screw speeds of 7, 9 and 11 rpm as shown in Table 3.2. These reduced speeds were attained with the aid of a reduction gear motor. Three detachable dies (Square, Inverted and Circular) were fabricated to give room for the production of different shapes of groundnut cake.

The maximum and minimum level of the factors considered in the performance evaluation of the groundnut cake extruding machine is presented in Table 3.2 to show the minimum level of speed at 7rpm and maximum speed at 11rpm, the moisture content in percentage at minimum of 5.04 and 10.65 and finally the categoric value of the square die shape at minimum and circular shape at maximum. Table 3.3 indicates the experimental layout of the groundnut cake extruder.

Table 3.2: Experimental design used to evaluate the groundnut cake extruding machine.

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

Table 3.3: Experimental layout for the groundnut cake extruder

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

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The result of the experiment carried out on the groundnut cake extruder is shown in Table 4.1.

Table 4.1: Experimental Result on the Groundnut Cake Extruder

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

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

4.2 Discussion of Experimental Results

4.2.1 The Effect of screw speed and moisture content on the product quality of groundnut cake

Statistical Analysis shows that screw speed, moisture content and Die shape have significant effect on some product parameters of extruded groundnut cake at 5% level of significance. The final equations in actual form obtained for length, weight, diameter, bulk density, extruding time, extrusion capacity, expansion ratio and specific length for each level of categoric variable (Square Die, Inverted Die and Circular Die) were discussed below.

4.2.2 Length

The results of the effect of the independent variables on the length of product extruded are shown in Table 4.2. The experimental result for the length ranged from 54-164.25 mm (Table 4.1). Figures 4.1, 4.2 and 4.3 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the length of the extruded groundnut cake. The statistical analysis shows that screw speed and die shape have significant effect on the length. The model F-value of 25.63 implies the model is significant. This conforms to Koksel *et al.* (2004) that the screw speed has effect on the length of extruded product. Basediya *et al.* (2013) observed that when screw speed increased then length increases. This is as a result of the increase in temperature as the speed increases thereby making it less binding. The predicted R^2 of 0.7920 is in agreement with the adjusted R^2 of 0.8243. The 3-D response surface plot for length in terms of moisture content and screw speeds shows that the model equation can be used to determine the relative impact of each factor. The response of length considering speed and moisture content interaction shows that the boundary region for all the analysis tend to be at the lower region.

Table 4.2: Analysis of Variance for length of Extruded Groundnut Cake

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	23791.36	4	5947.84	25.63	< 0.0001	Significant
A:Speed	2481.59	1	2481.59	10.69	0.0045	
B:Moisture	27.87	1	27.87	0.1201	0.7332	
C:Die Shape	20379.53	2	10189.77	43.91	< 0.0001	
Residual	3944.70	17	232.04			
Lack of Fit	3944.70	11	358.61			
Pure Error	0.0000	6	0.0000			
Cor Total	27736.06	21				

Fit Statistics

Std. Dev.	15.23	**R^2**	0.8578
Mean	98.51	**Adjusted R^2**	0.8243
C.V. %	15.46	**Predicted R^2**	0.7920
		Adeq Precision	13.1476

The equation model for the length of extruded product in terms of actual factor:

Equation for Square Die shape;

Length = +27.44 + 6.51A - 0.74B (4.1)

Equation for Inverted Die shape;

Length = +93.90 + 6.51A – 0.74B (4.2)

Equation for Circular Die shape;

Length = +28.91 + 6.51A - 0.74B (4.3)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

Equations 4.1, 4.2 and 4.3 shows the equations in terms of actual factors. This can be used to make predictions about the length of the extruded groundnut cake for the different die shapes (square, inverted and circular).

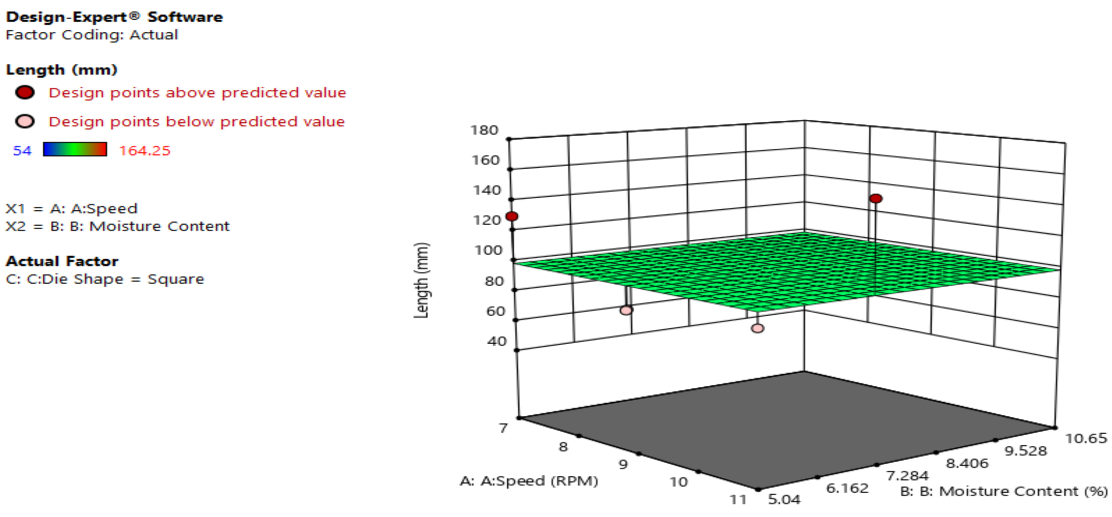

Figure 4.1: 3-D Response Surface Plot of Moisture Content and Speed effect on Square Shaped length

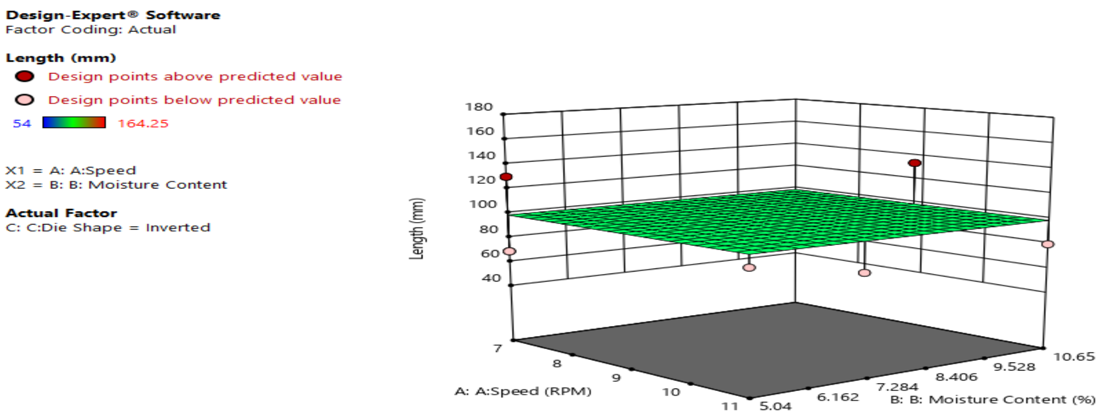

Figure 4.2: 3-D Response Surface Plot of Moisture Content and Speed effect on Inverted Shaped length

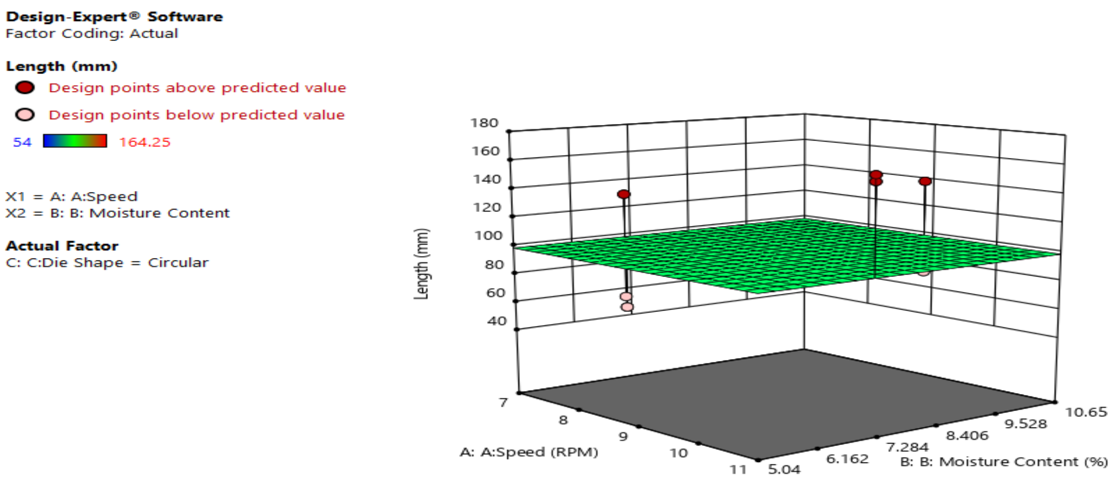

Figure 4.3: 3-D Response Surface Plot of Moisture Content and Speed effect on Circular Shaped length

4.2.3 Weight

The results of analysis of variance of the effect of the independent variables on the weight of product extruded are shown in Table 4.3. The experimental result for weight ranged from 10.9-25.54 g (Table 4.1). The statistical analysis shows that moisture content, screw speed and die shape has no significant effect on the weight. Ding *et al.* (2006) also observed the same result in the extrusion cooking of wheat flour extrudates. It was reported that this insignificant value in the weight extrudate was as a result of starch gelatinization occurring during extrusion cooking. The Lack of Fit F-value of 1.28 implies the Lack of Fit is not significant relative to the pure error. Figures 4.4, 4.5 and 4.6 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the weight of the extruded groundnut cake. The 3-D response surface plot for weight in terms of moisture content and screw speeds shows that the model equation in terms of actual factors can be used to make predictions about the response for given levels of each factor.

Table 4.3: Analysis of Variance for weight of Extruded Groundnut Cake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	189.88	11	17.26	1.43	0.2909	not significant
A:Speed	33.16	1	33.16	2.74	0.1286	
B: Moisture Content	3.43	1	3.43	0.2839	0.6058	
C:Die Shape	35.98	2	17.99	1.49	0.2717	
AB	0.0548	1	0.0548	0.0045	0.9476	
AC	0.5529	2	0.2764	0.0229	0.9774	
BC	4.50	2	2.25	0.1861	0.8330	
A^2	24.14	1	24.14	2.00	0.1879	
B^2	28.98	1	28.98	2.40	0.1525	
Residual	120.83	10	12.08			
Lack of Fit	55.56	4	13.89	1.28	0.3750	not significant
Pure Error	65.27	6	10.88			
Cor Total	310.72	21				

Std. Dev.	3.48	**R^2**	0.6111
Mean	15.37	**Adjusted R^2**	0.1833
C.V. %	22.62	**Predicted R^2**	-2.8741
		Adeq Precision	4.4566

The equation model for the weight of extruded product in terms of actual factor:

Equation for Square Die shape;

Weight $= 57.96 - 13.44A + 6.02B - 0.03AB + 0.72A^2 - 0.42B^2$ (4.4)

Equation for Inverted Die shape;

Weight $= 51.85 - 13.56A + 6.77B - 0.03AB + 0.72A^2 - 0.42B^2$ (4.5)

Equation for Circular Die shape;

Weight $= 57.19 - 13.71A + 6.71B - 0.03AB + 0.72A^2 - 0.42B^2$ (4.6)

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

AB= Interactions

Equation 4.4, 4.5 and 4.6 shows the equations in terms of actual factors. This can be used to make predictions about the weight of the extruded groundnut cake for the different die shapes (square, inverted and circular).

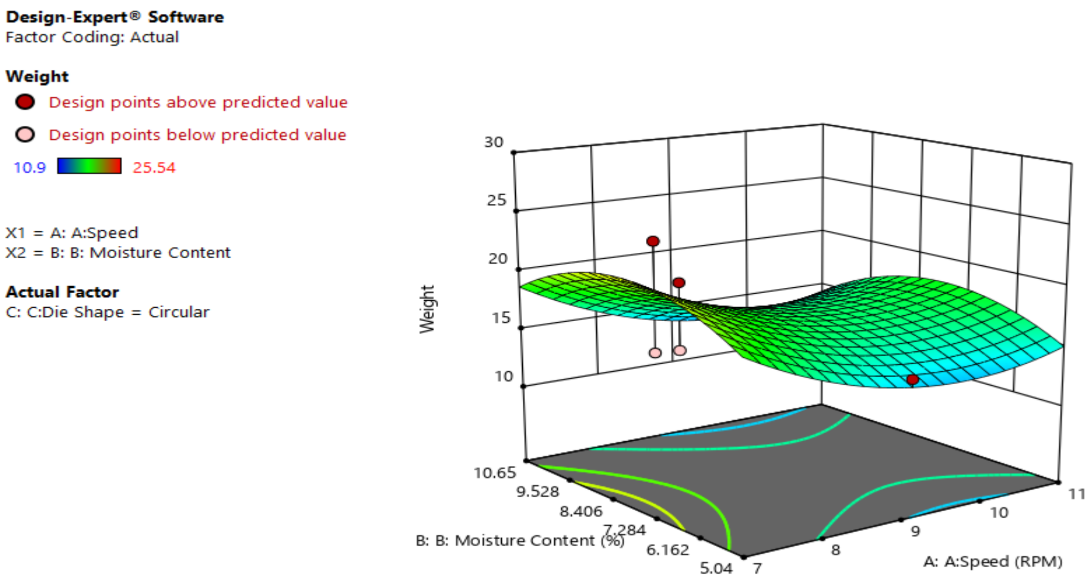

Figure 4.4: 3-D Response Surface Plot of Moisture Content and Speed effect on Circular Shaped Weight

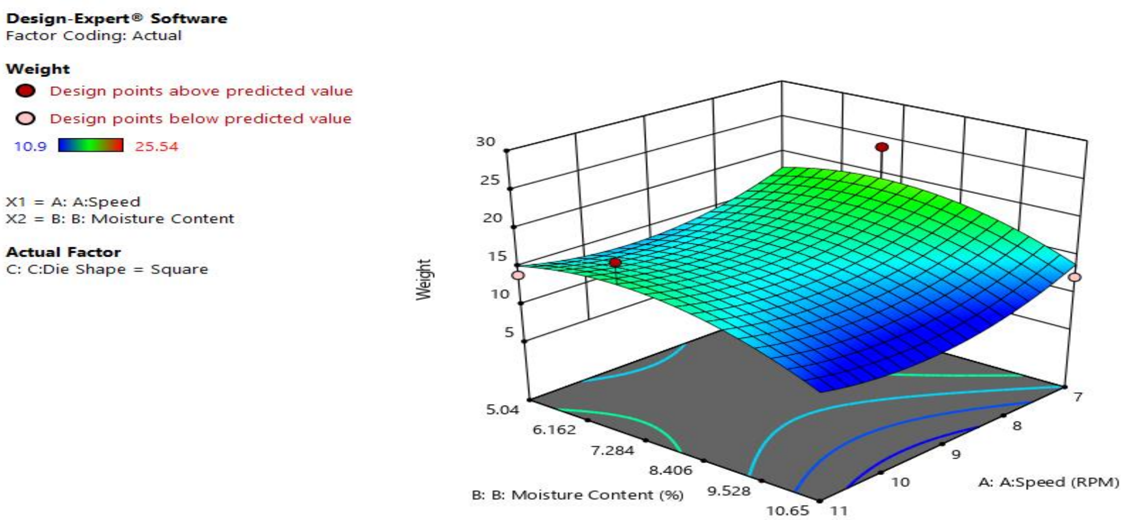

Figure 4.5: 3-D Response Surface Plot of Moisture Content and Speed Effect on Square Shaped Weight

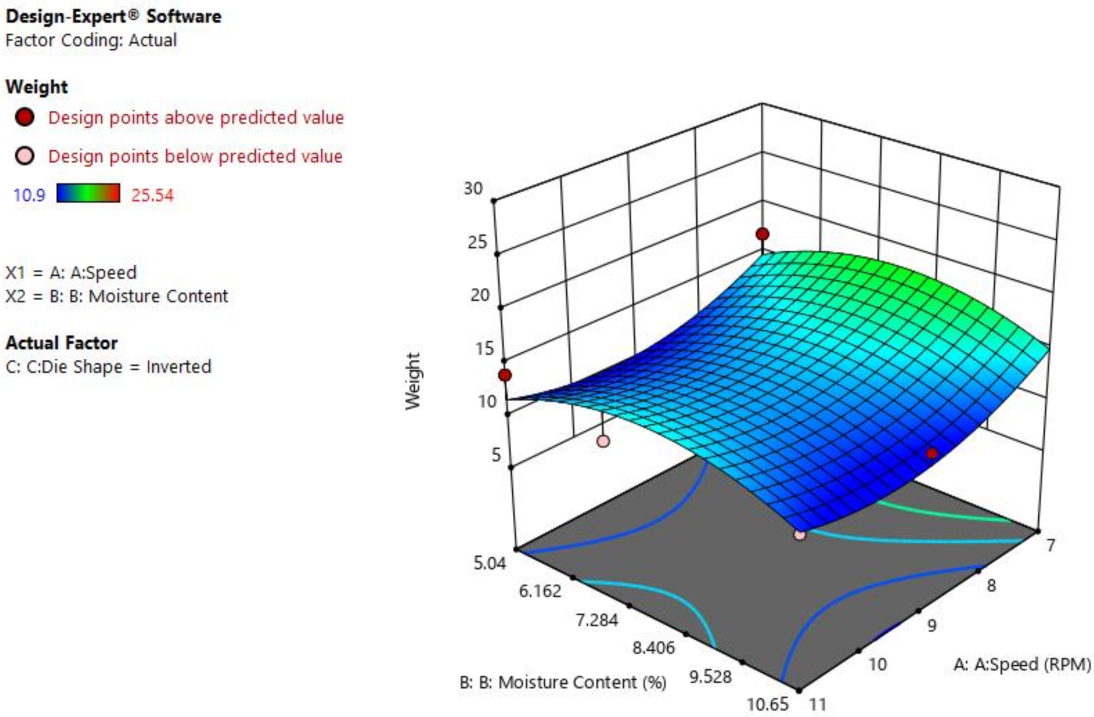

Figure 4.6: 3-D Response Surface Plot of Moisture Content and Speed effect on Inverted Shaped Weight

4.2.4 Diameter

The results Analysis of variance of the effect of the independent variables on the diameter of product extruded are shown in Table 4.4. The experimental result for diameter ranged from 10.9-25.54 g (Table 4.1). Figures 4.7, 4.8 and 4.9 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the diameter of the extruded groundnut cake. The statistical analysis shows that moisture content, screw speed and die shape has no significant effect on the diameter of the groundnut cake. The Model F-value of 2.62 implies there is a 6.13 % chance that an F- value this large could occur due to noise. The rheological and thermodynamic processes occurring inside the die during forming and stretching have little effect on the final diameter of extruded products (Mercier *et al.,* 1989). This is in agreement with Shukla *et al.* (2005) who investigated the effect of the die nozzle dimension and concluded that moisture content and screw has no significant effect on the diameter of extrudate product. The interaction of screw speed and die shape shows a P-value of 0.0225 which indicates that the model term is significant. A ratio greater than 4 is desirable hence the ratio 4.746 indicates an adequate signal. This model can be used to navigate the design space. The 3-D response surface plot for diameter in terms of moisture content and screw speeds shows that the model equation in terms of actual factors can be used to make predictions about the response for given levels of each factor.

Table 4.4: Analysis of Variance for diameter of Extruded Groundnut Cake

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	27.74	9	3.08	2.62	0.0613	not significant
A:Speed	4.73	1	4.73	4.02	0.0681	
B:Moisture	0.3012	1	0.3012	0.2560	0.6221	
C:Die Shape	0.3027	2	0.1513	0.1286	0.8805	
AB	0.0114	1	0.0114	0.0097	0.9233	
AC	12.45	2	6.23	5.29		
BC	1.23	2	0.6142	0.5219		
Residual	14.12	12	1.18			
Lack of Fit	13.13	6	2.19	13.23		
Std. Dev.	1.08		R^2	0.6627		
Mean	12.88		Adjusted R^2	0.4097		
C.V. %	8.42		Predicted R^2	-0.5431		
			Adeq Precision	4.7464		

The equation model for the Diameter of extruded product in terms of actual factor:

Equation for Square Die shape;

Diameter = +4.92 + 0.73A+ 0.27B – 0.01AB (4.7)

Equation for Inverted Die shape;

Diameter = +19.40 – 0.28A – 0.20B – 0.01AB (4.8)

Equation for Circular Die shape;

Diameter = +3.97 + 0.99A + 0.11B – 0.01AB (4.9)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

AB= Interactions

Equations 4.7, 4.8 and 4.9 shows the equations in terms of actual factors. This can be used to make predictions about the diameter of the extruded groundnut cake for the different die shapes (square, inverted and circular).

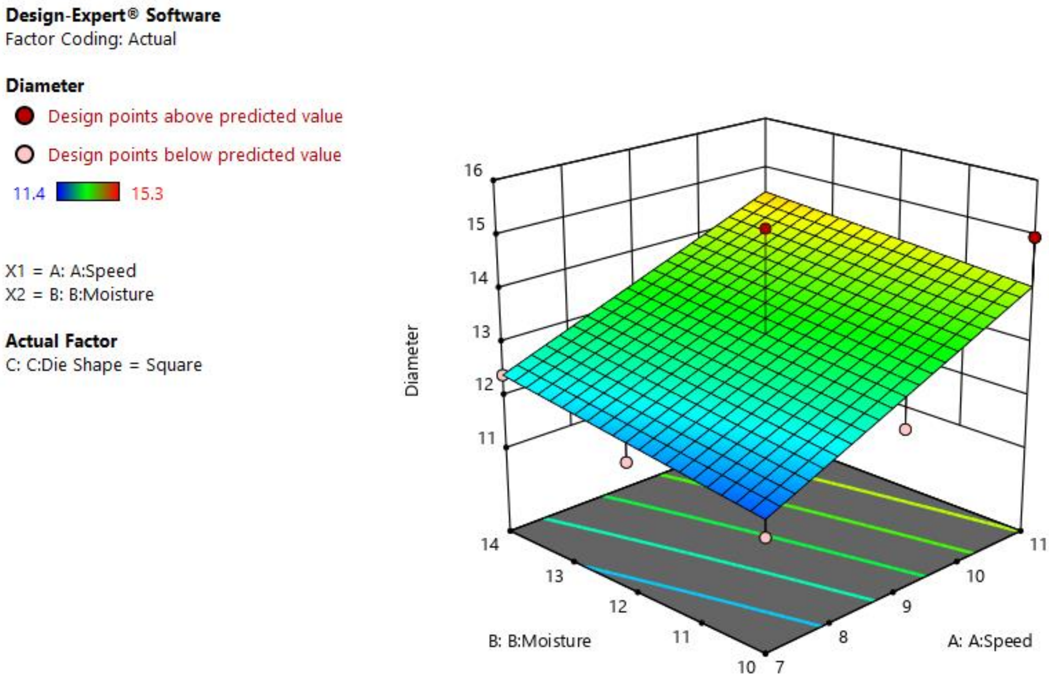

Figure 4.7: 3-D Response Surface Plot of Speed and Moisture Content Effect on Square Shaped Diameter

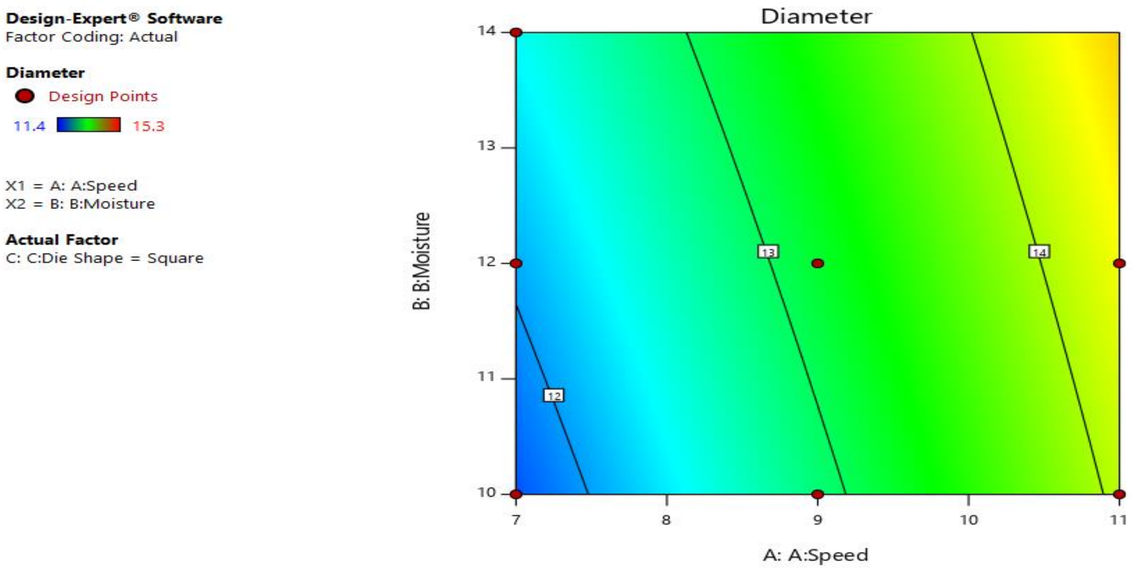

Figure 4.8: Contour Plot of Speed and Moisture Content Effect on Square Shaped Diameter

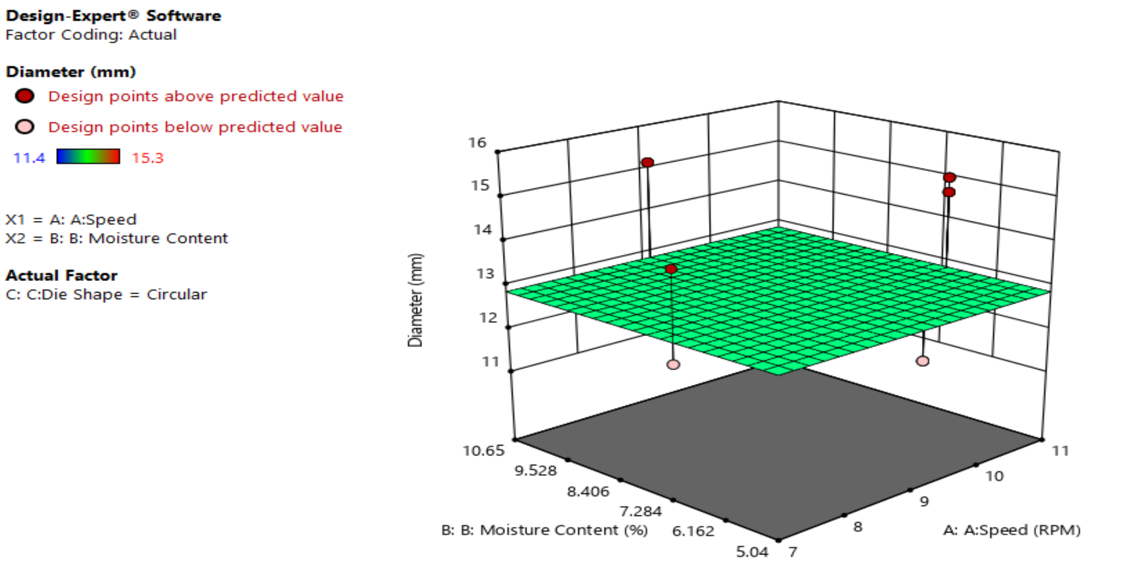

Figure 4.9: 3-D Response Surface Plot of Speed and Moisture Content Effect on Circular Shaped Diameter

4.2.5 Bulk density

The results of Analysis of variance of the effect of the independent variables on the bulk density of product extruded are shown in Table 4.5. The experimental result for bulk density ranged from 0.98-1.2 g/cm^3 (Table 4.1). Figures 4.10, 4.11, 4.12, 4.13, 4.14 and 4.15 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the bulk density of the extruded groundnut cake. The statistical analysis shows that moisture content and screw speed have significant effect on the bulk density while die shape is not significant. The effect of moisture content and screw speed on the extrudate shows that an increase in the moisture leads to an increase in the bulk density of the extrudates. Increased feed moisture content during extrusion may reduce the elasticity of the paste through plasticization of the melt, resulting in reduced SME and therefore reduced gelatinization, decreasing the expansion and increasing the density of extrudate (Ding *et al.,* 2006). It was depicted that bulk density increased with increase in moisture as higher water content produced extrudates denser than those produced with low water content (Koksel, 2004).

The Model F-value of 18.99 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case screw speed and moisture content are significant model terms. The Lack of Fit F-value of 1.10 implies the Lack of Fit is not significant relative to the pure error. There is a 47.66 % chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good. The density of extrudates produced varied between 0.98 and 1.2 g/cm^3 which is higher than 0.5 to 0.6 g/cm^3 obtained by Poulter *et al.* (2006). It however corresponds with 0.91 to 1.3 g/cm^3 obtained in a design by Tiwari *et al.* (2011). The 3-D response surface plot for bulk density in terms of moisture content and screw speeds shows that the model equation in terms of actual factors can be used to make predictions about the response for given levels of each factor.

Table 4.5: ANOVA for Linear model for Bulk Density of Extruded Groundnut Cake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0726	4	0.0182	18.99	< 0.0001	significant
A:Speed	0.0605	1	0.0605	63.25	< 0.0001	
B: Moisture Content	0.0108	1	0.0108	11.25	0.0038	
C:Die Shape	0.0040	2	0.0020	2.07	0.1567	
Residual	0.0163	17	0.0010			
Lack of Fit	0.0109	11	0.0010	1.10	0.4766	not significant
Pure Error	0.0054	6	0.0009			
Cor Total	0.0889	21				

Std. Dev.	0.0309	**R^2**	0.8171
Mean	1.12	**Adjusted R^2**	0.7741
C.V. %	2.77	**Predicted R^2**	0.7007
		Adeq Precision	14.9372

The equation model for the Bulk density of extruded product in terms of actual factor:

Equation for Square Die shape;

Bulk density = 0.88 + 0.03A – 0.01B (4.10)

Equation for Inverted Die shape;

Bulk density = 0.92 + 0.03A – 0.01B (4.11)

Equation for Circular Die shape;

Bulk density = 0.91 + 0.03A – 0.01B (4.12)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

Equations 4.10, 4.11 and 4.12 shows the equations in terms of actual factors. This can be used to make predictions about the bulk density of the extruded groundnut cake for the different die shapes (square, inverted and circular).

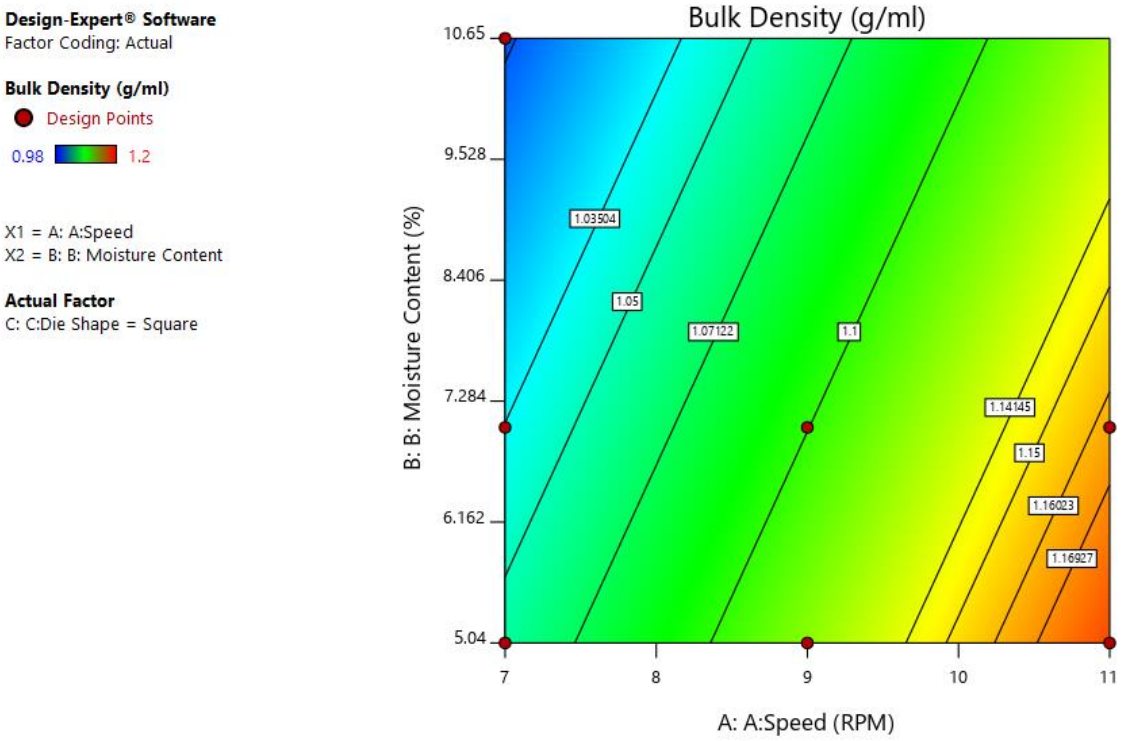

Figure 4.10: Contour Plot of Speed and Moisture Content Effect on Square Shaped Bulk Density

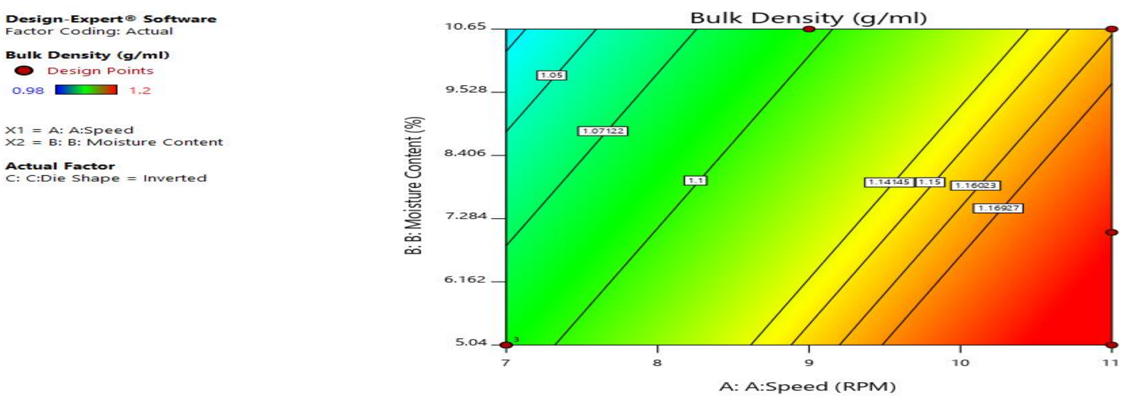

Figure 4.11: Contour Plot of Moisture Content and Speed Effect on Inverted Shaped Bulk Density

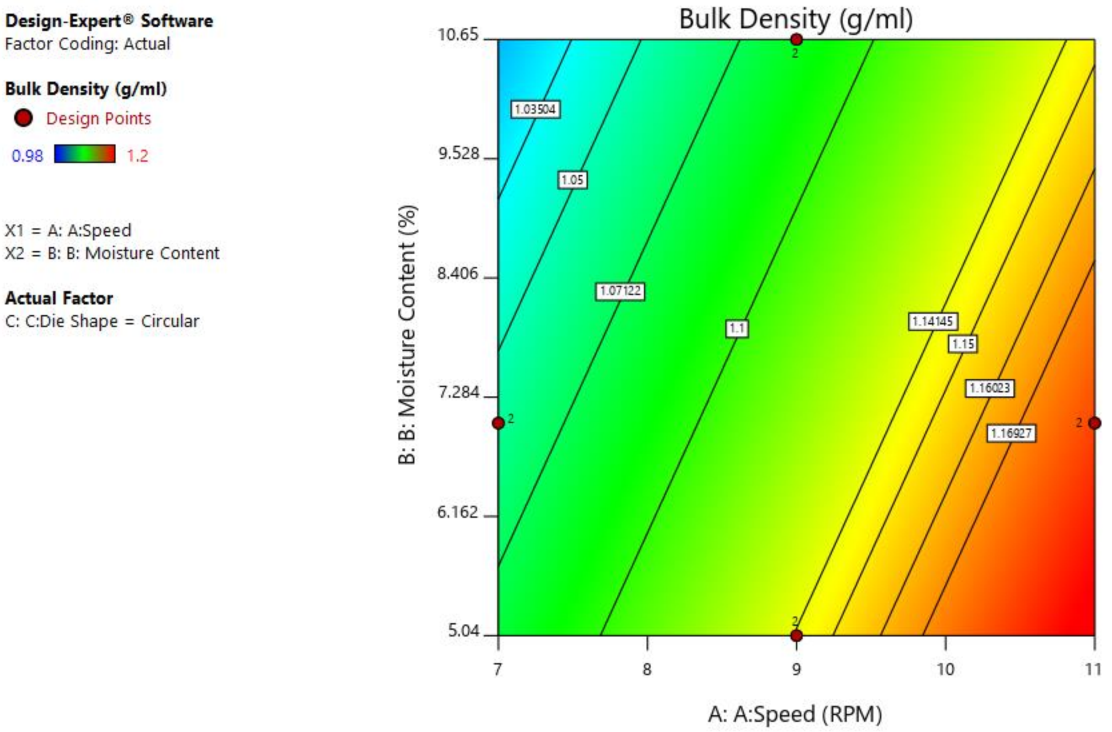

Figure 4.12: Contour Plot of Moisture Content and Speed Effect on Circular Shaped Bulk density

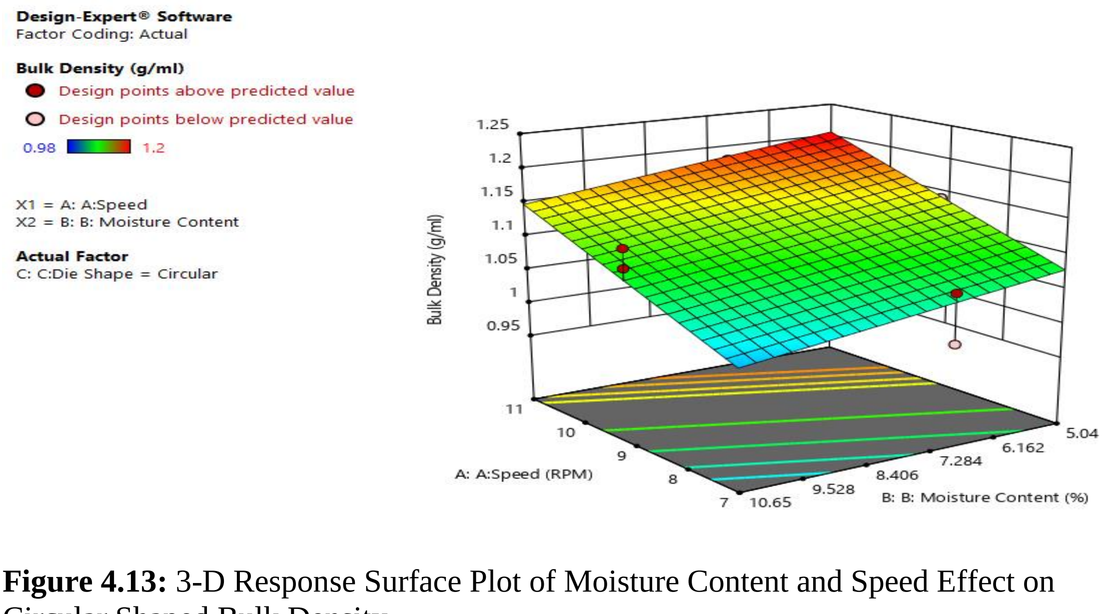

Figure 4.13: 3-D Response Surface Plot of Moisture Content and Speed Effect on Circular Shaped Bulk Density

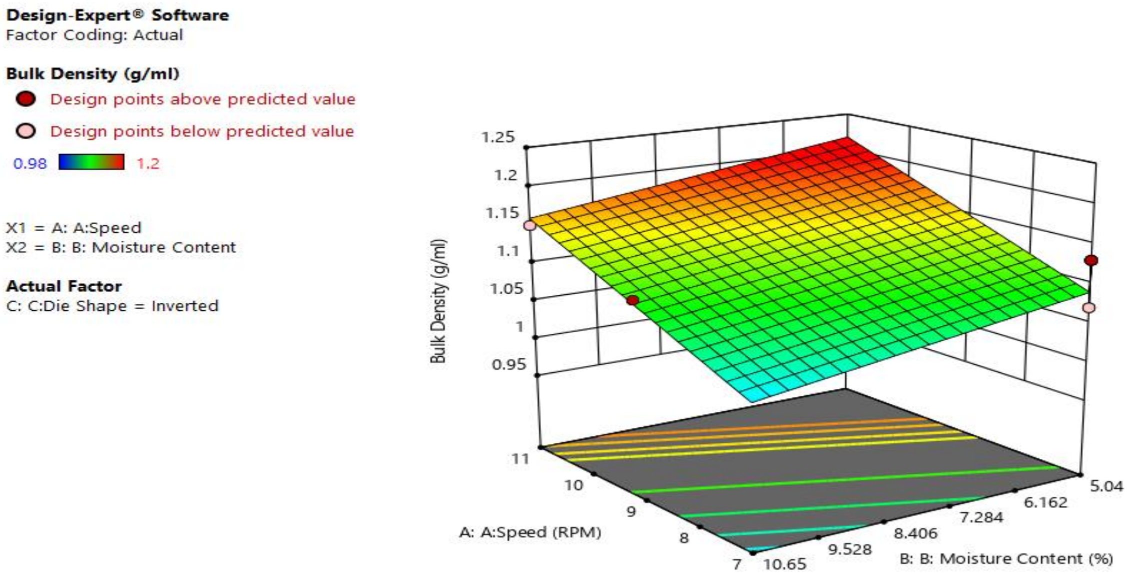

Figure 4.14: 3-D Response Surface Plot of Moisture Content and Speed Effect on Inverted Shaped Bulk Density

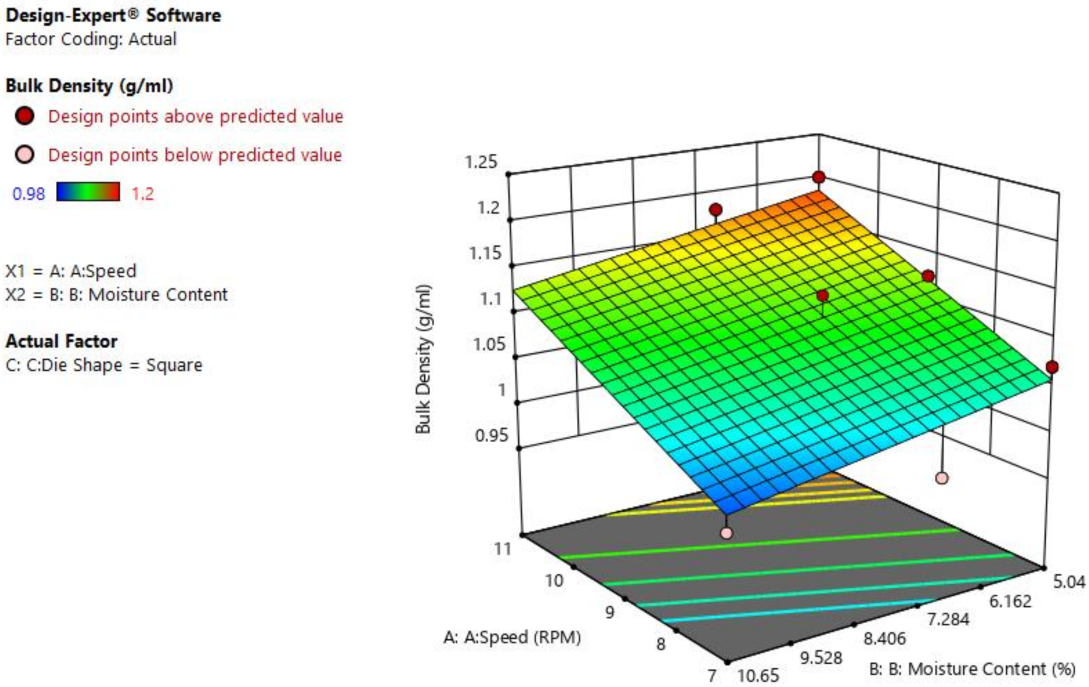

Figure 4.15: Response Surface Plot of Moisture Content and Speed Effect on Square Shaped Bulk Density

4.2.6 Extruding time

The results of analysis of variance of the effect of the independent variables on the extruding time of product extruded are shown in Table 4.6. The experimental result for extruding time ranged from 445-640 sec (Table 4.1). Figures 4.16, 4.17, 4.18, 4.19, 4.20 and 4.21 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the extruding time of the extruded groundnut cake. The statistical analysis shows screw speed has significant effect on the extruding time. It has been postulated that extruding time increased when the screw speed and the degree of starch gelatinization increases (Tester and Morrison, 1990).The Model F-value of 64.89 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case screw speed is the significant model term. The Lack of Fit F-value of 1.62 implies the Lack of Fit is not significant relative to the pure error. There is a 28.72 % chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good. The 3-D response surface plot for extruding time in terms of moisture content and screw speeds shows that the model equation in terms of actual factors can be used to make predictions about the response for given levels of each factor.

Table 4.6: Analysis of Variance for Extruding Time of Groundnut Cake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	76381.06	4	19095.27	64.89	< 0.0001	significant
A:Speed	75289.85	1	75289.85	255.86	< 0.0001	
B: Moisture Content	27.75	1	27.75	0.0943	0.7625	
C:Die Shape	310.35	2	155.18	0.5273	0.5995	
Residual	5002.39	17	294.26			
Lack of Fit	3741.23	11	340.11	1.62	0.2872	not significant
Pure Error	1261.17	6	210.19			
Cor Total	81383.45	21				

Std. Dev.	17.15	R^2	0.9385
Mean	548.55	**Adjusted** R^2	0.9241
C.V. %	3.13	**Predicted** R^2	0.9023
		Adeq Precision	18.7616

The equation model for the extruding time of extruded product in terms of actual factor:

Equation for Square Die shape;

Extruding time = 865.73 – 35.76A – 0.53B (4.13)

Equation for Inverted Die shape;

Extruding time = 875.07 – 35.7B – 0.53B (4.14)

Equation for Circular Die shape;

Extruding time = 871.64 – 35.76A- 0.53B (4.15)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

Equations 4.13, 4.14 and 4.15 shows the equations in terms of actual factors. This can be used to make predictions about the extruding time of the extruded groundnut cake for the different die shapes (square, inverted and circular).

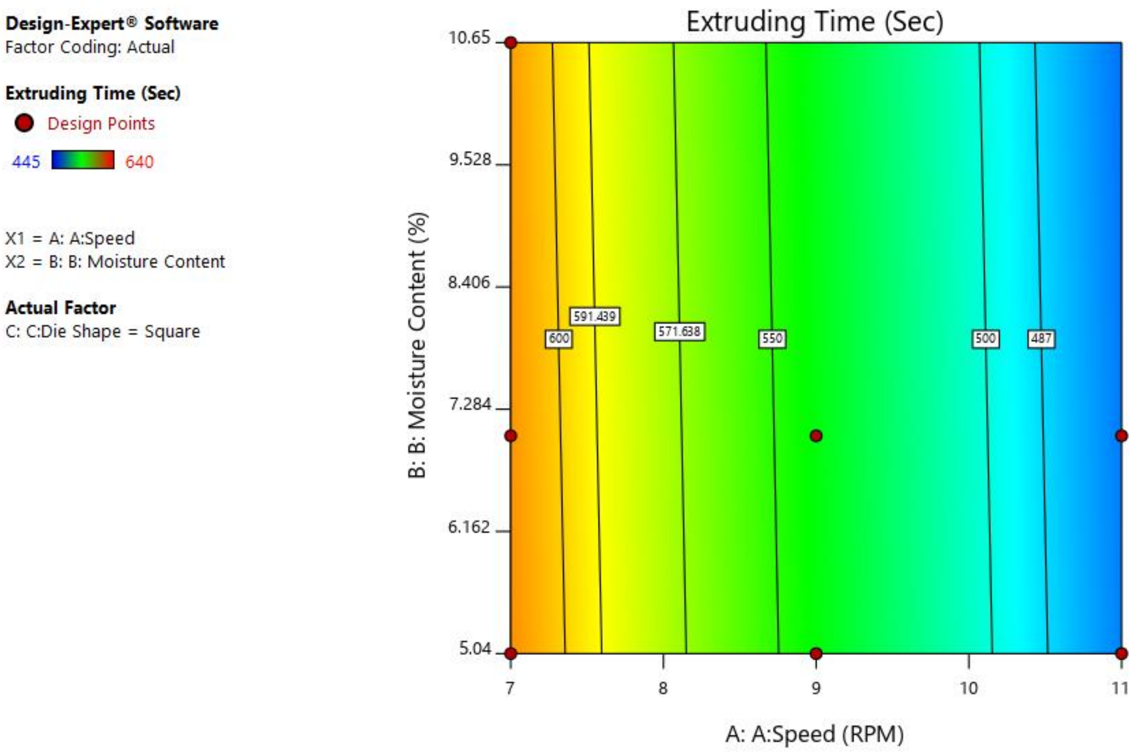

Figure 4.16: Contour Plot of Speed and Moisture Content Effect on Square Shaped Bulk Extruding Time

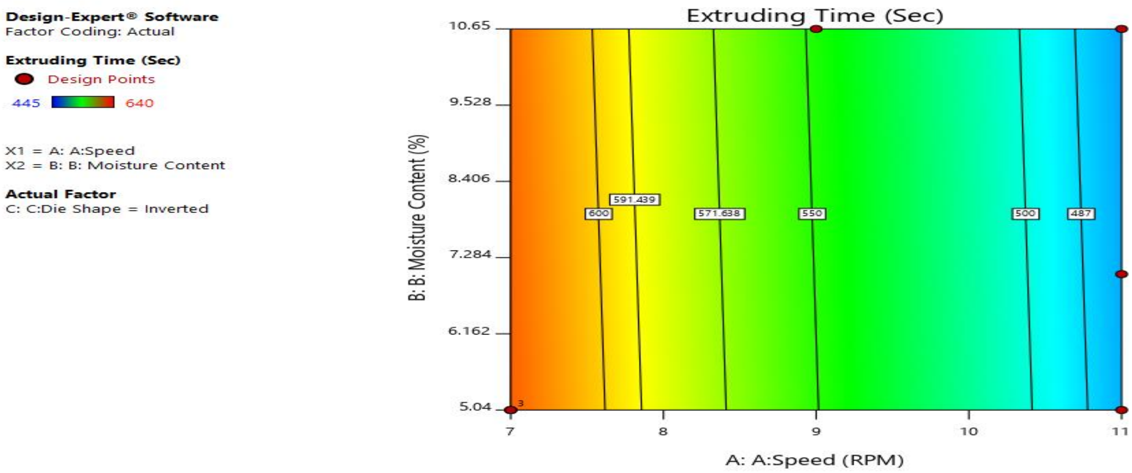

Figure 4.17: Contour Plot of Speed and Moisture Content Effect on Inverted Shaped Bulk Extruding Time

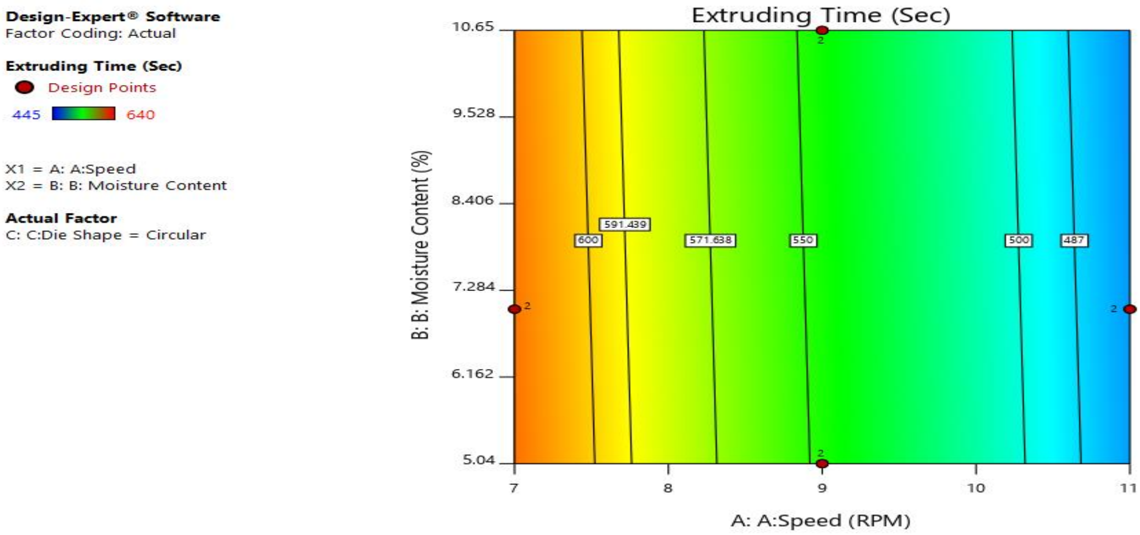

Figure 4.18: Contour Plot of Speed and Moisture Content Effect on Circular Shaped Extruding Time

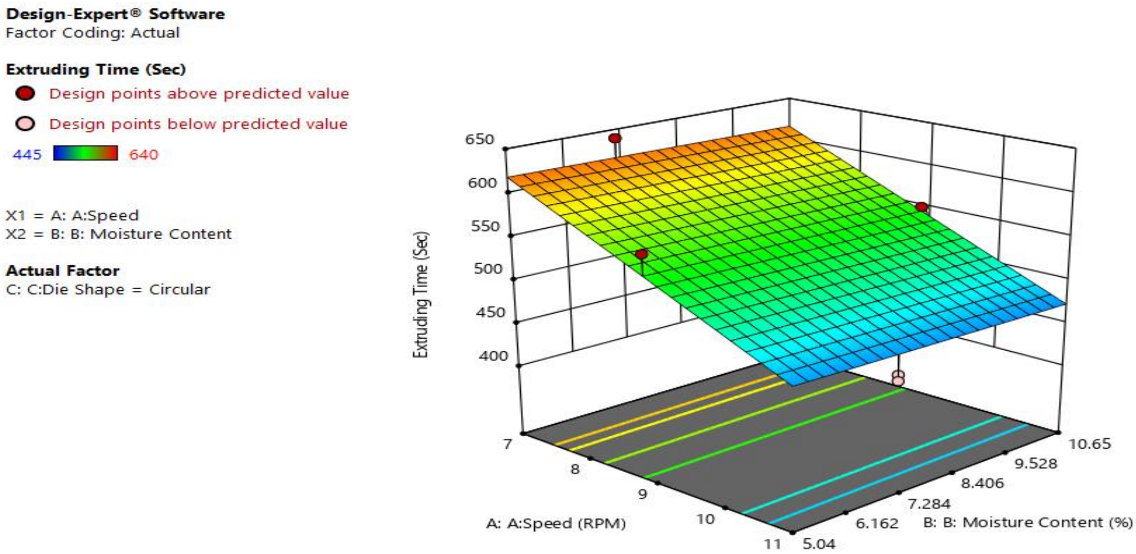

Figure 4.19: 3-D Response Surface Plot of Speed and Moisture Content Effect on Circular Shaped Extruding Time

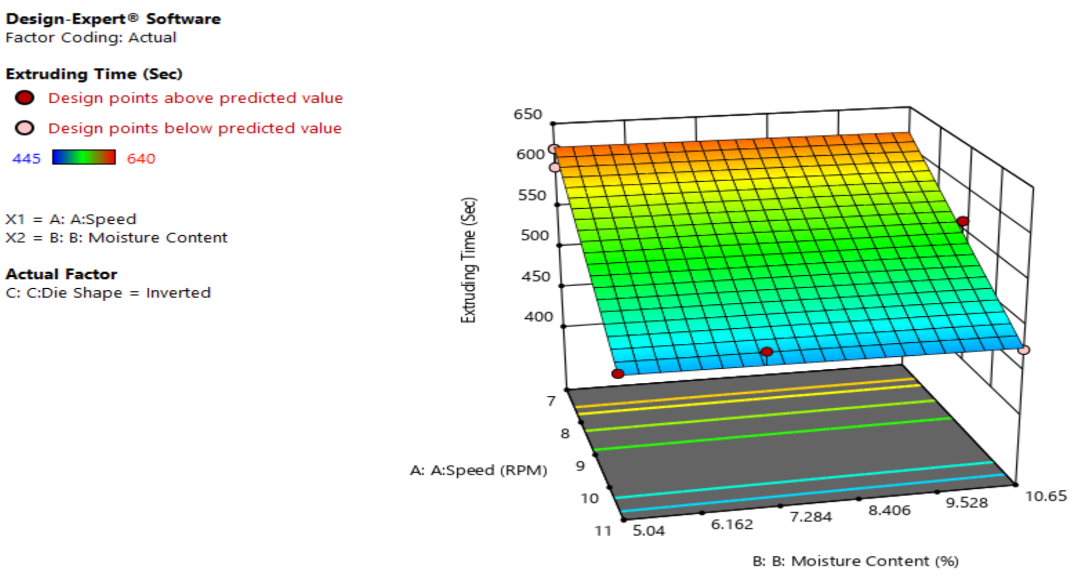

Figure 4.20: 3-D Response Surface Plot of Speed and Moisture Content Effect on Inverted Shaped Extruding Time

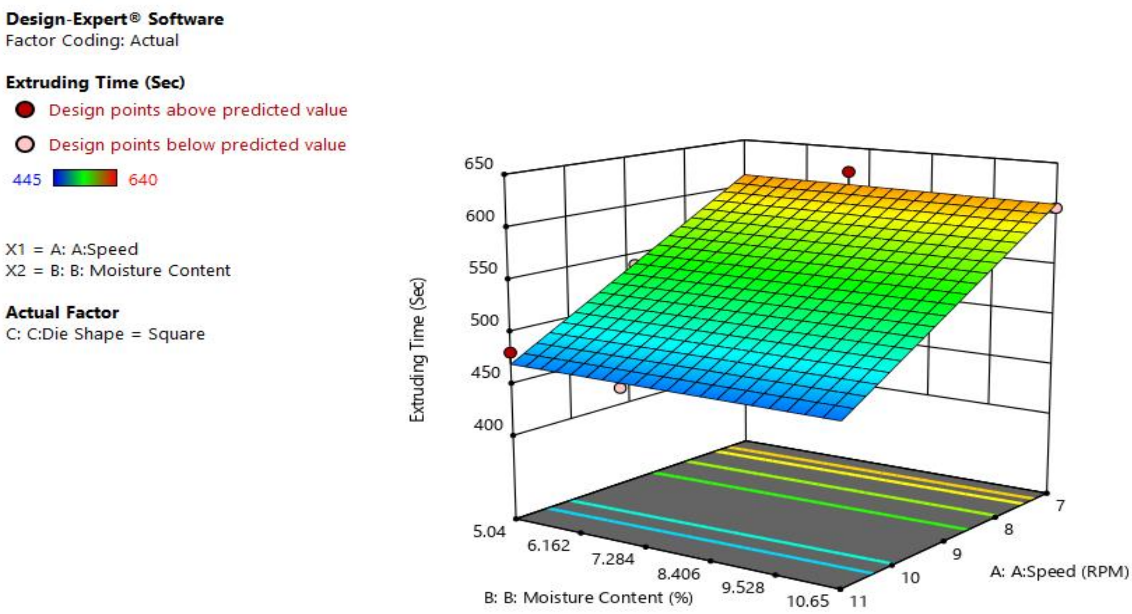

Figure 4.21: 3-D Response Surface Plot of Speed and Moisture Content Effect on Square Shaped Extruding Time.

4.2.7 Extrusion capacity

The results of analysis of variance of the effect of the independent variables on the extrusion capacity of product extruded are shown in Table 4.7. The experimental result for extrusion capacity ranged from 0.17-0.257 kg/min (Table 4.1). Figures 4.22, 4.23, 4.24, 4.25, 4.26 and 4.27 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the extrusion capacity of the extruded groundnut cake.

The statistical analysis shows screw speed has significant effect on the extrusion capacity while moisture content and die shape do not have significant effect. The Model F-value of 18.03 implies the model is significant. $P < 0.05$ indicate model terms are significant. In this case screw speed, interaction between moisture content and die shape, speed squared are significant model terms. With the increase of the screw speed, the extrusion capacity of the single screw extruder gets worse and the outlet pressure of the single screw extruder increases (Gao *et al.*, 2014). This conforms to Aguilar-Palaseulos (2006) who related that an increase in the speed has effect on the capacity of the extruder. The Lack of Fit F-value of 1.52 implies the Lack of Fit is not significant relative to the pure error**.** There is a 30.71% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good. This model can be used to navigate the design space. The 3-D response surface plot for extrusion capacity in terms of moisture content and screw speeds shows that the model equation in terms of actual factors can be used to make predictions about the response.

Table 4.7: ANOVA for Quadratic model for Extrusion Capacity of Groundnut Cake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0137	11	0.0012	18.03	< 0.0001	Significant
A:Speed	0.0098	1	0.0098	142.90	< 0.0001	
B: Moisture Content	0.0002	1	0.0002	2.85	0.1224	
C:Die Shape	0.0001	2	0.0001	0.8481	0.4569	
AB	0.0000	1	0.0000	0.5603	0.4714	
AC	0.0005	2	0.0002	3.38	0.0758	
BC	0.0007	2	0.0003	4.95	0.0320	
A^2	0.0004	1	0.0004	5.72	0.0379	
B^2	0.0000	1	0.0000	0.2789	0.6089	
Residual	0.0007	10	0.0001			
Lack of Fit	0.0003	4	0.0001	1.52	0.3071	not significant
Pure Error	0.0003	6	0.0001			
Cor Total	0.0143	21				

Std. Dev.	0.0083	**R^2**	0.9520
Mean	0.2062	**Adjusted R^2**	0.8992
C.V. %	4.02	**Predicted R^2**	0.6723
		Adeq Precision	11.9142

The equation model for the extrusion capacity of extruded product in terms of actual factor:

Equation for Square Die shape;

Extrusion capacity$= +0.29 - 0.037A + 0.008B - 0.0007AB + 0.003A^2 - 0.0003B^2$ (4.16)

Equation for Inverted Die shape;

Extrusion capacity$= +0.25 - 0.035A + 0.01B - 0.0007AB + 0.003A^2 - 0.0003B^2$ (4.17)

Equation for Circular Die shape;

Extrusion capacity $= +0.17 - 0.03A + 0.02B - 0.0007AB + 0.003A^2 - 0.00033B^2$ (4.18)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

AB, BC, A^2 , B^2 = Interactions

Equations 4.16, 4.17, 4.18 shows the equations in terms of actual factors. This can be used to make predictions about the extrusion capacity of the extruded groundnut cake for the different die shapes (square, inverted and circular).

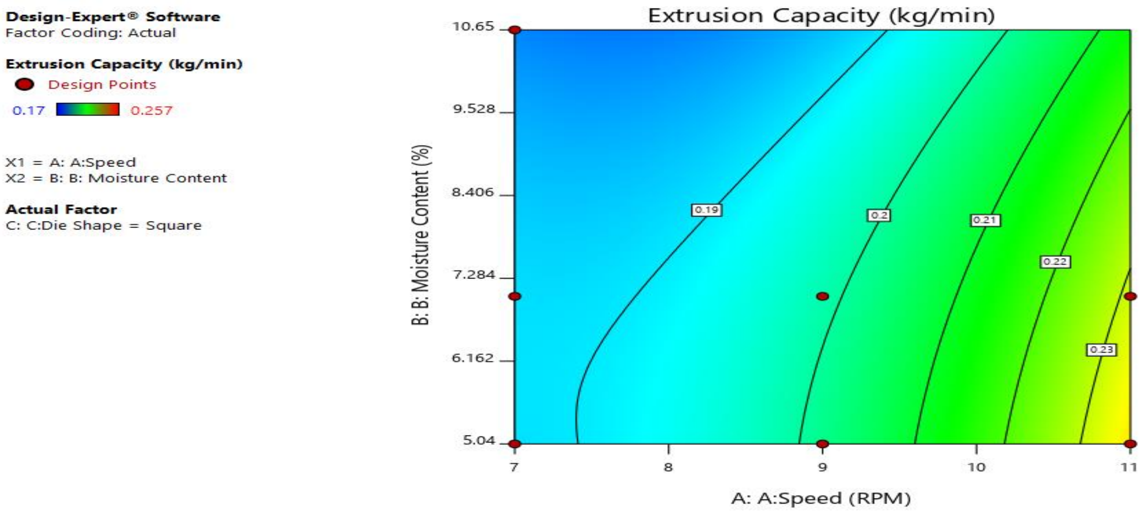

Figure 4.22: Contour Plot of Speed and Moisture Content Effect on Square Shaped Extrusion Capacity

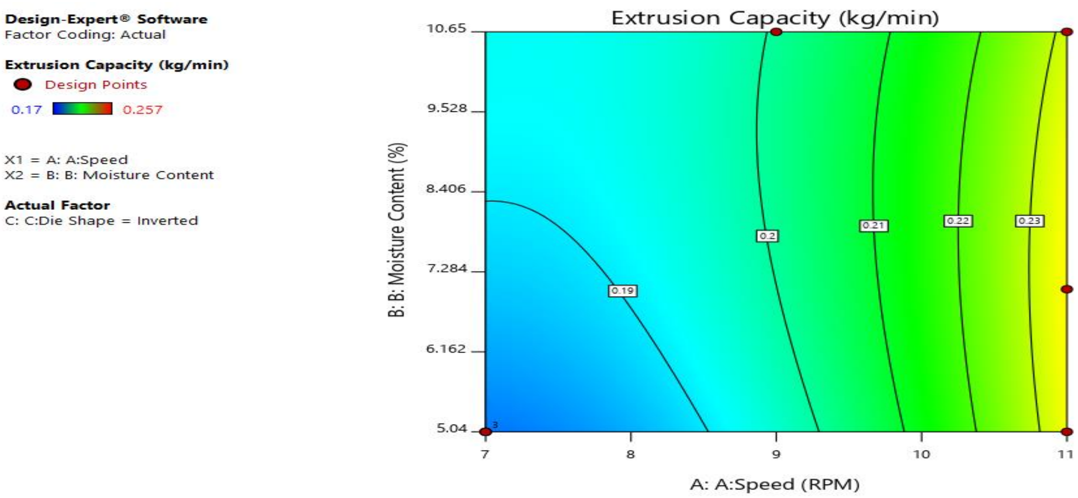

Figure 4.23: Contour Plot of Speed and Moisture Content Effect on Inverted Shaped Extrusion Capacity

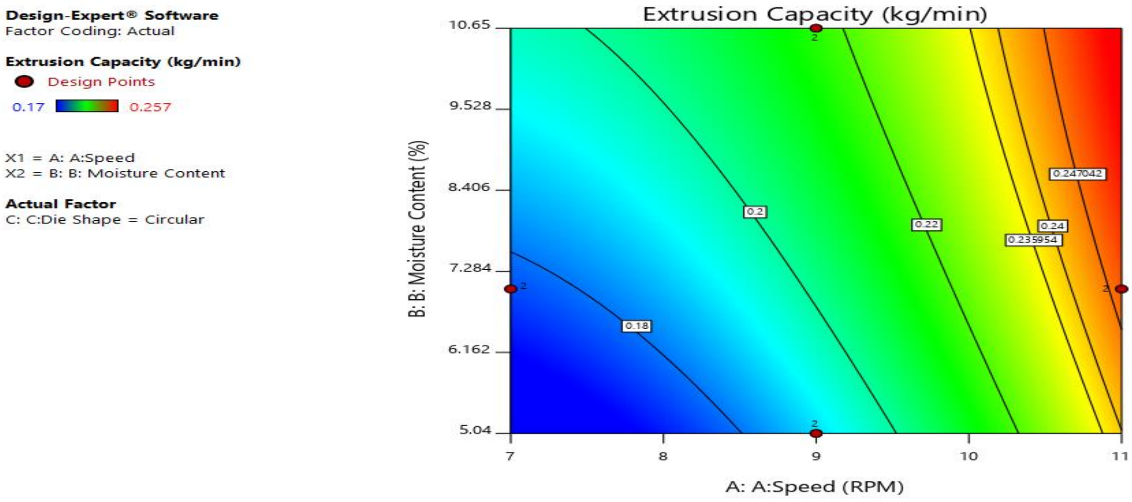

Figure 4.24: Contour Plot of Speed and Moisture Content Effect on Circular Shaped Extrusion Capacity

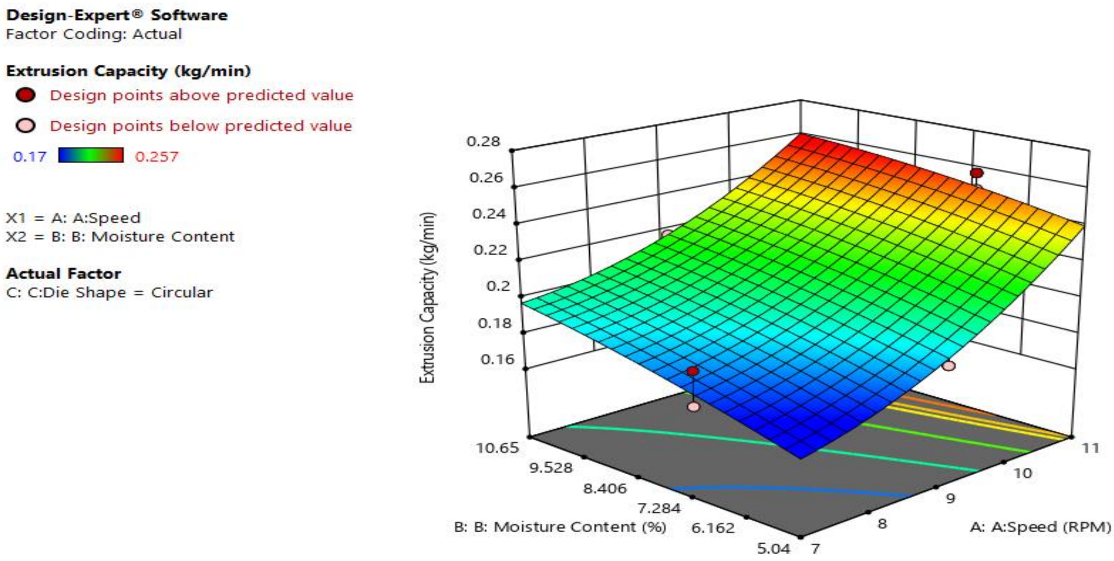

Figure 4.25: 3-D Response Surface Plot of Speed and Moisture Content Effect on Circular Shaped Extrusion Capacity

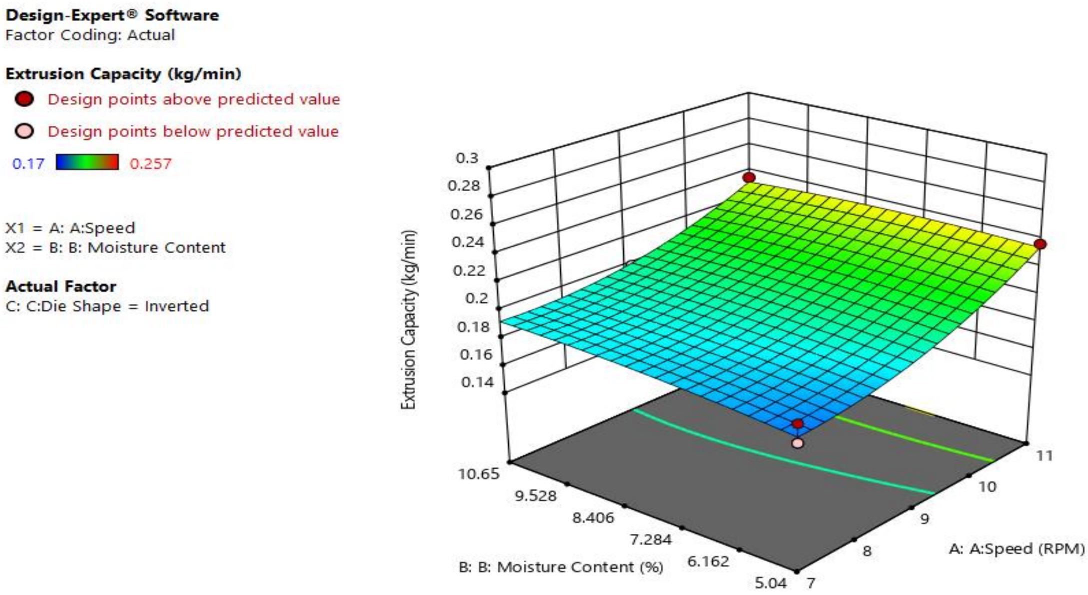

Figure 4.26: 3-D Response Surface Plot of Speed and Moisture Content Effect on Inverted Shaped Extrusion Capacity

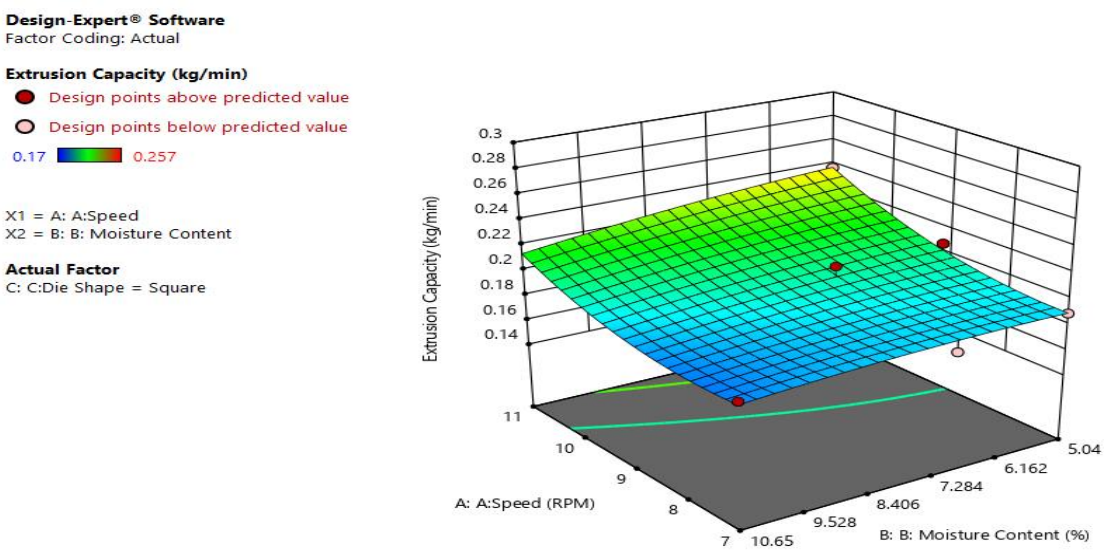

Figure 4.27: 3-D Response Surface Plot of Speed and Moisture Content Effect on Square Shaped Extrusion Capacity

4.2.8 Expansion ratio

The results of analysis of variance of the effect of the independent variables on the expansion ratio of product extruded are shown in Table 4.8. The experimental result for expansion ratio ranged from 1.3-1.63 mm (Table 4.1). Figures 4.28, 4.29, 4.30, 4.31 and 4.32 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the expansion ratio of the extruded groundnut cake. The statistical analysis shows that speed has significant effect on the expansion ratio. P-values less than 0.0500 indicate model terms are significant. In this case speed is a significant model term. The Lack of Fit F-value of 0.83 implies the Lack of Fit is not significant relative to the pure error. Non-significant lack of fit is good. The model showed good fit with adjusted $R^2 = 0.37$ for Expansion Ratio. This suggest a very good fit to the experimental data and the model could be used to describe the process. Chiyakul *et al.* (2009) reported that expansion was greatest for low protein, low moisture and high temperatures during the extrusion of high protein glutinous rice-based snack. The negative significant ($p < 0.05$) linear coefficients of moisture content indicated that their effects on expansion ratio were a decrease. Moisture plays a key role in the mechanism responsible for expansion. Food with lower moisture content tend to be more viscous than those having higher moisture content and therefore the pressure differential is smaller for higher moisture foods leading to a less expanded product. This is in agreement with Meng *et al.* (2010) that increasing screw speed tends to increase the shearing effect; this causes protein molecules to be stretched farther apart, weakening bonds and resulting in a puffer product.

Table 4.8: Analysis of Variance for Expansion Ratio of Groundnut Cake

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0816	4	0.0204	2.47	0.0840	not significant
A:Speed	0.0584	1	0.0584	7.06	0.0166	
B: Moisture Content	0.0143	1	0.0143	1.72	0.2065	
C:Die Shape	0.0150	2	0.0075	0.9088	0.4217	
Residual	0.1405	17	0.0083			
Lack of Fit	0.0847	11	0.0077	0.8287	0.6283	not significant
Pure Error	0.0558	6	0.0093			
Cor Total	0.2221	21				

Std. Dev.	0.0909	**R^2**	0.3675
Mean	1.46	**Adjusted R^2**	0.2187
C.V. %	6.21	**Predicted R^2**	-0.0976
		Adeq Precision	5.2033

The equation model for the expansion ratio of extruded product in terms of actual factor:

Equation for Square Die shape;

Expansion Ratio = +1.25 + 0.03A – 0.01B (4.19)

Equation for Inverted Die shape;

Expansion Ratio = +1.25 + 0.03A – 0.01B (4.20)

Equation for Inverted Die shape;

Expansion Ratio = +1.30 + 0.03A – 0.01B (4.21)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

Equations 4.19, 4.20 and 4.21 shows the equations in terms of actual factors. This can be used to make predictions about the expansion ratio of the extruded groundnut cake for the different die shapes (square, inverted and circular).

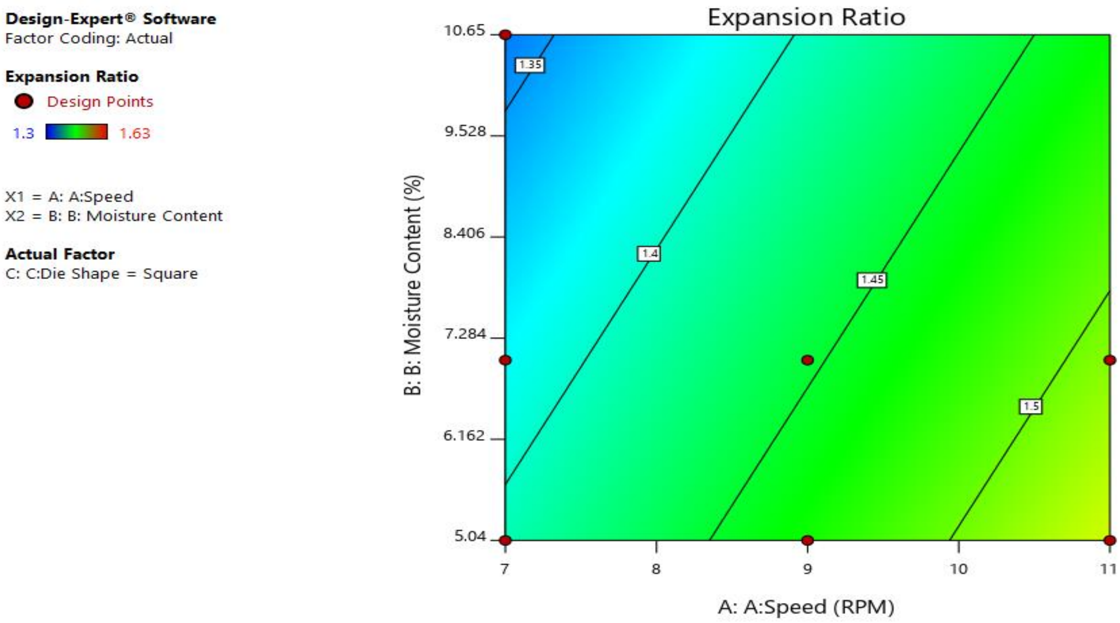

Figure 4.28: Contour Plot of Speed and Moisture Content Effect on Square Shaped Expansion ratio

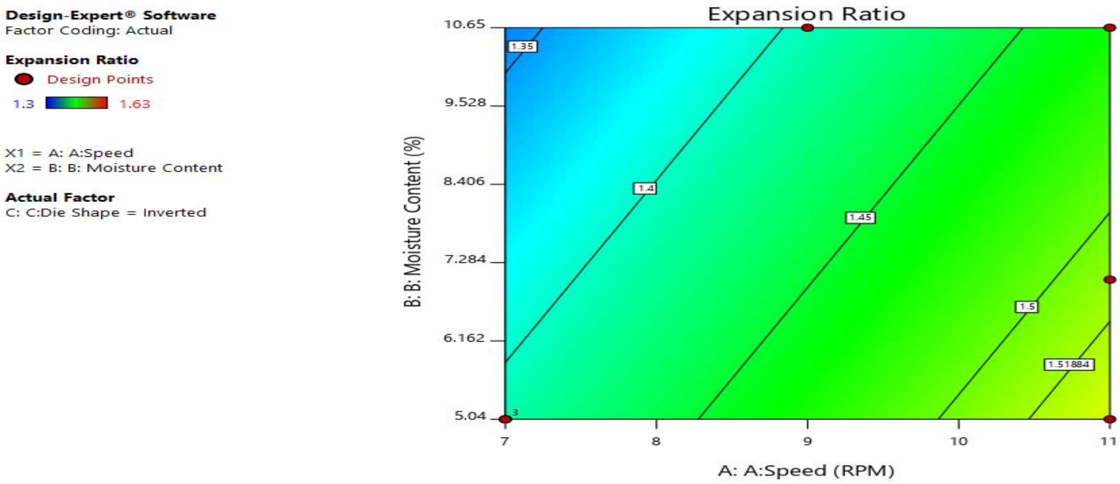

Figure 4.29: Contour Plot of Speed and Moisture Content Effect on Inverted Shaped Expansion Ratio

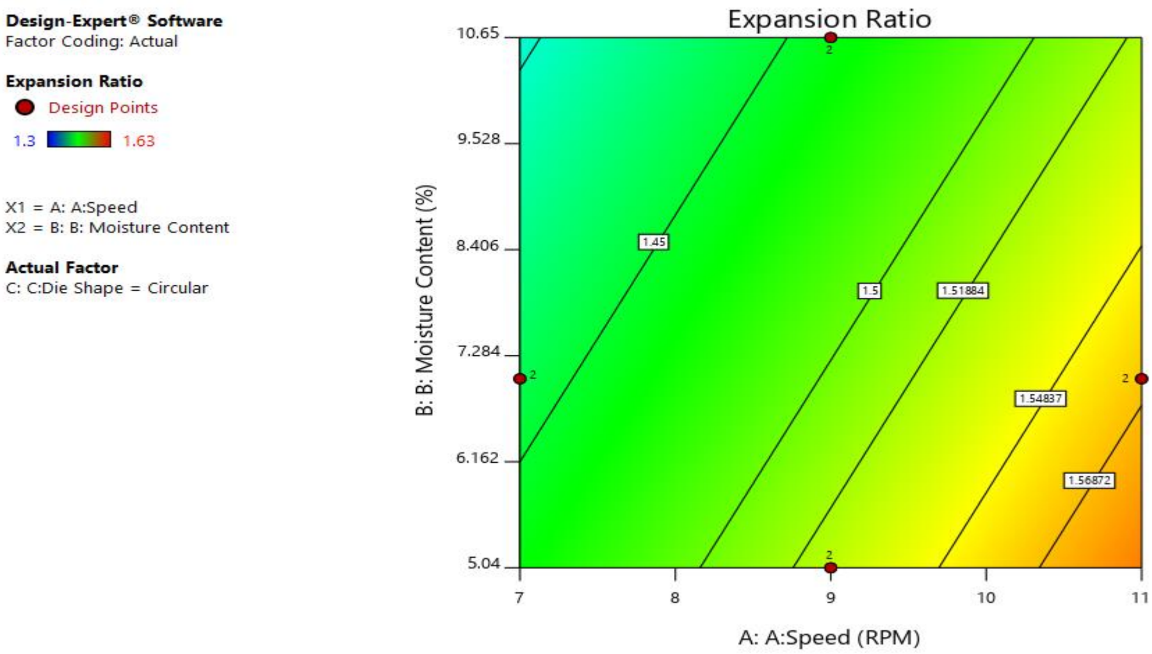

Figure 4.30: Contour Plot of Speed and Moisture Content Effect on Circular Shaped Expansion Ratio

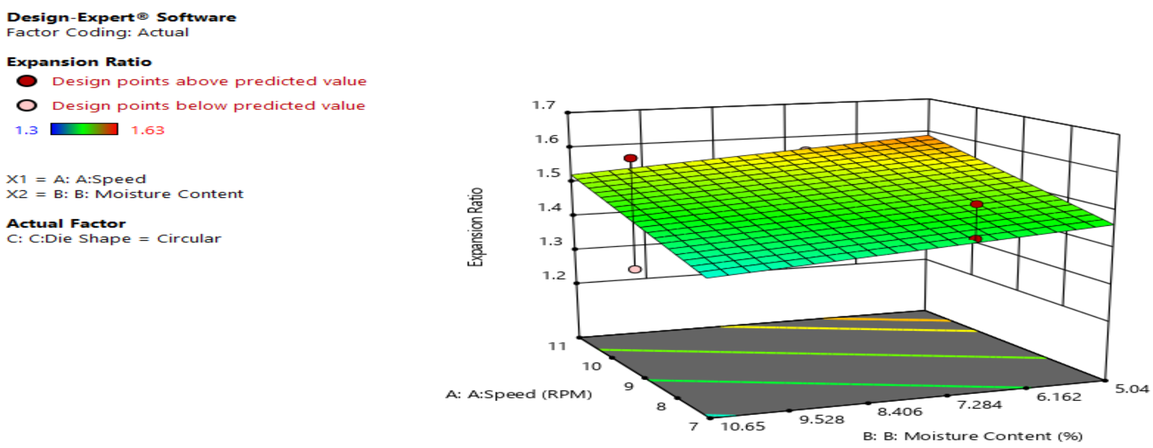

Figure 4.31: 3-D Response Surface Plot of Speed and Moisture Content Effect on Circular Shaped Expansion Ratio

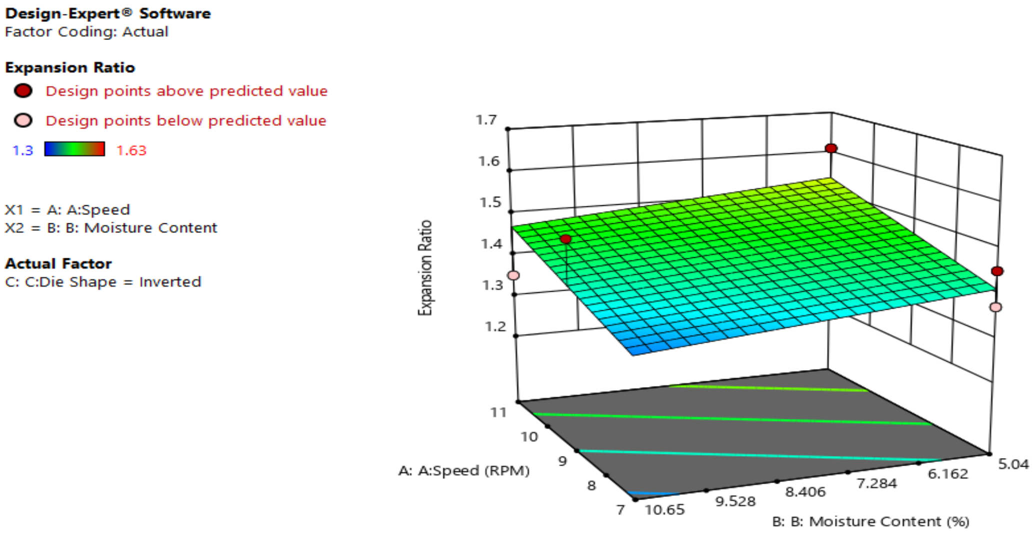

Figure 4.32: 3-D Response Surface Plot of Speed and Moisture Content Effect on Inverted Shaped Expansion Ratio

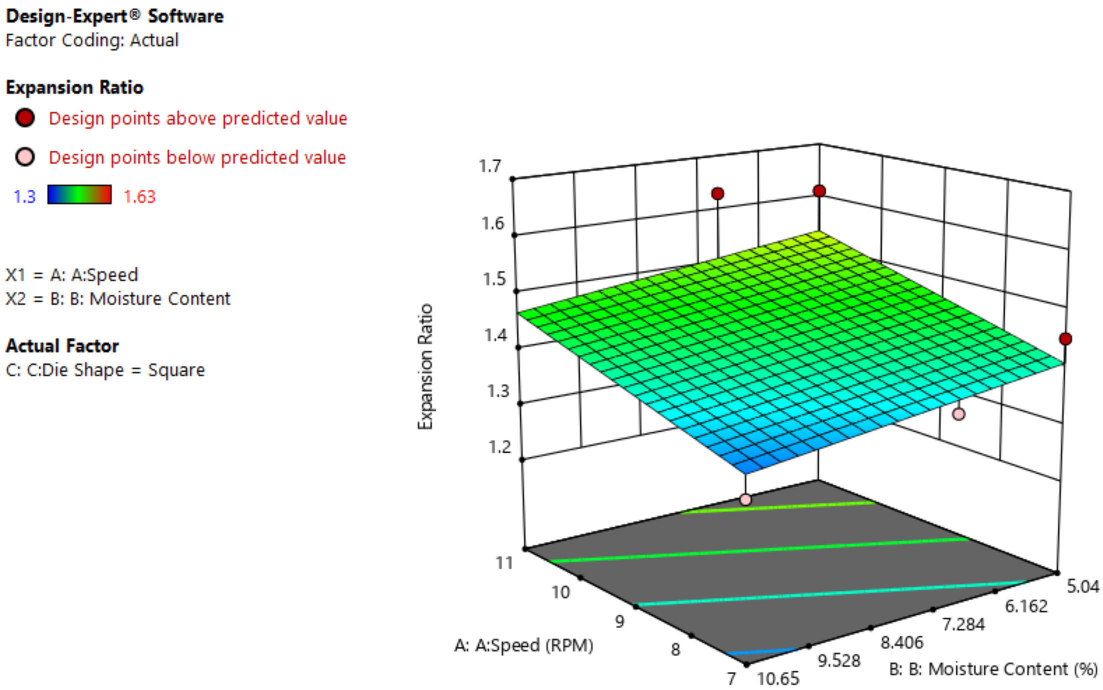

Figure 4.33: 3-D Response Surface Plot of Speed and Moisture Content Effect on Square Shaped Expansion ratio

4.2.9 Specific length

Specific length refers to length per unit weight and is the measure of the axial expansion of extrudates. The results of the effect of the independent variables on the specific length of product extruded are shown in Table 4.9. The experimental result for specific length ranged from 2.11-11.66 mm (Table 4.1). Figures 4.34, 4.35, 4.36, 4.37, 4.38 and 4.39 shows the graphical representations of the effect of screw speed, moisture content and the die shapes on the specific length of the extruded groundnut cake. The statistical analysis shows that there is no significant effect on the specific length. A decrease in specific length with decrease in screw speed was reported by Ali *et al.* (1996) for corn grits. The more the extrudates expand in either axial or radial direction, the less dense it becomes indicating a higher proportion starch gelatinization. The Model F-value of 1.49 implies the model is not significant relative to the noise. There is a 25.35 % chance that an F-value this large could occur due to noise. The Lack of Fit F-value of 1.21 implies the Lack of Fit is not significant relative to the pure error and non-significant lack of fit is good. The 3-D response surface plot for specific length in terms of moisture content and screw speeds shows that the model equation in terms of actual factors can be used to make predictions about the response for given levels of each factor.

Table 4.9: Analysis of Variance for Specific Length of Groundnut Cake

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	52.56	9	5.84	1.49	0.2535	not significant
A:Speed	8.25	1	8.25	2.11	0.1718	
B: Moisture Content	9.88	1	9.88	2.53	0.1378	
C:Die Shape	0.4235	2	0.2118	0.0542	0.9475	
AB	2.04	1	2.04	0.5226	0.4836	
AC	18.98	2	9.49	2.43	0.1301	
BC	11.62	2	5.81	1.49	0.2649	
Residual	46.88	12	3.91			
Lack of Fit	25.64	6	4.27	1.21	0.4125	not significant
Pure Error	21.24	6	3.54			
Cor Total	99.44	21				

Std. Dev.	1.98	**R^2**	0.5286
Mean	6.59	**Adjusted R^2**	0.1750
C.V. %	29.98	**Predicted R^2**	-1.3604
		Adeq Precision	4.5807

The equation model for the expansion ratio of specific length in terms of actual factor:

Equation for Square Die shape;

Specific Length= - 3.97 + 1.43A + 0.94B – 0.15AB (4.22)

Equation for Inverted Die shape;

Specific Length = - 3.67 + 1.61A + 2.18B – 0.15AB (4.23)

Equation for Circular Die shape;

Specific Length = - 15.67 + 2.19A + 1.72B – 0.15AB (4.24)

Where;

A = Factor 1: Screw speed (rpm)

B = Factor 2: Moisture Content (%)

AB, BC & AC = Interactions

Equations 4.22, 4.23 and 4.24 shows the equations in terms of actual factors. This can be used to make predictions about the specific length ratio of the extruded groundnut cake for the different die shapes (square, inverted and circular).

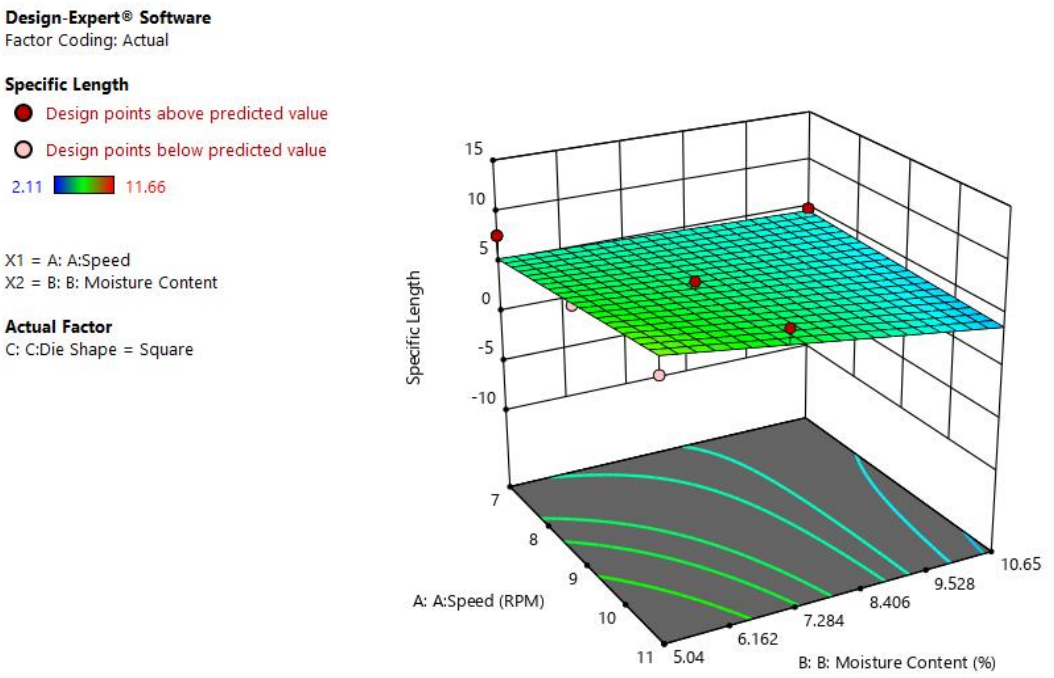

Figure 4.34: 3-D Response Surface Plot of Speed and Moisture Content Effect on Square Shaped Specific Length

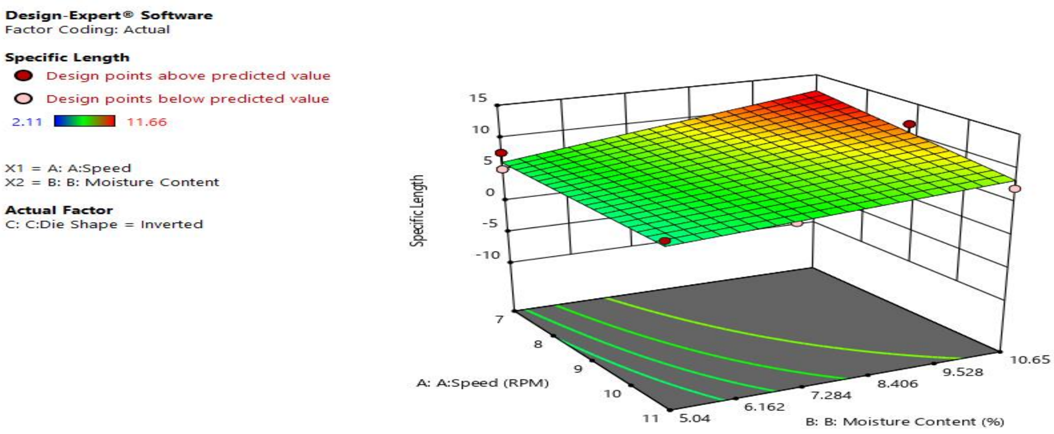

Figure 4.35: 3-D Response Surface Plot of Speed and Moisture Content Effect on Inverted Shaped Specific Length

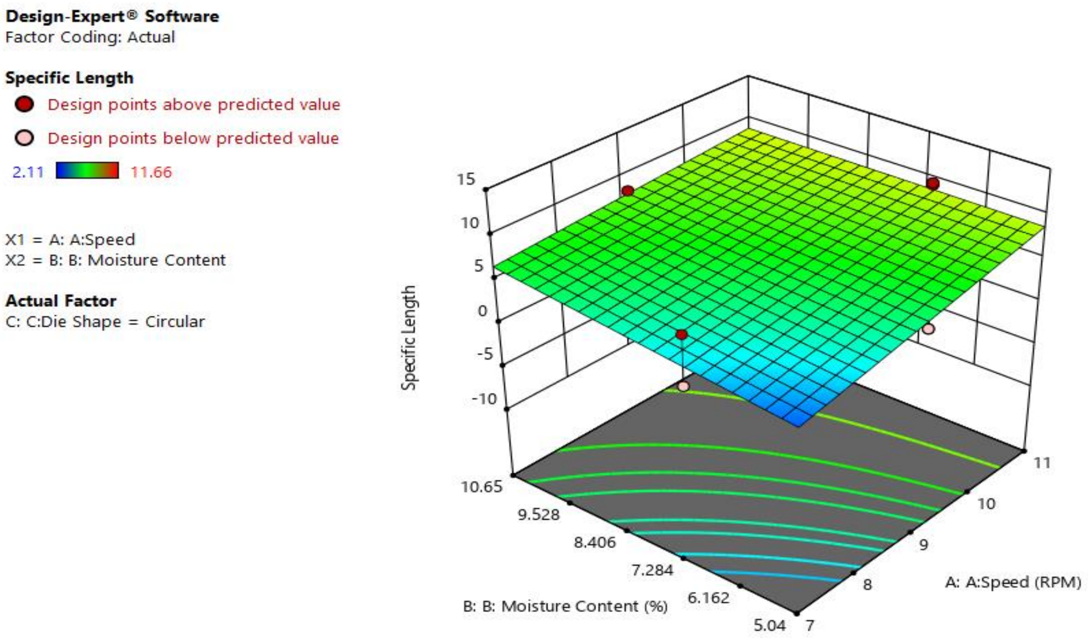

Figure 4.36: 3-D Response Surface Plot of Speed and Moisture Content Effect on Circular Shaped Specific Length

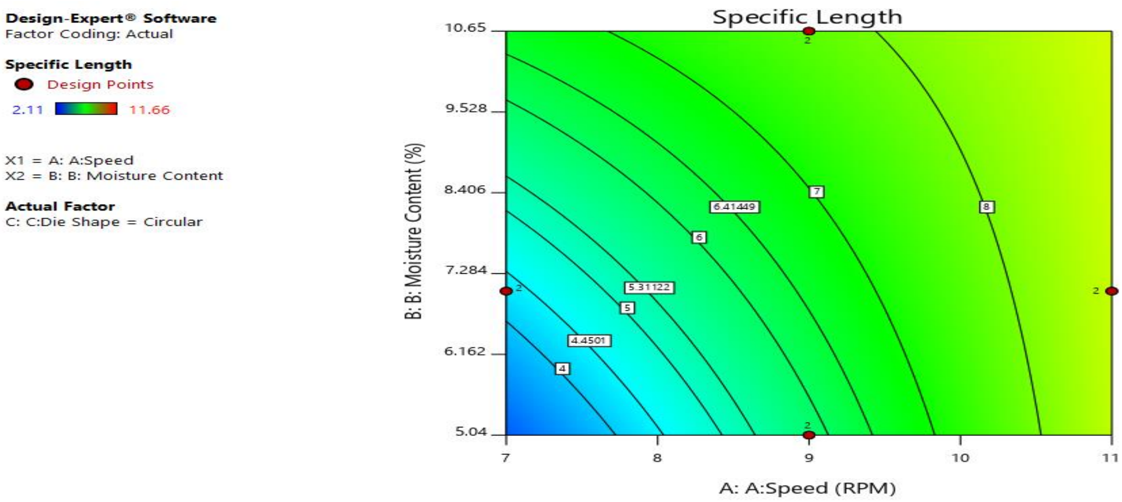

Figure 4.37: Contour Plot of Speed and Moisture Content Effect on Circular Shaped Specific Length

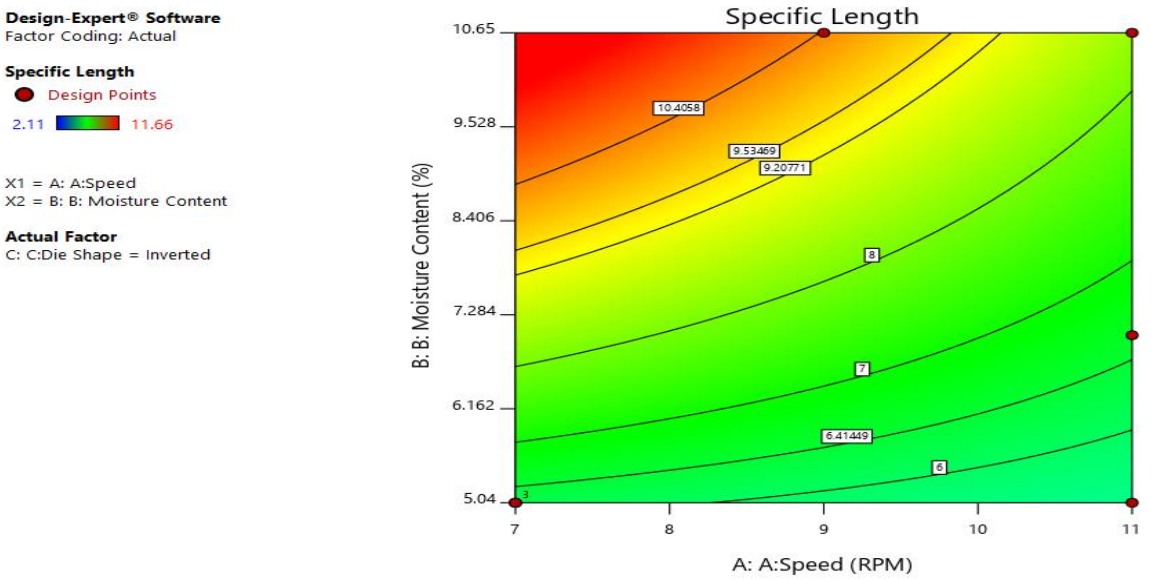

Figure 4.38: Contour Plot of Speed and Moisture Content Effect on Inverted Shaped Specific Length

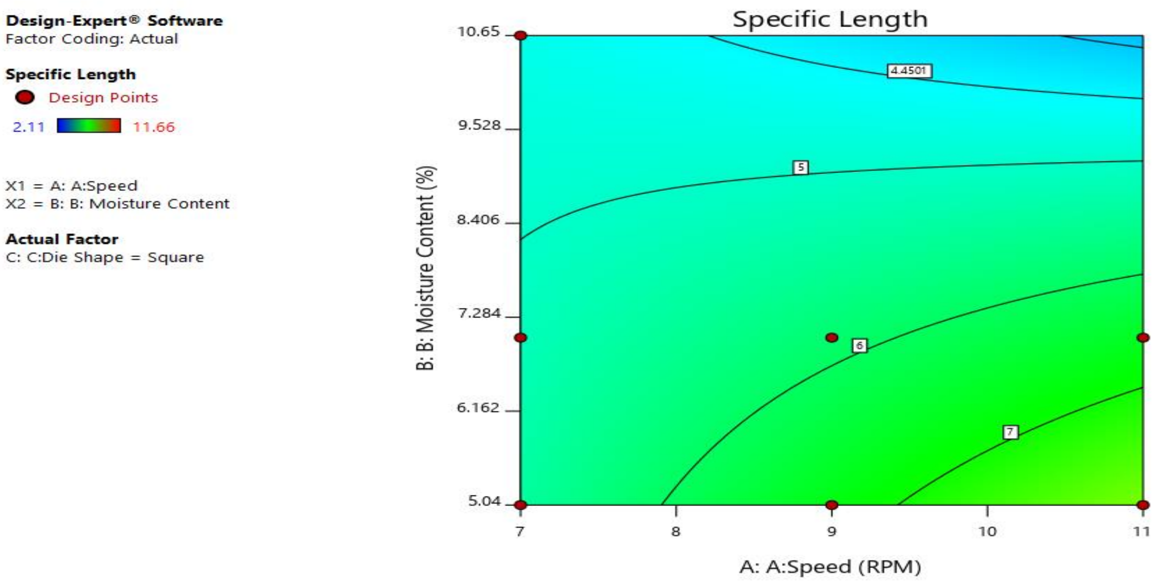

Figure 4.39: Contour Plot of Speed and Moisture Content Effect on Square Shaped Specific Length

4.3 Optimization of the Factors using Response Surface Methodology

Optimization of the factors was performed to find the point at which independent factors such as the screw speed, moisture content and the die shape will produce the best response of dependent factors. The minimum and the maximum values of the dependent variable factors were investigated and seventeen (17) solutions were gotten. The best set objectives of each of these parameters (maximum, minimum and within range) of extruded groundnut cake was investigated and the responses are as presented in Table 4.10. The optimization best solution give the process conditions for each process factors at the desirability prediction values, the selected condition with reference to the highest desirability prediction of 0.512 (Table 4.11) revealed the best reaction screw speed of 10.98 rpm, moisture content of 9.345 % and Circular Die shape.

Table 4.10: Constraints of Dependent and Independent Factors

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Screw Speed (rpm)	is in range	7	11	1	1	3
Moisture Content (%)	is in range	5.04	10.65	1	1	3
Die Shape	is in range	Square	Circular	1	1	3
Length	Maximize	54	164.25	1	1	3
Weight	Maximize	10.9	25.54	1	1	3
Diameter	Maximize	11.4	15.3	1	1	3
Bulk Density	Minimize	0.98	1.2	1	1	3
Extruding Time	Minimize	445	640	1	1	3
Extrusion Capacity	Maximize	0.17	0.257	1	1	3
Expansion Ratio	Maximize	1.3	1.63	1	1	3
Specific Length	Maximize	2.11	11.66	1	1	3

Table 4.11: Solutions for 3 Combinations of Categorical Factor Levels

No	SS	MC	DS	L	W	Dia	BD	ET	EC	ER	SL	Des	
1	**10.988**	**9.345**	**Circular**	**98.511**	**16.844**	**12.867**	**1.161**	**473.791**	**0.257**	**1.537**	**8.821**	**0.512**	**Sel**
2	10.985	9.370	Circular	98.511	16.806	12.867	1.160	473.862	0.257	1.537	8.821	0.512	
3	11.000	9.677	Circular	98.511	16.368	12.867	1.158	473.188	0.258	1.534	8.843	0.511	
4	11.000	6.984	Square	98.511	16.646	12.867	1.164	468.690	0.232	1.510	6.603	0.454	
5	11.000	6.960	Square	98.511	16.648	12.867	1.165	468.704	0.232	1.510	6.621	0.454	
6	11.000	7.011	Square	98.511	16.643	12.867	1.164	468.679	0.232	1.510	6.583	0.454	
7	11.000	6.930	Square	98.511	16.650	12.867	1.165	468.720	0.232	1.511	6.643	0.454	
8	11.000	7.039	Square	98.511	16.640	12.867	1.164	468.662	0.231	1.509	6.562	0.454	
9	11.000	6.902	Square	98.511	16.651	12.867	1.165	468.734	0.232	1.511	6.664	0.454	
10	11.000	7.066	Square	98.511	16.635	12.867	1.163	468.650	0.231	1.509	6.542	0.454	
11	11.000	6.872	Square	98.511	16.651	12.867	1.165	468.750	0.232	1.511	6.686	0.454	
12	11.000	7.205	Square	98.511	16.605	12.867	1.162	468.574	0.231	1.507	6.440	0.454	
13	11.000	9.227	Inverted	98.511	13.866	12.867	1.174	476.836	0.234	1.485	7.640	0.406	
14	11.000	9.248	Inverted	98.511	13.841	12.867	1.174	476.825	0.234	1.485	7.650	0.406	
15	11.000	9.197	Inverted	98.511	13.903	12.867	1.174	476.854	0.234	1.486	7.625	0.406	
16	10.997	9.264	Inverted	98.511	13.814	12.867	1.174	476.939	0.234	1.485	7.661	0.406	
17	11.000	9.152	Inverted	98.511	13.955	12.867	1.175	476.890	0.234	1.486	7.603	0.405	

No – Number, SS – Screw Speed, MS – Moisture Content, DS – Die Shape, L – Length, W – Weight, Dia – Diameter, BD – Bulk Density, ET – Extruding Time, EC – Extrusion Capacity, ER – Expansion Ratio, SL – Specific Length, Des – Desirability, Sel – Selected.

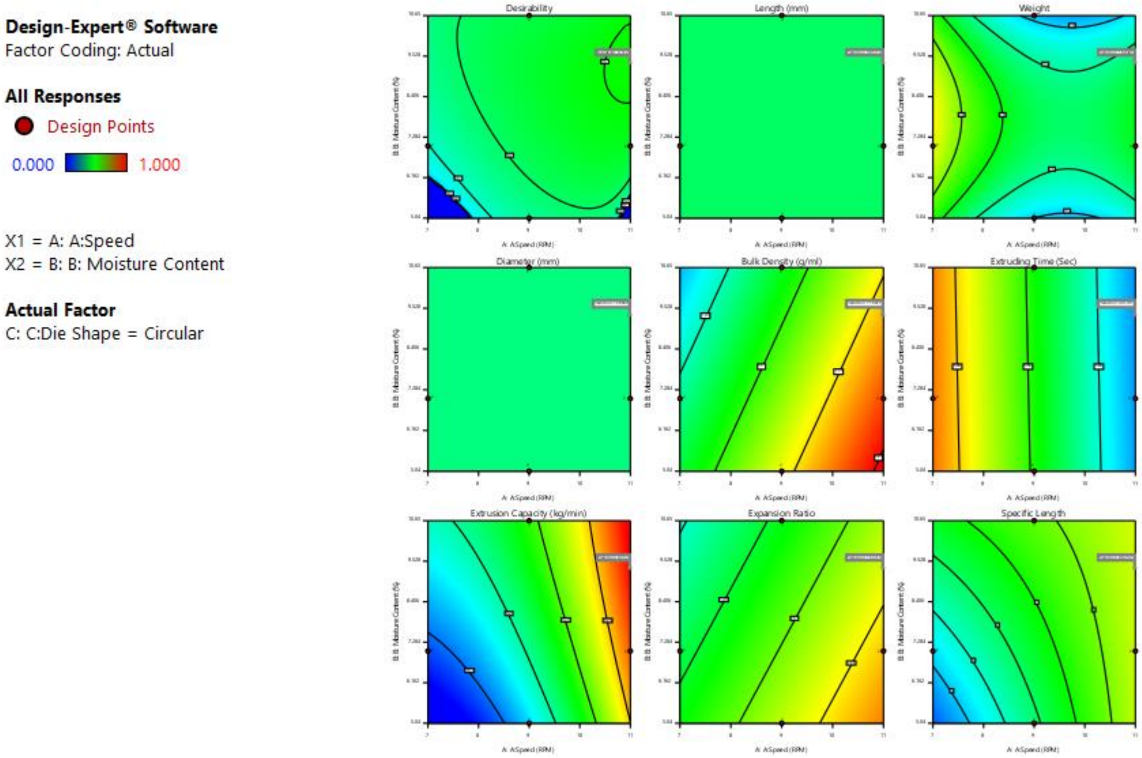

Figure 4.40: Contour Plot of Optimized Responses

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

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

5.2 Recommendations

1. The problem of the ineffectiveness of the cutting mechanism should be looked into and where possible, it is suggested that a separate variable speed running electric motor should be provided to exclusively power the cutting mechanism.
2. To guard against the stickiness of left over groundnut paste in the extrusion barrel, the extruder should be thoroughly flushed with plenty clean water immediately after completion of any given operation.

5.3 Contribution to Knowledge

The study successfully produced an electric gear motor operated groundnut cake extruding machine with different die geometry with an extruding efficiency of 93.5 %.

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APPENDICES

Appendix A

S/No	Weight of Paste Fed into Machine (kg)	Weight of Extrudates Produced (kg)
1	2	1.86
2	2	1.87
3	2	1.82
4	2	1.89
5	2	1.88
6	2	1.92
7	2	1.78
8	2	1.82
9	2	1.91
10	2	1.96
11	2	1.86
12	2	1.95
13	2	1.84
14	2	1.88
15	2	1.95
16	2	1.86
17	2	1.78
18	2	1.76
19	2	1.86
20	2	1.90
22	2	1.84
23	2	1.94
24	2	1.74
25	2	1.86
26	2	1.90
27	2	1.93

Appendix B

a. **Extruding Groundnut Cake**

b. **Inverted Shaped Cake**

c. **Inverted**

d. **Circular Shaped**

e. Square Shaped Groundnut Cake