CHARACTERIZATION AND OPTIMIZATION OF AN EXTRUDED CEREAL-BASED READY-TO-EAT SNACK

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DECLARATION

I, EWHORITSEMOGHA PRISCILLA DOTTIE, a M. Eng. student of the Department of Agricultural and Biosystems Engineering, Landmark University, Omu-Aran, hereby declare that this dissertation titled "Characterization and Optimization of an Extruded Cereal-based Ready-to-Eat Snack" submitted by me is based on my original work. Any material(s) obtained from other sources or work done by any other persons or institution have been duly acknowledged.

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CERTIFICATION

This is to certify that this thesis has been read and approved as meeting the requirement of the Department of Agricultural and Biosystems Engineering, Landmark University, Omu-Aran, Nigeria, for the Award of M. Eng.

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DEDICATION

This report is dedicated to the Almighty God, who has supernaturally provided and directed me throughout my study. Also, I dedicate this project to my parents, Pastor Samuel and Mutiat Dottie for their unwavering love and support throughout my study.

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ABSTRACT

Broken rice is a by-product which is generated in large quantity in the food sector in Nigeria. These broken rice are usually incorporated in the formation of animal feeds or sometimes discarded as waste. Repurposing food waste and utilization of legumes into more value added products is very germane because it reduces global warming challenges. This study is aimed at development and optimization of the extrusion cooking process for a novel cereal-based ready-to-eat (RTE) snack from the utilization of broken rice and cowpea blend. Central composite rotatable design (CCRD) with four independent variables having 5 levels each were used. The process parameters viz. blend ratio (broken rice flour: cowpea flour): 90:10 - 70:30, moisture content (10 - 18% wb), temperature of barrel (110 - 150℃) and the screw speed (280 - 360 rpm) are the independent variables employed in the experimental design. The specific mechanical energy (SME), the water absorption index (WAI), the water solubility index (WSI), the total colour (TC), the hardness, the bulk density (BD), the expansion ratio (ER), appearance (APP), colour, crunchiness (CRH), crispness (CRSP), taste (TA),mouth-feel and the overall acceptability (OA) were used to characterize the extrudates.

Moisture content was discovered to have the highest impact on the characterization with a large F-value for all the responses. The process parameters and responses were subjected to numerical optimization and it was discovered that the process parameter of blend ratio (83:17), moisture content (10% wb), barrel temperature (150℃) and the screw speed (307 rpm) from the experimental design produced the optimal extrudate with a desirability of 0.737. From the result obtained from the analysis of variance; SME, WAI, Hardness, ER and Overall acceptance were significant ($p<0.05$): whereas, WSI and BD were not significant ($p>0.05$). Indicating a 5% risk of concluding that a difference exits when there is no actual difference.

The proximate analysis of the optimal extrudate were; moisture (5.99%), crude protein (6.73%), crude fat (2.60%), total ash (0.96%), crude fibre (3.04%) and carbohydrate (80.68%). While, the mineral composition viz. Iron (0.41 mg/kg), phosphorus (16.21 mg/kg), manganese (0.02 mg/kg), copper (0.06 mg/kg), sodium (23.44 mg/kg). The economic viability of the optimized ready-to-eat snacks was conducted. From the economic analysis of the ready-to-eat snack, it showed that the commercialization of the product is feasible because the benefit cost ratio was 1.3, Payback period was 9 months and the break-even point was 45.3%. It was concluded that broken rice-cowpea blend is a suitable raw material for the production of gluten free ready-to-eat snack.

Keywords: Ready-to-eat, optimization, rice, cowpea, response surface.

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CHAPTER ONE

1 INTRODUCTION

1.1 Background of the Study

Snack is a light and casual meal that can be taken before or after a main meal. Snack foods, on the other hand, play a vital role in many people's diets, particularly among children, and can affect overall nutritional quality (Nicklas, Yang, Baranowski, Zakeri & Berenson, 2003). The majority of snacks are produced from starchy ingredients including corn, wheat, rice, oats, and potatoes. (Rivera-Mirón *et al*., 2020). Such snacks may lead to health issues due to the domination of refined grain cereals that are not balanced in nutrient quality (Wang & Lobstein, 2006). However, consumers can enjoy snack foods with good taste, flavour, pleasing textural mouth-feel and get "fun eating" with nutrient supplements. One of the latest processing technologies being employed in the development of new foods is extrusion cooking (Cuj-Laines *et al*., 2018).

1.1.1 Extrusion cooking

Extrusion technology is widely used in the plastic industry although now being used in the food processing industry (Fernandes *et al*., 2000; Zameer Hussain & Singh, 2014). Extrusion is from the Latin word *'extrudere,* which means the act of pushing out. Food preparation through extrusion is a well-known industrial method that entails pushing a dough-like material through a die to shape and mould it into various shapes (Grasso, 2020). It can be defined as a thermomechanical process which involves heat transfer, mass transfer, and pressure build-up.

This technology is utilized to create extended food matrices since it incorporates procedures including mixing, kneading, shearing, cooking, and shaping (Fellows, 2017). The optimization of extrudates produced from rice-cowpea blend based on its mineral composition has been studied by Danbaba *et al*. (2015). Information on the optimization of the blend as it relates to its physical, mechanical, economic, and sensory evaluation has not been reported in literature.

1.1.2 Cereals

Cereals are any edible grass-like plants cultivated for animal and human consumption. They are usually referred to as whole grains in their unprocessed form. Types of cereals include rice, wheat, millet, maize, and sorghum. Cereals are present in almost every food eaten and are employed in the food industry to create RTE snacks and other cereal-based breakfast and weaning meals.

Rice (*Oryza sativa L.*) is a cereal grain that is widely eaten as a staple food by a huge portion of the global population, particularly in Asia and Africa (Wikipedia Contributors, 2019). Rice is regarded as one of the cheapest source of food energy with a gyclemic index (GI) of 65 (Kubala, 2019). The rice grain consists of about 12% of water, 75 - 80% of starch and 7% of protein. The protein content of rice is digestible with excellent biological value and protein efficiency ratio of 2.02 to 2.04% with high concentration of lysine (Eggum, 1969; Ibukun 2008). In addition, it can also be part of a balanced diet. It also contains magnesium, phosphorus, and vitamin B (thiamine, niacin, and riboflavin).

1.1.3 Legumes

Protein, carbohydrate, dietary fibre, minerals, and vitamins are just a few of the components found in legumes. Legumes are generalized to contain low fat, low sodium, abundant fibre, low GI, vitamin B and gluten free (Otitoju, Otitoju, Nwamara & Baiyeri, 2015; Singh, Mukhi & Mishra, 2017). Hence, the need to focus on the development of a cereal-based RTE snack incorporated with a legume which is gluten free. Gluten is a protein found in cereal grains including wheat, barley, and rye that works as a binding agent in meals. The consumption of gluten in foods by gluten intolerant consumers may trigger health challenges such as celiac disease and other serious adverse reactions.

Cowpea (*Vigna unguiculata*), commonly known as beans in Nigeria is the most economic indigenous legume crop grown in Africa (Otitoju, Otitoju, Nwamarah, & Baiyeri, 2015). Globally, about 12-15 million hectares of land annually is cultivated with cowpea with Sub Saharan Africa accounting for the bulk of the total area of production (Kamara *et al*., 2016). Nigeria is responsible for about 1/3rd (4-5 million hectares) of the total world production area. With an estimated yearly production of 2-3 million tons, or roughly 60% of the world's total annual production of about 5 million tons, she is the highest producer and consumer of cowpea in the world (Ajetomobi & Abiodun, 2010; AATF, 2012; Oyewale & Bamaiyi, 2013; Kamai, Gworgwor & Wabekwa, 2014; Ahmad & Kiresur, 2016; CGIAR, 2017; FAOSAT, 2016; Akah & Onyeka, 2018). Cowpea is considered as one of the cheapest source of protein with GI of 42. It contains 11.1 grams of fibre, 13.22 grams of protein, 4.29 milligrams of iron, 475 milligrams of potassium, 0.91 milligrams of fat, and 198 calories, among other nutrients (Khalid *et al*., 2012). Cowpea can be an excellent fortification for rice in the development of nutritious extruded snacks. To create a nutritionally balanced extruded RTE, cereals and legumes must be combined in the right proportions.

1.2 Statement of Problem

Most of the RTE snacks do not contain a balance proportion of both carbohydrate and protein sources, which is needed for proper body growth. Some of them contain inferior nutrients which causes harm to consumers' health (Wang & Lobstein, 2006). Rice milling industries in developing countries have reported that about 22-30% of broken rice (Ojediran *et al*., 2020; Zameer & Singh, 2014). Broken rice have also been reported to contain the same nutrients as head rice, and are readily available (Hussain & Singh, 2015). Its utilization for the development of gluten-free value-added food products with higher economic value is of great interest. Although, cowpea is a readily available source of protein, iron, and minerals; it is still poorly utilized (Otitoju, Otitoju, Nwamarah & Baiyeri, 2015) and underutilized for commercial development of RTE snacks. However, its utilization for the production of RTE snack through extrusion technology can offer a better alternative.

1.3 Objectives of the study

The main aim of this work is to develop an extruded cereal-based (nutritionally fortified) RTE snack.

The specific objectives are to:

i. optimize the extrusion conditions and blending levels of rice and cowpea for the development of ready-to-eat extruded snacks.
ii. evaluate the effect of the blend ratio, moisture content, barrel temperature, and screw speed on the responses
iii. determine the functional and sensory properties of the extrudate.
iv. analyse economic viability of the final product.

1.4 Justification of Study

Although there has been a number of literature on the optimization of the development of RTE snacks from rice-cowpea flour blends using extrusion cooking technology. However, the optimization study of the blends was limited to the mineral composition. Therefore, this work is based on the production and optimization of rice-cowpea extrudate in respect to its physical, mechanical, and sensory properties. Other benefits are to;

i. reduce the health complications associated with gluten intolerant consumers because it is a balanced product.
ii. encourage the utilization of broken rice in the production of value-added products.
iii. increase the utilization of cowpea in the production of extruded snacks.

1.5 Scope of study

The scope of this study is to:

i. determine the extrusion experimental runs for blend ratio, moisture content, screw speed and barrel temperature for the production of the cereal-based ready-to-eat snack using Central composition rotatable design (CCRD).
ii. analyse the results using multiple linear regression method in response surface methodology (RSM).
iii. optimization of the extrusion process parameters (blend ratio, screw speed, barrel temperature, and moisture content) using the responses (specific mechanical energy, water absorption index, water solubility index, instrumental colour, bulk density, hardness and sensory evaluation; texture, appearance, colour, crunchiness taste, mouth-feel and overall acceptance) through RSM.
iv. determine the proximate (moisture content, crude fibre, crude fat, crude protein, total ash, and carbohydrate) and minerals (Iron -Fe, Copper -Cu, Phosphorus -P, Manganese -Mn, sodium -Na) of the optimized snack.
v. analyse the economic viability (breakeven point, benefit cost ratio and payback period) of the processed cereal-based read- to-eat snack.

1.6 Significance of the study

i. It helps to balance the nutrient value of ready-to-eat snacks compared to other carbohydrate dominant snacks.
ii. It helps to transform the broken rice into a more economic and useful product.
iii. It addresses the sustainable development goals: zero hunger (SDG 2), good health and well-being (SDG 3) and responsible consumption and production (SDG 12).

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Cereals

Cereals are commonly referred to as grains. They are members of the grass family which are cultivated majorly for their starchy seeds called Caryopsis (Makinde & Olmori, 2020). For thousands of years, cereal grains have been the most important component of human meals, and they have played a major role in human civilization. Rice, wheat, maize, sorghum, and millet, in that order, are essential commodities for the daily nutrition of billions of people all over the world. (FAO 2011). More than half of the world's daily caloric intake comes from cereal grain intake (Awika, 2011).

Cereal grains provide food energy greater than other food crops and are largely grown. In developing countries, cereal foods constitute a majority of daily food consumption (Okunola *et al*., 2019a). Cereal grains are the most common basic materials used to make extruded products (Reddy *et al*., 2014). The expansion rate of extruded snacks is one of the most desirable physical qualities since it impacts the structure and, as a consequence, the quality. Extrudate expansion varies greatly depending on processing conditions and feed content. To optimize the puffiness of the snack, starch-based components are the fundamental raw materials for the development of extruded snacks.

2.1.1 Rice

Rice (*Oryza sativa L*) is a stable food consumed by over 50% of the global population. According to USDA 2020, approximately 500 million tons of rice was produced globally in the 2019/2020 marketing year. Rice is consumed by about 5 billion people globally (FAO, 2011). In Nigeria, rice is consumed by every ethnic groups and its consumption has increased rapidly due to urbanization and population growth (Okunola *et al*., 2019a; Ojediran *et al*., 2020).

International Rice Research Institute (IRRI) records that about 20% of the world’s food calories are got from rice consumption (Kubo & Purevdorj, 2004; Courtois, Faessel, & Bonazzi, 2010).

2.1.1.2 Processing of rice

Rice kernel or grain comprises of several components as shown in Figure 2.1. The kernel constituents are the outer shell called the hull and the rice caryopsis or fruit. The hull comprises of two parts which are the lemma and the palea (Britannica encyclopedia,1996).

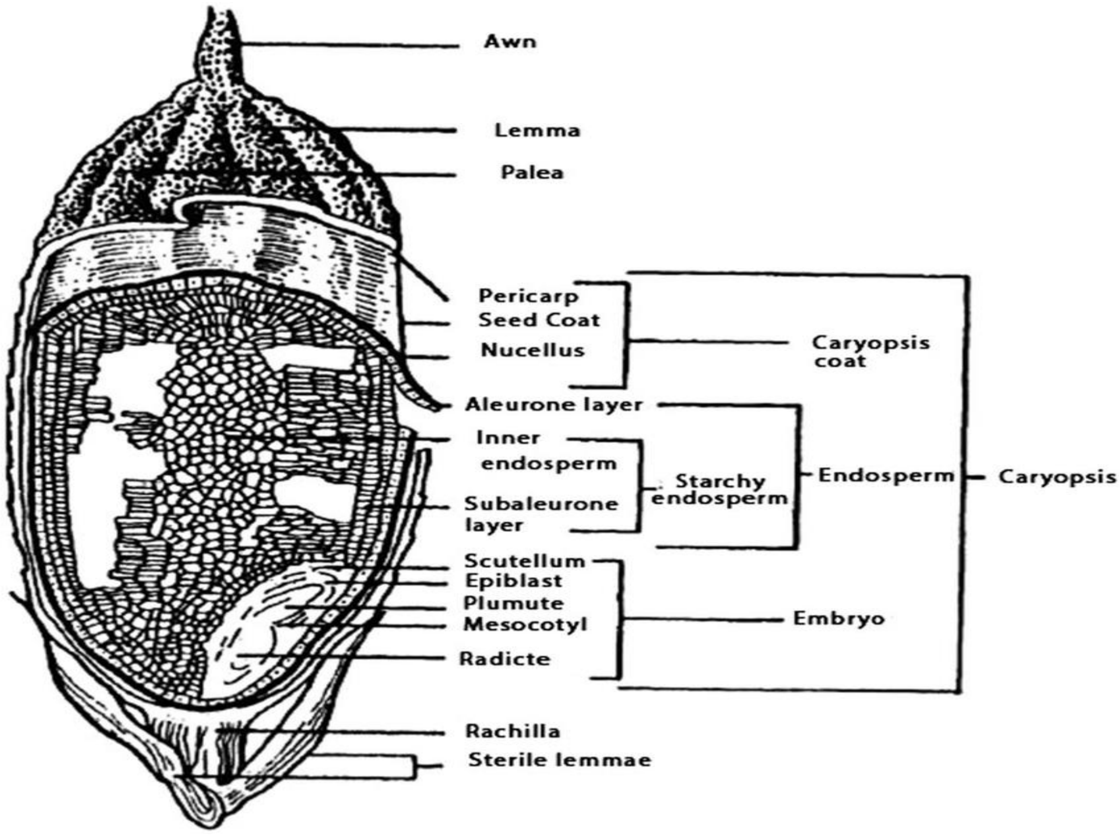


Figure 2.1: Structure of rice kernel

(Britannica encyclopedia, 1996)

However, there is a need to undergo some stages of processing before human and animal consumption. The processing of rice involves several unit operations after harvesting which includes; pre cleaning, milling and grading. The first step involved in rice milling is the removal of its outer covering. The kernel is made up of roughly 20% husk, 8 - 12% bran, and 68-72% milled rice depending on rice type (Wells, 1993; Mohd Esa, 2013).

The rice milling process includes procedures such as: cleaning, hulling (parboiling, drying, tempering), post-hulling processing (whitening, polishing, and grading), and de-stoning (Zabidin *et al*., 2018; Olayanju *et al*., 2021). Rice is used widely for the production of bread, alcoholic beverages and can also be cooked/fried in some traditional foods (Ojediran *et al*., 2018; Olayanju *et al*., 2021). Though, rice production and consumption in Nigeria is on the increase; the low quality of rice in Nigeria is one of the main restrictions influencing the rice producing business (Okunola *et al*., 2019a). Rice husk, grains bran, and broken rice are utilized as animal feed as by-products of rice milling (Grasso, 2020). Broken rice, a by-product of whole grain processed rice, has become a popular ingredient in many RTE breakfast cereals and snacks because of its bland flavour, ease of digestion, appealing white colour, and hypoallergenicity (Omwamba & Mahungu, 2014). The techniques involved in the processing of paddy rice, is an important determinant of rice quality. Rice milling differs from other cereal milling in that the goal is to generate as much whole grain as possible (milled rice yield) rather than flour as with most of other cereal grains. About 90% of locally produced rice in Nigeria is produced by small-scale farmers with little resources utilizing single pass rice mill, meanwhile, corporate farmers produce the remaining 10% (*Rice Production in Nigeria 2019/2020 – Steps to Make Money from it*, 2019). However, 95% of rice processors produce small quantities and are majorly operating with low capacity alongside the presence of obsolete mills (Okunola *et al*., 2019b).

When paddy is milled, approximately of 30% of the head rice gets broken (Grasso, 2020). Broken rice is defined as rice kernels that are smaller than three-quarters the length of the original grain (Sampang 2005; Courtois, Faessel & Bonazzi, 2010). It is currently utilized as a pet food ingredient and in the brewing of beer (Paranthaman, Alagusundaram & Indhumathi, 2009; Grasso, 2020). Broken rice has a similar nutritional content to head rice and is less expensive (Dar, Sharma & Kumar, 2014).

Thus, it has a great deal of potential as a raw material for extruded snack production (Hussain & Singh, 2015).

2.2 Cowpea

Legumes are plants with great importance to people in tropical and developing countries. Various species of legumes are consumed in teaming populations due to its low purchase cost. Legumes are great sources of protein (20 - 40%), carbohydrates (50 - 60%) and other nutrients and minerals which are beneficial to human health and immunity development (Otitoju, Otitoju, Nwamarah, & Baiyeri, 2015).

Cowpea (*Vigna unguiculata*) belongs to the leguminosea family and the Fabaceae subfamily. It is one of the most widely cultivated legumes in West Africa. Thiamine, riboflavin, folic acid, niacin, and biotin are all significant nutrients found in it (Otitoju, Otitoju, Nwamarah & Baiyeri, 2015). Cowpea is a starch-protein legume, unlike other pulses like soya beans and groundnuts, which are oil-protein seeds (Olapade *et al*., 2015). When compared to other legumes, cowpea seeds contain a 25% protein content (Jakkanwar, Rathod, & Annapure 2018). Cowpea has antinutritional components such as trysin inhibitors, which must be removed to improve its nutritional and organoleptic qualities. According to Doblado, Frías & Vidal-Valverde, (2007), most of the antinutritional properties of cowpea are heat-liable and can be reduced when subjected to heat treatment such as extrusion cooking.

Cowpea is eaten in Nigeria as a porridge or a mixture of other foods and vegetables. It can be further ground into paste for the preparation of various traditional meals such as beans cake (*moinmoin* when boiled) and bean fritter (Okunola, Okunola & Ofuya, 2019). Cowpea utilization can be increased with the use of food processing techniques to improve its protein and starch digestibility. The processing techniques includes soaking, dehulling, boiling or cooking, autoclaving, germination, and fermentation (Teye & Boamah, 2012). Tosh &Yada. (2010), conducted a study on the benefits of pulses as a source of dietary fibre and other nutrients. Legume flours were found suitable to fortify foods during processing in order to improve their dietary and nutritional value. Lentils, chickpeas, dry peas, and dry beans were examined for non-starch polysaccharides and oligosaccharides.

2.3 Extrusion

Single-screw extruders and twin-screw extruders are the two main types of extrusion systems (Riaz, 2000). These are shown in Figure 2.2. The single screw extruder comprises majorly of the feed section, compression section, metering section and die (Babagowda, Math, Goutham, & Prasad, 2018).

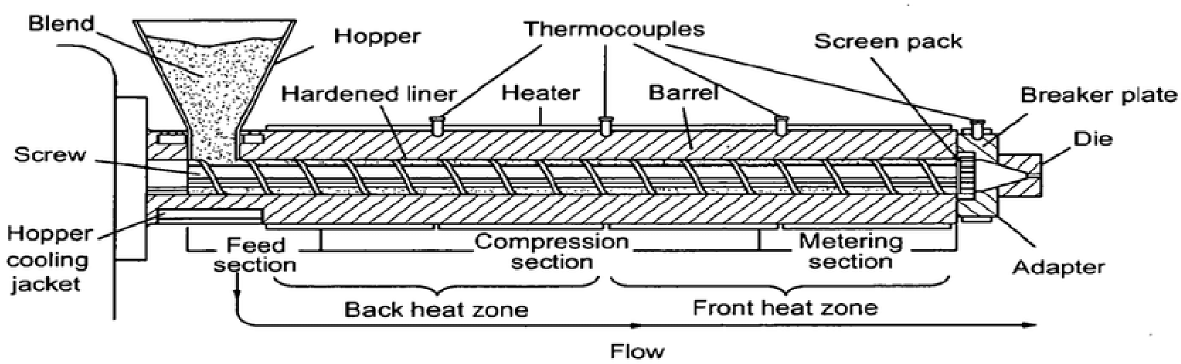


Figure 2.2: Single-screw extruder

(Babagowda, Math, Goutham, & Prasad, 2018)

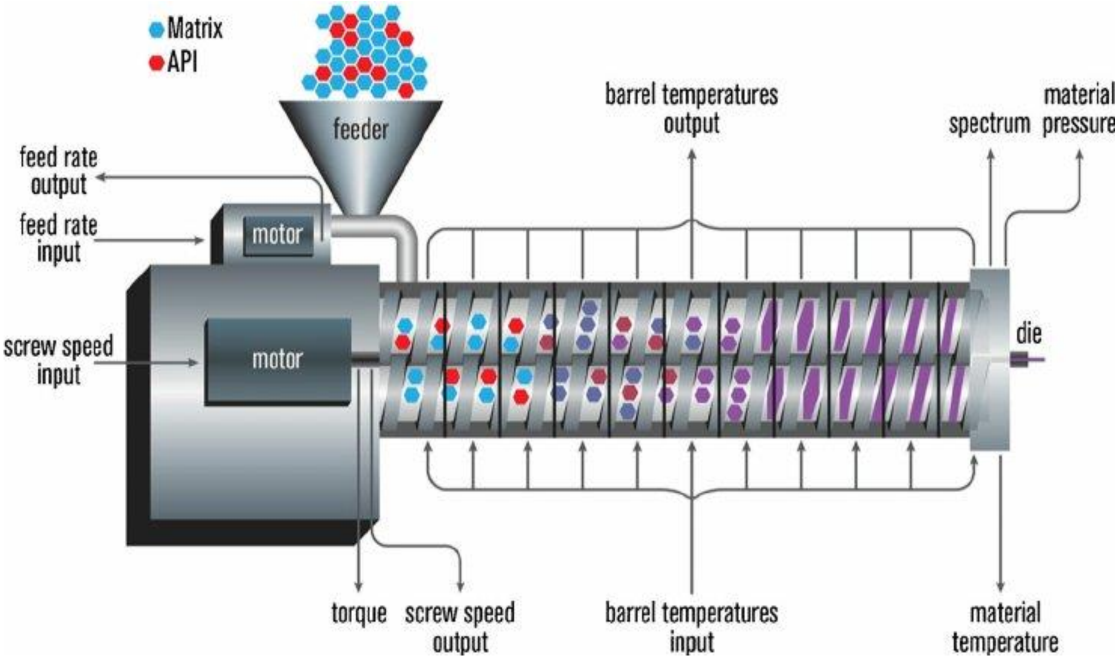


Figure 2.3: Twin-screw extruder

(Patil, Tiwari, & Repka, 2015)

The five essential components of an extruder are the preconditioning system, feeding system, auger, barrel, and die and cutting mechanism. The food blend mix is fed into the extruder through the hopper, where it is processed into a semi-solid mass by the barrel screw. The mass, on the other hand, is driven through the die, where it takes the shape of the die at the discharge end. Expansion of the food occurs as the extrudate is released from the system.

In the twin screw extruder, two screws revolve inside a single barrel chamber Depending on the position of the screw and rotational direction, four alternative configurations are possible in a twin screw extruder. They include: (i) co-rotating intermeshing screw; (ii) co-rotating non-intermeshing screws; (iii) counter-rotating intermeshing screws and (iv) counter-rotating non-intermeshing screws. Although intermeshing screws result in greater residence time of the material in the extruder, non-intermeshing screws cause greater degrees of shear, especially if they rotate in opposite directions (Patil,Tiwari & Repka, 2015).

In recent years, there has been a surge in demand for innovative products with complicated patterns and sizes that are beyond single-screw extruder capacity. Twin-screw extruders provide more control and versatility. The screws overlap in intermeshing twin screw extruders, resulting in positive pumping, effective mixing, and self-wiping action. However, the development of the extruded products is a complicated process. Changes in ingredients like sugar, salt, or fibre, as well as processing parameters like screw speed and temperature, can impact the product qualities including texture, structure, expansion, and sensory attributes (Navale *et al*., 2015). Product quality is influenced by extruder type, screw arrangement, feed moisture and temperature profile in the barrel session, screw speed, and feed rate (Kadan, Bryant & Pepperman, 2003).

Extrusion cooking requires a high-temperature short time (HTST) processing of food (Jakkanwar, Rathod & Annapure, 2018). This method entails moulding a material, driving it through a die with a certain design at high pressure and temperature for a short period of timed duration (Jing & Chi, 2013; Cuj-Laines *et al*., 2018). Extrusion technique has recently been popular in the food processing industry for the manufacturing of breakfast cereals, RTE snacks, baby supplementary foods, and dietary fibre (Navale *et al*., 2015). Extrusion cooking is employed extensively for the development of expanded snack foods due to the high demand for healthy and nutritious

RTE products from consumers of all ages. Extrusion produces highly expanded, low density products with distinct textural qualities by combining high temperature, pressure, and shear force (i.e. crispiness, crunchiness). Extrusion technique is highly versatile and depends on various independent variables (screw speed, barrel temperature, feed mixture ratio, and feed moisture content). These material and process variables determine the extent of macromolecular transformation during extrusion, which in turn influence the rheological properties of the food melt, the expansion ratio (ER), bulk density (BD), moisture content (MC), hardness and other physical characteristics of the final product (Singh, Rachna, Hussain, & Sharma, 2014). In several food production and processing research studies, response surface methodology (RSM) is frequently used for the optimization of different food processes such as extraction, product development, and functional food preparation due to the considerable number of design and response variables in extrusion (Jakkanwar *et al*., 2018; Kumar, Xavier, Lekshmi, Balange, & Gudipati, 2018). Hagenimana *et al*. (2006) used a twin-screw extruder to develop a snack from rice with the use of RSM to assess the effects of processing variables. The variables used were: MC (16 - 22%), BT (100 - 160℃) and SS (200 - 300 rpm) and other functional and physicochemical properties of the extrudates. The WAI was significant ($p< 0.05$) in the regression analysis, and the viscosity values of extrudates were lower than those of unprocessed flour. This indicated that the starch was partially gelatinized through extrusion cooking.

Extrusion cooking presently is utilized in the manufacturing of infant meals, breakfast cereals, dietary fibre, pasta, confectionary, RTE snacks, and modified starch cereals, among other products in the food processing industry (Pawar *et al*., 2014; Navale, Swami & Thakor, 2015; Han, Tra Tran & Man Le, 2018). Since the extrusion technique is diverse, highly prolific, energy efficient, and produces no effluents, the variety and appeal of extruded food has increased significantly. Twin-screw extruders provide much more freedom and better control. The screws overlap each other in intermeshing twin-screw extruders, resulting in positive pumping, effective mixing, and self-wiping action. Extruded product development, on the other hand, is a complicated procedure because a variation in the processing conditions may have influence on the processing variables as well as overall quality of the product (Desrumaux, Bouvier & Burri, 1999). Extruder design, screw position, feed moisture, barrel heat transfer, screw speed, and feed rate can all have an impact on the outcome of the final product (Kadan, Bryant &

Pepperman, 2003).

2.4 Production of Ready-to-Eat Snacks

One of the most important technologies that has shown amazing potential in the development of new items, including snacks, is the extrusion technique (Cuj-Laines *et al*., 2018). Consumer demand for nutritious extruded snacks has increased in recent years, necessitating the development of tasty goods that are also nutritionally beneficial to consumers. Cereals and legumes are used to replace ‘unhealthy foods' with nutritious snack options. Researchers have created healthy snacks by integrating legumes, vegetables, and fruits into the recipe (Ding *et al*., 2006; Hagenimana *et al*., 2006). As well as with squid meal, fish powder, tilapia meal, and shrimp powder (Valenzuela-Lagarda *et al*., 2017), this showed that extruded products with acceptable physical properties and commercially competitiveness can be produced.

2.5 Optimization of Ready-to-Eat Snacks

The term "Optimization" refers to the process of maximizing a desired quality while minimizing an undesirable characteristic. Processing variables with desired optimal values correspond to the optimal extrusion conditions (Hussain & Singh, 2015). Various studies have demonstrated the optimization of extrusion cooking using various composites. Awolu *et al*. (2015) explored the optimization of the extrusion process for the manufacture of RTE snacks derived from rice, cassava, and kersting's peanut composite flour using a locally constructed single screw extruder. Ingredients such as sugar, curry, chilli pepper, butter and egg white was included in blend preparation. The experimental design for the composite flours was carried out using the optimum mixture design of response surface methodology. ANOVA was used to evaluate the statistical analysis. The independent variables used were: MC (15 – 20%), screw speed (90 - 120 rpm) and barrel temperature (70 - 90°C); while the responses were lateral expansion and residence time. The parameters evaluated were: BD, Water absorption capacity (WAC), Oil absorption capacity (OAC), Swelling index, swelling capacity, Least gelation, Emulsion capacity and Proximate composition (moisture content, protein, fat content, carbohydrate, ash and fibre), the microbial analysis of the extruded snack was evaluated. However, some parameters like specific mechanical energy (SME), hardness, colour and sensory were not evaluated. The mineral composition of the snack was not also evaluated. The snacks extruded at relatively low temperature had the growth of these microorganisms due to the use of animal protein. Rivera-Mirón, Torruco-Uco, Carmona-García & Rodríguez-Miranda, (2020) carried out a study on the optimization of extrusion process for the development of fibre rice snack from pineapple by-products using a single screw extruder. The process variables studied were extrusion temperature (ET) (120 - 180℃), feed moisture content (FMC) (18 - 25 g/100 g), proportion of sweet whey powder/corn starch (SWP/CS = 0 - 59.5 g/100 g), and proportion of pineapple by-product powder (0 - 30 g/100 g), (PBP + [SWP + CS] = 100 g) in response to SME, BD, Hardness, water absorption index (WAI), water solubility index (WSI), expansion index (EI) total colour, protein content (PC), fibre content (FC). The goal set for the optimization process was at range for ET, FMC, WAI, WSI and total colour while, SWP/CS, PBP, EI, PC, FC and OA were set at maximum. SME, Hardness, and BD were targeted at minimum. The optimal extrusion conditions were observed at 160℃ extrusion temperature, 23.04 g/100 g, FMC, 52.08 g/100 g SWP/CS and 22.50 g/100 g PBP. Nath & Chattopadhyay, (2007) investigated how to improve the crispness and other quality features of potato-based snacks by optimizing oven toasting. The independent variables were temperature (85 - 115℃) and time (12 - 36 min). The crispness, L values, and overall acceptability was set at maximum while moisture content and ascorbic acid loss was set at minimum. At a temperature of 104.4 ˚C and a period of 27.9 minutes, the best product attributes for crispiness (38.7), MC (3.35%, db), ascorbic acid loss (20.87%, db), L value (52.03), degree of expansion (8.60), and overall acceptability (7.8) were achieved. Pandey, Kumar & Rao, (2021) researched on the optimization, modelling, and characterization of the physicochemical properties of raw banana and defatted soy composite extrudates. Singh, Rachna, Hussain & Sharma, (2014) studied the response surface analysis and optimization of potatoes based snack using a twin screw extruder. The effects of MC (12.6 - 19.4%), BT (116 - 184℃) and SS (349 - 601 rpm) on the process responses viz. SME, BD, WAI, WSI and hardness were studied. It was observed that the optimized extrusion parameters for the preparation of snacks were 14% moisture, 550 rpm screw speed, 170℃ temperature using numerical optimization in RSM. The optimization and characterization of taro flour-based snack enriched with mango pulp was studied by Pensamiento-Nino *et al*. (2018) using a single screw extruder. The three process variables used were mango pulp proportion in taro flour (MPP) (0 - 10 g/100 g), feed moisture content (FMC) (16 - 30 g/100 g) and extrusion temperature (ET) (80 - 150 ˚C). The optimal extrusion conditions were T = 135.81℃, FMC = 18.84 g/100 g, and MPP = 7.97 g/ 100 g, with a desirability value of 0.772, to obtain a snack with EI =

1.52, BD = 0.66 g/cm^3, hardness = 24.48 N, β-carotene content = 99.1µg/g. Omwamba & Mahungu, (2014), developed a protein-rich RTE snack by extrusion cooking from the composition of rice, sorghum and soya beans flour with the use of a co-rotating twin-screw extruder. The ratios of rice, sorghum and defatted soy bean flour were 65: 20: 15, respectively. The extruder was manually fed through the hopper at a rate of 30 kg/h. In this experiment, the independent variables were barrel temperature (110 - 150℃), screw speed of (350 - 450 rpm), and the feed moisture rate was between (12 - 14%). The ER, BD, proximate analysis, mineral analysis and amino acid analysis were evaluated in this work. However, several other evaluations were not made such as: specific mechanical energy (SME), WAI, WSI, sensory, and hardness. They came to the conclusion that feed moisture was the most important component impacting the expansion ratio because an increase in feed moisture from 10 to 13% led in a rise in ER, but an increase in MC to 14% resulted in a drop in the snack's expansion rate. According to the findings, a combination of rice, sorghum, and defatted soy flour can be utilized to make RTE snacks with a better nutritional profile and texture. The moisture content of the extruded snack product prepared under optimal conditions was moisture 6.72 ± 0.15%, protein 15.31 ± 0.12%, fat 1.89 ± 0.09%, ash 3.01 ± 0.11%, carbohydrates 73.07 ± 0.08% and dietary fibre of 5.20 ± 0.011%. Minerals such as calcium, iron, and zinc were also determined. The content was 52 ± 0.21 mg calcium, 3.01 ± 0.11 mg iron and 1.23 ± 0.92 mg zinc per 100 g product. Danbaba *et al*. (2015), used response surface methodology (RSM) and central composition design (CCD) to optimize rice-cowpea composite blend based on the mineral composition using a twin screw extruder. The input variables considered were BT (100 - 140℃), MC (15 - 25%), and BR (8 - 24%). It was observed from this study that the optimum conditions for the optimum mineral composition were; barrel temperature (100℃), feed MC (15%) and blend composition (8%) yielding Mg (12.06 mg/100 g), Mn (5.59 mg/100 g), Fe (10.98 mg/100 g), Cu (2.36 mg/100 g), Zn (4.24 mg/100 g), and Ca (25.99 mg/100 g). However, the physical, rheological, storage, and economic analysis were not evaluated.

2.6 Factors Affecting the Quality of Ready-to-Eat Snacks

Starch quantity and type for extrusion cooking determines the extrusion type to be utilized. The sensory and nutritional quality of the product is altered under high extrusion settings. Even functional qualities such as ER, BD, hardness, WAI, and WSI are influenced by the extrusion technology process. According to Kothakota, (2013), the ER mainly depends upon the barrel temperature as an increase in temperature increases ER. It was also reported that the BD decreases with an increase in the temperature and screw speed. Water absorption index is another factor that affects RTE products. Hagenimana *et al*., (2006) reported that the increase in water absorption with an increase in temperature was due to the increased dextrinization at high temperature.

2.7 Textual Properties of Ready- to-Eat Snacks

Moisture content has a big influence on the morphology of RTE snacks because it affects crispness, which is a key factor in customer approval. Mazumder *et al*. (2007) examined the textural properties of a model snack at various moisture levels. The textural properties of corn balls were investigated using a moisture content range of 2 to 10%. The essential moisture percentage for maize balls was found to be 4%. Li *et al*. (2004) used a co-rotating twin-screw extruder to evaluate the texture of soya bean-corn composite extrudates. The study investigated the effect of varying moisture content from 21 to 23% and soya flour of 0 to 40% on the texture of the snack. The findings revealed that increasing the quantity of soya beans (0 to 40%) increased the expansion ratio thereby, lowering the hardness and changing the specific volume and gumminess of the extrudates. The increase in moisture content from 21 to 23% resulted in a decrease in specific volume and increased hardness of the extrudate.

2.8 Quality Indices of Food Product

The consumer's acceptability of the final product of an expanded snack are evaluated by some physical factors such as density, hardness and expansion ratio (Patil, Berrios, Tang, & Swanson, 2007). According to Altan, McCarthy, & Maskan, (2008), the SME has relationship with the ER, textural properties and expansion. Onwulata, Konstance, Smith, & Holsinger, (2001), researched on the breaking strength of potatoes, corn and rice extruded snack fortified with whey. It was discovered that when the whey proportion in the feed composition increased, the breaking force and the expansion ratio of the snack decreased. This is because an increase in protein content in food composite prevents gel formation thus causes a decline in ER.

Water solubility and water absorption index prediction was determined for extruded food products by Oikonomou & Krokida, (2012). It was pragmatic that in most circumstances, the modelling of the WAI of food products exhibited a fitted satisfactory power law equation to the available experimental values. However, when modelling water solubility the fit of the power law equation to experimental data is adequate.

The BD and ER are highly correlative. The increase in expansion ratio corresponds to a decrease in BD and vice-versa. ER in extrudate is highly dependant on the BT and MC (Alam, Kaur, Khaira & Gupta, 2015). Thymi, Krokida, Pappa, & Maroulis, (2005) studied the structural properties of extruded corn starch product. The effect of extrusion process parameters such as temperature, rotation speed, residence time and FMC on the structural properties of extruded corn starch was examined. The apparent density improved slightly as the residence time increased for all temperature and moisture contents used, however, the ER and porosity of extruded products reduced with the residence time.

Higher feed moisture during extrusion process decreases the expansion and increases the BD of extrudates (Alvarez-Martinez, Kondury, & Harper, 1988). Ding, Ainsworth, Plunkett, Tucker, & Marson, (2006) studied the influence of extrusion conditions on the functional and physical properties of wheat-based extruded snacks. During the extrusion process, the viscosity of the dough, swell effect and bubble growth effect contributed to the structural change of the extrusion mix. The increase in feed moisture was discovered to decrease the degree of starch gelatinization and extrudate expansion.

Extrusion processes have an important effect on the antioxidant activity of various food materials. Many researchers have studied the effect on antioxidant capacity of various ingredients used for extrusion cooking technique. Sharma, Gujral, & Singh, (2012) predicted the antioxidant activity of barley as affected by extrusion cooking. Extrusion cooking showed a significant effect on the antioxidant properties of the extrudates from barley.

Delgado-Licon *et al.* (2009) observed a significant decrease in the total polyphenols and antioxidant activity during extrusion of bean-corn mixture. It was observed that the decrease in bioactive compounds was attributed to the process condition.

Extrusion technology increases the level of dietary fibre in non-gluten-free ready-to eat expanded snacks developed from cereal and vegetable products (Stojceska, Ainsworth, Plunkett, & İbanoğlu, 2009). Stojceska *et al.* (2010) reported the advantage of using extrusion processing for increasing dietary fibre level in gluten-free products. The formation of gluten-free expanded products with high dietary fibre levels can be attained by regulating the extrusion conditions, such as temperatures, solid feed rate and screw speed combinations and the selection of appropriate raw ingredients. The effect of extrusion cooking on mineral bioavailability in pea and kidney bean seed meals was studied by Alonso, Rubio, Muzquiz, & Marzo, (2001). MC decreased and iron increased in extruded compared with non-treated seed meals. Starch was reduced in both pea and kidney bean seed meals. Raffinose, stachyose and verbascose also dropped in kidney bean meal after extrusion, but only stachyose was reduced by thermal treatment in pea flours. The apparent absorption of iron, phosphorous and calcium from un supplemented pea-based diets significantly increased in the extruded product compared with raw seed meals.

The lipid binding to starch brings about changes in physio-chemical properties of extrudates. However, these are complex and have been shown to vary with the type, amount and the hydrophilic-lipophilic balance of lipids and the materials being extruded (Faubion, Hosenery & Seib, 1982). Bhattacharya & Hanna (1988) observed that decreasing the lipid content in the extrusion of corn gluten with defatted soy protein concentrates, lead to an increase in expansion of extrudate.

High temperature reduces the lipase and lipoxygenase activity and moisture level, thereby decreasing the factors responsible for free fatty acid development and oxidation of fatty acids (Alam, Kaur, Khaira & Gupta, 2015)

2.9 Research Gap

In literature, production of RTE snacks from rice-cowpea composite using a twin-screw extruder has been conducted. Although, optimization of the process conditions for its production was only centered on the mineral composition. However, other extrudate physicochemical properties needs to be explored for product development and standardization of rice-cowpea composites. Economic analysis has also not been reported, because of this the basis of the research is formed.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Raw Materials

Thirty-five (35) kg of rice (FARO 66) was obtained from International Institute of Tropical Agriculture (IITA), Ibadan, Oyo state, Nigeria. Cowpea (7kg) (IT97K-568-18) was obtained from a reputable farm produce shop in the local market in Warri Delta state, Nigeria. The raw materials were stored at 27℃ prior to usage.

3.2 Flour Preparation

Broken rice (FARO 66 variety) and Cowpea (IT97K-568-18) previously procured were used in the preparation of the flour. Prior to use, the raw materials were kept at room temperature in a desiccator. Cowpea and broken rice were cleaned by winnowing and handpicking of the debris. The cowpea was submerged in water at room temperature for 5 min to loosen the outer coat (Elina, Cornelio, Henry & Theobald, 2016). The dehulled cowpea was dried in a batch drier for 12 h at 60°C (Olaniran *et al*., 2020). Broken rice and dried cowpea were ground into flour using an Armfield FT2-A hammer mill, the flour was then filtered via a 1 mm sieve to guarantee particle size homogeneity. Prior to use, the individual flours were wrapped in low-density polythene (LDPE) pouches and maintained at room temperature in a desiccator. Proximate analysis of the samples was obtained prior to and after extrusion cooking using the Association of Official Analytical Chemists (AOAC, 2007).

3.3 Flour Composition

3.3.1 Composition of raw materials

The proximate of the raw materials which comprised of the percentages of moisture content, crude protein, crude fibre, crude fat, and carbohydrate were evaluated using AOAC techniques.

3.3.1.1 Moisture content

The AOAC (2007) method was used to calculate moisture content (%). In dry moisture cans, 5g of the sample was weighed. The can were placed at 105℃ in an oven for 4 hours. After that, it was removed and weighed after cooling in the desiccator for 45 minutes at room temperature. This procedure was continued until the weight remained constant.

$$MC_{wb} = \frac{\text{inital sample weight (g)} - \text{weight of dry sample(g)}}{\text{Inital sample weight (g)}} \times 100 \quad (3.1)$$

3.3.1.2 Crude fat (%)

The crude fat content was determined using the soxhlet extraction technique (AOAC 2007). The weight of the fat removed are used to determine fat content. This approach gives the sample a soaking effect without causing channelling.

$$\text{Percentage of wt} = \frac{\text{A}-\text{B}}{\text{C}} \times 100 \quad (3.2)$$

where:

A is the weight of empty cup in gram

B is the weight of cup + fat in gram

C is the weight of samples in grams

3.3.1.3 Crude fibre

The sample (about 1g) was weighed into a 500 ml flask, and 100 ml of tricarboxylic acid digestion reagent was added. This was left to boil and reflux for exactly 40 minutes, beginning with the start of the boiling. The flask was taken off the heater, cooled, and filtered through a known-weight of No 4 Whatman filter paper. The residue was washed six times with hot water and once wit industrial spirit. The filter paper was folded and placed in a known-weight porcelain dish. It was dried in the oven overnight at 105°C. Then removed, cooled for 45 minutes in a desiccator, and the weight was measured. The sample and filter paper in the dish were burnt in a hot plate for about one hour before transferring to muffle furnace at 600°C for 5 h. After ashing, the dish was cooled in the dessicator and weighed (AOAC method 978.10, 2007). It was calculated using the equation thus:

$$Crude\ fibre\ (\%) = Difference\ in\ weight\ \times 100 \quad (3.3)$$

3.3.1.4 Crude protein

The crude protein determination which is in three (3) stages was obtained using Kjeldah nitrogen method. About 3 g sample was weighed into the digestion tube and 5 g catalyst, 1 glass bead to prevent the solution from bumping and 25 ml sulphuric acid. The digestion tube was placed in the digester. To avoid foaming, the mixture was digested at a low temperature and then quickly boiled until the solution was clear and carbon-free. The digestion process was continued until a clear digest was achieved. After the liquid had become clear and all organic matter had been completely broken down, it was heated for another hour. It was placed in a 250 ml Erlenmeyer flask with 50 ml of 4% boric acid with the indicator as receiver to the distillation. Distilled water (100 ml) and 70 ml of 50% sodium hydroxide was added to the digest and the distillation continued. The receiver flask was lowered so that the delivery tube was above the liquid surface and distillation continued for 1-2 minutes. Finally, the delivery tube was drained into the flask after being washed with water. The distillate was titrated with 0.1 N hydrochloric acid until the pink colour appeared for the first time. A blank sample was also titrated to take into account any residual nitrogen which may be in the reagents used (FAO 2003).

The following formulas were used:

$$\% \, Nitrogen = \frac{V_s - V_b \times 0.0014 \times 100 \times 250}{W \times 25} \quad (3.4)$$

where:

$V_s = Vol\ (ml)$ acid to titrate the sample

$V_b = Vol\ (ml)$ acid to titrate the blank

$\mathrm{W} = $ Sample weight (g)

Note: 100% N in protein = conversion factor

$$\% \text{ Crude Protein } = \% \text{ N x F} \quad (3.5)$$

3.3.1.5 Total ash

This was accomplished utilizing the AOAC method 942.05 process (AOAC, 2007). The crucibles were dried in an oven at 100℃ for one hour before being placed in the desiccator to cool. About 5 g of samples were weighed into the dried weighed crucibles. The crucibles were placed in a hot plate for one hour to burn the samples. The crucibles were then placed in the muffle furnace and heated to 550℃ for six hours. The samples were taken out of the furnace and weighed after cooling in a desiccator. Total ash percentage was calculated thus;

$$\% \text{ Ash} = \frac{\text{weight of empty crucible+ash}-\text{weight of empty crucible}}{\text{sample weight}} \times 100 \quad (3.6)$$

3.3.1.6 Carbohydrate

Carbohydrate (%) was calculated by the difference of: [100 – (% moisture +% protein +% crude fibre +% fat +% ash)].

3.3.2 Mineral composition

Mineral components of the raw materials and the optimized extrudate were analysed by Atomic Absorption Spectrophotometric (AAS) [Iron (Fe), Phosphorus (P), Manganese (Mn), Copper (Cu) and Sodium (Na)] according to AOAC (1984).

3.4 Extrusion Process and Design

The extrusion conditions were determined using the CCRD for the four independent variables. Based on the input variables, 30 experimental runs with 24 non-centre points and 6 centre points were generated. The independent variables (process factors) are the blend ratio, rice: cowpea (BR = 90 - 70: 10 - 30), moisture content (MC = 10 - 18% wb), screw speed (SS = 280 - 360 rpm) and barrel temperature (BT = 110 - 150℃). The process variables were in 5 levels as shown in **Table 3.1.** The range of each variable was determined from preliminary analysis and previous studies. The dependent variables (responses) of the extrusion operation were evaluated based on: SME, BD, ER, WAI, WSI and hardness, instrumental colour, and sensory evaluation. The relationship between the input variables and responses was analysed using Response surface methodology in Design expert (version 11.1.0.1). The independent variables are shown in **Table 3.2**. The effect of each response on the process parameter was obtained.

Table 3.1: The process variables used in the CCRD and their levels

Process Variables	**Codes**	**Levels**				
		-2	**-1**	**0**	**+1**	**+2**
Blend Ratio (rice flour: Bean flour)	A	90:10	85:15	80:20	75:25	70:30
Moisture content (%)	B	10	12	14	16	18
Temperature (° C)	C	110	120	130	140	150
Screw Speed (rpm)	D	280	300	320	340	360

Table 3.2: The input variables generated by CCRD

Run	BR (%)	MC (%)	BT (℃)	SS (rpm)
1	80:20	10	130	320
2	75:25	16	140	340
3	80:20	14	130	280
4	85:15	16	120	340
5	80:20	14	130	360
6	85:15	16	140	340
7	80:20	14	130	320
8	85:15	16	140	300
9	80:20	14	130	320
10	75:25	16	140	300
11	85:15	12	120	300
12	75:25	16	120	300
13	80:20	14	130	320
14	75:25	12	120	300
15	80:20	18	130	320
16	85:15	12	140	340
17	75:25	12	120	340
18	70:30	14	130	320
19	80:20	14	130	320
20	75:25	12	140	300
21	80:20	14	130	320
22	80:20	14	150	320
23	85:15	12	140	300
24	90:10	14	130	320

25	80:20	14	110	320
26	85:15	16	120	300
27	80:20	14	130	320
28	75:25	16	120	340
29	85:15	12	120	340
30	75:25	12	140	340

BR = blend ratio (% of gram), MC = moisture content (% dry weight basis), BT = barrel temperature (℃), SS= (screw speed).

3.5 Preparation of Composite and Extrusion Process

A food mixer (EUROSONIC, ES-315) was used to homogenize the rice and cowpea flour for 3 min at defined ratios for uniformity. To the blend, salt, sugar, vegetable oil, and spice mix was added at 0.5%, 4%, 2% and 2.15% respectively. The ingredients were kept constant for all the experimental runs obtained from Central Composite Rotatable Design (CCRD) of RSM. The initial moisture content of the rice-cowpea blend was measured utilizing the oven dry method according to AOAC 2007.

3.6 Extrusion Process

The extrusion experiment was carried out at the University of Ibadan, Nigeria, using a co-rotating inter-meshing twin extruder (Baker Perkins, MPF 24, 190U2F250CACAA215320-GADD) for the development of the extruded RTE snack. It had a 25:1 length-to-diameter ratio. The first, second, and third barrel zones of the extruder were kept constant at 75, 90, and 90°C, respectively, with the exception of the last (fourth zone), which was adjusted according to the experimental design. A circular die opening had a 2 mm exit diameter. The torque indicator on the extruder displayed the percentage of torque in relation to the current drawn by the drive motor. A volumetric feeder was used for feeding the dry mixture to the extruder. The input feed rate was set at 7 kg/hr, and the cutter, which had two blades, rotated at 75 rpm. The extruder was meticulously calibrated for the feed rate and screw speed that was used. The extruder consists of two electrically powered jackets of about 10 litres each. One of the jackets contained water and the other vegetable oil. The moisture content was varied by injecting water into the extruder barrel chamber with a water pump using a metering device.

3.7 Determination of Response

3.7.1 Characterization of the extruded products

3.7.1.1 Specific mechanical energy

The mechanical energy utilized for gel formation of starch-based foods in a processing material is referred to as SME. It controls the rate of starch conversion according to Hussain, Ali, Jabeen & Zargar, (2017). Specific mechanical energy is the measure of energy being used during extrusion per unit mass in form of work from the motor. It was determined from the screw speed rate, power rating of motor, actual screw speed, percentage motor torque, and rate of mass flow ($\frac{kg}{h}$) using the formula in Equation 3.7

as described by Reshi *et al*., (2020). SME was calculated thus;

$$SME\left(\frac{Wh}{kg}\right) = \frac{Actual\ srcew\ speed\ (rpm)}{Screw\ speed\ rate\ (rpm)} \times \frac{\%\ motor\ torque}{100} \times \frac{power\ rating\ of\ motor}{rate\ of mass\ flow\ (\frac{kg}{h})} \times 1000 \quad (3.7)$$

3.7.1.2 Bulk density

This is very germane in quality control of food products, especially extruded snacks. It shows the volumetric expansion of the products (Reshi *et al*., 2020). It is a major parameter used in the food sector to determine the design of packaging material for RTE products (Nagaraju, Tiwari, & Sharma, 2021). BD was determined by measuring 10 random products each of the samples based on the diameter (D, mm) and length (L, mm) of the extrudates using a digital Vernier calliper with 0.01mm accuracy. An analytical balance was used to determine the weight (m, g) (OHAUS PA-214). The following formula in Equation 3.8, as stated by Jakkanwar, Rathod, and Annapure, (2018) was used to determine BD.

$$BD = \frac{4 \times m}{\pi \times D^2 \times L} \quad (3.8)$$

3.7.1.3 Expansion ratio

This is the degree of puffiness of an extrudate melt when exiting the die due to the presence of the atmospheric air which leads to a quick flash off of internal moisture (Nagaraju, Tiwari, & Sharma, 2021). ER was computed using the equation described by Rathod *et al*., (2016). The diameters of 10 randomly selected extruded products from each samples were obtained using a digital Vernier calliper. By dividing the average diameter of the products by the diameter of the die nozzle, the ER of the samples was calculated thus;

$$ER = \frac{Extrudate\ diameter\ (mm)}{die\ diameter\ (mm)} \quad (3.9)$$

3.7.1.4 Water absorption index

The WAI refers to the volume occupied by the granule or starch polymer after swelling in excess of water. The WAI of RTE snacks was calculated using the same procedure as cereals (Anderson *et al*., 1970; Yagci and Gogus, 2008; Yousf *et al*., 2017). Ground extrudate of 2.5g was suspended in water for 30min at room temperature and agitated every 5 minutes, then centrifuged for 15 minutes at 3,000 rpm. The supernatant was decanted into an evaporating dish with a specified weight. The WAI was calculated by dividing the weight of the gel by the dry solids weight per unit weight after the supernatant was removed (Singh *et al*., 2014). It is calculated as:

$$WAI\ \left(\frac{g}{g}\right) = \frac{weight\ of\ sediment}{weight\ of\ dry\ solids} \tag{3.10}$$

3.7.1.5 Water solubility index

The WSI is the quantity of free polysaccharides or polysaccharides discharged from the granule when excess water is applied to the sample (Singh, Rachna, Hussain & Sharma, 2014). A method developed for cereals was used to compute the WSI (Anderson *et al*., 1970; Yousf *et al*., 2017). The WSI was calculated as the mass of dry solids in the supernatant written as a percentage of the original weight of sample.

$$WSI\ (\%) = \frac{weight\ of\ dissolved\ solid\ in\ supernatent}{weight\ of\ dry\ solid} \times 100 \tag{3.11}$$

where, sediment represents the residue left over after the removal of the liquid portion while, the supernatant represents the liquid portion that is separated from the residue after centrifugation.

3.7.1.6 Hardness

Hardness is a subjective perception of a material's textural structure. It determines the product's cell structure and puffiness. It's the greatest force a probe needs to puncture an extrudate (Singh *et al*., 2014). The hardness was determined from the 30 mm length of extruded product using a universal testometric (Texture Analyser, M500-100AT) in National Centre for Agricultural Mechanization (NCAM), Kwara State, Nigeria. A 3-point flexural test was performed with a 100kg load cell. The hardness test was performed on three randomly selected extrudates of each sample, and the mean value of the reading was determined as the final value explained by Jakkanwar, Rathod, and Annapure (2018). Hardness was expressed in newton (N). The compression probe was used to determine the amount of force necessary to break the sample, which shows hardness (Singh, Rachna, Hussain & Sharma, 2014). The testing conditions were 90 mm/min, test speed, pre-load was off and 50 mm span

3.7.1.7 Colour

The total colour ΔE was estimated from the values of L* (luminosity/lightness), a* (red-green chromaticity), and b (yellow/blue chromaticity), which was determined by a Chroma meter (CR-400 & CR-410-KONICA MINOLTA EUROPE). The total colour change (ΔE) of the RTE snack was obtained using the equation as used by Thakur, Shahi, Mangaraj, Lohani, & Chand, (2021) in Equation 3.12.

$$\Delta E = \sqrt{\Delta L^2 + \Delta b^2 + \Delta a^2} \tag{3.12}$$

$$\Delta E = \left\{\{(L^*{}_1 - L^*{}_0)^2 + (b^*{}_1 - b^*{}_0)^2 + (a^*{}_1 - a^*{}_0)^2\}^{\frac{1}{2}}\right\} \tag{3.13}$$

where:

$\Delta L = L^*{}_1 - L^*{}_0$

$\Delta b = b^*{}_1 - b^*{}_0$

$\Delta a = a^*{}_1 - a^*{}_0$

3.7.1.8 Sensory quality

Sensory evaluation is a scientific test that uses the five sense organs to analyse the human response to the structure of food materials. The sensory evaluation of the RTE snack was determined on a 9-point hedonic scale (from 1 = 'extremely dislike' to 9 = 'extremely like') as described by Larmond, (1977) in **Table 3.3.** Panelists (n=50) which comprised of staff and students of Landmark University, Kwara state, Nigeria, were employed to evaluate the RTE snack for its appearance, colour, crunchiness, crispiness, taste, mouth feel and overall acceptability. Thirty coded samples were served to the panelists in batches of six samples daily. The sensory evaluation was done in the morning and panelist were asked not to eat anything 2 hrs before the evaluation to avoid compromise in taste. They were served with distilled water, unsweetened biscuit (crackers) and the sensory questionnaire. They were instructed to swallow the snack, rinse their mouths with distilled water to neutralize their taste buds and have a 5 min break between sample sets.

Table 3.3: The 9-point hedonic scale

CODE	Interpretation
1	Dislike extremely
2	Dislike very much
3	Dislike moderately
4	Dislike slightly
5	Neither like nor dislike
6	Like slightly
7	Like moderately
8	Like very much
9	Like extremely

Source: Larmond, 1977

3.8 Statistical analysis and numerical optimization

The proximate and mineral analysis data were analysed statistically with the use of Statistical Package for Social Sciences (SPSS) software (version 22). The experiments were replicated, and the data was analysed using a design factorial in a Complete Randomized Design (CRD). Duncan's Multiple Range Test (DMRT) was performed to determine the statistical difference in a one-way ANOVA at a 5% level of significance.

To analyse the data and explain the effects of dependent variables on the independent in the models that were generated, a multiple regression model was used. The regression coefficients were calculated after fitting the experimental data to the chosen models. Each variable's unique effects were determined. Regression analysis was used to evaluate the effects of blend ratio, moisture content, screw speed, and barrel temperature on product characteristics provided as a result of the recommended experimental design. For each of the response functions, Analysis of Variance (ANOVA) tables were established. Second order polynomial regression models were established for the dependent variables to fit the experimental data for each response using Design Expert 11.1.0.1 statistical software. The following given model was used:

$$y_i = b_0 + \sum_{i=1}^{4} b_i x_i + \sum_{i=1}^{4} b_{ii} {x_i}^2 + \sum_{i=1}^{4} \sum_{i=1}^{4} b_{ij} x_i x_j \qquad (3.14)$$

Using regression analysis, the experimental conditions (independent variables) which were represented by x_i (i = 1, 2, 3, and 4) representing BR, MC, BT, and SS respectively, were compared to the response/dependent variables (SME, BD, WAI, WSI, TC, hardness, ER and sensory of the extrudates) to assess their interactive effects. Coefficients of intercept, linear, quadratic, and interactive effects were represented respectively, as b_0, b_i, b_{ii}, and b_{ij}. The adequacy of the regression model was interpreted by correlation coefficients. The lack of fit test was used to ascertain the adequacy of the model fit. Three-dimensional (3D plot) response surface plots were generated to assess the changes in the responses with respect to the processing variables.

3.9 Numerical Optimization

Numerical optimization was carried out to determine the optimum levels of the four independent variables. This was performed according to the range, minimum and maximum of the software. The main goals were designated to every response parameter. Expansion ratio was kept at maximum; WAI and WSI were kept in range;

hardness and BD were at minimum (Seth *et al*., 2012; Wani & Kumar, 2016) as shown in **Table 3.4**.

Table 1.4: Numerical optimization variables

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
BR	in range	70.00	90.00	1	1	3
MC	in range	10.00	18.00	1	1	3
BT	in range	110.00	150.00	1	1	3
SS	in range	280.00	360.00	1	1	3
R1: SME	minimize	47.10	102.27	1	1	3
R2: BD	minimize	251.30	593.3	1	1	3
R3: ER	maximize	2.26	3.06	1	1	3
R4:Hardness	minimize	1.99	3.46	1	1	3
R5: WAI	in range	3.05	4.35	1	1	3
R6: WSI	in range	2.80	20.00	1	1	3
R7: TC	in range	36.85	45.89	1	1	3
R8: App	maximize	5.55	7.75	1	1	3
R9:Colour	in range	5.90	7.75	1	1	3
R10: CRH	maximize	3.60	8.15	1	1	3
R11: CRP	maximize	3.50	7.95	1	1	3
R12: TA	maximize	5.45	7.40	1	1	3
R13: MF	maximize	4.75	7.65	1	1	3
R14: OA	maximize	5.20	8.10	1	1	3

BR = blend ratio (% of gram), MC = moisture content (% dry basis), BT = barrel temperature (°C), SS = screw speed (rpm), SME = specific mechanical energy ($\frac{Wh}{kg}$), BD = bulk density($\frac{kg}{\mathrm{m3}}$), ER = expansion ratio (mm), WAI = water absorption index (g/g), WSI = water solubility index (%), TC = total colour (ΔE), APP = appearance, CRH = crunchiness, CRP = crispness, TA = taste, MF = mouth feel, OA = overall acceptance

3.10 Economic viability

To determine the feasibility of the extruded snack, the following parameter were calculated. The break-even point, payback period and the benefit cost ratio was computed with the equation as described by Nagaraju *et al*., (2021).

3.10.1 Break-even point

The break-even point, also known as profit contribution, is a critical analytical tool for determining the connection between total cost, total revenue, and total profits and losses across a certain output range. It is the point of sale at which costs and revenue are in equilibrium (Nissar, Ahad & Hussain, 2017). The break-even point was computed in units, Naira, and as a percentage of the expected capacity

$$\text{BEP (quantity)} = \frac{Fixed\ cost}{Unit\ selling\ price - Unit\ variable\ cost} \quad (3.15)$$

$$\text{BEP (naira)} = \frac{Fixed\ cost}{Unit\ selling\ price - Unit\ variable\ cost} \times Selling\ price/unit \quad (3.16)$$

$$BEP\ (as\ apercentage\ of\ capacity) = \frac{Break-even\ production}{Total\ production} \quad (3.17)$$

3.10.2 Benefit cost ratio

Benefit cost analysis considers a factor known as the benefit cost ratio, which must be greater than 1 in order to assess whether or not the business is profitable. Benefit cost is expressed as follows:

$$\text{BCR} = \frac{\text{Total cost}}{\text{Profit}} \quad (3.18)$$

3.10.3 Payback period

This is the time it takes for an investment to recoup its initial investment in profit savings. Payback period is expressed as follows:

$$PBP = \frac{Total\ investment}{Total\ sale} \quad (3.19)$$

Assumptions

Life span of equipment =10yrs

Life span of building = 20yrs

Salvage value = 10%

Depreciation of building = 3%

Rate of interest per annum = 15%

Unit selling price of 50g packet = ₦ 50

3.10.4 Fixed Cost

Equipment

		Cost (₦)
1.	Twin screw extruder	6,500,000.00
2.	Hammer mill	300,000.00
3.	Food mixer	200,000.00
4.	Automatic pouch packing machine	300,000.00
5.	Weighing balance	60,000.00
6.	Furniture	120,000.00
7.	Containers for raw materials and final products	80,000.00
8.	Tax	10,000.00
9.	Miscellaneous	150,000.00
	Total	**7,720,000.00**

Cost of building/land/renovation

1.	Land (100×50 sq)	4,000,000.00
2.	Construction	10,000,000.00
3.	Painting	100,000.00
4.	Bore hole	200,000.00
	Total building cost	**14,300,000.00**

Depreciation and interest

1.	Depreciation of building at 3%	439,000.00
2.	Depreciation of equipment at 10%	772,000.00
3.	Interest rate at 15% per annum on value on fixed cost	3,303,000.00

Total fixed cost (building cost + equipment cost + depreciation cost) **26,524,000.00**

3.10.5 Variable Cost

A twin screw commercial extruder with a capacity of 50kg/hr and working hours of 8h per day and 25 working days in a month is considered for use. Assuming the rice: cowpea flour (83:17) is available for purchase at ₦200/kg for rice and ₦500/kg for cowpea.

The quantity of raw material needed for the month therefore; = $25 \times 8 \times 50Kg = 10{,}000kg = 10{,}000{,}000g$. This implies that 8300 kg of broken rice and1700 kg of cowpea is needed on a monthly basis

	Cost of raw material	**(₦)**
1.	Rice (200×8300) =	1,660,000.00
2.	Cowpea (500×1700) =	850,000.00
3.	Spices at 2% @ 700/kg ($200kg \times 700$) =	140,000.00
4.	Packaging @ ₦1.8/packet ($1.8 \times 200{,}000$) =	360,000.00
5.	Maintenance of equipment @10% cost per year, for a month =	64,333.3
	Labour charges	
a.	Supervisor	100,000.00
b.	Operator (1)	60,000.00
c.	Assistant (2)	50,000.00
	Electricity charges	
	Electricity @500 kwh @₦35	17,500.00
	Total	**3,301,833.00**

If 10% of the final products was lost due to equipment malfunction and other environmental factors;

Therefore, the initial total quantity of snack produced per month =

$$\frac{10{,}000{,}000}{50} = 200{,}000\ units\ of\ 50g$$

Recording a 10% loss, the actual quantity produced =

$$200{,}000 - (10\%\ of\ 200{,}000) = 180{,}000\ units\ of\ 50g\ of\ snack\ per\ month$$

Sales per year/total return of selling = $180{,}000 \times 50 \times 12 =$ ₦$108{,}000{,}000.00$

Variable cost per unit = $\frac{variable\ cost\ per\ month}{quantity\ produced\ per\ month} = \frac{3{,}301{,}833.0}{180{,}000} =$ ₦18.3

Assuming cost of labelling, marketing, transportation, supply and advertisement is 25% of the variable cost, which ids $18.3 \times 0.25 =$ ₦ 4.6

Therefore, total variable cost per unit = $18.3 + 4.6 =$ ₦ 22.9

Total working capital (variable cost) per month including the cost of advertisement, labelling, supply and advertisement = $3{,}301{,}833 + (4.6 \times 180{,}000) =$ ₦ 4,129,833

Total working capital per year = $4{,}129{,}833 \times 12 =$ ₦ 49,557,996

Total cost (fixed cost + variable cost) = $26{,}524{,}000 + 49{,}557{,}996 =$ ₦ 76,081,996

Break-even Q = $\frac{Fixed\ cost}{Unit\ price - Variable\ cost} = \frac{26{,}524{,}000}{50-22.9}$ = 978,745.4 $\approx$ 978,746 units

Break-even point = $\frac{978{,}745.4}{2{,}160{,}000} \times 100$ = 45.3%

Absolute margin of safety = $(Actual\ production) - (Break - even\ production)$

$$= 2{,}160{,}000 - 978{,}745.4 = 1{,}181{,}255\ units$$

Profit = $Total\ return\ per\ year - Total\ working\ capital$

$$=108{,}000{,}000 - 49{,}557{,}996 = ₦\ 58{,}442{,}004.00$$

Payback period = $\frac{Total\ investment}{Total\ sale} = \frac{49{,}557{,}996 + 26{,}524{,}000}{108{,}000{,}000} = 0.7\ yrs \approx 9\ months$

Benefit cost ratio = $\frac{Total\ investment}{Profit} = \frac{76{,}081{,}996}{58{,}442{,}004} = 1.3$

CHAPTER FOUR

4 RESULTS AND DISCUSION

4.1 Mechanical and Functional effects of the Process Variables.

4.1.1 Effects of blend ratio, moisture content, barrel temperature and screw speed on specific mechanical energy of the extrudate

The MC of a material, screw speed, and viscosity of the material are all factors that influence SME (Kantrong, Charunuch, Limsangouan & Pengpinit, 2018). Table 4.1 showed that the minimum and maximum values of SME which were 47.1 Wh/kg at (80:20, 14%, 110 ^{0}C, 320 rpm) and 102.27 Wh/kg at (75:25, 12%, 140℃, 340 rpm) for the BR, MC, BT and SS respectively. The increase and decrease in BR, MC, BT, and SS affected the SME as observed in Figure 4.1 (a-c) and 4.2 (a-c). The regression analysis showed that the linear terms of BT and SS had a significant ($p < 0.05$) positive effect on SME (Table 4.2).

The increase in the cowpea proportion of the BR (90: 10 to 70:30) when MC was constant had no significant effect on SME. However, a slight reduction in SME (93.6 - 88.6 Wh/kg) was observed. At a constant BR, the increase in MC (10 - 18%) decreased SME value (93.7 - 66.7 Wh/kg) as shown in Figure 4.1a and Equation 4.1. This is because higher moisture contents create a plasticizing effect on starch based materials by resulting in less energy usage. This is in accordance to the findings of Reshi *et al*. (2020) in the production of low GI, iron-fortified barley extruded snack. They reported that SME decreased with an increase in MC from 10 to 22%. Kantrong *et al*. (2018) noticed a fluctuation in the decrease of SME for the moisture content range (12 - 18%) used in their research. They reported that SME increased with lower feed moisture (12 - 15%). Afterwards, SME decreased with the increase in MC (15 - 18%) in the study of process parameters and SME of healthy mushroom-rice snacks. This was due to the combined effect of both vegetable oil and water, which reduced the viscosity of the dough in the extruder barrel, causing the decrease in shear rate and torque. The interactive effect of the BR and MC showed that the combined increase in both input variables reduced the SME (93.6 - 61.3 Wh/kg) in the extrusion process as shown in Fig 4.1a. This is because increasing FMC during extrusion can reduce dough elasticity by plasticizing the melt, resulting in lower SME and, as a result, lower gelatinization. Furthermore, the increase in protein content and a reduction in starch content of a feed composition may result in a low melt viscosity, which could account for the low SME as observed by Meng *et al*. (2010). Ilo, Liu & Berghofer, (1999) compared the effect of varied amaranth flour with rice flour in the production of a snack. It was observed that increasing amaranth content in the blends generally decreased the SME in extrusion cooking.

At constant BR, the increase in BT (110 - 150℃) did not have a significant effect on SME. Although a slight increase in the SME (77.9 - 82.0 Wh/kg) was observed. The interactive effect of the increase in BR and BT had no significant effect, although it led to a slight decrease in SME (77.9 - 76.8 Wh/kg) as seen in Figure 4.1b. Moreover, at constant BR, the increase in SS (280 - 360 rpm) increased SME (68.8 - 91.1 Wh/kg) as shown in Figure 4.1c and Equation 4.1. This is because the increase in SS resulted in higher shear, which led to higher SME. Similar results were observed by Singh *et al.* (2014) in the development of potatoe-based snacks. The interactive effect of BR and SS showed that the combined increase in both variables increased the SME (68.9 - 86.0 Wh/kg) as shown in Figure 4.1c. This is because an increase in SS results in an increase in SME which results in a reduction in viscosity. The interactive effect of MC and BT as observed in Figure 4.2a showed that the combined increase in both variables decreased the SME (88.9 - 66.4 Wh/kg). This is because high MC has a lubricating effect, which implies less energy is used, resulting in lower SME. Hydrogen bonds inside starch granules are broken by high mechanical energy, allowing gelatinization to begin (Meng *et al*., 2010). Similar finding was observed by Singh *et al*. (2014) in the production of a potatoe-based snack. Higher temperature results in the transformation from solid flow to viscoelastic flow and reduces the melt viscosity which decreases SME. Reshi *et al*. (2020) also reported a similar finding for the production of barley-based snacks. Figure 4.2b showed that at a constant MC, the increase in SS (280 - 360 rpm) increased SME (80 - 102.2 Wh/kg). This is due to the high shearing force between the screws. The interactive effect of MC and SS showed that a combined increase in both variables led to a slight decrease in SME (79.7 - 75.3 Wh/kg). Reshi *et al*. (2020) observed similar findings.

The interactive effect of barrel temperature and screw speed showed that a combined increase in both variables increased the SME (64.5 - 90.5 Wh/kg) as shown in Figure 4.2c. This was not in accordance to the findings of Meng *et al*. (2010). They noted that there was a decrease in melt viscosity which lead to a decline in torque when barrel temperature and screw speed were increased. The variation in findings is possibly due to the range in BT and SS for their research. Barrel temperature (150 – 170℃) and screw speed (250 - 320 rpm) were used in their research.

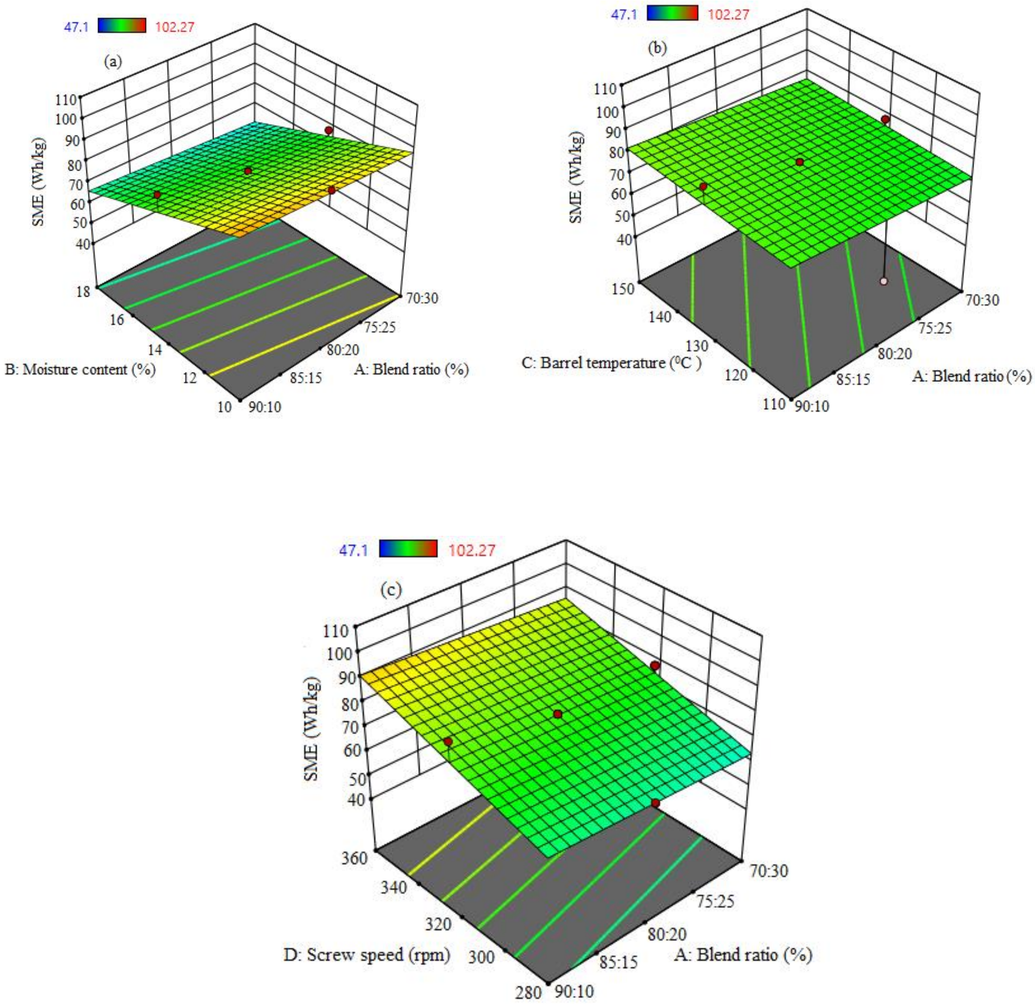


Figure 4.1: 3D response surface plot of specific mechanical energy against (a) blend ratio versus moisture content (b) blend ratio and barrel temperature, (c) blend ratio versus screw speed

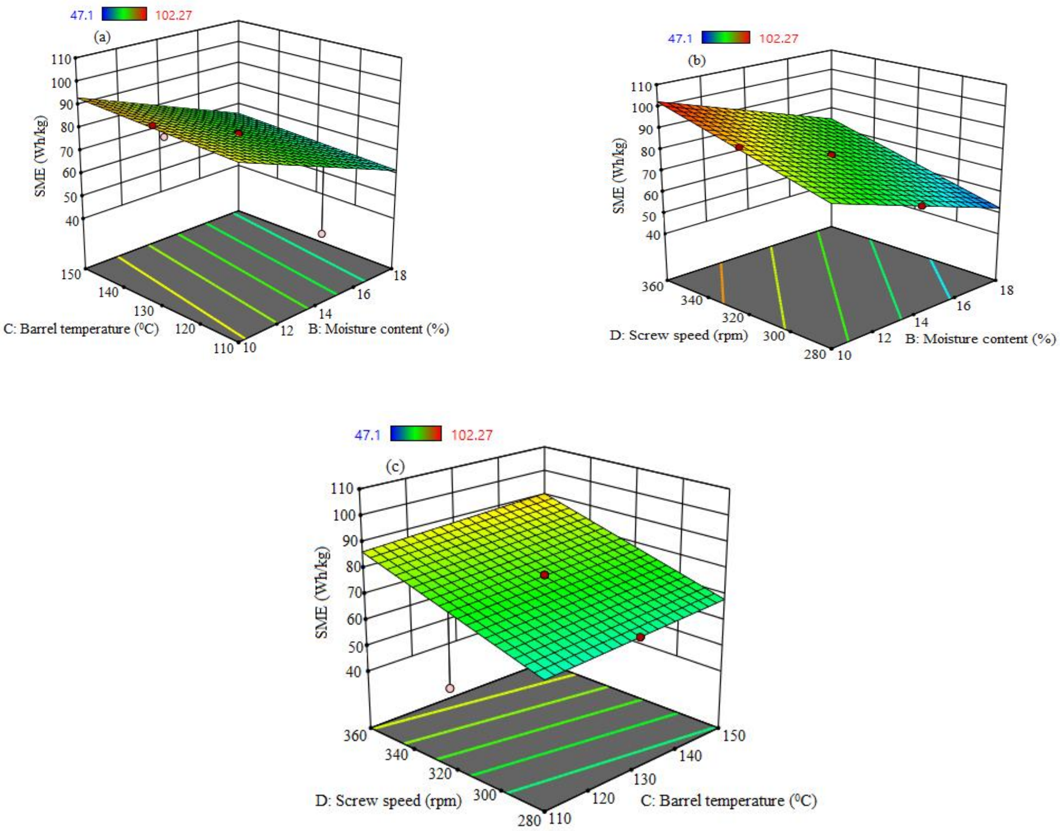


Figure 4.2: 3D response surface plots of specific mechanical energy against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed.

4.1.2 Effect of blend ratio, moisture content, barrel temperature and screw speed on water absorption index of the extrudate

Table 4.1 showed that the minimum and maximum values of WAI obtained were 3.05 g/g (85:15, 16%, 140 ^{0}C, 300 rpm) and 4.35 g/g (85:15, 12%, 140 ^{0}C, 340 rpm) for BR, MC, BT and SS respectively. The increase and decrease in BR, MC, BT, and SS affected the WAI as observed in Figures 4.3 (a-c) and 4.4 (a-c). The regression equation showed that the quadratic terms of (MC, BT, SS, BR*BT, BR*SS, MC*SS, and SS^2) had a significant ($p < 0.05$) positive effect on WAI (Table 4.2).

At a constant moisture content, the increase in the cowpea content of the blend ratio increased WAI. However, a slight decrease was observed in WAI at 70:30 blend ratio (rice: cowpea). Figure 4.3a and the regression Equation 4.2 depicted that the increase in cowpea content resulted in a quadratic decrease in WAI. This finding was in accordance with that of Altan *et al*. (2008) due to the competition of absorption of water between pomace and available starch. On the other hand; at a constant blend ratio, the increase in moisture content showed that WAI decreased from 10 to 12%. Thereafter, an increase occurred from 12 to 18% leading to an increase in WAI by 78.8%. Moisture has a plasticizing effect on starch and thus has a large control on starch degradation according to the findings of Reshi *et al.* (2020). At low MC, starch is bound to solubilize by dextrinization, consequently, diminishing the properties of the polymeric chains to form gel. At high moisture content, the plasticization impact supersedes dextrinization, where the starch polymers do not solubilize, however the granules break apart during gelatinization prompting higher WAI (Sharma, Singh & Singh, 2015). Therefore, an increase in MC increases WAI. The interactive effect of BR and MC showed that a combined increase in both variables at the lower range of BR (90:10 - 85:15) and MC (10 - 12%), WAI was decreased. However, an increase in WAI was observed from 85:15 to 70:30 and 12 to 18% BR and MC, respectively. Then after WAI decreased as shown in Figure 4.3a and regression Equation 4.2. At a constant BR, the individual interaction of BT on WAI shown in Figure 4.3b depicted that at 110℃ the WAI was low. However, an increase in WAI (2.86 - 3.5g/g) occurred at 120 to 150℃. This is most likely due to increased dextrinization when the temperature is raised. This finding was similar to the findings of Yousf *et al*. (2017) for the extruded products from rice and carrot blends. The BT used was within the range of 120 to 150$^{℃}$ in their research. The interaction between BR and BT revealed that an increase in both variables resulted in a fluctuation in WAI behaviour. It was observed that there was an increase in WAI at 130 to 150℃ BT, thereafter a decrease occurred as shown in Figure 4.3b and Equation 4.2. It is possible to observe a further decrease in WAI if a wider range of BR and BT is considered.

The increase in screw speed (280 - 360 rpm) decreased WAI from 3.9 to 3.1 g/g. The interaction between BR and SS revealed that a combined increase of both variables increased the WAI slightly (3.90 to 4.1 g/g) as shown in Figure 4.3c and Equation 4.2. The interactive effect of MC and BT showed that increasing both variables increased WAI from 2.9 to 4.1 as shown in Figure 4.4a. However, a slight depression in the graph was noticed. With a simultaneous increase in MC and SS, there was a constant increase in WAI. However, at 14% MC and 320 rpm SS, WAI increased from 4.17 to 4.69 g/g as shown in Figure 4.4b and Equation 4.2. The interaction between BT and SS showed that increasing both variables simultaneously increased WAI. However, at 130°C and 320 rpm, WAI was high but later reduced slightly from 4.3 to 4.0 g/g.

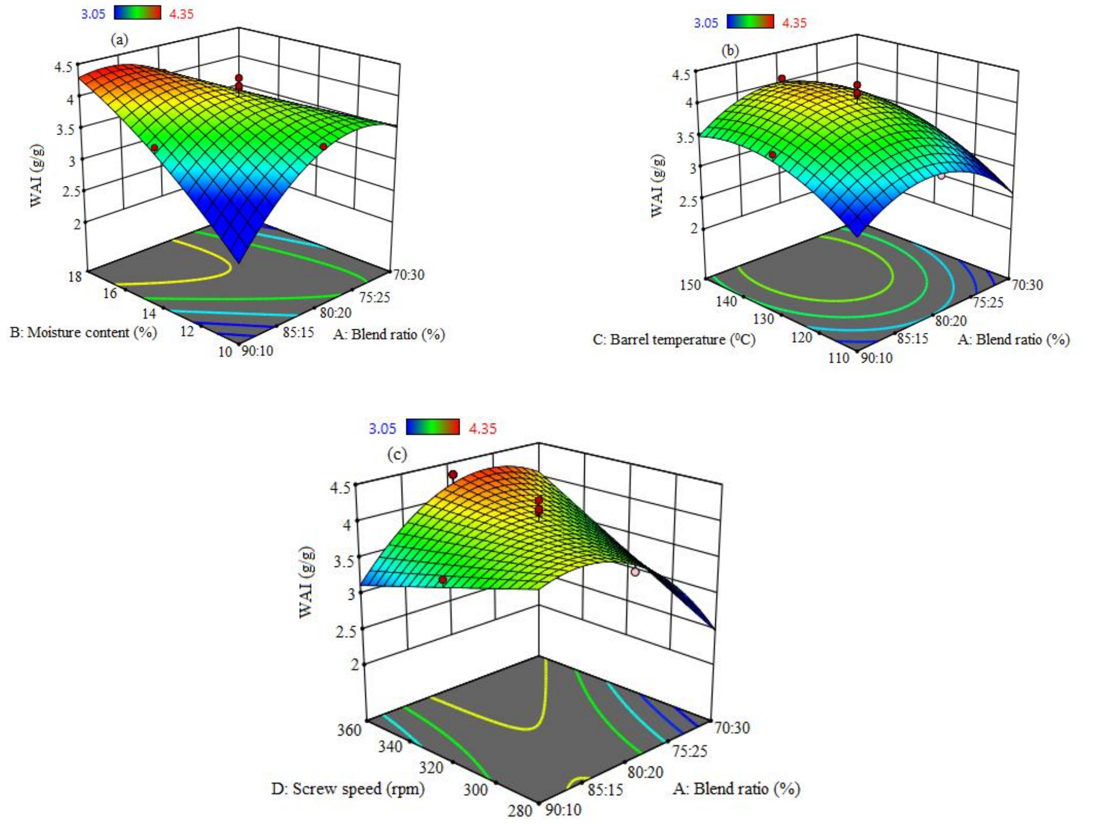


Figure 4.3: 3D response surface plot of water absorption index as against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

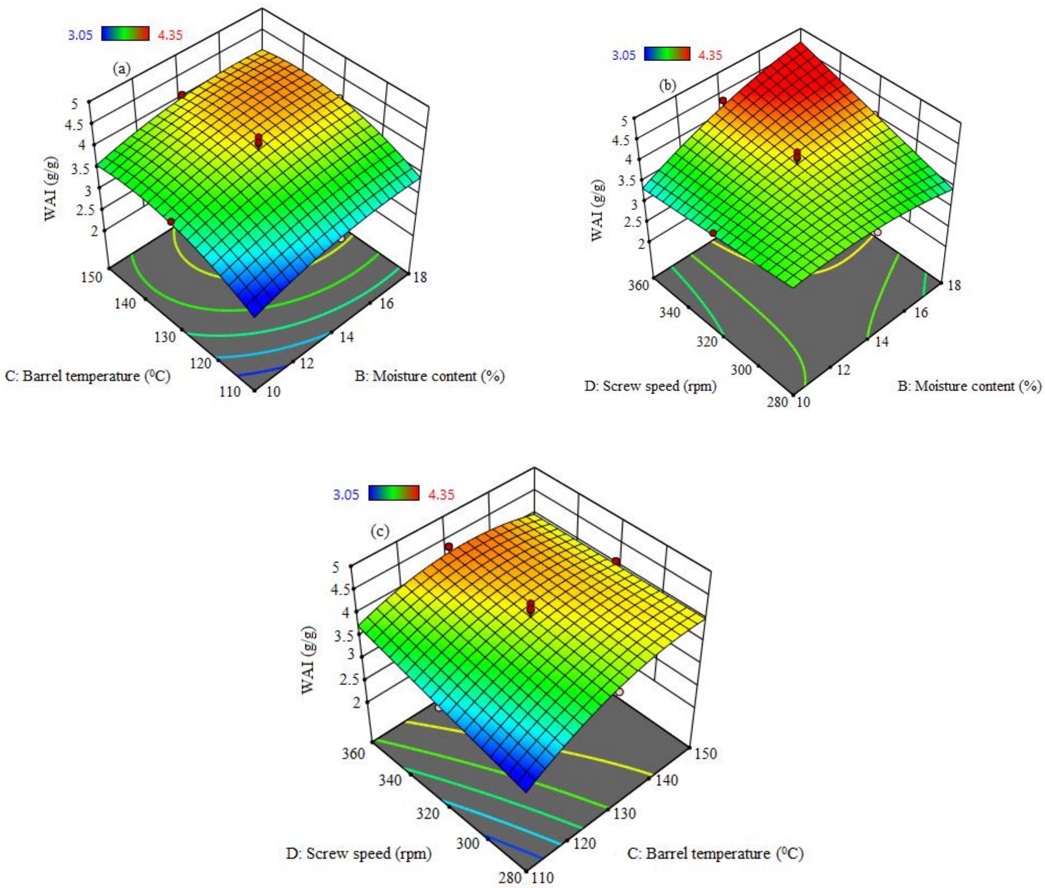


Figure 4.4: 3D response surface plots of water absorption index as against (a) moisture content versus barrel temperature, (b) moisture content versus screw speed, (c) barrel temperature versus screw speed

4.1.3 Effect of blend ratio, moisture content, barrel temperature and screw speed on water solubility index of the extrudate

Table 4.1 shows that the minimum and maximum values of WSI obtained were 2.8 and 20%. The increase and decrease in BR, MC, BT, and SS affected the WSI as observed in Figures 4.5 (a-c) and 4.6 (a-c.). Equation 4.3 showed the regression equation for the model.

At constant MC, the increase in blend ratio (90:10 -70:30) increased WSI from 9.6% to 13.7%. It's possibly attributed to an increase in the fibre content of the feed formulation. This same finding was observed in the analysis by Yousf *et al*. (2017) on rice and carrot blend extruded products. Whereas at a constant BR, the increase in MC (10 - 18%) decreased WSI from 9.6 to 2.5% as shown in Equation 4.3. This is due to greater gelatinization of starch and plasticizing effect at high MC, thereby resulting in the decrease in WSI. Low moisture content results in an increase in WSI probably due to higher starch degradation. This similar finding has been reported by Reshi *et al.* (2020) and Sibel & Fahrettin (2008). The interaction between the BR and MC showed that a combined increase in both variables slightly decreased WSI from 9.6 to 6.60 as shown in Figure 4.5a. At a constant BR, the increase in BT decreased WSI as shown in Equation 4.3. The interaction between the BR and BT showed that the combined increase in both variables increased slightly from 6.9 to 9.2% as shown in Figure 4.5b. Moreover, at constant BR, the increase in SS (280 - 360 rpm) decreased WSI (6.3 - 5.8%) as shown in Equation. 4.3. The interactive effect of BR and SS shown in Figure 4.5c implied that a combined increase in both variables increased WSI slightly from 6.3 to 9.8%. The interaction between the MC and BT shown in Figure 4.6a implies that a combined increase in the variables decreased WSI (12.6 - 3.5%) as seen in Figure 4.6a. This was similar to the finding by Reshi *et al*., (2020). The interaction between the MC and SS showed that a combined increase in both variables decreased WSI as shown in Figure 4.6b. This was similar to the findings of Reshi *et al*., (2020). BT and SS interactively were not significant on WSI (Figure 4.6c).

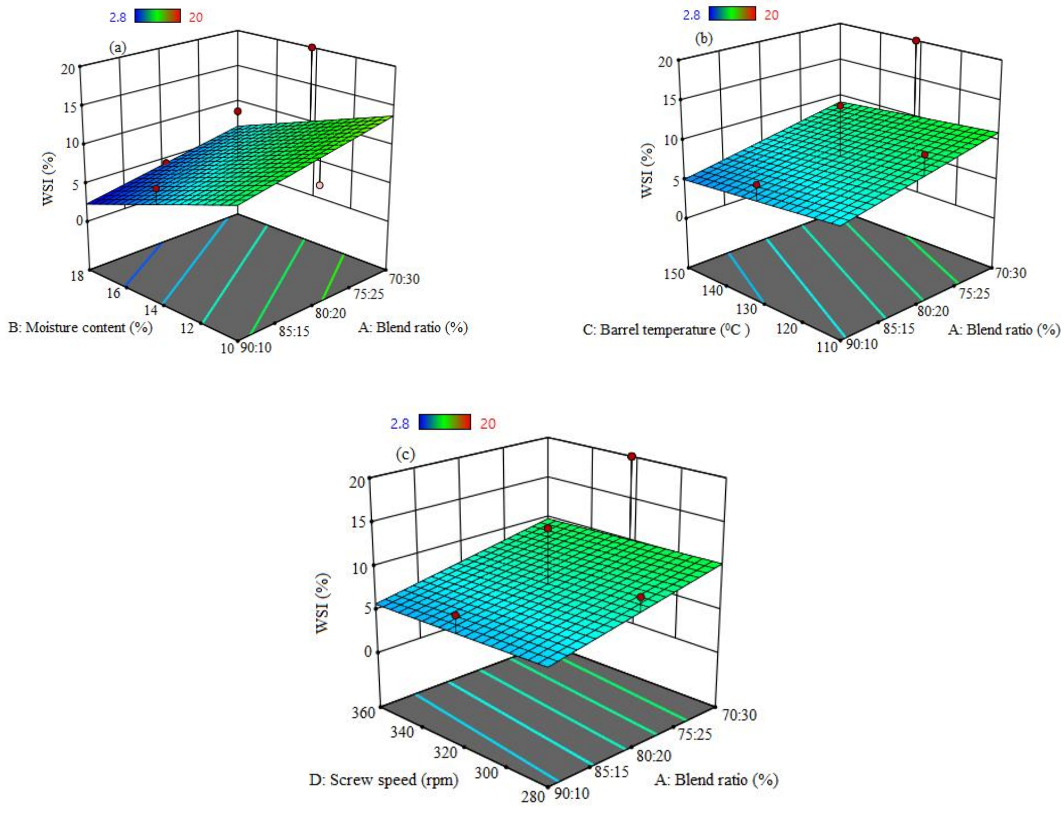


Figure 4.5: 3D response surface plot of water solubility index against (a) blend ratio versus moisture content (b) blend ratio versus barrel temperature (c) blend ratio versus screw speed

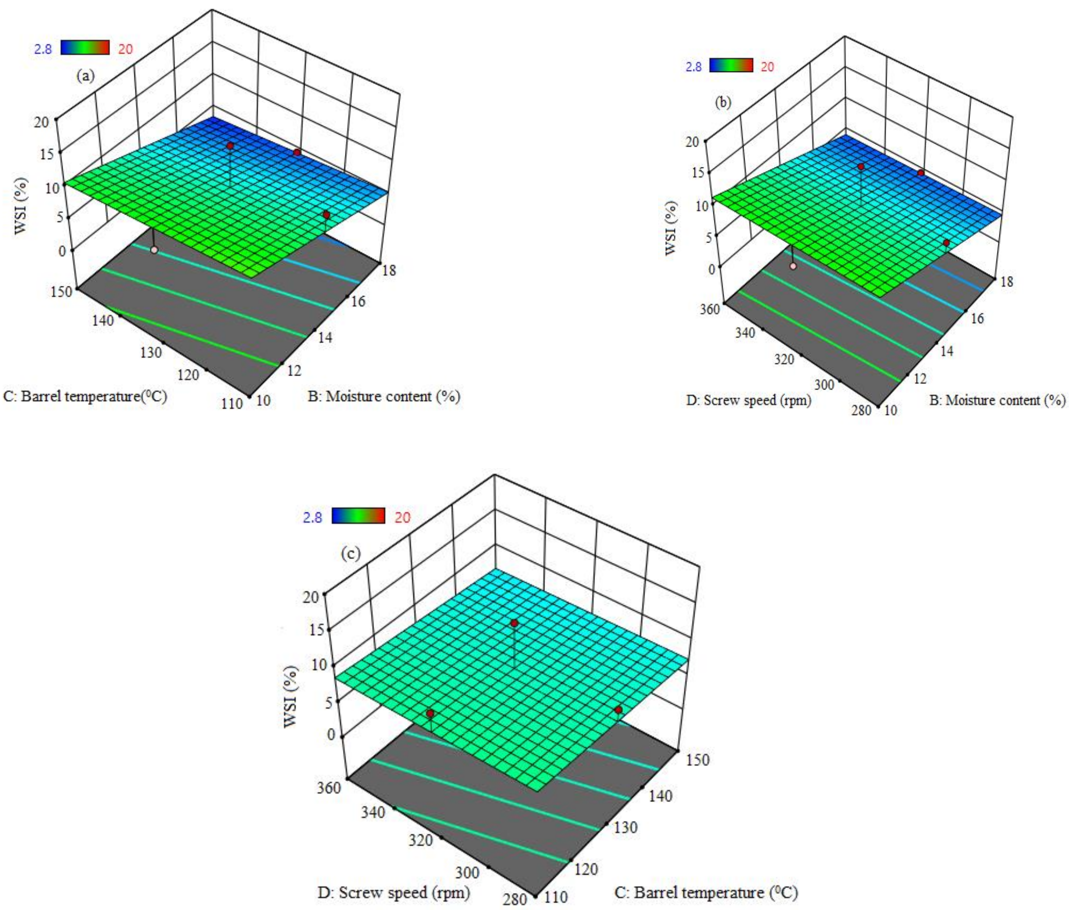


Figure 4.6: 3D response surface plot of water solubility index against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.1.4 Effect of blend ratio, moisture content, barrel temperature and screw speed on total colour of the extrudate

The increase in BR, MC, BT, and SS did not affect the hardness as observed from Figures 4.7 and 4.8 (a-c) for the extrusion process. This is why, in Equation 4.4, the mean value was chosen over any other model. Although an increase occurred from 36.85 to 45.89, however, it did not follow a particular order. The minimum and maximum TC obtained were 36.85 at (75:25, 12%, 140℃, 300 rpm) and 45.89 at (75:25, 12%, 120℃ and 300 rpm) for BR, MC, BT and SS respectively. The processing variables employed had no significant ($p > 0.05$) effect on TC. This finding was not in accordance with Cuj-Laines *et al*. (2018) whom reported an increase in TC with a temperature increase of 110-190℃ because at high temperatures, carbohydrates and protein in food tend to decline during processing, promoting the Maillard reaction and darkening the final product. They also reported an increase in TC with an increase in grasshopper meal composition. The variance in the findings is attributed to the range of BT used in this research.

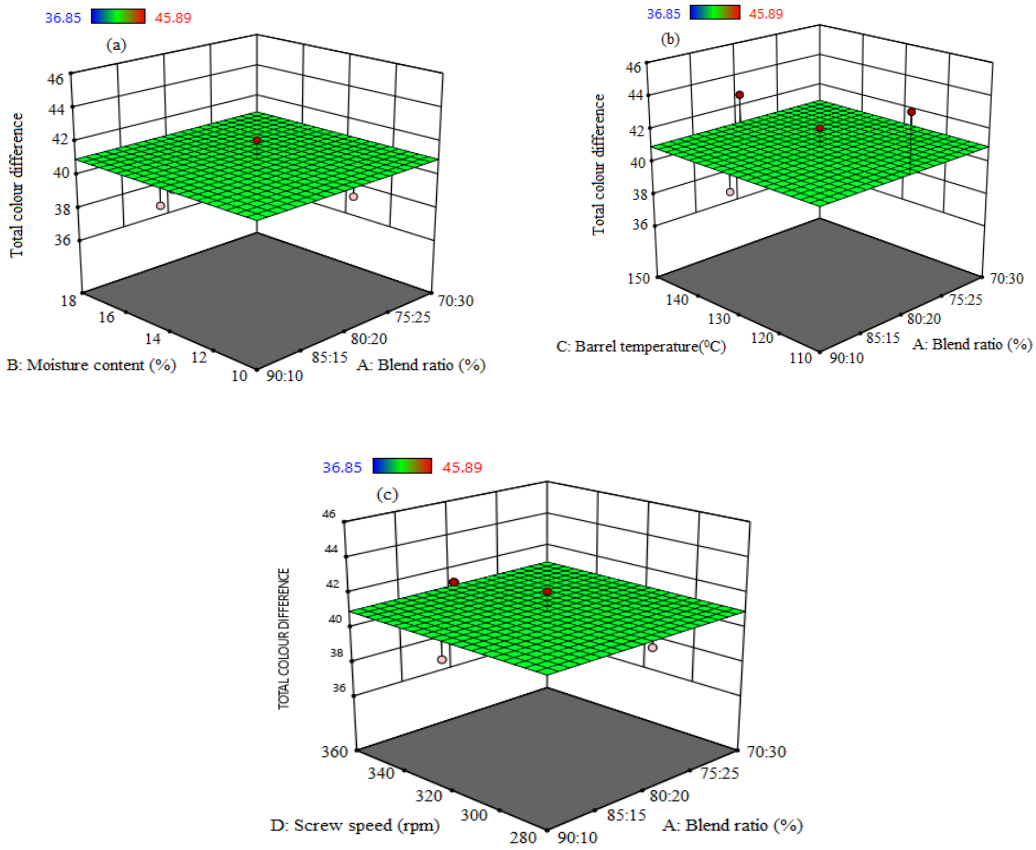


Figure 4.7: 3D response surface plot of total colour against (a) blend ratio versus moisture content (b) blend ratio versus barrel temperature (c) blend ratio versus screw speed

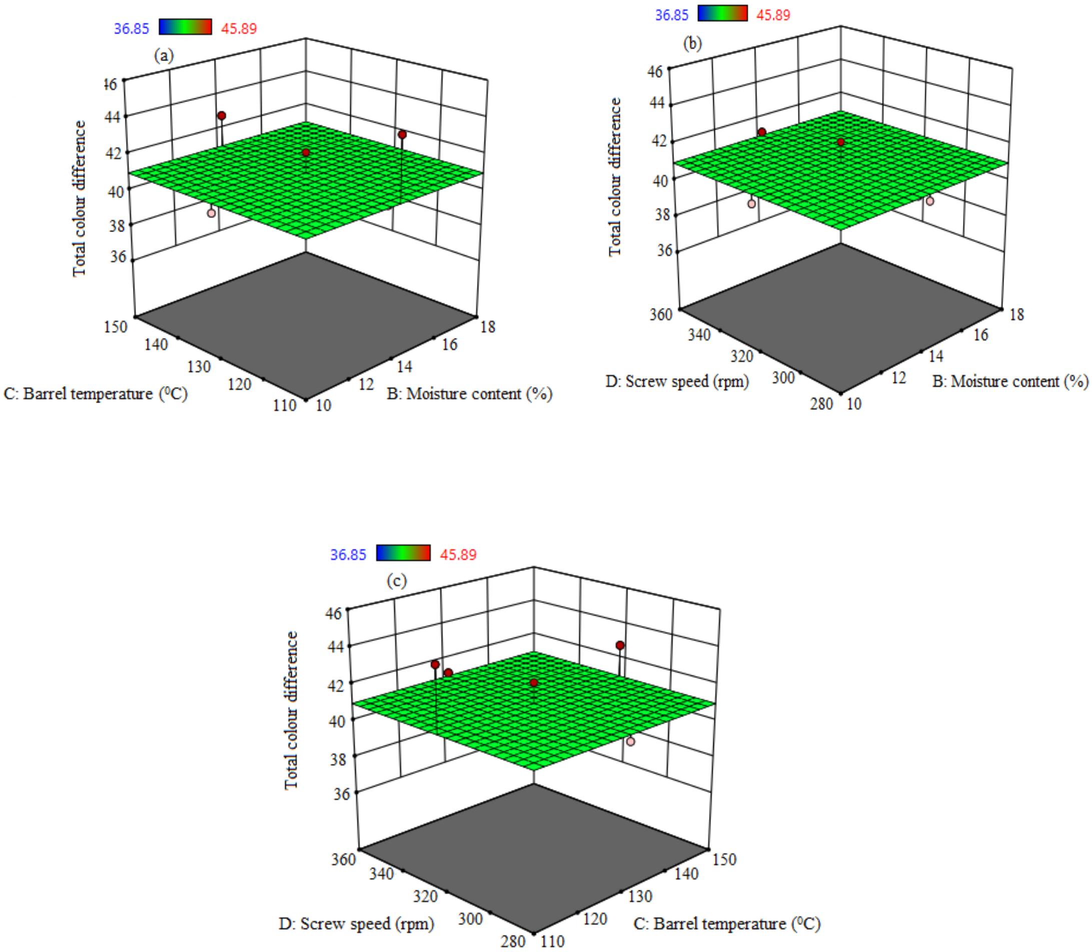


Figure 4.8: 3D response surface plot of total colour against (a) moisture content versus barrel temperature (b)moisture content versus screw speed (c) barrel temperature versus screw speed

4.1.5 Effect of blend ratio, moisture content, barrel temperature and screw speed on Hardness of the extrudate

The minimum and maximum values of Hardness obtained were 1.987 N at (80:20, 10%, 130 ˚C, 320 rpm) and 3.46 N at (85:15, 16%, 140℃, 340 rpm) for BR, MC, BT and SS respectively (Table 4.1). The increase and decrease in BR, MC, BT, and SS affected the Hardness as observed in Figures 4.9 (a-c) and 4.10 (a-c). The regression equation showed the individual and interactive effects of the variables (Equation 4.5).

The regression quadratic terms showed that BR^2, MC*SS, and SS had a significant ($p < 0.05$) positive effect on Hardness (Table 4.2).

At a constant moisture content, an increase in the cowpea content of the blend ratio from 90:10 to 80:20 resulted in a slight decrease in hardness. However, with further increase in the cowpea content, there was a steep increase in hardness. At a constant BR, the increase in MC increased hardness. This is because of the decrease in expansion caused by high MC. Meng *et al*. (2010) reported that hardness of chick pea flour-based snack increased as the MC increased. This claim was also supported by Altan *et al*. (2008). The interactive effect of the combined increase of BR and MC showed that the hardness increased as shown in Figure 4.9a and Equation 4.5. in addition, at constant BR, the increase in BT resulted in a decrease in hardness (Figure 4.9b and Equation 4.5). This observation was similar in literature for chick pea flour-based snack (Meng *et al*., 2010). The interactive effect of the combined increase in both BR and BT showed that the hardness increased (Equation 4.5). However, the increase in screw speed resulted in a gradual increase in hardness from 2.8 to 4.1 N as shown in Figure 4.9c. This could be as a result of the product being subjected to mechanical stress as a result of the high temperature. This observation was not in accordance with the result obtained by Reshi *et al*. (2020) and Meng *et al*. (2010). They observed that an increase in SS reduced hardness because high SS favours starch depolymerisation and bubble growth. Thus, the hardness of the product decreased with increased SS. The interactive increase of BR and SS resulted in a decrease. However, the interactive effect of the increase in MC × BT, MC × SS, and BT × SS showed that there was a steep increase in hardness as observed in Figure 4.10 (a-c) and Equation 4.5.

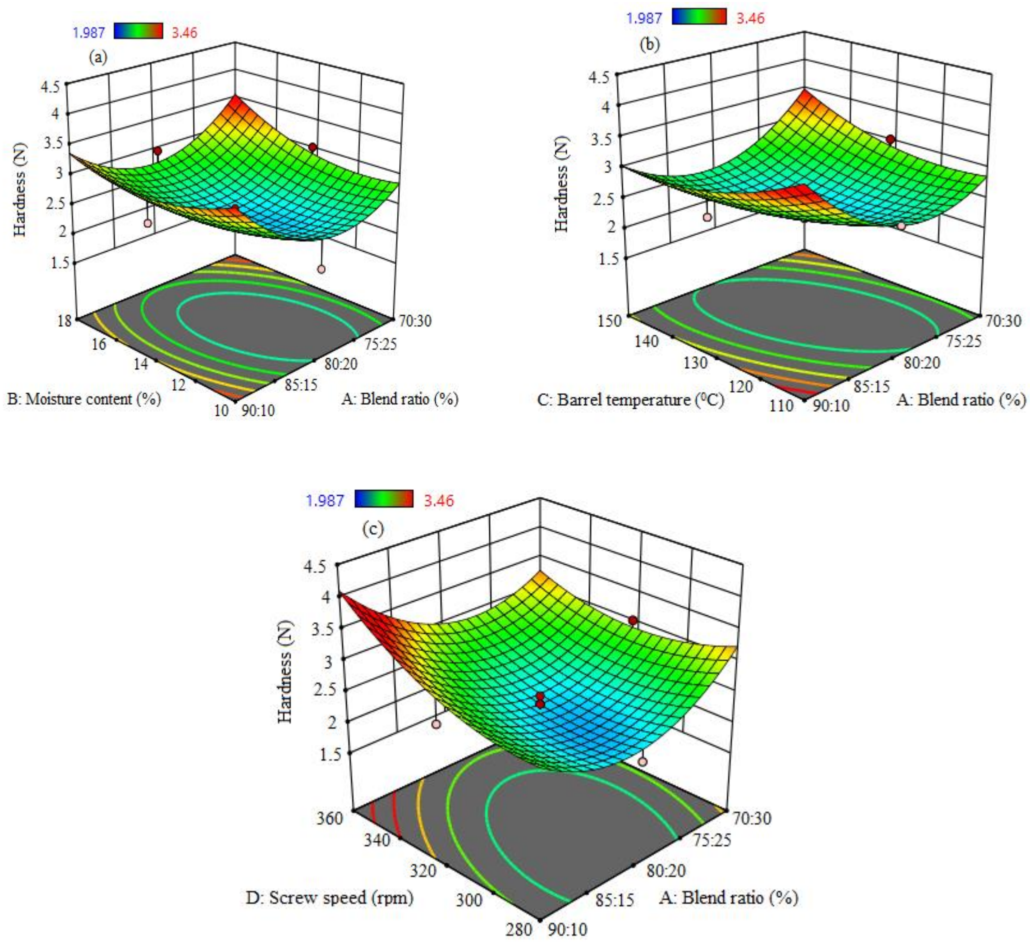


Figure 4.9: 3D response surface plot of hardness against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

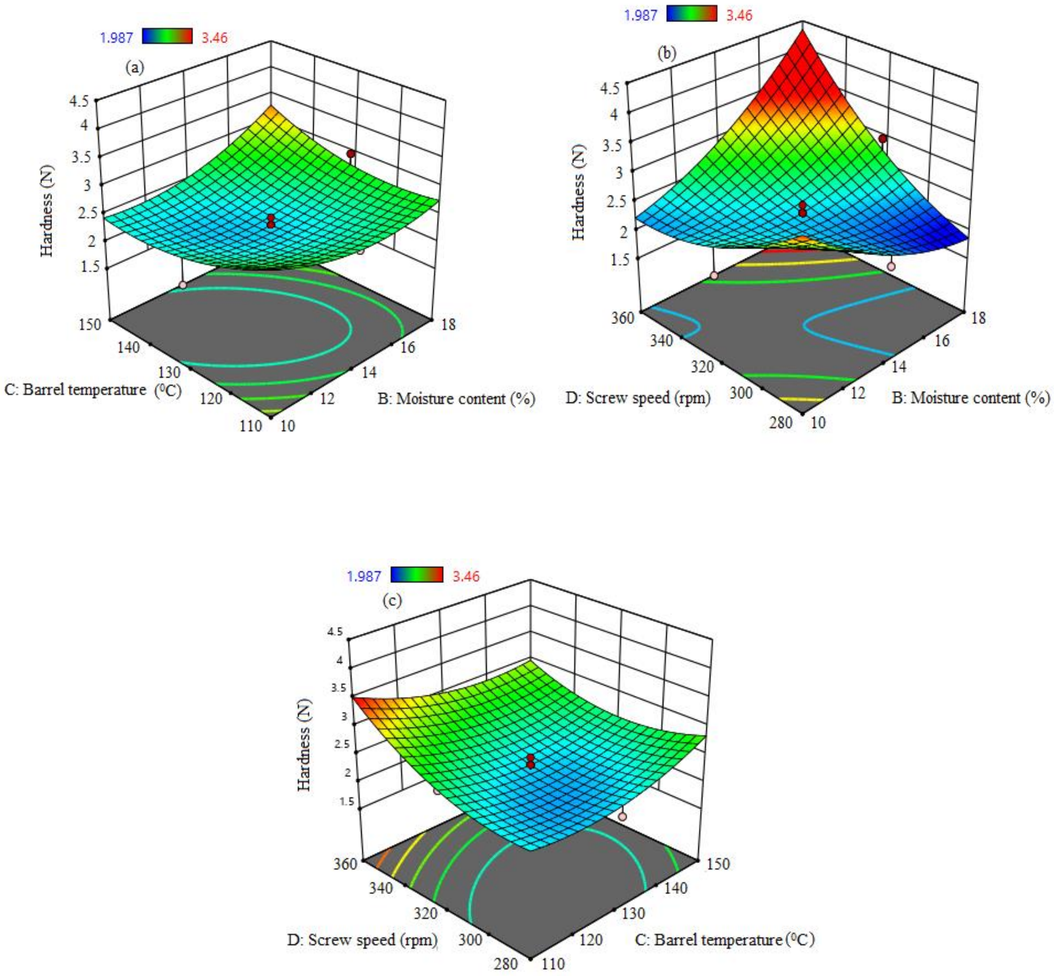


Figure 4.10: 3D response surface plot of hardness against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.1.6 Effect of blend ratio, moisture content, barrel temperature and screw speed on bulk density of the extrudate

The minimum and maximum values of bulk density obtained were 251.3 Kg/m^3 at (80:20, 14%, 110℃, 320 rpm) and 593.3 Kg/m^3 at (70:30, 14%, 130℃, 320 rpm) for BR, MC, BT and SS respectively (Table 4.1). The increase and decrease in BR, MC, BT, and SS affected the bulk density as observed in Figures 4.11 (a-c) and 4.12 (a-c). The regression equation showed the individual and interactive effects of the variables (Equation 4.6).

There was no significant model term effect on the bulk density ($p>0.05$) according to the regression linear terms (Table 4.2).

At a constant moisture content, the increase in cowpea proportion in the BR led to the increase in BD as observed in Figure 4.11a and Equation 4.6. This is because cowpea is highly dense than rice. Moreover, an increase in MC at constant blend ratio increased the bulk density as shown in Figure 4.11a. This is because a higher MC in the feed during extrusion can reduce dough elasticity by plasticizing the melt, reducing gelatinization and limiting expansion, resulting in a higher BD. Hagenimana *et al*. (2006) observed that an increase in MC increased the BD of rice-based extruded snacks. Singh *et al*. (2014) also noticed an increase in the BD with an increase in the MC of potatoes based snacks. The interactive increase in both variables showed that the BD increased (346.1 - 565.4 Kg/m^3) as shown in Figure 4.11a.

At a constant BR, the increase in BT decreased the BD as shown in Figure 4.11b and Equation 4.6. This is due to the fact that a higher temperature provides more potential energy for superheated water to flash out as the extrudates escape the die. The rise in BT results in moisture loss at the exit which causes the extrudate to become light in weight (Koksel *et al*., 2004). The same observation was noticed by Wani & Kumar, (2016). Singh *et al*. (2007) were also in agreement with the claim that an increase in BT results in decreased BD. The interactive effect of the increase of both variables shown in Figure 4.11b implied that an increase in BD was observed (444.2 - 468.1 kg/m^2). Furthermore, an increase in SS resulted in a decrease in BD. This finding was similar to that of Meng *et al*. (2010). The interactive effect of the increase in both variables as shown in Figure 4.11c implied that the BD increased. It was observed that the BT had a negative linear effect ($p>0.05$) in the regression model. The interactive variables showed an increase in the BD (Figure 4.12a). The interactive effect of the increase in moisture and screw speed shown in Figure 4.12b implied that the BD improved with the increase in both variables simultaneously. The interactive effect of the increase in both variables simultaneously reduced the BD (Figure 4.12c).

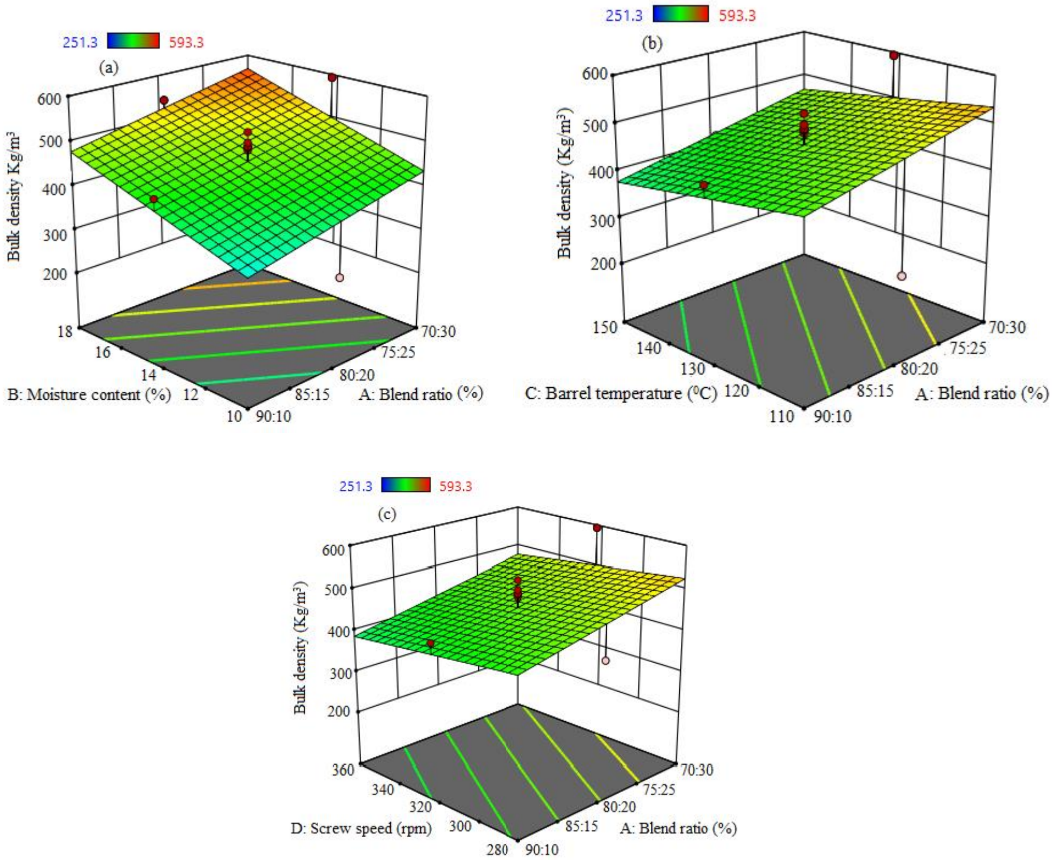


Figure 4.11: 3D response surface plot of bulk density against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

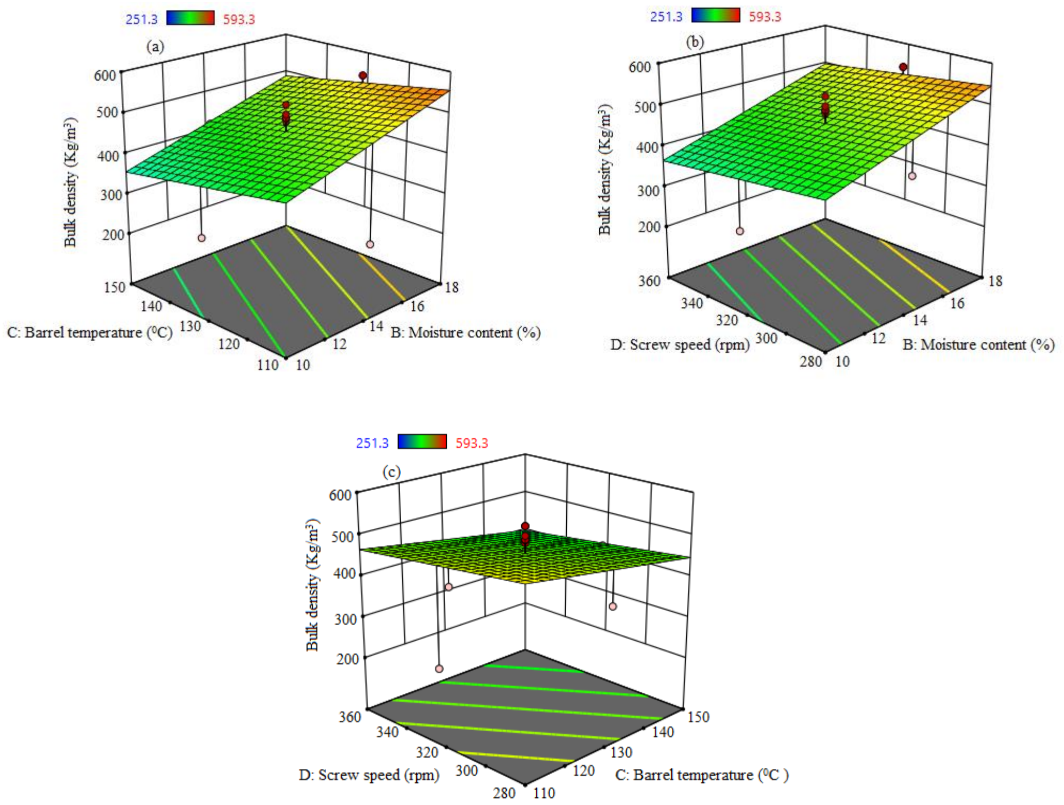


Figure 4.12: 3D response surface plot of bulk density against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.1.7 Effect of blend ratio, moisture content, barrel temperature and screw speed on expansion ratio of the extrudate

The minimum and maximum values of expansion ratio obtained were 2.26 mm at (70:30, 14%, 130℃, 320 rpm) and 3.06 mm at (80:20, 14%, 150℃, 320 rpm) for BR, MC, BT and SS respectively (Table 4.1). The increase and decrease in BR, MC, BT, and SS affected the expansion ratio as observed in Figures 4.13 (a-c) and 4.14 (a-c). The regression equation showed the individual and interactive effects of the variables (Equation 4.7). The regression linear terms showed that BR and BT were the significant regression terms affecting bulk density (Table 4.2).

At a constant moisture content, increase in the cowpea content of the BR reduced the ER (2.8 - 2.3 mm). This is due to the formation of starch-protein complexes, which reduces the extensibility of the starch polymer. As a result, the number of accessible water molecules for bubble production decreases, and the expansion is limited. (de Mesa *et al*., 2009). Pandey *et al*. (2021) and Robin *et al*. (2011) confirmed this finding. At a constant BR the increase in the MC decreased the rate of expansion as shown in Figure 4.13a and Equation 4.6. Pandey *et al*. (2021) observed a similar result. The interactive effect of the increase in both variables resulted in a decrease in the ER.

In addition, at a constant BR, the increase in BT increased the expansion as shown in Figure 4.13b. Reshi *et al*. (2020) agreed with this finding. This is due to the fact that high barrel temperatures cause starch gelatinization and, as a result, greater expansion. The interactive effect of the increase in both variables resulted in a decrease in the ER. At a constant blend ratio, increase in screw speed resulted to a decrease in ER as shown in Figure 4.13c. Increase in SS causes a negative effect on the ER, which can be attributed to the shorter residence time and inadequate temperature rise in the molten mix. This prevents the die from expanding due to flash vaporization (Kaur *et al*., 2014). This is comparable to the results obtained by Pandey *et al*. (2021) in which a rise in SS (200 - 300 rpm) resulted in a reduction in the ER for raw banana flour extrudate. The interactive effect of the increases in the BR and SS resulted in a decrease in the ER. The interactive effect of a combined increase in both variables MC × BT, MC × SS, and BT × SS resulted in a decrease in expansion ratio as shown in Figure 4.14 (a-c).

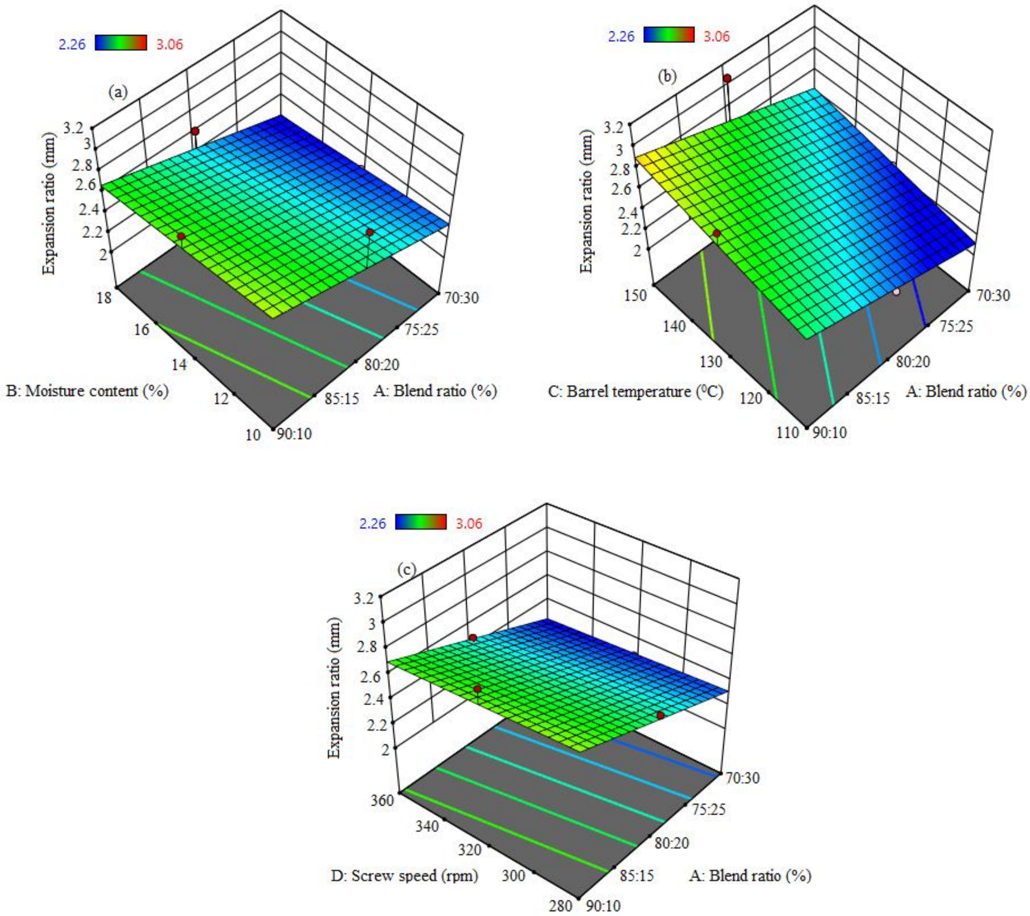


Figure 4.13: 3D response surface plot of expansion ratio against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

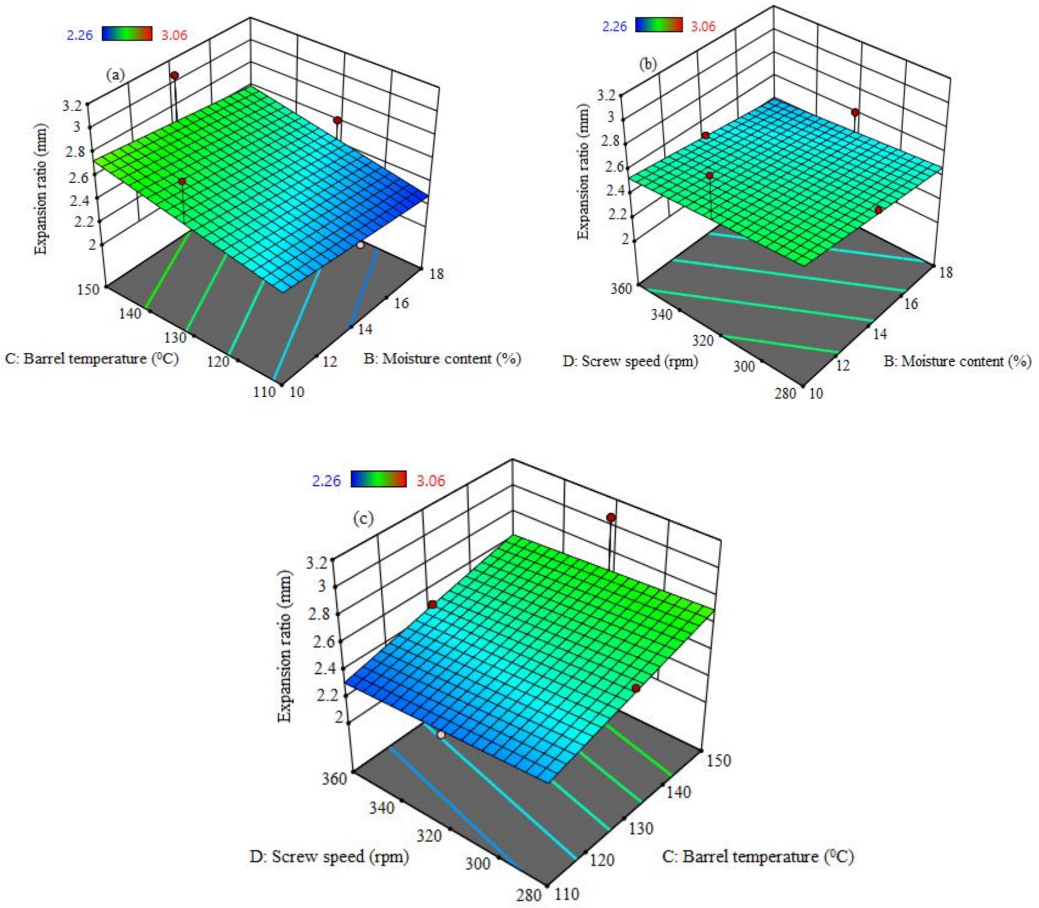


Figure 4.14: 3D response surface plot of hardness against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2 Sensory Evaluation On The Effect Of Extrusion Variables: Effect of Appearance, Colour, Crunchiness, Crispness, Taste, Mouth-feel and Overall Acceptance of The Extrudate

Sensory evaluation of a food product is essential because it provides information on the quality of the food and the overall acceptability of a new product by consumers (Gumul *et al*., 2014). The minimum and maximum sensory qualities for appearance, colour, crunchiness, crispness, taste, mouth feel, and overall acceptance of the extrudate were: 5.55 and 7.75, 5.9 and 7.75, 3.6 and 8.15, 3.5 and 7.95, 5.45 and 7.4, 4.75 and 7.65, 5.2 and 8.1 respectively as shown in Figure 4.1. The relationship between the sensory parameters and the input variables are shown in Figures 4.15 - 4.28(a-b).

4.2.1 Effect of blend ratio, moisture content, barrel temperature and screw speed on appearance

At constant moisture content, the increase in the cowpea content of the BR (90:10 to 75:25) resulted in an increase of appearance based on the consumer's preferences. Thereafter, it was observed that a decrease in the appearance acceptance occurred. On the other hand, at a constant BR, an increase in MC (10 to 16%) resulted in an increase of appearance, afterward the appearance decreased as shown in Figure 4.15a and Equation 4.8. The interactive effect between BR and MC as shown in Equation 4.8 suggests that the combined increase of both variables resulted in an increase in appearance. At a constant BR, further increase in BT could result in a decrease in appearance acceptability. The interactive effect of the simultaneous increase in BR and BT resulted in a decrease in appearance (6.82 - 6.46) as shown in Figure 4.15b. At a constant BR, the increase in SS resulted in a decrease in appearance. The appearance of the extrudate increased gradually as the SS increased. At 320 rpm, the appearance was 7.45 of 9.0. Thereafter, a sloppy reduction occurred from 320 to 360 rpm. The interactive effect of the increase in both variables resulted in a decrease in appearance (6.98 - 5.89) as shown in Figure 4.15c and Equation 4.8. The interactive effect of the simultaneous increase in MC × BT, MC × SS, and BT × SS as shown in Figure 4.16(a -c) and Equation 4.8 resulted in a decrease in appearance acceptability by the panelist.

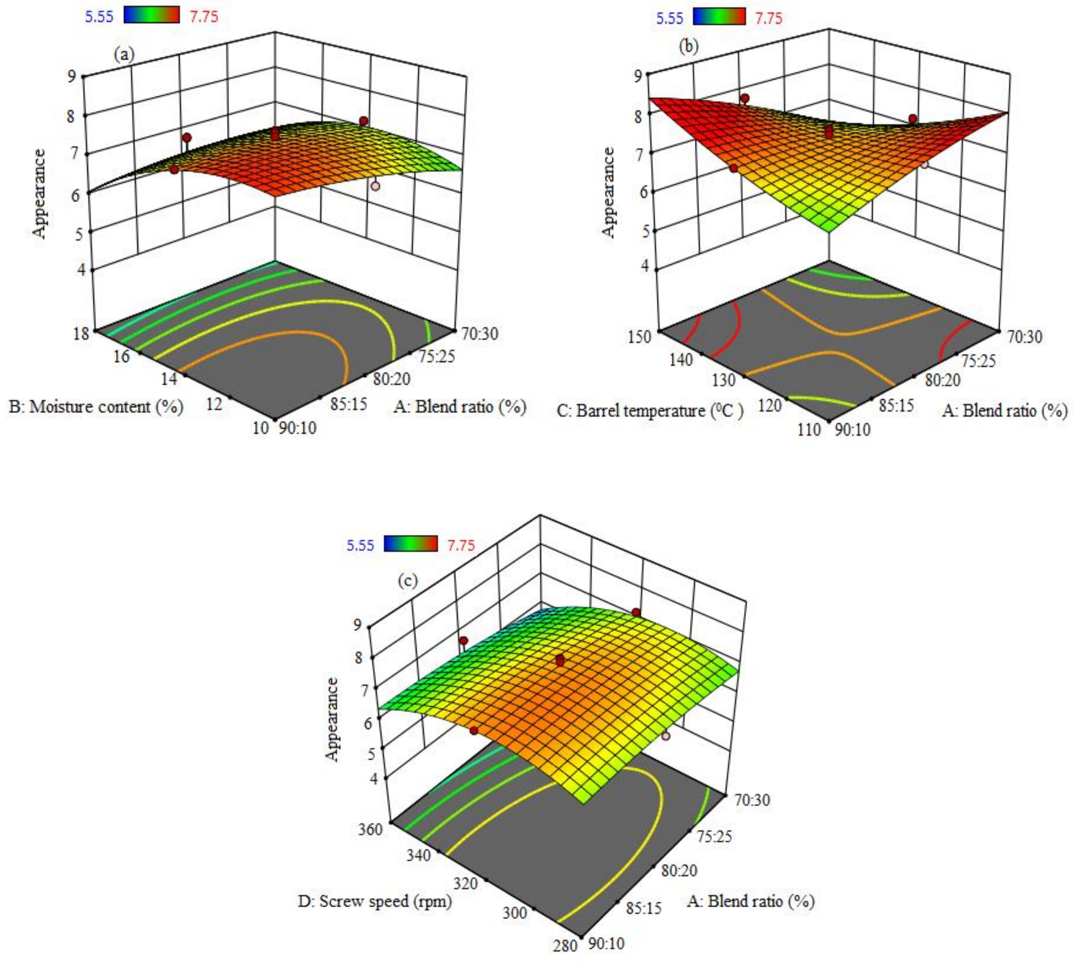


Figure 4.15: 3D response surface plot of appearance against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

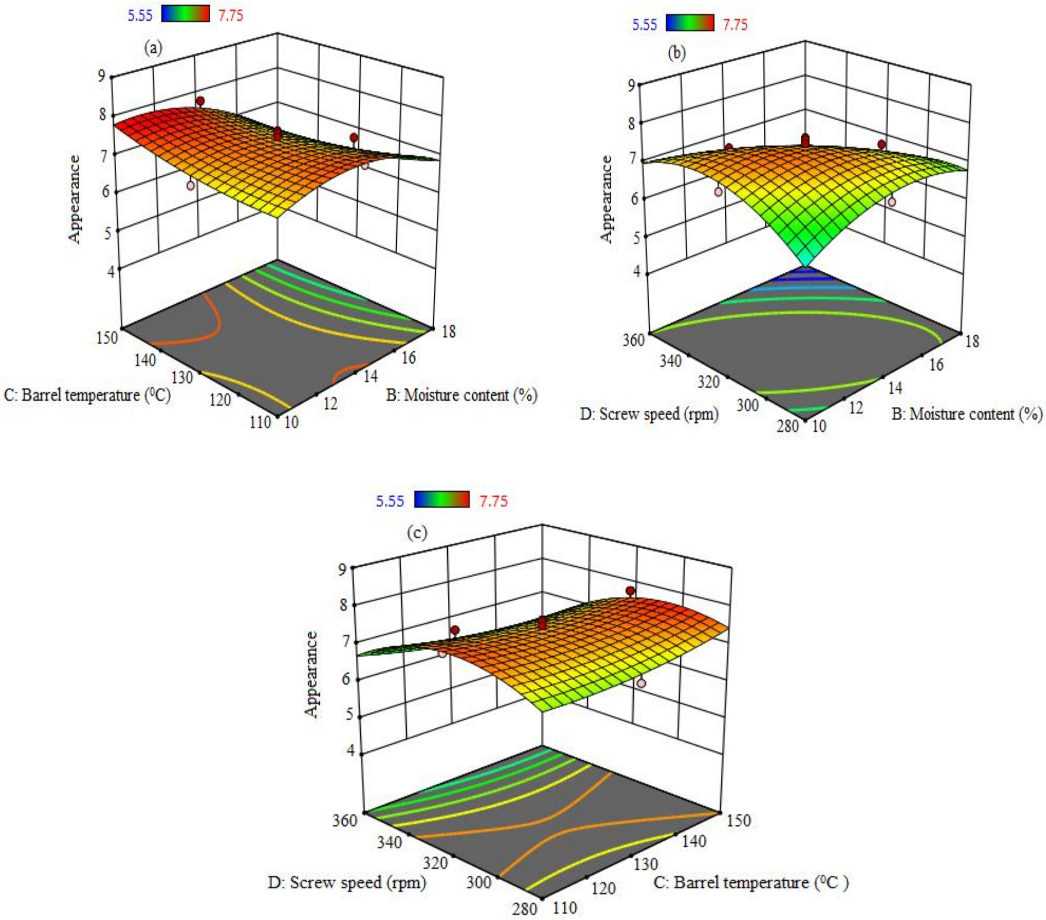


Figure 4.16: 3D response surface plot of appearance against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2.2 Effect of blend ratio, moisture content, barrel temperature and screw speed on colour

At a constant blend ratio, the increase in MC decreases the colour acceptability by the consumers. Furthermore, at a constant MC; the increase in the cowpea proportion of the BR resulted in the decrease of colour acceptance as shown in Figure 4.17a and Equation 4.9. The interactive effect of the increase in both variables decreased the colour acceptance. At a constant BR, the increase in the BT resulted in a slight decrease in the colour as shown in Figure 4.17b and Equation 4.9. The interactive effect of the increase in BR and BT resulted in a decrease in colour (7.41- 6.7). At constant BR, the increase in SS reduced the colour of the extrudate. The interactive effect of the increase in BR and SS resulted in a decrease of the colour of the extudate as shown in Figure 4.17c. The interactive effect of the simultaneous increase in MC × BT, MC × SS, and BT × SS as shown in Figure 4.18(a - c) resulted in a decrease in colour acceptability by the panelist.

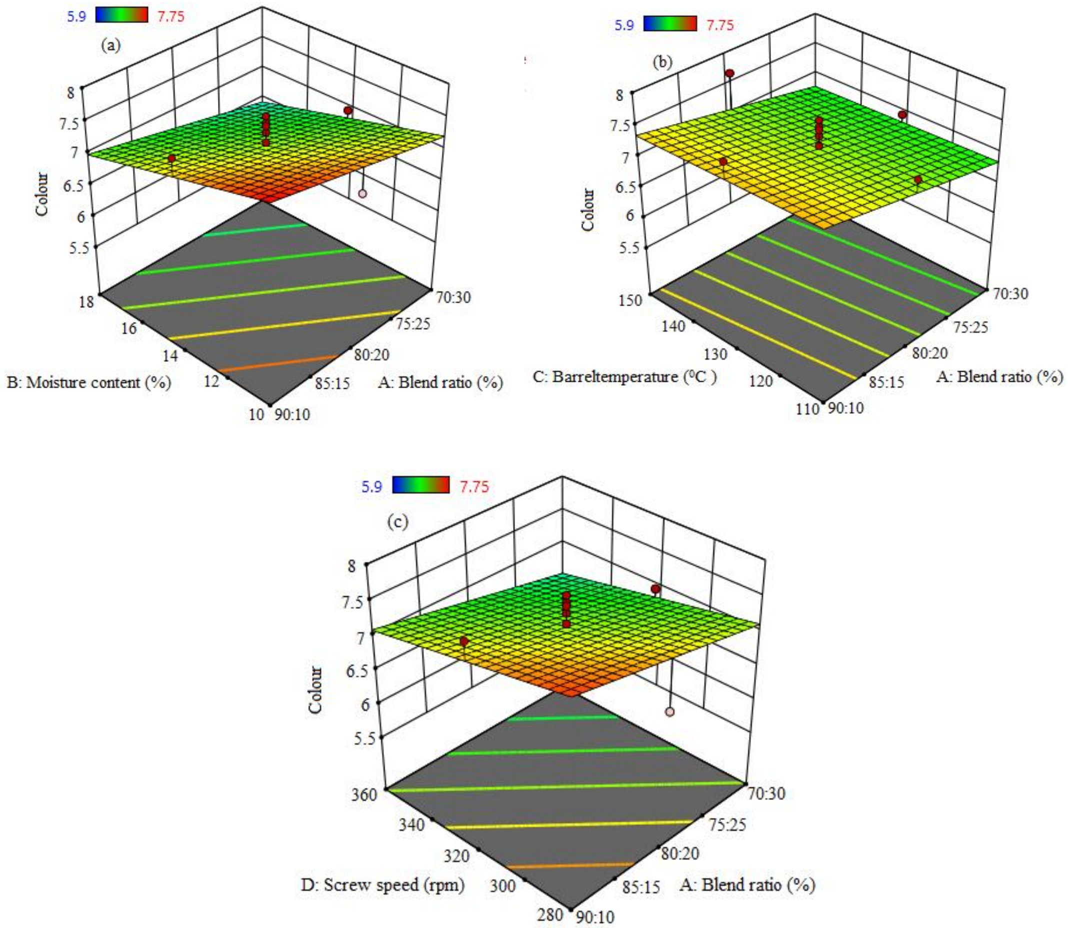


Figure 4.17: 3D response surface plot of colour against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

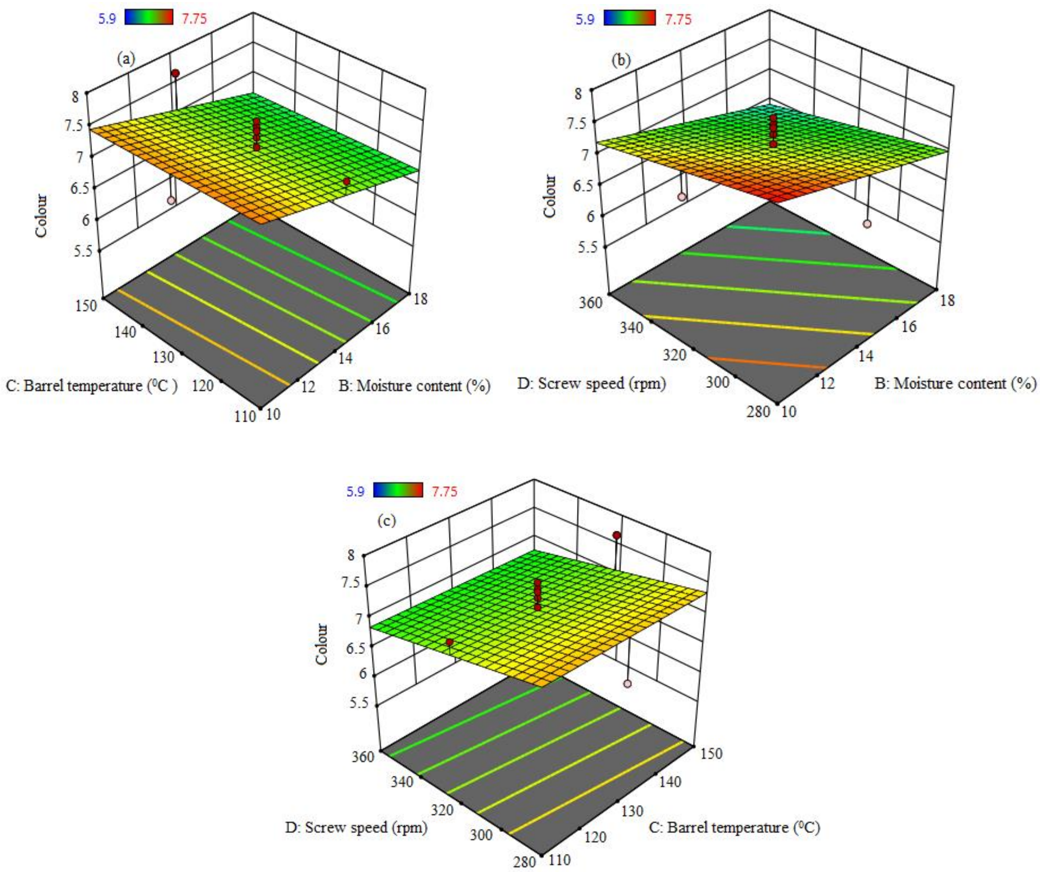


Figure 4.18: 3D response surface plot of colour against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2.3 Effect of blend ratio, moisture content, barrel temperature and screw speed on crunchiness

Increase in the moisture content at a constant BR resulted in a sloppy decrease in crunchiness (7.83 - 4.60) as shown in Figure 4.19a. Furthermore, the increase in the cowpea content of the BR at a constant MC resulted in a slight decrease in crunchiness (7.85 - 7.83). The interactive effect of the increase in BR and MC resulted in a decrease in crunchiness. BT had no significant effect on the crunchiness. The interactive effect of the increase in BR and BT implied that there was no significant effect (Figure 4.19b). SS has a negative significant effect on the model. There is no significant effect of the interactive increase in BR and SS (Figure 4.19c). The interactive effect of the simultaneous increase in MC × BT, MC × SS, and BT × SS as shown in Figure 4.20(a -c) resulted in a decrease in the crunchiness based on panellist evaluation.

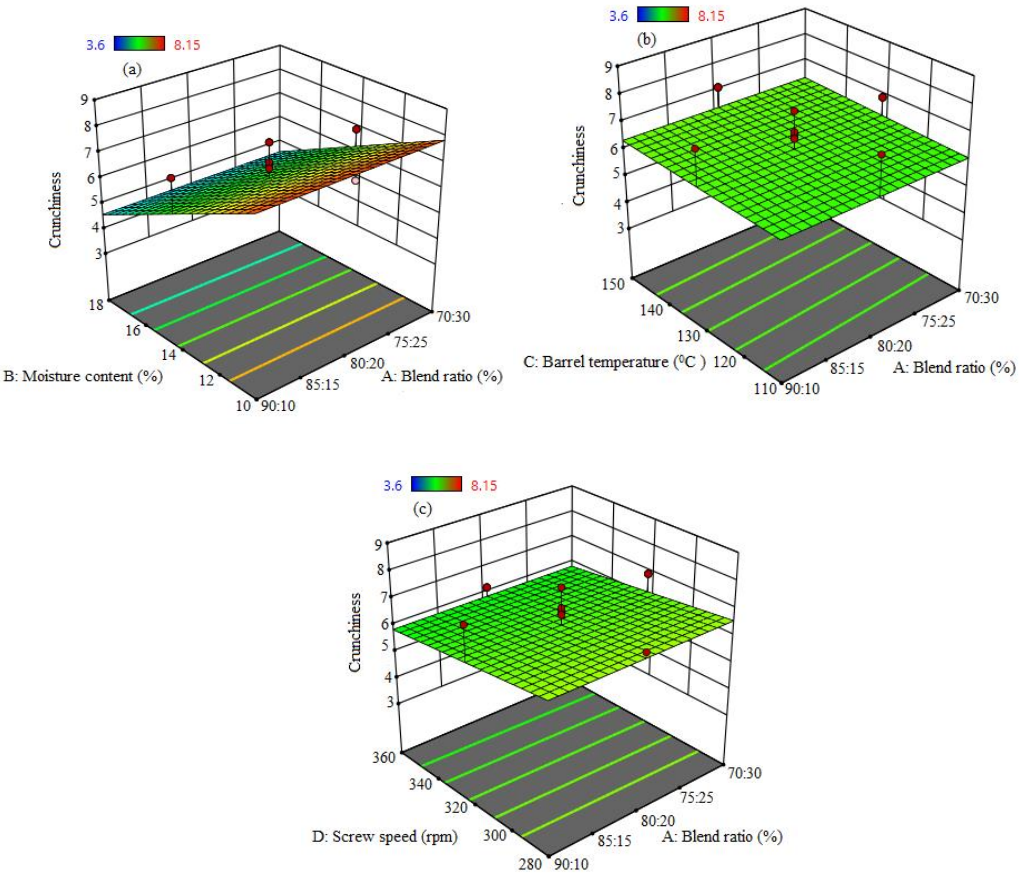


Figure 4.19: 3D response surface plot of crunchiness against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

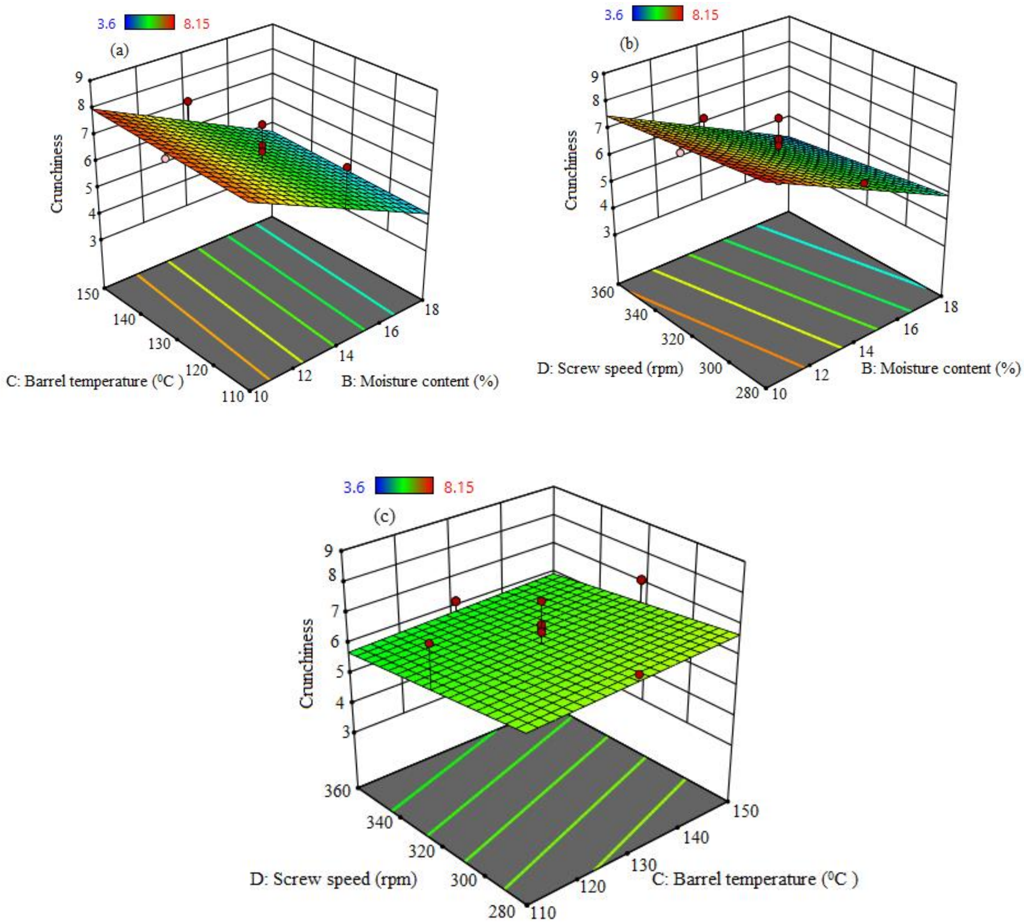


Figure 4.20: 3D response surface plot of crunchiness against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2.4 Effect of blend ratio, moisture content, barrel temperature and screw speed on the crispness of the extrudate

At a constant moisture content, increase in the cowpea proportion of the BR increased the crispness (Figure 4.21a and Equation 4.11). While at constant BR, the increase in MC (10 - 14%) increased the crispness of the extrudate. However, the crispness reduced with further increase in MC from 14 - 18% as shown in Figure 4.21a. The interactive effect of the increase in both variables decreased the crispness from 7.61 to 4.90. The increase in BT at constant blend ratio increased crispness as shown in Figure 4.21b and Equation 4.11. The interactive effect of the increase in BR and BT resulted in an increase of the crispness. Increase in SS at a constant BR resulted in the decrease of crispness of the extrudate from 6.5 to 6 as shown in Figure 4.21c. The interactive effect of the simultaneous increase in MC × BT and MC × SS as shown in Figure 4.22(a -b) resulted in a decrease of crispness, while BT × SS (Figure 4.22c) had no effect on the crispness of the extrudate.

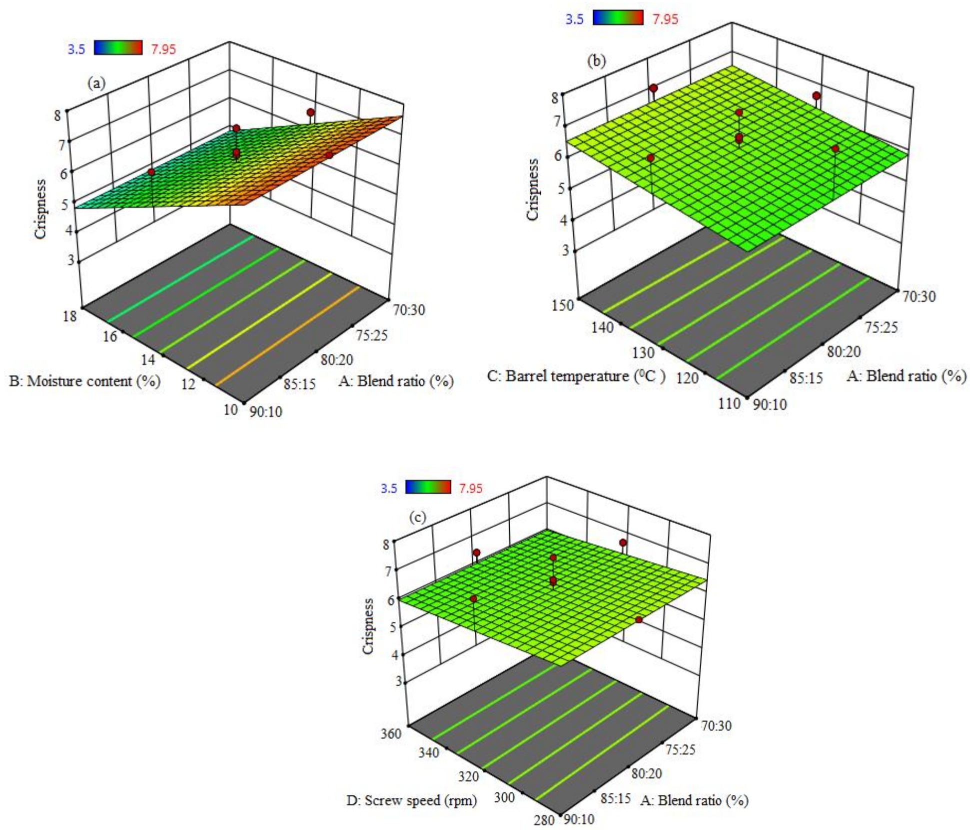


Figure 4.21: 3D response surface plot of crispness against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

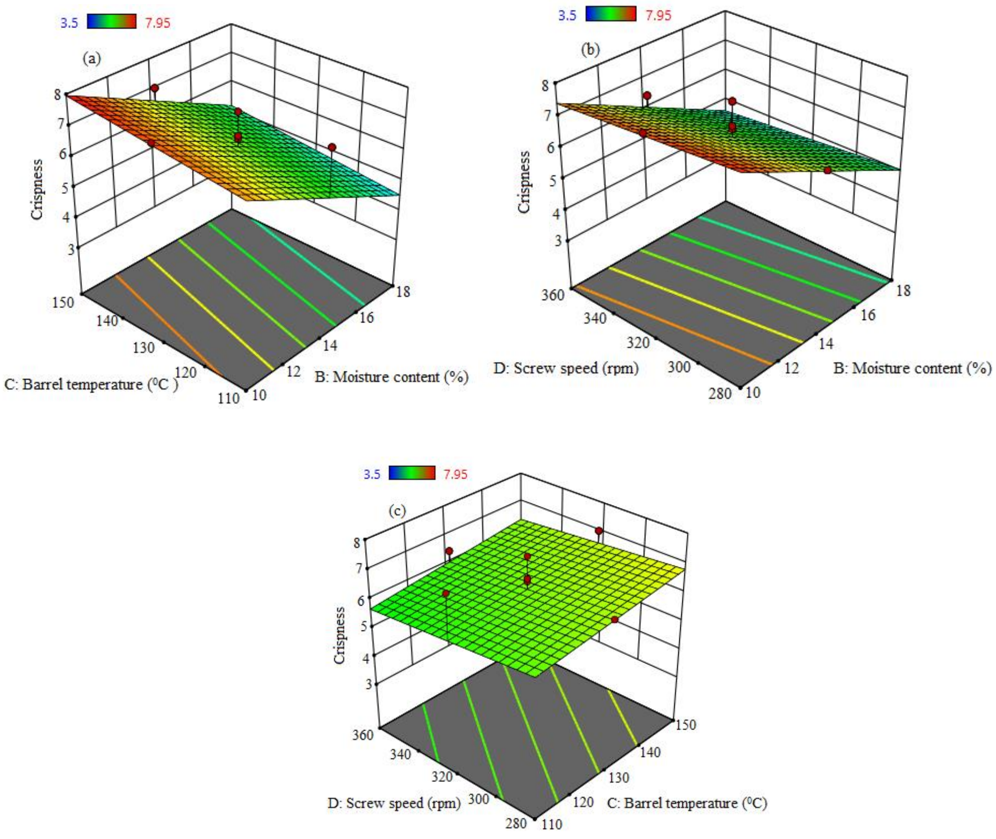


Figure 4.22: 3D response surface plot of crispness against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2.5 Effect of blend ratio, moisture content, barrel temperature and screw speed on the taste of the extrudate

At a constant blend ratio, an increase in MC (10 - 16%) increased the taste of the extrudate. Thereafter, the taste decreased from MC 16 to 18%. While at constant MC, the increase in the cowpea proportion of the BR increased the taste as shown in Figure 4.23a and Equation 4.12. The interactive effect of the increase in both variables caused a decrease in taste (7.06 - 5.91). At constant BR, the increase in BT increased the taste (6.28 - 6.67) as shown in Figure 4.23b and Equation 4.12. The interactive effect of the increase of BR and BT showed that the taste increased. However, at a constant BR, the increase in SS decreased the taste (6.72 - 6.22) as shown in Figure 4.23c. The interactive effect of the increase in BR and SS caused a decrease in taste. The interactive effect of the simultaneous increase in MC × BT, MC × SS, and BT × SS as shown in Figure 4.24(a -c) resulted to a decrease in the taste of the extrudate.

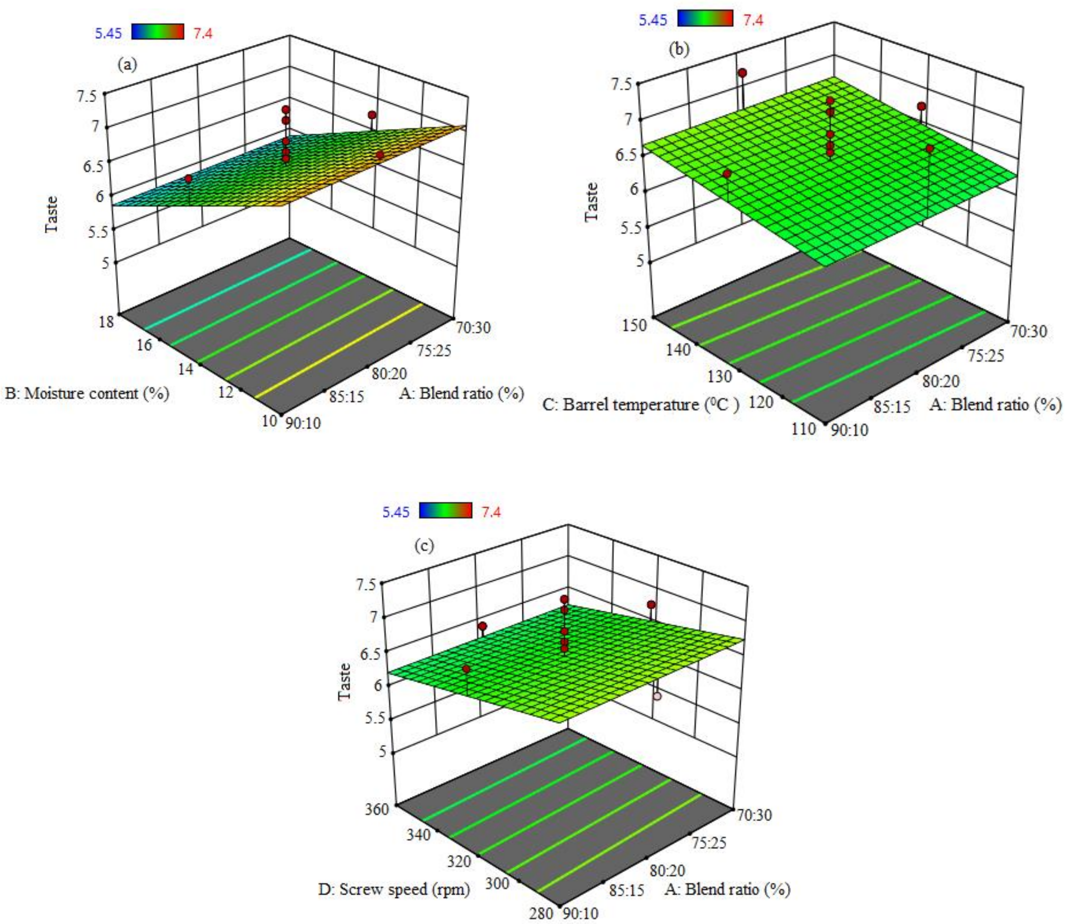


Figure 4.23: 3D response surface plot of taste against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

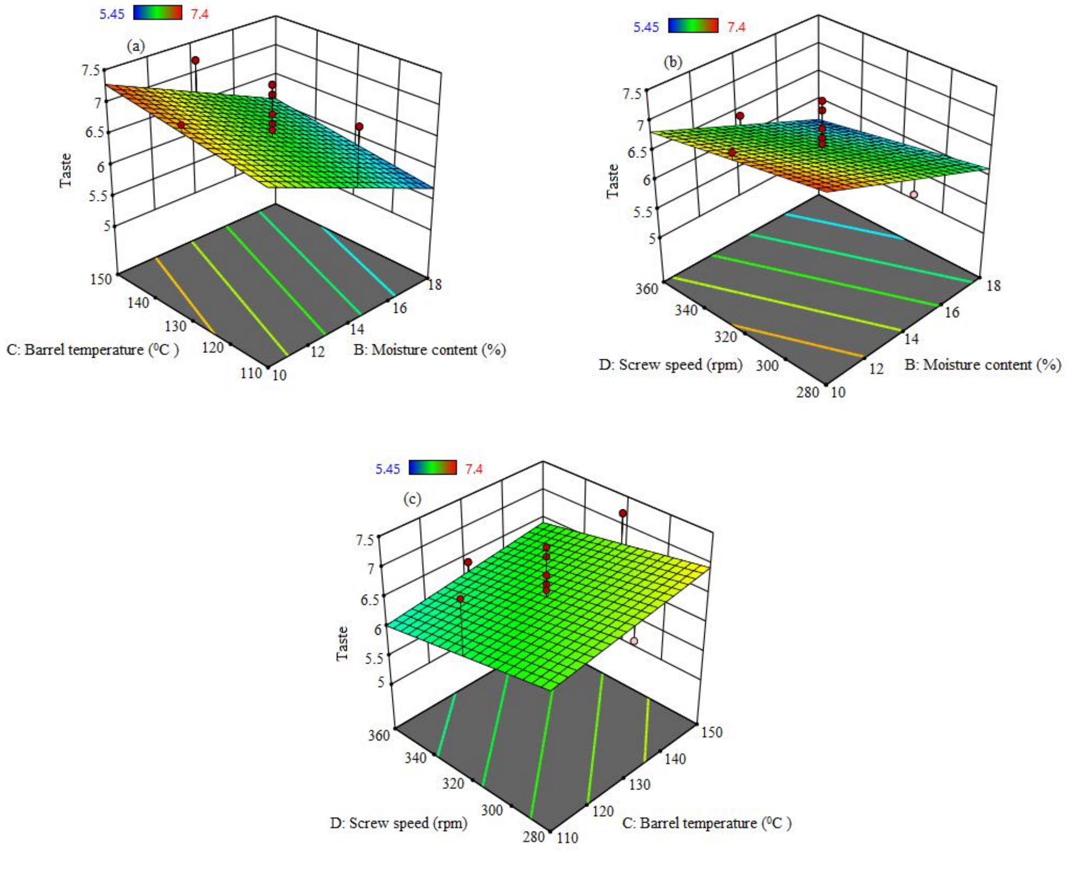


Figure 4.24: 3D response surface plot of taste against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2.6 Effect of blend ratio, moisture content, barrel temperature and screw speed on the mouth-feel of the extrudate

At a constant blend ratio, the increase of moisture content decreased the mouth-feel of the extrudate based on the consumer's evaluation. It was observed that mouth-feel was high from 10 to 15% MC afterwards, the mouth-feel decreased (Figure 4.25a and Equation 4.13). While at a constant MC, the increase of the cowpea proportion in the BR increased mouth-feel (7.25 - 7.35). The interactive effect of the increase in both variables resulted in a decrease in mouth-feel (7.25 - 5.66) as shown in Figure 4.25a. At a constant BR, the increase in BT increased the mouth-feel (6.09 - 6.78). The interactive effect of the increase in BR and BT increased mouth-feel (6.09 - 6.84) as shown in Figure 4.25b.

At a constant BR, the increase in SS decreased the mouth-feel (6.93 - 5.94). The interactive effect of the increase in both variables resulted in a decrease of mouth-feel (6.93 - 6.00) as shown in Figure 4.25c. The interactive effect of the simultaneous increase in MC × BT, MC × SS, and BT × SS as shown in Figure 4.26(a -c) resulted to a decrease in mouth-feel of the extrudate.

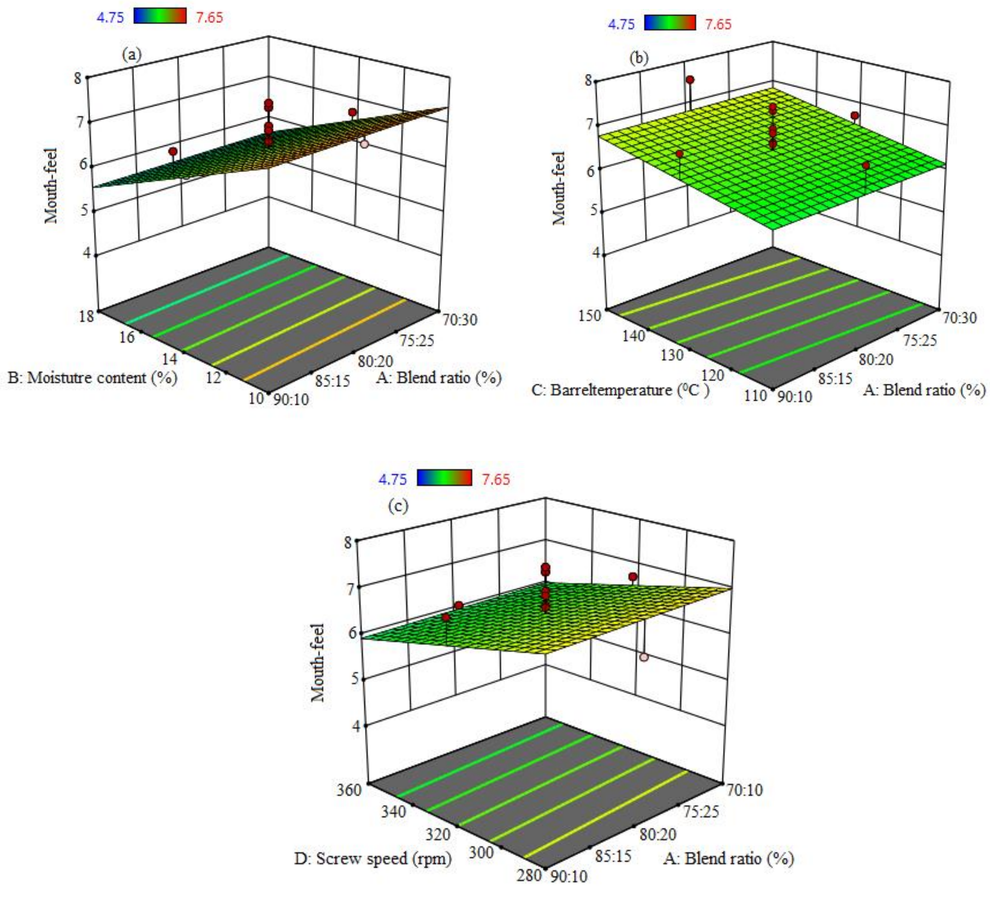


Figure 4.25: 3D response surface plot ofmouth-feel against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

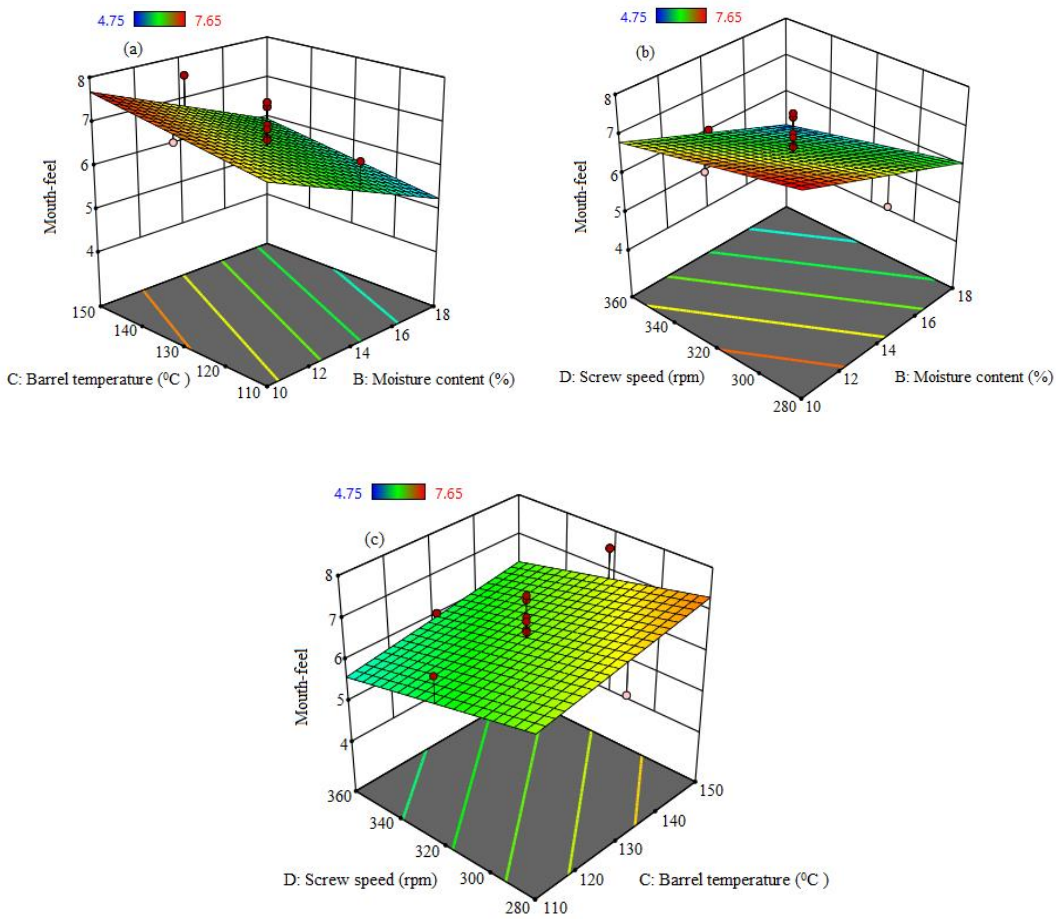


Figure 4.26: 3D response surface plot of mouth-feel against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

4.2.7 Effect of blend ratio, moisture content, barrel temperature and screw speed on the overall acceptance of the extrudate

At a constant blend ratio, the increase of MC decreased the overall acceptance. In addition, the increase in cowpea content of the BR reduced the overall acceptance as shown in Figure 4.27a and Equation 4.14. However, at constant BR, the increase in BT increased the overall acceptance (6.63 - 7.01). The interactive effect of the increase in both variables caused an increase in overall acceptance (6.63 - 6.82) as shown in Figure 4.27b.

Increase in SS decreased the overall acceptance. The interactive effect of the increase in BR and SS resulted in a decrease (7.26 - 6.20) in overall acceptance as shown in Figure 4.27c. The interactive effect of the simultaneous increase in MC × BT, MC × SS, and BT × SS as shown in Figure 4.28(a-c) resulted in a decline in the overall acceptance of the extrudate.

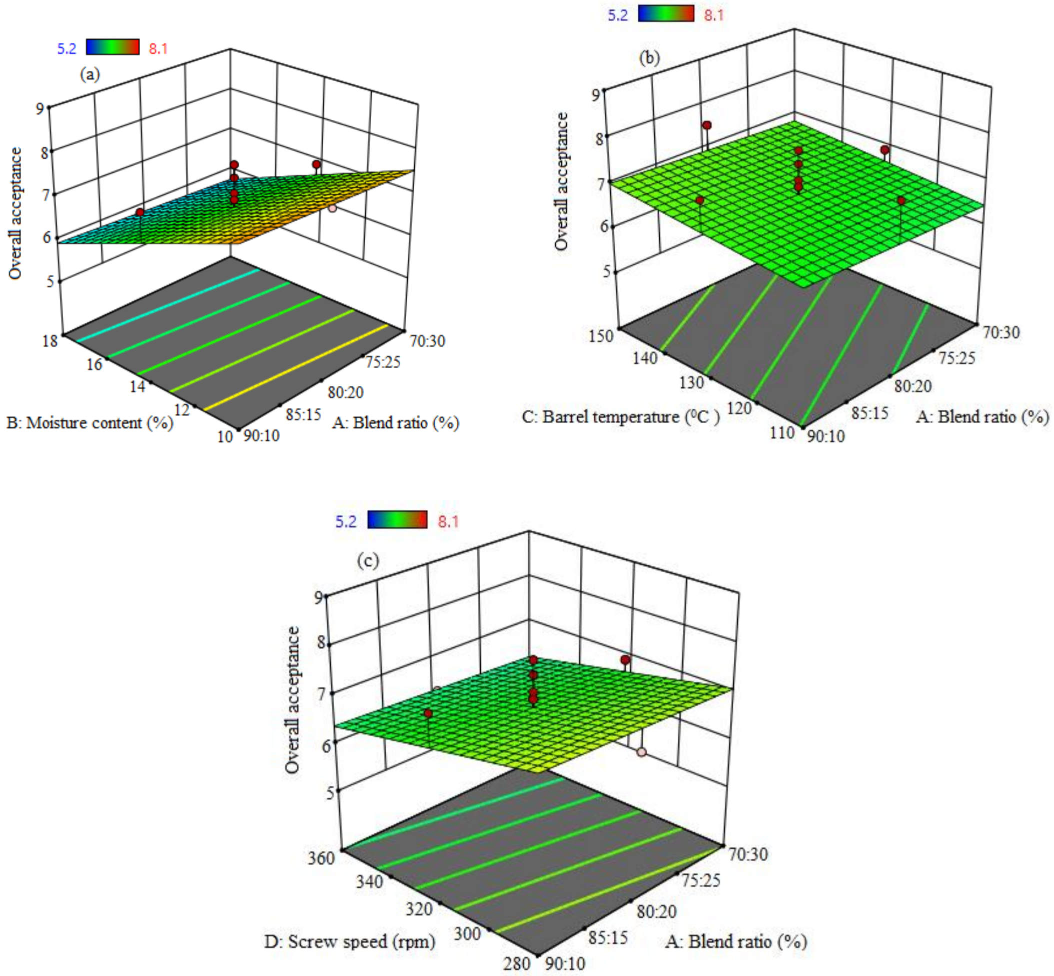


Figure 4.27: 3D response surface plot of overall acceptance against (a) blend ratio versus moisture content, (b) blend ratio versus barrel temperature, (c) blend ratio versus screw speed

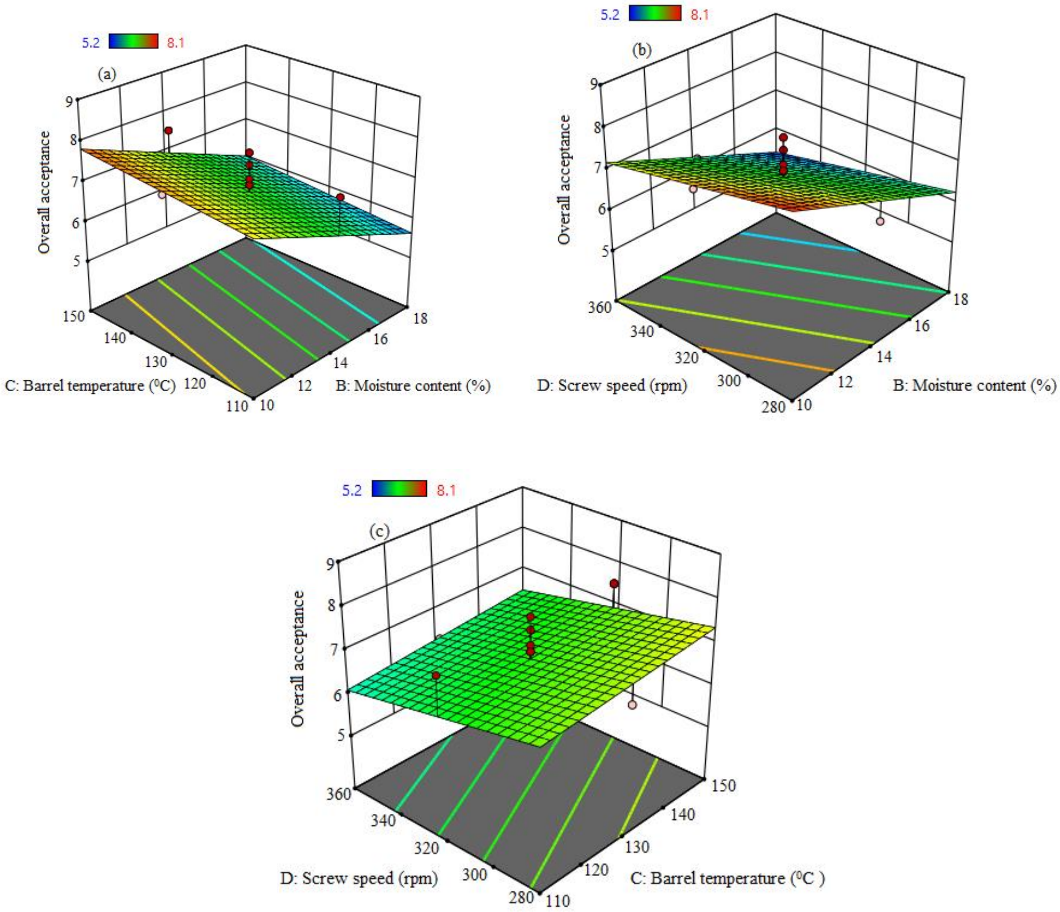


Figure 4.28: 3D response surface plot of overall acceptance against (a) moisture content versus barrel temperature (b) moisture content versus screw speed (c) barrel temperature versus screw speed

Table 4.1: Experimental data of ready-to-eat snack for response surface analysis

Run	BR (%)	MC (%)	BT (º C)	SS (rpm)	SME (Wh/kg)	WAI (g/g)	WSI (%)	TC	Hardness (N)	BD (Kg/m³)	ER (mm)	APP	Colour	CRH	CRSP	TA	MF	OA
1	80:20	10	130	320	92.16	3.63	8.4	40.48	1.99	266.8	2.93	7.05	7.1	7.65	7.7	7.2	7.15	7.55
2	75:25	16	140	340	84.86	4.06	6.8	41.58	3.02	354.3	2.47	5.55	5.9	4.1	4.7	5.5	5.15	5.3
3	80:20	14	130	280	66.3	3.71	10	40.62	2.14	396.9	2.58	6.8	6.65	6.8	6.5	6.5	6.2	6.7
4	85:15	16	120	340	84.86	4.03	7.6	40.02	3.23	541.4	2.49	5.85	6.5	3.6	3.5	5.45	4.75	5.2
5	80:20	14	130	360	82.94	4.33	4.8	41.16	2.89	309.8	2.48	6.65	6.5	6.2	6.4	6.4	6.05	6.25
6	85:15	16	140	340	73.98	4.26	4.4	41.38	3.46	413.3	2.69	6.6	6.85	5.1	6.15	6.55	5.75	6.45
7	80:20	14	130	320	77.82	3.97	3.6	40.2	2.31	498.4	2.38	7	6.85	5.3	5.65	6.6	6.85	6.9
8	85:15	16	140	300	65.28	4.35	2.8	39.1	2.14	443.2	2.56	7.4	7.1	5.55	5.85	6.6	6.75	6.9
9	80:20	14	130	320	75.78	3.78	3.6	40.71	2.31	489.3	2.43	7.5	7.15	5.3	5.5	6.85	6.6	6.65
10	75:25	16	140	300	74.88	3.34	2.8	45.72	2.86	481.5	2.27	6.8	6.55	5.6	5.7	5.65	5.95	5.85
11	85:15	12	120	300	84.48	3.38	7.6	44.5	3.08	441.4	2.54	7.25	7.05	4.6	4.65	5.65	5.6	5.65
12	75:25	16	120	300	65.28	3.39	10	37.85	2.05	508.4	2.41	7.4	7.45	7.25	7	7.05	7.25	7.45
13	80:20	14	130	320	77.82	4.17	5.2	39.77	2.32	521.5	2.38	7.3	7.4	6.6	6.6	6.7	6.95	7.05
14	75:25	12	120	300	80.64	3.33	10	45.89	2.55	506.5	2.47	7.3	7.3	7.4	7.3	6.6	6.95	7.35
15	80:20	18	130	320	55.3	4.05	4.4	37.42	2.96	541	2.61	6.75	6.65	4.35	4.4	5.45	5.2	5.45
16	85:15	12	140	340	84.86	3.05	16.8	40.43	2.82	434.6	2.56	7.5	7.3	7.1	6.8	5.65	6.2	6.3
17	75:25	12	120	340	87.04	3.58	9.6	39.08	2.76	536.1	2.4	7	6.95	5.6	5.35	5.75	5.8	6.1
18	70:30	14	130	320	77.82	3.21	20	39.39	3.03	593.3	2.26	7.2	6.95	6.9	6.65	6.75	6.7	6.9
19	80:20	14	130	320	77.82	3.64	14.4	42.12	2.13	481	2.42	7.65	7.45	6.7	6.6	7.15	7.35	7.4
20	75:25	12	140	300	65.28	3.76	10.4	36.85	2.94	513.2-	2.39	7.35	7.45	5.9	6.05	6.9	7.05	7.15
21	80:20	14	130	320	77.82	4.29	6.4	40.62	2.45	489.2	2.42	7.6	7.55	7.6	7.35	7.3	7.45	7.7
22	80:20	14	150	320	65.28	4.07	6	42.73	2.23	416.9	2.32	7.75	7.65	7.1	7	7.2	7.55	7.5

23	85:15	12	140	300	84.48	3.95	12	44.52	2.98	361.3	2.78	7.75	7.75	8.05	7.95	7.4	7.65	8.1
24	90:10	14	130	320	88.06	3.61	8	39.96	2.73	437.3	2.86	7.45	7.65	7.55	7.3	6.85	7	7.5
25	80:20	14	110	320	47.1	3.3	11.6	44.54	2.6	251.3	3.06	7.55	7.35	7.55	7.45	7.2	6.75	7.45
26	85:15	16	120	300	71.04	3.61	5.2	39	2.54	554.2	2.68	7.15	7.4	4.35	4.65	5.65	5.45	5.75
27	80:20	14	130	320	77.82	4.14	6.8	37.64	2.17	487.7	2.28	7.35	7.3	6.85	6.5	6.35	6.65	6.9
28	75:25	16	120	340	76.16	3.75	6.8	41.56	2.9	581.5	2.31	6.95	6.85	5	5.35	5.8	5.55	5.8
29	85:15	12	120	340	97.92	3.37	7.6	40.1	3.01	449.8	2.46	7.65	7.5	8.15	7.65	6.95	7.15	7.6
30	75:25	12	140	340	102.27	4.19	8.4	44.3	2.29	386.3	2.47	7	7.05	6.85	7.1	7	6.6	7.05

Table 4.2: ANOVA of response surface models for mechanical properties, functional properties and sensory of extruded ready-to-eat snack

SME (Linear)						
Source	SS	Df	MS	F-value	P-value	
Model	1937.82	4	484.46	6.01	0.0016	significant
BR	39.96	1	39.96	0.4957	0.4879	
MC	1125.46	1	1125.46	13.96	0.0010	
BT	25.69	1	25.69	0.3186	0.5775	
SS	746.72	1	746.72	9.26	0.0054	
Residual	2015.54	25	80.62			
Lack of Fit	2012.08	20	100.60	145.05	<0.0001	significant
Pure Error	3.47	5	0.6936			
Cor Total	3953.37	29				
WAI (Quadratic)						
Source	SS	Df	MS	F-value	P-value	
Model	3.22	14	0.2297	4.18	0.0047	significant
BR	0.0817	1	0.0817	1.48	0.2418	
MC	0.3800	1	0.3800	6.91	0.0190	
BT	0.6868	1	0.6868	12.49	0.0030	
SS	0.2440	1	0.2440	4.440	0.0524	
BR*MC	0.4970	1	0.4970	9.04	0.0089	
BR*BT	0.0004	1	0.0004	0.0073	0.9332	
BR*SS	0.3422	1	0.3422	6.22	0.0248	
MC*BT	0.0002	1	0.0002	0.0041	0.9498	
MC*SS	0.1681	1	0.1681	3.06	0.1009	
BT*SS	0.0462	1	0.0462	0.8405	0.3738	
BR^2	0.6292	1	0.6292	11.44	0.0041	
MC^2	0.0530	1	0.0530	0.9637	0.3418	
BT^2	0.1876	1	0.1876	3.14	0.0846	
SS^2	0.000	1	0.000	0.0005	0.9817	
Residual	0.8250	15	0.0550			
Lack of Fit	0.5135	10	0.0514	0.8243	0.6296	not significant
Pure Error	0.3115	5	0.0623			
Cor Total	4.04	29				

WSI (Linear)						
Source	SS	Df	MS	F-value	P-value	
Model	111.95	4	27.99	1.97	0.1308	not significant
BR	25.63	1	25.63	1.80	0.1918	
MC	80.67	1	80.67	5.67	0.0252	
BT	5.23	1	5.23	0.3671	0.5500	
SS	0.4267	1	0.4267	0.0300	0.864	
Residual	355.92	25	14.24			
Lack of Fit	275.07	20	13.75	0.8505	0.6444	not significant
Pure Error	80.85	5	16.17			
Cor Total						

TC (Mean)						
Source	SS	Df	MS	F-value	P-value	
Model	0.0000					
Residual	170.41	29	5.88			
Lack of Fit	159.56	24	6.65	3.06	0.1081	not significant
Pure Error	10.86	5	2.17			
Cor Total	170.41	29				

Hardness (Quadratic)						
Source	SS	Df	MS	F-value	P-value	
Model	3.09	14	0.2206	2.48	0.0459	significant
BR	0.0705	1	0.0705	0.7933	0.3872	
MC	0.1194	1	0.1194	1.34	0.2646	
BT	0.0023	1	0.0023	0.0254	0.8754	
SS	0.6179	1	0.6179	6.95	0.0187	
BR*MC	0.0421	1	0.0421	0.4739	0.5017	
BR*BT	0.1084	1	0.1084	1.22	0.2869	
BR*SS	0.0917	1	0.0917	1.03	0.3260	
MC*BT	0.0799	1	0.0799	0.8993	0.3580	
MC*SS	0.8478	1	0.8478	9.54	0.0075	
BT*SS	0.0636	1	0.0636	0.7157	0.4108	
BR^2	0.8608	1	0.8608	9.68	0.0071	
MC^2	0.1580	1	0.1580	1.78	0.2023	

BT^2	0.1223	1	0.1223	1.38	0.2591	
SS^2	0.2078	1	0.2078	2.34	0.1472	
Residual	1.33	15	0.0889			
Lack of Fit	1.30	10	0.1295	16.88	0.0030	significant
Pure Error	0.0384	5	0.0077			
Cor Total	4.42	29				

BD (Linear)						
Source	SS	Df	MS	F-value	P-value	
Model	48746.54	4	12186.64	1.83	0.15584	not significant
BR	12177.02	1	12177.02	1.82	0.1889	
MC	26467.04	1	26467.04	3.96	0.0575	
BT	6680.01	1	6680.01	1.00	0.3267	
SS	3422.48	1	3422.48	0.5127	0.4806	
Residual	1.669E+05	25	6675.52			
Lack of Fit	1.659E+05	20	8293.01	40.34	0.0003	significant
Pure Error	1027.83	5	205.57			
Cor Total	2.156E+05	29				

ER (Linear)						
Source	SS	Df	MS	F-value	P-value	
Model	0.5088	4	0.1272	5.32	0.0031	significant
BR	0.3197	1	0.3197	13.36	0.0012	
MC	0.0287	1	0.0287	1.20	0.2838	
BT	0.1520	1	0.1520	6.35	0.0185	
SS	0.0084	1	0.0084	0.3527	0.5579	
Residual	0.5980	25	0.0239			
Lack of Fit	0.5825	20	0.0291	9.36	0.0105	significant
Pure Error	0.0156	5	0.0031			
Cor Total	1.11	29				

Appearance (Quadratic)						
Source	SS	Df	MS	F-value	P-value	
Model	5.67	14	0.4051	3.32	0.0137	significant
BR	0.2204	1	0.2204	1.81	0.1987	
MC	1.35	1	1.35	11.11	0.0045	
BT	0.0017	1	0.0017	0.0137	0.9085	

SS	0.8817	1	0.8817	7.23	0.0168	
BR*MC	0.0900	1	0.0900	0.7384	0.4037	
BR*BT	0.6806	1	0.6806	5.58	0.0321	
BR*SS	0.0100	1	0.0100	0.0820	0.7785	
MC*BT	0.1225	1	0.1225	1.01	0.3320	
MC*SS	0.6806	1	0.6806	5.58	0.0321	
BT*SS	0.0625	1	0.0625	0.5128	0.4849	
BR^2	0.0407	1	0.0407	0.3343	0.5717	
MC^2	0.5750	1	0.5750	4.72	0.0463	
BT^2	0.0500	1	0.0500	0.4105	0.5314	
SS^2	0.9750	1	0.9750	8.00	0.0127	
Residual	1.83	15	0.1219			
Lack of Fit	1.54	10	0.1543	2.71	0.1416	not significant
Pure Error	0.2850	5	0.0570			
Cor Total	7.50	29				

Colour (Linear)

Source	SS	Df	MS	F-value	P-value	
Model	1.87	4	0.4682	3.49	0.0214	significant
BR	0.4676	1	0.4676	3.49	0.0737	
MC	0.9009	1	0.9009	6.72	0.0157	
BT	0.0084	1	0.0084	0.0629	0.8040	
SS	0.4959	1	0.4959	3.70	0.0660	
Residual	3.35	25	0.1342			
Lack of Fit	3.04	20	0.1518	2.38	0.1704	not significant
Pure Error	0.3183	5	0.0637			
Cor Total	5.23	29				

Crunchiness (Linear)

Source	SS	Df	MS	F-value	P-value	
Model	17.06	4	4.26	3.53	0.0204	significant
BR	0.0004	1	0.0004	0.0003	0.9853	
MC	16.17	1	16.17	13.38	0.0012	
BT	0.0817	1	0.0817	0.0676	0.7970	
SS	0.8067	1	0.8067	0.6677	0.4216	

Residual	30.20	25	1.21			
Lack of Fit	26.01	20	1.30	1.55	0.3314	not significant
Pure Error	4.19	5	0.08384			
Cor Total	47.26	29				

Crispness (Linear)

Source	SS	Df	MS	F-value	P-value	
Model	12.38	4	3.09	3.27	0.0277	significant
BR	0.0001	1	0.0001	0.0001	0.9917	
MC	11.41	1	11.41	12.04	0.0019	
BT	0.6501	1	0.6501	0.6859	0.4154	
SS	0.3151	1	0.3151	0.3325	0.5694	
Residual	23.69	25	0.9478			
Lack of Fit	21.34	20	1.07	2.26	0.1862	not significant
Pure Error	2.36	5	0.4717			
Cor Total	36.07	29				

Taste(Linear)

Source	SS	Df	MS	F-value	P-value	
Model	2.75	4	0.6872	1.90	0.1426	significant
BR	0.0009	1	0.0009	0.0026	0.9599	
MC	2.13	1	2.3	5.87	0.0229	
BT	0.2301	1	0.2301	0.6346	0.4332	
SS	0.3876	1	0.3876	1.07	0.3111	
Residual	9.06	25	0.3626			
Lack of Fit	8.44	20	0.4220	3.38	0.0903	not significant
Pure Error	0.6238	5	0.1248			
Cor Total	11.81	29				

Mouth-feel(Linear)

Source	SS	Df	MS	F-value	P-value	
Model	6.66	4	1.67	3.27	0.0277	significant
BR	0.0067	1	0.0067	0.0149	0.9038	
MC	4.42	1	4.42	9.88	0.0043	
BT	0.7350	1	0.7350	1.64	0.2116	
SS	1.50	1	1.50	3.35	0.0790	
Residual	11.18	25	0.4472			
Lack of Fit	10.55	20	0.5276	4.20	0.0592	not significant
Pure Error	20.6288	5	0.1258			

Cor Total	17.84	29				

Overall acceptance (Linear)						
Source	SS	Df	MS	F-value	P-value	
Model	6.30	4	1.58	3.23	0.0287	significant
BR	0.0504	1	0.0504	0.1034	0.7504	
MC	4.86	1	4.86	9.97	0.0041	
BT	0.2204	1	0.2204	0.4522	0.5075	
SS	1.17	1	1.17	2.40	0.1338	
Residual	12.19	25	0.4875			
Lack of Fit	11.45	20	0.5726	3.90	0.0687	not significant
Pure Error	0.7350	5	0.1470			
Cor Total	18.49	29				

The model F-values for SME, WA1, WSI, Total colour, Hardness, BD, Expansion ratio, Appearance, Colour, Crunchiness, Crispness, Taste, Mouth-feel, Overall acceptance were 6.01, 4.18, 1.97, NA, 2.48, 1.83, 5.32, 3.32, 3.49, 3.53, 3.27, 1.90, 3.72 and 3.23 respectively as indicated in Table 4.2. The F-values of the models for SME, WAI, Hardness, Expansion ratio, Appearance, Colour, Crunchiness, Crispiness, Mouth-feel, and Overall Acceptance were significant at p>F less than 0.05, indicating significant models with only a 0.05% probability that such a big F-value may be attributable to noise. Whereas, WSI, Bulk density, Taste were not significant (i.e p>F greater than 0.05). Except for total colour which had a mean model. Model terms with p>F less than 0.05 are considered significant. The significant model terms were SME (MC, SS), WAI (MC, BT, BR*MC, BR*SS, BR^2), WSI (MC), Hardness (SS, BR*SS, BR^2), Expansion ratio (BR, BT), Appearance (MC, SS, BR*BT, MC*SS, MC^2, SS), Colour (MC), Crunchiness (MC), Crispness (MC), Taste (MC), mouth-feel (MC) and Overall acceptance (MC) as indicated in the **Table 4.2**. From the results obtained, it was noticed that moisture content and screw speed both affected SME, blend ratio, moisture content and screw speed affected hardness while WAI and appearance were affected by blend ratio, moisture content, barrel temperature and screw speed. However, WSI, Colour, Crunchiness, Crispness, Taste, Mouth feel and Overall acceptance were only affected by moisture content and Expansion ratio by blend ratio and barrel temperature. The lack of Fit F-value for SME, WAI, WSI, Hardness, BD, Expansion ratio, Appearance, Colour, Crunchiness, Crispness, Taste, Mouth feel, Overall acceptance were 145.05, 0.8243, 0.8505, 3.06, 16.88, 40.34, 9.36, 2.71, 2.38, 0.3314, 2.26, 3.38, 4.20 and 3.90 respectively. We want the model to fit. A significant lack of fit is undesirable. SME, Hardness, BD, and Expansion Ratio all have substantial lack of fit values. The signal-to-noise ratio is measured by Adeq. Precision. It's preferable to have a ratio of at least 4. The Adeq. Precision (Table 4.5) for SME, WAI, WSI, Total colour, Hardness, BD, Expansion ratio, Appearance, Colour, Crunchiness, Crispness, Taste, Mouth-feel, Overall acceptance were 8.048, 7.2765, 4.7607, NA, 5.1122, 5.0581, 7.8659, 7.1394, 6.6319, 7.3169, 6.9402, 4.8476, 6.3795 and 6.3150 which indicated an adequate signal. A value greater than 4 indicates that the model can be utilized to navigate the design space. The R^2 values for SME, WAI, WSI, TC, Hardness, BD, Appearance, ER, Colour, Crunchiness, Crispness, Taste, Mouth-feel and Overall acceptance were 0.4902, 0.7958, 0.2393, 0, 0.6984, 0.2261, 0.2497, 0.7562, 0.3583, 0.3609, 0.3431, 0.2327, 0.3734, and 0.3408 respectively (Appendix). This indicates that SME, WSI, TC, BD, ER, Colour, Crunchiness, Crispness, Taste, Mouth-feel and OA were poorly correlated below 0.5. The quadratic terms were found to be the most significant. The summary of the ANOVA for the ready-to-eat extrudate indicates that blend ratio had effect on WAI, Hardness, ER and appearance while moisture content had effect on SME, WAI, WSI, Hardness, Appearance, Colour, Crunchiness, Crispness, Taste, Mouth-feel and Overall acceptance. Furthermore, barrel temperature had effect on WAI and ER, in addition, screw speed affected the SME, WAI, Hardness and Appearance. The moisture content was observed to have the highest impact on the variables.

4.3 Modelling Of The Functional And Sensory Properties Of The Extrudate

$$SME = 77.44 - 2.58BR - 13.70\mathrm{MC} + 2.07\mathrm{BT} + 11.16\mathrm{SS} \quad (4.1)$$

$$WAI = 4.00 - 0.1167\mathrm{BR} + 0.2517\mathrm{MC} + 0.3383\mathrm{BR} + 0.2017\mathrm{SS} - 0.7050\mathrm{BR} * \mathrm{MC} + 0.0200\mathrm{BR} * \mathrm{BT} + 0.5850\mathrm{BR} * \mathrm{SS} - 0.0150\mathrm{MC} * \mathrm{BT} + 0.4100\mathrm{MC} * \mathrm{SS} - 0.2150\mathrm{BT} * \mathrm{SS} - 0.6058BR^2 - 0.1758MC^2 - 0.3308BT^2 + 0.0042SS^2 \quad (4.2)$$

$$WSI = 8.07 + 2.07\mathrm{BR} - 3.67\mathrm{MC} - 0.9333\mathrm{BT} - 0.2667\mathrm{SS} \quad (4.3)$$

$$-Total\ colour = 40.97 \quad (4.4)$$

$$Hardness = 2.31 - 0.1084\mathrm{BR} + 0.1411\mathrm{MC} - 0.0194\mathrm{BT} + 0.3209\mathrm{SS} + 0.2053\mathrm{BR} * \mathrm{MC} + 0.3293\mathrm{BR} * \mathrm{BT} - 0.3027\mathrm{BR} * \mathrm{SS} + 0.2827\mathrm{MC} * \mathrm{BT} +$$

$0.9208\text{MC} * \text{SS} - 0.2522\text{BT} * \text{SS} + 0.7086BR^2 + 0.3036MC^2 +$
$0.2671BT^2 + 0.3481SS^2$ (4.5)

$$\text{Bulk density} = 456.25 + 45.05\text{BR} + 66.42\text{MC} - 33.37\text{BT} - 23.88\text{SS} \quad (4.6)$$

$$Expansion\,ratio = 2.51 - 0.2308\text{BR} - 0.0692\text{MC} + 0.1592\text{BT} - 0.0375\text{SS} \quad (4.7)$$

$\text{Appearance} = 7.40 - 0.1917\text{BR} - 0.4750\text{MC} - 0.0167\text{BT} - 0.3833\text{SS} +$
$0.3000\text{BR} * \text{MC} - 0.8250\text{BR} * \text{BT} - 0.1000\text{BR} * \text{SS} - 0.3500\text{MC} * \text{BT} -$
$0.8250\text{MC} * \text{SS} - 0.2500\text{BT} * \text{SS} - 0.1542BR^2 - 0.5792MC^2 +$
$0.1708CBT^2 - 0.7521SS^2$ (4.8)

$$Colour = 7.11 - 0.2792BR - 0.3875MC - 0.03375BT - 0.2875SS \quad (4.9)$$

$$Crunchiness = 6.22 - 0.0083BR - 1.64MC + 0.1167BT - 0.3667SS \quad (4.10)$$

$$Crispness = 6.25 + 0.0042BR - 1.38MC + 0.3292BT - 0.2292SS \quad (4.11)$$

$$Taste = 6.49 + 0.0125BR - 0.5958MC + 0.1958BT - 0.2542SS \quad (4.12)$$

$$Mouthfeel = 6.47 + 0.0333BR - 0.8583MC + 0.3500BT - 0.5000SS \quad (4.13)$$

$$Overall\ acceptance = 6.73 - 0.0917BR - 0.9000MC + 0.19197BT - 0.4417SS \quad (4.14)$$

4.4 Optimization Of The Extrusion Process Parameters And Responses

To attain the desired physical qualities and better functional properties of the rice-cowpea extruded snack, the process parameters were numerically optimized. The goal of the optimization was to maximize ER, APP, CRSH, CRISP, TA, MF and OA while minimizing SME, Hardness, and BD, the other responses namely: WAI, WSI, TC were kept in range. Other than that, BR, MC, BT and SS, were kept in range. The optimum values for the responses were obtained using the Design Expert 11.1.0.1 software. The values were at 83:17 BR, 10.3% MC, 150°C BT and 307.1 rpm SS; and predicted SME of 89.29 Wh/kg, WAI of 3.595 g/g, WSI of 9.943%, TC of 40.973, Hardness of 2.741N, BD of 355.58 Kg/m^3, ER of 2.82 mm, APP of 8.08, Colour of 7.60, CRH of 7.97, CRSP of 7.12, TA of 7.31, MF of 7.76 and OA of 7.92 with a desirability index of 0.737. Reshi *et al*. (2020) and Altaf *et al*. (2020) obtained desirability values of 0.62 and 0.839, respectively. Which is comparable to the desirability of this study.

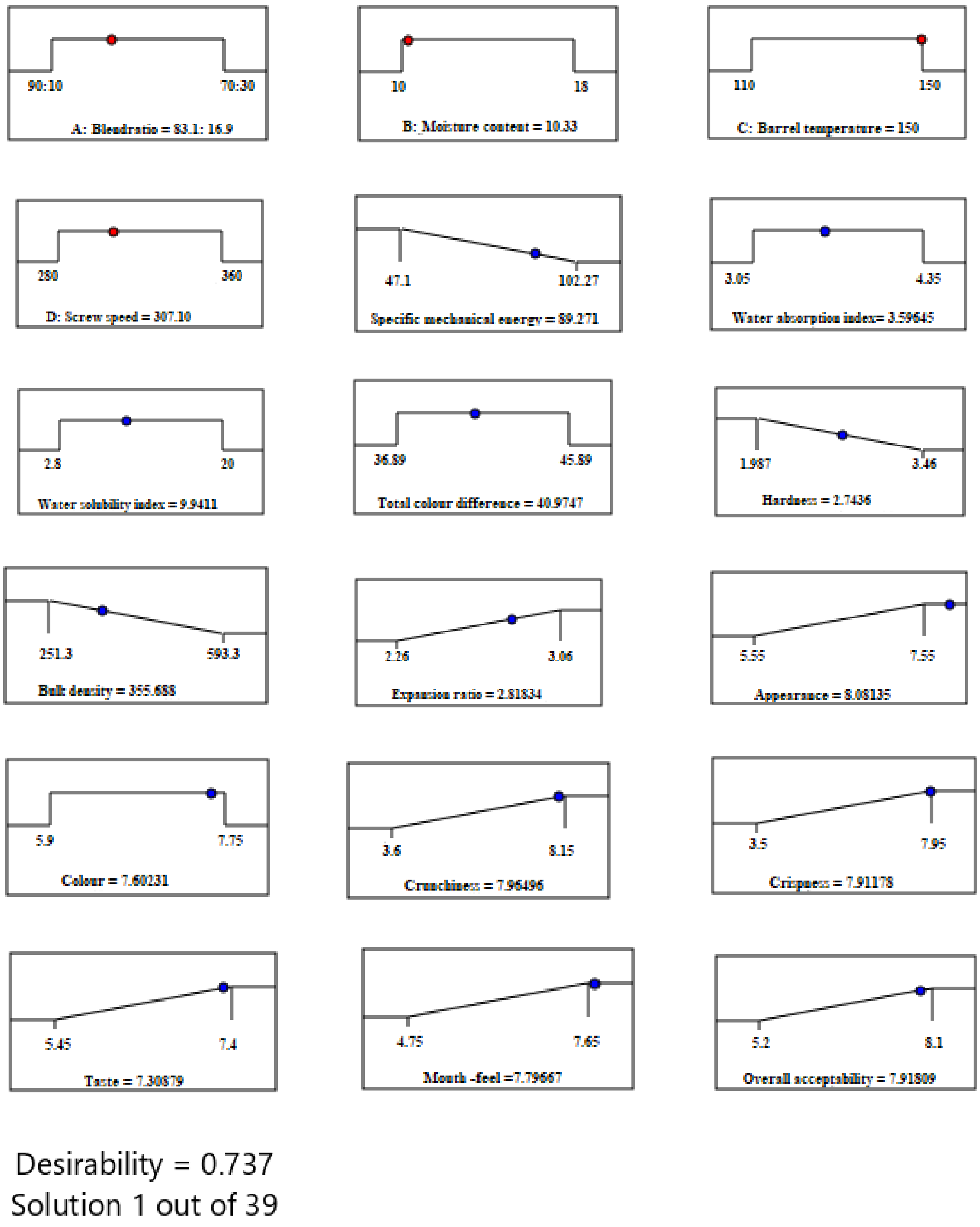


Figure 4.29: Graph of desirability of the optimal process

4.5 Proximate Analysis Result

4.5.1 Proximate and minerals of the raw materials and Optimized snack

The significance difference between the proximate and mineral composition of the snack and raw materials was evaluated. The results of the proximate composition and mineral composition of the final product as well as the raw materials (Broken rice and cowpea flour) are presented in **Tables 4.3** and 4.4. From the result in Table 4.3, the moisture of the snack was significantly lower (5.99%) than both rice and cowpea flour. There was a significant ($p<0.05$) decrease in moisture content, crude protein, total ash and crude fat compared to rice flour. The decrease in fat content could be attributed to the formation of lipid complexes with proteins and amylose, asides the loss of lipids in die (Altaf *et al*., 2020). The incorporation of cowpea flour resulted in the increase of fibre content of the snack compared to rice flour due to its high fibre content. In addition, during extrusion cooking, a change from insoluble to soluble dietary fibre occurs, as well as the development of resistant starch and enzyme-resistant indigestible glucans by transglycosidation (Alaf *et al*., 2020). The significant ($p<0.05$) decrease in moisture content and fat can be responsible for the significant increase in carbohydrate content of extrudates. This finding was similar to the study of Alaf *et al*. (2020) in rice and chickpea based snacks. From the result presented in **Table 4.4**, it was reveal that iron and sodium increased significantly ($p<0.05$) for the optimized snack. While phosphorus, manganese and copper of the optimized snack were decreased. This may be due to the variety of materials used, the moisture content and the barrel temperature used.

Table 4.3: Proximate composition of optimized snacks and the raw materials (%)

Samples	MC	CP	TA	CF	CFAT	CHO
Rice flour	10.1±0.02[c]	13.11±0.01[b]	4.68±0.01[c]	2.96±0.06[b]	8.56±0.01[c]	60.54±0.10[b]
Cowpea flour	7.98±0.01[b]	24.48±0.03[c]	4.01±0.01[b]	2.49±0.01[a]	7.94±0.03[b]	53.11±0.05[a]
Optimized extrudate	5.99±0.04[a]	6.73±0.01[a]	0.96±0.02[a]	3.04±0.02[b]	2.60±0.04[a]	80.70±0.01[c]

MC = Moisture content, CP = Crude protein, TA = Total ash, CF = Crude fibre, CFAT = Crude fat, CHO = Carbohydrate

Values are given as mean ± standard deviation

Values with different superscripts are significantly different at ($p<0.05$)

Table 4.4: Mineral composition of optimized snack and the raw materials before extrusion (mg/100 kg)

Samples	Fe	P	Mn	Cu	Na
Rice flour	0.46 ± 0.012^{b}	110.89 ± 0.19^{c}	0.07 ± 0.00^{b}	0.078 ± 0.00^{a}	0.02 ± 0.00^{a}
Cowpea flour	0.53 ± 0.042^{c}	106.57 ± 1.27^{b}	0.06 ± 0.00^{b}	0.80 ± 0.00^{b}	0.02 ± 0.00^{a}
Optimized extrudate	0.41 ± 0.07^{a}	16.21 ± 0.03^{a}	0.02 ± 0.00^{a}	0.06 ± 0.01^{a}	23.44 ± 0.04^{b}

Fe = Iron, P = Phosphorus, Mn = Manganese, Cu = Copper, Na = Sodium

Values are given as mean ± standard deviation

Values with different superscripts are significantly different at ($p<0.05$)

4.6 Results On Economic Viability Of A Cereal-Based Ready-to-Eat Snack

Table 4.5: Summarized result for economic viability

FC (₦)	VC (₦)	TWC per month (₦)	TWC per year (₦)	FC+VC=(TC) (₦)	BEP	AMS	Profit (₦)	PBP	BCR
26,524,000	3,307,833	4,129,833	49,557,996	76,081,996	45.3%	1,181,255 units of 50g	58,442,004	9 months	1.3

FC = fixed cost, VC = variable cost, TWC = total working capital, TC = total cost, BEP = break-even point, AMS = absolute margin of safety, PBP = payback period, BCR = benefit cost ratio

The selling cost of one unit of 50 g was fixed at ₦ 50 because at present, similar products are available at retail price of ₦ 80 and their factory selling price is at ₦ 50. It could also be sold for ₦ 60 or more to generate more profit.

The fixed cost and variable cost involved in the development of broken rice-cowpea extrudates were worked out and presented in **Table 4.5**. The total cost per year was found to be ₦ 76,081,996 the total variable cost per yer was ₦ 49,557,996. The break-even production was 978,746 units. The break-even point was 45.3% , which means up to this point there is no loss as well as no point. Benefit cost ratio was 1.3>1, it indicated that it is good, acceptable and profitable. In order to clear the total project cost,about 9 months is required. The benefit cost ratio was found to be 1.3 therefore, every one naira invested in the projectis expected to earn 1.3 Naira.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The use of extrusion technology was employed in this study for the development of a cereal-based RTE snack with the utilization of broken rice flour and cowpea flour. The interdependence of different process parameters, namely, blend ratio, moisture content, barrel temperature, and screw speed and their effects on the dependent variables (specific mechanical energy, water absorption index, water solubility index, bulk density, hardness, expansion ratio, appearance, colour, crunchiness, crispness, taste, mouth-feel and overall acceptability) was determined and assessed by the response surface graphs generated. Based on the data generated from the experiment established using CCRD and the analysis of the results by the RSM in the design expert software; the following was revealed:

1. The specific mechanical energy, water absorption index, hardness, expansion ratio, appearance, colour, crunchiness, crispness, mouth-feel, overall acceptance was significant ($p<0.05$) while water solubility, bulk density and taste were not significant ($p>0.05$). However, the total colour had no model p-value because the mean model was used.
2. The moisture content was observed to be the process parameter that greatly affected the extrudate responses.
3. The optimum machine parameters characterized for the most acceptable extrudate rice-cowpea blends out of 44 selections are:

S/N	Blend ratio	Moisture content	Barrel temperature	Screw speed	Desirability
1st	83:17	10.331	150.000	307.095	0.737
2nd	83:17	10.346	149.900	307.021	
3rd	83:16	10.312	150.000	307.464	

4. The cost evaluation of the extrudate by a twin screw extruder (with a production capacity of 180,000 packs of 50 grams) of RTE extruded snack of blended flour comprising of rice:cowpea in the proportion 87:13 indicates the breakeven

quantity of 978,745.4 units and break-even point of 45.3%. Thus, the product will be economically viable if a unit can be sold at ₦ 50 per unit of 50g.

5.2 Recommendations

Based on the developed cereal-based ready-to-eat snack using broken rice and cowpea, the following recommendations were made:

1. The use of high protein cowpea and other leguminous crops should be used to improve the protein content of the snack.
2. Other variables that may affect the overall acceptance of the extrudate should be explored.
3. Some essential food and nutrition test such as microbial loads, toxicity test, pathogenic test, chemical tests and bacteria count should be studied to determine the consumption safety.
4. Storage stability should be conducted to establish the shelf life of the developed product.
5. Practical application of this study should be adopted for use in the food industry.

REFERENCES

African Agricultural Technology Foundation (AATF) (2012). Cowpea for food and poverty alleviation: Potentials and constraints. Available from http://www.aatf.Africa.org/files/files/publications/ Cowpea%20brief.pdf. Accessed - August 8, 2021.

Ahmad, I.M., & Kiresur, V.R. (2016). Pulses production in India and Nigeria: Panacea to Food Security. Research Journal of Agriculture and Forestry Sciences, 4: (6), 11-19.

Ajetomobi, J., & Abiodun, A. (2010). Climate change impacts on cowpea productivity in Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*, *10*(3). https://doi.org/10.4314/ajfand.v10i3.54082

Akah, N. P., & Onyeka, E. U. (2018). Comparative effects of three levels of insect infestation on selected properties of five Nigerian cowpea (*Vigna unguiculasta (L.*) walp) varieties. *Agro-Science, 16*(3), 1. https://doi.org/10.4314/as.v16i3.1

Altaf, U., Hussain, S. Z., Qadri, T., Iftikhar, F., Naseer, B., & Rather, A. H. (2020). Investigation on mild extrusion cooking for development of snacks using rice and chickpea flour blends. *Journal of Food Science and Technology*, *58*(3), 1143–1155. https://doi.org/10.1007/s13197-020-04628-7

Alam, M. S., Kaur, J., Khaira, H., & Gupta, K. (2015). Extrusion and Extruded Products: Changes in Quality Attributes as Affected by Extrusion Process Parameters: A Review. *Critical Reviews in Food Science and Nutrition*, *56*(3), 445–473. https://doi.org/10.1080/10408398.2013.779568

Alonso, R., Rubio, L. A., Muzquiz, M., & Marzo, F. (2001). The effect of extrusion cooking on mineral bioavailability in pea and kidney bean seed meals. *Animal Feed Science and Technology*, *94*(1-2), 1–13. https://doi.org/10.1016/s0377-8401(01)00302-9

Altan, A., McCarthy, K. L., & Maskan, M. (2008). Evaluation of snack foods from barley–tomato pomace blends by extrusion processing. *Journal of Food Engineering*, *84*(2), 231–242. https://doi.org/10.1016/j.jfoodeng.2007.05.014

Alvarez-Martinez, L., Kondury, K. P., & Harper, J. M. (1988). A General Model for Expansion of Extruded Products. *Journal of Food Science*, *53*(2), 609–615. https://doi.org/10.1111/j.1365-2621.1988.tb07768.x

Anderson, R. A., Conway, H. F., & Peplinski, A. J. (1970). Gelatinization of Corn Grits by Roll Cooking, Extrusion Cooking and Steaming. *Starch - Stärke*, *22*(4), 130–135. https://doi.org/10.1002/star.19700220408

AOAC. (1984). Official Methods of Analysis.14th edition. Association of Official Analytical Chemists, Arlington, VA.

AOAC (1990): Approved Official Methods of Analysis, 13th edn. Washington, DC: Association of Official Analytical Chemists.

AOAC International (2007) Official methods of analysis, 18^{th} edn, 2005; Current through revision 2, 2007 (Online). *AOAC International*, Gaithersburg, MD

Awika, J. M. (2011). Major cereal grains production and use around the world. In *Advances in cereal science: implications to food processing and health promotion* (pp. 1-13). American Chemical Society. https://doi: 10.1021/bk-2011-1089.ch001

Awolu, O. O., Oluwaferanmi, P. M., Fafowora, O. I., & Oseyemi, G. F. (2015). Optimization of the extrusion process for the production of ready-to-eat snack from rice, cassava and kersting's groundnut composite flours. *LWT - Food Science and Technology*, *64*(1), 18–24. https://doi.org/10.1016/j.lwt.2015.05.025

Babagowda, Kadadevara Math, R. S., Goutham, R., & Srinivas Prasad, K. R. (2018). Study of Effects on Mechanical Properties of PLA Filament which is blended with Recycled PLA Materials. *IOP Conference Series: Materials Science and Engineering*, *310*, 012103. https://doi.org/10.1088/1757-899x/310/1/012103

Bhattacharya, M., & Hanna, M. A. (1988). Effect of Lipids on the Properties of Extruded Products. *Journal of Food Science*, *53*(4), 1230–1231. https://doi.org/10.1111/j.1365-2621.1988.tb13572.x

Britannica Encyclopedia 1996. Volume 19. Britannica Encylopedia Ltd. London, 501

Consultative Group for International Agricultural Research (CGIAR) (2017). Cowpea. Available from http://www.cgiar.org/our-strategy/cropfactsheets/cowpea/. Accessed August 8: 2017.

Courtois, F., Faessel, M., & Bonazzi, C. (2010). Assessing breakage and cracks of parboiled rice kernels by image analysis techniques. *Food Control*, *21*(4), 567–572. https://doi.org/10.1016/j.foodcont.2009.08.006

Cuj-Laines, R., Hernández-Santos, B., Reyes-Jaquez, D., Delgado-Licon, E., Juárez-Barrientos, J. M., & Rodríguez-Miranda, J. (2018). Physicochemical properties of ready-to-eat extruded nixtamalized maize-based snacks enriched with grasshopper. *International Journal of Food Science & Technology*, *53*(8), 1889–1895. https://doi.org/10.1111/ijfs.13774

Danbaba, N., Nkama, I., & Badau, M. H. (2015). Application of response surface methodology (RSM) and central composite design (CCD) to optimize minerals composition of rice-cowpea composite blends during extrusion cooking. *International Journal of Food Science and Nutrition Engineering*, *5*(1), 40-52.

Dar, A. H., Sharma, H. K., & Kumar, N. (2014). Effect of Frying Time and Temperature on the Functional Properties of Carrot Pomace, Pulse Powder and Rice Flour–Based Extrudates. *International Journal of Food Engineering*, *10*(1), 139–147. https://doi.org/10.1515/ijfe-2012-0044

Delgado-Licon, E., Ayala, A. L. M., Rocha-Guzman, N. E., Gallegos-Infante, J.-A., Atienzo-Lazos, M., Drzewiecki, J., … Gorinstein, S. (2009). Influence of extrusion on the bioactive compounds and the antioxidant capacity of the bean/corn mixtures. *International Journal of Food Sciences and Nutrition*, *60*(6), 522–532. https://doi.org/10.1080/09637480801987666

de Mesa, N. J. E., Alavi, S., Singh, N., Shi, Y.-C., Dogan, H., & Sang, Y. (2009). Soy protein-fortified expanded extrudates: Baseline study using normal corn starch.

Journal of Food Engineering, *90*(2), 262–270. https://doi.org/10.1016/j.jfoodeng.2008.06.032

Department of Agriculture, U. S. (2020). Rice. Retrieved September 12, 2021, from USDA Foreign Agricultural Service website: https://www.fas.usda.gov/commodities/rice

Desrumaux, A., Bouvier, J. M., & Burri, J. (1999). Effect of Free Fatty Acids Addition on Corn Grits Extrusion Cooking. *Cereal Chemistry Journal*, *76*(5), 699–704. https://doi.org/10.1094/cchem.1999.76.5.699

Ding, Q.-B., Ainsworth, P., Plunkett, A., Tucker, G., & Marson, H. (2006). The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *Journal of Food Engineering*, *73*(2), 142–148. https://doi.org/10.1016/j.jfoodeng.2005.01.013

Doblado, R., Frías, J., & Vidal-Valverde, C. (2007). Changes in vitamin C content and antioxidant capacity of raw and germinated cowpea (Vigna sinensis var. carilla) seeds induced by high pressure treatment. *Food Chemistry*, *101*(3), 918–923. https://doi.org/10.1016/j.foodchem.2006.02.043

Eggum B O. 1969. Evaluation of protein quality and the development of screening techniques. In: New Approaches to Breeding for Improved Plant Protein. Vienna, IAEA: 125–135.

Elina, M., Cornelio, N. N., Henry, L., & Theobald, C. E. M. (2016). Sensory evaluation of extruded quality protein maize-based supplementary foods. *African Journal of Food Science*, *10*(7), 105–111. https://doi.org/10.5897/ajfs2016.1445

FAO. 2011. Food and Agriculture Organization Statistical Data Base, Rome. Available at: http.fao.org/. Accessed 7 January 2021.

Faubion, J. M., Hoseney, R. C., and Seib, P. A. (1982). Functionality of grain components in extrusion. Cereal Foods World. 27: 212-215.

Fellows, P. J. (2017). Extrusion cooking. In P.J. Fellows (Ed.), Food Processing Technology (Fourth Edition) (pp. 753-780). Cambridge: Woodhead Publishing.

Fernandes de Aguiar Valim, M. F. C., & Batistuti, J. P. (2000). Efeito da extrusão termoplástica no teor de lisina disponível da farinha desengordurada de grão-de-bico (Cicer arietinum, L.). *Archivos Latinoamericanos de Nutrición*, *50*(3), 270-273.

Food and Agriculture Organization of the United Nations Statistics Division [FAOSTAT] (2016). Available at http://faostat3.fao.org/download/Q/QC/E. Accessed August 10: 2020.

Grasso, S. (2020). Extruded snacks from industrial by-products: A review. *Trends in Food Science & Technology*, *99*, 284–294. https://doi.org/10.1016/j.tifs.2020.03.012

Gumul, D., Ziobro, R., Gambuś, H., & Nowotna, A. (2014). Usability of residual oat flour in the manufacture of extruded corn snacks. *CyTA - Journal of Food*, *13*(3), 353–360. https://doi.org/10.1080/19476337.2014.984336

Hagenimana, A., Ding, X., & Fang, T. (2006). Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science*, *43*(1), 38–46. https://doi.org/10.1016/j.jcs.2005.09.003

Han, Y. J., Tra Tran, T. T., & Man Le, V. V. (2018). Corn snack with high fiber content: Effects of different fiber types on the product quality. *LWT*, *96*, 1–6. https://doi.org/10.1016/j.lwt.2018.05.014

Hussain, S. Z., & Singh, B. (2015). Physical Properties of Refabricated Rice as Affected by Extrusion: A Response Surface Analysis. *Cereal Foods World*, *60*(4), 171–176. https://doi.org/10.1094/cfw-60-4-0171

Hussain SZ, Ali F, Jabeen R, & Zargar I. (2017) Twin screw extrusion cooking of lotus rhizome and broken rice flour blends: A response surface analysis. JSIR 76:485–493

Ibukun, E. O. (2008). Effect of prolonged parboiling duration on proximate composition of rice. *Scientific Research and Essays*, *3*(7), 323-325.

Ilo, S., Liu, Y., & Berghofer, E. (1999). Extrusion Cooking of Rice Flour and Amaranth Blends. *LWT - Food Science and Technology*, *32*(2), 79–88. https://doi.org/10.1006/fstl.1998.0497

Jakkanwar, S. A., Rathod, R. P. & Annapure, U. S. (2018). Development of cowpea-based (Vigna unguiculata) extruded snacks with improved in vitro protein digestibility. *International Food Research* Journal 25(2): 804-813

Jing, Y., & Chi, Y.-J. (2013). Effects of twin-screw extrusion on soluble dietary fibre and physicochemical properties of soybean residue. *Food Chemistry*, *138*(2-3), 884–889. https://doi.org/10.1016/j.foodchem.2012.12.003

Kadan, R. S., Bryant, R. J., & Pepperman, A. B. (2003). Functional Properties of Extruded Rice Flours. *Journal of Food Science*, *68*(5), 1669–1672. https://doi.org/10.1111/j.1365-2621.2003.tb12311.x

Kamai, N., Gworgwor, N. A., & Wabekwa, J. W. (2014). Varietal Trials and Physiological Components Determining Yield Differences among Cowpea Varieties in Semiarid Zone of Nigeria. *ISRN Agronomy*, *2014*, 1–7. https://doi.org/10.1155/2014/925450

Kamara, A. Y., Tofa, A. I., Kyei-Boahen, S., Solomon, R., Ajeigbe, H. A., & Kamai, N. (2016). Effects of Plant Density on the Performance of Cowpea in Nigerian Savannas. *Experimental Agriculture*, *54*(1), 120–132. https://doi.org/10.1017/s0014479716000715

Kantrong, H., Charunuch, C., Limsangouan, N., & Pengpinit, W. (2018). Influence of process parameters on physical properties and specific mechanical energy of healthy mushroom-rice snacks and optimization of extrusion process parameters using response surface methodology. *Journal of Food Science and Technology*, *55*(9), 3462–3472. https://doi.org/10.1007/s13197-018-3271-2

Kaur, A., Kaur, S., Singh, M., Singh, N., Shevkani, K., & Singh, B. (2014). Effect of banana flour, screw speed and temperature on extrusion behaviour of corn extrudates. *Journal of Food Science and Technology*, *52*(7), 4276–4285. https://doi.org/10.1007/s13197-014-1524-2

Khalid, I. I., Elhardallo, S. B., & Elkhalifa, E. A. (2012). Composition and Functional Properties of Cowpea (Vigna ungiculata L. Walp) Flour and Protein Isolates. *American Journal of Food Technology*, *7*(3), 113–122. https://doi.org/10.3923/ajft.2012.113.122

Köksel, H., Ryu, G.-H., Basman, A., Demiralp, H., & Ng, P. K. W. (2004). Effects of extrusion variables on the properties of waxy hulless barley extrudates. *Nahrung/Food*, *48*(1), 19–24. https://doi.org/10.1002/food.200300324

Kothakota, A. (2013). A study on evaluation and characterization of extruded product by using various by-products. *African Journal of Food Science*, *7*(12), 485–497. https://doi.org/10.5897/ajfs2013.1065

Kubala, J. (2019, April). What Is the Healthiest Type of Rice? Retrieved from Healthline website: https://www.healthline.com/nutrition/healthiest-rice

Kubo, M., & Purevdorj, M. (2004). The future of rice production and consumption. *Journal of Food Distribution Research*, *35*(856-2016-57064), 128-142.

Kumar, R., Xavier, K. A. M., Lekshmi, M., Balange, A., & Gudipati, V. (2018). Fortification of extruded snacks with chitosan: Effects on techno functional and sensory quality. *Carbohydrate Polymers*, *194*, 267–273. https://doi.org/10.1016/j.carbpol.2018.04.050

Larmond, E. (1977). Laboratory Methods of Sensory Evaluation of Food Research Branch Canada. *Deptt. Agri. Publication*, *1637*.

Li-na, L. I. (2004). Study on application of extrusion technique in food industry [J]. *Journal of Harbin University of Commerce (Sciences Edition)*, *2*.

Makinde, F., & Olmori, D. (2020). Improvement of nutritional, functional and pasting properties of long and short local rice grains during germination. *Croatian Journal of Food Science and Technology*, *12*(2), 193–202. https://doi.org/10.17508/cjfst.2020.12.2.07

Mazumder, P., Roopa, B. S., & Bhattacharya, S. (2007). Textural attributes of a model snack food at different moisture contents. *Journal of Food Engineering*, *79*(2), 511–516. https://doi.org/10.1016/j.jfoodeng.2006.02.011

Meng, X., Threinen, D., Hansen, M., & Driedger, D. (2010). Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack. *Food Research International*, *43*(2), 650–658. https://doi.org/10.1016/j.foodres.2009.07.016

Mohd Esa, N. (2013). By-products of Rice Processing: An Overview of Health Benefits and Applications. *Rice Research: Open Access*, *01*(01). https://doi.org/10.4172/2375-4338.1000107

Nagaraju, M., Tiwari, V. K., & Sharma, A. (2021). Techno-economic feasibility study for production of finger millet-lentil extrudate. *The Pharma Innovation Journal 2021*: SP-10(8):566-569

Nath, A., & Chattopadhyay, P. K. (2007). Optimization of oven toasting for improving crispness and other quality attributes of ready to eat potato-soy snack using response surface methodology. *Journal of Food Engineering*, *80*(4), 1282–1292. https://doi.org/10.1016/j.jfoodeng.2006.09.023

Navale, S. A., Swami, S. B., & Thakor, N. J. (2015). Extrusion cooking technology for foods: a review. *Journal of Ready to Eat Food*, *2*(3), 66-80.

Nicklas, T. A., Yang, S. J., Baranowski, T., Zakeri, I., & Berenson, G. (2003). Eating patterns and obesity in children: The Bogalusa Heart Study. *American journal of preventive medicine*, *25*(1), 9-16.

Nissar, J, Ahad. T & Hussain S.Z. (2017). Development of honey incorporated snacks using extrusion technology. *Pharmacohnosy and Phytochemistry* 6(6): 818-825

Oikonomou, N. A., & Krokida, M. K. (2012). Water Absorption Index and Water Solubility Index Prediction for Extruded Food Products. *International Journal of Food Properties*, *15*(1), 157–168. https://doi.org/10.1080/10942911003754718

Okunola, A. A., Olayanju, A., Adewumi, A. D., & Abolusoro, S. A. (2019a). Evaluation of milling characteristics of some varieties of paddy rice in cottage industries of Ondo and Ekiti states in south west Nigeria. *International Journal of Engineering and Emerging Scientific Discovery.* 4(1), 30-35.

Okunola, A. A., Adekanye, T. A., Adewumi, A. D., & Asamu, F. (2019b). Assessment of rice processing operations in Ekiti State, Nigeria. *International Journal of Civil Engineering and Technology (IJCIET)*, *10*(2), 2197-2204.

Okunola, A.A., Okunola, C.O., & Ofuya, T. (2019). Accessibility and sensory evaluation of maize and cowpea products stored with some essential oils. *International Journal of Agricultural Research and Food Production*, 4(1), 40-45.

Ojediran, J. O., Okonkwo, C. E., Okunola, A.A., & Alake, A.S. (2018). Development of a motorized rice de-stoning machine. *Agricultural Engineering International: CIGR Journal*, 20, 202-209

Ojediran, J. O., Okonkwo, C. E., Olayanju, T. A., Hussain, S. Z., Olaniran, A. F., & Adewumi, A. D. (2020). Effect of polishing duration on physical, milling, cooking, and sensory properties of a novel mix-colored Nigerian parboiled rice. *Cereal Chemistry*, *97*(6), 1172–1182. https://doi.org/10.1002/cche.10337

Olaniran, A. F., Okonkwo, C. E., Osemwegie, O. O., Iranloye, Y. M., Afolabi, Y. T., Alejolowo, O. O., Nwonuma, C.O., & Badejo, T. E. (2020). Production of a Complementary Food: Influence of Cowpea Soaking Time on the Nutritional, Antinutritional, and Antioxidant Properties of the Cassava-Cowpea-Orange-Fleshed Potato Blends. *International Journal of Food Science*, *2020*, 1–10. https://doi.org/10.1155/2020/8873341

Olapade, A. A., Babalola, K. A., & Aworh, O. C. (2015). Evaluation of plantain and cowpea blends for complementary foods. *Agriculture and Food*.

Olayanju, A. T., Okonkwo, C. E., Ojediran, J. O., Hussain, S. Z., Dottie, E. P., & Ayoola, A. S. (2021). Interactive effects and modeling of some processing parameters on milling, cooking, and sensory properties for Nigerian rice using a one-step rice milling machine. *Heliyon*, *7*(4), e06739. https://doi.org/10.1016/j.heliyon.2021.e06739

Omwamba, M., & Mahungu, S. M. (2014). Development of a Protein-Rich Ready-to-Eat Extruded Snack from a Composite Blend of Rice, Sorghum and Soybean Flour. *Food and Nutrition Sciences*, *05*(14), 1309–1317. https://doi.org/10.4236/fns.2014.514142

Onwulata, C. I., Konstance, R. P., Smith, P. W., & Holsinger, V. H. (2001). Co-extrusion of Dietary Fiber and Milk Proteins in Expanded Corn Products. *LWT - Food Science and Technology*, *34*(7), 424–429. https://doi.org/10.1006/fstl.2000.0742

Otitoju, G. T. O., Otitoju, O., Nwamarah, J. U., & Baiyeri, S. O. (2015). Comparative Study of the Nutrient Composition of Four Varieties of Cowpea (Vigna unguiculata) and Their Products (Beans-Based Products). *Pakistan Journal of Nutrition*, *14*(9), 540–546. https://doi.org/10.3923/pjn.2015.540.546

Oyewale, R.O. and Bamaiyi, L.J. (2013). Management of Cowpea Insect Pests. Scholars Academic Journal of Biosciences, 1: (5), 217- 226.

Pandey, S., Kumar, A., & Rao, P. S. (2021). Optimization, modeling, and characterization study for the physicochemical properties of raw banana and defatted soy composite extrudates. *Food Chemistry*, *339*, 127865. https://doi.org/10.1016/j.foodchem.2020.127865

Paranthaman, R., Alagusundaram, K., & Indhumathi, J. (2009). Production of protease from rice mill wastes by Aspergillus niger in solid state fermentation. *World Journal of Agricultural Sciences*, *5*(3), 308-312.

Patil, R.T., Berrios, J. De. J., Tang, J., & Swanson, B.G., (2007). Evaluation of Methods for Expansion Properties of Legume Extrudates. *Applied Engineering in Agriculture*, *23*(6), 777–783. https://doi.org/10.13031/2013.24044

Patil, H., Tiwari, R. V., & Repka, M. A. (2015). Hot-Melt Extrusion: from Theory to Application in Pharmaceutical Formulation. *AAPS Pharm SciTech*, *17*(1), 20–42. https://doi.org/10.1208/s12249-015-0360-7

Pawar, S. G., Pardeshi, I. L., Borkar, P. A., & Rajput, M. R. (2014). Optimization of process parameters of microwave puffed sorghum based ready-to-eat (RTE) food. *Journal of Ready to Eat Foods*, *1*(2), 59-68.

Pensamiento-Niño, C. A., Gómez-Aldapa, C. A., Hernández-Santos, B., Juárez-Barrientos, J. M., Herman-Lara, E., Martínez-Sánchez, C. E., … Rodríguez-Miranda, J. (2018). Optimization and characterization of an extruded snack based on taro flour (Colocasia esculenta L.) enriched with mango pulp (Mangifera indica L.). *Journal of Food Science and Technology*, *55*(10), 4244–4255. https://doi.org/10.1007/s13197-018-3363-z

Rathod, R. P., & Annapure, U. S. (2016). Effect of extrusion process on antinutritional factors and protein and starch digestibility of lentil splits. *LWT - Food Science and Technology*, *66*, 114–123. https://doi.org/10.1016/j.lwt.2015.10.028

Reddy, M. K., Kuna, A., Devi, N. L., Krishnaiah, N., Kaur, C., & Nagamalleswari, Y. (2014). Development of extruded Ready-To-Eat (RTE) snacks using corn, black gram, roots and tuber flour blends. *Journal of Food Science and Technology*, *51*(9), 1929–1937. https://doi.org/10.1007/s13197-013-1251-0

Reshi, M., Shafiq, F., Hussain, S. Z., Naseer, B., & Amin, T. (2020). Physicochemical properties of iron-fortified, low glycemic index (GI) barley based extruded ready-to-eat snacks developed using twin-screw extruder. *Journal of Food Processing and Preservation*, *44*(8). https://doi.org/10.1111/jfpp.14606

Riaz M.N, (2000). Introduction to extruders and their principles. In: Extruders in food applications, CRC Press, Boca Raton, United States of America. Pages 1- 23.

Rice Production in Nigeria 2019/2020 – Steps to Make Money from it. (2019, February 28). Retrieved February 19, 2021, from Information Guide in Nigeria website: https://infoguidenigeria.com/rice-production-nigeria-2018-2019/

Rivera-Mirón, M. I., Torruco-Uco, J. G., Carmona-García, R., & Rodríguez-Miranda, J. (2020). Optimization of an extrusion process for the development of a fiber-rich, ready-to-eat snack from pineapple by-products and sweet whey protein based on corn starch. *Journal of Food Process Engineering*. https://doi.org/10.1111/jfpe.13532

Robin, F., Théoduloz, C., Gianfrancesco, A., Pineau, N., Schuchmann, H. P., & Palzer, S. (2011). Starch transformation in bran-enriched extruded wheat flour. *Carbohydrate Polymers*, *85*(1), 65–74. https://doi.org/10.1016/j.carbpol.2011.01.051

Sampang, R.L. (2005). Physical grain characteristics of paddy and milled rice. *In paddy and milled rice grading*. Retrieved from: http://fao.org/docrep/x5048e/x5048E02.htm. Accessed 11th September, 2021.

Seth, D., & Rajamanickam, G. (2012). Development of extruded snacks using soy, sorghum, millet and rice blend - A response surface methodology approach. *International Journal of Food Science & Technology*, *47*(7), 1526–1531. https://doi.org/10.1111/j.1365-2621.2012.03001.x

Sharma, P., Gujral, H. S., & Singh, B. (2012). Antioxidant activity of barley as affected by extrusion cooking. *Food Chemistry*, *131*(4), 1406–1413. https://doi.org/10.1016/j.foodchem.2011.10.009

Sharma, S., Singh, N., & Singh, B. (2015). Effect of extrusion on morphology, structural, functional properties and in vitro digestibility of corn, field pea and kidney bean starches. Starch-Stärke, 67(9–10), 721–728. https://doi.org/10.1002/star. 201500021.

Sibel, Y., & Fahrettin, G. (2008). Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. Journal of Food Engineering, 86, 122–132. https://doi.org/10.1016/j.jfoodeng.2007.09.018

Singh, B., Sekhon, K. S., & Singh, N. (2007). Effects of moisture, temperature and level of pea grits on extrusion behaviour and product characteristics of rice. *Food Chemistry*, *100*(1), 198–202. https://doi.org/10.1016/j.foodchem.2005.09.042

Singh, B., Rachna, Hussain, S. Z., & Sharma, S. (2014). Response Surface Analysis and Process Optimization of Twin Screw Extrusion Cooking of Potato-Based

Snacks. *Journal of Food Processing and Preservation*, *39*(3), 270–281. https://doi.org/10.1111/jfpp.12230

Singh, D. V., Mukhi, S. K., & Mishra, S. N. (2017). Phasic pattern of dry matter production and accumulation in different parts of cowpea cultivars (Vigna unguiculata L. Walp.) during growth and development stages under varied seasons. *International Journal of Current Microbiology and Applied Sciences*, *6*(4), 347-355.

Stojceska, V., Ainsworth, P., Plunkett, A., & İbanoğlu, Ş. (2009). The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. *Food Chemistry*, *114*(1), 226–232. https://doi.org/10.1016/j.foodchem.2008.09.043

Stojceska, V., Ainsworth, P., Plunkett, A., & İbanoğlu, Ş. (2010). The advantage of using extrusion processing for increasing dietary fibre level in gluten-free products. *Food Chemistry*, *121*(1), 156–164. https://doi.org/10.1016/j.foodchem.2009.12.024

Teye, G. A., & Boamah, G. (2012). The effect of cowpea (Vigna unguiculata) flour as an extender on the physico-chemical properties of beef and ham burgers. *African Journal of food, Agriculture, Nutrition and Development*, *12*(7).

Thakur, R. R., Shahi, N. C., Mangaraj, S., Lohani, U. C., & Chand, K. (2021). Development of an organic coating powder and optimization of process parameters for shelf life enhancement of button mushrooms (Agaricus bisporus). *Journal of Food Processing and Preservation*, *45*(3). https://doi.org/10.1111/jfpp.15306

Thymi, S., Krokida, M. K., Pappa, A., & Maroulis, Z. B. (2005). Structural properties of extruded corn starch. *Journal of Food Engineering*, *68*(4), 519–526. https://doi.org/10.1016/j.jfoodeng.2004.07.002

Tosh, S. M., & Yada, S. (2010). Dietary fibres in pulse seeds and fractions: Characterization, functional attributes, and applications. *Food Research International*, *43*(2), 450–460. https://doi.org/10.1016/j.foodres.2009.09.005

Valenzuela-Lagarda, J. L., Gutiérrez-Dorado, R., Pacheco-Aguilar, R., Lugo-Sánchez, M. E., Valdez-Torres, J. B., Reyes-Moreno, C., & Muy-Rangel, M. D. (2017). Expanded snacks based on squid, corn and potato flours mixtures: effect of the extrusion variables on the physicochemical properties. *CYTA-Journal of Food*, *15*(1), 118-124.

Yousf, N., Nazir, F., Salim, R., Ahsan, H., & Sirwal, A. (2017). Water solubility index and water absorption index of extruded product from rice and carrot blend. *Journal of pharmacognosy and phytochemistry*, *6*(6), 2165-2168.

Wang, Y., & Lobstein, T. (2006). Worldwide trends in childhood overweight and obesity. *International Journal of Pediatric Obesity*, *1*(1), 11–25. https://doi.org/10.1080/17477160600586747

Wani, S. A., & Kumar, P. (2016). Development and parameter optimization of health promising extrudate based on fenugreek oat and pea. *Food Bioscience*, *14*, 34–40. https://doi.org/10.1016/j.fbio.2016.02.002

Wells JH (1993) Utilization of rice bran and oil in human diets. *Louisiana Agric* 36: 4-8

Wikipedia Contributors. (2019, February 2). Rice. Retrieved from Wikipedia website: https://en.wikipedia.org/wiki/Rice

Yağcı, S., & Göğüş, F. (2008). Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. *Journal of Food Engineering*, *86*(1), 122–132. https://doi.org/10.1016/j.jfoodeng.2007.09.018

Zabidin, Z., Omar, F. N., Hafid, H. S., Md Yunos, N. S. H., Mohammed, M. A. P., Samsu Baharuddin, A.S, Omura, T., & Wakisaka, M. (2018). Micromechanical investigation of milled and unmilled rice grains through experimental study and finite element analysis. *Biosystems Engineering*, *176*, 48–58. https://doi.org/10.1016/j.biosystemseng.2018.10.006

Zameer Hussain, S., & Singh, B. (2014). Functional Properties of Re-Fabricated Rice as Affected by Die During Extrusion Process. *International Journal of Food Engineering*, *10*(3), 417–426. https://doi.org/10.1515/ijfe-2013-0074

APPENDICES

APPENDIX A1: REGRESSION TABLE

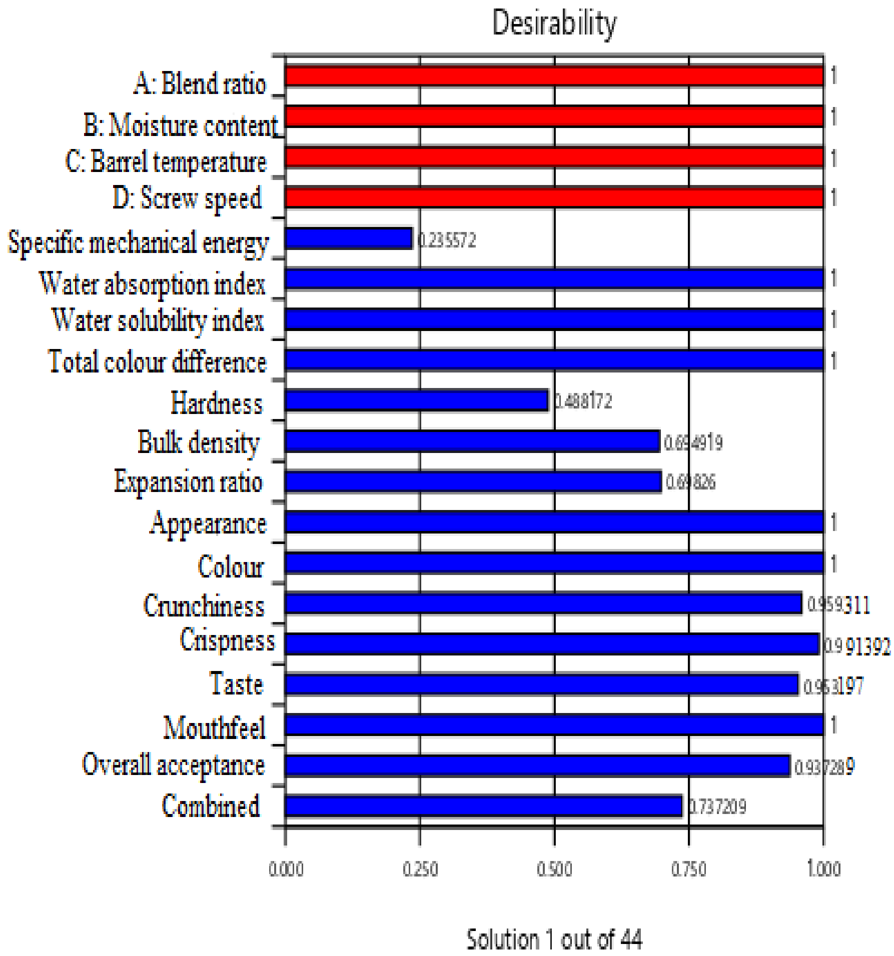
Regression	SME	WAI	WSI	TC	HARDNESS	BD	ER	APP	Color	CRH	CRISP	TA	MF	0A
SD	8.90	2.2345	3.77	2.42	0.2982	81.70	0.1547	0.3491	0.3663	1.10	0.9735	0.6022	0.6687	0.6982
R^2	0.4902	0.7958	0.2393	0.0000	0.6984	0.2261	0.2497	0.7562	0.3583	0.3609	0.3431	0.2327	0.3734	0.3408
Mean	77.44	3.78	8.07	40.97	2.64	456.25	2.51	7.14	7.11	6.22	6.25	6.49	6.47	6.73
Adj. R^2	0.4086	0.6053	0.1176	0.0000	0.4169	0.1022	0.3733	0.5287	0.2557	0.2587	0.2381	0.1099	0.2731	0.2354
C.V%	11.59	6.21	46.77	5.92	11.31	17.91	6.16	4.89	5.16	17.67	15.59	9.28	10.34	10.37
Pred. R^2	0.2038	0.1570	-0.0912	-0.0702	-0.6999	-0.1869	0.2058	-0.2401	0.0454	0.0469	0.0071	-0.1446	0.0808	0.0115
PRESS	3147.57	3.41	510.53	182.37	7.52	2.556E+05	0.8791	9.30	4.99	45.04	35.82	13.52	16.40	18.28
Adeq.prec.	8.0482	7.2765	4.7607	NA	5.1122	5.0581	7.8659	7.1394	6.6319	7.3169	6.9402	4.8476	6.3795	6.3150

A production cost of ₦ 121,912.00 as at March, 2021 was incurred as shown in Appendix A2 of the Bill of Materials.

APPENDIX A2: Cost of production Extruded cereal-based snack

S/N	Material	Qty	Unit Price (₦)	Quantity Price
1	Rice	35 kg	200	7,000
2	Cowpea	7 kg	773	5,412
3	Spice Mix	2kg		2,700
4	Packaging bag (Ziploc, polythene bags)	5 packs		4,400
5	Containers for raw material and finished products			2,000
6	Hardness test	30 samples	333.3	10,000
7	Color test	30 samples	333.3	10,000
8	Minerals (Fe, P, Mn, Cu, Na)	3 samples	2600	7,900
9	Proximate	3 samples	2500	7,500
10	Extrusion fee	30 samples	833.3	25,000
11	Diesel			10,000
12	Miscellaneous			30,000
	Total			**121,912**

APPENDIX B: OPTIMIZATION GRAPH



APENDIX C: PICTORIALVIEW OF THE EXTRUDED SNACK

Figure C1: rice-cowpea ready-to-eat extruded snack

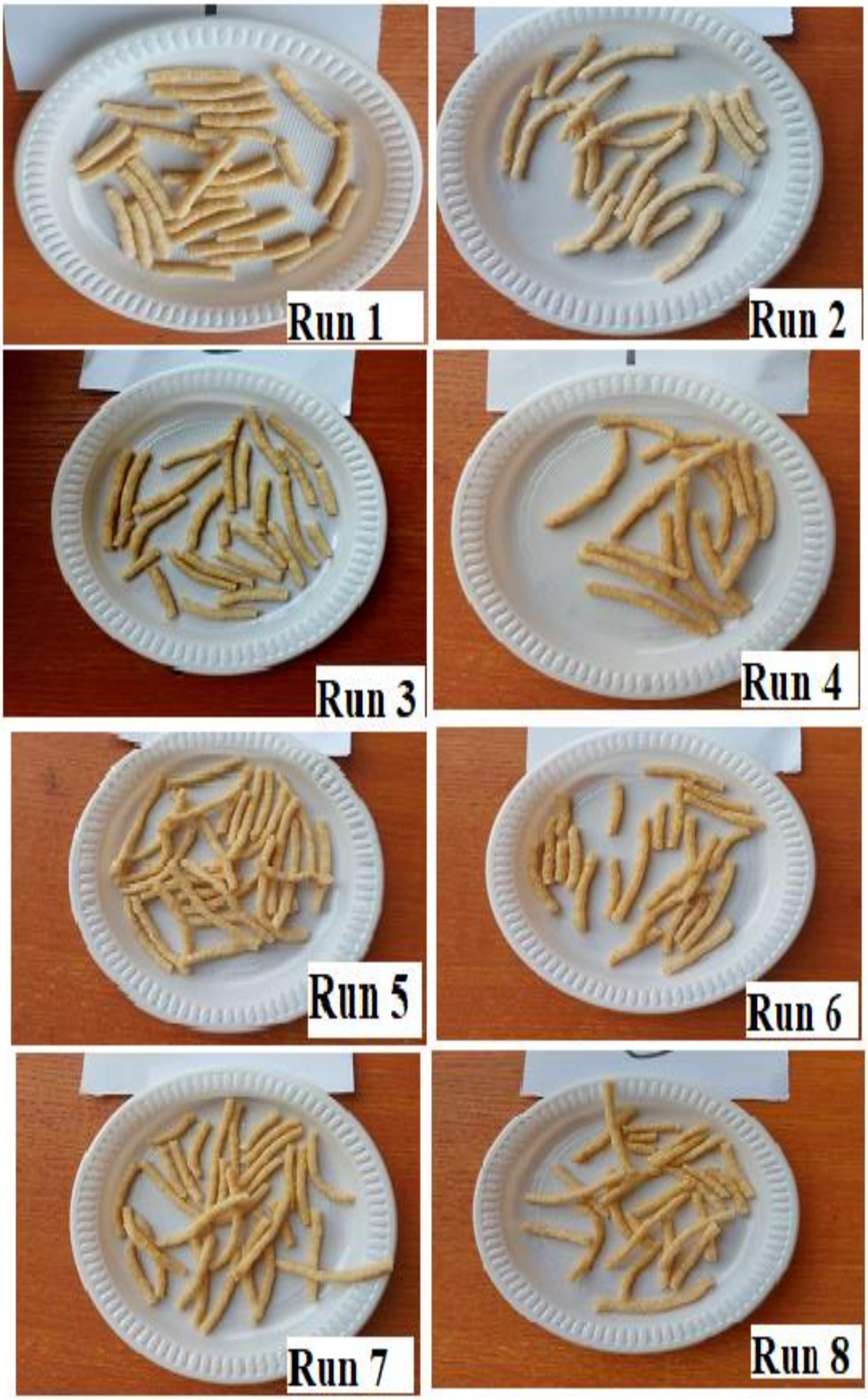


Figure C2: Pictorial view of the extrudates from experimental runs

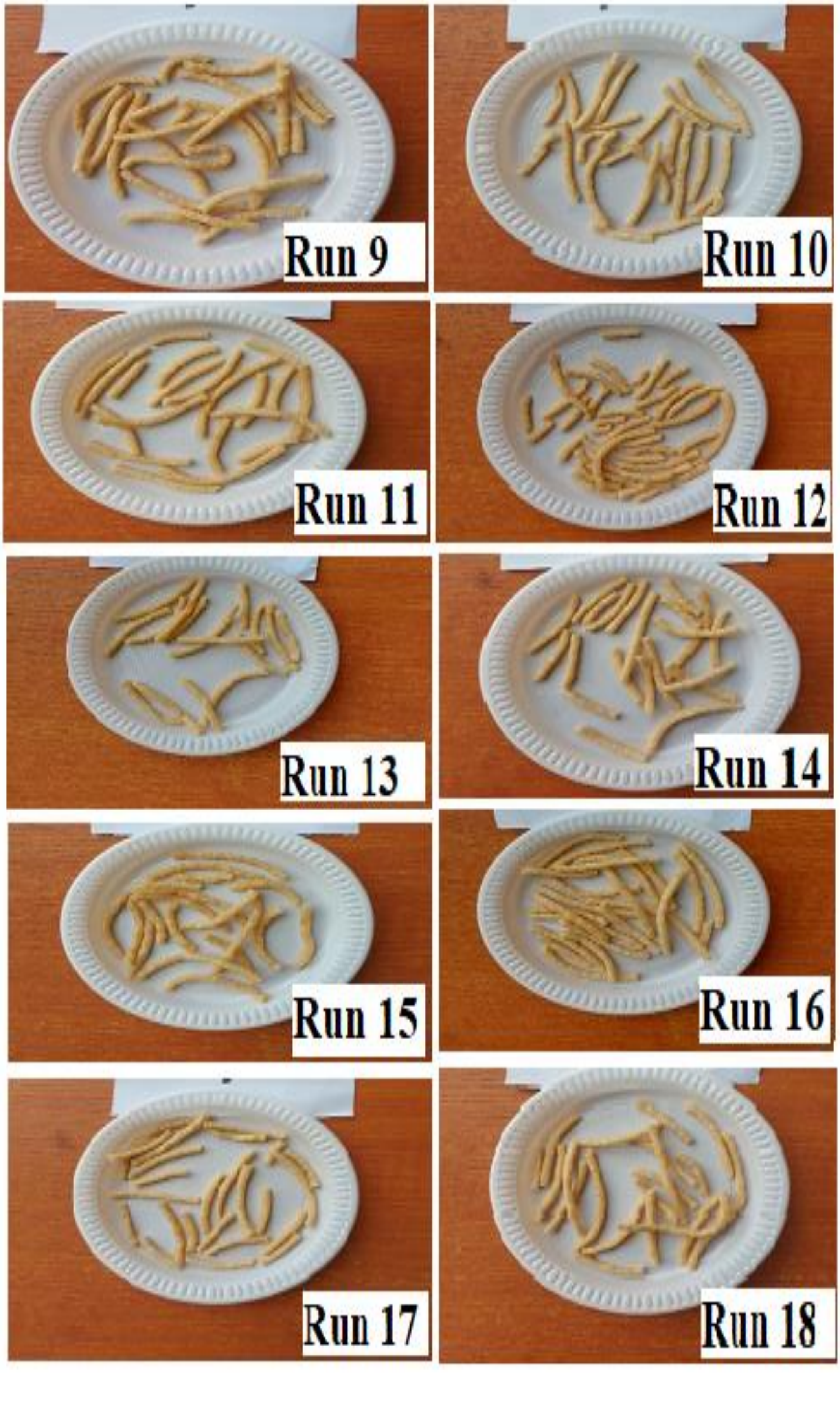


Figure C3: Pictorial view of the extrudates from experimental runs

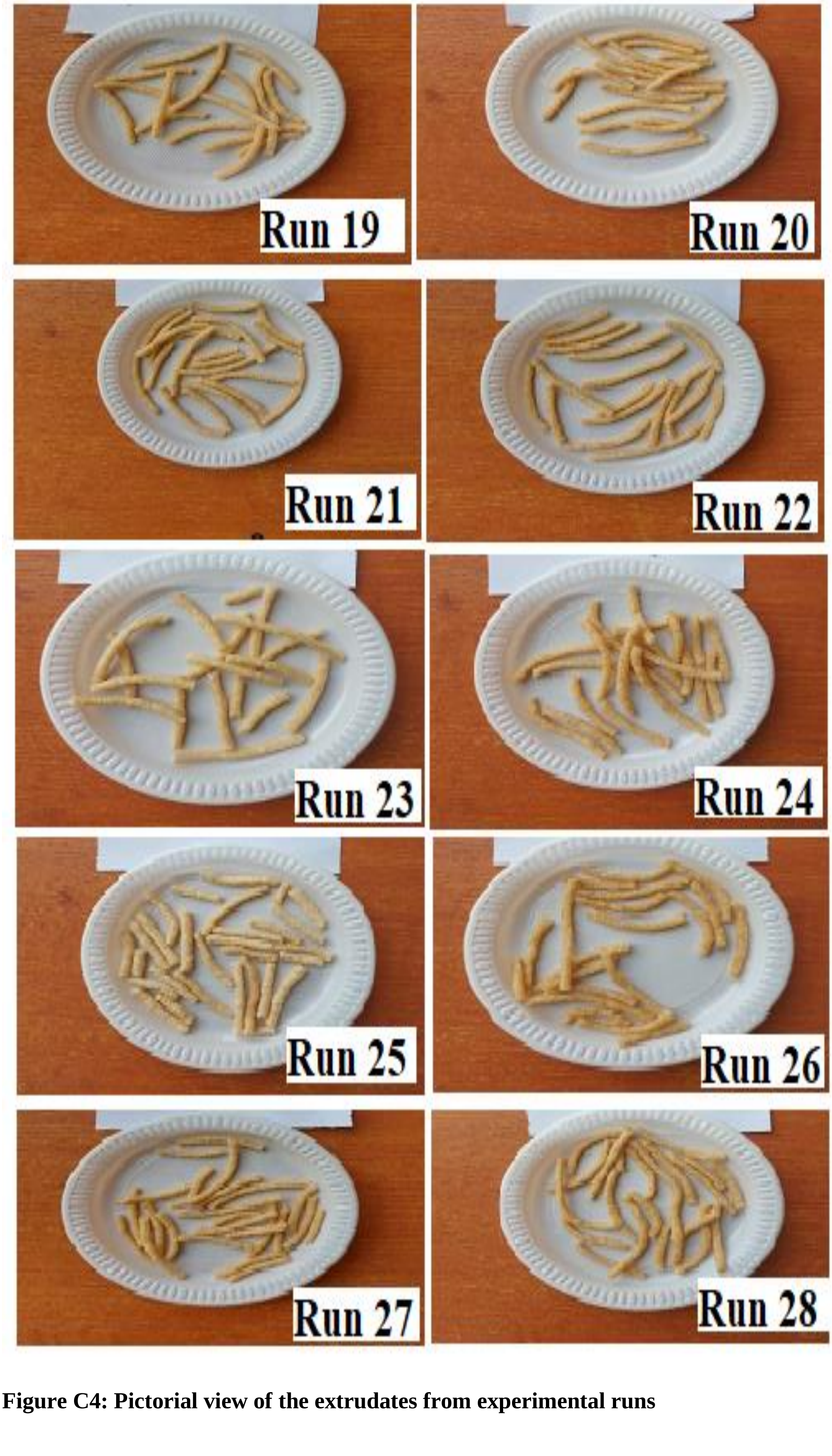


Figure C4: Pictorial view of the extrudates from experimental runs

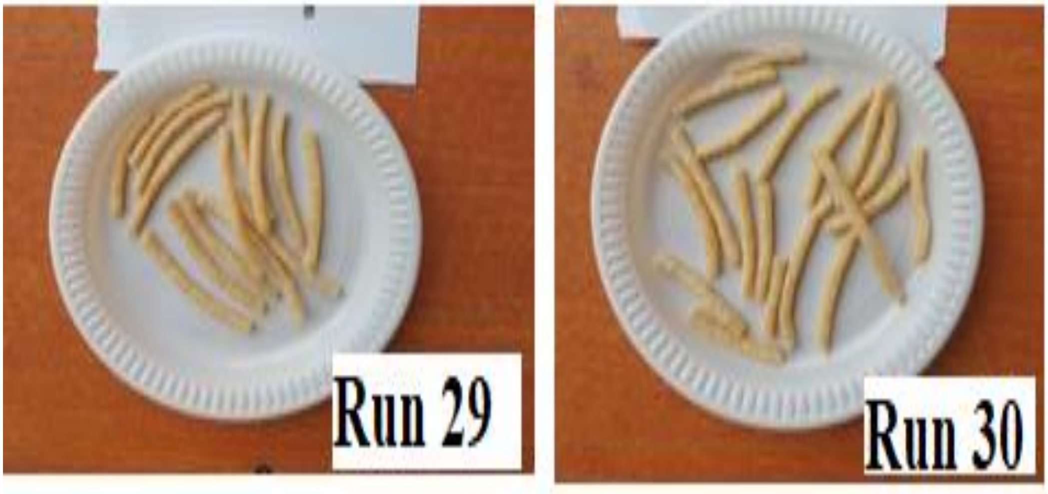


Figure C5: Pictorial view of the extrudates from experimental runs