EXTENDING THE APPLICATION OF ROOT AND TUBER CROPS INTO READY-TO-EAT BREAKFAST FOODS

BY

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A THESIS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL IN FOOD SCIENCE DEGREE.

JULY 2019

DECLARATION

This is to certify that this thesis presents the result of research undertaken by Pamela Owusu Osei, towards the award of Master of Philosophy in the Department of Nutrition and Food Science, University of Ghana under the supervision of Prof. Firibu Kwesi Saalia and Prof. Agnes Simpson Budu.

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ABSTRACT

The demand for convenience, instant breakfast foods has resulted in importations and some local production of expensive products. Since these are generally high carbohydrate foods, exploring and diversifying the use of underutilized local food resources could provide inexpensive and interesting alternatives. This study investigated the use of locally abundant roots and tuber crops to partially substitute maize as the sole carbohydrate in the production of ready-to-eat breakfast foods. Extreme vertices mixture designs were employed to formulate blends of Cassava, Orange-fleshed sweet potato (OFSP) and Bambara groundnut flours to substitute 55% of maize in a ready to eat breakfast food. The flour blends were slurried in water in a ratio of 1:2 and drum dried at a temperature of 175 °C and a drum speed of 35rpm. The products were analysed for proximate composition, functional and physical characteristics. The in vitro protein and starch digestibility for raw and drum dried samples were also determined. Storage stability and conditions were evaluated by modelling the sorption behaviour of the precooked (drum dried) samples. Microbial load, and sensory characteristics were also determined.

Generally, protein, fat and ash contents increased with an increase in bambara groundnut whereas carbohydrate and fibre content increased with an increase in both cassava and orange flesh sweet potato flour. With regards to β- carotene content, an increase in OFSP substitution resulted in a significantly higher concentration ranging from 7.1mg/100g for high OFSP content to 1.5mg/100g for samples with the lowest OFSP. Product colors ranged from yellowish products with high orange sweet potato flour to creamy-white colour for samples with high cassava flour. The protein digestibility was significantly influenced by drum drying and an increase in bambara groundnut. Furthermore, the starch

digestibility of the formulations was improved as OFSP increased. All formulated product fell under low glycemic foods with values ranging from 40.49±1.82 to 47.39±1.92 were observed amongst all formulations. The formulations were mostly smooth as more than 70% of the milled product passed through a sieve size of 140µm. Water solubility index, bulk density and soluble solids increased with an increase in OFSP flour substitution whilst water absorption index, oil absorption capacity, swelling power and viscosity decreased with increase in OFSP substitution. Increase in bambara groundnut increased the oil absorption capacity, emulsion capacity and emulsion stability of the formulations. Similarly, an increase in cassava flour increased the water absorption index and swelling power of flour blends.

Sensory evaluation indicated significant differences ($p < 0.05$) within formulations in terms of colour, sweetness, and overall acceptability of the breakfast product. Generally, flours with high sweet potatoes were rated higher and flours with high bambara rated lower by sensory panellists.

From this study, it can be implied that, orange-fleshed sweet potato, cassava and bambara groundnut flour are promising ingredients that can be used by processors to substitute some amount of cereal in breakfast food production in order to add value, improve nutritional composition (where OFSP will reduce vitamin A deficiency and bambara groundnut contribute protein), as well as contribute to food and nutritional security in Ghana and Sub-Sahara Africa.

DEDICATION

I dedicate this project to the Lord Almighty and to mother, Mrs. Theodora Hammond.

ACKNOWLEDGEMENT

I thank God Almighty for His guidance and shield for these past years in the university and also for His sustenance throughout this project work. I believe He will continue to shower his Blessings on me wherever I go and make me a blessing unto many others as He has promised.

I would like to also acknowledge my supervisors Prof. F.K. Saalia and Prof Agnes Simson Budu for their time, patience, corrections and encouragement that developed this research thesis. God richly bless them.

Also, to Dr. Winfred Nii Okai Hammond and his family for their support. To Dr. Egbi for allowing me to use his laboratory at the Noguchi Memorial Institute for Medical Research, Papa Toa Akonor and Mr. Solomon Dowuona from CSIR-FRI.

I am very appreciative of the help rendered unto me by all the lab technicians of the Nutrition and Food Science Department, thank you very much.

I am also grateful to all my friends who contributed to the success of this project work.

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LIST OF ACRONYMS

AACC	American Association for Clinical Chemistry
AOAC	Association of Official Analytical Chemists
ANOVA	Analysis of Variance
BOPP	Biaxially Oriented Polypropylene
BG	Bambara Groundnut
BGF	Bambara Groundnut Flour
CAC	Codex Alimentarius Commision
CS	Cassava Flour
CIE	Commission Internationale de l'Eclairage
CSRI	Council for Scientific Research Institute
FAO	Food and Agriculture Organization of the United Nations
IITA	International Institute of Tropical Agriculture
LDPE	Low-Density Polyethylene
MF	Maize Flour
MoFA	Ministry of Food & Agriculture
OFSP	Orange Fleshed Sweet Potato
UN	United Nations
WHO	World Health Organization**.**

CHAPTER 1

1.0 INTRODUCTION

1.1BACKGROUND

Breakfast is the first meal consumed in the morning before undertaking a day's work. It is considered the most important part of a day's diet, and this could be attributed to the fact that intake of micronutrient of people who consume breakfast regularly (particularly breakfast cereals) become elevated as compared to breakfast skippers (Fayet-Moore, 2019; Albertson, 2013; Wilson *et al*., 2006). With many people working far away from home due to increasing urbanization, long preparation times for breakfast has led to them skipping it. This trend has created the demand for ready to-eat and convenience foods. Increased demand has also led to the development of processing technologies for the manufacture of ready-to-eat breakfast products to guarantee convenience, safety and quick preparation times. Some of these novel technologies include extrusion cooking, gun puffing, drum drying, freeze drying, and spray drying.

Typically, ready to eat breakfast foods are carbohydrate dense low-fat foods that are usually fortified with vitamins and minerals and may be consumed with milk, which is a significant source of protein, minerals and vitamins (Kanu *et al*., 2009). Cereal grains are the commonest raw materials employed in the manufacture of breakfast products (Ding *et al.*, 2006) and consequently many ready to eat breakfast products are usually referred to as breakfast cereal. Breakfast cereals can be categorized into conventional (traditional) cereals which require further cooking or heating prior to consumption and ready-to-eat cereals that do not need additional cooking or preparation and can be consumed directly from the

package or with the addition of (hot/cold) milk or water (Selvarajn, 2012). Some traditional breakfast cereals consumed in Ghana, include Tom-Brown (roasted and milled maize–rice–groundnut blends), corn porridge, rice porridge, and millet porridge.

Wheat and corn are the major cereal crops used in processing of ready-to-eat breakfast products due to their unique functional properties (Fast *et al.*, 2000). It is estimated that wheat imports (wheat grain and flour) into Ghana stands at approximately 700,000 MT per annum (Sachroede, 2018).

This constitutes a huge strain to the Ghanaian economy, and alternative commodities for wheat need to be evaluated for breakfast cereal applications. Complete elimination of wheat in the local food systems may create technical challenges as it contains gluten protein which imparts exceptional functional characteristics in food applications. Nevertheless, the use of food resources such as maize and the application of appropriate processing technologies could provide convenient products with consumer acceptable qualities.

Other food resources that could be considered for such applications are the roots and tubers, to replace the cereals. They are popularly used as staple foods (Liu *et al*., 2006) and they play a very important role in food security because they are tolerant to environmental stress and produce reasonable yields under marginal soil conditions. Roots and tubers (particularly cassava and sweet potato) are quite abundant in Ghana, and have been the subject of a great deal of research effort to process them into flour and use to substitute wheat flour in some foods (Rahman *et al.*, 2003). Apart from them being very high sources of carbohydrates (starches and fiber), roots and tubers generally have relatively very low and poor protein quality. On the other hand, legumes, which also abound in Ghana, are

rich in proteins, minerals and vitamins. Legume proteins have been established to be a natural protein suitable to complement the proteins in cereal grains (since cereals lack both lysine and threonine which are abundant in legumes). By supplementing cereals with legumes, a complete protein would be obtained (Dhingra and Jood, 2002).

1.2 RATIONALE

In Ghana, ready-to-eat breakfast food products on the market are generally relatively expensive. This has been associated with importation of wheat as the raw material, or the finished product. Maize on the other hand is locally cultivated, but suffers fluctuations in yield of production from year to year. Root crops (particularly cassava) is abundant in Ghana, are carbohydrate dense and rich in minerals. Furthermore, a specific sweet potato variety, the orange fleshed variety, is very rich in beta carotene and consequently has the potential to improve the vitamin A status if it is part of the meal hence the need to promote its cultivation and utilization (Adenuga, 2010).

Significant amount of work has been done by partially substituting wheat flour with high quality cassava flour and/or sweet potato flour in bread making (Abioye *et al*, 2016; Bonsi *et al*.,2014; Chiu *et al*., 2013; Eduado *et al.*, 2013; Adeleke and Odedeji 2010; Jisha *et al*., 2010). Furthermore, extensive work has been done using several combinations of cereal-legume blends (Afoakwa *et al.*, 2007; Mensa-Wilmot *et al.*, 2001) in complementary foods formulations. Formulation of ready to eat breakfast food products using local food resources will not only reduce the market cost, but also promote their cultivation and diversify their utilization. Cassava and sweet potato are high starch food crops that can be used to partially replace corn which is frequently used in breakfast cereals. Orange flesh sweet potato has been promoted for its high carotene content. More over sweet potato has

high amounts of β-amylases that help transform the starches during heat processing into maltose thereby improving the sweetness and flavor of the product. Bambara beans are locally produced starchy legumes that are highly underutilized in food applications despite their high protein and minerals profile. Incorporation of Bambara beans in a breakfast food would improve its utilization and at the same time improve the protein and mineral profile of the food. Application of cassava, sweet potato and Bambara beans in a ready to eat breakfast food formulation to partially replace maize and improve the protein and mineral profile could afford an interesting product with unique characteristics.

1.3 MAIN OBJECTIVE

The main aim of the study was to develop a ready-to-eat breakfast using cassava, sweet potato, bambara beans and maize flours and to evaluate the physical, chemical, functional and sensory properties of the product.

1.4 SPECIFIC OBJECTIVES

The specific objectives are to:

- Formulate a breakfast food blend consisting of high-quality cassava flour, orange fleshed sweet potato flour and bambara bean flour.
- Assess the physicochemical properties of the pre-cooked (drum dried) breakfast food formulations
- Investigate the individual effects of cassava flour, orange fleshed sweet potato flour and bambara groundnut flour on the functional properties of the drum dried breakfast food formulation.
- To determine the sensory properties of the drum dried breakfast food formulations.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Breakfast Foods

Cereals are used in producing breakfast foods. They are dry seeds from the grass family grown purposely for their seeds. Breakfast foods can be defined as dry seeds eaten during breakfast, which have been transformed through roasting, grinding, soaking, rolling or flaking and sometimes shredded or puffed (Mbaeyi-Nwaoha & Uchendu, 2016).

2.1.1 Categories of Breakfast Cereals

Breakfast cereals can be classified into two major groups. Namely; hot cereals (HC) and ready-to-eat (RTE) breakfast foods. HCs are products of a single grain or a simple mixture that require cooking or heating in water to form a gelatinized starch before consumption (Kadan and Caldwell, 2003). In Ghana, cereals such as maize, sorghum and millet are locally fermented and used in the preparation of porridges. These cereals are often complemented with legume to provide a high quality and cheaper protein (Temba *et al*., 2016).

RTE cereals are prepared from one or several grain components with other ingredients (such as nuts) and are mostly fortified with vitamins and mineral. They require extensive processing and are normally produced on industrial basis. However, RTE breakfast cereals when purchased do not require further cooking. Most of these RTE breakfast cereals, may or may not contain milk and are usually reconstituted before consuming. These include; oven-puffed cereals, flaked cereals, drum dried cereals, gun-puffed whole grains, extruded flaked cereals, shredded whole grains extruded shredded cereals, and extruded gun-puffed cereals (Kadan and Caldwell, 2003).

2.1.2 Advantages of Breakfast Consumption

Numerous studies have confirmed a positive outcome of continual breakfast consumption. Deshmukh-Taskar *et al*., (2010) and Song *et al*., (2006) reported that, the quality of a diet and intake of some essential nutrient such as macronutrient profile of children and adolescent in particular is dependent on breakfast consumption. Barton *et al*. (2005) also supported this assertion by reporting that, children who consume breakfast have a higher chance of absorbing essential vitamins and minerals compared to children who skip. Breakfast foods are also important sources of antioxidants (Ryan *et al*, 2011).

Again, breakfast food consumption was re-counted by Rampersaud *et al*., (2005) and Williams (2007) to have improved nutrient status and positive dietary health benefits. In terms of obesity, regular consumption of breakfast has been disclosed to have been prevented the onset of obesity among adolescents (Panagiotakos *et al*., 2008). Kent and Worsley (2010) also reported that regular consumption of breakfast has been one of the strategies used by successful long-term weight loss maintainers in the National Weight Control Registry. Intake of breakfast has been related to cognitive performance in children and adolescents. Studies by Reeves *et al*. (2013), Panagiotakos *et al*. (2008), Barton *et al*. (2005) and Wesnes *et al*. (2003) corroborated this claim.

2.1.3 Production of Ready-To-Eat Breakfast Cereals

Consumption of ready-to-eat breakfast cereals have increased and this may mostly be because of the absence of time for preparing food in the present times. In the last two decades, efforts have been put in place to limit the amount of time in preparing food. The

technology behind breakfast cereal has advanced from the basic method of grinding grains to highly complex ready-to-eat products that are suitable and rapidly prepared.

The driving forces that has contributed as an advantage to Breakfast Cereals Market include;

1. Convenience: Rapid lifestyle transformation of parents leaving home early to attend to businesses and children to school.
2. Nutrition: Increased consumer preference for healthy diets
3. Innovation: Development of a variety of products with diverse ingredients, flavours, amongst others.

Some major technologies used in the production of RTE breakfast foods are extrusion and drum drying. Several studies have proven that drum drying is an efficient and safe technology to use in the production of ready-to-eat foods. Arrage *et al.* (1992) studied the effect of drum-drying and extrusion at different temperatures on protein quality and concluded that drum drying method improved protein digestibility much better than the extrusion method. Mustafa *et al*. (2014), also suggested that drum drying can be used to improve the sensory attributes of food products.

Also, several studies have investigated the use of composite flours in the production of RTE breakfast foods (Asaam *et a*l, 2018; Saalia *et al.*, 2012; Asare *et al.*, 2004; Amankwah *et al.*, 2009). Cereals are considered the major food group used in the formulation of these composite flours. However, the use of roots and tubers including cassava, sweet potato and

yam as carbohydrate and other nutritional sources have gradually been introduced. (Amagloh *et al.*, 2012, Laryea *et al* (2018).

2.2 Composite Flour Production

Composite flours are described as "two or more mixtures of flours from other crops with or without wheat flour" (Shittu *et al.* 2007). Composite flours are traditionally identified as the combination of wheat flour with cereal and/or legume flours for production of bread, pasta, porridges, snack foods, amongst others (Chandra *et al.*, 2015). Siebel (2011), also defined composite flours as a combination of high starch tubers and legumes which are processed into flour. Examples of these are cassava and peanuts flour, which in turn increases the essential nutrients in human diet.

Duodu and Minaar (2011) explained that the main reason of making composite flours is to improve nutritional quality. In addition, the use of composite flour in developing countries would lead to the saving of hard-earned foreign currency and promotion of high-yielding indigenous crops, enhancing a proper source of energy and nutrients for human nutrition and improving the general use of agricultural produce domestically (Duodu and Minaar, 2011; Bugusu *et al.*, 2001). Reports by Noorfarahzilah *et al.* (2014); Abdelghafor *et al.* (2011) and Falade and Akingbala (2008) suggested that continuous application of composite flours to partially or completely substitute wheat flour would greatly reduce importation of wheat.

A wide range crops may be used in formulation of composite flours. These may include; maize, rice, millet, sorghum, barley, cassava, sweet potato and yam. The different formulations of composite flours significantly affect the content of crude proteins, fat, fibre and ash (Shahzadi *et al.*, 2005). Amagloh *et al.* (2012) observed a significant nutritional

benefit in sweet potato-based composite flour than the maize-based composite flour to be used for complementary feeding. Nonetheless, in selection of raw materials, factors such as availability and cost of crop, compatibility as well as the nutritional aspect of the crop must be taken into considerations.

2.3.0 Components to be used in formulation of ready to eat breakfast

Root and tubers are the most important staple in most tropical countries especially Africa. Examples include cassava, sweet potato, yam, cocoyam, taro, Irish potatoes and a variety of aroids but the most widely produced and consumed is the cassava root (Padmaja, 2012; Scott *et al*., 2000).

2.3.1 Cassava

Cassava (*Manihot esculenta* Crantz) also called manioc is a high yielding crop, which originated from South America along the Amazon Basin. It was introduced in the sixteenth century to Africa by Portuguese explorers (Onwueme, 2002). It is a major root crop and an important staple food for over 500 million people in the developing world (Falade, 2010). It is cultivated and consumed in approximately 102 countries. Among several crops rich in starch, it is known to be very important (Afoakwa *et al*., 2012). It is essential to Africa because; it is starchy, has a thick-tuberous root, serve as a source for readily available calories, whereby it supplements developing countries that face problems of malnourishment (Montagnac *et al*., 2009).

2.3.2 Distribution of Cassava

Cassava is a dicotyledonous perennial plant grown in tropical and sub-tropical Africa regions with mean rainfall ranging from 500mm- 8000mm (Allem, 2002). Cassava can also be grown with other crops such as melons, yams, sweet potatoes and groundnuts and its roots can be reaped between six to thirty-six months.

This crop is widely distributed in tropical South America, South East Asia and West Africa (the Congo basin) (Onwueme, 2002). In sub Saharan Africa, cassava contributes to one third of all the staples and is also grown exclusively in 39 African countries (Oluwamukomi *et al*., 2011). It is probably Ghana's most important root crop. Over the past decade, annual production has steadily increased and is currently estimated at ten million tons of fresh roots per year. Cassava roots have contributed significantly to the economy of the country as regards its share of Agricultural Gross Domestic Product (AGDP) and the production of the crop over the years. Ghana is one of the largest cultivators of cassava in world, producing more than 13 million metric tonnes all year round (FAO STAT 2011), this makes it an essential agriculture product, making up of over 20 % of Agricultural Gross Domestic Product (Ministry of Food and Agriculture, 2005).

In Ghana, cassava is considered as an important source of carbohydrate (Bayitse *et al*, 2017). It is able to grow on marginal lands and requires less cultural practices even under unfavourable conditions, making it an important crop (Howeler, 2002).

2.3.3 Nutritional Composition and Health Benefits of Cassava Roots

Cassava cultivation is greatly expanding due to the extensive range of foods, which could be made from the roots and nutritious leaves (Lebot, 2009.) Cassava is rich in energy and contains an appreciable amount of water and carbohydrate content. It has a moisture composition between 60 to 64 per cent, and about 34 and 94 percent for carbohydrates for fresh and dry matter basis respectively (Balagopalan *et al*, 1988). However, it is a very poor source of nutrients comparing it to other tubers, as it has minimal amounts of proteins and fat and is mainly a source of carbohydrates. It is relatively rich in calcium as well as vitamins B and C (Chijindu and Boateng, 2008). A cassava-based diet must be supplemented with enough protein source of good quality to balance its nutritional content. Factors that affect the nutritional content of cassava include; age, variety, conditions of soil, climate and other environmental factors ((Montagnac *et al*., 2009). Mostly, the slight change in composition occurs as its ages becoming more fibrous leading to a decline in levels of starch (Balagopalan *et al* 1988).

2.3.4 Traditional uses or importance of cassava in Ghana

Cassava is a very reliable source of carbohydrate and very affordable. It is tolerant to extreme environmental conditions, is available all year round and has high calorie production, it is recognized as a major crop that alleviates food security problems in the tropics where it is mostly cultivated (Afoakwa *et al*., 2012, Hillrock *et al*., 2002). It does not require major input in terms of labour compared to maize, rice and wheat. However, it efficiently converts solar energy and supplies dietary energy per land unit.

Fresh cassava has a lot of uses. The root may be eaten from the fresh form, boiled, pounded to make fufu, fried or roasted. The local people are able to make different food products such as gari, tapioca production, yakayeke, agbelima, agbelikaklo, and cassava dough, as well as starch. Starch made from cassava has varied uses in the paper, textile, pharmaceutical, oil drilling and petrochemical industries. Other traditional products such as fufu flour and kokonte are obtained through the cutting, drying and milling of cassava into fine powder (flour). Institutions like; Food Research Institute of the Council for Scientific and Industrial Research and other private businesses has begun producing fresh convenient cassava products such as fufu flours to encourage cassava consumption and add root value. Though these products are popular to the Ghanaian consumer, they are not on high demand (Ministry of Food and Agriculture, 2005).

2.3.5 Cassava Flour

Cassava flour is powder obtained from cassava roots and is white or cream coloured containing no modified starch. The quality of the flour is however affected by manufacturing processes. The quality is judged by factors such as the granule size, flour colour, smell and purity, fibre and ash contents, humidity, acidity and viscosity (Maneepun, 1996). Adejumo *et al.* (2011) reported that influences such as being relatively cheaper than wheat flour is what gives cassava flour an advantage as a partial substitute for wheat in some foods. Also, functional advantages such as higher water absorption capacity and greater crispiness is possessed by the cassava flour (Falade and Akingbala, 2008)

High quality cassava flour (HQCF) is an un-fermented, odourless, smooth and white cassava flour that has been processed from 10 to 12 months from healthy cassava roots

after planting. They are first peeled, washed, grated, sliced, pressed, disintegrated, sifted, dried, milled, screened, packaged and stored. Processing of HQCF must be completed within 12 hours of harvesting the fresh cassava roots.

HQCF production process was developed to serve as a substitute to the newly introduced wheat flour used in the food and non-food industry and this initiative was formerly conceived by the International Institute for Tropical Agriculture (IITA) in Nigeria (Falade and Akingbala, 2008). In 1998, through an IFAD (International Fund for Agricultural Development committed) funded project in collaboration between IITA (Nigeria), and the Food Research Institute (FRI) of Ghana, HQCF was introduced in Ghana.

Besides the traditional use of HQCF, it has varied uses in the food and beverage, plywood, paper and pharmaceutical industry (Chuzel, 2001). In the food industry it may be used in the manufacture of noodles, pastries, baby foods, amongst others. There is therefore the need to investigate the operations involved in the processing of the various cassava- based products of industrial potential.

2.4.0 Sweet potato

Sweet potato (Ipomoea balatas (L) Lam) is an herbaceous perennial dicotyledonous plant which comes from the botanical family Convolvulaceae, consists of 55 genera and over 1000 species (Watson and Dallwitz, 2000). As a source of food, it is only Ipomoea batatas from the family that is of economic importance (Onwueme and Charles, 1994). Sweet potato (Ipomoea batatas) is a native crop cultivated on soils low on nutrient and can grow well in harsh weather conditions. It is an important crop for tropical soils because of its

ability to do well without fertilizer. According to Van oirschot *et al*, (2003), it earned the name "hot weather crop" due to its ability to tolerate drought

2.4.1 Origin and Distribution of Sweet Potato

Central America saw the domestication of Sweet potato over 4000 years ago, and known to be its birthplace (Ishiguro *et al*., 2003). According to (FAOSTAT, 2013), Sweet potato is an equally important crop in the world just like other grain, tuber and leguminous crop terms of production. In Ghana, it is known to be fourth most significant root crop after cassava, yam and cocoyam of which annually production is estimated around 135, 000 tonnes. Sweet potato root is grown more than 100 countries and are cultivated on about nine million hectares, yielding 140 million tons with an average yield of about 1 ton/ha (FAO, 2015; Ishiguro *et al*., 2003). China and some African countries are known to be the highest producers of sweet (FAO, 2015). They are cultivated primarily in developing nations, accounting for more than 95% of world production. Asia grows majority of the world's sweet potatoes, whilst Africa produces 15%, and just 5% are produced by the rest of the world. In Ghana, the sweet potato is an important food crop since it is widely grown on subsistence basis, and serves primarily as an insurance crop for the food security of smallholder households in certain areas of the country. Relatively, sweet potato is a short season crop grown from the vines that requires little labour and inputs outside the farmers' household. It is also very useful based on its cash income generation per unit land area, time and other inputs.

2.4.2 Nutritional Composition

Sweet potato is a starch material containing vitamins (thiamin, riboflavin, niacin, ascorbic acid) biologically active phytochemicals namely antioxidant, beta-carotene, polyphenols, amongst others; and natural sugars, such as glucose and fructose (Lai *et al*., 2013; Vimala *et al*., 2009; Ahmed *et al*., 2010). The storage root of sweet potato provides considerable amount of carbohydrates compared to other root crops but has lower protein content (Tomlins *et al.*, 2010). The leaves contain calcium, zinc, sodium, potassium, iron, magnesium, manganese, vitamin C and are high in fibre (Antia, 2006).

Sweet potato comes in different varieties as well as skin colour, which can affect levels of phenolics, carotenoids and anthocyanins. Some varieties in Ghana may include; Apumoden, Ligri, Faara, Bohye, Dadanyui, Okumkom and Sauti. Their skin colours come in dissimilar shades of white, creamy, red, reddish-purple, tan and yellow-orange. Sweet potatoes are rich in other minerals such as ß-carotene, complete phenolics, anthocyanins, ascorbic acid, nutritional fibre, folic acid and other minerals (Bovell-Benjamin, 2007, ILSI, 2008). According to Van den Berg *et al*, (2000) and, Steed, and Truong (2008), large quantities of anthocyanin and β-carotene are found in the red and orange-fleshed sweet potatoes. Darker orange flesh sweet potatoes are rich in β-carotene content, and are lower in cream coloured sweet potatoes and deep orange coloured sweet potatoes (Burgos *et al*., 2001). The β-carotene is common in vegetables and fruits (Bureau and Bushway, 1986).

2.4.3 Importance and Health Benefits of Sweet Potatoes

Owing to the high nutritive qualities of sweet potato, it is being used in health campaigns all over the world. By ensuring dietary fortification, diversification, supplementation,

amongst others endemic health problems such as vitamin A deficiency (VAD) may be addressed.

The yellow and orange fleshed variety are great sources of carotenoids for pro-vitamin A. It is one of the sweet potato varieties promoted as a food-based measure in sub-Saharan Africa to complement other attempts to reduce VAD (Low *et al*, 2009; van Jaarsveld *et al.*, 2005). It has the potential to combat blindness that results from the deficiency in Vitamin A and reduced mortality among African children a year (CGIAR, 2000).

Several dietary strategies have been in place to combat VAD. These may include dietary diversification, which may be achieved by producing β-carotene-rich crops such OFSP (van Jaarsveld *et al.*, 2005). Attaluri and Ilangantileke, (2007), observed that consumption of 100g per day of orange fleshed sweet potato roots would provide children with the recommended daily amount of vitamin A. A study conducted in South Africa through a feeding program proved that consumption of OFSP would improve vitamin A stores. After OFSP was feed to the consumers, the vitamin A liver stores were elevated (van Jaarsveld *et al*., 2005).

In addition, these carotenoids have antioxidant properties. The β-carotene, vitamin C and anthocyanins function by eliminating free radicals in the body. These Free radicals destroy cells and cell membranes that are known to prevent illnesses such as cancer, atherosclerosis, heart disease, liver dysfunction and protect the body from infection (Saigusa et al., 2005). Other health benefits of sweet potatoes include enhancing memory function, lower insulin resistance and stabilize blood sugar levels (Han *et al*., 2007; Ray and Tomlins, 2010; Wu *et al*., 2008). Again, because they digest easily, their residues are removed and they detoxify the mammalian system by binding to heavy metals. The roots

and leaves are sometimes used as traditional medicines to address important sicknesses night blindness, asthma, and diarrhoea (Loebenstein, 2009).

The major sugars occurring in raw storage roots are sucrose, glucose and fructose (Woolfe, 1992). However, low concentrations of maltose in raw storage roots have been reported (Bradbury and Holloway, 1988; Truong *et al*., 1986). Sugars that are present in the uncooked roots (principally sucrose, fructose, and glucose) and maltose, which is formed during baking, are responsible for the sweetness (Kays *et al*., 2001). The concentration of maltose increases significantly during cooking due to starch hydrolysis (Woolfe, 1992), whilst enzymes found in sweet potatoes are able to accelerate the processes within the tissues of an individual (Woolfe, 1992). Amylases are the most important enzyme found in both cooked and processed sweet potatoes, they are the alpha- and beta- amylases, originally known as diastase.

2.4.4 Uses of Sweet Potatoes

Sweet Potato is a staple food for millions of people. It is a versatile crop with multiple uses. The leaves may be consumed as vegetables or may be processed into starch, soy sauce, flour, feed for animals and alcohol (Lebot, 2009; Yadav *et al*., 2006).

More than eighteen percent of the world's starch is derived from sweet potatoes (Ishiguro *et al*., 2003). These starches are used in the bakeries and for producing some pastries., In Ghana, sweet potato is mainly used in place of rice, cassava, yam, plantain and other well-integrated staples (Adu-Kwarteng *et al*., 2002; Zuraida, 2003). Thus, they can be boiled, steamed, roasted, fried, baked and canned.

Sweet potatoes also serve as raw materials for industrial purposes. They are mixed with other grains such as wheat or maize in other to produce bakery products. This goes a long way in preventing post-harvest loss of fresh produce thereby extending the shelflife of sweet potatoes (Adeleke and Odedeji, 2010)

Consumption has improved owing to a number of global trends and changing lifestyles (Kreger, 2011), which has a resulted in the demand for healthy snack, sweet potato is being add to other flours in the production of extruded snack as an alternative for healthy food production.

2.5.0 Bambara Groundnut

2.5.1 Botany and Agronomy of Bambara

Bambara groundnut or sometimes called bambara beans (Vigna subterranea (L.) Verdc.) is a pulse that is believed to have originated from West Africa and is widely cultivated in tropical regions (Borget, 1992; Okine, 2013). They are grown throughout West Africa, sub-Saharan Africa, and occasionally cultivated in some parts of the world (Baudoin and Mergeai, 2001). In West Africa, they are known to originate of from northern parts of Cameroon and Nigeria. In addition, it is found in parts of Asia, America, and Australia; especially in the tropics (Brink *et al*., 2006).

Bambara groundnut (BG) is an indigenous African leguminous crop and is said to be highly ranked legume following cowpea and peanuts (Mkandawire, 2007). It is known to derive its name from a tribe in central Mali, the Bambara people, near Timbuktu (Goli, 1997). The crop has been dispersed throughout Africa by the migrating indigenous people.

It is considered to be drought resistant, and produces higher yields when planted in low nutrient soils (Berchie *et al*., 2012; Azam-Ali *et al*., 2001). Growth may be observed in areas with annual rainfall less than 500 mm (Ocran *et al*., 1998). It is highly resistant to pests (Tweneboah, 2000).

Bambara groundnut is an important legume due to the fact that it is a food security crop, highly nutritious and high in protein hence has a great prospective in addressing the protein deficits in developing countries.

Bambara also helps to maintain soil fertility as a nitrogen-fixing legume. Although usually cultivated in fields where cowpea and groundnut are cultivated, in its adaptation to bad soils and tolerance to drought, BG is regarded to have a benefit over these plants. BG performs well when groundnut, corn and even sorghum are too arid (Thottappilly and Rossel, 1997).

2.5.2 Nutritional Composition and Uses

Not only are these legumes nutritious, they are healthy crops. Several studies have reported the nutritional make-up of these seeds, particularly as a protein source (Oyeleke e*t al*., 2012; Ijarotimi and Esho, 2009; Belewu *et al*., 2008).

Nutritional analyses performed by various researchers documented the average levels of carbohydrates, protein and fat in the form of oil were about 65%, 20% and 6.7% respectively (Ijarotimi and Esho, 2009; Azam-Ali *et al*., 2001). In addition to its reported drought tolerance, bambara groundnut seed also makes a complete feed for both humans and animals. Essential amino acids are well-balanced (Belewu *et al*., 2008).

Bambara groundnut plays a vital role in the traditional meal preparation in the western part of Africa and Yao *et al*. (2005). Consumption of the bean is common in Côte d'Ivoire, Zimbabwe, Nigeria and Cameroon (Uvere *et al*., 1999; Goli, 1997). Beans from Bambara can be consumed fresh or boiled while they are still immature. The seed is used to make flour in Côte d'Ivoire, making it more digestible. The beans are cooked, pulverized and used to create a sauce in East Africa. It is also possible to use the flour to create a rigid porridge. Bambara groundnut may be boiled, crushed or roasted (Hillocks *et al*, 2012). In Ghana it is boiled and consumed with sugar.

Some varieties of Bambara have been observed to have relatively high amounts methionine and lysine, though legumes lack sulphur- containing amino acids (NRC, 2006; Azam-Ali *et al*., 2001). Less effort has, however, been dedicated to the potential of bambara groundnut seeds and other parts of the bambara plant, as an avenue to source nutrients for both humans and animals.

2.6.0 Maize

2.6.1 Maize Distribution and Production

It is scientifically known as Zea mays and belonging to the family Poacea (Matsuoka *et al*., 2002). The origin of maize has long been a controversial ethno-botanical problem because the origin of maize remains uncertain, although it is generally agreed that its evolution into modern forms took place primarily in Central (Roney & Hard, 2009).

The Portuguese introduced maize to Africa for planting in in the Congo basin and the crop spread throughout the continent due to its high yield and numerous uses however, actual scientific research on the continent started in the early part of the 20th century around the

1930's when white settler farmers in Eastern and Southern Africa especially in Kenya and Zimbabwe set up research stations in maize producing regions to research into maize production and improvement (Gilbert *et al*., 1994).

In terms of production, maize is the leading crop in the world, with 825 MMT (million metric tonnes) produced in 2010. The United States of America is by far the largest producer of maize, producing more than 300 million metric tonnes every year. Besides rice and wheat, it is the next most important cereal grown. However, unlike the other two major cereals, maize is mostly used as animal feed, with only 15% of grain used for food. Africa consumes about 30% of world food maize with an average per capita consumption of about 50 kg with Sub Saharan Africa consuming the vast majority (FAOSTAT, 2011). The crop is also grown under a wide range of conditions ranging from soil type, soil fertility, moisture level, temperature and cultural practice (Abdulai *et al*., 2007). Maize is consumed by many people, particularly in developing countries (Chemeurope, 2013).

In Ghana, maize is mostly grown by peasant farmers and on small scale with low yielding cultivars and therefore leading to low output. It is a staple for most ethnic groups on Ghana (IFPRI, 2014). It makes up to 90 percent of crops cultivated by local farmers and accounts for more than 50% of cereal produced. Apart from cocoa, it is considered as the second largest crop cultivated. This makes it vital crop for food security in the agriculture sector.

Maize is grown in all the agro-ecological zones of Ghana. However, the main areas are in the middle parts of Ghana or the transitional forest zone (FAO, 2010). The area includes Brong Ahafo and parts of Ashanti and Eastern regions. The area planted to maize in Ghana in 2012 was 1,042,083 with production of up to 1,949,897 metric tons (FAOSTATS, 2013).

Based on the demand and usage, maize has replaced many traditional starchy foodstuffs, such as sorghum and millets, particularly in the Northern part of Ghana (Darfour & Rosentrater, 2016; Smith *et al*., 1994) and has become a major source of cash for smallholder farmers (Smith *et al*., 1997). There are a number of industries that are involved in the production and utilization of the maize. They come in as input supplier, processors and marketing channels. All these industries create employment for people in the country and as such provide them with a source of income for their livelihood.

2.6.2 Nutritional Composition and Uses

The crop is of great importance in Africa as a major crop for improving food security on the continent. Maize still provides a major source of calories, especially in parts of Ghana, Nigeria, Benin, Mali and Cote d‟lvoire. Sources of maize include vitamin B, protein, minerals, and above all carbohydrates. It possesses a high antioxidant property and free of gluten. Maize makes-up an contribute immensely to the diet of rural and urban Ghanaians, accounting for 50% of food consumption (Tweneboah, 2000).

The maize plant is economically valuable: the grains are used for food, the leaves and stalk are consumed by animals, and the tassel and the cob possess aesthetic values. The cob is eaten fresh or allowed to mature and dried before it is used to prepare various dishes according to the locality. Some popular dishes prepared from maize in Ghana are kenkey, maize porridge (fermented and unfermented), apapransa, amongst others.

The dried grains are used in making industrial foods such as breakfast foods, snacks, and beverages. It also serves as a good adjunct for the brewing industry. Maize is also used in

the production of quality starch and recently, the emphasis is gradually shifting towards the production of biofuel especially in the United States. (Mishra *et al.,* 2014). other pharmaceutical products.

In the poultry sector, it constitutes about 80 percent of feed. The matured grain is also used as concentrates especially in the temperature regions to feed pigs and ruminants as supplements. The immature plant can also be harvested and fed to livestock in the form of fodder, hay or silage.

2.7.0 Technologies Used in Processing of breakfast foods

2.7.1 Traditional Processing Technologies

2.7.1.1 Soaking

Soaking is a commonly practiced technique used in processing cereal based foods. It has been said to eliminate antinutritional factors such as phytates in food products (Wang, 2008; Perlas & Gibson, 2002). Hotz *et al.* (2001) reported that, soaking followed by decanting reduced the quantity of phytate in maize flour by about 57% however micronutrient was leached into the decanted water hence a significant loss of micronutrient. Soaking accelerates enzymatic activities leading to the breakdown several components into simpler compounds which alter the texture, flavor, aroma and taste (Zamindar *et al.,* 2013; Parveens and Hafiz, 2003). The mineral bioavailability of the food material (cereal) was also seen to have improved when soaking was done for longer period of time without onset of fermentation or malting (Duhan *et al.,* 2002). Again, soaking causes grain to imbibe water thereby softening the seed coat and making it easier be removed. Soaking of rice grains before wet milling was reported by (Chiang & Yeh, 2002) to have enhanced the

loosening of the fine structure of the rice and reduced starch damage. Softening of grain may also shorten cooking time Typically grains such as maize, millet, sorghum, and legumes such as beans, peas and soybeans are soaked during processing.

2.7.1.2 Roasting

Roasting is the process used to describe any food material tossed over dry heat. It is done over a low temperature for a longer time (140- 200ºC for 2–3 min). Roasting causes gelatinization of starch, denaturation of protein, Maillard reaction, sugar caramelization and also inactivation of antinutritional factors (Toledo and Brody, 1999).The process exhibits an intense change in the moisture content, appearance, taste, aroma and texture, and also inactivates enzymes and microorganisms, thereby enhancing the shelf-life of the product (Fellows, 2009). Mridula (2007) also reported that roasting improves the flavour, texture, and nutritive value of grains. The time and temperature at which food is roasted may affect the colour of the flour and this may vary between brown to yellow. Colour is an essential quality indicator of roasting. Toledo and Brody (1999) recorded that, more appealing flavours such as carbonyls compounds were developed during roasting whiles volatile substances such as hexanal were removed by evaporation. Roasting is also one of the simplest methods used to remove the outer seed coat or hull of some pulses.

2.7.2 Industrial Technologies Used In Production Of Ready-To-Eat Breakfast Foods

2.7.2.1 Drum Drying

Drum drying (roller drying) is a conductive food dehydration method in which moisture is removed from a thin paste of slurry applied to the surface of revolving hollow metal drum

(or drums), that are heated internally by steam (Valous *et al.*, 2002). A typical drum dryer must have a revolving drum (drums), a boiler to produce steam, feeding system and a scraper (Tang *et al.*, 2003).

Drum drying is one of the most energy efficient drying methods and is predominantly effective for drying high viscous liquid or slurries (Tang *et al.*, 2003). Drying takes about three-quarters of a revolution from the point of feeding. The residence time of the product on the drum ranges from a few seconds to dozens of seconds to reach final moisture contents of often less than 5% (wet basis). The short exposure to a high temperature reduces the risk of damage to the product (Courtois, 2013). After drum drying, the dried product obtained may be ground into flakes or powder. This product is porous and easy to rehydrate. Courtois (2013), proposed that drum drying is an ideal drying choice for products which need to be cold water soluble, like starches and breakfast cereals.

In food industries, drum drying is used to produce concentrated liquids such as food mixes, powdered milk, potato flakes, fruit pulps, vegetable purees precooked cereals, baby foods, amongst others (Kostoglou and Karapantasios, 2003; Rodriguez *et al.*, 1996). Some studies have shown that drum drying is an efficient and safe technology to use in the production of ready-to-eat foods. Drum drying has been found to affect the chemical, functional and physical properties of the product. Occena *et al*. (1997) reported that, drum drying reduced the amount of antinutrients such as tannins, trypsin inhibitor and phytohemagglutinin in food this was also corroborated by Mbugua *et al*., (1992) and Arrage *et al.* (1992) who also added that drum drying improved protein digestibility. Bencini (1986) reported that chickpea flours with different flavors and functionality can be produced by drum drying with the end products looking very porous and easily rehydrate (Daud, 2006). Laryea *et al.*

(2018) and Amaglo (2012) both deduced that drum drying enhanced the nutritional content and the functional properties of the sweet potato based complementary breakfast food.

2.7.2 **Extrusion Cooking**

Extrusion technology is a novel one that employs high temperature, short-time (HTST), pressure and shear force to produce highly expanded and low-density products with unique functional properties and texture (Villamiel, 2006, Chanvrier *et al.*, 2013). The product's color, flavor, shape, and texture are also affected by the extrusion process. Aside processing advantages, extrusion cooking can also produce some beneficial nutritional and chemical changes in foods (Camire 2002). The food material is forced through a die to puff or form final product. Extrusion cooking combines several unit operations such as mixing, cooking, kneading, shearing, shaping, and forming (Steel *et al*, 2012). The temperature used during extrusion cooking could go as high as 180-190 °C and residence time is usually 20-40 seconds.

Among extruded products, ready-to-eat (RTE) breakfast cereals have gained space because of the convenience and practicality claims associated to these products (Albertson *et al.*, 2013). Several studies have been carried out on the extrusion cooking of cereals and legumes, as well as roots and tubers (Weber et a*l*, 2017; Ding *et al.*; 2006; Pelembe *et al.*, 2002). A wide range of food products have been generated using this method; these include breakfast cereals, pasta, snacks, baby foods, pet foods, and texturized vegetable protein from starchy food material (İbanoğlu *et al.*, 2006).

2.8 Physicochemical and Functional Characteristics of Flour Blends

2.8.1. Colour

Colour is the first characteristic a consumer uses in determining the quality of a food product. This makes it very important. Sometimes, instead of chemical analysis, it is use to determine the presence and absence of a chemical component of food, such as caramelization, deterioration, and pigment degradation, amongst others. For example, instead of running a chemical analysis to determine the carotenoid content of squash, measurement of colour intensity may be used, and this may be due to the fact that there is a correlation between colour and carotenoid content (Guy, 2001). The colour of a product or material may be evaluated using a colour analyzer or colorimeter.

The lightness (L*) is an indication of the brightness, a* redness and b* yellowness of a value and these are used to assess the total colour difference (ΔE*) of a product

2.8.2 Particle Size Distribution

Particle sizes of flours do have a tremendous effect on functionality and quality of end products. These involves the flowability, texture, flavour and mouthfeel (Benkovic and Bauman, 2009; Toth *et al.* 2005; AACC, 2000). It has also been proven that particle size of flour has an effect on the chemical and physical characteristics of flours (Farheen *et al.*, 2012, Wang and Flores, 2002). These particle sizes in foods are determined by the cell structure and the level of which they are processed. Particle size distribution of flour is primarily dependent on the hardness of the grain. The particle size distribution is also affected by a flow sheet of the mill, types of sifter sieves and openings or orifice (Sakhare *et al.*, 2014).

Separation of particles can be achieved by; Air elutriation method involves the use air stream in separating particles with less diameter, which are later suspended and collected, Settling, sedimentation and centrifugation method; particles are separated from the fluid by force of gravity acting on the particles. Finally, the screening method involves separating various particles into fractions by moving them over a screen over a period. The particles recollected on each screen are collected and weighed. Studies on particle size distribution using these methods indicated that flours with fine particle size separated by air circulation method and with medium particle size separated by screening method had better baking quality.

2.8.3 Rheological Behaviour of Fluids

Rheological data are required in defining product quality. Rheological properties are defined as mechanical properties that result in deformation and the flow of material in the presence of a stress.

Rheologically, fluids are grouped into Newtonian and Non-Newtonian fluids. In Newtonian fluids, the shear rate (dv/dz) is directly proportional to shear stress (τ) however, non-newtonian fluids, requires additional parameters in describing their flow behaviour (Steffe, 1996). Non- Newtonian fluids could be shear thinning (pseudoplastic), shear thickening (dilatants), time dependent and time independent (Steffe,1996). A lot of fluid foods have been found to be shear thinning and the power law model has been used to describe their rheological behaviour. Examples of these include fruit pulp and juices (Dak *et al*., 2007; Krokida *et al.,* 2001). For shear thinning fluids viscosity decreases with

increasing shear rate while for shear thickening fluids viscosity increases with increasing shear rate.

Shear stress (τ) is the force applied on the fluid for example the revolutions per minutes (RPM) applied for the determination of viscosity. Whereas shear strain (dv/dz) is the effect of the shear stress on the viscosity of the fluid. Viscosity is defined as the resistance of a fluid to flow.

2.8.4 Functional Properties

Determination of functional properties regarding water-protein or water/oil interactions are of major importance due to the fact that they play essential roles in the sensory characteristics of foods as well as their compatibility with other food components and physical behaviour (rheological characteristic) as ingredients in food systems.

Sreerama *et al*., (2009) defined bulk density as the weight of fibre per unit volume. Bulk density is a good index of structural changes. It indicates porosity of food products and is used in determining the expansion rate of flour (Kraithong, Lee, & Rawdkuen, 2018). On the other hand, increment in fibre also plays a role in the bulky nature of flour sample (Akinjayeju & Ajayi, 2011). To be able to acquire excellent packaging, bulk densities of flour could be increase, since space does not affect the quantity of flour (Fagbemi, 1999). Bulk density can be determined using three different methods, namely; poured bulk density, aerated bulk density and Tapped bulk density. Aerated bulk density is when the volume of the powder is at a maximum, caused by aeration, just prior to complete breakup of the bulk. Poured bulk density (loose) refers to the volume that is measured after pouring

powder into a cylinder. Otegbayo *et al.* (2013) found out higher loose bulk density results in a large oxygen reservoir making it undesirable in packaging of foods.

Water Absorption Capacity (WAC) measures the amount of water absorbed by starch and can be used as an index of gelatinization (Anderson *et al.*, 1969). WAC depends on the availability of hydrophilic groups which bind water molecules and the gel forming capacity of the macromolecules involved. Kaur & Singh, (2005) recounted that, flours with high-absorption capacities for water may also contain high-hydrophilic constituents such as starches and polar amino acid residues which influence their gelation and hydrophilicity capacity Odoemelam, 2003). Onweluzo & Nwabugwu, (2009) also reported that composite flours with low water absorption produce thin meals which are also desirable for infant formulations.

Water solubility index (WSI) describes the rate and extent to which the component of powder material or particles dissolves in water. WSI is often used as an indicator of degradation of molecular components such as degradation of starch (Kirby *et al*., 1988). It also reflects the amount of free polysaccharide or soluble polysaccharide released from the granule after addition of excess water which maintains the integrity of starch in aqueous dispersion (Ding *et al.*, 2006; Chavez-Jauregui *et al*, 2000; Sriburi and Hill, 2000).

The flavour or tastiness of food is improved upon by fat, this makes Oil Absorption Capacity absorption (OAC) an important property in food (Odoemelam, 2003). Popov-Raljić *et al*., (2013) also confirmed that flours with higher oil capacity produced products with adequate flavor. Flour proteins that bind efficiently to oils are useful in food industries. The hydrophobic part of the flour protein interacts with hydrocarbon chains of

the lipid (Eltayeb *et al*., 2011)**.** Oil absorption capacity is critical in bakery because it retains the flavour, improves tastiness and extends the shelf life of food products particularly (Aremu *et al*., 2007; Adebowale & Lawal, 2004).

The differences in the EC of protein could be because of their solubility shown in their lowest emulsifying activity and highest emulsion stability. In addition, Hydrophobicity of protein influences their emulsifying properties (Kaushal *et al*., 2012). Factors such as solubility, pH and concentration influence their properties. These properties are important and are applicable to food products like coffee, whiteners, cake, and frozen desserts. Due to their several compositions and processes, these products should vary in their emulsifying and stabilizing capacity are required (Adebowale *et al*., 2005).

Protein and starch are influencers of Swelling power (Woolfe,1992). Swelling power is restricted when flour has a higher protein content, this causes the starch granules to be buried in a complex protein matrix, restricting the starch to get access to water (Aprianita *et al.*, 2009). Swelling power indicates the ability of starch to hold water (Kaur *et al.*, 2011). Swelling power can be increased if amylose content is low (Adebowale *et al*., 2005). The amylopectin present in flour is primarily responsible for granule swelling (Tester and Morrison, 1990). Moorthy and Ramanujam (1986) reported the extent of associative forces is indicated by the swelling power of granules.

Swelling capacity is a criterion in bakery because, it allows non covalent bonding between molecules in starch and a ratio of α-amylose and amylopectin (Rašper, 1969).

2.8.5 Sensory Evaluation of product

A major aspect of product development is product testing. A new product to be introduced into the market ought to be evaluated in order to ascertain the product's attributes and preference from the consumer's point of view.

Sensory evaluation is a scientific technique used to identify different sensory attributes of products which help to categorize them and asses product acceptability. Sensory evaluation is subjective as it is dependent on the five human senses to perceive the food properties

Measurement of the characteristics of any food product may be based on three main categories (Stone *et al.*, 2012). Namely; Qualitative Descriptive analysis; which requires the use of trained panelists. The panelist uses lexicons with anchors to best describe the product. Preference/likeness test describes how much a consumer likes a product whilst discrimination test determines whether a difference exists between two or more products.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 MATERIAL

Cassava, Bambara groundnut and Maize were procured from Madina market in Accra. The orange-fleshed sweet potatoes were procured from E. Darkey and Associates Limited in Accra. The equipment and chemicals were obtained from the Department of Nutrition and Food Science, University of Ghana, Legon as well as FRI (Food Research Institute).

3.2 Location of study

Various parts of the study were conducted in the Department of Nutrition and Food Science University of Ghana, the Food Research Institute of the Council for Scientific and Industrial Research (CSIR-FRI) and Noguchi Memorial Institute for Medical Research in Legon.

3.3 Methodology

The required agricultural produce used as ingredients in the formulations, ie Sweet potato, Cassava, Maize and Bambara groundnut were individually processed into fine smooth flours as described below:

3.3.1 High Quality Cassava Flour Preparation

Fresh cassava tubers were procured and washed before manually peeling with a knife. The peeled cassava was washed again and then grated into a smooth pulp. The pulp was then pressed/dewatered using a manual screw press to facilitate drying. The pressed pulp was sifted to obtain fine grits and then dried in an air oven at 65°C for 10hrs to obtain a free-

flowing dry cassava flour. The flow chart for producing High Quality Cassava Flour is shown in Figure 3.1.

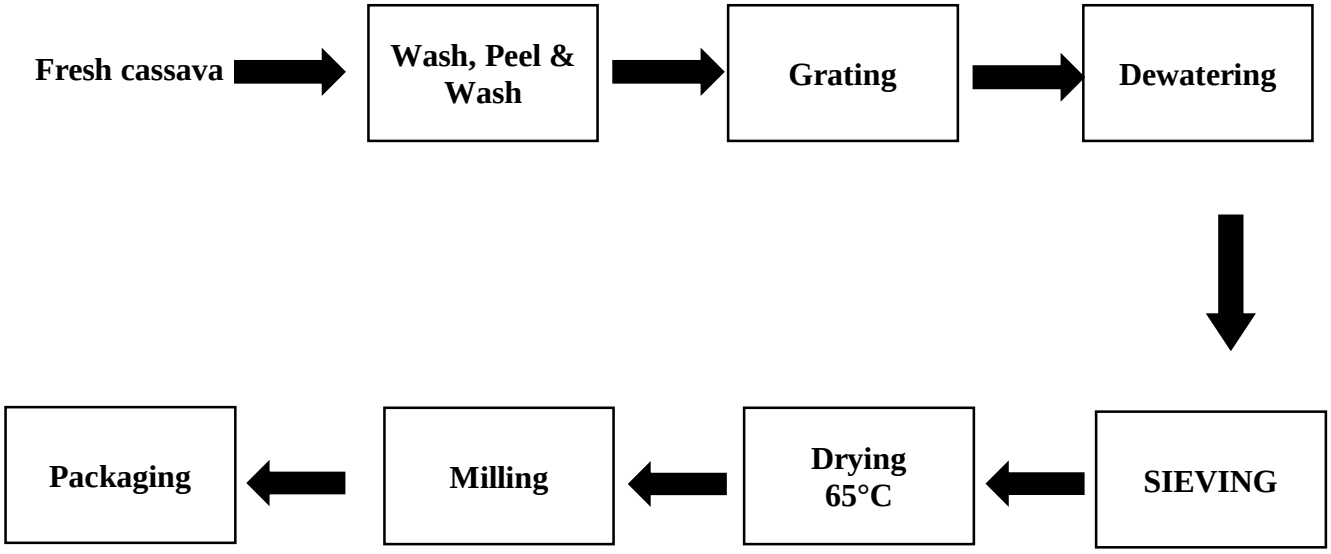

Figure 3.1: Flow diagram for the preparation of High Quality Cassava Flour

3.3.2 Sweet Potato Flour

Sweet potato flour was obtained following the method described by Olapade and Ogunade (2014) with few adjustments as presented in Figure 3.2. Orange fleshed sweet potatoes (*Ipomoea batatas*) were sorted out, prewashed, peeled and washed twice with clean water. The washed tubers were sliced to about 5 mm thickness. They were then submerged in a solution of 0.075% sodium metabisulphite for 5 minutes (to prevent enzymatic browning of sweet potato) and dried at 60 °C in an air oven for 8hours. The dehydrated samples were ground in a disintegrator to pass through a sieve size of 250-µm. The sieved samples were collected into storage bags and stored below 16 ^{O}C for later use in the drum drying process.

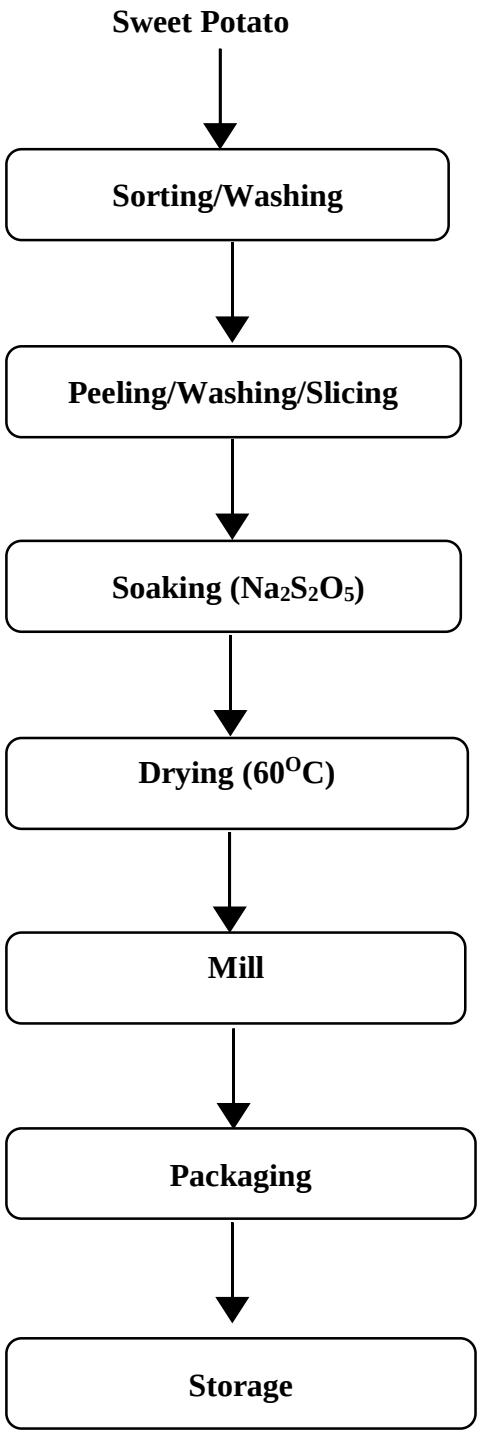

Figure 3.2: Flow diagram for Sweet Potato flour preparation

3.3.3 Bambara Groundnut Flour Preparation

Bamabara groundnuts (Vigna subterranea (L.) Verdc.) were sorted to remove foreign materials and damaged seeds. The nuts were submerged in water and allowed to soak at room temperature for 12hrs. The seeds were dehulled and left to dry in a hot air oven for 6 hours at 60°C and then further roasted for 30 min at 120 °C with the air oven. Seeds that were roasted were milled into flour using a hammer mill. The flow chart of the process to obtain bambara groundnut flour is shown in Figure 3.3

3.3.4 Maize Flour Preparation

Maize grits were obtained from the market and milled using a hammer mill and sieved through a mesh of 250-µm in the same way as the roots and tubers.

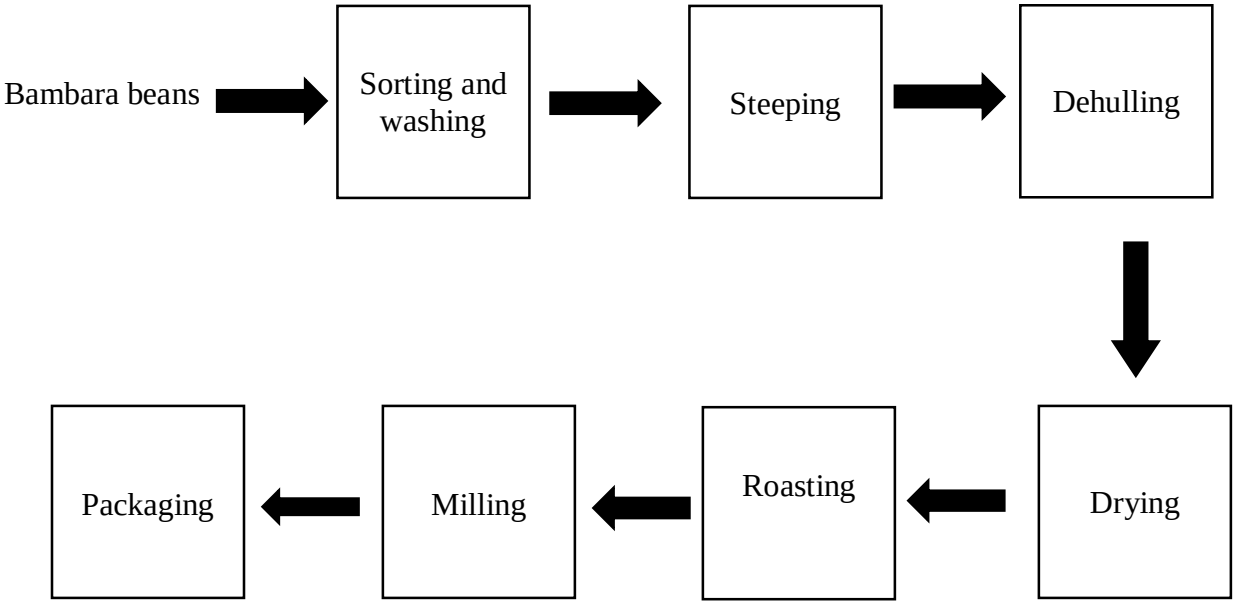

Figure 3. 3: Flow diagram for Bambara groundnuts flour preparation

3.4 Formulation of Composite Flour

A three-component constrained extreme vertices design (Cornell, 1983) was used to generate different formulations for the preparations of the Ready-to-Eat breakfast food. The major ingredients which made up the mixture components were Cassava Flour, Sweet Potato flour, Bambara groundnut flour and Maize Flour, which added up to a 100% (Table 3.1). A lower limit of (0% cassava flour, 10% Sweet Potato flour and 5% Bambara groundnut flour) and upper limit (30% cassava flour, 40% Sweet Potato flour and 15% Bambara groundnut flour) were set to generate the various components for each formulation. Maize flour was maintained at 45% for every formulation. A total of 9 different formulations were obtained as shown in Table 3.2. A composite flour was prepared by mixing different ratios of Cassava, Sweet potato, Maize and Bambara groundnut flours. The flours were packed in polyethene bags and store below 5 °C for further use.

Table 3.1: Mixture design for components of the Ready-to-Eat breakfast food

Ingredients	Low (%)	High (%)
Cassava Flour	0	30
Sweet potato Flour	10	40
Bambara Groundnut Flour	5	15

Mixture total = 55% + Maize flour (45%) = 100%

Table 3. 2: Design matrix for ingredient combination (Using a three-component constrained extreme vertices design)

Formulations	Cassava Flour	Sweet Potato Flour	Bambara Flour
S1	30	10	15
S2	14	34	7
S3	9	34	12
S4	24	24	7
S5	10	40	5
S6	0	40	15
S7	17	28	10
S8	30	20	5
S9	24	19	12

Maize flour 45%. Total ingredient mixture for each formulation = 100%

3.5 Drum Drying

The individual formulations (S1-S9) were reconstituted with distilled water in a ratio of 1:2 [formulation (g): water (ml)] to prepare a slurry. Drum drying was done using a laboratory atmospheric double GOUDA drum dryer (Andritz Douda Coenecoop 88 2741 PD Waddinxveen-Holland). The drum dryer was set to a temperature of 175 °C and a speed of 35rpm.The slurry prepared was fed into the single drum dryer. The thin precooked flakes obtained were collected and milled into a clean polyethylene bag and stored in a refrigerator (4° C) for further analyses.

3.6 Analytical Methods

3.6.1 Chemical Analysis

3.6.1.1 Moisture

A gravimetric method as described in AOAC (2000) was used to determine moisture contents of the various samples. An empty but clean, aluminium dish was weighed. The flour sample was weighed with precision amounting to 2g and moved to the dish. Dishes

containing samples were dried at approximately 100℃ in the oven for 5 hours. The samples were kept in a desiccator after drying in order to cool for 30 min and the final weight was recorded.

The moisture content was calculated using:

$$Moisture\ percent\ by\ weight\ = \frac{100(W1 - W2)}{W1 - W}$$

where: W1 = Weight of dish with sample before drying(g),

W2 = Weight of dish with sample after drying (g)

W = Weight of empty dish (g)

3.6.1.2 Crude Protein

Crude Protein was determined according to AOAC (2000). 100mg of sample was weighed into a 30 mL Kjeldahl digestion tube, followed by 40 mg of yellow HgO, 1.9 g of K_2SO_4 and 5 mL of undiluted H_2SO_4. Samples were digested to a clear fluid. The digester was transferred into a volumetric flask, and filled with distilled water to 100ml. Ammonia gas from the digest was collected in 10ml of undiluted boric acid (containing an amount of 3 drops of a mixed indicator) by distilling 10ml of the digest with NaOH (50%). One part of 0.2% methyl red and five parts of 0.2% alcoholic bromo-cresol green solution in order to prepare the mixed indicator. About 70 mL of distillate was titrated against 0.02N HCl. The procedure was performed using a blank.

The total protein content was calculated as percent N_2 x factor. Where N_2=6.25.

$$\%Nitrogen = \frac{14.007\ (\mathrm{A} - \mathrm{B}) \times \text{Normality of HCl} \times \text{dilution factor} \times 100}{1000 \times \text{ Weight of sample}}$$

where:
A= mL of HCl required for sample

B= mL of HCl required for blank

N= Normality of HCl used, and

W= Weight of the sample (mg)

3.6.1.3 Total fat

Two grams of each sample was weighed in a fat-free thimble by following AOAC (2005) method. The thimbles were then plugged with cotton wool and introduced into the Soxhlet extractors containing hexane (boiling point 60-80◦C). Clean round bottom flasks were weighed. Fat was extracted using petroleum ether in soxhlet apparatus for 3hours, after which the petroleum ether was recycled. After refluxing for a number of times the Petroleum ether was recollected and round bottom flasks were weighed. The thimbles containing the samples were then removed and placed in an oven at 60◦C for 3 hours until a constant weight was achieved weight. The results were expressed as;

$$Total\ fat\ \% = \frac{Weight\ of\ fat\ (g)\ x\ 100)}{Weight\ of\ sample\ (g)}$$

3.6.1.4 Total Ash

The Standard AACC 2000 procedure given under 08-01 was followed. 5g of sample was weighed and charred on hot plate and incinerated in furnace at 550^0C for 5 hours. It was then cooled in a desiccator and weighed at room temperature to get the weight of the ash. Ash content was expressed as percent ash.

$$\% \text{ Ash } = \frac{\text{Weight of ash (g) x 100)}}{\text{Weight of sample (g))}}$$

3.6.1.5 Crude fibre

One gram of flour was added to 200ml of boiling sulphuric acid solution (0.225N) and digested for 30 min. The mixture was filtered, cleaned with hot water (100°C). 200ml boiled sodium hydroxide solution (0.313N) was added to the filtrate and digested for another 30 minutes following a second filtration. Filtrates were washed with water and 10% hot potassium sulphate solution. The samples were washed with water, filtered into gooch crucible, and again washed with 15ml alcohol. The contents were dried at 110 ^{o}C to constant weight. Lastly, the dried samples were flamed until the materials containing carbon was destroyed, followed by cooling and weighing. The weight loss is the crude fibre (AACC, 2000)

Crude fibre % = Loss in weight noted x 100 Weight of sample

3.6.1.6 Carbohydrate content

Carbohydrate contents were calculated by;

%Carbohydrate = 100 – (%TF + %CF +%CP + %MC)

Where; TF = Total Fat

CF = Crude Fibre

CP = Crude Protein

MC = Moisture Content

3.6.1.7 Determination of Beta Carotene Content

a) Extraction of active compound

Beta carotene content was determined by the procedure described by Rodriguez-Amaya and Kimura (2004) with slight modification. The extraction process was carried out in an environment with minimum light. This was done by turning off laboratory light bulbs.

5g of sample was grounded and homogenized in 50ml of cold acetone (refrigerated overnight) and a small amount of pyrogallol was added to prevent oxidation of active compound. The resulting extract was filtered using Whatman no.4 filter paper, the extraction was repeated on the residue until it was colourless. The extract obtained was further saponified to remove fat that could interfere with the HPLC separations. Saponification was done by adding about 10ml 0f 20% KOH dissolved in methanol to the extract. The extract was then stored in the dark for about 3hours prior to washing. With the aid of a retort stand, a clean separating funnel (500ml) was mounted and it was filled with 20ml petroleum ether. The filtrate was then poured into a separating funnel and then topped up with distilled water (the distilled water was carefully introduced with the aid of a wash

bottle such that the water trickles down the walls of the separating funnel in order to prevent formation of emulsion and entrapment of air bubbles). It then separated into two layers, the aqueous layer and organic layer. The aqueous layer was discarded by opening the separating funnel whilst the organic layer was topped up with more distilled water. The process was repeated until a clear organic layer was obtained. The residue was then filtered by adding anhydrous sodium sulphate to filter paper to dry out excess water present in the residue. Nitrogen gas was used to remove excess petroleum ether.

b) HPLC Procedure

The agilent HPLC equipment was used. The dried residue was reconstituted with mobile phase (1ml of hexane) and vortexed. Stock solution was prepared from Standard of beta carotene by taking 10mg in 100ml n-hexane. The HPLC system was calibrated using the blank (mobile phase) and was washed thoroughly using the mobile phase (a mixture of Hexane and methanol by the ratio of 1:9 respectively) at a flow rate of 1 ml/min. The total run time was 35 minutes and the injection volume of the filtrate was 10µl. UV Lamp was used as a detector at a wave length of 450nm. HPLC readings of each sample was done in duplicate.

3.6.1.8 Total Starch

Megazyme complete starch assay kit was used to determine the total starch content of the flour samples (Megazyme International Ireland, Bray, Wicklow, Ireland). Based on dry weight, all complete starch findings were recorded.

3.6.1.9 In vitro Starch digestibility

10ml of double-distilled water was added to 0.7g of flour and cooked. The cooked sample was mixed with 10ml of an enzyme solution. The enzyme was prepared following a protocol by Englyst *et al*, (1992). The mixture was incubated at 37°C, followed by pipetting 0.1ml of the hydrolysed sample to 0.9ml of 80 % ethanol at 20 mins interval for 2hours to stop hydrolysis. Products such as glucose were determined using glucose oxidase peroxidase (GOPOD).

According to Englyst et al, (1992), hydrolysed starch is categorized in in three main groups, resistant starch (RS), Rapidly digestible starch (RDS) and Slowly digestible starch (SDS).

These were determined by;

RDS = glucose detected at 20 min × 0.9

SDS = (glucose detected at 120 min − glucose detected at 20 min) × 0.9

The hydrolysis kinetics of the sample was determined using a mathematical formula suggested by Goñi *et al.* (1997).

$$\text{Hydrolysis index (HI)} = \frac{\text{Area under the hydrolysis curve (AUC) of the samples}}{\text{Area under the hydrolysis curve (AUC) of white bread}}$$

Where AUC=C∞ (tf −to) −(C∞/k)[1−e−k(tf−to)] where C = starch hydrolysed at a chosen time t; C_∞ = equilibrium concentration at the final time (120 min); and k = kinetic constant tf is the final time and t_0 is the initial time

The Expected Glycemic Index (eGI) was calculated in accordance to Granfeldt *et al*, (1992):

$$eGI = 8.198 + 0.862 \times HI$$

3.6.1.10 In Vitro Protein digestibility

1.5mg of pepsin was dissolved in HCL (0.1N). The stock solution was added to 0.2g of the sample in a 50mL tube. After blending, the samples were incubated at 37°C for 3 hours. 3.3ml of NaOH (0.5M) was added to the suspension in order to neutralize it, followed by the addition of 4mg of pancreatin. The mixture was carefully swirled and incubated for 24 hours at 37°C. In order to access the nitrogen in the supernatant of the sample, it was centrifuged at 2000g for 20 mins after treating it with 10mL of trichloroacetic (10%) the supernatant (Saunder et al., 1973).

Protein digestibility was determined by using micro-Kjeldhal formula;

$$\text{Protein Digestibility\%} = \frac{\text{Nitrogen in Supernatant}}{\text{Nitrogen in Sample}} \text{ x } 100$$

3.6.2 Determination of Physical Properties

3.6.2.1 Colour Analysis

Finely grounded samples were collected into a glass holder of height 2cm. The sides were tapped gently in order to allow trapped air escape. The colorimeter was calibrated following manufactures protocol (L_t= 97.95, a_t= -0.12, b_t= +1.64). Data obtained were interpreted as; Lightness (L*), Redness (a*), and yellowness (b*), following the

International Commission on Illumination (CIE) (Hunter Associated Laboratory, Inc., USA).

Where,

L*= darkness to lightness, indicating 0 as black and 100 as White,

a *= green (-60) to red (+60)

b* =blue (-60) to yellow (+60)

3.6.2.2 Total Soluble Solids

Total soluble solids of each sample were determined by preparing 10% slurry and filtered with a no. 4 Whatman filter paper. One drop of the filtrate was used to determine the brix of the samples using a handheld Refractometer equipped with a sugar scale in triplicates using a. The result was expressed as degree brix (Brix)

3.6.2.3 Flow behaviour of slurries of drum dried formulations

Apparent viscosity measurement of the different formulations was done using a Brookfield viscometer (Model DV-1 + viscometer). 10%, 15% and 20% slurries were prepared and the viscosity of the samples were taken at different spindle speeds. Viscosity (cp) readings for each sample were taken at five (5) different shear rates. Readings were taken in triplicates and the means were calculated. Shear stress and shear strain data obtained from apparent viscosity readings (rpm and cP) were fitted to the power law equation (equation 1) to obtain the flow behaviour index (n) and the consistency index (K).

$$\tau = K(\gamma)^n \quad \text{Equation 1}$$

Where τ = shear stress

γ = shear rate

K= consistency index

n= flow behaviour index

3.6.2.4 Particle Size Distribution

The method by Sakhare, *et al.* (2014) was used with slight modifications. The particle size distribution of each sample was determined using (Ro-Tap model RX-29, W.S. Tyler, Mentor, Ohio) shaker fitted with screen sieves ranging from 230μm-60μm. About 200g of milled product was shaken for 3 min at an amplitude of 3.00. The initial weight of the sieves was recorded. After shaking, the powder retained by each sieve was weighed this was expressed as a percentage of the total sample taken to obtain the particle size distribution of the samples.

3.6.2.5 Sorption Behaviour (ISOTHERMS)

The standard gravimetric method by Ocheme *et al.* (2013) was followed with modifications. Different concentrations of sulphuric acid (H_2SO_4) solution were prepared ranging from of 5, 15, 35, 45, 55 and 65% with their corresponding water activities known. The flour samples to be analyzed were weighed and hanged above the acid in tightly closed glass containers and stored at different temperatures (23°C and 30°C). After every 48hrs, the samples are reweighed until an equilibrium is reached then the moisture content determined. The data obtained were fitted into several sorption isotherms models using linear regression. The model that best fitted the sorption behaviour were determined.

3.6.3 Functional Properties

3.6.3.1 Water Absorption Index (WAI)

Samples were weighed at 5g and dissolved in distilled water with temperatures of 27°C and 70°C. The samples were mixed and left at room temperature for 30 minutes. The mixture was centrifuged for 15mins at 3000rpm using Danley Centrifuge. Increased weights were recorded after decanting the supernatants. Percentages were used to represent the water absorption capacities (Sefa-Dedeh *et al*., 2004)

3.6.3.2 Water Solubility Index (WSI)

The WSI, the weight of dry soluble solids in the supernatant (supernatant decanted from WAI) was expressed as a percentage of the original weight of sample.

3.6.3.3 Bulk Density (BD)

Flour samples were weighed into a 100ml measuring cylinder. Uniformity was ensured by tapping the sides of the cylinder. The volumes of the samples were determined by the level marked by the sample in the cylinder. Sample's weight per volume defined their bulk densities (Olapade and Ogunade, 2014)

3.6.3.4 Swelling Power

In order to determine the swelling power of the samples, some adjustments were made to the method used by Oladale and Aina (2007). Samples were weighed, 1g each, and mixed in a test tube containing 10ml of distilled water. The mixture was heated at 80°C for 30 mins in a shaking water bath. The mixture was left to cool at room temperature and then centrifuged for 15mins at 2200rpm. The paste precipitates were carefully separated from the supernatant and weighed (Wo). The supernatant was the evaporated at 105°C in a hot

air oven and the weight of the residues were recoded (Wr). The test was performed in triplicates and calculations were made for both solubility index (SI) and swelling power (SP);

SP = Weight of precipitated paste (Wp) X 100%

Weight of sample (Wo)

3.6.3.5 Oil (Fat) Absorption Capacity (OAC)

The study modified Lin *et al.* (1974) method to determine the fat absorption capacity. Flour samples were mixed with canola oil and transferred into a centrifuge tube. They were incubated at room temperature for 30 minutes. Samples were centrifuged for 20 minutes at 2000 rpm, and the supernatant were carefully poured into measuring cylinders. The tubes were inverted several times to remove the adhered oils and weighed. The weight of oil absorbed by flour was calculated and expressed as fat absorption capacity in percentage. The resulting value was multiplied by 0.93, which is the density of oil.

3.6.3.6 Emulsifying Capacity and Stability

To determine the emulsion activity of the samples, 1g of the sample was dissolved in equal volumes of distilled water and soybean oil (10mL) to form an emulsion. The mixture was centrifuged for 5 mins at 2000 x g in a calibrated centrifuge tube.

Emulsion activity was calculated by;

$$Emulsion\ activity = \frac{Heighht\ of\ emulsion\ layer}{total\ height\ of\ mixture}\ x\ 100$$

The emulsion in the calibrated tubes was heated for 30 mins at 80°C in a water bath and cooled under running water. The mixture was centrifuged immediately for 15mins at

2000 x g. this was done to determine the emulsion stability under running water (Yasumatsu *et al.*,1972).

$$Emulsion\ stability = \frac{Height\ of\ emulsified\ layer}{Total\ height\ of\ mixture}\ x\ 100$$

3.6.4 Microbiological Safety Analysis

3.6.4.1 Protocol

The microbial analysis was done prior to sensory testing to ensure that all the 9 formulations were safe for consumption.

90 mm disposable Petri dishes were used. Plate Count Agar from Park Scientific Ltd., Merck Malt Extract Agar, Oxoid Eosin Methylene Blue Agar and Nutrient Agar from Park Scientific Ltd. were prepared according to the manufacturer's instructions and used to culture the total viable cells, coliforms, yeast and mould. Peptone Water from Park Scientific Ltd. was used to prepare 0.1% solution for the diluent. Media were prepared using sterile distilled water. All plates, pipettes and diluents were sterilised in an autoclave. The accuracy of sterilisation was monitored using autoclave. Agar that were prepared were stored in water bath (45°C), and poured when needed Serial dilutions were made for each sample by diluting 10g of sample in 90ml of peptone and were plated in duplicates.

3.6.4.2 Aerobic mesophiles

One ml of the appropriate serial dilutions was placed in a sterile petri dish and plated by the pour plate method (Morello *et al.*, 2003) using molten Plate Count Agar. Agar plates that were set, were incubated at 37°C for 24 hours. Single forming colonies were counted.

3.6.4.3 Yeast and Mould Count

One ml each dilution (10^{-1}) was pipetted into a sterile petri dish. Malt Extract Agar was added to it using the pour plate method. Incubation was done for 48-96 hours at 25°C preceding to enumeration.

3.6.4.4 Coliform count

One ml each dilution ($10^{-1}$and 10^{-2}) was pipetted into a sterile petri dish. Molten Violet Red Bile Agar was poured into it using the pour plate method. Incubation was for 24 hours at 37°C prior to enumeration.

3.6.5 Sensory Analysis

3.6.5.1 Qualitative Descriptive Analysis (QDA)

Quantitative descriptive analysis (QDA)

Nine trained panellists were used for the sensory evaluation. The test was carried out in the sensory laboratory at Nutrition and Food Science Department, College of Basic and Applied Sciences, UG. Panellists were required to evaluate the appearance, aroma, mouth feel and aftertaste of the samples. Panellists were required to come out with lexicons that best describes the product. The lexicons were scrutinized and final lists of lexicons were developed by the descriptive panel with the guidance of the panel leader after several sessions. The samples were then evaluated based on the lexicons obtained using the10cm line scale.

About 10g of the ready-to-eat breakfast food was prepared by adding 75ml of warm water and served in same cup sizes. The product evaluation was conducted in three sessions.

Panellists were required to evaluate 5 samples per session in order to prevent sensory fatigue. Water was used as a pallet cleanser.

3.6.5.2 Consumer Acceptance Test

A consumer acceptance test was done using 75 untrained panellists. Using the 9-point Hedonic scale Test (1 – Dislike extremely, 5 – Neither like nor dislike and 9 – Like extremely), panellists were asked to rate products based on how much they liked the attributes listed (overall acceptance, colour, sweetness, aroma, mouthfeel and aftertaste). About 10g of the ready-to-eat breakfast food was prepared by adding 75ml of warm water. Each panellist was presented with 80 mL of reformulated breakfast. Water was used as pallet cleaner. Biases were reduced by using same colour, size of cups and equal volume of reformulated breakfast. Ballot and work sheet for this test can be found in the appendix.

3.7 Statistical Analysis

The mean values, standard deviations and graphical presentation of the data were computed using Microsoft Office Excel, 2013. All experiments were conducted in at least duplicates. The results were analysed using ANOVA procedures to compare means of treatments and where there were significant differences at $p<0.05$, it was ascertained by Least Significance Difference $p\leq0.05$. The StatGraphics software Centurion 16.11.1 was used to fit models of sorption isotherm. Illustrations of tables and figures were done using Microsoft excel.

CHAPTER 4

4.0 RESULTS AND DISCUSSIONS

4.1 Physical Characterization of Composite Flour Blends

4.1.1 Hunter colour parameters

Colour is an important characteristic of foods, especially when it comes to the choice of ready-to-eat breakfast products and has a substantial influence on consumer acceptability Colour and its uniformity are essential factors of physical quality of food and therefore has a pronounced effect on the appearance of a product (Pathare *et al*., 2013).

All Hunter values recorded (L*, a* and b*) were affected significantly by an increase or decrease in cassava, sweet potato and bambara ground nut flours. L* value gives a measure of lightness of the products colour from 100 for perfect white and 0 for black. The redness/greenness is denoted by a* and yellowness/blueness by b* values (Stojceska *et al.*, 2008).

From Table 4.1, it can be observed that the L* values increased with increases in percentage of cassava flour and a decrease in sweet potato flour. Comparing formulations S1(30:10:15) and S8 (30:20:5), even though they both contained same amounts of cassava flour, S1 with a lower sweet potato flour substitution recorded the highest L* value (84.97) as opposed to S8(80.58). Mesquita (2013) recorded a brightness of 94.7 on cassava flour only. The introduction of the different raw materials which were darker than the cassava flour may have reduced the brightness to 84.97 and below. This clearly shows the influence of the colour of the starting material on the final product.

Formulations that had higher percentages of sweet potato flour recorded higher a* and b* values. For example, Samples 5 and 6 which contained 40% sweet potato flour recorded the highest intensity of a* values (2.8 and 2.81) as well as b*values (29.94, 30.43) respectively for both the drum dried flour and the uncooked ones. This suggests that formulations S5 and S6 contains more reddish and yellowish pigments thus implying that the formulations were rich in carotenoids. On the other hand, S1 which contained the lowest percentage of sweet potato recorded low values for both raw and drum dried formulation.

Further observations showed that, there was a significant decrease in all the colour values after raw flour were drum dried (Table 4.1 and Appendix 3). Guy (2001), reported that the colour of an extruded product is influenced by temperature, residence time and raw material composition. Takahashi *et al* (2005) also recorded reduction in CIE (Commission Internationale de l'Elcairage) values when different method of processing techniques was used to treat raw flours. Changes in colour could be as result of reactions such as non-enzymatic browning (Millard reaction and caramelization) and pigment degradation (Guy, 2001).

Total colour difference (ΔE) is the difference between two colours taking into consideration the three tristimulus difference of L*, a* and b*. The higher the ΔE, the greater the colour difference between the product and the raw material. Lower ΔE values observed by formulation S1 showed similarity of product to the raw formulation. The higher ΔE values confirms that the colour (red and yellow) pigments were reduced by the drum drying process.

Table 4.1: Mean colour parameters of drum dried formulations

Formulations	Colour parameters			
CF: SP:BF	l* value	a* values	b* values	ΔE
S1(30:10:15)	84.97±0.23 [f]	-0.6±0.03 [i]	19.77±0.07 [ef]	7.8
S2(14:34:7)	81.43±0.13 [hi]	2.36±0.04 [e]	27.90±0.12 [a]	12.3
S3 (9:34:12)	81.77±0.13 [h]	2.66±0.08 [e]	27.90±0.12 [a]	12.65
S4 (24:24:7)	83.90±0.20 [g]	1.53±0.03 [gh]	27.41±0.15 [ab]	12.15
S5 (10:40:5)	77.11±0.21 [l]	2.80±0.17 [e]	29.94±0.06 [a]	11.68
S6 (0:40:15)	76.40±0.28 [m]	2.81±0.16 [e]	30.43±0.11 [a]	12.02
S7 (17:28:10)	80.22±0.26 [k]	2.26±0.29 [ef]	30.43±0.11 [a]	12.26
S8 (30:20:5)	80.58±0.37 [jk]	1.07±1.47 [h]	26.42±0.13 [abc]	12.01
S9(24:19:12)	81.08±0.56 [ij]	1.10±0.08 [h]	25.87±0.06 [abcd]	11.68
P-value	0.00	0.00	0.00	

Means in same column with different superscripts are significantly different ($p \leq 0.05$)
L* - lightness – dark. a*= redness - greenness, b* = yellowness -blueness, the composite flour formulations. Means in same column with different superscripts are significantly different ($p \leq 0.05$)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.1.2 Particle Size Distribution of Milled Product

Particle size distribution significantly affects flour functionality (Noort *et al*., 2010). Wang *et al*. (2017) implied particle size of flour influences water absorption and retention, as well as end product quality. Table 4.2 shows the particle size distribution for the various formulations. It was observed that, more than 70% of milled drum dried product had particle size below 140µm. Suggesting that the samples were smooth. Drum drying causes change in structure of the starches and proteins. John *et al.* (2018) studied the effect of different drying method on the particle size distribution of soy protein isolate and observed that the different drying methods influence particle size distribution.

Chen *et al.* (2004) also found out that, not only does the physical characteristics of a crop affect the particle size distribution but the chemical compositions also affects it. Therefore, the various chemical compositions of the raw materials could have played a majored role in the particle size distribution. Fibre component of the food such as the cellulose, and pectin are the most resistant to size reduction during milling and mostly remain as the larger particles whereas other components such as starches and proteins with higher densities are far more friable and hence form the finer fractions of the milled product (Hemery *et al*., 2009). Therefore, the finer particles gained would find it easier to settle or pass through the sieves due to their high densities. Studies have shown that, functional properties, structure and surface areas are affected when plants rich in fibre have their particle sizes reduced (Chau *et al*., 2007). It should also be noted that even though the maize flour also contributed an amount of fibre to the particle size distribution, its amount was constant through all formulations.

Table 4.2: Particle Size Distribution of drum dried Product

Formations	60 (µm)	100(µm)	120(µm)	140(µm)	200(µm)	230(µm)
CF: SP:BF	Loose particles (%)					
S1(30:10:15)	35.26±0.21^{a}	27.57±0.12^{e}	26.06±0.93^{g}	8.48±0.05^{g}	2.42±0.04^{d}	0.00±0.00^{e}
S2(14:34:7)	15.4±0.25^{f}	36.43±0.71^{b}	32.48±0.05^{cd}	11.43b±0.07^{c}	3.90±0.11^{b}	0.30±0.01^{b}
S3 (9:34:12)	17.65±0.05^{e}	32.89±0.18^{c}	33.38±0.35^{b}	11.20±0.07^{c}	4.07±0.08^{b}	0.34±0.06^{b}
S4 (24:24:7)	22.10±0.95^{c}	32.48±0.05^{c}	31.99±0.02^{d}	9.73±0.49^{e}	3.50±0.01^{c}	0.21±0.02^{d}
S5 (10:40:5)	11.75±0.25^{g}	37.36±0.69^{a}	34.12±0.21^{a}	11.65±0.00^{b}	4.23±0.05^{a}	0.59±0.02^{a}
S6 (0:40:15)	11.99±0.23^{g}	37.00±0.14^{a}	34.32±0.06^{a}	10.79±0.12^{a}	4.40±0.15^{a}	0.62±0.06^{a}
S7 (17:28:10)	18.75±1.07^{d}	32.83±0.62^{c}	32.97±0.63^{e}	11.54±0.07^{b}	3.63±0.17^{c}	0.27±0.03^{cd}
S8 (30:20:5)	23.4±1.0^{f}	31.71±0.04^{d}	30.38±0.06^{bc}	10.48±0.06^{e}	3.44±0.18^{cd}	0.05±0.14^{d}
S9(24:19:12)	26.1±2.19^{b}	31.66±0.08^{d}	29.03±0.35^{f}	10.53±0.08^{e}	2.65±0.14^{d}	0.00±0.14^{e}
P-value	0.00	0.00	0.00	0.00	0.00	0.00

Means in same column with different superscripts are significantly different ($p \leq 0.05$)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

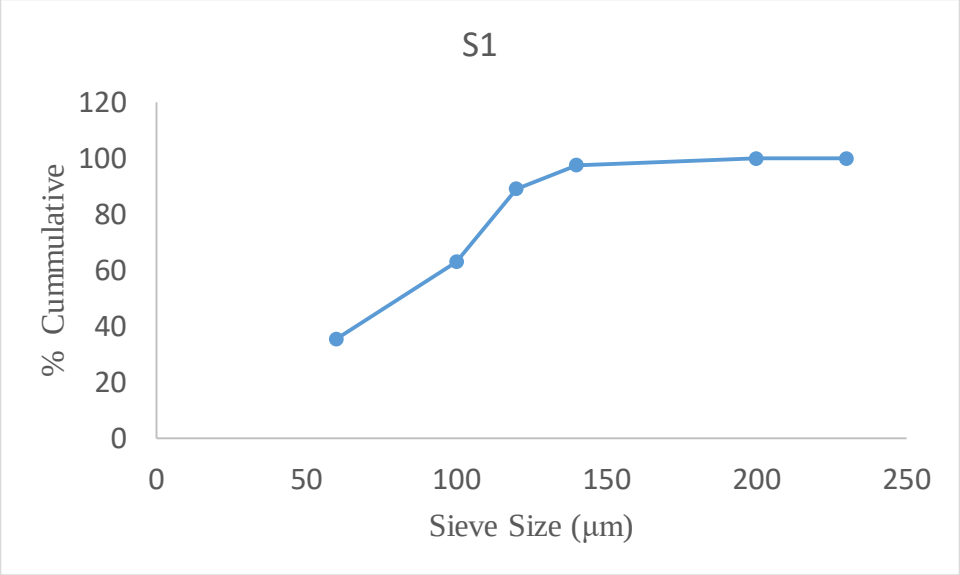

Figure 4.1 A typical example of the particle size distribution of the breakfast product

The distribution of particle size of all the formulations was typically sigmoid and the cumulative distribution for all samples show that about 90% of the particles were smaller than 200microns, indicating that if the sample is used to make a breakfast product it will have a smooth texture.

4.1.3 Flow behaviour of reconstituted drum dried slurries

Viscosity, which is the resistance to or rate of flow of fluids, has an important effect on the efficiency of unit operations in the food industry. The viscosity of many liquids' changes during heating, cooling, concentration, amongst others. Table 4.3 presents the consistency coefficients (k) and the flow behaviour indices (n) of the various formulations obtained from Figure 4.2 as solid concentrations were increased.

Table 4.3 Power law parameters for the formulations as a function of solids (%) content

Formulations **CF: SP:BF**	Percentage Solid					
	10%		15%		20%	
	n	K	n	K	n	k
S1(30:10:15)	0.59	2104.63±0.03^{a}	0.58	80519.80±1.23^{a}	0.58	363915.89±0.82^{b}
S2(14:34:7)	0.38	580.25±0.60^{e}	0.48	14342.68±0.00^{e}	0.53	143782.79±0.34^{d}
S3 (9:34:12)	0.32	214.22±0.32^{i}	0.53	14169.22±0.45^{e}	0.54	148288.24±0.69^{d}
S4 (24:24:7)	0.53	1349.54±0.05^{c}	0.55	22868.52±0.17^{c}	0.56	167034.25±1.12^{c}
S5 (10:40:5)	0.44	395.66±0.43^{g}	0.52	9645.23±0.00^{f}	0.64	103374.42±0.09^{f}
S6 (0:40:15)	0.39	341.11±0.28^{h}	0.50	9008.34±0.17^{f}	0.63	105878.94±0.23^{f}
S7 (17:28:10)	0.48	414.52±0.05^{f}	0.89	18835.65±0.90^{d}	0.62	134681.84±0.21^{e}
S8 (30:20:5)	0.56	1725.16±0.16^{b}	0.29	11103.41±0.25^{e}	0.64	393914.98±0.44^{a}
S9(24:19:12)	0.46	1110.13±0.29^{d}	0.58	31518.24±0.11^{b}	0.54	216074.47±0.15^{c}

Means in same column with different superscripts are significantly different ($p \leq 0.05$)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

From Table 4.3, it was observed that, there was a rapid drop in viscosity of all the formulations as the shear rate (or rpm) increased. This shows that the flow behaviour of all the samples when mixed with water was non-Newtonian (pseudoplastic or shear thinning behaviour), and this was confirmed by a flow behaviour index of 'n' being less than 1. Materials that exhibit a direct proportionality between shearing stress and rate of shear are called Newtonian materials, and they have "n" parameter being approximately equal to 1. It has been suggested that, most cereal fluid products are best explained using the power law model and described to be shear thinning (n is less than 1) or pseudolastic flow behaviour.

The flow behaviour parameters “k” and “n” in Table 4.3 demonstrated that the different solid concentrations modified the viscosity of the products differently. It was observed that, there was a significant ($p \leq 0.05$) increase in the apparent viscosity “k” as solid concentration increased. A profound increase was observed in the apparent viscosity “k” as well as “n” when solid concentration increased. Also, addition of cassava flour was seen to have increased “k” and “n” values of product while OFSP flour (Orange Fleshed Sweet Potato) had the least effect. The increment in the viscosity could be attributed to the high starch content of the cassava flour. Amaglo *et al*. (2012), reported that sweet potato-based formulations can be best used as complementary food because, they have endogenous sugars, low in starch, which makes them highly soluble, less viscous, produce desired sensory features and retain excess energy. Thus, the beta-amylase present in sweet potato is activated during drum drying and this hydrolyze the starch into maltose units (Yadav *et al*., 2006). This causes a gradual decrease in viscosity. Consequently, an increase in OFSP flour would reduce the viscosity of the formulations.

The consistency of the reconstituted drum dried product is important for product acceptability by the consumer and also has significance in the manner in which it will be presented to the consumer. On a larger scale such slurries need to be pumped, and understanding the flow behaviour will facilitate choice of pumps and related operations.

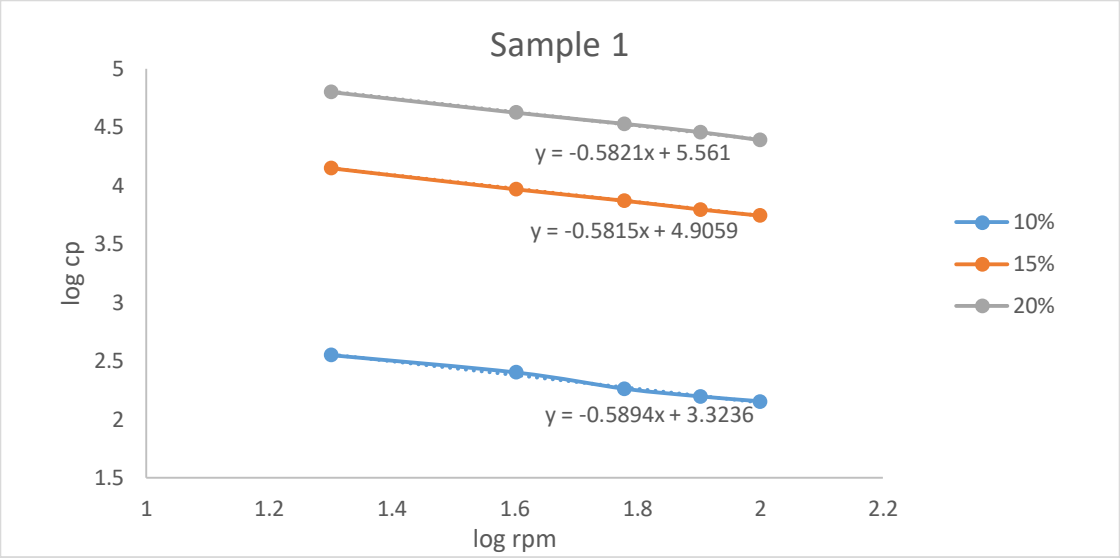

Figure 4.2 : An example of fitted cp and rpm values into Power law model for apparent viscosity

4.1.4 Soluble solids

From figure 4.3 it is observed that the brix of the various formulations increased with increasing substitution of orange fleshed sweet potato flour. Formulation S6 and S5 recorded the highest brix of 2.73 and 2.67 respectively whilst formulations S1 recorded the least with a brix of 1.5. During the pre-gelatinization state (drum drying), the starch granules are broken down by the heat in the sweet potato which then facilitates hydrolysis by beta -amylase present in the sweet potato. This produces simple sugars, largely maltose (Dreher *et al.*, 1984) that contributed to the increment in brix of formulations with higher sweet potato substitution

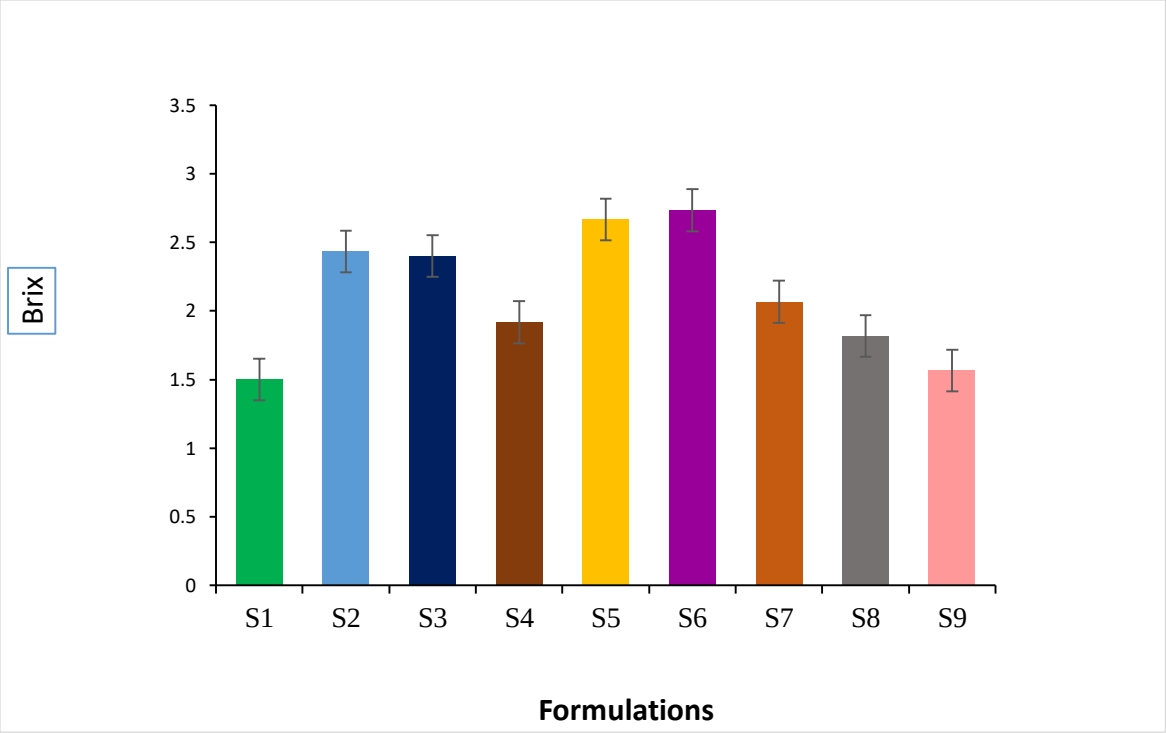

Figure 4.3: Soluble solids (brix content) of the various Formulations
S1(30:10:15), S2(14:34:7), S3 (9:34:12), S4 (24:24:7), S5 (10:40:5), S6 (0:40:15), S7 (17:28:10), S8 (30:20:5), S9(24:19:12);
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.2.0 Functional Properties

4.2.1 Water Absorption Index

From table 4.4 significant differences ($p \leq 0.05$) were observed within the formulations. An increase in cassava flour increased the water absorption index (WAI) of the formulation whilst an increase in orange fleshed sweet potato flour decreased the WAI. However, at same level of cassava substitution, formulations with lower Bambara groundnut substitution recorded a higher WAI than that with higher Bambara groundnut substitution. Although sweet potato also contains starch, a percentage of it was hydrolysed during drum drying. Sample 1 and 8 which both contained 30% cassava flour and 15% and 5% Bambara groundnut respectively showed 8.10 and 7.71g/g. The water absorption index (WAI) measures the amount of water absorbed by starch and is related

to the degree of starch gelatinization. Thus, higher value of WAI can be attributed to higher degree of gelatinization. The hydrophilic nature of starch granules is able to imbibe more water (Kaur and Singh, 2005). Determination of the WAI value would help the producer have an idea of the reconstitution ability of the product. That is, Water absorption capacity of product enables the processor to know how much of water to add to a product in order to obtain acceptable viscosity and texture, amongst others

4.2.2 Oil Absorption Capacity

Estimation of the OAC of the formulations is essential as it enhances flavour and mouth feel of the product (Chandra *et al*., 2015). The studies showed that, OAC increase significantly ($p \leq 0.05$) with an increase in bambara groundnut substitution. The higher protein content of Bambara groundnut may have contributed to this increase. Babu and Parimalavalli (2012) opined that, OAC is influenced by the lipophilic nature of a flour. Proteins contain hydrophilic and hydrophobic parts which bind to fat by capillary attraction. The non-polar amino acid side chains can form hydrophobic interactions with hydrocarbon chains of fat (Eltayeb *et al*., 2011; Jitngarmkusol *et al*. 2008). From Table 4.4 the OAC values obtained, ranged from 1.93- 1.18g/g. Thus, formulations S6 and S1 recorded the highest OAC values. A product with higher oil absorption capacity tend to have an improved mouth feel.

4.2.3 Swelling Power and Water Solubility Index

The swelling power represented the degree to which the starch granules in the flour can absorb and hold water. Singh *et al*. (2005) also indicated that, solubility is the percent amount of starch leached out into the supernatant in the swelling volume determination. An increase in WSI may influence digestibility of foods (Van Hoan *et al*., 2010). From Table 4.4, it was observed that SP

and WSI of the formulations ranged from 6.87 - 9.27 mL/g and 17.70 - 27.63 mL/g respectively. Incorporation of higher percentage of cassava flour significantly increased the swelling power whilst an increase in sweet potatoes and Bambara groundnut significantly decreased the SP. The reverse was observed with respect to WSI. Swelling power is often related to the protein and starch content (Yadav *et al*., 2006). The swelling power may also be influenced by the amylopectin/ amylose ratio. Swelling power is generally dependent on the amylopectin molecule rather than the amylose which functions as a diluent. Starch granules are more hydrophilic hence would absorb and retain more moisture causing the granules to swell. An increase in protein content of flour may cause the starch granules to be embedded within a stiff protein matrix, which subsequently limits the access of the starch to water there restricts the swelling power (Aprianita *et al.*, 2009). Increase in WSI could be as a result of increase in alpha amylase activity owing to the sweet potato substitution. Higher WSI is an indicator of a good starch digestibility. The drum dried product upon reconstitution in water would swell and provide viscosity to the slurry. Information on the swelling power of a product would also help to know the amount of water to add to reconstitute or use in preparation of the product.

4.2.4 Bulk Density

The bulk density is a reflection of the weight the flour samples can carry if allowed to rest directly on one another (Akubor and Obiegbuna 1999). There were significant differences ($p \leq 0.05$) in the bulk density amongst flours blends which ranged from 0.53 to 0.63 g/mL. The highest bulk density was observed in formulations with higher sweet potato substitution. This shows that the composite blend of samples with higher sweet potato addition was more porous and hence would have more pack volume (Kraithong, Lee, & Rawdkuen, 2018). The slight variation in bulk density could be as a result of the variation in starch content. Knowledge of bulk density of a flour may help

determine the appropriate packaging material for the product. Thus, a flour with a higher bulk density would require a denser packaging material.

4.2.5 Emulsifying Stability and Capacity

The emulsion capacity reflects the ability of the sample to rapidly adsorb at the water-oil interphase during the formation of emulsion, thereby preventing flocculation and coalescence whiles the emulsion stability is dependent on its ability to uphold the emulsion in subsequent processing stages such as cooking and canning (Subagio, 2006; Tsaliki *et al.*, 2004). Table 4.4 indicated slight differences amongst formulations based on ES and EC. The data obtained ranged from 48.83 – 57.70% for ES and 47.43- 62.78 % for EC. The difference seen were as a result of increment in Bambara groundnut flour substitution. Hydrophobicity of protein has been attributed to influence their emulsifying properties (Kaushal *et al*., 2012). These properties are influenced by many factors among which are solubility, pH and concentration. The emulsifying capacity of protein molecules is generally composed of nonpolar amino acids, charged amino acids and non-charged polar amino acids. These types of amino acid cause hydrophobic and hydrophilic properties such that proteins can interact with both oil and water molecules and act as emulsifiers. Knowledge of ES and EC are very important since the producer would want to know which of the formulations would form the best emulsion since a consumer would not want to see the product separate into water and solids whilst eating the food.

Table 4.4: Functional properties of drum dried products

Formulations (CF: SP:BF)	30 °C WAI (g/g)	OAC (g/g)	SP_1 (g/g)	WSI (%)	BD (g/ml)	ES%	EC%
S1(30:10:15)	8.10±0.02^{a}	1.93±0.08^{a}	9.05±1.20^{b}	17.70±0.042^{f}	0.53±0.00^{bc}	57.57^{a}	62.78^{ab}
S2(14:34:7)	7.11±0.26^{c}	1.37±0.07^{c}	7.50±0.43^{c}	22.66±0.14^{d}	0.56k±0.01^{b}	49.90^{bc}	51.48^{bc}
S3 (9:34:12)	6.66±0.13^{d}	1.59±0.05^{b}	8.52±0.45^{ab}	24.33±0.80^{c}	0.53±0.01^{bc}	57.57^{a}	59.62^{bc}
S4 (24:24:7)	7.10±0.02^{c}	1.40±0.01^{c}	7.10±0.11^{d}	22.04±0.63^{d}	0.53±0.00^{bc}	52.46^{b}	54.44^{bc}
S5 (10:40:5)	6.09±0.03^{e}	1.19±0.04^{d}	6.92±0.15^{d}	26.98±0.92^{ab}	0.62±0.00^{a}	48.83^{bc}	50.14^{c}
S6 (0:40:15)	6.27±0.12^{e}	1.88±0.07^{a}	6.87±0.07^{d}	27.63±0.83^{a}	0.63±0.01^{a}	57.23^{a}	67.17^{a}
S7(17:28:10)	6.02±0.31^{e}	1.47±0.04^{bc}	7.79±0.11^{c}	26.33±0.68^{b}	0.61±0.01^{a}	57.57^{a}	58.13^{b}
S8 (30:20:5)	7.71±0.19^{b}	1.18±0.07^{d}	9.28±0.27^{a}	20.40±0.69^{e}	0.60±0.01^{ab}	49.90^{bc}	47.43^{c}
S9(24:19:12)	7.39±0.02b^{c}	1.61±0.12^{b}	8.40±0.14^{ab}	26.00±0.02^{b}	0.58±0.00^{ab}	53.42^{b}	55.36^{b}
P-value	0.000	0.000	0.001	0.000	0.020	0.001	0.000

WAC= Water absorption Index; OAC= Oil absorption capacity; SP_1= Swelling Power; EC, Emulsion Capacity; ES = Emulsion stability, BD = Bulk density.
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.3 Chemical Characterization of Composite Flour Blends

4.3.1 Proximate Composition

The proximate composition of all nine drum dried samples were determined and the results are presented in Table 4.5.

4.3.1.1 Moisture content

Moisture content is an important factor in the storage stability of food products. Furthermore, apart from its influence on product shelflife, the amount, of moisture contained in a food may affect the general appearance, taste, weight, and texture (Appoldt and Raihani, 2017). The moisture content of all samples was almost uniform. They ranged from 3.48-4.54% with flour from S7 having the lowest, while flour S2 had the highest value. Even though the same quantity of moisture was added to the composite flours in preparation of the slurry before drum drying, the individual formulations had different capacities in holding on to the water during the drum drying operation and moisture flush off. Specifications of flours are generally limited to a moisture content to 14% or less. Flours with moisture content above 14% are not stable at room temperature and as such organisms present in them will start to grow, thus producing off odours and flavours (Shahzadi *et al*., 2005). The moisture contents recorded were relatively low enough indicating storage stability.

A higher retention of water was observed in formulation S2(14:34:7) which has a higher OFSP substitution and this could be due to the fact that, Sugars are naturally occurring humectants and hence are able to retain water. However, this trend was not observed throughout the formulations and this could also be due to the different compositions of the flours.

Table 4.5: Proximate composition of all drum dried product

Formulation CF: SP:BF	Energy (Kcal)	Moisture (%)	Protein (%)	Fat (%)	CHO (%)	Ash (%)	Fibre (%)
S1(30:10:15)	379.00±0.03 ^{d}	4.46 0.02 ^{a}	8.01 ±0.29 ^{b}	2.82±0.03 ^{a}	80.41±0.20 ^{de}	2.34 ±0.07 ^{a}	1.96±0.04 ^{a}
S2(14:34:7)	379.13±0.0.69 ^{d}	4.54 ± 0.07 ^{a}	7.56±0.01^{cd}	1.62±0.1 ^{c}	83.57±0.06 ^{bc}	1.43±0.07 ^{d}	1.28±0.04 ^{f}
S3 (9:34:12)	383.76±0.33 ^{b}	4.13±0.20 ^{a}	8.13 ±0.00 ^{bc}	2.67±0.03 ^{ab}	81.80±0.16 ^{c}	1.80±0.11 ^{c}	1.48±0.04 ^{d}
S4 (24:24:7)	381.53±0.05 ^{c}	3.99 ±0.00 ^{ab}	6.98 ±0.00 ^{d}	1.77±0.03 ^{c}	84.42±0.06 ^{b}	1.44±0.03 ^{d}	1.40±0.00 ^{e}
S5 (10:40:5)	385.82±0.11^{a}	3.54± 0.07 ^{b}	8.09 ±0.00 ^{bc}	1.60±0.00^{c}	84.76±0.03 ^{b}	1.00±0.3 ^{b}	1.00±0.00 ^{g}
S6 (0:40:15)	382.66±1.52 ^{bc}	3.99± 0.71 ^{ab}	9.40 ±0.03 ^{a}	2.87±0.3 ^{a}	79.80±1.25 ^{e}	2.09±0.10 ^{b}	1.84±0.05 ^{b}
S7(17:28:10)	382.30±.0.03 ^{bc}	3.48±0.04 ^{b}	8.14 ±0.7 ^{b}	1.57±0.03^{c}	83.89±0.79 ^{bc}	1.49±0.03 ^{d}	1.42±0.04 ^{de}
S8 (30:20:5)	385.12±0.31 ^{a}	3.52± 0.04 ^{b}	7.29 ±0.02 ^{d}	1.50±0.00^{c}	85.62±0.06 ^{a}	1.05±0.03 ^{e}	1.06±.0.01 ^{g}
S9(24:19:12)	380.75±0.14 ^{cd}	3.99 ±0.00 ^{ab}	8.54 ±0.01^{b}	2.37±0.03 ^{b}	81.31±0.12 ^{d}	2.03±0.07 ^{b}	1.76±0.01 ^{c}
P-value	0.00	0.013	0.00	0.00	0.00	0.00	0.00

Means in same column with different superscripts are significantly different ($p \leq 0.05$)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.3.1.2 Protein

Proteins play an essential role in sustaining life. They are significant in an individual's growth and development especially in children. Protein content of the blends increased significantly with every increase in BG flour substitution. This increase was expected because pulses contain significant amounts of proteins. The highest recording was seen in S6 which contained highest amounts of BG flour however S4 which contained 7.5% BG flour recorded the least protein content even though the least BG substitution was 5%. Similarly, protein content increased with increasing OFSP flour substitution at the same level of BG flour. This trend was seen in S6 and S1 with S6 having the highest BG flour and highest OFSP flour substitution whilst S1 had the highest substitution for BG flour and lowest for OFSP substitution. They both recorded 9.40 and 8.01% protein content respectively.

4.3.1.3 Carbohydrate content

The carbohydrate content of the sample ranged from 79.80-85.62 %. Higher values were recorded due to the fact that the samples were composed of mainly carbohydrate rich materials. The carbohydrate contents of these flour samples indicate that the products made from them will be good sources of energy. Carbohydrates also have a significant effect on the general appearance, textural characteristics amongst others, of foods. From Table 4.5, it was observed that carbohydrate content decreased with increasing BG flour and increased with increasing OFSP flour and Cassava flour. Formulation S8 (30:20:5) recorded the highest carbohydrate content of 85.62±0.06 and S6 (0:40:15) the lowest carbohydrate content of 79.80±1.25.

4.3.1.4 Fat

The fat content of all the blends were generally low. This was anticipated, since all the contributing raw materials were low in fat. Cereals, roots and tuber crops mostly store their energy in a form of starch rather than lipids hence the reason for the low values. Fat content of the flour blends ranged from 1.5 – 2.87%. There were significant differences in all the values obtained. The increase in BG substitution lead to the augmentation of flour blends in fat. Foods with relatively higher fat contents produce certain undesirable characteristics during storage. Higher fat content may promote oxidative rancidity which may lead to development of unpleasant and odorous compounds, whereas low fat levels would ensure longer shelf life of the products (Reebe, *et al*, 2000).

4.3.1.5 Energy

The energy content represents the physiological fuel value. A serving of 100 g of the formulated breakfast food provided energy less than 400 Kcal. There were significant differences observed between the energy value recorded for all formulated breakfast food, ranging from 379.00 - 385.12Kcal. Formulations with higher contents of cassava flour and OFSP flour recorded higher values for energy. Addition of milk to the formulated breakfast product may increase the energy levels and the protein content.

4.3.1.6 Crude fibre

Dietary fibre may be defined as “edible carbohydrate polymers which are not broken down by the endogenous enzymes in the small intestine of humans” (Jones, 2014). It slows down the release of

glucose into the blood and decreases intercolonic pressure hence reducing the risk of colon cancer. However, consumption of fibre above 5% hinders the absorption of several nutrients, makes food bulky and as well induces flatulence (Asma *et al*., 2006).

Crude fibre contents of the blends increased slightly as the level of BG flour substitution increased. Likewise, this may be attributed to the high crude fibre content of legumes which had a greater effect on the formulations. Cassava also proved to increase the fibre content of the formulation. An increase in both BG flour and cassava flour resulted in a formulation with higher crude fibre content but this was not so in the case of OFSP flour. Olaoye *et al.* (2006) corroborated these results.

4.3.1.7 Total Ash Content

The ash content in a given food sample gives an idea of the level of inorganic elements present in the food (Kavitha & Parimalavalli, 2014). The ash content of the blends ranged from 1 to 2.34%. The total ash content determined increased with increasing BG and cassava flour formulation.

S1 which contained the highest proportion of BG flour (15%) and cassava flour (30%) contained 2.34% ash whilst S5 which was made up of 5% BG flour and 10% CS flour contained 1% ash. This discovery was in agreement with the findings of Ukom *et al*. (2009), who showed that soy beans and cassava flour increased total ash flour of the formulation. Thus, it can be established that ash content will be increased as the level of legumes and cassava flour are increased.

4.3.2 Beta carotene

The results for β-carotene content in both the raw and drum dried formulations are displayed in figure 4.4. The β-carotene content in raw formulations ranged from 3.99 ± 0.02 -16.08±0.08 mg/100g and that of the drum dried formulations ranged from 1.53±0.02 -7.10 ± 0.11 mg/100g. It was observed that, there was a significant drop in β-carotene content after samples were drum dried. Sample 6 which contained 16.08mg/100g of β-carotene was degraded to 7.10 mg/100g. Drum drying was executed at a temperature of 175 ^{O}C for a short period of time (35rpm). Owing to the exposure of formulations to a high temperature, it may be implied that temperature (for that matter drum drying) greatly affects β-carotene content during heat processing. Vimala and Hariprakash (2011), reported that β-carotene content of raw sweet potato flour obtained from cream cultivars and orange cultivars falls within the range of 0.01 to 26.6mg/100g with orange cultivars having higher β-carotene content. Burgos *et al.* (2001) reported the β-carotene content of orange fleshed sweet potato flour was within the range 4.29 mg / 100g - 18.55mg/ 100g which is in agreement with the range 3.99 ± 0.02 -16.08±0.08 mg/100g obtained from this study. A significant difference was observed within β-carotene content of cooked and uncooked formulations. As expected, the β-carotene content in the formulations were significantly affected by an increase in the orange fleshed sweet potato in the formulations. As the orange fleshed sweet potato substitution increased and bambara groundnut flour decreased, beta carotene content was elevated. S1 which had the least the orange fleshed sweet potato (10%) substitution and highest bambara groundnut flour substitution (15%) recorded the least, indicating that the orange fleshed sweet potato has an important nutritional value. Beta carotene plays an essential role in the growth and development of babies and young children especially and promote other health benefits such as such as reduction in cardiovascular disorders (Njoku et al., 2011).

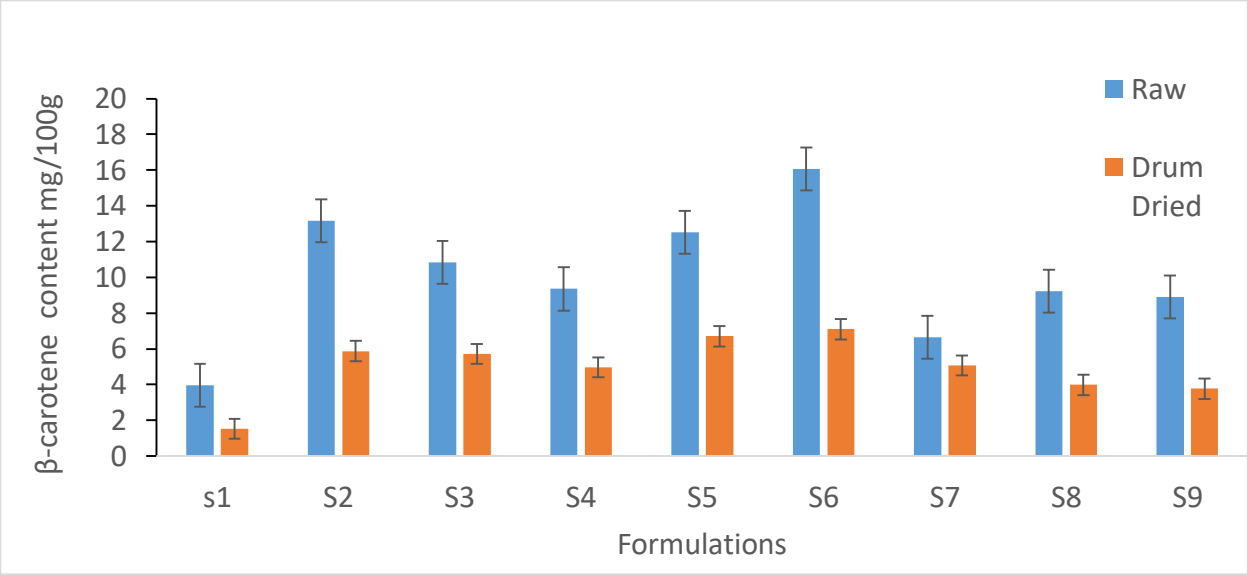

Figure 4.4: Effect of drum drying on beta carotene content of the various breakfast flour Formulations
S1(30:10:15), S2(14:34:7), S3 (9:34:12), S4 (24:24:7), S5 (10:40:5), S6 (0:40:15), S7 (17:28:10), S8 (30:20:5), S9(24:19:12)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.3.3 In vitro Protein Digestibility (IVPD)

The quality of protein in raw materials and their products is determined by the protein digestibility factor (Chinma *et al.*, 2011). In vitro protein digestibility has made available information on how some specific proteins are digested and their corresponding qualities identified (Day and Swanson, 2013). In vitro protein digestibility (IVPD) has been related to true digestibility, and is normally used as a quicker and more convenient alternative (Adam *et al.*, 2013). The IVPD of the formulations ranged from 48 - 65% for raw formulation and 68.34 - 88.6 % for the drum dried samples. Studies have shown that, thermal processing such as drum drying improves digestibility (Abdel-Aal, 2002; Giami, 2001). The alteration of protein structure in the presence of heat increases structural changes of protein such as globulin, and this allows accessibility to proteases consequently increasing digestibility of the proteins (Occena *et al*, 1997; Swaisgood and Catignani, 1991). Furthermore, application of heat to food can also reduce the levels of heat labile

antinutrients such as enzyme inhibitors, oligosaccharides and improve the digestibility of protein in the legume, in this case Bambara groundnut.

Increasing the amount of in OFSP substitution was seen to have increased protein digestibility. The digestible protein content of increased BG and OFSP substitution was higher as compared to a formulation with higher BG flour and CF flour. Therefore, inclusion of sweet potato in instant breakfast foods would enhance in vitro protein digestibility of foods.

Table 4.6: Invitro Protein Digestibility of the Formulations

Formulations CF: SP:BF	Raw (%)	Drum Dried (%)
S1(30:10:15)	65.88±0.23^{e}	80.4±0.45^{ab}
S2(14:34:7)	54.37±0.13^{g}	71±0.72^{c}
S3 (9:34:12)	61.47±1.5^{f}	76.81±0.58^{b}
S4 (24:24:7)	53.28±0.80^{g}	70.34±0.38^{cd}
S5 (10:40:5)	48.26±0.38^{h}	72.3±0.80^{c}
S6 (0:40:15)	67.32±1.0^{e}	88.6±2.32^{a}
S7 (17:28:10)	63.89±0.05^{ef}	72.98±0.89^{c}
S8 (30:20:5)	46.32±.56^{hi}	68.34±0.54^{d}
S9(24:19:12)	63.14±1.57^{ef}	74.88±1.67^{b}
P-value	0.00	0.011

Means in same column with different superscripts are significantly different ($p \leq 0.05$)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.3.4 Invitro Starch Digestibility

Based on rate of digestion, starches are categorized into rapidly digestible starch, slowly digestible starch and resistant starches (Englyst *et al*. 1992). Starch digestion rate with its resulting glycemic effect is greatly influenced by the food composition, processing conditions and source of starch (Niba, 2003). From Table 4 significant differences were observed in the total starch content for all formulations. Values for total starch content ranged from 66.96 – 77.00. Starch granules are broken down during heat, this enables pancreatic α-amylase to facilitates hydrolysis the starch. RDS content ranged from of 19.06–23.90, while the SDS contents ranged from 29.16 to 40.51.

Generally, values for rapidly digestible starch (RDS) and slowly digestible starches (SDS) were statistically similar ($p \leq 0.05$). However, for formulation S7, the RDS was significantly lower than formulations S8 and for formulation S6, the SDS was significantly higher from S1, S2 and S9. An increase in Bambara groundnut content was seen to have increased the starch digestibility. A study by Mahmood *et al*. (2006) and Rooney and Pflugfelder, (1986) reported that, proteins form a film around the starch granules and thus prevent starch-hydrolyzing enzymes from accessing the starch granules therefore prolonging digestion.

Nonetheless, SDS recorded were higher than RDS. Foods containing high amounts of slowly digestible starches are thought to be expedient to people with metabolic disorders such as diabetes or glycogen storage diseases since the release of glucose is gradual and prolonged (Zhang and Hamaker, 2009). Also, foods with higher SDS extends satiety (Miao *et al*.,2015).

In terms of glycemic index, foods may be classified into three categories of: low GI; ≤ 55, medium GI = 55-69, and high GI; ≥ 70 (SBS, 2011) which is equivalent to good, better, and the best choices for nutrition. The calculated values for all formulations ranged from 40.49 – 47.39. Therefore,

since the eGI values obtained were below ≤ 55, all formulations produced can be considered as low glycemic food. Consumption of food incorporated with slowly digestible carbohydrates and low glycemic index may improve glucose tolerance in both healthy and diabetic patients.

Table 4.7: Starch Digestibility of the Drum Dried Formulation

Formulations	Total Starch	RDS	SDS	eGI
S1(30:10:15)	74.12±0.037 ^{b}	23.12±1.12^{ab}	29.16±2.10^{b}	42.80±2.29 ^{bc}
S2(14:34:7)	72.60±0.01 ^{b}	23.90±2.44^{ab}	28.43±3.99^{b}	43.27±2.82 ^{b}
S3 (9:34:12)	70.193±0.03 ^{bc}	23.00±2.29^{ab}	32.11±4.87^{ab}	44.11±3.97 ^{b}
S4 (24:24:7)	66.96±0.130 ^{ab}	20.55±3.28^{ab}	32.78±2.53^{ab}	41.64±4.67 ^{bc}
S5 (10:40:5)	70.59±0.09 ^{bc}	20.55±3.20^{ab}	34.88±8.45^{ab}	42.23±4.32 ^{b}
S6 (0:40:15)	69.01±0.32^{ab}	20.51±1.75^{ab}	40.51±6.35^{a}	42.79±5.08 ^{bc}
S7 (17:28:10)	70.18±0.177 ^{bc}	19.06±2.48^{b}	34.62±5.13^{ab}	47.39±1.92^{a}
S8 (30:20:5)	76.60±0.59 ^{a}	24.96±3.7^{a}	31.72±3.44^{ab}	45.60±5.87 ^{ab}
S9(24:19:12)	77.00±0.15 ^{a}	21.05±2.38^{ab}	29.19±2.37^{b}	40.49±1.82 ^{c}
P-value	0.02	0.27	0.39	0.776

RDS: rapidly digestible starch; SDS: slowly digestible starch, eGI: expected glycemic index,
Values with different letters in columns are significantly different ($p < 0.05$) from each other
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.3.5 Microbiological Safety

Microbiological evaluations were done prior to sensory analysis. Thus, to determine whether the products were safe for human consumption. The microbial loads of the various formulations were as presented on Table 4.8. The results obtained corresponded to standards set by Ghana Standard Boards (GS 955: 2013). This shows that the cooking (drum drying) process inactivated all enzymes as well as kill heat-sensitive and pathogenic microorganisms. Also, preparation of the products was done under hygienic conditions and environment. Precautions (such as using aseptic techniques) were taken so as to be able observe accurate microbial count in the product and rather not counts from contamination that might have occurred during the microbial analysis since microbes are ubiquitous. The results showed that there was no significant difference ($p \leq 0.05$) between the mean values calculated. The products produced were free of molds and yeast as well as coliforms. With the low moisture content of the samples, 3.48 to 4.54%, it is expected that the samples will have a long shelf life with the population of aerobic mesophiles of 0 – 2.15 $\log_{10}$ CFU/g of samples provided they were packaged well to avoid picking up of moisture during storage.

Table 4.8: Microbial load the different formulations.

Microorganisms	**Microbial load the different formulations (log10 CFU/g)**								
	S1	S2	S3	S4	S5	S6	S7	S8	S9
Aerobic mesophiles	0.86±1.43	2.15±0.21	0.60±0.33	0.16±0.05	ND	2.05±0.21	1.00±0.30	2.10±0.57	2.00±0.21
Total Coliform Count	ND	ND	ND	ND	ND	ND	ND	ND	ND
Yeast and Mold Count	ND	ND	ND	ND	ND	ND	ND	ND	ND

-CFU- colony forming units. -ND=Not Detected
S1(30:10:15), S2(14:34:7), S3 (9:34:12), S4 (24:24:7), S5 (10:40:5), S6 (0:40:15), S7 (17:28:10), S8 (30:20:5), S9(24:19:12)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.4.0 Sensory Evaluation Of Drum Dried Products

4.4.1 Qualitative Descriptive Analysis

Nine trained panelists were used for the descriptive analysis. The panelists came out with attributes that best described the reformulated ready-to-eat breakfast products (refer to appendix for list of descriptors). The formulated breakfast products were described to have a cream colour ranging from yellowish to creamy, Particles, having a grainy or particulate nature which was likened to that of cerelac (an infant cereal manufactured by Nestlé Ghana). It was also described to be sticky, viscous and having a cooked corn aroma and flavour. Again, it was described to be sweet, has a gritty and viscous mouthfeel and an astringent aftertaste.

Generally, at ($p<0.05$), the panelists were unable to detect differences between the aroma, stickiness, flavour, astringency and grittiness of mouthfeel. However, there were significant differences ($p<0.05$) in terms of colour, viscosity, as well as sweetness of the formulated breakfast products as shown in Figures 4.5 and 4.6. Attributes with (*) means that there was no significant difference between formulations.

Using the 10cm line scale with 10cm having higher intensities, formulations S6, S5, S2 and S3 recorded higher intensities of colour, showing that an increase in OFSP substitution increased colour intensity. Same trend was observed in sweetness and the reverse in viscosity. Ratings given to sweetness was generally low. Values ranged from 0.12- 0.89. It should be noted that, these samples were served without the addition of an external sweetener. This confirm that, utilization of OFSP in RTE breakfast foods would require less addition of external sweeteners. An increase in OFSP substitution caused a decrease in viscosity of the various formulation and this was corroborated by the findings of Amaglo *et al*, (2012).

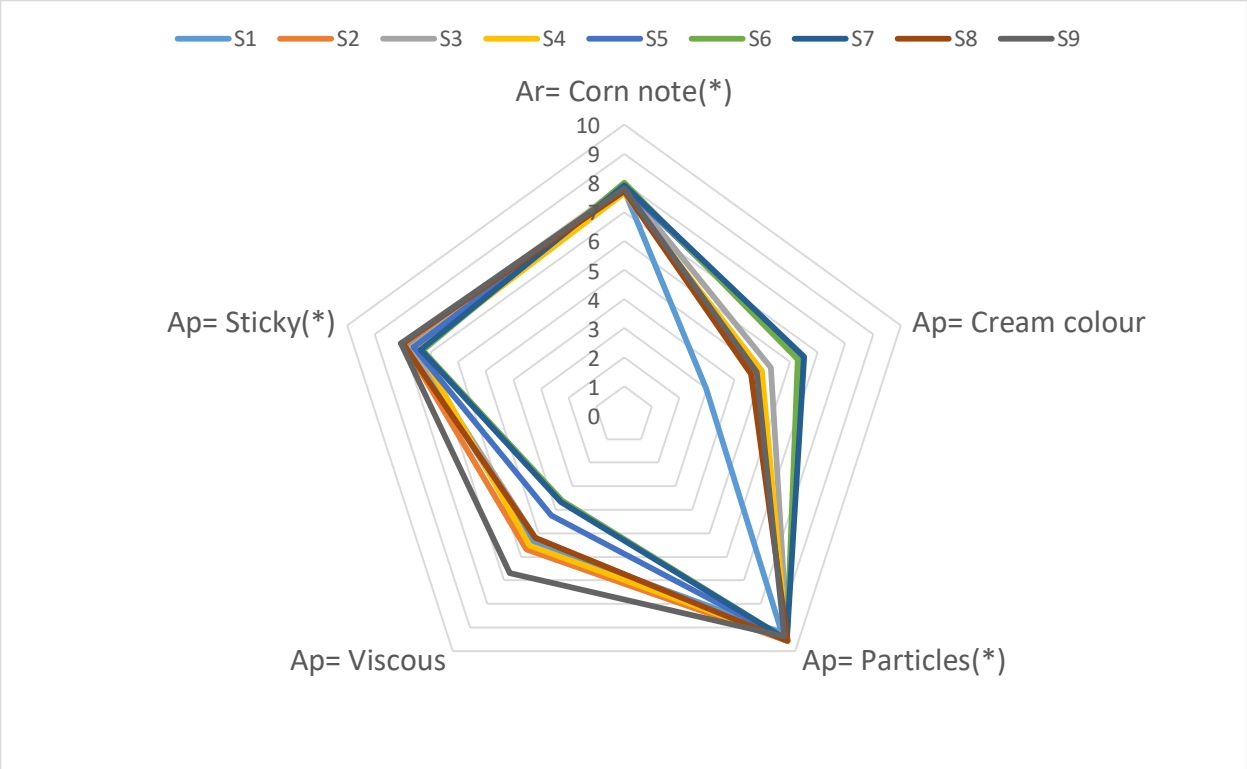

Figure 4.5: Qualitative descriptive analysis of Formulations for Appearance (Ap) and Aroma (Ar)
S1(30:10:15), S2(14:34:7), S3 (9:34:12), S4 (24:24:7), S5(10:40:5), S6(0:40:15), S7(17:28:10), S8(30:20:5), S9(24:19:12)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

It should be noted that, some of results obtained for viscosity were similar to of instrumental methods. For instance, the descriptors that showed significant differences at $p<0.05$ (colour, viscosity, sweetness), was observed to have followed a similar trend when compared to analytical parameters that had been measured. That is, samples which recorded higher CIE values for lightness (L*) thus S1 and S8 (refer to Table 4) were seen to have amassed low scores from panelists (2.96 and 4.59 respectively), whilst samples S5 and S6 which recorded high intensities for redness (a*) and yellowness (b*) had high scores(6.50 and 6.42).

Again, the results obtained from the descriptor 'viscous-Ap' (defined by the descriptive panellist as resistance to flow of the formulation) also correlated with the results obtained when the flow

behaviour was determined. In both instances, 'viscosity' or 'viscous' was observed to have increased significantly with an in increase in OFSP substitution. As a result, this would assist manufacturers in deciding which formulation to use for production, based on the preference of the consumer. Another similar trend that could be compared was that of the solube solids (instrumental) and the descriptor 'sweetness'. Likewise, formulations with higher sweet potato substitutions were high in both sweetness and soluble solids (samples S5 and S6 with 40% OFSP substitution).

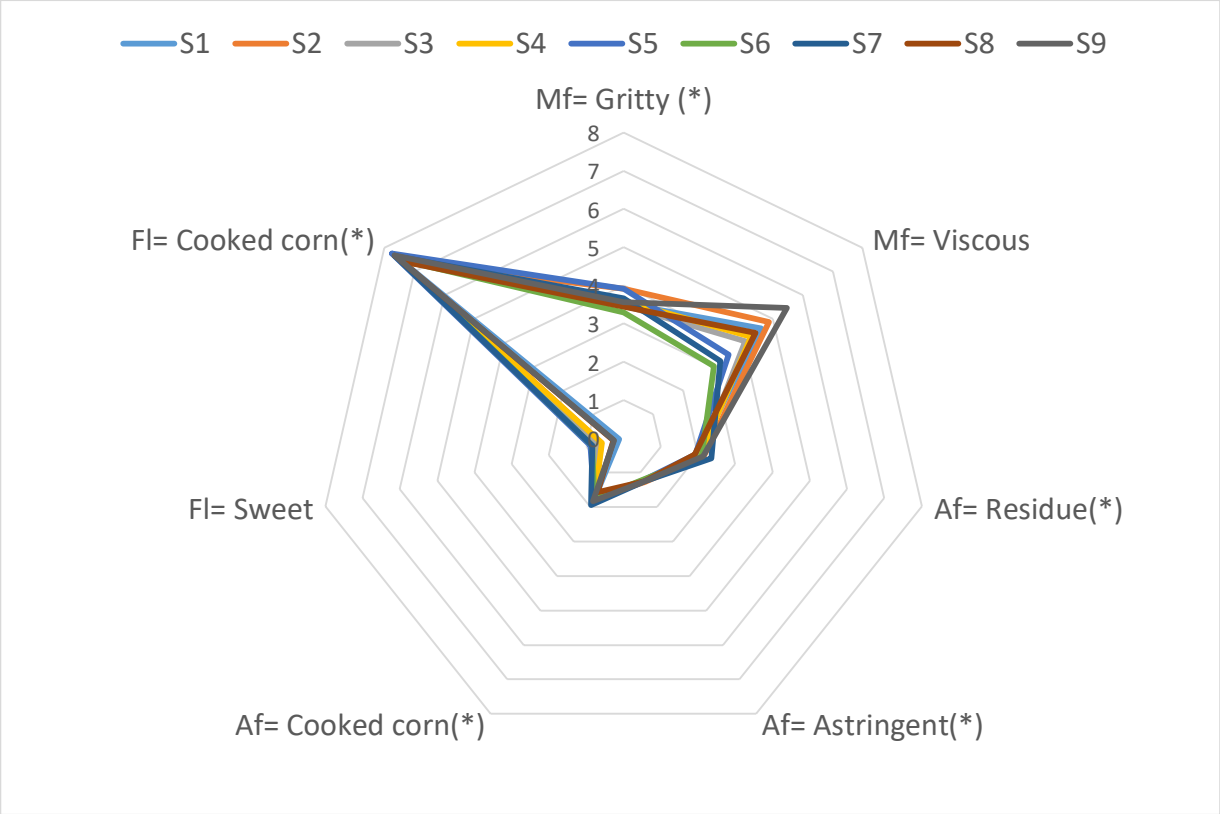

Figure 4.6: Qualitative descriptive analysis of Formulations for Mouth feel (mf), Flavour (fl) and Aftertaste (af). S1(30:10:15), S2(14:34:7), S3 (9:34:12), S4 (24:24:7), S5 (10:40:5), S6 (0:40:15), S7 (17:28:10), S8 (30:20:5), S9(24:19:12)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.4.2 Consumer Acceptance Tests

Sensory response to colour, taste, aroma and texture of foods help determine food preference and dietary patterns (Fellows, 2000). Variations within ingredients have substantial influence on acceptability and this may be due to the effect of ingredient mixtures on sensory attributes. Table 4.9 shows the mean liking scores on sensory attributes for the nine drumdried formulations. A total of 75 untrained panelists were used in this study. Average consumer acceptability scores for aroma, sweetness, viscosity, colour and overall acceptability ranged from 6-like slightly to 8-like very much on the 9-point hedonic scale.

The appearance of a product is often a critical attribute on which a consumer can base his/her decision to purchase or consume a product. One of such attributes is colour. Colour usually depicts freshness of a product. Statistically significant differences ($p< 0.05$) were observed with regards to colour. The formulations decreased in their intensity from yellowish to cream with increasing proportion of OFSP. The most preferred sample in terms of colour was formulation 6 (with a likeness score of 8.4) while the least preferred was formulation 1 (with a likeness score of 6.7).

Taste is also another important parameter when it comes to sensory evaluation of food products. The appearance of the product may attract a consumer to purchase it for the first time but to ensure continues procurement the flavor, sweetness and aroma must be taken into consideration. Significant differences were not detected in terms of aroma. This could be attributed to the cooked corn note perceived by the trained panelists. The equal amounts of maize flour used in preparation of the products masked the aroma of all other ingredients present. Likeness for sweetness was observed to increase as proportions of OFSP increased.

Significant differences ($p < 0.05$) were observed for mouth feel in terms of how viscous or how they like the thickness of the product in the mouth. High scores were observed for samples with high OFSP. The descriptive test proved that samples with high OFSP had a lower viscosity indicating that the consumers preferred samples with a lower viscosity. After the sample has been swallowed, no significant differences were detected for aftertaste for formulations. The consumers generally liked the general sensation in the mouth after swallowing the product.

The overall acceptability has to do with the approval of the product when all attributes have been taken into consideration. The overall acceptability of the formulations ranged from 6.98 - 8.50. This indicates that all the formulations were generally liked by all the consumers. However, Formulation 6 was most accepted by consumers with mean preference value of 8.50 which was significantly different ($p < 0.05$) from the others while formulation 1 was the least preferred. The results revealed that addition of OFSP to the RTE breakfast formulations significantly improved their overall acceptability.

In order for a new product to thrive on the market, acceptability by consumers should be of great concern. Thus, by enquiring from the panelists, about 78 % of them claimed that they were more likely to buy the products if made available on the market. Correspondingly, the mean scores obtained for overall acceptability is a good indication that the product would be patronized. Asante (2015) mentioned that, higher scores credited to overall acceptability indicate that the product has good chances of being patronized by consumers.

Table 4.9: Consumer acceptance of drum Dried Formulations

Formulation CF:SP:BF	Overall Acceptability	colour	Aroma	Sweetness	MouthFeel	Aftertaste
S1(30:10:15)	6.98±1.32^{bc}	6.70±0.89^{e}	7.87 ± 1.31^{a}	6.45±1.31e	6.67±1.03^{ab}	7.50 ± 1.76^{a}
S2(14:34:7)	7.55±0.82^{ab}	8.35±1.23^{a}	8.00 ± 1.41^{a}	7.70± 1.05b	7.67± 1.75^{ab}	7.71± 1.79^{a}
S3 (9:34:12)	7.70± 1.52^{d}	8.23± 1.76^{a}	7.82 ± 1.31^{a}	7.60± 1.23^{b}	7.33±1.37^{ab}	7.50±2.74^{a}
S4 (24:24:7)	7.00±1.21^{cd}	7.30 ±1.94^{d}	7.83 ± 1.47^{a}	7.15± 1.79d	7.00±1.67^{ab}	7.33±1.97^{a}
S5 (10:40:5)	7.90± 0.84^{a}	8.35 ±0.52^{a}	7.640± 1.05^{a}	8.40± 1.54b	8.16±0.41^{a}	7.83±1.47^{a}
S6 (0:40:15)	8.50±1.47^{a}	8.40±1.47^{a}	7.95 ± 1.23^{a}	8.55±2.04a	8.67±0.52^{a}	7.33±0.82^{a}
S7(17:28:10)	7.90±0.82^{ab}	7.25 ±0.55^{d}	7.80 ± 2.04^{a}	7.30± 1.05c	7.83±1.94^{a}	7.67±1.03^{a}
S8(30:20:5)	7.20±1.79^{ab}	7.15 ±0.82^{d}	8.16 ± 0.41^{a}	7.00± 1.47d	6.67±1.03^{ab}	7.67±1.03^{a}
S9(24:19:12)	7.26±0.75^{bc}	7.25±0.52d	7.73 ± 2.24^{a}	7.15± 1.03c	7.17±1.17^{ab}	7.83± 2.99^{a}
P-value	0.00	0.00	0.37	0.02	0.25	0.20

Means in same column with different superscripts are significantly different ($p \leq 0.05$). Interpretation of scores: 1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = indifferent; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely.
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)

4.5 Sorption Behaviour Of Formulations

Because of their large surface to volume ratios, food powders have variable capacities to sorb water when exposed to the atmosphere. The ability to sorb water for any flour depends on its components as well as environmental conditions of temperature and relative humidity. Moisture sorption isotherms were determined for all formulations at 23 and 30 ^{o}C. The isotherms were fitted to models suggested by Brunauer, Emmett and Teller (BET), Guggenheim-Anderson-deBoer (GAB), Smith, Oswin and Henderson sorption equations (Appendix3). These models were chosen for their versatility, relative simplicity, mathematical computations and their reported fit for food systems. The derivatives of the models for moisture sorption of all formulations are shown in Table 4.10. From the Table it was observed that, the experimental data fitted the Oswin model better (Figure 4.7) than the other models (Figure 4.8), with R^2 ranging from 99.02 to 99.94. This was because amongst all the fitted models, the Oswin's model described the isotherms with the highest % R^2. The knowledge of sorption behaviour and water activity is useful to predict chemical, physical and microbial stability of foods as a function of moisture content of the product.

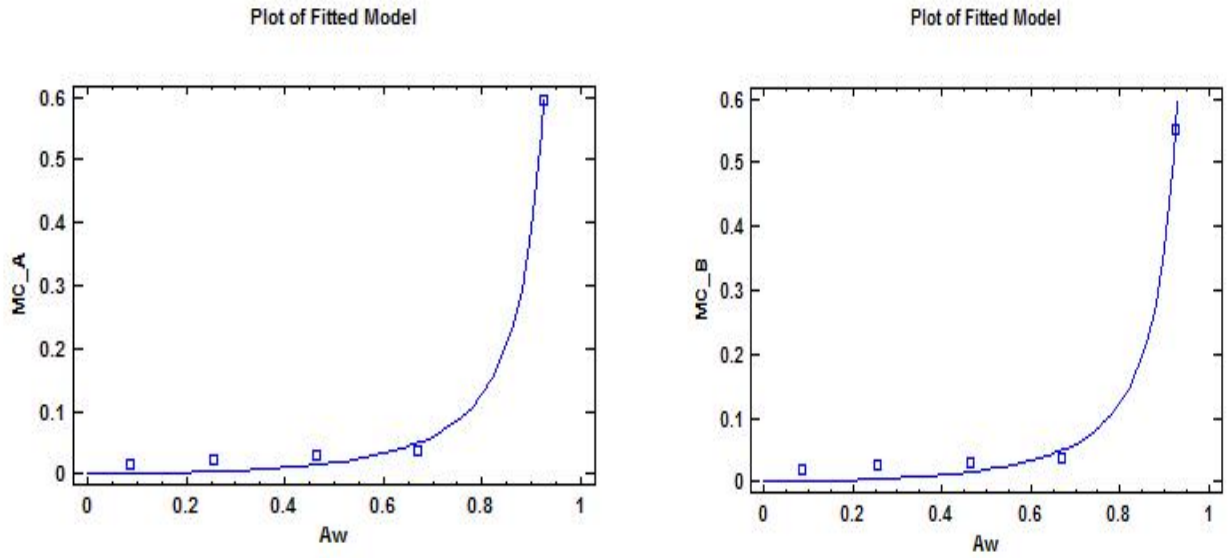

Figure 4.7. An example of a good fitted model using Oswin's Model
Mc_A (moisture content of Product 1), Mc_B (moisture content of Product 2), Aw (water activity)

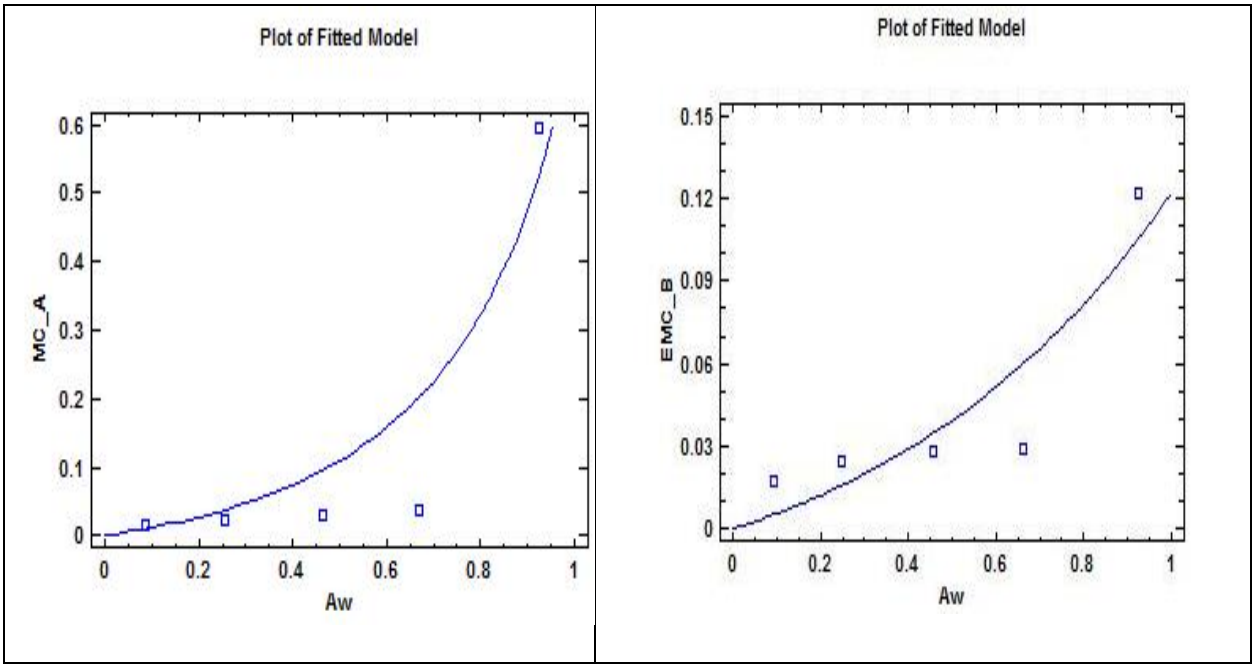

Figure 4.8 An example of a bad fitted model using GAB's Model
Mc_A (moisture content of Product 1) Mc_B (moisture content of Product 2)
Aw (water activity)

Table 4.10: Evaluation of goodness of fit and Sorption parameters of the various Formulations using different models

Formulation	Temp ° C	GAB Model				BET Module			Smith Model			Oswin Model			Henderson Model			
		M_o	K	G	R^2	M_o	C	R^2	A	B	R^2	A	B	R^2	T	A	B	R^2
S1	23	0.07	0.77	1.83	86.05	0.20	0.47	96.91	-0.08	0.24	87.42	0.02	1.38	99.65	0.78	0.12	0.78	80.97
S2		0.08	0.73	1.85	83.81	0.19	0.46	96.86	-0.07	0.22	87.04	0.02	1.35	99.47	0.80	0.12	0.80	81.20
S3		0.08	0.72	1.87	84.04	0.20	0.43	97.30	-0.06	0.20	87.90	0.02	1.24	99.45	0.83	0.11	0.83	82.55
S4		0.09	0.67	1.89	81.59	0.20	0.45	97.28	-0.10	0.28	87.94	0.02	1.29	99.65	0.81	0.12	0.81	82.17
S5		0.01	0.71	2.07	83.08	0.23	0.47	96.96	-0.08	0.22	88.55	0.02	1.38	99.72	0.75	0.13	0.75	81.15
S6		0.09	0.67	1.90	82.48	0.20	0.43	97.64	-0.07	0.21	89.07	0.03	1.21	99.59	0.82	0.11	0.82	83.30
S7		0.07	0.75	1.84	84.57	0.19	0.47	96.67	-0.08	0.23	86.65	0.02	1.39	99.44	0.79	0.12	0.79	80.68
S8		0.08	0.64	1.90	80.61	0.17	0.00	97.46	-0.06	0.17	89.41	0.02	1.25	99.82	0.89	0.11	0.89	82.92
S9		0.09	0.68	1.89	82.74	0.18	0.44	97.43	-0.07	0.20	89.28	0.02	1.26	99.78	0.85	0.11	0.85	82.67
S1	30	0.04	0.74	1.93	88.90	0.18	0.35	97.88	-0.03	0.12	90.28	0.02	1.04	99.17	0.99	0.10	0.99	86.20
S2		0.07	0.40	2.00	80.34	0.31	0.16	93.93	0.01	0.04	91.06	0.03	0.57	95.19	1.29	0.07	1.29	90.26
S3		0.01	0.98	1.62	93.71	0.18	0.37	97.43	-0.04	0.13	88.59	0.02	1.11	99.09	0.96	0.10	0.96	84.59
S4		0.14	0.74	1.99	89.89	0.27	0.56	95.97	-0.19	0.47	87.02	0.01	1.74	99.94	0.62	0.14	0.62	78.13
S5		0.49	0.26	1.56	62.43	0.18	0.40	97.66	-0.05	0.16	89.79	0.02	1.19	99.68	0.90	0.11	0.90	84.09
S6		0.08	0.65	1.78	82.70	0.18	0.39	97.83	-0.05	0.15	89.99	0.02	1.14	99.64	0.93	0.11	0.92	84.75
S7		0.08	0.64	1.76	79.59	0.17	0.40	96.71	-0.04	0.15	87.10	0.02	0.12	99.02	0.93	0.11	0.93	82.54
S8		0.09	0.58	1.79	78.44	0.15	0.39	97.61	-0.04	0.13	90.46	1.19	0.02	99.82	0.98	0.10	0.98	84.27
S9		0.07	0.67	1.77	82.61	0.16	0.40	97.44	-0.05	0.14	89.99	0.02	1.23	99.81	0.95	0.11	0.95	83.62

S1(30:10:15), S2(14:34:7), S3 (9:34:12), S4 (24:24:7), S5 (10:40:5), S6 (0:40:15), S7(17:28:10), S8(30:20:5)S9(24:19:12)
CF: SP:BF (Cassava flour: Sweet Potato flour: Bambara groundnut flour)
M= equilibrium moisture content, M_O = monolayer moisture content, T = temperature, C, G, k, A and B = constants.

The moisture sorption isotherm of the formulations at different temperatures is displayed in Figures 4.10. The equilibrium moisture content of formulations increased with increase in values of water activity at all temperatures. It was observed that, the equilibrium moisture content at increasing water activity was almost constant from water activities of 0.09-0.069 was more profound within water activities of 0.6–0.9. This implies that at a water activity greater than 0.6, there will be a rapid increase in moisture sorption by the flour, which might lead to microbial growth, enzymatic reactions and lipid oxidation with a consequent rapid spoilage of all formulations. A J shaped (type III) sorption isotherms known as the Flory-Huggins isotherm, were obtained (Table 4.10) throughout all the formulations Mathlouthi and Roge (2003). Blahovec and Yanniotis (2009), reported that, this type of isotherm is relatively rare and are observed with ingredients like sugar which are soluble in water. The J-shaped isotherms exhibited by formulations may be due to the OFSP flour contributing sugars to the formulation of the product.

From figure 4.9, by comparing both temperatures, the observance made was that, as the water activity was increasing, the equilibrium moisture content was also increasing. Conversely, as the temperature increased, the equilibrium moisture contents decreased at a constant water activity. This may suggest that, an increase in temperature will cause the product to be less hygroscopic. An increase in temperature would cause agitation in water molecule and break away from their binding sites of the food material and this may lead to a decrease in the monolayer moisture content (Ahmed *et al.*, 2004); Hossain *et al.*, 2001). Again, increasing temperature would lower the isotherm curves causing an increase in water activity at constant equilibrium moisture content thereby shifting the values above the critical level. Hence, storing these products under an increased temperature would make the product more susceptible to spoilage by microorganisms.

Consequently, at constant equilibrium moisture content, the product will deteriorate faster at a higher temperature than that at a lower temperature (Ariahu *et al*., 2006).

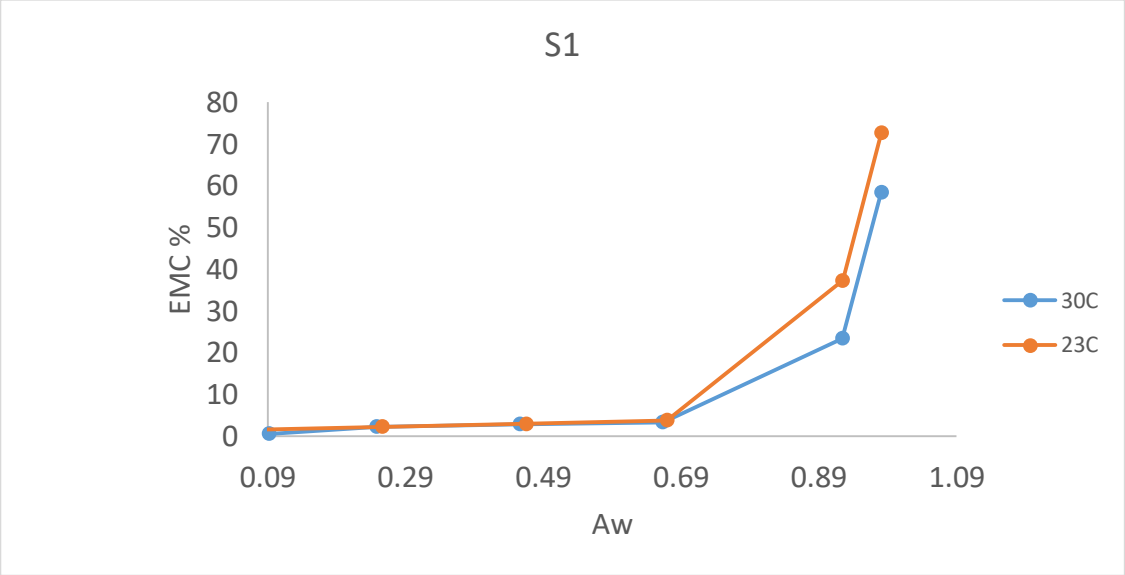

Figure 4.9: A typical example of Moisture Sorption Isotherm of the breakfast product (Sample 1) at different temperature

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study proved that, incorporation of Cassava and Orange-fleshed sweet potato flours with Bambara and Maize flours could be effectively used to produce drum dried RTE breakfast products with improved nutritional properties. Bambara groundnut appreciably increased products protein and ash content whereas an increase in cassava flour and orange-fleshed sweet potato flours increased carbohydrate and fibre content. Beta carotene content and soluble solids were elevated with a higher substitution of OFSP flour. Inclusion of orange-fleshed sweet potato would serve as a source of β-carotene and help curb vitamin A deficiency. Addition of external sweeteners would also be minimized.

Increment in sweet potato substitution significantly improved the functional and flow behaviour of the flour blends. The water solubility index and bulk density increased with an increase in OFSP flour whilst water absorption index, oil absorption capacity, swelling power and viscosity decreased with increasing OFSP flour. Bambara groundnut increased the oil absorption capacity, emulsion capacity and emulsion stability of the formulations. Likewise, an increase in cassava flour increased the water absorption index and swelling power of flour blends.

The drum drying process as well as an increase in Bambara groundnut substitution increased the digestibility of proteins. The digestibility of the starches was significantly improved with an increase in orange-fleshed sweet potato flour. Higher Slowly Digestibility Starches suggests prolonged satisfaction. The findings also displayed low glycemic index of formulated product

proving that the formulations were not high glycemic foods and that can be also be consumed by people with type two diabetes.

The product was safe to be consumed as it met microbial standards. Sensory evaluation showed that increase in sweet potato significantly improved the organoleptic quality of formulated product and hence contributed to high acceptance of formulated product. The most preferred formulation among the products with regards to sensory evaluation was blends with 40% orange-fleshed sweet potato flours, however addition of cassava flour to about 20% was also ranked high. This suggests that, based on consumer acceptance, inclusion of cassava, orange-fleshed sweet potato and Bambara groundnut in RTE breakfast foods would be successful.

The moisture sorption isotherms of the product presented a J-shape suggesting that whilst the products could be stable for a short while, they can be hygroscopic later and rapidly sorb moisture leading to spoilage. The sorption data were best fitted to the Oswin model. The equilibrium moisture content increased with increasing water activity but decreased with increasing temperature. Consequently, there was a steep rise in moisture content from 0.6 to 0.9. Therefore, storage of products must be below 30^{o}C and below a relative humidity of 70% in order to prolong its shelf life.

5.2 RECOMMENDATION

I recommend that:

1. Additional studies such as the mineral bioavailability and amino acid profile of the formulations should be investigated.
2. Further studies should be done on optimizing the processing conditions of drum drying (thus the effect of speed (rpm), temperature and moisture content of slurry) in the development of the most preferred product
3. Additional studies should be done to monitor fluctuation of light in regards to storage conditions and packaging material that is conducive for the most preferred products.

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Appendix 1

Mean scores of Descriptive Evaluation of formulations

Formulations	Appearance				Flavour		
CF:SP:BF	Lumpy	Sticky	Viscous	Particles	Cream Colour	Cooked Corn	Sweetness
S1(30:10:15)	4.89±2.13^{b}	7.79±3.37^{a}	5.35±1.55^{b}	9.22±1.74^{a}	2.96±1.83^{c}	7.50±1.44^{a}	0.12±0.38^{d}
S2(14:34:7)	5.63±1.88^{ab}	7.95±3.31^{a}	5.72±1.58^{b}	9.56±1.01^{a}	4.83±1.86^{b}	7.37±1.73^{a}	0.59±0.63a^{b}
S3 (9:34:12)	5.67±1.67^{ab}	7.67 ±3.41^{a}	5.19±1.63^{b}	9.56±1.02^{a}	5.30±1.61^{b}	7.62±1.23^{a}	0.74±0.64a^{b}
S4(24:24:7)	5.96±1.54^{a}	7.39±3.43^{a}	5.51±2.08^{b}	9.50±1.32^{a}	4.98±1.86^{b}	7.691.17^{a}	0.45±0.55b^{c}
S5(10:40:5)	4.70± 2.37^{b}	7.60± 3.40^{a}	4.25±1.39^{c}	9.48±1.29^{a}	6.42±1.40^{a}	7.75±1.23^{a}	0.89± 0.64^{a}
S6(0:40:15)	5.40±1.87^{ab}	7.28±3.46^{a}	3.61±1.39^{c}	9.53±1.13^{a}	6.50±1.49^{a}	7.47±1.74^{a}	0.84±0.76^{a}
S7(17:28:10)	6.33±1.73^{a}	7.34±3.43^{a}	3.67±1.32^{c}	9.52±1.19^{a}	6.27±1.55^{a}	7.641.29^{a}	0.83±0.72^{a}
S8 (30:20:5)	4.86±1.26^{b}	8.00±3.36^{a}	5.20±1.26^{b}	9.56±1.01^{a}	4.59±1.79^{b}	7.43±1.80^{a}	0.27±0.39^{cd}
S9(24:19:12)	6.07±1.56^{a}	8.05±3.28^{a}	6.691.63^{a}	9.39±1.22^{a}	4.780±1.81^{b}	7.66±1.23^{a}	0.25±0.42^{cd}

Mean scores of Descriptive Evaluation of formulations

Formulations2	Aroma	Mouth feel			After taste		
CF:SP:BF	Cooked corn	Viscous	Gritty	Lumpy	Cooked corn	Astringent	Residue
S1(30:10:15)	7.73±1.02a	4.60±1.50bc	3.52±1.45a	4.15±2.24cd	1.77±1.44a	1.25±0.55a	1.96±0.91[a]
S2(14:34:7)	7.87±0.91a	4.86±1.51ab	3.92±1.28a	5.27±1.8ab	1.77±1.69a	1.28±0.70a	2.16±1.19[a]
S3 (9:34:12)	7.89±0.89a	4.07±1.56cd	3.47±1.35a	4.73±2.06cd	1.77±0.63a	1.26 ±0.57a	2.06±0.97a
S4 (24:24:7)	7.66±0.91a	4.26±1.83bcd	3.59±1.26a	5.17±1.89abc	1.71±1.49a	1.25±.53a	2.04±0.9a
S5 (10:40:5)	7.87±1.01a	3.52±1.27de	3.9±1.01a	4.53±2.17bcd	1.77± 1.63a	1.21± 0.60a	1.92±0.97a
S6 (0:40:15)	8.00±0.97a	3.03±1.09e	3.30±1.39a	4.69±1.96abcd	1.77± .54a	1.19±0.54a	2.10±0.96a
S7(17:28:10)	7.92±0.97a	3.23±1.41e	3.66±1.10a	5.63±1.80a	1.94 ±1.2a	1.248±0.55a	2.35±1.21a
S8(30:20:5)	7.71±1.13a	4.42±1.27bc	3.45±1.36a	4.13±1.55d	1.56±1.17a	1.26± 0.68a	1.91±0.81a
S9(24:19:12)	7.80±0.99a	5.45±1.49a	3.56±1.28a	5.191.72ab	1.83±1.65a	1.252±0.65a	2.14±1.03a

REF: Reference food

APPENDIX 2

List of sensory descriptors with their definitions and anchors for reconstituted Drum dried Product

MODALITY ATTRIBUTE	DEFINITION	PROTOCOL	ACHOR
APPEARANCE Cream colour	Ref: Cerelac	Open sauce cup and observe from all angles. Insert spoon into product and lift spoon to check if it is firm	Light to Dark
Particles	Presence of tiny specks in the sample	√	None to many
Viscous	Resistance to flow	Tilt the sauce cup	Runny to thick
Lumpy	Presence of lumps	√	Not to Very
Rough	Having uneven surface	√	Smooth to Rough
AROMA Cooked corn note	Characteristic aroma of cooked corn flour like that of cerelac mixed with hot water	Swirl sauce cup in an eight motion (five times). Open and bring product closer to your nose to perceive aroma.	Not to Very

MODALITY ATTRIBUTE	DEFINITION	PROTOCOL	ACHOR
FLAVOUR Sweet	Basic taste	Scoop ¾ spoon full	Not to Very
Cooked corn	Flavour like that of cerelac mixed with hot water	√	Not to Very
Corn flour	Flavour like that of milled dry corn		Not to Very
MOUTH FEEL Gritty	Having a sandy feel in the mouth		Not to Very
Viscous	Resistance to flow		Runny to thick
Lumpy	Presence of lumps in the mouth		None to many
AFTERTASTE Residue	Presence of tiny particles in the mouth		Not to Very
Astringent			Not to Very
Lingering corn flour	Flavour like that of cerelac mixed with hot water		Not to Very
Sweet	Basic taste		Not to Very

DEPARTMENT OF NUTRITION AND FOOD SCIENCE.

BALLOT SHEET FOR SENSORY EVALUATION OF BREAKFAST CEREAL

ID: _____ Date:_____

Please read the following carefully.

You will be provided with nine coded samples of breakfast Cereal. Taste the samples and rank each product based on how much you like it for the attributes listed.

Use the 9-point hedonic scale below to rank the samples based on the attributes listed.

No two samples should have the same rank.

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

OVERALL ACCEPTABILITY

Indicate how much you would rank the overall liking of each of the samples by writing the appropriate rank score from the 9-point hedonic scale below the code.

Code

_____

Rank

_____

Colour

Observe the colour of the samples you have been provided. Indicate your liking for the colour of the samples by writing the appropriate rank score from the 9-point hedonic scale (above) in the space below the code.

Code

_____

Rank

_____

AROMA

Please take each sample provided and bring it close to your nose to detect the aroma. Indicate your liking for the aroma of the samples by writing the appropriate rank score from the 9-point hedonic scale (above) in the space below the code.

Code

_____

Rank

_____

Sweetness

Take a spoon full of sample to taste and indicate how much you like the sweetness of the samples by writing the appropriate rank score from the 9-point hedonic scale (above) in the space below the code.

Code

_____

Rank

_____

Mouthfeel

Swirl each sample in your mouth. Indicate how much you like the heaviness of the sample in your mouth by writing the appropriate rank score from the 9-point hedonic scale (above) in the space below the code.

Code

_____

Rank

_____

After Taste

Swallow the sample and wait for about 5seconds. Indicate how much you like the feel of particles (residue) in your mouth by writing the appropriate rank score from the 9-point hedonic scale (above) in the space below the code.

Code

_____

Rank

_____

Probability of purchasing product.

On a scale of 1 to 3 indicate how likely you are to purchase the products if made available on the market

1-Not interested 2- Not so sure 3- I would purchase

Code

_____

Rank

_____

Thank you very much.

APPENDIX 3

Formulations	Uncooked formulation		
CF: SP:BF	l* value	a* values	b* values
S1(30:10:15)	90.32±0.18 [a]	1.76±0.07 [fg]	14.54±0.07 [f]
S2(14:34:7)	88.10±0.09 [d]	4.59±0.02 [fg]	18.16±0.05 [ef]
S3 (9:34:12)	88.15±0.02 [cd]	4.57±0.02 [c]	19.18±0.09 [ef]
S4 (24:24:7)	88.62±0.90 [bc]	4.27±0.02 [c b]	16.56±0.23 [ef]
S5 (10:40:5)	87.49±0.13 [e]	6.21±0.01 [a]	21.11±0.11 [cde]
S6 (0:40:15)	87.50±0.74 [e]	5.54±0.05 [b]	21.71±0.08 [bcde]
S7 (17:28:10)	87.11±0.19 [a]	4.67±0.05 [c]	20.79±0.19 [cde]
S8 (30:20:5)	88.55±0.20 [bcd]	4.45±0.11 [c]	17.58±0.12 [ef]
S9(24:19:12)	88.97±0.56 [b]	3.40±0.04 [d]	17.33±0.05 [ef]

Mean colour parameters of uncooked formulations

APPENDIX 4

Moisture sorption isotherm model used to fit moisture sorption data

Model	Expression
BET	$m = \frac{\mathrm{MoCaw}}{(1 - \mathrm{aw})(1 - \mathrm{aw} + \mathrm{C\,aw})}$
GAB	$\mathrm{M} = \frac{\mathrm{MoGkaw}}{(1 - k\mathrm{aw})(1 - k\mathrm{aw} + \mathrm{Gkaw})}$
Smith	$\mathrm{M} = A - B\ ln(1 - \mathrm{aw})$
Oswin	$\mathrm{M} = A[\frac{\mathrm{aw}}{1 - \mathrm{aw}}]\hat{}B$
Henderson	$ln(1 - \mathrm{aw}) = -\mathrm{AT\ M\hat{}B}$

a_W = water activity

APPENDIX 5: Analysis of Variance Tables

ANOVA Table for Ash Content of the diets formulated

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Formulations	8	4.69392	0.586740	205.59	0.000
Error	9	0.02569	0.002854		
Total	17	4.71961			

ANOVA Table for Protein Content of the nine formulations

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Formulations	8	8.1287	1.01609	15.47	0.000
Error	9	0.5910	0.06567		
Total	17	8.7197			

ANOVA Table for Fibre Content of the nine formulations

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Formulations	8	1.84796	0.230996	298.69	0.000
Error	9	0.00696	0.000773		
Total	17	1.85493			

ANOVA Table for Fat Content of the nine formulations

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Formulations	8	5.4653	0.68316	37.11	0.000
Error	9	0.1657	0.01841		
Total	17	5.6309			

ANOVA Table for Carbohydrate Content of the nine formulations

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Formulations	8	15.6334	1.95418	46.69	0.000
Error	9	0.3767	0.04186		
Total	17	16.0101			

ANOVA Table for Energy of the nine formulations

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Formulations	8	349.417	43.6771	107.93	0.000
Error	9	3.642	0.4047		
Total	17	353.059			