EFFECT OF EXTRUSION FEED PARAMETERS ON PHYSICOCHEMICAL, SENSORY AND SHELF-LIFE PROPERTIES OF CASSAVA *(Manihot esculenta .C)* – CHIA *(Salvia hispanica. L)* INSTANT PORRIDGE FLOUR

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AUGUST, 2021

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

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Recommendation

This research thesis has been submitted with our approval as university supervisors.

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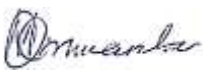
Signature…………… **Date**.........03/08/2021..................................

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DEDICATION

This thesis is dedicated to my son and daughter, Bruno Otieno Otondi and Leah Antonate. My father and mother Mr. David Otondi and Mrs Scholastica Otondi. My sisters Danny, Faith and Winny and my brothers Mark and Seko-toure Otondi. Thank you for your prayers, motivation and inspiration throughout my education.

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ABSTRACT

Cassava is an important root crop in sub-Saharan Africa due to its high resistance and easy ecological adaptability. However, its processed products have a high starch content and short shelf life. Thus, processing interventions are required to ensure its widespread utilisation. This study aimed at developing a high-quality cassava-chia instant porridge flour using extrusion cooking to enhance value addition and broader utilization of cassava and chia seeds. For the study, 4 chia seed/cassava incorporation ratios (0%, 20%, 40%, and 60%) and 3 feed moisture ratios of 10, 15 and 20% were used to identify optimal ingredient ratio levels for cassava-chia instant porridge flour which can provide 10gm/100gm protein of the recommended daily requirement protein of 19.7gms for pre-school children (4-5yrs.). The instant flour was subjected to proximate (ash, protein, moisture, carbohydrate and fat), physical properties (bulk density, water solubility index (WSI), water absorption index (WAI) and swelling power), sensory and shelf life stability analyses. Acceptability studies were conducted using a five-point hedonic scale, descriptive sensory properties were evaluated using principal component analysis (PCA) and shelf life of the product through accelerated shelf-life testing on the 1 month Q_{10} principle, and peroxide value (PV) analyzed on the 1, 3, 7, 14, 21 and 28 days. A completely randomized design with two factors (chia/cassava ratio and conditioning feed moisture); four levels for chia/cassava ratio and three levels for conditioning feed moisture was applied, and data analysed using ANOVA at 95 % confidence level and Tukey's Honest Significant Difference. The results showed that protein, fat and ash increased significantly ($p<0.05$) with chia/cassava ratios at all moisture levels. Similarly, the (WAI) increased ($p<0.05$) with chia seed incorporation at the 10 and 20% feed moisture. For colour; a^* and b* were significantly different ($p<0.05$) while L^* was not significantly different at ($p<0.05$) for different ratios of chia/cassava. Flavour, aroma and appearance had the highest score at 20:80chia/cassava ratio and 10% feed moisture. The PCA showed that only four factors were retained due to their higher variability on the correlation matrix on sensory attributes of appearance, texture, and flavour. Shelf life studies showed that peroxide value(PV) increased with chia/cassava ratio, storage temperature and storage duration, and the recommended shelf life of the chia/cassava instant flour is 212 days, the point at which acceptable PV limit is attained, for chia/cassava having a substitution ratio of 60:40. The instant flour was found to have a higher nutritional composition and had better physical properties compatible with diets for school-going children, hence is recommended to be used in combating malnutrition.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOAC	Association of Official Analytical Chemists
ASALS	Arid and Semi-Arid Lands
BD	Bulk density
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics
GDP	Gross Domestic Product
KDa	Kilo Daltons
Mo ALF	Ministry of Agriculture, Livestock & Fisheries
Mo PHS	Ministry of Public Health and Sanitation
PCA	Principal Component Analysis
PUFAs	Poly-Unsaturated Fatty Acids
UNICEF	United Nations International Children's Emergency Fund
WAI	Water Absorption Index
WSI	Water Solubility Index

CHAPTER ONE

INTRODUCTION

1.1 Background information

Secure access to affordable and nutritious food, which is an indication of food security is one of the key developmental strategies in Africa. It is achievable through the defined Food and Agriculture Organization of the United Nations (FAO) objectives which are; physical accessibility of food, economic affordability, food utilisation and stable food supply (Schouten *et al*., 2018).

According to the FAO (2017), 821 million people in the world are undernourished, a situation more pressing in sub-Saharan Africa whereby 23.2 % of the population suffered from chronic food scarcity. This figure is higher compared to 804 million, as observed in the year 2016, and is an indicator of the rise in the percentage of people in the world having insufficient dietary energy consumption. An example is Kenya, which experiences a 20-30% deficit in staple foods annually due to; low agricultural productivity, climate change, post-harvest losses and lack of appropriate technologies for value addition (MoALF, 2017- 2022). For instance in the year 2017, 1.6 million children in Kenya did not have enough food, which led to 370,000 children facing acute malnutrition, low access to high-quality foods, high protein/energy malnutrition levels and deficiencies in vitamins and minerals (MoALF, 2017-2022; UNICEF, 2017).

The second of Kenya's big four developmental agenda is to enhance food security and nutrition to all Kenyans (Laibuni *et al.*, 2018). Additionally, the second agenda for Sustainable Development Goal 2030 addresses challenges of hunger, food insecurity and malnutrition (FAO, 2018), and has led to the implementation of structural adjustment programs in African countries, whereby administrations put more efforts into decreasing cost on food imports by developing markets for locally produced foods and raw materials (Abass *et al*., 2018).

Cassava (*Manihot esculenta* C); has been identified as a staple food crop in Africa due to its ease to adapt to a wide range of sub-Saharan Africa environmental conditions. It is a tuberous root crop, and fourth-most important dietary source of energy in the tropics after rice, wheat and maize (Adebayo, 2010). Chandrasekara and Kumar (2016) stated that the tuber belongs to the family *Euphorbiaceae*, genus *Manihot* and is the most widely cultivated member out of 98 species. According to FAOSTAT (2016), cassava production in sub-Saharan Africa was 157,271,697 metric tons where Kenya produced 571,848 metric tons. Despite its advantages, post-harvest losses of fresh cassava are about 23% due to a short shelf life, which is shorter than 72 hours after harvest (Abong *et al.,* 2016). To counter this, large-scale production use of cassava roots in product development will create products with longer shelf life, hence reduce postharvest losses while maintaining product quality and safety (Uchechukwu *et al.,* 2015). Abass, (2008) and Abong *et al.* (2016) have indicated that there is demand for better quality processed cassava in Eastern and Southern Africa since consumers are substituting it for other foods like maize and rice during scarcity. For instance, Migori (67%), Busia (57%) and the coastal region (51%) are the regions in Kenya where cassava demand was rated to be quite high. Uchechukwu *et al.* (2015) showed that cassava is utilized by roasting, boiling, frying, drying and milling within these regions in Kenya. While studies by Abong *et al*. (2016), Githunguri (1995) and Karuri *et al.* **(**2001) showed that dried cassava chips are usually milled into flour and used to prepare porridge or thick porridge locally known as *ugali.* However, these processing practices do not guarantee safety in the microbial, nutritional and toxicological status of the end products as stated by Kolawole and Akingbala (2011), since these products are mostly of poor quality, which necessitates improvements in the processing of cassava into stable, diversified and nutritious products (Abong *et al*., 2016; Githunguri, 1995; Karuri *et al*., 2001). Moreover, nutritionally, cassava is low in protein and has a high carbohydrate content of 80-90% (Montagnac *et al.,* 2009). Which implies that its utilization in the food industry to produce nutritious end-products should be enhanced through fortification with protein-rich sources such as legumes (Jisha *et al.*,2010).

Chia *(Salvia hispanica L.)* is an herbaceous plant whose seeds are mainly used as food (Falco *et al*., 2017). It belongs to the family *Labiatae*, genus *Salvia*.The plant was originally cultivated by the Aztecs of ancient Mexico who consumed the seeds in their daily diet due to their high nutritive and medicinal value (Suri *et al.,* 2016). Eventually, its usage as a novel food in a wide range of foods was permitted by the European Parliament in the year 2009 (EFSA, 2009). Nutritionally, Chia seeds have a dietary fiber of 21.14 -21.30 %, Protein 20.90 - 21.34% and Lipids 29.06 - 29.07% (Kibui *et al.,* 2018; Suri *et al.,* 2016). It is also reputed to be gluten-free, anti-allergenic and non-toxic when consumed, with high protein and an excellent amino acid balance, especially methionine and cysteine (Boukid *et al*., 2018; Ullah *et al.,* 2016). These characteristics make chia seeds to be a suitable raw material in production of instant foods, which according to Paudyal and Kotzekidou (2016), are processed foods that are ready for consumption without prior preparation or cooking.

One method of producing instant foods is through extrusion; Food extrusion is a process that entails a combination of moisture, pressure, heat and mechanical shear to moisten and expand starchy protein-rich food materials through a die (Maurya *et al.,* 2015).

The extrusion cooking process has specific features that differentiate it from other heating /cooling processes, which are; low cost of production, the product shape variability, high-quality products, higher productivity and inactivation of anti-nutritional elements (Fallahi *et al*., 2016; Navale *et al.,* 2015). Additionally, mild extrusion conditions (high moisture content, low residence time and low temperature) are favoured due to their capacity of production of extrudates with lower glycaemic index (Feng & Lee, 2014).

Cereals that are rich in carbohydrates and fibres but quite low in protein content have been used in the production of many extruded products in the market (Omwamba & Mahungu) The development of composite extrudates through a mixture of starchy raw materials with other products has been adopted to be an alternative for obtaining extrudates with better sensory and physicochemical characteristics (Reddy *et al.,* 2014). Intake of functional foods not only improves the nutritional status of the overall population but also helps those suffering from degenerative diseases connected with daily changes in lifestyles (Noorfarahzilah *et al.*, 2014). In line with this, the manufacture of a product from cassava and chia seeds composite will form an excellent nutritious instant porridge flour.

1.2 Statement of the problem

Cassava has the potential of being a major raw material for food processing but has a short shelf life and its products are of low nutrient quality and acceptability. This is due to high starch content, a factor that has been associated with obesity and protein/energy malnutrition in children. Moreover, traditionally, cassava utilization in Kenya is limited to frying, roasting, and boiling and flour production. However these processing practices do not guarantee safety in the microbial, nutritional and shelf stability of the end product, necessitating an upgrade in the processing and nutritional status of cassava products through extrusion and introduction of high protein-rich seeds like chia which will not only contribute to nutrition but also enhance cassava utilization in Kenya. The aim of this study was to upgrade the nutritive value of cassava by blending it with chia seed to make enriched instant porridge flour.

1.3 Objectives

1.3.1 General objective

To contribute to food security and nutrition by blending cassava with protein rich chia seeds flour through extrusion to increase utilization.

1.3.2 Specific objectives

(i) To determine the effect of feed ratio and moisture content on the physical-chemical properties of extruded cassava-chia instant porridge flour.

(ii) To determine the effect of feed ratio and moisture content on the sensory properties of extruded cassava-chia instant porridge flour.

(iii) To determine the effect of feed ratio and moisture content on the shelf life properties of extruded cassava-chia instant porridge flour.

1.4 Hypotheses

(i) Feed ratio and moisture content have no significant effect on the physical-chemical properties of extruded cassava-chia instant porridge flour.

(ii) Feed ratio and moisture content have no significant effect on sensory properties of extruded cassava-chia instant porridge flour.

(iii) Feed ratio and moisture content have no significant effect on shelf life properties of extruded cassava-chia instant porridge flour.

1.5 Justification

The integration of cassava into the food manufacturing industries as a reliable raw material will increase the availability of good quality food products for both rural and urban consumers. Its processing will improve shelf-life, reduce bulkiness, diversify products and enhance acceptability and marketability (Abong *et al.*, 2016). Higher retention of nutrients will be achieved by mild extrusion conditions (high moisture content, low residence time and low temperature) in production of extrudates with lower glycaemic index (Feng & Lee, 2014). Consumption of starchy foods like cassava leads to lifestyle diseases and malnutrition, which is estimated that 18% of pre-school children are overweight and 4% obese, 26% stunted, 4% wasted and 11% underweight (MoPHS 2012-2017; UNICEF, 2017). Hence, enrichment of cassava with Chia seeds will provide a highly nutritious flour because it is composed of 24.34 % protein, 29.0 % fat, 21.30 % dietary fiber, 19.40 % carbohydrates (Kibui e*t al.*, 2018). Additionally, the production of enriched instant porridge flour will be a contribution to food security by providing more nutritious and easy to prepare food. The aim of this study, therefore, was to enrich cassava with chia seeds flour and evaluate its physical, shelf life, sensory characteristics and consumer acceptability to add value to cassava and improve its utilization.

CHAPTER TWO
LITERATURE REVIEW

2.1 Instant foods

Instant foods are defined by Paudyal and Kotzekidou (2016) as foods that are ready for consumption without prior preparation or cooking. These foods have largely become very common lately, a situation attributable to today's busy lifestyle, and the demand for quick-to-serve foods having the required nutritional proportions and also imparting the desired organoleptic qualities. Additionally, these foods are easy to prepare, and have advantageous properties which include storage and consumer acceptance properties, textural and nutritional superiority (Brennan *et al.,* 2013; Dhumal *et al.,* 2014; Kocheria *et al*., 2012).

2.2 Cassava

Food crops which are resistant to global warming like sweet potato, potatoes and cassava can be utilised to maintain global food security. They contain 70–80 % water, 16–24 % starch, <4 % proteins and lipids in low quantities and like grain crops, are affected by different climatic conditions with variations in crop yields ranging from about 15% to 10% (Adhikari *et al*., 2015). Cassava was introduced into Africa in the 16th century and can survive in adverse environmental conditions as food security and income-generating staple crop for many millions of people in sub-Saharan African countries. (Adebayo *et al.,* 2008; Carvalho *et al.,* 2014). In East Africa, cassava is produced in mid-altitude areas while in Kenya cassava is grown in both semi-arid and high rainfall areas for food security and as a cash crop, with the highest production in Western, Coastal and Eastern regions of Kenya (Kamau *et al.,* 2010; Karuri *et al.,* 2001). In Nyanza and Western regions of Kenya, the roots are peeled, chopped into small pieces, dried and milled into flour for *ugali,* or sometimes the flour is combined with cereals such as (maize or sorghum) to make composite flour for *ugali* or porridge while in Coastal region, Machakos and Kitui counties cassava roots are used as a snack (Karuri *et al*., 2001). To improve its contribution to the national gross domestic product (GDP), training on agronomical aspects and value addition have been carried out in different parts of the country (Mutuku *et al.,* 2013).

The major limitations of cassava as food is the presence of toxic cyanogenic glucosides, low protein content and short post-harvest shelf-life which can be reduced through traditional processing to improve palatability as well as serve as a means of preservation (Oyewole, 1995). Starchy tubers are used in food processing due to their chemical, physical and functional properties which are early gelatinization, high peak viscosity, large paste breakdown, and low retrogradation tendency hence can replace portions of wheat flour and reduce cost of production (Abass *et al*., 2018).

2.2.1 Nutritional composition of cassava

The nutritional content of cassava is as given in Table 2.1 and is dependent on the specific plant part and agronomical aspects. Cassava is a highly starchy (80%) tuber with an amylose content of 17% (percentage of starch) and amylopectin of 83% (percentage of starch), very low protein content (1-3%) and dietary fiber of 4% and hence classified as nutritionally poor.

Table 2.1: Nutritional composition of cassava roots

Nutrient	**% dry matter basis**
Carbohydrate	80 – 90%
Starch	80%
Amylopectin	83%†
Amylose	17%†
Sucrose	17% sweet variety
Lipid	0.1-0.3
Dietary fiber	4%
Protein	1 – 3%

† Indicated as percentage of starch

Source: Montagnac *et al.* (2009)

Consumption of high starchy foods like cassava has been associated with a high prevalence of Non-Communicable Diseases (NCDs) (Montagnac *et al.*, 2009; Morgan & Choct, 2016). Cassava is also limited in essential amino acids (Table 2.2) especially, methionine (1% protein), threonine (1% protein), phenylalanine (1% protein), and cysteine (40:600 % protein). This deficiency implies that cassava-based diets must be supplemented with other foods to enhance the protein level for growth and maintenance.

Table 2.2: Amino acid profile in cassava

Amino acid	Dry matter. (g/100g protein)	Amino acid	Dry matter. (g/100g protein)
Arginine	20:809	Valine	0.04
Histidine	0.07	Alanine	0.15
Isoleucine	0.03	Aspartic acid	0.13
Leucine	0.31	Cysteine	0.01
Lysine	0.07	Glutamic acid	0.15
Methionine	0.03	Glycine	0.01
Phenylalanine	0.03	Proline	0.03
Threonine	0.03	Serine	0.04
Tryptophan	20:809	Tyrosine	0.01

Source: Montagnac *et al.*(2009)

2.2.2 Cassava utilization and quality aspects in Kenya

Cassava crisps, flour and dry chips represent the major products from the major cassava producing regions of Kenya (Figure 2.1). To have an impact on food security in Kenya improving cassava chips, crisps and flour quality remains an important task (Abong *et al.*, 2016).

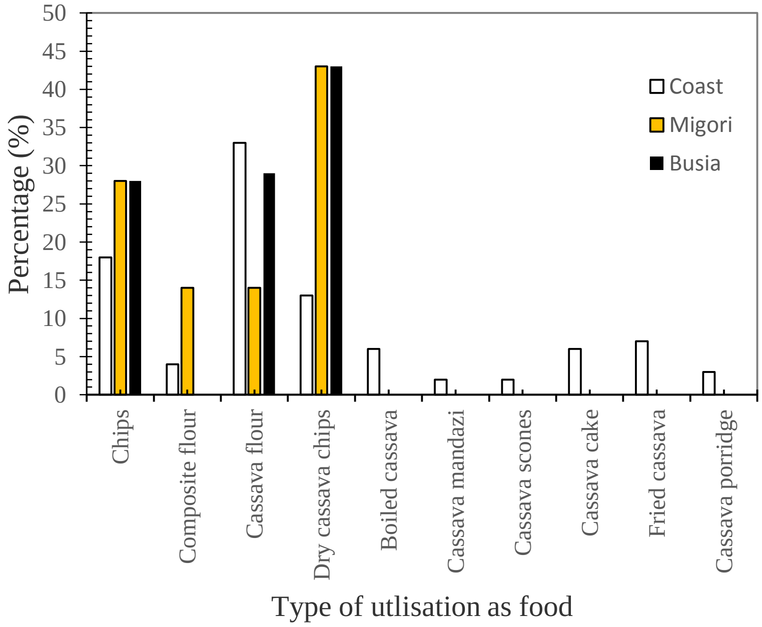


Figure 2.1: Comparative Utilization of different Cassava Processed products in Kenya Adopted from: Abong *et al*. (2016)

2.2.3 Extrusion of cassava

Cassava can be blended with different raw materials to produce highly nutritious snacks through extrusion (Taverna *et al*., 2012). Moreover, cassava starch is one of the raw materials used in extruded products since its extrudates show a close structure, light colour, smooth surface and neutral flavour (Chang *et al*., 1998). According to Spinello *et al*. (2014); Tarvena *et al*.(2012) during extrusion, the expansion of starchy materials is inversely proportional to raw material moisture content and increased moisture changes the molecular structure of amylopectin reducing the elastic viscosity which in turn, decreases the expansion ratio. Several studies have found that raw material properties or operational properties determine the kind of snack to be produced. For instance, an increase in feed moisture content increases the bulk density (BD), Water Solubility Index (WSI), Water Absorption Index (WAI) and hardness but decreases the expansion ratio. Similarly, higher barrel temperature increases the expansion ratio and reduces the hardness of the extrudates while high fiber ingredient is associated with a low expansion of extrudates (Dibyakanta *et al.*, 2015).

Further research by Yadav *et al.* (2015) showed that increasing barrel temperature resulted in an increase in expansion ratio with a decrease in BD, WAI and WSI and a higher proportion of cassava flour in feed resulted in maximum expansion with a minimum BD, WAI and WSI. The extrusion of mixtures of jatoba and cassava starch led to the production of snacks of diverse characteristics concerning expansion, water absorption and solubility, viscosity, colour, appearance, texture, and flavour. Surface response analysis and contours revealed that all mixtures conditioned to a moisture content of 170 g/ kg and extruded at 150°C produced acceptable extrudates (Chang *et al*., 1998). The addition of 5% pigeon pea flour to cassava flour increased the protein content and produced suitable crisps to hard-textured extrudates (Rampersad *et al*., 2003).

2.3 Chia seeds

Salvia hispanica. L, also known as chia, is an herbaceous plant cultivated annually from the family *Labiatae*, division *Spermatophyta* and kingdom *Plantae*. Chia is native to the region that stretches from northern Mexico to Guatemala. Its seeds were widely used by Aztec tribes for food (Coelhoe & Salla-Melado, 2014). The genus Salvia consists of 900 species and its name comes from the Latin word ‘‘salvere’’, referring to the curative properties of the well-known culinary and medicinal herb *Salvia officinalis* (Falco *et al*., 2017). According to Boukid *et al.* (2018) and Segura-campos *et al*. (2014) there are three main species of chia seeds: *Salvia columbariae Benth*, *Salvia polytachya* Cavan and *Salvia hispanica* Labiatae. Only *Salvia hispanica.* L, species of the genus *Salvia*, can be grown domestically. Ullah *et al.* (2016) and Deka and Das (2017) noted that the word chia is derived from the Spanish word chian which means oily. It is an oilseed that can be used in the form of whole seeds, mucilage, flour, and oil seed. Figure 2.2a and 2.2b show pictures of the chia plant and chia seeds, respectively.

According to Alexandra *et al.* (2016), Deka and Das (2017) and Ullah *et al.* (2016) Chia seeds are highly valued for their nutritional properties and medicinal value. These include the healthy omega-3 fatty acids, polyunsaturated fatty acids (PUFAs), dietary fiber, protein-including all essential amino acids, vitamins, calcium and other important minerals and a wide range of polyphenol antioxidants which act as antioxidant and safeguard the seeds from chemical and microbial breakdown. The approval of chia seed as a Novel Food by the European Parliament has led to its high degree of usage in a wide range of foods (EFSA, 2009). Putten (2011) defines "novel foods" as foods or food ingredients with no history of widespread and safe consumption whose benefits may relate to improvements in public health, diversification of nutritional intake, improved food security or quality. Chia seeds can thus be used in fortification and enrichment of biscuits, pasta, cereal bars, snacks, yoghurt, cakes and many other foods. (Ullah *et al.*, 2015).

Figure 2.2: Chia plant (a) and Chia Seeds (b)

Source**:** Deka and Das (2017).

2.3.1 Nutritional composition of chia seeds

Deka and Das (2017), Kibui *et al.* (2018), Ullah *et al.* (2016) and Segura- campo *et al.* (2014) assessed and studied the nutritional composition of chia seeds. The seeds are considered to be of nutritional significance in view of their fatty acid composition as well as the fibre and protein contents (Table 2.3). Chia seed plays a very important role as functional food and nutritional supplement; It is rapidly gaining popularity worldwide due to a high desire in people to change to healthier lifestyles because of increased incidence of Non-Communicable Diseases (NCD_S) such as cardiovascular diseases, type - 2 diabetes, colorectal cancer, obesity, and other related illnesses (Coelhoe & Salla-Melado, 2014; Nduko *et al.,* 2017).

Table 2.3: **Nutritional composition of chia seeds**

Nutrient	**% dry matter**
Protein	20.90 - 21.34
Carbohydrate	19.24 - 19.40
Fat	29.06 - 29.07
Dietary fibre	21.14 - 21.30
Ash	4.45 - 4.66
Moisture	5.16 - 5.26

Source: Kibui *et al.*(2018)

Protein

Table 2.3 shows the nutritional composition of chia seeds, which are high in fat, protein and dietary fiber. The major protein in chia seed is globulin, and constitutes about 52 % of the total protein which is mostly 11S and 7S proteins having molecular sizes of 15 to 50 kDa. This is advantageous since according to Falco *et al.* (2017) and Ullah *et al.* (2016) denaturation temperatures for albumins, globulins, prolamins and glutenins are 103, 105, 85.6and 90°C, respectively, which indicate good thermal stability for albumins and globulins. Moreover, chia seed protein isolates have water-holding (4060 g/kg) and oil-holding (4040 g/kg) capacities similar to those of the fiber rich fraction (Vazquez- Ovando, 2013). Table 2.4 shows that chia has a high amount of good amino acid balance, especially methionine (3.555g/100g protein) and cysteine (2.461g/100g protein) (Boukid *et al*., 2018). Moreover, the protein-rich fraction has high essential sulphur amino acids (55 g/kg protein) and non-essential amino acids (286 g/kg protein) contents, but, like other vegetable proteins, also contains limited amino acids such as tryptophan (2.3636 g /100g protein) and lysine (5.562 g/100g protein). This implies that chia seeds can be used for the enrichment of starchy foods like cassava.

Table 2.4: Amino acid content of chia seeds

Amino acid	Content (g/100g)		Amino acid	Content(g/100g)	
	chia seeds	Total protein		chia seeds	Total protein
Arginine	2.143	12.956	Valine	0.950	5.744
Glutamic acid	3.500	21.161	Alanine	1.044	6.312
Threonine	0.709	4.232	Glycine	0.943	5.701
Tryptophan	40:6036	2.636	Methionine	0.588	3.555
Isoleucine	0.801	4.843	Lysine	0.920	5.562
Leucine	1.371	8.289	Cysteine	40:6007	2.461
Phenylalanine	1.016	6.143	Aspartic acid	1.689	120:8012
Tyrosine	0.536	3.241	Proline	0.776	4.692
Histidine	0.531	3.210	Serine	1.049	6.342

Source: Suri *et al.*(2016)

Dietary fibre

Dietary fibre is an important components of a healthy diet, adequate intake of dietary fibre is associated with the prevention of cardiovascular diseases like stroke, myocardial infection, vascular diseases, obesity, hypertension, hyperglycaemia, and hyperlipidaemia (Suri *et al.,* 2016). The fibre rich fraction has high insoluble dietary fibre content and good functional properties, particularly water-holding, oil-holding and organic molecule absorption capacities (Falco *et al.,* 2017 ;Vazquez- Ovando, 2013).

The fibre in chia seed is a polysaccharide with a high molecular weight (0.8-2 × 10^6 Da), whose basic structure is a tetrasaccharide with 4-O-methyl-α-D-glucoronopyranosyl residues that branch β-D-xylopyranosyl on the main chain structure. Its monosaccharide composition is 16% D-xylose plus D-mannose, 2% D-arabinose, 6% D-glucose, 3% galacturonic acid, and 12% glucuronic acid. Chia seeds produce between 35g and 40g of dietary fibre per 100g, equivalent to 100% of the daily recommendations for the adult population (Orona-tamayo *et al.,* 2017). Falco *et al*. (2017) found out that chia seeds also has soluble dietary fibre which is partially expelled from the seed as a mucilaginous gel when it comes in contact with water. Furthermore, gum can be extracted from its dietary fibre fractions for use as an additive to control viscosity, stability, texture, and consistency in the food system (Segura-campos *et al.,* 2014).

Lipids

The most important characteristic of chia is its high content of essential Polyunsaturated Fatty Acids (PUFA) which aren't synthesized by the human body and must be obtained from the diet (Silva *et al.,* 2016). The seed has around 25-40% fat comprising 55-60% linolenic acid (ω-3) and 18-20% linoleic acid (ω-6). Additionally, Mono-saturated Fatty Acids (MUFA) accounts for 7-11% of all the fatty acids with oleic acid occurring as the major MUFA. The high PUFAs concentrations in chia seeds provides potent lipid antioxidants (Ixtaina *et al.,* 2011;Orona-tamayo *et al.*,2017;) these are; omega-3 fatty acids comprising three essential fatty acids; alpha-linolenic acid, Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA) which are reputed to have cardio-protective effects, plus omega-6 acids is comprising linoleic acid and arachidonic acid (Ullah *et al.,* 2015).

Antioxidants

Chia seeds and oil also contain several bioactive compounds namely quercetin, myricetin, kaempferol, chlorogenic acid and 3, 4 Di hydroxy-phenyl ethanol-elenolic acid di-aldehyde (DHPEA-EDA***).*** Several in-vitro assays have confirmed that these polyphenols possess high antioxidant capacities and their presence is associated with lower levels of lipid autoxidation (Marineli *et al.,* 2014; Sargi *et al.,* 2013; Suri *et al.,* 2016). Most important among them are the phenolic compounds (tocopherols), which are primary synergic antioxidants and contribute greatly to the total antioxidant activity in chia of 238–427 mg/kg (Munoz *et al.,* 2013). Chia seed antioxidant activity is also said to have physiological effects, such as anti-cancer and anti-mutagenic activity, which remediate problems resulting from free radicals. This is attributed to the seed content of caffeic and chlorogenic acid, which protects against free radicals and inhibits the peroxidation of fats, proteins, and DNA radicals. Moreover, quercetin, also present within chia is a powerful antioxidant with cardio protective effect (Coelhoe & Salla-Melado, 2014; Munoz *et al*., 2013).

Vitamins and minerals

Chia seeds have also been found to be a good source of several vitamins and minerals particularly niacin, zinc, calcium, phosphorus and magnesium. The Niacin content of chia is higher than other cereals (corn, soybeans and rice), whereas the riboflavin and thiamine content is similar to that present in corn and rice (Suri *et al*., 2016). It also contains 6 times more calcium, 11 times more phosphorus, and 4 times more potassium than 100g of milk (Orona-tamayo *et al.,* 2017). Generally, chia has a favourable mineral concentration comprising; calcium 631, potassium 407, magnesium 335, phosphorus 860 and Sodium 16 mg/100g, and a microelements concentration comprising; selenium 55.2, copper 0.924, iron 7.72, manganese 2.72, molybdenum 20:80, and zinc4.58 µ g/100g (Ullah *et al*., 2016).

Carbohydrates

Chia seeds has carbohydrate-based fibres composed of hydrocolloids, which are associated with reducing inflammation, lowering cholesterol and regulating bowel function (Falco *et al.,* 2017). These hydrocolloids or food gums are key ingredients in food processing and industry. A study by Segura-campo *et al.* (2014) obtained ß-D-xylose, α D-glucose, and 4-O-metil- α D-glucoronic monosaccharides in the proportions 2:1:1, respectively, through acid hydrolysis.

2.3.2 Incorporation of chia in food

Constantini and Pirazzo (2014) showed that it is possible to produce bread with better nutritional characteristics by the addition of whole chia flour to the formulation. Higher lipid, protein and ash contents and better lipid profiles were found in the bread produced with 10 % whole chia flour when compared to the standard loaf and an incredible amount of n-3 α linolenic was observed as well a better omega-6/omega-3 ratio.

The use of whole chia flour also contributed to a reduction in specific volume, lightness and weakened the bread dough protein network, resulting in a denser product. Similar studies have also shown that the addition of chia into dough at 5%, 10%, and 15% improved gas retention and reduced the time required to reach maximum dough development (Verdu *et al.,* 2015). Likewise, the addition of chia increased the content of fibre, total antioxidant activity, and ω-3 fatty acid in the final products (Coelhoe & Salla-Melado, 2014). Furthermore, according to Fernandez *et al.* (2017) bakery products, bread and chocolate cake having lyophilized chia mucilage, and dried at 50ºC showed efficiency in the fat replacement in the formulation and from the sensorial point of view, products with chia mucilage dried at 50°C were more acceptable, which presents an advantage, since this type of drying is less expensive.

The replacement of hydrogenated vegetable fat by inclusion of chia (*S. hispanica L.)* seeds or flour in bread was possible to reduce the levels of saturated fat and increase the levels of polyunsaturated fat, mainly α-3 fatty acid, in addition to increasing the level of fibre. This also yielded products with good functional properties with high acceptability levels and purchase plans, demonstrating the commercial viability of these products (Coelhoe & Salla-Melado, 2014). An investigation by Byars and Singh (2014) showed that extrusion of whole chia seeds with cornmeal was effective in grinding the chia seeds and incorporating the oils into the product matrix. This increased oil levels, reduced the expansion ratio and the hardness at chia levels of 5 and 10g/100g. The increased chia content also led to a reduction of the specific mechanical energy of the extrusion process, and the total colour of the extrudates (Byars & Singh, 2014). A study by Naumova (2017) revealed that introduction of ground chia into noodle formula did not affect the microstructure of freshly cooked products vitamin value, physicochemical indicators of quality of pasta products stored for 15 days in a dark area at the temperature of 20 ± 2°C and relative humidity of 75% maximum.

Meat incorporation studies by Ding *et al.* (2017) using Scanning Electron Microscopy (SEM) showed that addition of chia improved emulsification and juiciness and, consequently, the overall acceptance of restructured ham-like product. Finally, chia gel has also been used as a stabilizer in ice creams, eliminating the requirement of additives or other ingredients that improve the structure and texture of ice cream (Chavan *et al.*, 2017).

2.4 Composite flour

Composite flour technology refers to the process of mixing various flours from tubers with cereals or legumes with or without the addition of wheat flour in proper proportions to make economic use of locally cultivated crops in the production of high-quality food products (Tharise *et al.*,2014). Development of composite extrudates by mixing starchy raw materials with other products has increased in obtaining extrudates with better sensory, physicochemical and nutritional characteristics (Reddy *et al*., 2014). In developing countries utilization of locally grown crops as flour is encouraged as it reduces the importation of wheat (Noorfarahzilah *et al*., 2014).

Mostly cassava flour has been used in combination with other flours like pigeon pea flour and jatobá flour in extrusion cooking (Chang *et al.,* 1998; Rampersad *et al.,* 2003). The eff ect of cassava bran, moisture content, barrel temperature and screw speed in extrusion cooking were significant on radial expansion ratio, while specific volume was aff ected by moisture content and barrel temperature only. The results showed that cassava starch blended with diff erent levels of cassava bran could be used as raw material for extruded snack production if the appropriate operational conditions were applied. The best combination of variables to obtain an optimally expanded product (higher specific volume) was low moisture (16–18%) and high temperature (180–200°C), irrespective of the bran level utilized (Hashimoto *et al*., 2003). In another study, cassava starch, wheat and amaranth flour, in the proportion of 10:60:30, respectively, allowed for the development of a non-conventional pasta formulation with improved nutritional value as compared to pasta with regular or whole wheat flour, obtaining pasta that was not very sticky and with adequate firmness, as well as presenting a light yellowish colour (Fiorda *et al*., 2013).

2.5 Extrusion process

Food extrusion is the process by which moistened, expansible, starchy and proteinaceous food materials are plasticized through a die by a combination of moisture, pressure, heat and mechanical shear (Maurya *et al.,* 2014). It has been widely used to produce extruded products, dependent on the expansion at the die to produce the desired texture and sizes (Rampersad *et al.,* 2003). It is a thermal process where high temperature, pressure, and shear forces are applied to an uncooked mass; combining mixing, forming, texturizing and cooking of raw material to form a food product (Mesquita *et al*., 2013; Rubi *et al*., 2018 ;Sumathi *et al.,* 2007). Extrusion technology is among the most economic processes gaining utility within the food industries for the development of new products such as snacks, baby foods, breakfast cereals and modified starch from cereals and tubers (Oke *et al*., 2011). The technology has many distinct advantages like versatility, low cost, better product quality and zero effluent (Deshpande *et al.,* 2011). Direct-puffed snacks made through extrusion are usually low in bulk density and marketed as high fibre, low-calorie, high-protein, and nutritional products. These cereals are rich in carbohydrates and fibres but low in protein content, requiring an enhancement of the protein component in the extruded products (Omwamba & Mahungu, 2014; Rampersad *et al.,* 2003).

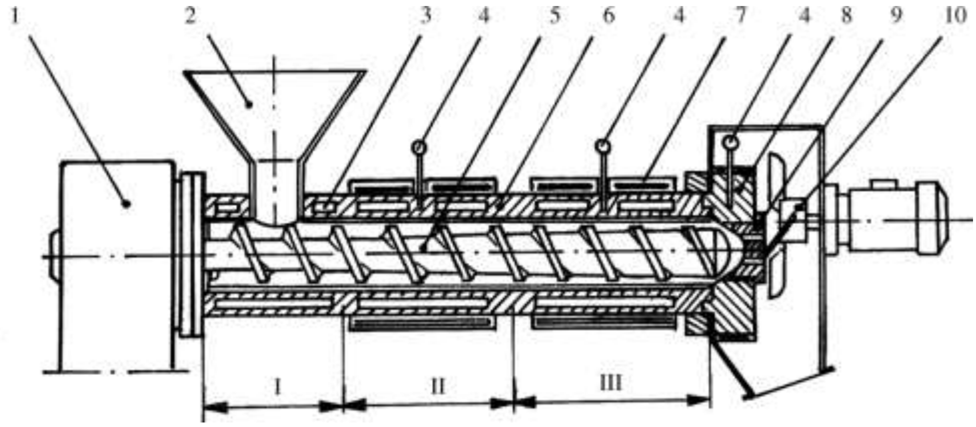
In the study of the complex process of extrusion, the number of parameters involved can be grouped into three distinct groups which are; process, system and product parameters (Bouvier & Campanella, 2014). Process parameters include barrel temperature, moisture content, screw rotation, throughput rate and die diameter, while system parameters are composed of material residence time distribution, mechanical and thermal energy during the process and product parameters are appearance, texture and taste (Spinello *et al*., 2014). Raw materials characteristics include particle size distribution, protein fiber and lipid content etc. which have a great influence on hardness, expansion, colour and external structure of the expanded products, with direct consequences on their acceptance. Complex physical and chemical transitions during extrusion depend on processing variables such as screw profile and rotating speed, barrel temperature profile, feed rate and composition of the material being extruded (Feng *et al.,* 2014). Structural properties are of major importance since they characterize the texture and quality of expanded products by controlling their taste and appearance, as well as they are indexes of the extent of puffing (Bisharat *et al.,* 2013).

The high temperatures associated with extrusion, contribute to the fact that starch will be made more readily available to amylolytic enzymes during digestion, and hence extruded snack products tend to yield a lower glycaemic response compared with their unprocessed raw ingredients (Brennan *et al*., 2013). Extrusion of whole chia seeds with cornmeal was shown to be effective in grinding the chia seeds and incorporating the oils into the product matrix which increased oil levels reduced the expansion ratio and decreased the hardness (Byars & Singh, 2014).

2.5.1 Types of extruders

There are two types of extruders are used for extruded food products: these are single-screw extruders and twin-screw extruders; Single Screw Cooking Extruders (SSCE) are used to produce dry and semi-moist pet foods, expanded snacks, breakfast cereals, puddings, soup and drink bases, gelatinized starch, and texturized vegetable proteins (Ajita, 2018). Their performance is defined by parameters such as conditioning moisture content (dry or wet), type of screw (solid or segmented), desired degree of shear and heat source, and torque operation at different screw speeds (Maurya *et al.*, 2014). The Figure 2.3 gives a cross-section of a single screw extruder, within which the screw conveys raw material from the feed section to the die, provides necessary pressure and shear to the material to form the structure of the extruded product and regulates the degree of cooking and gelatinization. Plasticizing process starts with the mixing of the feedstock materials at high pressures and temperatures, causing the feedstock to compact and melt. Use of simple single screw extruders can be promoted in developed countries to produce weaning and other foods because they are fairly inexpensive and simple to maintain (Camire *et al*., 1990)

The other type of extruder is the twin-screw extruder; which are used for high moisture extrusion, products that include higher quantities of components such as fibres, fats, etc. and more sophisticated products. Twin extruders are composed of two axis that rotate inside a single are four types of twin extruder configurations, classified according to the position of the screws and their direction of rotation, these are; co intermeshing screws; co rotating non screws; counter- rotating intermeshing screws counter-rotating non-intermeshing-screw extruders (Maurya *et al.*, 2014).



Key: 1 – engine; 2 – feeder; 3 – cooling jacket; 4 – thermocouple; 5 – screw; 6 – barrel; 7 – Heating jacket; 8 – head; 9 – dies; 10 – cutter.

I – transport / feed section; II – compression section; III –melting and plasticizing Section.

Figure 2.3: Across-section view of a single screw food extruder

Source: Moscicki and Zuilichem (2011).

2.5.2 Nutritional content and sensory properties of extruded food products

During extrusion, the control of process, system and product parameters determines the extent of macromolecular transformations during extrusion. This in turn influences the rheological properties of food melt in the extruder and consequently, the product characteristics of extrudates. Physical characteristic such as expansion, density and hardness are important parameters to evaluate the consumer acceptability of the final product (Singh *et al.,* 2015). The extrusion process also results in gelatinization, dextrinization, denaturation, and modification of the starch, fibre, and protein molecular structure, since the ingredients are transported in a laminar flow by the action of the rotating screw, creating both cutting forces and drag along the barrel (Brennan *et al.*, 2013).

Proteins are a group of highly complex organic compounds that are made up of a sequence of amino acids. Extrusion may improve protein digestibility by denaturation of proteins and exposing enzyme-accessible sites (Ajita, 2018). Similarly, in extrusion, the quaternary structure of the protein opens, which leads to protein structure polymerization and cross-linking forming new structures which reduces protein solubility (Pelemba *et al.*, 2002), Similarly, proteins are fractionated during the extrusion process leading to a loss of quaternary, tertiary, and secondary structures, which directly impacts their physicochemical properties like solubility (Rubi *et al.*, 2018). In some cases, through extrusion, proteins undergo a conformational change called denaturation, which exposes the proteins to proteases thereby increasing the bioavailability of the proteins to the organism.

Starch also undergoes changes during extrusion, for instance, a high degree of starch gelatinization and dextrinization will occur in extrusion resulting in increased susceptibility of starch to enzymes and a low Glycaemic Index (GI) (Gomez *et al.*, 2018). Producing expanded foods with potentially lower glycaemic index can be achieved by mild extrusion conditions (high moisture content, low residence time and low temperature), which would favour higher retention of nutrients (Yeng *et al*., 2014). Finally, the level of antioxidants in foods depends on the level and composition of bioactive materials and the processing conditions; there are instances that it increases or decreases during extrusion with an increase in barrel temperature (Brennan *et al*., 2011).

2.6 Sensory evaluation of foods

Sensory evaluation is a quantitative science in which numerical data is collected, measured, analyzed then interpreted to establish lawful and specific relationships between product characteristics and human perception through the senses of sight, smell, touch, taste, and hearing. Acceptability and descriptive tests are analytical and affective test types for the sensory test used in evaluating food quality whereby analytical tests are based on noticeable differences whereas effective tests are based on individual acceptability or preferences which shows how the consumer perceives food product (Lawless & Heymann, 2010). The descriptive type of sensory evaluation deals with quantifying the intensities of the sensory attributes of the food product (Muoki *et al.*, 2015). When conducting this type of sensory evaluation; you should train judges to have common understandings in rating food attributes that help to improve an individual`s sensitivity and memory to provide precise, consistent, and standardized sensory measurements (Watts *et al.*, 1989). PCA is used to examine the overall pattern among the food products, to reduce the number of variables, and observe relations among these variables by extracting new factors which explain the maximum amount of variability in the original data.

2.7 Effect of ingredients on sensory characteristics

The characteristics of foods and their ingredients are perceived differently by our five senses; sight, smell, touch, taste and sound. In sight, the eyes perceive the initial quality of the foods through seeing one can judge on colour, shape, size, texture, consistency and opacity. Colour may accurately show the strength of dilution and the degree to which the food has been heated, while shapes are different; round, oval, spherical, size; small, medium and large. (Lawless & Heyman, 2010). The sensory perception of smell or olfactory sense also contributes to our evaluation of food quality. The volatility of odours in foods is related to temperature because only volatile molecules in terms of gas carry odour since it is easier to smell hot foods than cold ones. Human subjects have varying sensitivities to odours depending on hunger, satiety, mood, concentration, presence or absence of respiratory infections and gender (Watts *et al.,* 1989).

Taste is perceived by taste buds which are primarily on the surface of the tongue by the mucosa of the palate and in areas of the throat. The sense of taste varies by gender and race. It also depends on the value a consumer places on other factors such as health and convenience (Lawless & Heymann, 2010). Finally, touch is a sense that brings the impression of a food texture to us through oral sensation or the skin. Food texture is the sensory manifestation of the structure or inner makeup of the products in terms of their reactions to stress which are measured as mechanical properties such as hardness, firmness, adhesiveness, cohesiveness. Viscosity by senses in the muscle of the hands, fingers tongue, jaw or lips. Texture also includes tactile feel properties which are measured as geometric properties or moisture properties by the tactile nerves in the surface of the skin, hands, lips, or tongue (Meilgaard *et al.,* 2007).

2.8 Food shelf life studies

Food shelf life is defined by Manzocco *et al.* (2020) as a finite length of time after production and packaging during which food retains a required level of quality under specified storage conditions. It is an important feature of all aspects of the food chain, which includes raw materials, ingredients, and semi-manufactured products, since any of these products has its own shelf life Nicoli. (2012) and hence require monitoring. A number of studies have been done in the determination of food shelf life, for instance Calligaris *et al.* (2008) used a 4-step method comprising: evaluation of the physical properties, performance of an accelerated shelf life test, evaluation of sensory acceptance limit and the relevant chemical index limit and finally setting up the shelf life prediction model. Similarly, Yoon *et al.* (2017) have also applied the method in evaluating the shelf life of a milk beverage product. According to Singh and Anderson (2004), the main types of food spoilage are chemical, physical and microbiological spoilage. These are manifested by change in inherent properties of foods like Free Fatty Acids (FFA), Peroxide Value (PV) (Manzocco *et al.*, 2020). Microorganism content and sensory scores among other indicators (Yoon *et al.*, 2020). This implies that the rate of food spoilage can be reliably predicted through modelling of the rate of changes in chemical, physical and sensory indicators (Calligaris *et al.*, 2012).

2.8.1 Accelerated Shelf Life Testing (ASLT)

When the change in food quality with duration occurs at a slow rate, it is much more useful to accelerate shelf-life tests by monitoring food quality depletion under environmental conditions which allow deteriorative events to proceed faster. The procedure of achieving this is known as accelerated shelf-life testing (ASLT). It allows the estimation of the shelf life data at storage conditions normally experienced by the product within the market by using data acquired under accelerated storage conditions (Corradini & Peleg, 2007; Mizrahi, 2011). This approach is advantageous for those products characterized by a long shelf life, such as ambient-stable and frozen foods. In these cases, the producers of the food products are required to generate shelf-life data in times that fit with industrial and market needs.

2.8.2 Modelling of shelf life indicators

The prediction of food shelf life involves monitoring of changes in indicative food quality parameters, also described as descriptors, with respect to storage conditions. These changes are evaluated through sensory (Hu & Jacobsen, 2016) or instrumental methods. From these descriptors, critical indicators are identified that determine the acceptability limit of the food quality. According to Nicoli (2012), this is the amount of quality change, described by the selected critical indicator that differentiates acceptable products from the ones that are no longer acceptable. These descriptor changes can be evaluated in the zeroth, first and second order of reaction are evaluated though correlation with the Arrhenius equation (Equation 3.1) i.e.

$$A = A_0 e^{\left[\frac{-E_a}{RT}\right]} \qquad \text{… (Equation 3.1)}$$

CHAPTER THREE
MATERIALS AND METHODS

3.1 Experimental sites

During the study, extrusion of the product was carried out at Soy Afric Ltd, Kenya, then sensory analysis studies were performed at the Guildford Dairy Institute within Egerton University, Kenya. Finally, the physico-chemical evaluation and shelf life analysis experiments were conducted at the government chemists, Nairobi, Kenya.

3.2 Materials

3.2.1 Sample preparation

Low cyanide cassava roots (MH95/083) were obtained from Kenya Agricultural and Livestock Research Organization (KALRO) Kakamega County, Kenya and chia seeds (Figure 3.1a) were obtained from Momentum Trust Siaya County, Kenya**.**

Cassava roots were processed into High-Quality Cassava Flour (HCQF) using the method described by Iwe *et al.* (2017). The fresh cassava roots were weighed to get net weight, peeled manually using a stainless knife, washed with portable water grated to slurry/mash, dewatered and the cake pulverized and subjected to sun drying for 3 days to attain 8-10% moisture level. After drying, the grits were milled using SG 40 diesel hammer mills with a 7.5Kw motor and the 2.0mm particle size of HQCF (Figure 3.1b) obtained packed in airtight packets. Chia seeds (*Salvia hispanica* L.*)* were cleaned manually by removing foreign matter such as stones, dirt and broken seeds using a 0.075mm sieve and packaged in clean gunny bags for extrusion processing after milling.

Figure 3.1 (a) and (b): Chia seeds and Cassava flour

3.2.2 Composite flour blends formulation

Blending of formulations

The blending of formulations was carried out linearly by substituting High Quality Cassava Flour (HQCF) with chia seeds at different proportions of 0%, 20%, 40%, and 60% (0:100, 20:80, 40:60 and 60:40) by mass to find the optimal proportion for the blend which will provide 60% of the recommended daily allowance protein for pre-school children (Golden, 2009).

3.3 Extrusion process

A single screw dry extruder (InstaPro 2000R, serial No. 563 Chelworth UK) having a motor speed of 1480rpm was used and preliminary trials were carried out before extrusion using 0%, 20%, 40% and 60% chia/cassava ratios and feed moisture content of 10, 15 and 20%. The extruder had a 150 mm barrel diameter, 900mm barrel length and L/D ratio of 900/150. Constant operational parameters were 3:1 screw compression ratio; a round die shape, 10 mm die diameter, 45°pitch screw angle, 100rpm screw speed, and a35rpm feed rate. The barrel shaft was electrically driven with a 415V induction motor (DY2-250M-4P) having a speed of 1480 rpm. The heat was generated mechanically to achieve barrel temperatures of 50°C, 150°C, 250°C in the first, second, and third zones respectively. Extrudates were oven-dried for 1 hour at 50°C in a Memmert oven (Gmbh Co KG, type UM400) to a moisture content of 8%, then cooled to 25°C and milled into flour using a disk mill mount (Tai model FFC-45A) with a rotor speed of 3000rpm, power of 10kW and a 0.12mm screen.

3.4 Objective 1: Effect of feed ratio optimization on physical-chemical properties of extruded instant cassava-chia porridge flour

3.4.1 Determination of chemical properties

Moisture content

Moisture content was determined by the use of a forced draft oven method (AOAC 2005, 950:46). 2g of the sample was weighed in aluminium dishes using analytical balance: (Shimadzu AUW 220.max 220g) and dried at 105°C for 3h in the forced draft oven (memmert GmbH Co KG, type UM400) then cooled in a desiccator and reweighed. Percent moisture content was determined according to Equation 3.5:

$$\%\ \text{Moisture}\ \left(\frac{\text{wt}}{\text{wt}}.\right) = \frac{\text{Wt.of}\ H_2O\ \text{in Sample}}{\text{Wt of wet sample}} \text{x}100 \qquad \ldots \text{(Equation 3.5)}$$

Ash

Ash content in both the cassava and chia samples was determined using the method according the (AACC 2010, 08-01). 5g of the dry sample was weighed in clean dry crucibles using an analytical balance (Shimadzu AUW 220.max 220g) then combusted using a bunsen burner in a fume hood before further incineration in a muffle furnace (Bamford, Sheffield England S30 2AU) at 550°C for 5 hours. The muffle furnace was turned off and opened for the temperature to drop to at least 250°C. Crucibles were then transferred quickly to a desiccator, and allowed to cool before weighing. Weight of ash was calculated using equation 3.6:

$$\%\ \mathrm{Ash} = \frac{\mathrm{Wt.after\ ashing - tare\ Wt.of\ crucible}}{\mathrm{Wt.of\ dry\ sample - tare\ crucible\ wt}}\ \mathrm{x}100 \qquad \ldots \text{(Equation 3.6)}$$

Crude protein

The crude protein content of the samples was determined using the improved Kjedahl method (AACC 2010, 46-11), whereby 20:80g of the sample was accurately weighed and placed in a digestion flask. 8g catalyst (96% $NaSO_4$ + 3.5% $CuSO_4$) and 20 ml concentrated H_2SO_4 was added to the digestion flask (Figure 3.2). Flask was heated at 350°C for 3h.45min until dense white fumes were cleared and a clear blue solution formed; then it was swirled gently; cooled for 1hr but not allowed to crystallize. 10ml of ammonia was added, glass beads and a small quantity of phenolphthalein indicator was added before distillation. Blank was determined using all reagents except sample. 50ml of 2% boric acid and 1ml of methyl red/orange indicator was measured in a conical flask. Distillation apparatus (Figure 3.2) was connected with delivery tube dipped into 1mm below boric acid solution, then distiller was switched and digest diluted with 50% NaOH solution (75ml). NaOH solution was added slowly until the mixture turned pink (an indication that complete neutralization has been obtained). The distillate was titrated with 0.1N $H_2SO_{4.}$

Calculation of % crude protein in the sample (Equation 3.7 and 3.8).

0.1N $H_2SO_{4.}$ = 0.0014gm Nitrogen

Moles of HCI = moles NH_3= moles N in the sample

$$\%\mathrm{N} = \mathrm{NH_4Cl} \times\ \mathrm{Corrected\ acid}\frac{\mathrm{volume}}{\mathrm{gm}}\mathrm{of\ sample}\ \times \frac{\mathrm{14gN}}{\mathrm{mole}} \times 100 \qquad \ldots \text{(Equation 3.7)}$$

N = normality of HCI, in moles/l000 ml, corrected acid vol. = (ml std. acid for sample) – (ml std. acid for blank), 14 = atomic weight of nitrogen. The percentage protein is then determined using Equation 3.8;

% PROTEIN % N × 6.25 … (Equation 3.8)

The conversion factor for other grains (6.25) is used to convert percent N to percent crude protein.

Figure 3.2: Digestion and distillation units for protein determination

Crude fat in flour

Crude fat was determined using (AACC 2010, 30-10); 2g of the sample was weighed in triplicate in thimbles. The thimbles were placed in clean dry siphon tubes fitted to clean dried weighed round bottom flask and connected to a condenser. 60ml of petroleum spirit (B.P 40-60°C) and 60ml of diethyl ether was added into the flask and heated with a heating mantle to reflux for 5h (Figure 3.3). Heating was then stopped; solvent in round bottom flasks evaporated in the water bath and thimbles with the spent samples were oven-dried at 100°C for 30min, remains in round bottom flasks dried in the oven for 1hr, cooled in the desiccator, and then weighed. Calculations for the fat content is according to (equation 3.9);

$$\% fat = \frac{Wt.of\ extracted\ fat}{Wt.of\ dried\ sample} \times 100$$ ... (Equation 3.9)

Figure 3.3: Extraction of fats using Soxhlet apparatus

Carbohydrate content determination

Carbohydrate content was determined by difference (equation 3.10)

$$100 - (\%\, moisture + \%\,\text{protein} + \%\,\text{fat} + \%\,\text{ash}) \quad \text{… (Equation 3.10)}$$

Determination of cyanogenic potential content

The cassava cyanogenic potential was determined using (AOAC, 2005 915.03B) method whereby 10g of the sample was weighed and dissolved in 100 ml distilled water. The mixture was kept at room temperature for 2 hours, then distilled until 200ml was obtained. The distillate was divided into 2 portions, 8ml of 5% KI added to each portion, and then titrated using 0.02 N $AgNO_3$ until the solution turned turbid and light blue. The blank was also titrated by including all the reagents in the same quantity except the sample. Titre reading was recorded and cyanide content determined using equation 3.11

$$Mt. = (\text{T} - \text{B}) \times \text{Vt.} \times \frac{200}{\text{At}} \times \text{Qt} \quad \text{… (Equation 3.11)}$$

Where; Mt – Total cyanide in the sample,

Vt.-Total volume of cyanide after final dilution,

T- Titre for $AgNo_3$, B Titre for blank,

Qt. – Aliquot of the sample used for titration,

At the Total volume of the sample.

3.4.2 Experimental design

Factorial arrangement in a 4x3 Completely Randomized Design was applied as shown in Table 3.1.

Table 3.1: **Setup of the Completely Randomized Design used in objective one of the study**

		Feed moisture (%)		
		10	15	20
Feed ratio %w/w	0	x_{11}	x_{12}	x_{13}
	20	x_{21}	x_{22}	x_{23}
	40	x_{31}	x_{32}	x_{33}
	60	x_{41}	x_{42}	x_{43}

The feed substitution levels were attempted at all the three feed moisture levels.

3.4.3 Statistical model of the extrusion process

Experimental data were fitted in a completely randomized design (CRD) in a factorial arrangement. The statistical model for the experiment was:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijkl} \quad \text{(Equation 3.12)}$$

Where;

Y_{ijkl} = the observation on the response variable;

μ = the overall mean of the respective response variable (the measured physical and chemical indicators of food quality);

α_i = the effect due to the i^{th} chia substitution level;

β_j = the effect due to the j^{th} level of moisture conditioning;

$\alpha\beta_{ij}$ = the interaction effect between the i^{th} chia substitution ratio and j^{th} moisture conditioning;

ε_{ijkl} = the random error associated with Y_{ijkl}.

3.4.4 Data analysis

Data were analyzed using (PROCGLM) on SAS software (v.9.3, SAS Institute, Cary, NC) and hypotheses were tested by performing an analysis of variance. Tukey's Honest Significant Difference (HSD) was used in means separation at a significance level of $p < 0.05$.

3.4.5 Determination of physical properties

Bulk Density (BD)

Bulk density (BD) was determined according to the method of Coulibaly *et al*. (2012).10 g of the sample was weighed into 50ml graduated measuring cylinder. The samples were packed by gently tapping the cylinder on the bench top 10 times from a height of 5 cm. The volume of the sample was recorded. BD was calculated using equation 3.1.

$$\text{BD (g/ml or g/cm}^3) = \frac{\text{wt of thesample}}{\text{volumeof the sample after tapping}} \qquad \text{(Equation 3.1)}$$

Water Absorption Index (WAI) and Water Solubility Index (WSI)

The technique developed for cereals by Dibyakanta *et al.* (2012) was modified and used to measure the WAI and WSI. A 2.5g sample of extrudates were ground and sieved through 500µm sieve. The resultant flour was suspended in 8 mL distilled water at 30°C in a 50ml tube, stirred continuously for 30min, and centrifuged at 171.36xG for 10min. The supernatant liquid was poured carefully into a tarred evaporating aluminium dish and oven-dried. The remaining gel was weighed and the WAI calculated from its weight (equation 3.2). The number of dried solids was recovered by evaporating the supernatant from the water absorption test and was expressed as a percentage of dry solids (equation 3.3).

$$\text{WAI} = \frac{\text{Weight of sediment}}{\text{Weightof dry solids}} \qquad \text{(Equation 3.2)}$$

$$\text{WS I}(\%) = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100 \qquad \text{(Equation 3.3)}$$

Swelling power

Swelling power was determined according to Abdoulaye *et al*. (2012) method where 1g of the sample was weighed in triplicate and suspended in 20ml deionized water heated at 90°C for 1 hour while stirring in a water bath. The suspension cooled to 30°C and centrifuged at 1200rpm (417g) for 10 minutes, poured in aluminum dish decanted and the swollen granules weighed. It was further dried at 110°C for 12 hours and weighed. Swelling power was determined according to (Equation 3.4);

$$\text{Swelling power} = \frac{\text{Wt.of sediment}}{\text{sample weight}} \times (100 - \text{So}) \qquad \text{(Equation 3.4)}$$

Where $S_{o.}$ = water solubility index

***Determination of colour*.**

Colour measurements (CIE L*, a*, b* colour space) were performed on raw materials before extrusion and on-ground extruded samples using a Minolta CR-400 model colorimeter (Konica Minolta, Ramsey, NJ, USA). The colour of extrudates was expressed as the average of three L*, a*, and b* readings, where L* stands for luminosity (lightness), +a* redness, –a* greenness, +b* yellowness, and –b* blueness. A white calibration plate was used to standardize the equipment before colour measurements (Magali *et al*., 2009).

Preliminary test: Microbial quality of extruded cassava – chia blends

The microbiological assessment was done on all the formulated samples on the day after formulation. The assay was done to ensure that the product was safe during handling and consumption. Total plate count (TPC), yeast and moulds count, coliforms and *Staphylococcus aureus* in aqueous extracts of the samples were analyzed using standard methods described in the manual of the Food and Agriculture Organization, United Nations (Andrews, 1992).

3.5 Objective 2: Effect of feed ratio optimization on sensory properties of extruded instant cassava-chia porridge flour

3.5.1 Sensory Analysis

Preparation of the instant porridge

Instant porridge was prepared by the method of Akade *et al*. (2017) where 200g of instant flour was dissolved in 800mls water cooked for 5min then served in 10ml disposable cups coded with three letters. Sensory analysis was carried out in sensory booths and the order of the sample presentation was randomized under controlled conditions.

Descriptive sensory analysis

Descriptive sensory analysis was carried out according to Muoki *et al.* (2015) by trained panellists to have common understandings in the rating of attributes. Nine panelists were recruited from Egerton University, Daftec Postgraduate club then screened through training in three sessions for 1hr each in the identification of fundamental tastes.

Principal Component Analysis was done on the 14 sensory parameters to determine the factors that contributed to the variability among the porridge samples. A lexicon detailing the indices evaluated during descriptive sensory tests was prepared and its summary is as shown in Appendix VI. It indicates that four sensory attributes namely; texture, appearance, aroma and flavour were used in sensory evaluation of the porridge. Each sensory attribute had descriptors describing the product, whereby texture had descriptors of stickiness, consistency, sliminess and viscosity; appearance had glossiness, smoothness and translucency as its descriptors. The other two sensory attributes of aroma and flavour had starchy and caramel, and grainy, cooked and dense flavour, as their descriptors.

Each of the descriptors was graduated using scores between 1 and 9 basing on the 9 point hedonic scale with the following representations with respect to each descriptor; 1 – extremely high negative sensory perception, 2 – very high negative sensory perception, 3 – moderate negative sensory perception, 4 – slight negative sensory perception, 5 – indifference between negative and positive sensory perception, 6 - slight positive sensory perception, 7 - moderate positive sensory perception, 8 – very high positive sensory perception and 9 – extremely high positive sensory perception. Any sensory score below the midpoint of two adjacent scores was considered to belong to the lower limit of the two scores, while a score above the midpoint of two adjacent scores was considered to belong to the upper limit of the two scores.

Consumer acceptability study

Consumer acceptability was carried out according to Lawless and Heymann (2010). Where five sensory attributes namely; consistency, texture, appearance, aroma and flavour were used in evaluation of the porridge. The ratings was carried out by 30 mothers, untrained sensory panellist. Attributes were scored ranging between 1 and 5 based on the 5 point acceptance rating with the following representations with respect to each descriptor; 1 – strongly dislike, 2 – dislike, 3 – neither like nor dislike, 4 – like, 5 – strongly like. Any attribute score below the midpoint of two adjacent scores was considered to belong to the lower limit of the two scores, while an attribute score above the midpoint of two adjacent scores was considered to belong to the upper limit of the two scores. (Appendix VIII).

3.5.2 Experimental design

Factorial arrangement in a 4x3 completely randomized design (CRD) was applied as shown in **Table 3.2**: **Setup of the Completely Randomized Design used in objective two of the study**

		Feed moisture (%)		
		10	15	20
Feed ratio %w/w	0	x_{11}	x_{12}	x_{13}
	20	x_{21}	x_{22}	x_{23}
	40	x_{31}	x_{32}	x_{33}
	60	x_{41}	x_{42}	x_{43}

The feed substitution levels were attempted at all the three feed moisture levels

3.5.3 Statistical model

Experimental data were fitted in a complete randomized design (CRD) in a factorial arrangement.

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijkl} \quad \text{(Equation 3.13)}$$

Where;

Y_{ijkl} = the observation on the response variable;

μ = the overall mean;

α_i = the effect due to the i^{th}chia substitution level;

β_j = the effect due to the j^{th} level of moisture conditioning;

$\alpha\beta_{ij}$ = the interaction effect between the i^{th} chia substitution ratio and j^{th} moisture conditioning; and

ε_{ijkl} = the random error associated with Y_{ijkl}.

3.5.4 Data analysis

Data were analyzed using (PROCGLM) on SAS software (v.9.3, SAS Institute, Cary, NC) and hypotheses were tested by performing an analysis of variance. Tukey's Honest Significant Difference (HSD) was used in means separation at a significance level of $p < 0.05$.

3.6 Objective 3: Effect of feed ratio optimization on shelf life properties of extruded instant cassava-chia porridge flour

3.6.1 Accelerated shelf-life testing

Accelerated shelf-life testing by use of a single accelerating factor (Temp) was carried out at different temperatures of 20, 30, and 40°C based on the Q_{10} principle for 1 month and Peroxide Values (PV) readings taken at days 1, 3, 7, 14, 21 to 28.

3.6.2 Determination of Peroxide Value (PV)

The PV of the samples was determined using the Acetic Acid-Chloroform method (AACC 2010, 58-16.01), whereby 5g sample was weighed into 250-ml glass-stoppered Erlenmeyer flask and 30ml acetic acid-chloroform solution added. Flask was swirled until sample dissolved and 0.5ml saturated KI added. The solution was allowed to stand with occasional shaking for exactly 1 min and then 30ml distilled water added, then titrated with 0.1N $Na_2S_2O_3$, adding gradually and with constant and vigorous shaking, until yellow colour almost disappeared. 0.5ml starch indicator solution was added. Titration continued while shaking flask vigorously near endpoint to liberate all iodine from the chloroform layer until blue colour disappeared. A blank was prepared daily whose titration did not exceed 0.1ml 0.1N $Na_2S_2O_3$ solution. The calculation was carried out using (equation 3.15).

$$\text{Peroxide value as } \frac{\text{mill equivalents peroxide}}{\text{1000 g sample}} = \frac{(S-B)(N)(1000)}{\text{Sample weight.}} \qquad \text{(Equation 3.15)}$$

Where B = titration of blank,

S = titration of sample,

N = normality of $Na_2S_2O_3$, solution.

3.6.3 Determination of product shelf life

A slope, an intercept, and a correlation coefficient were calculated based on the Arrhenius equation through a linear regression analysis of PV by accelerating temperature (25, 35, and 45ºC) to predict the shelf-life of the chia/cassava instant flour The deterioration equation was initially assumed to follow a zero-order of a first-order reaction formula, indicated as Equation 3.16:

$$-\frac{dA}{dt} = (kPV)^n \qquad \text{(Equation 3.16)}$$

Whereby for a zero order reaction, n = 0

Thus, by integration of Equation 3.16, Equation 3.17 was obtained i.e.

$$PV_t = PV_0 - k_t \qquad \text{(Equation 3.17)}$$

Where PV_t is the quality measurement at time t,

PV_0 is the measurement at time t_0,

n is the order of the reaction,

t is the reaction time in days, and;

k is a constant

Also, the first-order reaction was analyzed with Equation 3.18, obtained from Equation 3.16;

$$-\frac{dA}{dt} = (kPV)^n \ (n = 1) \qquad \text{(Equation 3.18)}$$

Then Equation 3.19 was obtained by integrating the first-order reaction Equation 3.18 where equation 3.19 is;

$$PV = PV_0 e^{-kt} \qquad \text{(Equation 3.19)}$$

Which can be simplified to Equation 3.20, i.e.

$$\ln PV_t = \ln PV_0 - kt \qquad \text{(Equation 3.20)}$$

Where k is the gradient of the PV versus time t plot i.e. Equation 4.6

$$k = \frac{\ln PV}{t} \qquad \text{(Equation 3.21)}$$

The PV versus time data obtained from the accelerated shelf-life studies at temperatures of 25, 35 and 45ºC was then evaluated for its fit with Equations 4.2, by the evaluation of the regression coefficients. A regression coefficient (R^2) below 0.90 implied that the PV versus duration data poor fit with the zero-order model (Equation 4.1) necessitating a selection of a better fit, i.e. the 1st order model (Equation 4.4) which incidentally has a correlation with the Arrhenius equation (Equation 4.6) i.e.;

$$k = k_0 e^{\left[\frac{-E_a}{RT}\right]} \qquad \text{(Equation 4.7)}$$

Where k is the quality degradation constant, Ea. is the activation energy and T is the temperature. Through regression analysis, the k value for different extrusion feed parameters and storage temperatures and storage duration was determined and hence, the shelf life of the chia/cassava instant flour determined too, based on acceptable limits for PV.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effect of extrusion feed parameterson physical-chemical properties of extruded instant cassava-chia porridge flour

4.1.1 Proximate composition and physical properties of the raw materials

The data obtained on proximate composition of cassava and chia seeds flour on dry matter basis, is as presented in Table 4.1. It indicates that chia seeds showed high protein content of 19.96g/100g (*SD* = 0.097), which is higher than cassava at 2.39g/100g (*SD* = 0.008). The chia protein content obtained is lower than that presented by Kibui *et al.* (2018), a factor which is attributable to the plant source. However, the protein content in cassava is in agreement with data obtained by Montagnac *et al.* (2009), confirming that cassava has low protein content. With regard to carbohydrates, chia seeds reported a dry basis carbohydrate content of 32.53g/100g (*SD* = 0.01), while cassava had 83.56g/100g (*SD* = 0.084). The carbohydrate content data obtained exhibited the same trend as that observed by Kibui *et al.* (2018) and Montagnac *et al.* (2009) for chia seeds and cassava respectively. This data confirms cassava to be an energy-dense food product, but low in proteins and micronutrients (Morgan and Choct, 2016). Conversely, chia seeds was found to have higher a protein content (19.96g/100g (*SD* = 0.097), hence can be used in the formulation of the extruded instant chia/cassava flour. This was in accordance with previous studies that recommend compositing of food products to improve nutritional value (Boukid *et al*., 2018 ;Coelho *et al*., 2014; Kibui *et al*., 2018; Ullah *et al.,* 2016). Additional data showed a fat and moisture content of 36.61g/100g (*SD* = 0.013) and 6.35g/100g (*SD* = 0.014), respectively, for chia seeds and 0.79 g/100g (*SD* = 0.097) and 10.09g/100g (*SD* = 0.017), respectively, for cassava flour.

Table 4.1: Nutritional Composition of raw materials (dry basis)

	Cassava flour (g/100g)	**Chia seeds (g/100g)**
Protein	2.39 ±0.008	19.96±0.097
Fat	0.79±0.097	36.61±0.013
Moisture	10.09±0.017	6.35±0.014
Ash	2.59±0.039	4.98±0.073
Carbohydrates	83.56±0.084	32.53±0.010
HCN	2.16±0.001	-

Results are means ± SD (n = 3)

The physical properties of dry cassava flour and chia seeds are as presented in Table 4.2. It indicates that Bulk Density (BD), Water Absorption Index (WAI) and Water Solubility Index (WSI) were higher in chia seeds at 0.55 g/cm^3 (*SD* = 0.01), 2.92 g/g (*SD* = 0.18) and 9.18 % (*SD* = 0.21), respectively compared to cassava flour having 40:60 5 g/cm^3 (*SD* = 0.05), 1.53 g/g (*SD* = 0.36) and 5.58 % (*SD* = 0.96). A one-way ANOVA showed a significant difference (p< 0.05) in the BD for cassava and chia. Similar results were observed for WAI (p< 0.05) and WSI (p<0.05), which is an indication that the physical properties of the two samples were dissimilar. Conversely, the swelling power values for cassava and chia was 4.80 g/g (*SD* = 0.87) and 4.62 g/g (*SD* = 0.92), respectively, and had no significant differences (p> 0.05), indicating a non-discernible difference in swelling power of cassava and chia samples. The obtained chia seeds WAI and WSI values are almost similar to those from findings by Ramos *et al.*(2017) and Rana (2019), while for those for cassava were within the limits stated by Magali *et al*. (2009). Regarding density, the findings obtained are lower than those of Ixtania *et al*. (2008), who reported a black chia seed bulk density of 0.66 - 0.72g/cm^3. This discrepancy may be due to differences in ecological conditions from which the seeds were sourced from. The higher bulk density in chia seeds as opposed to cassava flour could be attributable to the fact that having been milled, cassava flour had a lower packing per unit volume, compared to chia which was unmilled.

Table 4.2: Physical properties of raw materials

Physical properties	**Cassava Flour**	**Chia seeds**
Bulk density (g/cm^3)	0.65±0.05^a	0.55±0.01^b
WAI(g/g)	1.53±0.36^a	2.92±0.18^b
WSI (%)	5.58±0.96^a	9.18±0.21^b
Swelling Power (g/g)	4.80±0.87^a	4.62±0.92^a

Results are means ± SD (n = 3)

4.1.2 Nutritional content of cassava-chia extruded instant flour

Ash

Table 4.3 presents the results obtained from proximate analysis of the extruded cassava-chia instant flour. It indicates that as the ratio of chia/cassava increased from 0:100 to 60:40, there occurred a corresponding increase in ash content of cassava-chia extruded instant flour from 2.26 % (*SD* = 0.03) to 3.55 % (*SD* = 0.02), 2.29 % (*SD* = 0.02) to 3.55 % (*SD* =

0.02) and3.55 % (*SD* = 0.02 to 3.56 % (*SD* = 0.02) for 10, 15 and 20% feed moisture contents, respectively. One-way ANOVA results showed that feed moisture had a significant effect ($p < 0.05$) on ash content of the chia/cassava instant flour hence difference in the ash contents of the cassava/chia extrudates. The increase in ash content in the extrudates was due to higher ash content in chia seed compared to that of cassava (Table 4.3). This is notable since chia is rich in phosphorus, calcium, potassium and magnesium manifested in the ash and according to Kulczy'nski, (2019), are important for growing children.

Table 4.3: Proximate composition (dry basis) of different blends of extruded cassava/chia seeds instant porridge flour at 10, 15 and 20%feed moisture

Feed Moisture (%)	Chia/ cassava ratio	Proximate Analyses (%)				
		Ash	Moisture content	Proteins	Fat	Carbohydrates
10	0:100	$2.26{\pm}0.03^{f}$	$4.64{\pm}0.05^{f}$	$2.41{\pm}0.02^{f}$	$0.51{\pm}0.01^{g}$	$90.18{\pm}0.89^{g}$
	20:80	$2.78{\pm}0.02^{e}$	$4.16{\pm}0.17^{f}$	$6.03{\pm}0.09^{e}$	$5.83{\pm}0.30^{f}$	$81.20{\pm}0.42^{f}$
	40:60	$3.78{\pm}0.07^{b}$	$5.17{\pm}0.26^{ef}$	$10.02{\pm}0.07^{b}$	$9.42{\pm}0.07^{c}$	$71.61{\pm}0.53^{b}$
	60:40	$3.55{\pm}0.02^{c}$	$5.11{\pm}0.14^{ef}$	$12.23{\pm}0.02^{a}$	$11.77{\pm}0.23^{a}$	$67.34{\pm}0.59^{a}$
15	0:100	$2.29{\pm}0.02^{f}$	$7.48{\pm}1.32^{c}$	$2.51{\pm}0.06^{f}$	$0.600{\pm}0.01^{g}$	$87.12{\pm}0.59^{f}$
	20:80	$2.96{\pm}0.02^{d}$	$5.56{\pm}0.57^{e}$	$6.04{\pm}0.01^{e}$	$7.14{\pm}0.15^{e}$	$78.30{\pm}0.25^{e}$
	40:60	$4.05{\pm}0.09^{a}$	$4.53{\pm}0.42^{f}$	$9.01{\pm}0.02^{c}$	$9.55{\pm}0.10^{bc}$	$72.86{\pm}0.39^{c}$
	60:40	$3.55{\pm}0.02^{c}$	$4.68{\pm}0.01^{f}$	$10.32{\pm}0.04^{b}$	$10.93{\pm}0.02^{b}$	$70.52{\pm}0.91^{b}$
20	0:100	$3.55{\pm}0.02^{c}$	$10.46{\pm}0.19^{a}$	$3.10{\pm}0.25^{f}$	$0.67{\pm}0.03^{g}$	$82.22{\pm}0.51^{f}$
	20:80	$3.53{\pm}0.02^{c}$	$8.67{\pm}0.08^{b}$	$8.15{\pm}0.15^{d}$	$7.31{\pm}0.31^{e}$	$72.34{\pm}0.44^{d}$
	40:60	$4.04{\pm}0.01^{a}$	$8.50{\pm}0.05^{b}$	$8.93{\pm}0.09^{c}$	$8.45{\pm}0.11^{d}$	$70.08{\pm}0.74^{c}$
	60:40	$3.56{\pm}0.03^{c}$	$6.65{\pm}0.05^{d}$	$12.16{\pm}0.09^{a}$	$10.78{\pm}0.29^{bc}$	$66.85{\pm}0.54^{a}$

Values are means ± Std. error of triplicate measurements (n=3).

Different superscript's letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

Moisture content

A different trend in results was observed for moisture content (Table 4.3) as the ratio chia/cassava increased from 0:100 to 60:40; for instance, an erratic variation was observed ranging from 4.64% (*SD* = 0.05) to 5.11% (*SD* = 0.26) for 0:100 and 60:40 chia/cassava ratio, respectively, at 10% feed moisture content. On the other hand, at feed moisture contents of 15 and 20%, the moisture content reduced from 7.48% (*SD* = 1.32) to 4.68% (*SD* = 0.01) and 10.46% (*SD* = 0.19) to 6.65% (*SD* = 0.05) respectively. Additionally, one-way ANOVA results showed a significant difference ($p< 0.05$) in the moisture content for cassava/chia instant flour for 15 and 20 % feed moisture, however at 10% feed moisture, there was no significant difference ($p> 0.05$), indicating that the chia to cassava ration in the feed had no appreciable impact on the product moisture content. The low moisture contents of the extrudates (<10%) imply a longer shelf- life of the products as this minimizes the growth of microorganisms and rancidity. The slight variations in moisture contents of the different blends could be due to changes in water hydration capacity of the extrudates (Tadesse *et al*., 2019).

Protein

During the analysis of the chia/cassava instant flour protein content, it was discerned that as the ratio of chia/cassava in the feed increased from 0:100 to 60:40, there occurred a corresponding increase in extrudate instant flour protein content from 2.41 % (*SD* = 0.02) to 12.23 % (*SD* = 0.02), 2.51 % (*SD* = 0.06) to 10.32 % (*SD* = 0.04) and 3.10 % (*SD* = 0.25 to 12.16 % (*SD* = 0.09) for 10, 15 and 20% feed moisture ratios, respectively. Related results obtained from one-way ANOVA revealed a significant difference ($p<0.05$) in the protein content of the chia/cassava extrudate, an indication that an increase in feed chia/cassava ratio resulted in corresponding increase in the protein content of the extrudate. Thus with higher chia seed incorporation levels, protein contents of greater than 10% in the extruded products were achieved Naumova *et al*. (2017) also analyzed the quality and nutritional value of pasta products with added ground chia seeds and reported that 10% of chia seeds incorporation improved the nutritional composition. WHO/FAO recommends a protein intake of 0.9 g/kg/day for boys aged between 3 to 18 years and girls from 3 to 15 years (Ellis *et al*., 2000). From this study, the 60:40chia/cassava ratio extrudate has a protein content of 10.06%, thus a 100 g ration will supply 10 g of protein, which is enough for an 11 kg child in a day as opposed to consuming cassava alone.

Fat

Similar results as those for protein were observed for fat content; it was perceived that for a change in the ratio of chia/cassava from 0:100 to 60:40, there occurred a matching increase in extrudate instant flour fat content from 0.51 % (*SD* = 0.01) to 11.77 %(*SD* = 0.23), 0.60 % (*SD* = 0.01) to 10.93 % (*SD* = 0.02) and 0.67 % (*SD* = 0.03) to 10.78 % (*SD* = 0.29) for 10, 15 and 20% feed moisture contents, respectively. Corresponding one-way ANOVA showed a significant difference ($p<0.05$) in the ash content for cassava and chia. The Fat contents of >10%, in chia seeds which is particularly rich in ω-3 *alpha*-linolenic acid, ω-6 *alpha*-linoleic acid and oleic acid significantly enriches the extrudates and makes them suitable in diets for school-going children.

Carbohydrates

The carbohydrate content in extrudate chia/cassava instant flour, as the chia/cassava ratio in the feed increased from 0:100 to 60:40, decreased from 90.18 % (*SD* = 0.89) to 67.34 % (*SD* = 0.59), 87.12 % (*SD* = 0.59) to 70.52 % (*SD* = 0.91) and 82.22 % (*SD* = 0.51) to 66.85 % (*SD* = 0.54) for 10, 15 and 20% feed moisture ratios, respectively. Correspondent one-way ANOVA showed a significant difference ($p<0.05$) in the carbohydrate content of the chia/cassava instant flour. Extrusion cooking is a unique process because gelatinization occurs at much lower moisture levels (12– 22%) than other forms of food processes (Singh *et al*., 2007).In this study, cassava was supplemented with chia seeds to make extruded instant porridge floor. The proximate components (protein, fat and ash contents) significantly ($p<0.05$) increased with increasing chia seed incorporation levels at all moisture levels, owing to the higher protein, fat and ash contents in chia seeds. Sandri *et al*. (2017) stated that incorporating 5–14% whole chia flour in a formulation while baking bread increased the levels of ash, lipid, protein and dietary fibre, similar to the results obtained in the current study (Table 4.2).

4.1.3 Physical properties of cassava-chia extruded instant flour

Bulk density

Table 4.4 presents the results obtained from analysis of physical properties of the extruded cassava-chia instant flour. The Bulk Density (BD)of cassava-chia extruded instant flour increased from 0.50g/cm^3 (*SD* = 0.01) to 0.53 g/cm^3 (*SD* = 0.02), 0.52 g/cm^3 (*SD* = 0.02) to 0.63 g/cm^3 (*SD* = 0.01) and 0.51 g/cm^3 (*SD* = 0.01) to 0.60 g/cm^3 (*SD* = 0.01) for 10, 15 and 20% feed moisture ratios, respectively, as the ratio of chia/cassava increased from 0 to 60:40. One-way ANOVA results showed a significant difference ($p<0.05$) in the BD of the cassava-chia extruded instant flour**.** On physical properties, Bulk Density (BD) showed a slight increase with an increase in chia seed incorporation (Table 4.4). However, the effect of feed moisture was not apparent although increased feed moisture is the main factor affecting extrudate density because plasticization of the melt decreases the elasticity of the dough (Ajita, 2018). Bulk density is one of the parameters that describe the degree of puffing of extrudates, and is used as a measure of packaging where the lower the bulk density, the less the cost on the packaging. It ranged between 0.50–0.63 g/cm^3 for cassava-chia composite flour at different moisture content and was highest at 60% chia seeds incorporation level and 15% moisture content. This was also reported by Leonard *et al*. (2019) that at higher moisture content there is a reduction in viscosity which affects friction within the barrel and starch gelatinization. Bulk density is also desirable for dispensability and reduction of paste thickness (Awolu *et al.,* 2015). Julien *et al*. (2016) found that the bulk density of the rapoko-corn blend instant flour was 0.56–60:401 which is comparable to cassava chia instant flour. Badrie and Mellowes (1992) reported that there is a positive correlation of crude protein with a bulk density of extrudates, which corroborates with findings in this study.

Table 4.4: Physical properties of different blends of extruded instant cassava/chia seeds porridge flour at 10, 15 and 20% feed moisture

Feed Moisture (%)	Chia/cassava ratio	Physical properties			
		Bulk density (g/cm^3)	WAI (g/g)	WSI (%)	Swelling power(g/g)
10	0:100	0.50±0.01^{d}	1.94±0.06^{g}	55.48±0.84^{b}	5.17±0.12^{e}
	20:80	0.52±0.02^{c}	3.86±0.07^{e}	32.38±1.03^{c}	5.80±0.05^{d}
	40:60	0.58±0.01^{b}	4.74±0.06^{c}	20.43±0.97^{f}	4.92±0.02^{e}
	60:40	0.53±0.02^{c}	5.92±0.16^{a}	17.48±2.18^{g}	5.69±0.28^{d}
15	0:100	0.52±0.02^{c}	1.56±0.03^{h}	57.81±0.48^{a}	5.14±0.14^{e}
	20:80	0.59±0.01^{b}	3.46±0.02^{f}	23.95±0.56^{e}	2.44±0.07^{g}
	40:60	0.60±0.01^{b}	4.72±0.18^{c}	20.48±1.01^{f}	8.86±0.17^{a}
	60:40	0.63±0.01^{a}	5.51±0.10^{b}	19.81±0.66^{f}	6.11±0.16^{c}
20	0:100	0.51±0.01^{cd}	5.82±0.07^{a}	57.10±0.42^{a}	6.48±0.33^{b}
	20:80	0.59±0.01^{b}	5.94±0.08^{a}	32.38±1.03^{c}	4.93±0.22^{e}
	40:60	0.51±0.20^{cd}	4.45±0.02^{d}	29.52±0.62^{d}	4.26±0.08^{f}
	60:40	0.60±0.01^{b}	4.06±0.05^{e}	17.48±2.18^{g}	6.57±0.11^{b}

Values are means ± Std. error of triplicate measurements (n=3).

Different superscript's letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

Water Absorption Index (WAI)

The ability of a structure to spontaneously adsorb water when exposed to an atmosphere of constant relative humidity is its Water Absorption Index (WAI), as defined by Segura-Campos *et al*. (2014). Its results (Table 4.4) indicate that, as the ratio of chia/cassava within the extruder feed increased from 0:100 to 60:40, an increase in extrudate WAI was observed ranging from 1.94g/g (*SD* = 0.06) to 5.92g/g (*SD* = 0.16) for 0 and 60:40 chia/cassava ratio, respectively, at 10% feed moisture ratio, and 1.56g/g (*SD* = 0.03) to 5.51g/g (*SD* = 0.10) at feed moisture ratios of 15%. On the other hand, at 20%, the WAI decreased from 5.82g/g (*SD* = 0.07) to 4.06g/g (*SD* = 0.05) respectively. One-way ANOVA results showed significant differences ($p< 0.05$) in the WAI of extruded instant cassava-chia seeds porridge flour with respect to feed moisture. The Water Absorption Index (WAI) from the control (0:100 chia/cassava ratio) increased with an increase in chia seed incorporation for the 10 and 20% feed moisture levels (Table 4.4). However, for control sample at the 15% feed moisture, WAI was highest. This discrepancy could be attributable to a deviation in extrusion conditions, especially barrel temperature, since Oikonomou and Krokida (2012) stated that barrel temperature affects the WAI of an extrudate, yet during the study, this parameter was not measured. A similar deviation was also observed for 20:80, 40:60 and 60:40 chia/cassava ratios at the 15% feed moisture. It was however noticed that for the 10 and 20% feed moisture ratios, the WAI increased, which could be attributed to an interaction of hydrophilic sites present in the gums/ chia mucilage with water during dissolution (Yeh *et al*., 2005). Similarly, the increase in WAI in the extrudates could have also been contributed by the high fiber content of chia seeds (18–30%), due to the ability of fibres to form gels and hold water (Vazquez-Ovando *et al*., 2013). The result obtained are in agreement with Abioye *et al.* (2016), Kharat *et al.* (2018), Nyombaire *et al.* (2011) and, Hashimoto and Grossmann (2003) who indicate that an increase in WAI is due to starch degradation through gelatinization in extrusion.

Water Solubility Index (WSI)

According to Awolu *et al.* (2015) and Singha *et al*. (2018), WSI is an indication of the solubility of biomolecules including starches, water soluble fibre, proteins and/or sugars in water, and also measures the components that are released from starch after extrusion. From the study it was observed that as the ratio of chia/cassava within the feed increased from 0:100 to 60:40, there occurred a corresponding decrease in extrudate instant flour WSI from 55.48 % (*SD* = 0.84) to 17.48 %(*SD* = 2.18), 57.81 % (*SD* = 40:608) to 19.81 % (*SD* = 0.66) and 57.10 % (*SD* = 0.42) to 17.48 % (*SD* = 2.18) for 10, 15 and 20% feed moisture content, respectively (Table 4.4). The results obtained from one-way ANOVA revealed a significant difference ($p < 0.05$) in the ash content of extrudate. The results indicate that the amount of starch in extrudate was reduced with chia seed incorporation, due to its replacement with proteins, fibre, and fats, hence reducing the WSI. This is in agreement with results by Hashimoto and Grossmann (2003) and Jisha *et al.* (2010), during production of chickpea/cassava and cassava bran/cassava extrudate, respectively, a negative correlation between cassava bran and WSI and crude protein and WSI, respectively, was observed. Additionally, the reduction in WSI is also attributable to dextrinization of the starch polymers as also observed by Kharat *et al.* (2018). Similarly, Mercier *et al.* (1980) reported that extrusion of cassava formed amylose – lipid complexes with polyunsaturated fatty acids and reduced the solubility and hence the WSI of the extrudates. Moreover, possible denaturation of proteins within chia during the extrusion process results in a reduction of protein solubility, due to cross-linking reactions and covalent bonds formation at high temperatures (Maurya & Said, 2014). These results are in contradiction with those observed by Abioye *et al.* (2016), since in his study with soya/cassava extrudates, high temperatures led to a disruption in covalent bonds, hence an increase in WSI.

Swelling power

A mixed trend in the results were observed for swelling power as the chia/cassava ratio in the feed increased from 0:100 to 60:40 (Table 4.4). It was apparent that for a change in the ratio of chia/cassava from 0 to 60:40, at 10% extrusion feed moisture content, the swelling power had an erratic variation between 5.17g/g (*SD* = 0.12) and 5.69g/g (*SD* = 20:808). This was also observed at 15% extrusion feed moisture where the swelling power varied between 5.14g/g (*SD* = 0.14) and 6.11g/g (*SD* = 0.16), and at 20% extrusion feed moisture (6.48g/g (*SD* = 0.38) and6.57g/g (*SD* =0.11)). Despite correspondent one-way ANOVA showing a significant difference ($p<0.05$) in the swelling powers, the results did not exhibit a meaningful trend. Swelling power is the ability of starch in the extrudates to absorb water to the extent of causing starch granules to increase in size, which is an indication of the level of exposure of the internal structure to the action of water (Ruales *et al.*, 1993). From the responses in this study, the swelling power ranged between 2.44 and 8.86 with no apparent effect of the level of chia seed incorporation and feed moisture (Table 4.4). This shows that the level of chia seed incorporation and feed moisture interactively affected the ability of the extrudates to absorb water.

Colour

Table 4.5 presents the results obtained from analysis of colour properties of the extruded cassava-chia instant flour. As the chia/cassava ratio increased from 0 to 60:40, the lightness index L*, redness index a* and yellowness index b* of cassava-chia extruded instant flour had an erratic variation between 64.93 (*SD* = 1.15) and 47.83 (*SD* = 3.38), 2.53 (*SD* = 0.45) and 3.43 (*SD* = 0.28) and, 21.30 (*SD* = 0.70) and 21.67 (*SD* = 0.52), for 10% feed moisture content. One-way ANOVA results showed a significant difference ($p< 0.05$) in the L*, a* and b* of the cassava-chia extruded instant flour**.** The mixed trend in the L* a* and b* data for the chia/cassava instant flour is indicative of different effects of extrusion on the colour of the product. It is also noted that despite being significantly different, the means had a tendency to cluster, which calls for an alternate method in the evaluation of the extrudate colour as opposed to L* a* and b* indices.

A similar trend was observed at the 15% feed moisture, whereby the lightness index L*, redness index a* and yellowness index b* of cassava-chia extruded instant flour had variations between 68.60 (*SD* = 0.67) and 54.27 (*SD* = 2.22), 2.53 (*SD* = 0.45) and 3.43 (*SD* = 0.28) and, 21.30 (*SD* = 0.70) and 21.67 (*SD* = 0.52), as chia/cassava ratio increased from 0 to 60:40. One-way ANOVA results showed a significant difference ($p<0.05$) in the colour of the cassava-chia extruded instant flour. Finally, similar results to 10% and 15% feed moisture were also observed at the 20% feed moisture where whereby the lightness index L*, redness index a* and yellowness index b* of cassava-chia extruded instant flour had variations between 60.83 (*SD* = 2.67) and 58.53 (*SD* = 2.77), 2.47 (*SD* = 0.09) and 2.03 (*SD* = 0.23) and, 23.07 (*SD* = 0.47) and 21.17 (*SD* = 0.20).

Colour properties of different blends of extruded instant cassava chia seeds porridge flour at 10, 15 and 20% feed moisture

According to the results, L* was affected by the amount of water added during extrusion and chia seed incorporation levels. At high moisture, there are low levels of browning thus there is low caramelization and Maillard reaction caused due to shear effect during extrusion. The higher the chia seed incorporation levels the lower the L* and the higher the b^*. The mixed trends in the results especially for L* are however in agreement with Magali *et al*. (2009) where there was a decrease in luminosity L* after the extrusion of cassava starch at a higher moisture content as compared with native cassava flour before extrusion. Also, according to Mesquita *et al*. (2013), low moisture content in the material may restrain its flow inside the extruder, increasing shear and residence time which can lead to Maillard reaction and hence low value for L* while high moisture content will lead to low shear and hence the high value of L*.

Table 4.5: Colour properties of different blends of extruded instant cassava chia seeds porridge flour at 10, 15 and 20% feed moisture

Moisture (%)	Chia /cassava ratio	Colour properties		
		Lightness (L*)	**red (a*)**	**yellow (b*)**
10	0:100	64.93±1.55[ab]	2.53±0.45[d]	21.30±0.70[c]
	20:80	50.47±3.07[d]	4.70±0.23[a]	23.67±0.88[c]
	40:60	60.13±3.03[b]	3.83±0.30[b]	24.67±0.97[a]
	60:40	47.83±3.38[d]	3.43±0.28[bc]	21.67±0.52[c]
15	0:100	68.60±0.67[a]	2.53±0.45[d]	21.30±1.22[c]
	20:80	52.53±0.15[cd]	3.37±0.09[bc]	21.77±0.24[c]
	40:60	54.07±2.44[cd]	2.27±0.12[d]	21.17±0.23[c]
	60:40	54.27±2.22[cd]	2.63±0.19[cd]	22.50±0.51[c]
20	0:100	60.83±2.83[b]	2.47±0.09[d]	23.07±0.47[b]
	20:80	65.63±1.13[a]	3.00±0.21[c]	24.17±0.33[ab]
	40:60	55.33±3.71[c]	2.43±0.09[d]	22.00±0.10[c]
	60:40	58.53±2.77[bc]	2.03±0.23[d]	21.17±0.20[c]

Values are means ± Std. error of triplicate measurements (n=3).

Different superscripts letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

The results are similar to those reported by Brayars and Singh (2014), which showed that increase in chia concentration on chia- corn extrudate reduced L* and b* with a slight increase in a*. According to Mesquita *et al*. (2013), under conditions of low percentage of flaxseed flour and high extrusion temperature the L* of products becomes higher. Aranibar *et al*.(2018) also reported that the L* value decreased with increase of chia seeds inutilization of a partially-deoiled chia flour to improve the nutritional and antioxidant properties of wheat pasta.

Preliminary safety quality analysis of extrudate - microbial tests

Prior microbial tests on extrudates were carried out to ensure that it was safe for human consumption and the results are presented in Table 4.6. From the results, at 10% moisture conditioning, the microbial counts ranged between 10.00 (SD = 0.00) and 3.14 (SD = 0.00) $\log_{10}$ $cfug^{-1}$, 0.39 (SD = 0.39) and 2.81 (SD = 0.05) log $cfug^{-1}$, 2.11 (SD = 0.06) and 3.68 (SD = 0.01) log $cfug^{-1}$ and, 0.73 (SD = 0.37) and 2.95 (SD = 0.04) log $cfug^{-1}$ for Total Viable Count (TVC), coliforms, yeast and molds and *S. aureus,* respectively. Additionally, at 15% moisture conditioning TVC was in the range 2.33 (SD = 0.03) - 4.09 (SD = 0.01) log $cfug^{-1}$, however, at a chia/cassava ratio of 40:60, a high TVC of 4.09 (SD = 0.01) log $cfug^{-1}$ was observed. On the other hand, at the same moisture conditioning percentage (15%), the coliform, yeast and molds and *S. aureus* counts ranged between 1.51 (SD = 0.06) to 3.09 (SD = 0.01) log $cfug^{-1}$, (0.00 (SD = 0.00) to 3.49 (SD = 0.01) log cfu g^{-1} and 2.06 (SD = 0.03) to 3.01 (SD = 0.05) log $cfug^{-1}$, respectively. Finally at 20% moisture conditioning, the TVC and coliform count ranged between 0.00 (SD = 0.00) to 3.45 (SD = 0.02) log $cfug^{-1}$, and 0.00 (SD = 0.00) to 3.44 (SD = 0.01 log $cfug^{-1}$), respectively, with the highest counts observed at a chia/cassava ratio of 0. Yeast and molds count ranged between 1.56 (SD = 0.02) and 3.78 (SD = 0.01) log $cfug^{-1}$ with the highest at a chia/cassava ratio of 60:40, while *S. aureus* ranges between 1.67 (SD = 0.03) to 3.70 (SD = 0.01) log $cfug^{-1}$) with the highest was at chia/cassava ratio of 0. The results indicate that the amount of conditioning moisture added significantly affected ($p < 0.05$) the microbial load counts in the sample. Similarly, the substitution ratios and interaction effect also affected the microbial load ($p < 0.05$).

Foodborne pathogens can survive in low water activity foods and dry food processing and preparation environments (Beuchat *et al*., 2013). According to KEBs standards (DKS 523-2:2010 ICS 67.060), extruded flour is expected to have no microbes or very low levels due to reduced survival rates. There was a significant difference of microbes at $p < 0.05$ and the model was significant at $p < 0.05$ for the samples analyzed. According to Rampersad *et al*. (2003) on extrusion processing, the colony-forming units per gram of sample ($cfug^{-1}$) decreased to 2×10^3mesophiles/g, 10×10^2 thermophiles with nil coliforms, yeasts, and moulds. The high-temperature range of 120 to 125°C was effective in destroying/reducing the number of microorganisms. These products were deemed microbiologically safe for consumption according to the DKS 523-2:2010 ICS 67.060 (Kenya Bureau of Standards, 2010) standards on breakfast cereals and the study proceeded to sensory analysis.

Table 4.6: Microbial load of different blends of extruded instant cassava chia seeds instant porridge flour at 10, 15 and 20% feed moisture

Moisture Content (%)	Chia/Cassava ratio	Microbial load (log cfug^{-1})			
		TVC	coliforms	Yeast and moulds	*S. aureus*
10	0:100	0.00±0.00^{h}	0.39±0.39^{g}	2.11±0.06^{f}	0.73±0.37^{g}
	20:80	2.77±0.08^{f}	2.49±0.04^{d}	2.59±0.02^{e}	2.95±0.04^{b}
	40:60	2.77±0.09^{f}	2.33±0.03^{e}	3.68±0.01^{a}	2.52±0.07^{c}
	60:40	3.14±0.05^{d}	2.81±0.05^{c}	2.49±0.01^{e}	2.30±0.01^{d}
15	0:100	2.80±0.03^{ef}	1.69±0.10^{f}	1.87±0.07^{g}	2.06±0.03^{e}
	20:80	3.42±0.01^{b}	1.51±0.06^{f}	0.00±0.00^{i}	2.82±0.05^{b}
	40:60	4.09±0.01^{a}	3.09±0.01^{b}	2.79±0.07^{d}	2.95±0.03^{b}
	60:40	2.33±0.03^{g}	2.81±0.01^{c}	3.49±0.01^{b}	3.01±0.05^{b}
20	0:100	3.45±0.02^{b}	3.44±0.01^{a}	2.73±0.16^{d}	3.70±0.01^{a}
	20:80	0.00±0.00^{h}	0.00±0.00^{h}	1.56±0.02^{h}	1.96±0.01^{e}
	40:60	3.27±0.03^{c}	2.23±0.01^{e}	3.11±0.02^{c}	1.67±0.03^{f}
	60:40	2.86±0.10^{e}	3.03±0.03^{b}	3.78±0.01^{a}	1.86±0.04^{e}

Values are means ± Std. error of triplicate measurements (n=3).

Different superscripts letters on means in the same column indicate significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

4.2 Effect of extrusion feed parameters on sensory properties of extruded instant Cassava-chia porridge flour

4.2.1 Descriptive sensory test

Texture

Table 4.7 presents the results obtained from analysis of texture of the extruded cassava/chia porridge. They show that for a 10% feed moisture, as the chia/cassava ratio increased from 0:100 to 60:40, the stickiness scores of the porridge changed from 5.75 (*SD* = 0.36) to 8.70 (*SD* = 0.41), representing slightly runny and very sticky, respectively. At the 15% feed moisture, as the chia/cassava ratio increased from 0:100 to 60:40, the stickiness in the porridge also increased from 5.93 (*SD* = 0.33) to 8.53 (*SD* = 0.50), which represented slightly sticky, and very sticky stickiness, respectively. Lastly, the stickiness results obtained at the 20% feed moisture showed a similar trend to those obtained at 10% and 15% feed moisture, with the stickiness varying between 4.10 (*SD* = 0.40) and 6.75 (*SD* = 0.43), representing slightly runny and moderately sticky, respectively. Significant differences (p<0.05) were observed among stickiness scores due to change in chia/cassava ratio, which implies that an increase in chia/cassava ratio had a positive effect on the stickiness, unlike feed moisture, since at higher feed moistures, lower scores in stickiness were observed.

Another parameter in texture is consistency, whose sensory scores varied between 8.18 (*SD* = 0.54) and 7.82 (*SD* = 0.59) as the chia/cassava ratio increased from 0:100 to 60:40, at 10% feed moisture, denoting a slightly high consistency and a slight inconsistency, respectively. At the 15% feed moisture, as the chia/cassava ratio increased from 0:100 to 60:40, the consistency scores varied between 8.19 (*SD* = 0.54) and 7.65 (*SD* = 0.52) which denoted a moderate inconsistence across all chia/cassava ratios. Finally, at the 20% feed moisture, the consistency varied between 8.18 (*SD* = 0.69) and 7.43 (*SD* = 0.53), which represented moderate runniness, and indifference in stickiness, respectively. Similarly, significant differences (p<0.05) were observed among consistency scores due to change in chia/cassava ratio.

Regarding the textural parameter of sliminess, its score decreased from 8.18 (*SD* = 0.54) to 7.82 (*SD* = 0.59) for 10% feed moisture ratio, as chia/cassava ratio increased from 0:100 to 60:40, which signified extreme porridge sliminess in the porridge across all chia/cassava ratios. Similarly, at 15%, the sliminess decreased from 8.19 (*SD* = 0.54) to 7.62 (*SD* = 0.52), exhibiting the same deductions as those made at 10%. At the 20% feed moisture the sliminess results obtained showed similar results to those obtained at 10 and 15% feed moisture, with sliminess reducing from 8.18 (*SD* = 0.69) to 7.43 (*SD* = 0.53), representing extremely slimy and very slimy, respectively. An ANOVA analysis of the means reveals insignificant differences (p>0.05) among sliminess indicators with change in feed moisture and chia/cassava ratio, which implies that both treatments had minimal effect on the porridge's sliminess.

Table 4.7: Effect of chia/cassava ratio and feed moisture during extrusion on the texture of the chia/cassava instant porridge

Feed moisture (%)	Chia/cassava ratio	Texture parameters			
		Stickiness	Consistency	Sliminess	viscosity
10	0:100	5.75 ± 0.36^{b}	8.18 ± 0.54^{ab}	8.18 ± 0.48^{ab}	4.98 ± 0.35^{c}
	20:80	6.40 ± 0.29^{bc}	8.00 ± 0.34^{a}	8.15 ± 0.57^{b}	8.18 ± 0.59^{ab}
	40:60	6.58 ± 0.31^{bc}	7.93 ± 0.63^{b}	8.17 ± 0.39^{ab}	8.18 ± 0.39^{ab}
	60:40	8.70 ± 0.41^{a}	7.82 ± 0.59^{ab}	8.16 ± 0.45^{ab}	8.35 ± 0.46^{ab}
15	0:100	5.93 ± 0.33^{b}	8.19 ± 0.54^{ab}	8.35 ± 0.43^{ab}	6.22 ± 0.31^{bc}
	20:80	6.22 ± 0.54^{bc}	8.07 ± 0.34^{ab}	6.75 ± 0.68^{b}	6.50 ± 0.34^{bc}
	40:60	6.23 ± 0.54^{bc}	7.99 ± 0.38^{ab}	7.10 ± 0.63^{ab}	7.15 ± 0.36^{bc}
	60:40	8.53 ± 0.50^{ab}	7.65 ± 0.52^{ab}	8.00 ± 0.33^{ab}	8.00 ± 0.50^{ab}
20	0:100	4.10 ± 0.60^{d}	8.18 ± 0.69^{b}	8.45 ± 0.66^{ab}	6.80 ± 0.71^{c}
	20:80	4.93 ± 0.33^{c}	8.18 ± 0.54^{ab}	8.35 ± 0.43^{ab}	6.75 ± 0.46^{bc}
	40:60	5.15 ± 0.32^{c}	7.58 ± 0.51^{a}	7.27 ± 0.37^{ab}	8.00 ± 0.44^{ab}
	60:40	6.75 ± 0.43^{bc}	7.43 ± 0.53^{a}	8.70 ± 0.24^{a}	8.89 ± 0.50^{ab}

Values are means ± Std. error of triplicate measurements (n=3).

Different superscript's letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

The last parameter that was tested among the textural attributes is the viscosity, it increased from 4.98 (SD = 0.35) to 8.35 (SD = 0.46) with an increase in chia/cassava ratio from 0 to 60:40, signifying indifference in viscosity and very viscous porridge, respectively. Similarly, at the 15% feed moisture, as the chia/cassava ratio increased from 0:100 to 60:40, the porridge viscosity also increased from 6.22 (SD = 0.31) to 8.00 (SD = 0.50), representing a moderately viscous porridge and a very viscous porridge, respectively. Finally, viscosity results obtained at the 20% feed moisture showed a similar trend to the results obtained at 10 and 15% feed moisture, where by the viscosity increased from 6.80 (SD = 0.71) to 8.89 (SD = 0.50), which signified a very viscous and an extremely viscous porridge, respectively. An ANOVA analysis indicates that, chia/cassava ratio only had a significant effect ($p<0.05$) on the viscosity when a comparison was performed between the control samples, and the porridge samples having chia incorporated (20:80 – 40:60 chia/cassava ratio). A further comparison of viscosities within samples containing different chia/cassava ratios revealed insignificant differences ($p>0.05$) between the viscosities, which implied that an increase in chia/cassava ratio had a minimal effect on porridge viscosity. This scenario was also observed in the feed moisture.

Appearance

The chia/cassava instant porridge samples were also subjected to appearance testing and the results are as presented in Table 4.8, showing appearance parameters of glossiness, smoothness, jelly and transparency. These results indicate that at an extrusion feed moisture of 10%, an increase in chia/cassava ratio from 0:100 to 60:40, reduced the glossiness from 8.00 (*SD* = 0.47) to 5.20 (*SD* = 0.65), symbolizing a very glossy porridge, and a porridge giving an indifferent perception in glossiness, respectively. A similar trend was observed at the 15% feed moisture where the glossiness changed from 8.53 (*SD* = 0.47) to 6.30 (*SD* = 0.41), indicating extreme glossiness and slight glossiness, respectively, with no significant differences in the glossiness scores ($p> 0.05$). At the 20% feed moisture, glossiness reduced from 8.85 (*SD* = 0.62) and 6.05 (*SD* = 0.36), which also implied extreme glossiness and slight in glossiness in the porridge, respectively. For the three moisture levels, one-way ANOVA results showed insignificant difference ($p< 0.05$) in glossiness, which was also true for chia/cassava ratio. Generally, the results show that increase in chia/cassava ratio and feed moisture reduced the glossiness of the porridge.

A similar trend was observed regarding the change in smoothness of the porridge with increase in feed moisture and chia/cassava ratio (Table 4.8). For instance, at the 10% feed moisture. It decreased from 7.82 (*SD* = 0.45) to 6.58 (*SD* = 0.48) implying a very smooth porridge and a slightly smooth porridge, respectively, with the smoothness scores showing significant differences ($p<0.05$). Comparatively, similar results were observed at the 15% feed moisture where smoothness reduced from 8.00 (*SD* = 0.47) to 6.58 (*SD* = 0.51), indicating a very smooth, and porridge for all chia/cassava ratios at this feed moisture. Finally, at the 20% feed moisture, the smoothness changed from 8.00 (*SD* = 0.67) and 5.50 (*SD* = 0.47), which was indicative of a porridge perceived as very smooth, and the other with an indifferent perception in smoothness, respectively. However, significant differences ($p< 0.05$) were observed in the scores at the 10 and 15% feed moisture, and are indicative of the observation that a change in smoothness in the product was neither due to feed moisture nor chia/cassava ratio.

Table 4.8: Effect of chia/cassava ratio and feed moisture during extrusion on the appearance attributes of the chia/cassava instant porridge

Moisture (%)	Chia/cassava ratio	Appearance parameters			
		Glossiness	Smoothness	Jelly	Translucency
10	0:100	8.00±0.47[ab]	7.82±0.45[ab]	6.53±0.47[ab]	8.18±0.48[ab]
	20:80	6.93±0.24[b]	7.42±0.42[a]	6.59±0.50[ab]	6.40±0.65[b]
	40:60	5.34±0.41[bc]	6.90±0.60[c]	6.29±0.55[b]	5.50±0.56[bc]
	60:40	5.20±0.65[bc]	6.58±0.48[b]	6.16±0.61[b]	4.62±0.42[c]
15	0:100	8.53±0.47[ab]	8.00±0.47[ab]	6.81±0.44[bc]	8.70±0.29[a]
	20:80	6.98±0.51[bc]	8.18±0.42[ab]	6.72±0.55[bc]	6.75±0.49[b]
	40:60	6.75±0.49[bc]	7.65±0.62[b]	6.66±0.42[bc]	6.75±0.47 [b]
	60:40	6.30±0.41[ab]	6.58±0.51[b]	6.34±0.46[ab]	4.58±0.46[c]
20	0:100	8.85±0.62[ab]	8.00±0.67[ab]	6.61±0.39[bc]	8.71±0.60[a]
	20:80	8.53±0.47[ab]	8.00±0.47[ab]	6.16±0.35[b]	8.70±0.23[a]
	40:60	6.93±0.53[b]	6.93±0.60[b]	6.84±0.35[a]	6.22±0.51[bc]
	60:40	6.05±0.36[bc]	5.50±0.47[c]	6.59±0.44[ab]	4.01±0.29[c]

Values are means ± Std. error of triplicate measurements (n=3).

Different superscript's letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

A look at jellyness (gel-like appearance) showed that, at an extrusion feed moisture of 10%, and an increase in chia/cassava ratio from 0:100 to 60:40, the jellyness decreased from 6.53 (*SD* = 0.47) to 6.16 (*SD* = 0.61), implying moderate jellyness of the porridge at all chia/cassava ratios. Additionally, the one-way ANOVA results showed insignificant difference ($p > 0.05$) at this feed moisture. A similar trend was observed at the 15% feed moisture where jellyness changed from 6.81 (*SD* = 0.44) to 6.34 (*SD* = 0.46), also indicating moderate jellyness of the porridge. The same trend was observed at the 20% feed moisture, where a reduction in jellyness from 6.61 (*SD* = 0.39) and 6.59 (*SD* = 0.44), was observed with the one-way ANOVA results showing significant difference (*p*> 0.05) at this feed moisture, indicative of the fact that increase in chia/cassava ratio an effect on the jellyness of the final product, unlike the feed moisture.

Finally, regarding translucency, it was observed that at an extrusion feed moisture of 10%, the translucency reduced from 8.18 (*SD* = 0.48) to 4.62 (*SD* = 0.42) as the chia/cassava ratio increased from 0:100to 60:40, indicative of a very translucent porridge and a porridge having indifference in translucency, respectively. A similar trend was observed at the 15% feed moisture where translucency changed from 8.70 (*SD* = 0.29) and 4.58 (*SD* = 0.46), indicating extremely high translucency and indifference in translucency, respectively in the porridge. ANOVA results showed significant difference (*p*> 0.05) in translucence at this feed moisture, especially between the control and the other chia/cassava ratios. The largest reduction in translucence of 8.71 (*SD* = 0.60) and 4.01 (*SD* = 0.29) denoting extremely high translucency and a slight opacity respectively, was observed at the 20% feed moisture with the one-way ANOVA results showing significant difference (*p*< 0.05) at this feed moisture, indicative of the fact that increase in chia/cassava ratio had a greater effect on the translucency of the final product than the feed moisture.

Aroma

The Table 4.9 presents the results obtained from analysis of aromatic attributes of the extruded chia/cassava porridge, namely starchiness and caramel flavour. The results show that at a feed moisture of 10%, and an increase in chia/cassava ratio from 0:100 to 60:40, the starchiness reduced from 8.53 (*SD* = 0.41) to 4.80 (*SD* = 0.44), representing extremely high starchiness and indifference in starchiness, respectively. Moreover, one-way ANOVA results showed significant difference (*p*< 0.05) in starchiness at this feed moisture. An extrusion feed moisture of 15% had the starchiness reducing from 7.75 (*SD* = 0.49) and 4.05 (*SD* = 0.28), representing very starchiness, and slight non starchiness, respectively. A similar trend was also observed at the 20% feed moisture level, whereby starchiness reduced from 7.82 (*SD* = 0.65) to 4.04 (*SD* = 0.28), also representing very high starchiness, and a slight non-starchiness, respectively. It was noted that there were insignificant differences (*p*> 0.05) between starchiness values at extrusion feed moistures of 15 and 20%, unlike at 10%. These results indicate that chia/cassava ratio had greater effect on starchiness compared to the feed moisture.

A similar trend was observed regarding the results showing the effect of feed moisture and chia/cassava ratio on the caramel nature of the chia/cassava porridge. It was observed that the caramel aroma of the porridge reduced from 8.35 (*SD* = 0.52) and 5.70 (*SD* = 0.50) as the porridge chia/cassava ratio increased from 0:100 to 60:40, at a feed moisture of 10%, representing a very caramel flavour and a slight caramel flavour, respectively. Moreover, there were significant differences ($p < 0.05$) between caramel scores. A similar phenomenon is observed at the 15% and 20% feed moisture, whereby the caramel scores reduced from 7.65 (*SD* = 0.36) to 5.87 (*SD* = 0.41), which also indicating a very caramel flavour and a slight caramel flavour, respectively, and 7.47 (*SD* = 0.69) to 5.87 (*SD* = 0.78), representing a moderate caramel flavour and a slight caramel flavour, respectively. Similarly to the 10% feed moisture, there were significant differences ($p < 0.05$) between starchiness values at this feed moistures. The results indicate that both the feed moisture and chia/cassava ratio had a significant effect on the caramel aroma in the porridge.

Table 4.9: Effect of chia/cassava ratio and feed moisture during extrusion on the aroma attributes of the chia/cassava instant porridge

Moisture (%)	Chia/Cassava ratio	starchy	Caramel
10	0:100	8.53 ± 0.41^{a}	8.35 ± 0.52^{a}
	20:80	6.05 ± 0.28^{b}	7.47 ± 0.41^{ab}
	40:60	5.70 ± 0.58^{b}	6.58 ± 0.39^{b}
	60:40	4.80 ± 0.44^{c}	5.70 ± 0.50^{b}
15	0:100	7.75 ± 0.49^{ab}	7.65 ± 0.36^{ab}
	20:80	5.80 ± 0.50^{bc}	6.07 ± 0.55^{b}
	40:60	5.22 ± 0.52^{bc}	6.05 ± 0.55^{b}
	60:40	4.05 ± 0.28^{ab}	5.87 ± 0.41^{b}
20	0:100	7.82 ± 0.65^{ab}	7.47 ± 0.69^{ab}
	20:80	5.93 ± 0.47^{bc}	7.65 ± 0.36^{ab}
	40:60	6.40 ± 0.47^{bc}	5.97 ± 0.32^{b}
	60:40	4.04 ± 0.28^{ab}	5.87 ± 0.78^{a}

Values are means ± Std. error of triplicate measurements (n=3).

Different superscript's letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$).

Flavour

The effect of extrusion parameters on the flavour attributes of the chia/cassava porridge, namely graininess, cooked flavour, starchy flavour and denseness was also evaluated. Its results are presented in Table 4.10 and indicate that for graininess, at 10% feed moisture, as the chia/cassava ratio in the porridge increased from 0:100 to 60:40, the graininess in the porridge increased from 4.80 (*SD* = 0.33) to 8.35 (*SD* = 0.46), representing a change in graininess from slight non-graininess to very high graininess, respectively, with significant differences ($p < 0.05$) between the graininess scores. Similarly, at 15 and 20% feed moisture, the grainy flavour increased from 3.33 (*SD* = 0.41) to 8.00 (*SD* = 0.65) and 3.00 (*SD* = 0.69) to 7.67 (*SD* = 0.24), respectively, representing moderate velvetiness and very high graininess, respectively, for both extrusion feed moistures. One-way ANOVA results showed a significant difference ($p < 0.05$) in the graininess of the porridge, which was an indication that chia /cassava ratio had a greater effect on the graininess compared to feed moisture.

A different trend was observed regarding cooked flavour score, since at the 10 and 15% feed moistures, as the chia/cassava ratio increased from 0:100 to 60:40, it reduced from 8.00 (*SD* = 0.37) to 6.12 (*SD* = 0.55), and 8.00 (*SD* = 0.37) to 6.22 (*SD* = 0.56) representing a very cooked flavour and a slightly cooked flavour, respectively. Similarly, at the 20% feed moisture, the cooked flavour score reduced from 8.15 (*SD* = 0.72) to 4.44 (*SD* = 40:601) also denoting uncooked flavour and a slightly uncooked flavour, respectively. One-way ANOVA analysis for all the three feed moistures indicated insignificant difference ($p > 0.05$) between the cooked flavour scores. This indicated that both feed moisture and chia/cassava ratio had minimal effect on the cooked flavour of the chia/cassava instant porridge.

A similar trend was observed in the results regarding the starchy flavour score, whereby at the 10% feed moisture, as the chia/cassava ratio increased from 0:100 to 60:40, the starchy flavour score decreased from 8.43 (*SD* = 0.40) to 4.70 (*SD* = 0.43), representing very starchy flavour and an indifference in starchy flavour, respectively. Similarly, at the 15% feed moisture, the starchy flavour score reduced from 7.65 (*SD* = 0.48) to 4.02 (*SD* = 0.29) denoting a very starchy flavour and a slightly non starchy flavour. Finally, at the 20% feed moisture, a similar trend saw the starchy flavour score reducing from 7.72 (*SD* = 0.66) to 4.03 (*SD* = 0.28), which also represented very starchy flavour and a slightly non starchy flavour. One-way ANOVA for all the three feed moistures indicated significant difference ($p<0.05$) between the cooked flavour scores, denoting that the chia/cassava ratio had a greater effect on the starchy flavour of the porridge compared to the feed moisture.

Table 4.10: Effect of chia/cassava ratio and feed moisture during extrusion on the flavour of the chia/cassava instant porridge

Moisture (%)	Chia/cassava ratio	Flavour attributes			
		Grainy	Cooked	Starchy	Dense
10	0:100	4.80±0.33^{c}	8.00±0.37^{a}	8.43±0.40^{a}	5.69±0.44^{b}
	20:80	7.30±0.44^{b}	7.47±0.44^{ab}	6.15±0.27^{bc}	6.93±0.65^{bc}
	40:60	7.30±0.69^{b}	6.22±0.51^{b}	5.60±0.59^{bc}	7.25±0.36^{a}
	60:40	8.35±0.46^{ab}	6.12±0.55^{b}	4.70±0.43^{bc}	8.00±0.67^{a}
15	0:100	3.33±0.41^{c}	8.00±0.37^{a}	7.65±0.48^{ab}	5.50±0.41^{bc}
	20:80	5.12±0.28^{bc}	6.75±0.46^{ab}	5.70±0.51^{bc}	5.87±0.53^{b}
	40:60	6.22±0.32^{bc}	6.41±0.46^{ab}	5.12±0.51^{bc}	6.22±0.48^{b}
	60:40	8.00±0.65^{ab}	6.22±0.56^{b}	4.02±0.29^{ab}	7.98±0.48^{a}
20	0:100	3.00±0.69^{c}	8.15±0.72^{a}	7.72±0.66^{ab}	3.38±0.39^{d}
	20:80	3.33±0.41^{bc}	6.39±0.37^{b}	5.83±0.87^{bc}	5.50±0.41^{b}
	40:60	6.42±0.24^{ab}	5.97±0.41^{bc}	6.30±0.46^{bc}	5.31±0.46^{c}
	60:40	7.67±0.24^{a}	4.44±0.60^{c}	4.03±0.28^{ab}	7.67±0.48^{a}

Values are means ± Std. error of triplicate measurements (n= 3).

Different superscript's letters on means in the same column indicate a significant difference ($p<0.05$).

Same superscripts letters on means in the same column indicate insignificant difference ($p>0.05$.

Finally, the denseness results obtained show that at the 10% feed moisture, an increase in chia/cassava ratio had the denseness score increasing from 5.69 (*SD* = 0.44) and 8.00 (*SD* = 0.67), representing moderately light mouth-feel and a very dense mouth-feel, respectively, with the means exhibiting insignificant differences ($p>0.05$). A similar occurrence was observed at 15% feed moisture with denseness varying between 5.50 (*SD* = 0.41) and 7.98 (*SD* = 0.48) denoting an indifference in denseness, and a very dense mouthfeel, respectively. At the 20% feed moisture however, a greater variation in denseness had it increasing from 3.38 (*SD* = 0.39) and 7.67 (*SD* = 0.48), representing moderate light mouth-feel and a very dense mouthfeel, respectively. Its one-way ANOVA results showed a significant difference ($p<0.05$). This was indicative of the fact that feed moisture and chia/cassava ratio had mixed effect on the denseness of the porridge, and is attributable to the molecular structure of chia seeds.

4.2.2 Principal Component Analysis (PCA)

For this study, PCA was done on the 14 sensory parameters to determine the factors that contributed to the acceptability/differences among the porridge samples. The eigenvalues indicated in Table 4.11 showed that only four Principal Components (PCs) were deemed significant according to Kaiser's criterion. Each of the Eigen values represented the amount of standardized variance that had been captured by one component and it ranged between 3.1-1.5. The first eigenvalue 3.1091 accounted for the largest possible amount of variance hence was most significant.

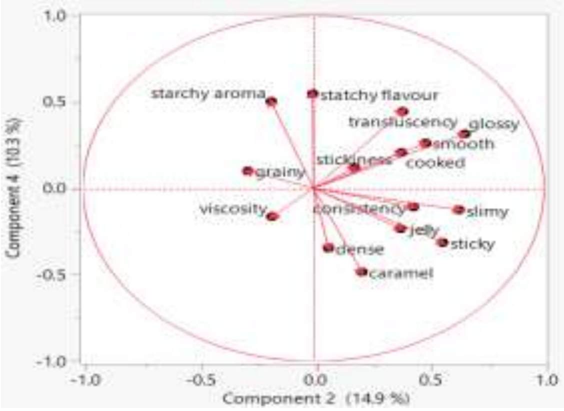
Table 4.11: Loadings of the chia/cassava instant flour sensory attributes on the first four principle components

Attribute	**Principle Components**			
	PC_1	**PC_2**	**PC_3**	**PC_4**
Glossy	-0.1634	60:40566	-0.0369	0.3153
Jelly	40:60674	0.3776	-0.3830	-20:80334
Sticky	0.5697	0.5896	-20:80117	-20:80937
Translucency	-40:60218	0.3863	-0.1655	40:60446
Slimy	0.5139	60:40599	-20:80686	-0.105
Smooth	-40:60201	40:60867	20:80546	20:80620
Dense	0.5883	0.0943	-0.1664	-0.3258
Starchy aroma	0.5445	-0.1840	-0.0202	0.5026
Caramel	-0.3010	20:80099	0.5451	-40:60836
Consistency	0.07193	40:60329	0.5995	-0.1085
Viscosity	60:40875	-0.1517	0.5151	-0.1442
Starchy flavour	0.7225	0.0258	0.0208	0.5671
Cooked	0.1173	0.3810	0.5973	20:80077
Grainy	0.7006	-20:80556	0.3857	0.1200
Eigenvalue	3.1091	2.2309	1.8193	1.5458

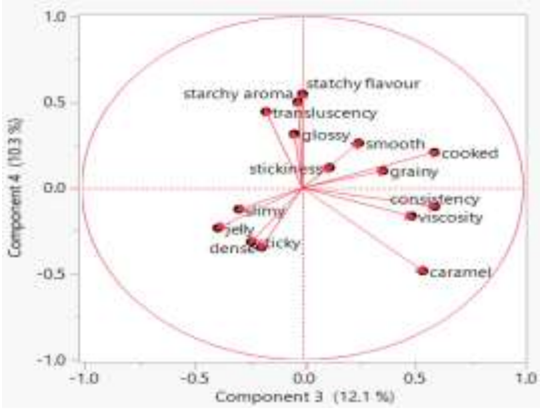
% of variance	20.7	14.9	12.1	10.3
Cum % of variance	20.7	38.6	50.7	61.0

The loading matrix presented in Table 4.11 indicated different attributes of the four PCs. Attributes on appearance; glossy showed a higher correlation in $PC_2$and lower in PC_4, Jelly had a high correlation in PC_1 but low in PC_2 while sticky and slimy had a high correlation PC_2 but low in PC_1. The translucence of the product was high in PC_4 and low in PC_2, whereas smooth had a high correlation in PC_2, PC_3 and PC_4. Viscosity was found to be high in PC_2 and low in PC_3, consistency had a high correlation in PC_3 and low inPC_2. In aroma, starchiness was high in PC_1 and low in PC_4 while caramel was high in PC_3 and low in PC_2. Regarding flavour, starchy was high in PC_1 and low in PC_4, while cooked flavour was high in PC_3 and low in PC_2 and grainy flavour was high in PC_1 and low in PC_4. With respect to mouth feel, dense mouth feel was high in PC_1 and low in PC_2. The overall results show that attributes on appearance were more significantly correlated in the PCA analysis.

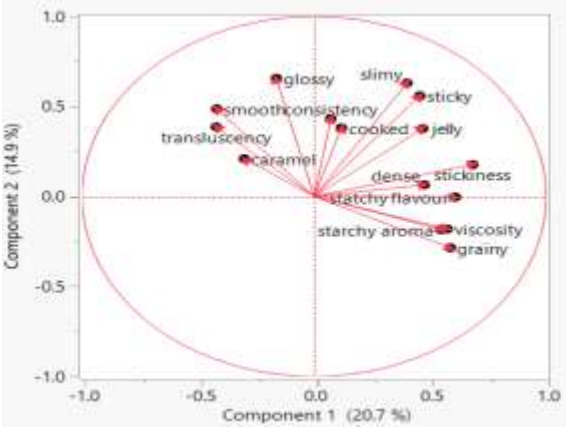
The four PCs explained 61.0 % of the total variance (PC_1- 20.7, PC_2-14.9, PC_3- 12.1 and PC_4- 10.3%), as indicated in Table 4.8. The interaction between PC_2 and PC_4 showed that starchy flavour scored high while cooked scored lower, PC_3 and PC_4 showed that starchy flavour scored higher it was smooth and less dense while caramel aroma was low. There were relatively high slimy results in the extruded cassava -chia porridges despite its higher solid content which could be because extrusion cooking caused depolymerisation of amylopectin which led to the formation of degraded short chain amylopectin branches which do not associate to form a gel network. Singh *et al*. (2007) showed that during extrusion shear causes reduction in molecular weight of amylose and amylopectin.



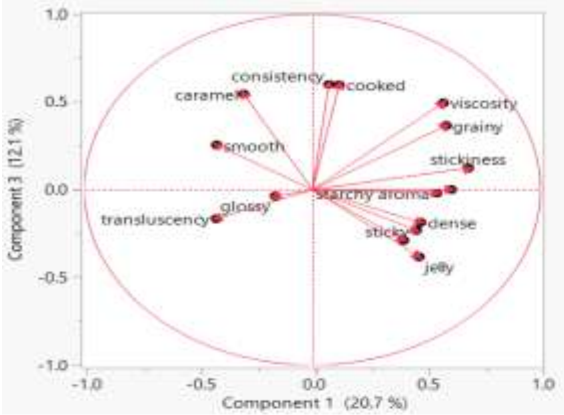
(a)



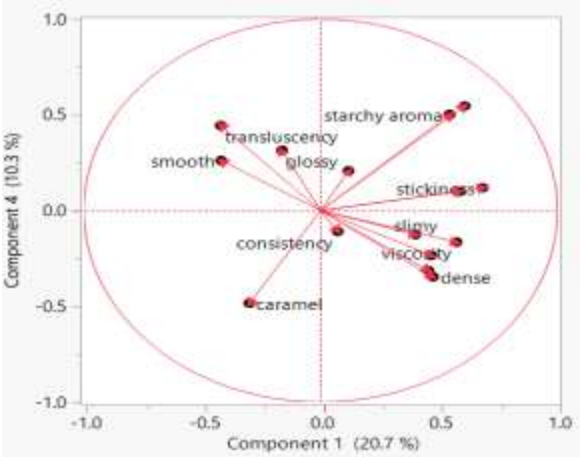
(b)



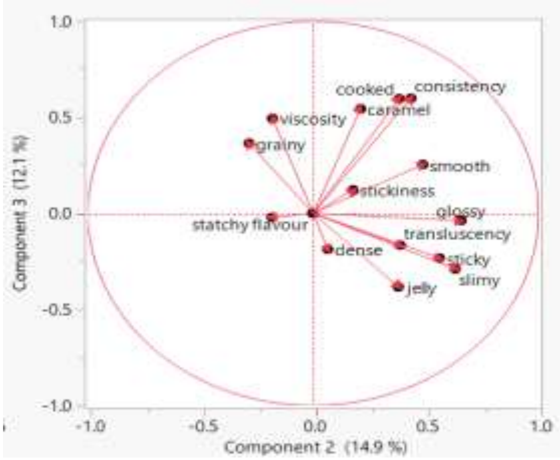
(c)



(d)



(e)



(f)

Figure 4.1(a) to (f): Loading plots of Interaction effect of components using principal component analysis.

The caramel aroma could have been triggered by a reaction between protein and carbohydrates. Muoki *et al.* (2015) reported that flavour development are due to maillard reaction and oxidation of oil (oleic, linoleic, and linolenic acids) present in soy seeds to produce furans, pyridines, and hexanal, respectively. According to Ma *et al.* (2012) caramelization is influenced by the water content and end formation fromdue to starch degradation by shear during extrusion. The Figure 4.1 (a) to (f) shows loading plots of interaction effect of components using PCA. The bi-plots shows the interaction effect of PC's and their variability to different attributes. In (a) PC_2 has a higher loading on appearance attributes and low loading on flavour while PC_4 has a higher loading on attributes on appearance, flavour while low in aroma, (b) shows that PC_4 has a large negative loadings on appearance attributes while PC_3 shows a large positive loading on consistency, viscosity and caramel aroma, (c) PC_1 and PC_2 shows strong variability in appearance, aroma and flavour with PC_2 having no negative effect on all attributes.

4.2.3 Consumer acceptability studies

Sensory scores obtained from the acceptability results are shown on table 4.12 below.

Table 4.12: Sensory scores of acceptance attributes of different blends of extruded instant cassava chia seeds porridge flour at 10, 15 and 20% feed moisture

		Acceptance attributes				
Moisture (%)	**Chia/cassava ratio**	**Consistency**	**Appearance**	**Flavour**	**Texture**	**Aroma**
10	0:100	2.83 ± 0.54^{ab}	2.59 ± 0.47^{ab}	2.34 ± 0.46^{b}	1.97 ± 0.29^{bc}	2.72 ± 0.42^{ab}
	20:80	3.02 ± 0.34^{a}	3.01 ± 0.38^{a}	3.03 ± 0.41^{a}	2.53 ± 0.41^{ab}	2.96 ± 0.60^{a}
	40:60	2.16 ± 0.63^{b}	2.53 ± 0.41^{ab}	2.28 ± 0.31^{b}	2.96 ± 0.41^{ab}	2.22 ± 0.55^{b}
	60:40	2.71 ± 0.59^{ab}	2.96 ± 0.55^{a}	2.96 ± 0.44^{a}	2.83 ± 0.42^{ab}	2.53 ± 0.47^{ab}
15	0:100	2.83 ± 0.54^{ab}	2.78 ± 0.41^{ab}	2.34 ± 0.46^{b}	2.41 ± 0.53^{ab}	2.59 ± 0.41^{ab}
	20:80	2.53 ± 0.34^{ab}	2.84 ± 0.35^{a}	1.98 ± 0.34^{b}	2.34 ± 0.22^{b}	2.22 ± 0.33^{ab}
	40:60	2.46 ± 0.38^{ab}	2.90 ± 0.32^{a}	2.04 ± 0.33^{b}	2.28 ± 0.59^{b}	2.28 ± 0.31^{b}
	60:40	2.65 ± 0.52^{ab}	2.65 ± 0.46^{ab}	2.16 ± 0.42^{b}	1.61 ± 0.56^{c}	2.34 ± 0.43^{b}
20	0:100	1.85 ± 0.69^{b}	2.04 ± 0.71^{b}	1.98 ± 0.56^{b}	1.67 ± 0.76^{c}	2.10 ± 0.76^{b}
	20:80	2.83 ± 0.54^{ab}	2.78 ± 0.41^{ab}	2.34 ± 0.46^{b}	2.41 ± 0.53^{ab}	2.42 ± 0.55^{ab}
	40:60	2.28 ± 0.51^{a}	2.78 ± 0.41^{ab}	2.78 ± 0.41^{ab}	2.10 ± 0.36^{bc}	2.84 ± 0.31^{ab}
	60:40	2.41 ± 0.53^{b}	2.22 ± 0.33^{b}	2.10 ± 0.52^{b}	2.04 ± 0.44^{b}	2.16 ± 0.45^{b}

Values are means ± Std. error of measurements (n=3).

Different superscripts letters on means in the same column indicate a significant difference (p<0.05).

Same superscripts letters on means in the same column indicate insignificant difference (p>0.05).

The results obtained from sensory attribute of consistency show that, for feed moisture ratios of 10, 15 and 20%,the scores varied between 2.16 (*SD* =0.63) and 3.02 (*SD* = 0.34), 2.46 (*SD* = 0.34) and 2.83 (*SD* = 0.54)and 1.85 (*SD* =0.69) and 2.83 (*SD* = 0.54), respectively, for chia/cassava ratios of 0:100 to 60:40.These scores indicated that regardless of the feed moisture and chia/cassava ratio, the sensory ratings were clustered between 2.0 (dislike) and 3.0 (neither dislike nor like). Notably also, was the fact that there was insignificant differences (p>0.05) between the means for all the attribute scores, for either feed moisture or chia/cassava ratio.

Regarding the sensory attribute of appearance, it is observed that for feed moisture ratios of 10, 15 and 20%, as the chia/cassava ratios increased from 0 to 60:40, the appearance sensory scores varied between 2.53 (*SD* = 0.41) and 3.01 (*SD* = 0.38), 2.65 (*SD* = 0.46) and 2.90 (*SD* = 0.32) and 2.04 (*SD* = 0.71) and 2.78 (*SD* = 0.41), respectively,. These scores exhibit a similar observation with those obtained from the sensory attribute of consistency, due to their cluster between 2.0 (dislike) and 3.0 (neither dislike nor like). Similarly, there was insignificant difference (p>0.05) between the means for all the attribute scores, for either feed moisture or chia/cassava ratio, indicative of no change in sensory rating due to extrusion parameters.

The results also show that for sensory attribute of flavour, at feed moisture ratios of 10, 15 and 20%, the flavour scores varied between 2.28 (*SD* = 0.63) and 3.03 (*SD* = 0.34), 1.98 (*SD* = 0.34) and 2.34 (*SD* = 0.54), and 1.98 (*SD* = 0.69) and 2.78 (*SD* = 0.54), respectively, for chia/cassava ratios of 0:100, 20:80, 40:60 and 60:40. A similar deduction on the scores was arrived at since, regardless of the feed moisture and chia/cassava ratio, the sensory ratings were still clustered between 2.0 (dislike) and 3.0 (neither dislike nor like).Moreover, there was insignificant differences (p>0.05) between the means for all the flavour scores.

The same trend is replicated in the sensory attribute of texture, whose results indicate that for feed moisture of 10, 15 and 20%, the scores varied between 1.97 (*SD* = 0.29) and 2.96 (*SD* = 0.41), 1.61 (*SD* = 0.56) and 2.41 (*SD* = 0.53) and 1.67 (*SD* = 0.76) and 2.41 (*SD* = 0.53), respectively, as the chia/cassava ratio increased from 0:100 to 60:40. This was also observed in the sensory attribute of aroma, whose results indicate that for feed moistures of 10, 15 and 20%, the scores varied between 2.22 (*SD* = 0.55) and 2.96 (*SD* = 0.60), 2.22 (*SD* = 0.33) and 2.59 (*SD* = 0.41) and 2.10 (*SD* = 0.76) and 2.84 (*SD* = 0.31), respectively, as the chia/cassava ratio increased from 0:100 to 60:40.

Table 4.13 presents the demographic results obtained from the panelists with respect to their sensory perception of the instant chia/cassava porridge, with respect to consistency, appearance, flavour, aroma and texture. It is noted that for consistency, a majority of the panelists (34.4 – 45.7%) had a neutral (neither dislike nor like) perception of the porridge, while a minority of 1.8 to 15.91% and 13.0 to 16.1% gave a strongly dislike and strongly like rating respectively. It thus means that the addition of chia to cassava flour generally imparts acceptable response from the population. Regarding appearance, it was noted that the general acceptance was skewed to the negative with 25.1 to 33.5%, 13.8 to 17% and 11.9 to 30.8% having a neutral perception, dislike and strong dislike, respectively, the appearance of the product. It thus meant that the inclusion of chia into cassava during porridge preparation rendered the product's appearance to be generally unappealing to consumers. This trend was also observed in the flavour scores since 23.8 to 33.5%, 21.3 to 36.0% and 11.9 to 30.8% having a neutral perception, dislike and strong dislike, respectively, of the product. This is attributable to the fact that both chia and cassava has almost no simple sugars, each of them is relatively bland in taste, hence the neutral score in flavor. The results from aroma however present a different trend with 31.3 to 39.2%, 8.8 to 11.6% and 10.4 to 28.8% having a neutral perception, dislike and strong dislike, respectively, of the product. The slightly low score in the aroma could be attributed to formation of caramel sugars during extrusion since in raw form cassava and chia are non-aromatic. Finally, the results from texture are indicative of a negative perception of the product texture with 16.5 to 24.8%, 25.2 to 34.9% and 17.1 to 22.8% having a neutral perception, dislike and strong dislike of the product. This implied that the mucilaginous property of chia negatively affected the textural score.

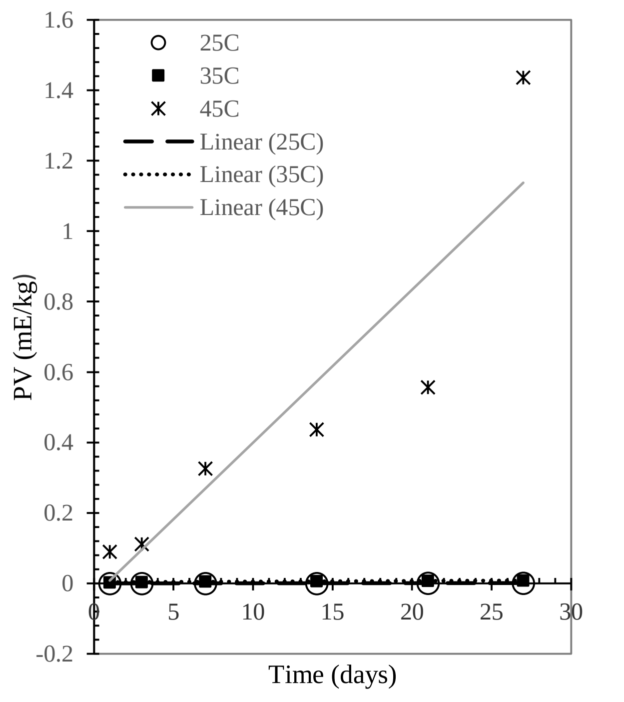
Table 4.13: ***Percentage of the panellists who gave different acceptance ratings for the sensory values of porridge produced from flour extruded at 10, 15 and 20% feed moisture and 0:100, 20:80, 40:60 and 60:40 chia/cassava ratio (n=30)***

Attribute	**Rating**	**Extrusion feed parameters**											
		10				**15**				**20**			
		0:100	**20:80**	**40:60**	**60:40**	**0:100**	**20:80**	**40:60**	**60:40**	**0:100**	**20:80**	**40:60**	**60:40**
Consistency	Strongly dislike	10.6	2.4	1.8	14.9	11.6	3.41	2.81	15.9	12	3.8	3.2	16.3
	Dislike	11.3	15.8	13.9	14	11.0	15.5	13.6	13.7	11.6	16.3	14.3	14.4
	Neutral	42.4	44.4	43.7	34.7	42.1	44.1	43.4	34.4	44.3	46.4	45.7	36.2
	Like	21.4	24.1	25.0	22.2	21.1	23.8	24.7	21.9	22.2	25.1	26.0	23.1
	Strongly like	14.3	13.3	15.6	14.2	14.0	13.0	15.3	13.9	14.7	13.7	16.1	14.6
Appearance	Strongly dislike	11.9	16.6	25.4	29.8	12.9	17.6	26.4	30.8	13.3	18	26.8	31.2
	Dislike	16.4	15.7	15.3	14.1	16.1	15.4	15	13.8	17.0	16.2	15.8	14.5
	Neutral	31.3	32.1	27.3	25.4	31.0	31.8	27	25.1	32.6	33.5	28.4	26.4
	Like	28.3	24.1	21.3	20.8	28.0	23.8	21	20.5	29.5	25.1	22.1	21.6
	Strongly like	12.1	11.5	10.7	9.9	11.8	11.2	10.4	9.6	12.4	11.8	11.0	10.1
Flavour	Strongly dislike	19.7	22.3	22.8	25.2	20.7	23.3	23.8	26.2	21.1	23.7	24.2	26.6
	Dislike	21.6	24.8	29.1	34.5	21.3	24.5	28.8	34.2	22.4	25.8	30.3	36.0
	Neutral	31.9	28.3	25.9	23.8	31.6	28	25.6	23.5	33.3	29.5	27.0	24.7
	Like	17.3	15.5	13.9	10.1	17.0	15.2	13.6	9.8	17.9	16.0	14.3	10.3
	Strongly like	9.5	9.1	8.3	6.4	9.2	8.8	8.0	6.1	9.7	9.3	8.4	6.4
Aroma	Strongly dislike	10.4	19.9	27.4	27.6	11.4	20.9	28.4	28.6	11.8	21.3	28.8	29.0
	Dislike	11.3	10.8	9.1	10.8	11.0	10.5	8.8	10.5	11.6	11.1	9.3	11.1
	Neutral	39.2	34.3	31.6	32	38.9	34	31.3	31.7	41.0	35.8	33.0	33.4
	Like	20.2	18.7	15.2	14.9	19.9	18.4	14.9	14.6	21.0	19.4	15.7	15.4
	Strongly like	18.9	16.3	16.7	14.7	18.6	16	16.4	14.4	19.6	16.8	17.3	15.2
Texture	Strongly dislike	19.1	20.9	21.8	17.1	20.1	21.9	22.8	18.1	20.5	22.3	23.2	18.5
	Dislike	25.6	25.2	27.9	33.4	25.3	24.9	27.6	33.1	26.6	26.2	29.1	34.9
	Neutral	23.7	24.8	21.9	16.8	23.4	24.5	21.6	16.5	24.6	25.8	22.7	17.4
	Like	20.3	19.4	18.5	20.4	20.0	19.1	18.2	20.1	21.1	20.1	19.2	21.2
	Strongly like	11.3	9.7	9.9	12.3	11.0	9.4	9.6	12.0	11.6	9.9	10.1	12.6

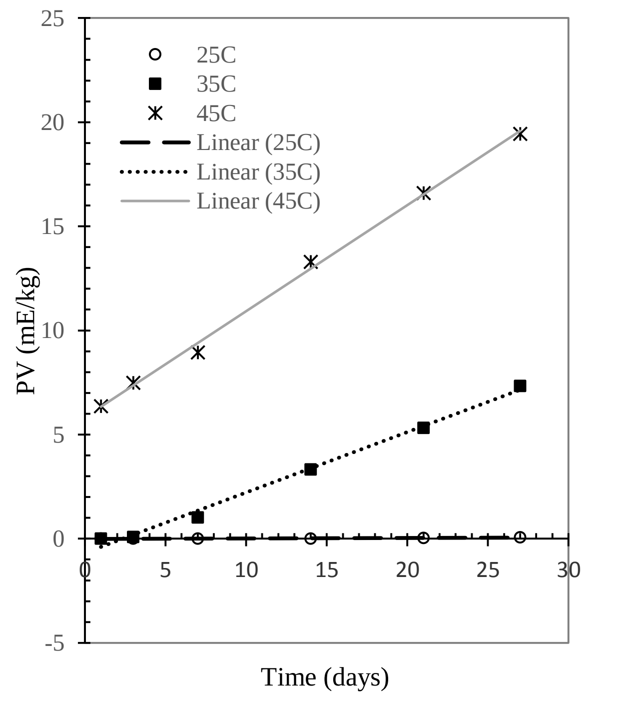
4.3 Effect of extrusion feed parameters on shelf life properties of extruded instant cassava-chia porridge flour.

4.3.1 Peroxide value

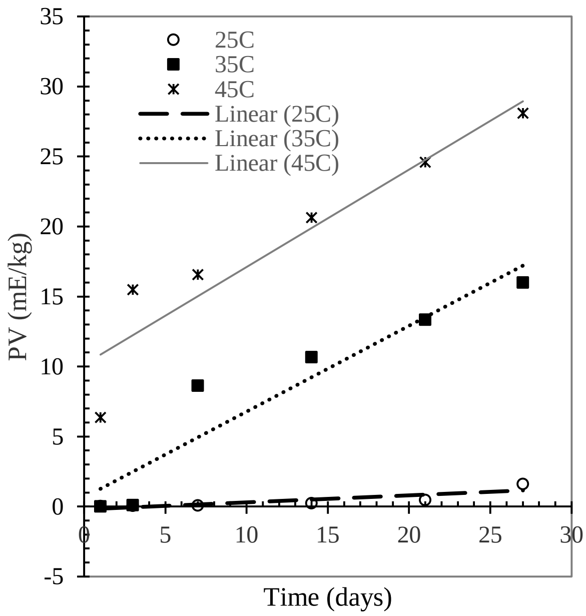
The Figures 4.2 (a) to (d) show the changes in Peroxide Value (PV) with storage duration from day 1 to 27 at storage temperatures of 25, 35 and 45ºC for 10% feed moisture and 0:100, 20:80. 40:60, 60:40 chia/cassava ratio. From the figures it is observed that with increase in temperature from 25 to 45ºC, the rate of change in PV increased with storage duration as observed from the regression equations. At 25ºC storage temperature there was no change in PV, whereas at 45ºC considerable change in PV with storage duration was observed, while the change at 35ºC was intermediate between 25 and 45ºC. The samples that had a chia/cassava ratio of 0 exhibited the lowest change in PV with storage, while the samples with the highest chia cassava ratio (60:40) exhibited the highest change in PV with storage duration. The lower peroxide values at 0:100 chia/cassava ratio are attributable to the absence of chia within the extrudate, hence low levels of rancidity.



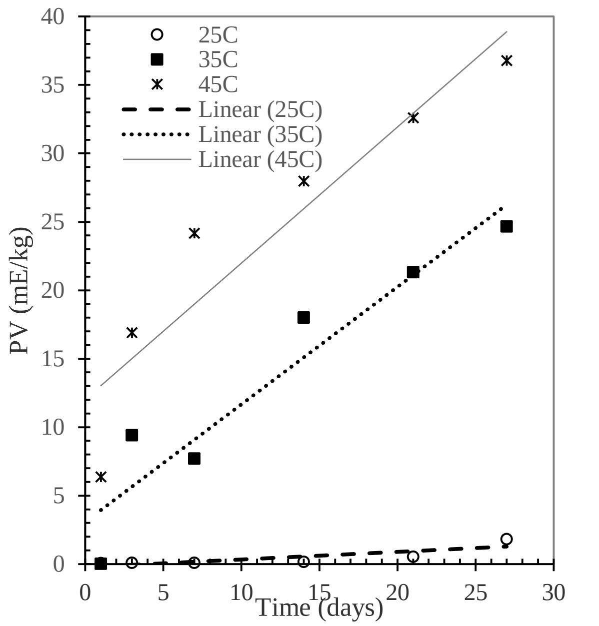
(a)
45ºC; PV=0.8110+0.03385t
35ºC; PV=-20:80360+0.04209t
25ºC; PV=0.0000+0.0000t



(b)
45ºC; PV=2.402+1.251t
35ºC; PV=0.5100+20:80641t
25ºC; PV=0.000+0.000t



(c)
45ºC; PV=4.321+1.187t
35ºC; PV=-0.1976+20:80333t
25ºC; PV=-20:80130+0.03472t



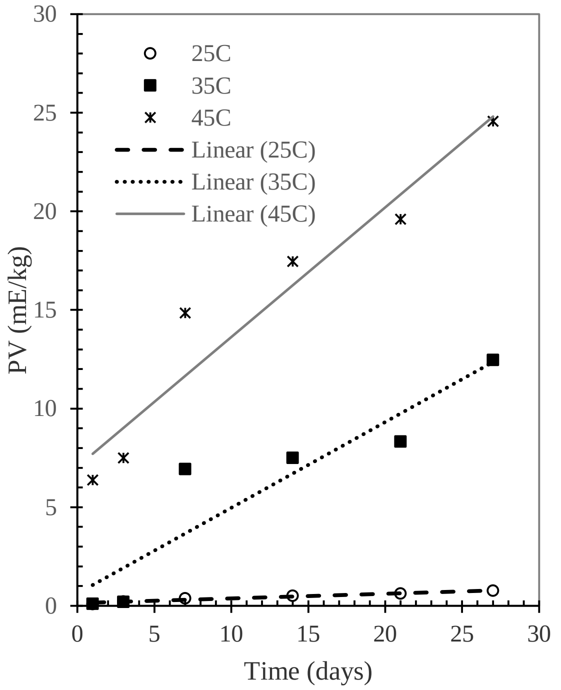
(d)
45ºC; PV=11.00+1.051t
35ºC; PV=3.339+40:60338t
25ºC; PV=-20:80486+0.0405t

Figure 4.2(a) – (d): Change in PV with storage duration t (days) of the chia/cassava instant flour at accelerated temperatures of 25, 35 and 45ºC for 10% feed moisture and (a) 0:100 (b) 20:80, (c) 40:60 and (d) 60:40 chia/cassava ratios

An increase in feed moisture ratio from 10 to 15% resulted in comparatively higher PV valued and higher rates of change in PV with storage temperature. Figures 4.3 (a) to (d) show the changes in PV with storage duration from day 1 to 27 at temperatures of 25, 35 and 45ºC for 15% feed moisture and 0:100, 20:80. 40:60, 60:40 chia/cassava ratio. A similar trend in PV with temperature is observed, however, the rate of increase in PV is higher compared to 15% feed moisture. This implies that the residual moisture in the food has an effect on PV, a phenomenon attributable to the water activity of the product.

The highest changes in PV were observed at 20% feed moisture, as presented in Figures 4.4 (a) to (d). For instance at 25ºC storage temperature unlike at 10% and 15% feed moisture where there were comparatively lower changes in PV with storage temperature, a maximum change was observed. Similarly the rate of change at 35 and 45ºC was the highest for all the chia/cassava ratios, which might be due to oxidation of polyunsaturated fatty acids leading to rancidity. Ahlawat *et al*. (2017) showed that peroxide values of noodles stored at different temperatures increased significantly with increase in temperature hence increase in rancidity and off flavours. This is due to changes that occur during extrusions such as increased surface of lipid, enzyme inactivation and decrease of concentration of endogenous antioxidants. Lipid-binding with starch, an increase of iron level due to wear out of the screw and Maillard reaction could decrease oxidation of the lipid. According to Ilo *et al.* (2000), lipids play an important role in most of the extrusion cooking processes by acting as plasticizers or emulsifiers. Products that contain a large amount of polyunsaturated fatty acids such as DHA, EPA, and ALA (alpha-linolenic acid) are readily oxidized than animal fats during extrusion (Hu, 2016). Omega-3 fatty acids have many health benefits and during extrusion can undergo lipid oxidation reducing nutritional and sensory quality in foods and feeds (Camire *et al.*, 1990). Many factors contribute to lipid oxidation in extruded foods like screw wear results in higher concentrations of pro-oxidant minerals, increased surface area in expanded products also increases the exposure of lipids to oxygen (Bouvier & Campanella, 2014).

During extrusion cooking, several chemical and physical changes occur which could have effects on the matrix microstructure, oxidative stability, and shelf life of extruded foods. These changes may include starch gelatinization, protein denaturation, enzymes inactivation, lipid binding within the starch, iron level increase because of the wearing of the screw and barrel during extrusion, endogenous antioxidant tocopherols and carotenoid levels decrease, increased surface area due to expansion, and Maillard reaction (Bouvier & Campanella, 2014; Hu, 2016). The study showed that peroxide values increased with an increase in temperature and an increase in storage days. According to Ilo *et al.* (2000) extrusion cooking of lipids results in an increase in peroxide value due to the reaction of transition metals in the extrudates and also degradation of natural antioxidants at high temperatures. He also reported that screw and barrel wear increased pro-oxidants that promote oxidative rancidity to extruded lipid products. Shelf life decreased with increase in chia seed incorporation in the formulation this is because there was a direct correlation between lipid oxidation and sensory changes of the instant porridge.

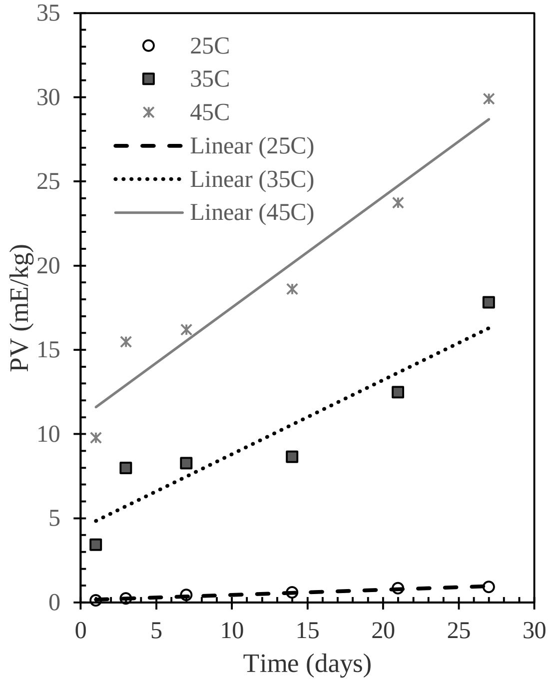


(a)

45ºC; PV=2.802+0.0103t

35ºC; PV=0.3699+0.03174t

25ºC; PV=0.000+0.000t

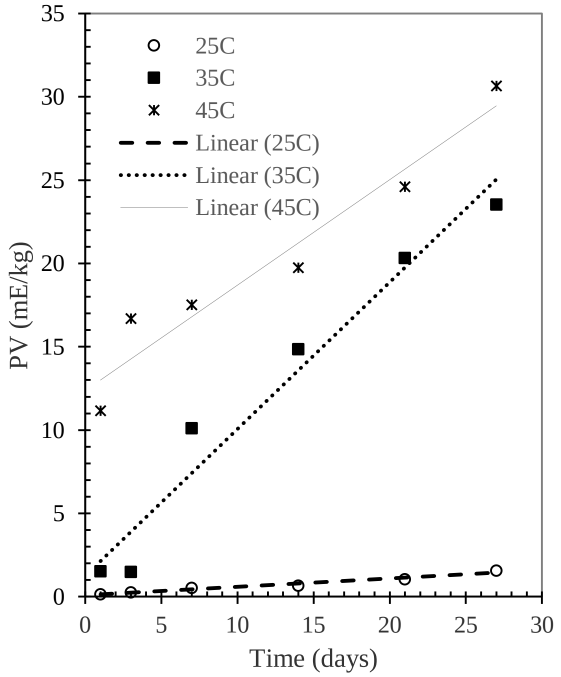


(b)

45ºC; PV=8.896+0.7112t

35ºC; PV=0.778+20:80817t

25ºC; PV=0.000+0.000t

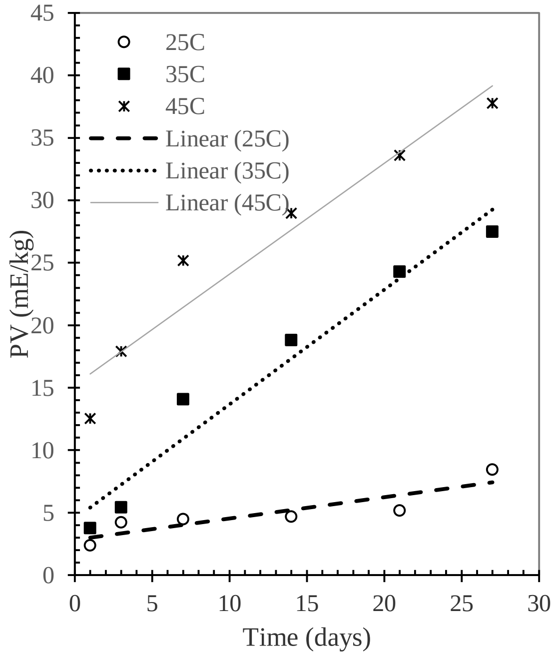


(c)

45ºC; PV=8.219+0.7951t

35ºC;PV=1.805+0.3167t

25ºC; PV=0.7740+0.1391t



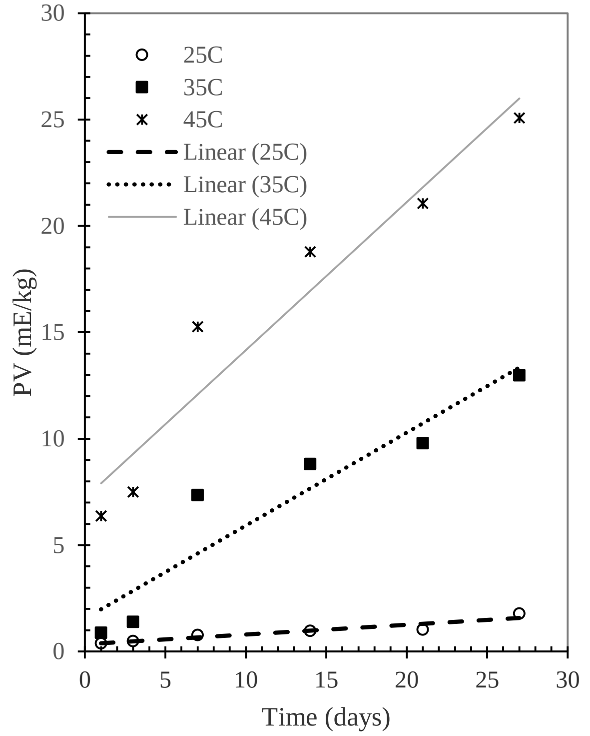
(d)

45ºC; PV=9.901+0.3134t

35ºC; PV=2.375+40:60460t

25ºC; PV=-0.5651+0.1062t

Figure 4.3(a) – (d): Change in PV with storage duration t (days) of the chia/cassava instant flour at accelerated temperatures of 25, 35 and 45ºC for 15% feed moisture and (a) 0:100 (b) 20:80, (c) 40:60 and (d) 60:40 chia/cassava ratios

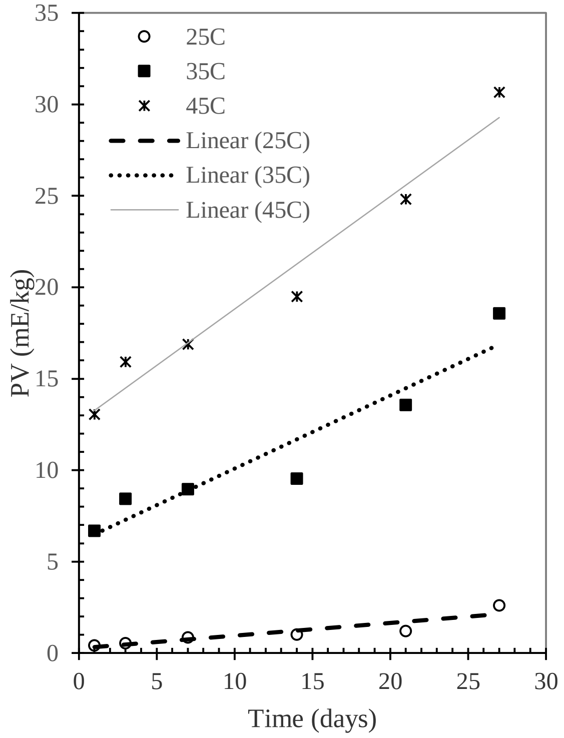


(a)

45ºC; PV=6.926+0.099269t

35ºC; PV=-20:80883+0.06434t

25ºC; PV=-0.3095+0.05484t

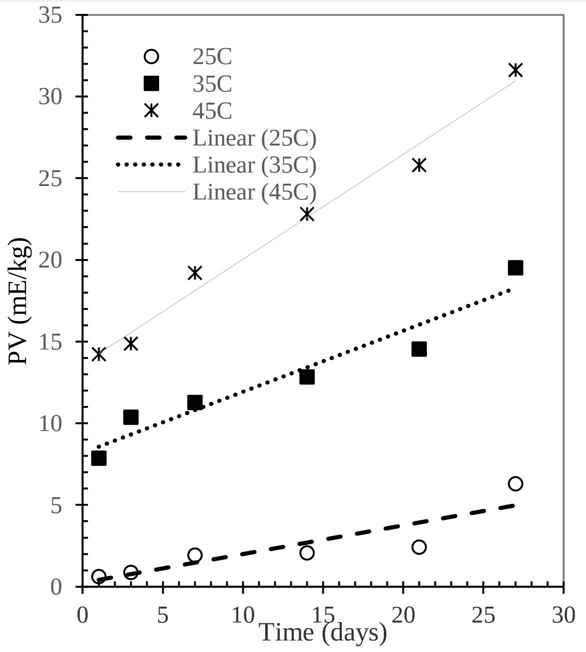


(b)

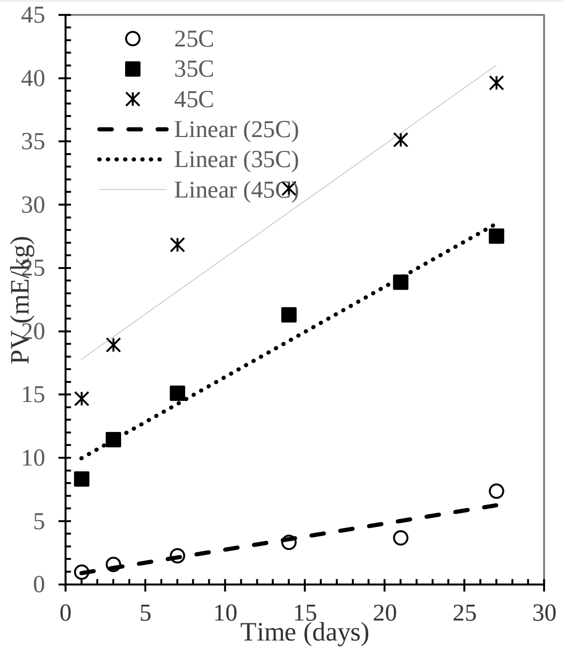
45ºC; PV=16.96+0.5285t

35ºC; PV=2.935+20:80735t

25ºC; PV=40:60882+0.09400t



(c)



(d)

45ºC; PV=4.690+0.828t 35ºC; PV=4.900+0.1096t 25ºC; PV=-0.05707+0.00902t	45ºC; PV = 10.79+0.7748t 35ºC; PV= 3.9575+0.3911t 25ºC; PV=-0.5009+0.1075t

Figure 4.4(a) – (d): Change in PV with storage duration t (days) of the chia/cassava instant flour at accelerated temperatures of 25, 35 and 45ºC for 20% feed moisture and (a) 0:100 (b) 20:80, (c) 40:60 and (d) 60:40 chia/cassava ratios

4.3.2 Product shelf life

The determination of product shelf life is achieved through modelling of the changes in product quality parameters that are symptomatic of spoilage, with the aim of determining a quality parameter threshold, also known as the acceptable limit. According to Nicoli (2012), at the acceptable limit, the product is deemed to have achieved its shelf life as evidenced through sensory testing or instrumental analysis. During the study, the change in PV with storage duration at different feed moisture conditions and chia/cassava ratios was modelled using regression equations from the Accelerated Shelf Life Testing (ASLT) results. These results are presented in the Figures 4.2(a) to (d), 4.3(a) to (d) and 4.4(a) to (d), which were in the zeroth order (Equation 4.2).

Table 4:14: First order regression equations showing the effect of storage duration on peroxide value (PV) at 25, 35 and 45ºC storage temperatures for chia/cassava instant flour extruded at 0:100, 20:80, 40:60 and 60:40 chia/cassava ratio and 10, 15 and 20% feed moisture

Feed Moisture	Chia/cassava ratio	Storage temperature (ºC)	Regression equation	Coefficient (R^2)
10	0:100	25	ln PV =-0.775t-4.807	0.965
		35	ln PV=-0.036t-4.804	0.995
		45	ln PV=0.096t-2.294	0.917
	20:80	25	ln PV=0.011t-5.761	0.951
		35	ln PV=0.231t-3.231	0.761
		45	ln PV=0.344+1.879	0.978
	40:60	25	ln PV=0.140t-3.359	0.909
		35	ln PV=0.261t-2.840	0.652
		45	ln PV=0.543t+2.305	0.706
	60:40	25	ln PV=0.1175t-0.345	0.925
		35	ln PV=0.157t-0.130	0.725
		45	ln PV=0.551t+2.428	0.708
15	0:100	25	ln PV=0.017t-1.948	0.908
		35	ln PV=0.168t-1.267	0.665
		45	ln PV=0.558t+2.012	0.845
	20:80	25	ln PV=0.018t-1.754	0.772
		35	ln PV=0.247t+1.589	0.779
		45	ln PV=0.635+2.456	0.887
	40:60	25	ln PV=0.082t-1.645	0.940
		35	ln PV=0.323t+1.846	0.887
		45	ln PV=0.732t+2.565	0.892
	60:40	25	ln PV=0.094t-1.344	0.875
		35	ln PV=0.446t+2.164	0.772
		45	ln PV=0.837t+2.745	0.841
20	0:100	25	ln PV=0.051t-0.850	0.991
		35	ln PV=0.494t+0.397	0.729
		45	ln PV=0.805t+2.023	0.835
	20:80	25	ln PV=0.061t-0.828	0.821
		35	ln PV=0.499t+1.917	0.935
		45	ln PV=0.830t+2.600	0.974
	40:60	25	ln PV=0.076t-0.316	0.931
		35	ln PV=0.511t+2.155	0.923
		45	ln PV=0.851t+2.729	0.953
	60:40	25	ln PV=0.086t+0.161	0.923
		35	ln PV=0.540t+2.350	0.809
		45	ln PV=0.834t+2.850	0.862

However, the rate of product deterioration as evidenced by changes in quality indicators has been determined to conform to the first order reaction kinetics (Equation 4.5), analogous to the Arrhenius relation (Manzocco *et al.,* 2020). An attempt was thus made to transform the regression relations (Found in figures 4.2(a) to (d), 4.3(a) to (d) and 4.4(a) to (d)) from zeroth order to first order and the results are as presented in Table 4.9.

The results indicate variations in first order reaction rates (day^{-1}) with time for 10, 15 and 20% feed moisture and 0:100, 20:80. 40:60, 60:40 chia/cassava ratio at 25, 35 and 45ºC storage temperatures. The data was then modeled using the classic kinetic approach above described to compute the reaction rate (k), which yielded the Arrhenius relation parameters. These are presented in Table 4.10.

Table 4.15: Arrhenius equation values for PV for chia/cassava instant flour extruded at 10, 15and 20% feed moisture and 0:100, 20:80, 40:60 and 60:40chia/cassava ratio

Feed moisture (%)	Chia/cassava ratio	Arrhenius equation	R^2
10	0:100	ln k = -17,100(1/T) + 34.789	0.8624
	20:80	ln k = -16,442(1/T) + 51.704	0.8491
	40:60	ln k = -6,414(1/T) + 19.535	0.9957
	60:40	ln k = -7,269(1/T) +22.090	0.8726
15	0:100	ln k = -16,564(1/T) +51.761	0.9740
	20:80	ln k = -16,937(1/T) + 53.074	0.9803
	40:60	ln k = -10,397(1/T) + 32.466	0.9842
	60:40	ln k = -10,404(1/T) +32.687	0.9518
20	0:100	ln k = -13,160(1/T) + 41.457	0.8899
	20:80	ln k = -12,447(1/T) +39.213	0.9011
	40:60	ln k = -11,513(1/T) +36.271	0.9109
	60:40	ln k = -11,119(1/T) + 35.055	0.9086

From the Arrhenius relations, the shelf life of the products of 10, 15 and 20% and feed moisture of 0:100, 20:80, 40:60 and 60:40 at storage temperatures of 25, 35 and 45ºC was then computed, and the results for 25ºC are presented in Table 4.11, while those for 35 and 45ºC are presented as Appendix 7. From the table it is discerned that with increase in feed moisture the shelf life reduced, while the k factor increased. For instance at a chia substitution ratio of 60:40, with increase in feed moisture from 10 to 20%, the shelf life reduced from 212.19 to 55.73 days, with a corresponding increase in k from 0.098 to which were the lowest in the 25ºC range. At chia/cassava ratio of 0, the shelf life reduced from 285.12 to 88.35 days, which is basically the shelf life of cassava flour. The longer shelf life is attributable to the fact that nutritionally, cassava flour has low lipid levels, hence the onset of rancidity is delayed with storage.

Table 4.16: Shelf life at 25ºC of chia/cassava instant flour extruded at 10, 15and 20% feed moisture and 0:100, 20:80, 40:60 and 60:40 chia/cassava ratio

Storage temperature (ºC)	Chia/cassava ratio	Feed moisture (%)	K value	Shelf life (days)
25	0:100	10	0.057	285.12
		15	0.242	174.86
		20	0.516	88.35
	20:80	10	0.084	240.01
		15	0.333	135.34
		20	0.689	74.68
	40:60	10	0.088.	231.39
		15	0.564	128.63
		20	0.777	61.82
	60:40	10	0.098	212.19
		15	0.636	103.28
		20	0.965	55.73

Conversely, at a chia substitution ratio of 60:40 the comparatively lower shelf life is due to the presence of lipids, which accelerate rancidity. At the intermediate chia/cassava ratios of 20:80 and 40:60, the k value increased from 0.084 to 0.689 and 0.088 to 0.777, respectively, while the shelf life reduced from 240.01 to 74.68 days and 231.39 to 61.82 days, respectively. At the accelerated temperatures of 35 and 45ºC (Appendix 7), it was observed that the k value and shelf life exhibited the same response as at 25ºC, however, the k values at 35ºC were higher than those at 25ºC for the same chia/cassava substitution ratio. Similarly the k values at 45ºC were the highest, with the shelf life being the lowest.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study arrived at the following conclusions;

i. Increase in Chia substitution level (0 – 60%) and feed moisture (10 – 20%) has a highly significant effect on extrudate at (p< 0.05) for physicochemical properties.

ii. Increase in Chia substitution level (0 – 60%) and in feed moisture content (10 – 20%) has significant (p< 0.05) effects on sensory properties, whereby appearance, texture and mouthfeel exhibits high correlations.

iii. At a storage temperature of 25ºC and 212 days shelf life, the cassava-chia product with 60/40 ratio is still deemed to be safe for consumption. Beyond this, the acceptable limit of PV is exceeded.

5.2 Recommendations

The following recommendations have been arrived at, at the end of the study;

i. Extrusion processing of cassava flour will offer the food industry a method to produce consumer acceptable RTEs from relatively inexpensive tuber based raw materials.

ii. Blending of chia seeds in other food products will enhance the nutritional benefits in these food products due to its nutritional composition and medicinal value.

iii. Future research should be done to investigate the possibilities of chia seed flour encapsulation during incorporation as an ingredient in food products due to presence of essential fatty acids which degrade during processing.

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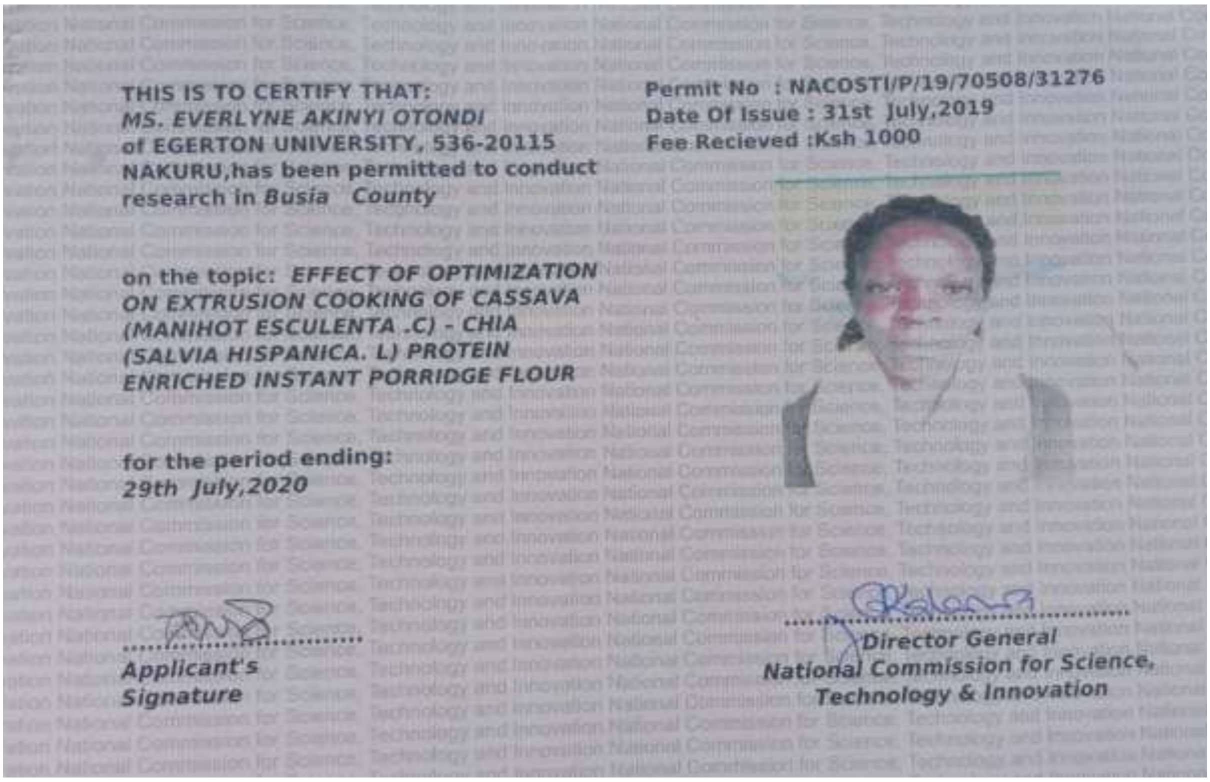
APPENDICES

Appendix 1: Research Permit



THIS IS TO CERTIFY THAT:
MS. EVERLYNE AKINYI OTONDI
of EGERTON UNIVERSITY, 536-20115
NAKURU,has been permitted to conduct
research in *Busia County*

on the topic: *EFFECT OF OPTIMIZATION ON EXTRUSION COOKING OF CASSAVA (MANIHOT ESCULENTA .C) - CHIA (SALVIA HISPANICA. L) PROTEIN ENRICHED INSTANT PORRIDGE FLOUR*

for the period ending:
29th July,2020

Permit No : NACOSTI/P/19/70508/31276
Date Of Issue : 31st July,2019
Fee Recieved :Ksh 1000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix II :Research Publication

Journal of Agriculture and Food Research 2 (2020) 100058

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Physico-chemical properties of extruded cassava-chia seed instant flour

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Instant flour
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ABSTRACT

This study evaluated the effects of extrusion process parameters and blends of chia seed and cassava flours on the nutritional and functional properties of flour blends aiming at improving the nutritive quality of cassava flour and enhancing the use of cassava in the production of extruded products. Extrusion was carried out using a single-screw extruder with constant parameters; screw compression ratio (3:1); die shape (round), die diameter (10 mm), pitch angel 45° screw, screw speed (100 rpm), and feed rate (35 rpm). The effect of feed moisture and amount of chia seed on the proximate composition, and physical and functional properties was determined using standard methods. The protein, fat and ash contents significantly ($p < 0.05$) increased from 2.39 to 12.23%, 0.79–11.77%, and 2.59–4.04%, respectively, with increasing chia seed incorporation. Increase in chia seed incorporation significantly ($p < 0.05$) increased Bulk Density (BD) of cassava from 0.45 to 0.63 g/cm^3 for 60% chia seed substitution ratio and 15% moisture conditioning and the Water Absorption Index (WAI) of cassava from 1.53 to 5.94% for 20% chia seed incorporation and 20% moisture conditioning, while reducing significantly the Water Solubility Index (WSI) from 55.48 to 17.48 g/g for 60% chia seed incorporation and 20% moisture conditioning. On the other hand, solubility and swelling power of the extruded flour blends varied in no particular direction with chia seed incorporation and feed moisture conditioning. The cassava-chia seeds blends exhibited potential for the production of nutritive extruded instant porridge flour (extrudate was milled to flour) with good physical and functional properties.

Appendix III: Anova Table

Table A1: Anova table for main factor and factorial effect for different depend variables of proximate, colour and physicochemical properties for different.

Proximate Composition					
SOV	**DoF**	**Ash**	**Moisture**	**Protein**	**Crude fat**
MC	2	1.12***	48.20***	3.83***	20:8038*
Ratio	3	2.67***	6.79***	131.30***	188.95***
MC*Ratio	6	0.34***	3.32***	1.90***	1.182***
Reps	2	0.000^{ns}	40:605^{ns}	0.004^{ns}	40:6017***
Error	22	0.005***	60:4013***	0.032***	0.0666***
CV	**-**	***2.09***	***12.43***	***2.35***	***3.74***
R^2	**-**	***99.14***	***91.07***	***99.83***	***99.75***
MSD	**-**	***0.071***	***0.803***	***0.813***	***20:8065***

Physicochemical Properties						
SOV	**DoF**	**Bulk density**	**WAI**	**WSI**	**Solubility**	**Swelling power**
MC	2	0.008***	5.13***	42.11***	40:601*	0.18^{ns}
Ratio	3	0.009***	6.90***	2646.79***	0.040**	5.67***
MC* Ratio	6	0.004***	6.58***	40.32***	0.051***	9.95***
Reps	22	0.001^{ns}	0.005^{ns}	15.53*	0.016^{ns}	0.13^{ns}
Error		0.004***	20:8058***	2.907***	0.008***	0.084^{ns}
CV		***3.99***	***3.71***	***5.32***	***17.48***	***5.25***
R^2		***85.70***	***99.20***	***99.24***	***75.46***	***97.66***
MSD		***0.023***	***0.165***	***1.746***	***0.091***	***20:8098***

Appendix IV: Anova data for colour properties of the extrudate

Table A2: Anova table of colour properties of the extrudate

Colour Properties		
Luminosity	**a-red**	**b-yellow**
54.25^{ns}	4.41^{***}	4.39^{*}
212.79^{***}	2.43^{***}	3.99^{**}
102.78^{***}	0.56^{*}	4.98^{***}
15.92^{ns}	0.054^{ns}	3.48^{*}
18.95^{***}	$20{:}8012^{***}$	0.816^{***}
7.53	***15.67***	***4.04***
77.00	***80.82***	***76.23***
4.464	***40:6072***	***0.927***

Appendix V: Mean square table for the different microorganism

Table A3 : Mean square table for different microorganisms

SOV	DoF	LOGPCA	LOGMCC	LOGY&M	LOGBPA
MC	2	3.23^{***}	$20:802^{*}$	2.07^{***}	1.09^{***}
Levels	3	3.58^{***}	4.39^{***}	7.08^{***}	$20:806^{***}$
M.C.*Levels	6	6.19^{***}	4.07^{***}	1.86^{***}	2.91^{***}
Reps	2	0.02^{ns}	0.05^{ns}	0.01^{***}	0.07^{***}
Error	22	0.01^{***}	0.04^{***}	0.01^{***}	0.03^{***}
R^2	-	99.74	97.61	99.37	96.40
CV	-	3.14	9.56	4.08	7.86
MSD	-	0.08	20:801	0.11	0.19

Key: DoF = Degrees of Freedom, SOV=Source of variation, MC = Moisture content added, CV = Coefficient of Variation, R^2 = Coefficient of determination; MSD = Minimum Significant Different;***=very highly significant at p<0.001, ***=highly significant at p<0.01 and *=significant at p<0.05, PCA = Plate Count Agar, Y$M= Yeast and molds; BPA = Baird parker Agar and MCC = Coliform counts

Table A4: Microbial load due to the effect of % moisture content added to cassava – chia instant porridge flour

MC (%)	LOGPCA	LOGMCC	LOGY&M	LOGBPA
10	2.17^{c}±0.38	2.01^{b}±0.30	2.72^{a}±0.18	2.12^{b}±20:807
15	3.16^{a}20:800	2.28^{a}±20:801	2.04^{b}±40:600	2.71^{a}±0.12
20	2.40^{b}±40:602	2.17^{ab}±40:600	2.80^{a}±20:805	2.30^{b}±20:805

Values are means ± Std. error of triplicate measurements. Different superscripts letters on Means in the same column indicate significant difference (p<0.05). Key; PCA = Plate Count Agar, Y$M= Yeast and molds; BPA = Baird parker Agar and MCC = Coliform count

Table A5: Microbial counts due to effect of substitution levels of cassava – chia seeds instant porridge flour

LEVELS	LOGPCA	LOGMCC	LOGY&M	LOGBPA
0	2.08^{c}±0.53	1.84^{c}±40:606	2.24^{b}±0.14	2.16^{b}±40:604
20	2.06^{c}±0.52	1.33^{d}±0.36	1.38^{c}±0.38	2.58^{a}±0.16
40	3.38^{a}±0.19	2.55^{b}±0.14	3.19^{a}±0.13	2.38^{ab}±0.19
60	2.78±^{b}0.12	2.88^{a}±0.04	3.25^{a}±20:800	2.39^{ab}±0.17

Values are means ± Std. error of triplicate measurements. Different superscripts letters on means in the same column indicate significant difference (p<0.05). Key; PCA = Plate Count Agar, Y$M= Yeast and molds; BPA = Baird parker Agar and MCC = Coliform counts

Appendix VI: Mean square table for the main factor and factorial effect for different dependent variables of the different products due to different ratios of cassava and chia seeds for sensory parameters

Table A6a: Mean square table for the main factor and factorial effect for different dependent variables of the different products due to different ratios of cassava and chia seeds for sensory parameters

SOV	DoF	viscosity	sticky	cooked	grainy	appearance	flavour	texture	aroma
Subst.	3	16.87^{***}	5.69*	0.77^{ns}	24.02^{***}	2.69^{ns}	0.85^{ns}	3.88^{ss}	0.52^{ns}
MC	2	5.45^{ns}	19.51^{***}	0.18^{ns}	20:09^{ns}	4.28^{ns}	8.36^{ns}	8.95	2.23^{ns}
Sample*MC	6	4.57^{*}	6.13^{***}	4.79^{ns}	2.76^{ns}	1.87^{ns}	4.05^{*}	4.27^{ns}	3.19^{ns}
Reps	8	3.07^{ns}	1.84^{ns}	2.50^{ns}	0.98^{ns}	2.37^{ns}	4.36^{**}	4.71^{*}	3.38^{ns}
Error	88	1.98^{***}	1.48^{***}	2.26^{ns}	1.95^{***}	1.74^{ns}	1.45^{***}	2.05^{ns}	1.98^{ns}
R^2	-	39.48	45.28	20.58	36.13	23.37	38.02	33.99	23.12
CV	-	32.53	28.91	34.08	32.49	27.43	28.36	35.15	31.89
MSD	-	1.00	0.86	0.98	1.07	1.00	0.94	0.86	1.02

Key: DoF = Degrees of Freedom, SOV=Source of variation, MC = Moisture content added, CV = Coefficient of Variation, R^2 = Coefficient of determination; MSD = Minimum Significant Different; ***=very highly significant at $p<0.001$, ***=highly significant at $p<0.01$ and *=significant at $p<0.05$.

Table A6b: Mean square table for the main factor and factorial effect for different dependent variables of the different products due to different ratios of cassava and chia seeds for sensory parameters.

SOV	DoF	glossy	jelly	sticky	Trans	slimy	Smooth	dense	starchy	caramel
Subst.	3	3.18^{ns}	2.74^{ns}	9.84^{***}	22.33^{***}	5.96^{*}	15.32^{***}	19.72^{***}	4.04^{ns}	4.22^{ns}
MC	2	2.48^{ns}	7.95^{*}	8.12^{**}	4.23^{ns}	7.51^{*}	1.68^{ns}	12.86^{**}	1.15^{ns}	4.70^{ns}
Sample*MC	6	6.04^{**}	7.40^{**}	2.44^{ns}	3.31^{ns}	9.16^{***}	5.21^{*}	3.57^{ns}	3.51^{ns}	4.77^{*}
Reps	8	4.80^{*}	2.00ns	4.11^{**}	3.45^{ns}	5.46^{**}	4.88^{*}	2.23^{ns}	$60:406^{ns}$	3.42^{ns}
Error	88	1.84^{**}	1.98^{**}	1.42^{***}	1.94^{***}	1.83^{***}	2.24^{***}	2.15^{***}	1.89^{ns}	2.19^{*}
R^2	-	35.54	32.70	42.74	41.83	44.94	37.74	39.56	20.07	28.80
CV	-	31.82	33.58	28.85	32.85	29.77	33.21	36.18	34.03	33.89
MSD	-	0.97	1.00	0.85	0.99	0.95	1.07	1.05	0.98	1.06

Key: DoF = Degrees of Freedom, SOV=Source of variation, MC = Moisture content added, CV = Coefficient of Variation, R^2 = Coefficient of determination; MSD = Minimum Significant Different; ***=very highly significant at $p<0.001$, ***=highly significant at $p<0.01$ and *=significant at $p<0.05$.

Appendix VII: Lexicon indicating the descriptors for the sensory parameters used in descriptive studies

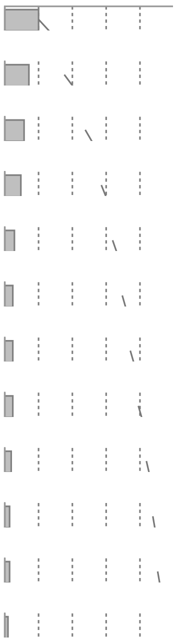
Table A7: Lexicon indicating the descriptors for the sensory parameters used in descriptive studies.

Attribute	Description	Rating scale
Texture		
Stickiness	The degree to which the product adheres to a surface	Extremely sticky (adhesive) – 9 Extremely non-sticky (runny) - 1
Consistence	The rate to which the porridge settles after stirring	Extremely consistent – 9 Extremely inconsistent- 1
Sliminess	Degree of cohesiveness as porridge flows over an inclined surface	Extremely slimy – 9 Extremely sluggish - 1
Viscosity	Resistance to flow when stirred with a spoon once clockwise	Extremely thick – 9 Extremely thin - 1
Appearance		
Gloss	The amount of shine or gloss perceived on the surface of the product.	Extremely glossy – 9 Extremely dull - 1
Smoothness	Absence or presence of lumps in the product	Extremely slimy – 9 Extremely lumpy - 1
Translucence	The degree to which a product looks translucent when poured from a spoon	Extremely translucent – 9 Extremely opaque - 1
Aroma		
Starchiness	Aroma associated with the starchy nature of cassava	Extremely starchy – 9 Extremely non starchy - 1
Caramel aroma	Aroma of associated with roasted sugar	Extremely caramelised – 9 Extremely non caramelised - 1
Flavour		
Graininess	The degree of coarseness felt in the mouth palate	Extremely grainy – 9 Extremely velvety - 1
Cooked flavour	Intensity of cooked flavour	Extremely cooked – 9 Extremely raw - 1
Dense	The degree to which food feels heavy in the mouth and does not move easily	Extremely dense – 9 Extremely light - 1

Appendix VIII: Eigenvalues for the sensory descriptors

Table A8: Eigenvalues for the sensory descriptors

Eigenvalue
3.1091
2.2309
1.8193
1.5458
0.9115
0.8321
0.7868
0.7297
60:40234
0.5562
40:60860
40:60210



Appendix IX: Hedonic Scale

Table A9: Hedonic Scale

Score card : Hedonic Rating Scale

Tray number………………….. Date…………………………..

In front of you are 15 samples tick √ which one you like or dislike.

	Appearance	Flavour	Aroma	texture	Mouthfeel
Like a lot	…….......	…….....	……..	………	………….
Like a little	…………	……….	....	……….	………….
Neither like nor dislike	…………	……….	……….	……….	…………
Dislike little	………..	………..	…….....	……….	…………
Dislike a lot	………...	………..	………..	……….	…………

To calculate the score for each product each descriptor was assigned a score value:

Like a lot = 5, like a little = 4, neither like nor dislike = 3, dislike a little = 2, dislike a lot = 1.

Sensory descriptors, evaluation guidelines used by sensory panel to evaluate cassava – chia porridges

Appendix X: Shelf life at 25, 35 and 45ºC of chia/cassava instant flour extruded at 10, 15 and 20% feed moisture and 0, 20:80, 40:60 and 60:40 chia/cassava ratio

Table A10: Shelf life values at 25, 35 and 45ºC, feed moisture of 10, 15 and 20% and 0, 20:80, 40:60 and 60:40 chia/cassava ratio

Storage temperature (ºC)	Chia/cassava ratio	Feed moisture (%)	K value	Shelf life (days)
25	0	10	0.057	285.12
		15	20:8042	174.86
		20	0.516	88.35
	20:80	10	0.084	240.01
		15	0.333	135.34
		20	60:4089	74.68
	40:60	10	0.088	231.39
		15	0.564	128.63
		20	0.777	61.82
	60:40	10	0.098	212.19
		15	60:4036	103.28
		20	0.965	55.73
35	0	10	0.061	189.77
		15	0.382	124.43
		20	60:4026	72.33
	20:80	10	0.084	167.94
		15	40:6075	112.35
		20	0.750	64.84
	40:60	10	0.095	157.84
		15	60:4083	99.47
		20	0.917	54.78
	60:40	10	0.187	145.21
		15	0.748	87.54
		20	1.554	43.47
45	0	10	0.077	159.46
		15	40:6041	110.38
		20	0.748	65.31
	20:80	10	0.091	147.38
		15	60:4029	97.36
		20	0.812	52.59
	40:60	10	0.188	132.43
		15	0.774	83.84
		20	0.826	46.88
	60:40	10	20:8098	1220:803
		15	0.855	71.32
		20	1.732	31.54