DEVELOPMENT OF READY TO EAT (RTE) BREAKFAST CEREAL FROM SORGHUM-PIGEON PEAS BLENDS

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BSC. FOOD SCIENCE AND TECHNOLOGY (HONS),

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DEPARTMENT OF FOOD SCIENCE, NUTRITION AND TECHNOLOGY

FACULTY OF AGRICULTURE

JUNE, 2021

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This thesis is my original work and has not been presented for a degree in any other university.

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SHUKRAN!!

LIST OF ACRONYMS

ASALs-Arid and Semi Arid Lands

ASAT-Arid and Semi-Arid Tropics

EABL-East African Breweries Limited

ERA- Economic Review of Agriculture

FAO- Food agriculture organization

FFA-Free Fatty Acids

FGD- Focus group discussion

GIT-Gastrointestinal Tract

HTST-high Temperature Short Time

KEBS-Kenya Bureau of Standards

KII- Key informant interview

MoA-Ministry of Agriculture

PV-Peroxide Value

RTE-Ready to eat

SSA-Sub-Saharan Africa

TVC-Total Viable Counts

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GENERAL ABSTRACT

Sorghum is under-utilized crop and one of the most important cereal crops in semi-arid tropics. In Kenya, sorghum is grown in the often drought prone marginal agricultural areas and has great potential to be an important commodity in the fight against food insecurity. Although sorghum production is well below its potential, there are well established traditional food products made from sorghum which can be easily commercialized with new technological improvement on quality. It was against this background that the project was conceptualized to fill in the gaps in value addition efforts of sorghum. The main objective was to develop sorghum-pigeon peas flour blends towards addressing food and nutrition security in Kenya. To accomplish this, the study first assessed the utilization and processing of sorghum by small holder farmers and farmer groups/SMEs in Makueni County. A cross sectional study design was used to collect data using key informant interviews (20), household survey questionnaires (300), and focus group discussions (12) with the small holder farmers. The farmers' average sorghum farming experience was found to be 8.2 years. The age of the farmer was positively correlated with their experience in sorghum production. Level of education also had direct impact in sorghum production with those who had lower levels of education having significantly ($P<0.05$) higher number of years of involvement in sorghum farming. The main uses of sorghum include: Thin porridge (uji) (42.6%), stiff porridge (ugali) (35.2%), githeri (sorghum mixed with legumes) (11.5%), fried dough (mandazi) (3.1%), flat bread (chapatti) (2.6%), beverage (sorghum tea) (1.2%) and other uses such as preparation of sorghum cake (3.8%). Female farmers reported significantly ($P<0.05$) higher utilization level (59%) with more diversified products compared to their male counterparts. The greatest challenges that hinders utilization and limits processing of sorghum were found to be limited market access (12.3%), low volumes of production due to low productivity (3.5%), lack of capital (4.6%), pest and diseases (38.2%), lack of equipment (24.6%) and lack of processing knowledge (16.8%.). The study also sought to establish the effect of fermentation, dehulling and malting techniques on nutritional, ant-nutritional, sensory quality, microbial quality, and shelf life of formulated sorghum-pigeon peas flakes. Malting and fermentation had significantly ($P<0.05$) increased the protein content (11.3% and 13.6% respectively). The protein content increased significantly ($P<0.05$) with increase in the ratio of the pigeon peas. Dehulling accompanied by fermentation was the most effective treatment in reducing total phenolics, tannins and phytates with 50%, 19% and 57% reduction respectively. Malting was found to be the best treatment regarding nutritional and sensory quality with 11%, 12%, and 4.5% increase in protein, fat, and fibre contents respectively while also scoring highest in all sensory attributes with overall acceptability of 4.19. Product samples formulated from 100% untreated whole grain sorghum were also acceptable with overall acceptability score of 3.5. The formulated products were packaged using two different packaging materials-laminated kraft paper and retortable pouch (stand up pouch) for shelf life analysis. The physicochemical and microbial qualities of the formulated breakfast cereal product were within the acceptable limit up to day 9 of accelerated storage at $55^{o}C$. Product samples packed in retortable pouches exhibited better keeping quality since it had lower quality changes of the stored samples during their storage compared to the kraft paper. Therefore laminated kraft paper was least suitable for packaging of sorghum-pigeon pea breakfast cereal. The study concludes that malting, dehulling and fermentation are simple and inexpensive processes that can be leveraged to increase the nutritional and sensory quality of sorghum based products while at the same time reducing the antinutritional contents.

CHAPTER 1: GENERAL INTRODUCTION

1.1 BACKGROUND INFORMATION

Water stress and food insecurity are currently significant problems in Sub-Saharan Africa (SSA), and they are expected to worsen in the coming years (Hadebe *et al.*, 2017). Rain-fed small-scale agriculture is the primary source of income in Sub-Saharan Africa's dry and semi-arid regions. Rainfall and water are two of the most important agricultural constraints in East and Central Africa (ECA) (Mitaru *et al.*, 2012).

Sorghum (*Sorghum bicolor* (L) Moench) is one of the most important under-utilized crops in Arid and Semi-Arid Tropics (ASAT). Sorghum is highly tolerant to drought and able to withstand periods of water-logging (Muui, 2018). After wheat, rice, maize and barley, sorghum is the fifth most important cereal crop in the world and is able to grow and produce in hot climates of arid and semi-arid tropical regions of the world (Singhal and Kaushik, 2016). In Kenya, sorghum is grown in Eastern, Nyanza and Coastal regions which are usually described as marginal agricultural areas, prone to droughts and crop failure (Muui, 2018). Sorghum is a C4 crop, which is highly suited to a broad range of environmental conditions, including arid and marginal agricultural regions, which means that the crop can be cultivated without competing with other climate-sensitive crops (Khawanja *et al.*, 2014).

Sorghum is expected to remain to be an important crop particularly in regions where it is better suited than other cereal crops such as draught prone regions and in areas that experience high temperatures and water logging. The grain is used to make various foods, such as *ugali* (stiff porridge), *uji* (thin porridge), and alcoholic drinks (Okuthe *et al.*, 2013).

Sorghum is one of the priority food commodities in Kenya's Vision 2030 and is the staple food for many households especially for the resource-poor low income households. Sorghum is typically grown by small-scale, poor farmers and is primarily used for household consumption (Kiambi and Mugo, 2016); as feed for animals and raw materials for industrial use (Agrama and Tuinstra 2003; Mamoudou *et al.*, 2006). The grain is also used for the processing of several commercial products such as edible oils, dextrose agar, wax, starch, syrup, alcohol and alcoholic products (Mamoudou *et al* 2006; Rainford, 2005). Locally, sorghum is used as food in the production of fermented and unfermented porridges, *ugali, pilau,* and other traditional dishes where the grain is mixed with legumes (ministry of agriculture 2010). The grain could be used to reduce micronutrient malnutrition since it has good levels of iron (>70 ppm) and zinc (> 50 ppm) (Muui *et al*., 2013).

In Kenya, most sorghum grain is eaten by rural households, who usually grind it into flour to make '*ugali*'. Some of the grain is also processed into flour by commercial mills which is then marketed in urban markets. In many cases, composite flour of sorghum enriched with different flours such as cassava flour is packaged and sold to consumers (Chemonics, 2010). The by-products from the processing of sorghum are used for the production of animal feeds.

Recently, there has been rising demand for sorghum grain in the brewing industry for use in beer production. Owing to its low production volumes and weak marketing networks, sorghum trade in Kenya is generally limited. Most farmers produce only enough sorghum for their household consumption with very little surplus grains to sell (Ochieng, 2011). Sorghum's potential to address food security, malnutrition, income and job creation as well as general economic development for Kenyans has barely been tapped.

The significance of sorghum products in Kenya can be pronounced from the way that there is an all-around appreciated assortment of Kenyan customary sorghum products (food and beverages). These are among others: sorghum *ugali*, *chapatti*, *mandazi*, sorghum *pilau*, beverage (tea or choco-like drink), and porridge. Sorghum is not only a traditional grain in Kenya, but it is also additionally becoming a key component in profoundly effective novel, mechanical and industrial food and drink products, some of the potential commercial products include: instant soft porridge, malt beverages, lager beer, bread, cookies and biscuits, sorghum sausages and chocolate bars (Rooney and Waniska, 2000).

Pigeon pea is one of the most important legumes in Kenya and is the third most consumed legume in after bean (*Phaseolusvulgaris* L.) and cowpea (*Vignaunguiculata* L.). Counties in the Eastern region such as Machakos, Makueni, Kitui, Meru and Embu are the most important pigeon pea producing areas. Pigeon pea is a multipurpose drought tolerant crop and provides many benefits to low-income families. The grain is rich in protein and is also used as fuel, animal feed, fencing material, improves soil fertility and controls soil erosion (Ojwang, 2015). They can be cooked alone to be served with a wide range of foods e.g. rice, or mixed with grains like maize or sorghum as "githeri" or "muthokoi" (WFP, 2018).

Cereal and legume based composite flour is a staple diet for many communities in Africa and is often used as porridge (thick or thin), child weaning food including other uses. Cereals such as sorghum have high carbohydrate content and are therefore good source of calories but have low protein and lysine content. On the other hand, legumes such as pigeon peas have relatively higher proteins content and dietary fiber. They also have a significant number of vitamins and minerals more than the cereals (Udomkun *et* *al*., 2019). Therefore combination of the two enhances the nutritional quality of the resulting product.

Sorghum is a promising cereal grain that can be used in the fight against hunger as well as spark income generation and employment opportunities for small scale farmers and the country in general especially for the communities residing in ASAL and marginalized regions. This potential has not been exploited significantly. There are limited commercial sorghum based products in the market. There is also need for increased research on sorghum products like development of new sorghum based products with high nutrient dense. This research project was therefore designed to develop highly nutritious and acceptable products from sorghum to address the problem of underutilization and losses along the sorghum value chain and to diversify sorghum products in the market.

1.2 PROBLEM STATEMENT

Sorghum grain has a great potential to diversify and improve food security in Kenya at the household level and also spark economic development at regional level. However, the sorghum sub-sector remains largely neglected and under-utilized. And despite the ever increasing population of Kenya which for the most part relies upon cereal grain as their fundamental staple food, the importance of utilization of sorghum and its products at both small scale and large scale level is well underneath its potential.

There is limited data on commercially viable value added sorghum products in terms of quality, cost, and safety and very little sorghum is industrially processed for commercial purpose. Estimates suggest that approximately only less than 3% of Kenya's sorghum production is used in the formal food and feed industries. Most of the processed sorghum is used in the manufacturing of alcoholic drinks such as lager and opaque beers. There is also less product development and research in the sorghum sub-sector.

Generally sorghum trade in Kenya is low due to low production volumes and lack of diversity in sorghum products. Most sorghum growers produce only sufficiently enough grains for their household and domestic demand, with just minimal surplus to sell. In fact, it has been reported that only 30% of the local sorghum produce is actually marketed for sale. On the other hand, there is a potential market for the sorghum products to address the food security issues faced by many Kenyan households as well as the need of the increasing health education and awareness of the urban dwellers.

Although sorghum possesses almost similar nutritional content compared with other grains, it is misjudged by many communities and consider it as an inferior grain and should only be eaten by the poor and vulnerable people. This is one of the challenges that hinder sorghum consumption in the urban centers and its products to be unpopular and therefore numerous urban inhabitants lean toward maize hence bringing down the market capability of sorghum and its products. Interventions are therefore required to grow the market, diversify its products and increase acceptance of sorghum among the more financially blessed white collar class living in urban centers.

1.3 JUSTIFICATION

Sorghum is a major staple crop for many people around the world and due to its draught resistance and diversity it is usully grown in the arid and semi-arid lands for rural food security where it is processed into a wide range of attractive and nutritious traditional foods (Chepng'etich, 2014). In terms of quantity, sorghum is the second most important cereal grain in Kenya preceded by only maize. Sorghum is grown in almost all agro-ecological zones in Kenya because traditionally all farming communities regard it as an important food crop and as a food secure crop (Kilambya and Witwer, 2019). Therefore sorghum can possibly upgrade food security in the ASAL regions where maize and other crops perform poorly. On the other hand assessing and improving sorghum product qualities will improve awareness and marketability of sorghum products.

Sorghum has the ability to unlock the potential of Kenya's ASALs where most people are food insecure and have no or few resources. There are sorghum varieties which are dry season and heat tolerant that are able to withstand such harsh environmental conditions as flooding and water scarcity (Bonfim-Silva *et al.*, 2011). As a staple food crop, sorghum can add to the food security, reduce malnutrition, expanded employment opportunities and contribute practical financial improvement in the country and especially for people who live in the ASAL regions. Sorghum grain contains carbohydrates, minerals like iron, magnesium, potassium, calcium and phosphorus however it has low protein content and other basic minerals, for example, zinc and Vitamin A.

Bio-fortifying the sorghum products with basic minerals, nutrients and different supplements that are in restricted amount in the grain could be a useful tool in the fight against hunger in farmers that rely upon a single yield lasting through the year (Taylor, 2011; Lipkie *et al.*, 2013). Although sorghum trade in Kenya is limited, this is probably going to change sooner rather than later. This is because of expanded wellbeing concerns and health consciousness among the public, and therefore the utilization of sorghum products have seen a slow increment, as indicated by the amount and scope of prepared sorghum products sold in local grocery stores. Sorghum flour is attracting a lot of attention and is likely to be the future of sorghum industry. With proper packaging design and diversification, the sorghum flour business could be expanded to larger retail outlets.

1.4 OBJECTIVES

1.4.1 MAIN OBJECTIVE

To develop sorghum-pigeon peas flour blends towards addressing food and nutrition security in Kenya.

1.4.2 SPECIFIC OBJECTIVES

1. To assess the current situation on utilization and processing of sorghum by small holder farmers and farmer groups in Makueni County.
2. To formulate a ready to eat breakfast cereal from sorghum-pigeon peas blends.
3. To determine the physico-chemical and microbial quality of the developed ready to eat breakfast cereal.
4. To evaluate the acceptability of the developed ready to eat breakfast cereal.
5. To determine the shelf life of the ready to eat breakfast cereal under different packaging conditions.

1.5 HYPOTHESIS

- Are there sorghum products utilized and processed by small holder farmers and farmer groups in Makueni County?
- High quality, nutritious and acceptable ready to eat breakfast cereal can be developed from sorghum pigeon peas blends.
- Sorghum-pigeon pea ready to eat breakfast cereal has acceptable physico-chemical characteristics and has high nutritional quality.
- Ready to eat breakfast cereal developed from sorghum and pigeon peas have acceptable sensory quality.

- Ready to eat breakfast cereal from sorghum and pigeon peas can have a stable shelf life for an extended period of time.

CHAPTER 2: LITERATURE REVIEW

2.1 OVERVIEW OF THE SORGHUM VALUE CHAIN IN KENYA

Sorghum is one of the most important cereal food crops for many low income and poor farmers and families in Kenya. It is typically cultivated by small scale and asset-less poor farmers. The grain is mainly used for domestic purposes with little surplus to sell. Sorghum grain is Kenya's only indigenous cereal species and is cultivated throughout the country, even in areas which have low potential for agricultural production (Kilambya and Witwer, 2013).

It is generally cultivated on small scale basis mainly for household utilization. The crop could thrive in areas where others crops fail due to harsh environmental conditions. Being an indigenous cereal crop, majority of the farmers are familiar with it and that it can go long way in the fight against food insecurity. Sorghum is a draught tolerant crop which can grow in different agro-ecological zone of the country and can be cultivated from sea level to 2500m ASL with low rainfall of 250 mm per year and as low as temperatures of 10°C (Chemonics, 2010; Kilambya and Witwer, 2013).

In Kenya, sorghum is grown in the often drought prone marginal agricultural areas such as Eastern, Nyanza and coast regions (Muui *et al.*, 2013) for example, the Eastern, Nyanza, Western and Rift Valley regions represented about 43%, 40%, 9% and 7% of the total sorghum in Kenya in 2011 respectively. These areas collectively accounted for 99% of Kenya's sorghum production in that year (MoA-ERA, 2012).

Marketing of agricultural produce is very important because selling the products produced to the final consumer is the main reason farmers produce products. Most of sorghum grain produced in Kenya is consumed by rural dwellers; where the grain is typically ground it into flour to make *uji* (thin porridge) and to lesser extent *ugali (*thick porridge). Some commercial mills also process sorghum grain into flour and sell it in town markets. Sometimes, flour from sorghum is fortified with other cereals and legume flours and then it is packaged and taken to urban markets (Chemonics, 2010). The sorghum processing by-products are commonly used for the manufacturing of different animal feeds.

Recently, there is a promising interest for sorghum grains in the production of both alcoholic and non-alcoholic drinks by the brewing industry. Approximately only 53 percent of all sorghum produce in the country each year is utilized as food in the form of grain or ground in to flour, whereas another 24% is processed to make other different products (like beer), 11% of the sorghum produce is estimated to be wasted, 10 percent is used by the animal feed manufacturing industries and around 2 percent is used as seed for planting (FAOSTAT, 2012).

Generally sorghum trade is limited because of low sorghum production volumes and poor product marketing. A large portion of the farmers produce just sufficiently enough grains to meet their household needs, with little or no surplus to sell (Ochieng, 2011). Only 30 percent of the domestic sorghum produced in the country is estimated to be actually marketed. Although sorghum marketing is restricted in Kenya, there is a promising market in the near future due to expanded wellbeing concerns and health consciousness among the public. The use of sorghum products is gaining popularity and increasing gradually, and this is shown by the increasing number and diversity of commercial sorghum products that are sold in the local markets and supermarkets. However, it is the sorghum flour that sees the greatest potential and seems to be the future for the sorghum commercial products (Chemonics, 2010).

Sorghum value chain contains several activities interconnected together notably: research institutions, seed multiplication (improvement) and distribution, grain production, market channels, brewing (home and commercial), processing (mainly milling) and lastly to the end user to be used as *uji, ugali* and other products. It also has many other key chain actors, such as the farmers, middlemen, wholesalers, processors and millers, retailers, exporters and consumers (Kilambya and Witwer, 2013). Sorghum consumption is usually at the household level as most of the sorghum produced is processed in to flour at home for utilization within the producing farmers, mainly to make *uji* or *ugali*. However, very little amount of the cultivated sorghum grain is actually marketed and sold directly to consumers (e.g. breweries, institutions and individual households) or to brokers and small-scale traders for wider distribution (Chemonics, 2010; Ochieng, 2011).

2.1.1 SORGHUM VALUE CHAIN ACTORS

Generally, traders and middlemen buy the grains in bulk at local markets and from the farmers directly then transport it to the wholesalers. Retailers, grain millers and exporters buy directly from wholesalers (Chemonics, 2010). In Nairobi, Nyamakima and Gikomba are the main markets for sorghum, where about 200 wholesalers and retailers exist. Close to162 millers are working in Kenya of which a good number of them have sorghum flour as one of their products, which is traded through small scale retailers, where the by-products from the milling process is sold to the animal feed manufactures. Sorghum flour is most of the time mixed with cassava flour as well as other cereals and legumes to fortify the flour product before it is sold, especially in urban markets (Kilambya and Witwer, 2013).

Sorghum trading is not organized to any form since trading from field to retail is normally carried out by independent groups, rather than well organized groups. Brewers and the alcohol industry has begun to take part and even assume a crucial role in the sorghum marketing, this is fundamental because of the east African brewers expanding interest for higher quality sorghum varieties, for example, gadam or gatiga. This has created new marketing routes for sorghum farmers. There are several farmers who are contracted and paid by the brewers (Chemonics, 2010).

Farmers receive farm inputs such as seeds, fertilizers, pesticides, and other inputs from input suppliers. They also get loans of different forms from financial institutions. Farmers take their products to aggregation and collection centers where the product is stored on behalf of traders. Opportunistic brokers may often purchase sorghum from farmers as well, but usually at a lower price because they appear when farmers are in dire need of cash. The brokers sell the product to traders who deliver it to the brewery (Dijkxhoorn *et al*., 2019).

Besides being an essential grain for home utilization, sorghum has an immense potential industrially for the production of commercial products. These utilizations incorporate commercially prepared food products for local consumers as well as exportation, production of gluten free products, feed for animals, production of malt drinks and commercial starch production. EABL has as of late created a sorghum beer manufacturing plant and in 2012 their sorghum demand stood at 2.5mt.

2.2 SORGHUM PRODUCTION IN KENYA

The agricultural sector is the main economic contributor in the country, but still the agricultural sector continues to be confronted by many challenges in production because of the frequent, recurrent and prolonged droughts witnessed all over the world. Plant growth, survival and productivity are severely affected by drought which is perhaps the most prevalent abiotic factor causing food insecurity in the world (FAO and ICRISAT, 1996). Drought effect is more severe in the Arid and Semi-arid areas with characteristic low, erratic and poorly distributed rainfall.

Growing drought tolerant crops such as sorghum can be an effective tool to reduce the drastic effect of droughts. Sorghum is primarily grown in areas receiving low rainfall where other grains might fail or do not produce unless irrigation is done (Ogeto *et al*., 2013). Sorghum has extraordinary capacity to develop under a wide scope of unforgiving ecological conditions where different crops can't develop or yield ineffectively. It can do well under limited water availability and low fertilizer application or other inputs by a large number of smallholder farmers in numerous countries (FAO, 1995).

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most essential grain crop on the planet after rice (Oryza sativa), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum*) and maize (*Zea mays*) (Taylor, 2009). Sorghum is exceptionally adapted to a wide variety of climatic conditions including semi-desert conditions and along these lines can be produced without rivalry with other grains which are climate sensitive (Khawanja *et al*., 2014). Environmental conditions necessary for sorghum growth include: altitude of 900m-2500m, temperatures 12°C -37°C and optimum rainfall of 550-800 mm (Srinivasa, *et al*., 2012). Sorghum is quite adaptable to a wide range of soils, for example, alvisols and vertisols and can endure pH of 5.5 - 8.5 (Moses *et al.*, 2016). In Kenya, there are wide ranges of climatic conditions that can favour sorghum growth and production but despite high production potential, sorghum production remains underutilized (Muui *et al.*, 2013).

The total world cereal consumption has seen a considerable rise during the past half a century, but the global utilization of sorghum has not changed much, simply because the crop is regarded by many communities to be of low quality grain, but sorghum has similar nutritional content with other cereal staples (Ogeto *et al*., 2013). Due to frequent and recurrent droughts facing Kenyan farmers, more and more farmers are switching to sorghum from maize since sorghum can withstand drought, is sturdy, and also easy to grow (Ogeto *et al*., 2013). Sorghum is indigenous crop to Kenya and to East Africa, therefore Kenyan farmers are trying to return to a crop that is better adapted to their environment and was popular among them long before maize was introduced to them by the colonialism. Sorghum farming has many benefits to the farmers including but not limited to eating its highly nutritious grains, feeding the grains to their livestock, and using it for production of traditional alcoholic drinks, they also use the stems for building materials, and the leaves for animal fodder (FAO, 2018).

2.2.1 CHALLENGES IN SORGHUM PRODUCTION

Generally in Africa, sorghum yields are very minimum with estimates suggesting 0.85 tons per ha (Gerda and Christopher, 2007). In Kenya, sorghum grain is locally cultivated under rain fed conditions in the arid and semi-arid regions of Eastern, North-eastern, Coast and Nyanza regions (EPZ, 2005; CFC and ICRISAT, 2004). Approximately, over 35 percent of sorghum produce is used for human utilization, while the rest is utilized for feed manufacturing, alcoholic drinks and as an industrial raw material (Mamoudou *et al.*, 2006). A good number of poor families in Kenya depend on sorghum farming to increase their food security. Most farmers in drought prone marginal regions of Kenya opt for maize than sorghum since maize is less labour intensive in terms of bird chasing. However, due to recent global climate change witnessed all over the world, small scale farmers may require to think of cultivating sorghum and, therefore, there is a dire need to cultivate sorghum cultivars that can survive in the harsh climatic conditions.

Sorghum production in Kenya is mostly concentrated in Western (43%), Eastern (41%), Nyanza (9%), and Rift Valley regions (7%), of the total sorghum production in Kenya in 2011. Those regions collectively accounted for 99 percent of the country's sorghum production in the year under review. Sorghum production and utilization in Kenya fluctuates over the years but consumption was gradually increasing since 2008 and is estimated about 81,000 tonnes (Kilambya and Witwer, 2013).

The frequent attack by Quelea birds has been reported to make sorghum farming more labour intensive, which forces many small scale farmers in the ASALs to prefer maize production to sorghum, which is at higher risk (Mwadalu and Mwangi 2013; Miano *et al.*, 2010). The red-billed Quelea bird often referred to as pest bird is a popular Sub-Saharan Africa bird species with high populations that can severely destroy cereal farms and is a key factor for farmers to reject sorghum especially white sorghum varieties without tannin (Habindavyi, 2009). Stem borer and *Cercosporios* are the other main biotic constraints that cause high sorghum cultivation losses (Mwadalu and Mwangi 2013).

Figure 2.1 Red-beaked Quelea birds which feed on sorghum at the milking stage (Source: Mwadalu and Mwangi 2013).

Figure 2.2 Gadam sorghum head whose grain has been destroyed by Quelea birds (Source: Mwadalu and Mwangi 2013).

Dorcas and others, (2019) reported that the major constraint to sorghum production in Makueni County is inadequate rainfall. The second most significant challenge is bird invasion, with more than 70 percent of the farmers identifying it as a challenge. Farmers also suggested that in the production of sorghum, bird invasion can be catastrophic and could lead to a 100 percent loss of the crop.

Another challenge affecting the sorghum sub-sector is the reduced effectiveness of extension services. Mwadalu and Mwangi, (2013) indicated that inadequate personnel have impaired the effective delivery of services because the existing staff-to-farmer ratio is 1:978 compared to the recommended FAO ratio of 1:400 (GoK, 2006). As a result, many small scale farmers, especially in the arid and semi-arid regions, do not have access to important information on how their crop productivity can be improved, which also contributes to the low crop production in the region. The effectiveness of the extension service system in Kenya, especially with regard to sorghum cultivation, has deteriorated due to low rates of technology adoption caused by high poverty indices, poor research extension farmer linkages and inappropriate technologies (Mwadalu and Mwangi, 2013).

The other major challenge facing the sorghum sector is lack of reliable marketing channels. EABL has partially tried to address and resolve the marketing dilemma facing the sorghum sub-sector but it has also contributed to a scenario where farmers do not have alternative marketing channels to sell their surplus produce that do not meet the requirements set by EABL (Mwadalu and Mwangi, 2013). In certain instances, below standard grains have been detected caused by seed impurities particularly, mixing of different varieties which is usually encountered with commercially supplied seed lots (Miano *et al*., 2010).

The sorghum sub-sector is also facing an image and reputation issue where many people regard sorghum to be a food crop for the marginalized and poor communities usually in the arid and semi-arid regions. As such, utilization of sorghum in urban areas is relatively low, and many urban residents prefer maize, thereby reducing sorghum's market potential. Therefore, strategies are needed to intervene and expand the sorghum market and improve the acceptance of sorghum and sorghum products among the more economically stable middle class in urban areas.

2.3 SORGHUM CONSUMPTION AND UTILIZATION

It is reported that sorghum is the main staple food grain for many poor households in the world who are asset-less and face food shortages (Timu *et al*., 2012). Sorghum is cultivated worldwide due its tolerance to drought, water logging, high temperature and infertile soils which are saline-alkali (Mwadalu and Mwangi, 2013). For many years now, sorghum has been considered to be an ideal crop for the resource poor, small scale farmers in the marginalized ASAL regions (USAID, 2010). In terms of cereal production in Kenya, sorghum is placed third after maize and wheat and can grow over a broad variety of soils and conditions including soils with very low fertility (Ashiono *et al*., 2006; KIRDI, 2011). Sorghum has high potential to increase regional development and is promising grain to be used in the fight against hunger and malnutrition.

Sorghum is a good source of nutrients and phenolic compounds. It makes adaptable flour for multiple uses and has good flavour which is sometimes described as slightly sweet. Some of the products that can be made from wholegrain sorghum flour include cookies, cakes, fermented and unfermented flat bread, brownies, breads, pasta, pancakes, waffles, porridges, alcoholic and non-alcoholic beverages and extruded products (Asif, 2011).

Sorghum has many uses as human food, some of the traditional food products made from sorghum include: dehulled and boiled sorghum, sorghum stew, sorghum *pilau*, *githeri* (mixed with legumes), *ugali*, biscuits, bread, queen cakes, *chapatti*, *uji*, sorghum arrowroot mash and sorghum tea (MOA, 2007). Sorghum stalks are used as dry season fodder for animal feed and as fencing materials, starch manufacturing and alcohol production. Sorghum is mostly consumed by rural households with few processed products available in urban centres.

Sorghum can be utilized either whole or dehulled; dehulling is the removal of the outer coat (pericarp) which can be done industrially or even at home. Some of the dehulled grain products include

- Plain boiled dehulled grain
- Sorghum *githeri*

- Sorghum mashed potatoes (yam)
- Sorghum *pilau*

The grains are also dried and ground to make several products which include

- Sorghum *uji* (fermented and non-fermented)
- Sorghum *ugali*
- *Mandazi*
- *Chapatti*
- Cakes
- Biscuits
- Beverages like sorghum tea

2.4 SORGHUM VALUE ADDED PRODUCTS

2.4.1 SORGHUM MALT BEVERAGES

The demand for innovative non-alcoholic drinks is increasing rapidly due to the increasing trends towards more health conscious nutrition. Malt drinks from cereals contain only natural sugar and are also excellent sources of antioxidants and other health promoting substances. Sorghum is a significant source of energy, vitamin B-complex, and also good source of other minerals like phosphorous, magnesium, calcium and iron but low in protein (Mohammed *et al*., 2011).

Traditionally, sorghum is a successful ingredient in different traditional foods and beverages; however, sorghum is progressively turning into a key ingredient in profoundly successful business and non-conventional food and refreshment products. For example in Nigeria, several alcohol free malt beverages are prominent including those packaged alcohol free malt beverages like malta. Sorghum malting in Nigeria has turned into a settled industry for beers with roughly 1.5mt being malted yearly (Mohammed *et al*., 2011).

Sorghum malt solution has sweet taste and contains sugar, this can be made to concentrate by heating to remove water and form black coloured solution which is rich in flavour and can even be dried into powder. Steps in malting of sorghum include; steeping the grains, germinating and kilning or drying under controlled conditions. α- And β-amylases which contain in the sorghum grain hydrolyze the starch to produce fermentable sugars in these processes. They modify the sorghum grain structure during malting so that the grain is more easily solubilized during the brewing process. Malted sorghum has good α-amylase activity but low β-amylase while starch in sorghum has high gelatinization temperature of about 70°C (François *et al*., 2012).

Malting of sorghum in Africa is usually done to develop alcoholic drinks such as beer. The African beer is nutritionally rich but it is usually less attractive and inferior compared to Western beers mainly because of its poorer hygienic quality of the product, poor organoleptic qualities and has shorter shelf life (François *et al*., 2012). Traditional manufacturing processes of African sorghum beer essentially involves many and tedious stages such as malting and germination, drying, milling into flour, souring, boiling, mashing and fermentation, however, the dissimilarities sometimes occur depending on the geographic region (Haggblade and Holzapfel, 2004). Traditional African sorghum alcoholic drinks are very rich in energy, vitamin B-complex, minerals, and essential amino acids such as lysine (Chevassus-Agnes *et al*., 1979).

2.4.2 SORGHUM COMPOSITE FLOUR

Sorghum flour is a gluten-free product tolerated by patients with celiac disease giving high potential in the gluten-free food market. The world has made a considerable scientific progress to understand the nature of celiac disease, but up to now, the only treatment for patients with celiac disease is strict gluten free diet for life. The number of people being diagnosed with celiac disease are increasing worldwide there is therefore a potential market for gluten-free products and great opportunity to create new gluten free products using sorghum composite flour (Winger *et al*., 2014), which can be used as a substitute for wheat flour.

Composite flour is a type of flour made from blends of different flours from cereals, legumes or other crops such as root crops that are mixed to satisfy specific functional and nutritional properties. It could be made from mixture of wheat flour (usually more than 80%) with other cereal flours such as maize, rice, sorghum etc. (usually less than 20%). Due to its economic and nutritional advantages, composite flours are gaining popularity in the bakery industry especially those based on wheat flour and other cereals (Bolarinwa *et al.,* 2015).

The nutritional quality of sorghum is low and it is necessary to improve it to suit the consumer needs, therefore several attempts have been made to fortify it with legumes, nuts and other cereals to make it nutritionally superior and acceptable. Sorghum products fortified with legumes and nuts have been successfully used in feeding programs. Sorghum and pearl millet fortified with soybean flour has been used to develop infant mixes (Bolarinwa *et al.*, 2015).

There are also many other products developed from sorghum composite flour to increase the nutritional content and improve the sensory quality of the final products. Composite flour innovation has been generally received round the globe for improvement and development of functional properties of foods. Attempts have been made to develop bread from blends of wheat and non-wheat flours to attain desirable dough elasticity and consistency (Raihan and Saini, 2017). Different types of composite flours have had the capacity to be utilized in the production of bread of various kinds, spaghetti, cakes and cookies (Ho *et al.*, 2013; Asta *et al.*, 2013, Seczyk *et al.*, 2016, Cheng and Bhat, 2016; Zouari *et al.*, 2016).

In Asinge, Busia County, farmers prepared sorghum composite flour from sorghum 50%, green grams 12.5%, amaranth 25% and orange fleshed sweet potato flour 12.5%. This flour was then used to make thick *chapatti* and *uji* (porridge) while farmers in Makueni prepared porridge from composite flour of sorghum 60%, millet 20% and pigeon peas 20%. Sorghum composite flour with other cereals and legumes have been developed in the production of many food products, including breads, chapatti, cookies, porridge, noodles, biscuits and infant products.

Many attempts have been made to increase the use of composite flours whereby some wheat flour is replaced with other cereal crops and used in bread and other bakery products, leading to decreased cost related to imported wheat (Olaoye *et al.*, 2006). There are many products made using sorghum composite flour mainly baked products as well as flours used for porridge and infant foods. The Food Research Centre in Khartoum, Sudan, carried out acceptability studies on breads made with composite flour of 70% wheat and 30% sorghum and indicated that the bread was acceptable (Abdelghafor *et al.*, 2011).

Sorghum provides necessary calories, protein, vitamins and minerals to numerous people in Africa, who are poor and depend on the grains as their principle staple cereal. Sorghum products lack essential amino acids such as lysine, methionine, and tryptophan but contain several anti-nutritional factors such as tannins and phytates which have a profound effect on its nutritional value. Sorghum is nutritionally poor and therefore several attempts have been made to fortify it with other grains especially legumes to make it nutritionally superior and highly acceptable (Bolarinwa *et al*., 2015).

2.4.3 SORGHUM BAKED PRODUCTS

Baked products are preferred by many people and have gained huge popularity in the processed food market due to their convenience, longer shelf life and easily availability. Baked products made from wheat such as bread, cookies, and cakes are known to most of the consumers of the baked products (Chavan *et al.*, 2016). With growing portion of the population preferring gluten free products, there are many opportunities to use sorghum to develop baked products. One of the popular uses of sorghum is the production of sorghum-wheat composite flour for use in the production of leavened baked products. Composite flours are blends of wheat and other flours for the production of leavened and unleavened baked breads, pastas, porridges, and other snack foods (Trappey *et al.*, 2015).

Wheat is the grain of choice in baking and wheat based baked products are the most popular among the baked products. Cookies are very important in the snack food and are cherished by many consumers due to its varieties in taste, crispiness, availability and digestibility. Recently, sorghum flour is being used increasingly in gluten free baked products, mainly due to its similar nutritional qualities to wheat (Lovis, 2003). There are varieties of traditionally baked products made from sorghum such as cookies, bread, cakes, biscuits, *injera* etc. while sorghum lacks the functional properties of making bread alone, but bread made from sorghum composite flour is regarded to be nutritionally important (Ratnavathi and Patil, 2013).

2.4.3.1 BREAD

It is possible to make bread from sorghum flour by blending with 60% maida (finely milled flour without any bran, refined, and bleached) or by using modified starches like carboxymethyl. To sorghum bread, very fine flour is mixed with different ingredients like sugar, salt, bread improvers, oil or fat and then is made to dough. Fermentation of sorghum bread usually takes longer period compared to the normal wheat bread, which is then baked. Higher quantity of yeast is added as well as external gluten to improve the leavening and softness of the resulting bread. The dough is then baked for one hour (Ratnavathi and Patil, 2013).

Bread made with sorghum composite flour is nutritionally good. However, sorghum alone cannot make good bread as it lacks the functional properties (proteins) for making bread. Sensory evaluation and organoleptic tests done for the sorghum composite bread indicated that the taste panelists concluded the overall quality of 70:30 S:W composite bread to be good (Ratnavathi and Patil, 2013). Proximate composition analysis of bread made from sorghum composite flour showed that it has much less protein content but higher crude fiber than normal 100 percent wheat bread. The shelf life analysis of sorghum composite bread at 25°C (accelerated shelf life) was less than that of the bread made from 100% wheat. The use of 24% pentosan in sorghum composite flour (up to 50% of substitution level) has been found to enhance the quality of the bread. Long hours pre-aging of the sorghum composite flour up to 19 hours was found to positively influence the preparation nature of wheat-sorghum composite flour (Ratnavathi and Patil, 2013).

Experience demonstrated that sorghum composite flour blends needed extra amounts of sugar, yeast and water compared to the normal wheat based bread, to make the bread scrumptious. Baking of sorghum composite flour products required higher baking temperatures and the surface of composite bread was less satisfactory. One of the biggest challenges facing bread makers is the smaller volume of composite bread when contrasted with 100 percent wheat bread from comparative amounts of composite flours and wheat flours (Ratnavathi and Patil, 2013).

Figure 2.3 Sorghum bread

(Source: Ratnavathi and Patil 2013).

2.4.3.2 CAKE

Making of cakes from sorghum is like that of cakes made from wheat. Fine sorghum grain flour is utilized for the production of cakes. Sorghum flour is seemingly better than the wheat flour for cake making. Fine sorghum grain flour is blended with required amounts of sugar, egg, emulsifiers, and fat. The dough is made little soft and nuts are decorated on the top and kept in oven for baking after keeping the dough in a mould (Ratnavathi and Patil, 2013).

Figure 2.4 Sorghum cake

(Source: Ratnavathi and Patil 2013).

2.4.3.3 BISCUITS

Fine sorghum flour is used in the baking of sorghum biscuits which is mixed with wheat flour up to 15% (Ratnavathi and Patil, 2013).

Sorghum flour is blended with wheat flour, vegetable oil, sugar, baking powder and other substances required. The blended batter is then compacted in a form and baked at the required temperature. Research on the parameters like compressibility, breaking quality and so forth demonstrated that sorghum biscuits are having lesser breaking quality. It is possible to make biscuits of satisfactory quality utilizing 1:1 blends of wheat and sorghum flour. Incorporation of 25% wheat flour with sorghum flour in manufacturing of short and hard biscuits and wafers was savvy without influencing quality, breakages, and plant effectiveness.

It was suggested that improved milling techniques to produce sorghum flour with particle size comparable to that of wheat flour can increase the possibility of higher substitution. One of the extraordinary organoleptic properties of sorghum baked products is its non-stickiness to the mouth. Sorghum-soy flour mixes recorded the most noteworthy pinnacle viscosity contrasted with different mixes (Ratnavathi and Patil, 2013).

Figure 2.5 Sorghum cake

(Source: Ratnavathi and Patil 2013).

2.4.4 POPPED AND FLAKED SORGHUM PRODUCTS

Popping is the least difficult, economical and speediest conventional strategy for dry heat application, where sorghum grains are subjected to high temperature for short time (HTST). Excessively warmed vapour are created within the grains through quick heating, which makes the grain cooked and grow the endosperm while getting away with incredible power through the small pores in the grain structure. When popping, the grain becomes sterile and a large portion of the seed micro-flora is killed and some of the proteins are additionally denatured. There are different methods of popping used such as conventional method of dry heat, sand and salt treated, hot air popping, gun puffing, popping in hot oil and microwave popping throughout the world (Gundboudi, 2006).

Popcorn is a kind of maize which is utilized uniquely to pop. Popcorn, the first snack is without a doubt the most established one and has been eaten for hundreds of years. The current increase in popcorn product is because of the expansion of microwavable popcorn items to buyers who request improved comfort (Gundboudi, 2006). Likewise, there has been an expansion as of late of seasoned prepared popped popcorns on top of the typical salted, buttered and caramel covered popcorns. Other than household utilization, popcorn is broadly eaten at theaters, entertainment and games (Gundboudi, 2006).

A couple of reports done on popping of sorghum found that, sorghum grain expands greatly when exposed to high temperature short time (HTST) treatment. Popping grants good taste and desirable flavours to popped sorghum (Gundboudi 2006). Popping is a dry heat procedure and may denature lipase enzymes and improve the shelf life of the product. Popped sorghum is a ready to eat product and can be utilized as a snack food, specialty products and as a base for advancement of valuable nourishments (Gundboudi 2006).

Food products processed from sorghum for human consumption such as flakes, pasta, vermicelli, semolina and so forth, are emerging. In Kenya, many varieties of sorghum and hybrids are being developed to increase yield and process sorghum (Dayakar and Singh, 2010). In several countries, especially in Africa, sorghum will continue to be a major food crop. The grains are used for both traditional and novel foods (Chavan *et al* 2014).

Some of the different processes used to make ready to eat cereal products include extrusion, flaking, puffing, shredding and granule formation and are usually used in processing of wheat, maize and rice. Corn flakes are the most popular flakes among the cereal flakes but there are several other flakes prepared from other cereals. Sorghum flakes may be possible to develop by suitable processing method. Flakes are popular ready to eat food and have unique characteristics such as being crisp and friable in texture (Chavan *et al.*, 2014).

Millets are the most suitable cereal for production of ready to eat flakes due to their relatively smaller size and quick hydration. Little information is available regarding the technologies required to prepare flakes from sorghum and the nutritional values of the developed product. Several researches attempted to develop sorghum semolina and their products it might therefore be feasible to make flakes from sorghum (Chavan *et al.*, 2014).

2.5 TRADITIONAL SORGHUM-BASED PRODUCTS

2.5.1 INJERA

Injera (Enjera) is the staple food and the most undisputed food of choice for Ethiopians. *Injera* is produced from a number of cereal flours, but primarily *tef* (*Eragrostis tef*) and sorghum, either singly or in combination. What is interesting is that despite the fact that neither of these grains contains gluten, *injera* is leavened bread with an attractive spongy texture (Taylor, 2003). *Enjera* making starts with dehulling the grain manually or mechanically before milling into fine flour. The resultant flour is blended with water to form a dough, then a pre-fermented portion called *ersho* is added, and stored for 2 to 3 days for fermentation (Blandino *et al.*, 2003).

The starter *ersho* is a viscous fluid remained from previously fermented dough which is used to start the process of fermentation. When fermentation is complete, the viscous dough is diluted slightly with water to a thick batter and baked by spreading onto a hot, oil smeared flat pan, which is closed with a tightly fitting cover to contain the steam generated. The enjera gets ready in about less than 5 min, then it is put in a basket-like containers. The shelf life cannot normally reach beyond three days at room temperature (Blandino *et al.*, 2003). Yeast and fungi sp including *Pullaria sp., Aspergillus sp., Penicillium sp., Rhodotorula sp., Hormodendrum sp., Candida sp*. and a number of other different microbes are found to be the main microorganisms causing fermentation of *enjera*. A well baked *enjera* is usually round, about 5 mm in thickness and 60 cm in diameter, soft, spongy and resilient, it has uniformly distributed 'bread eyes' on the top and has a unique sour flavour which is the main quality characteristics of a good *enjera*. It has been reported the *enjera* is rich in Ca and Fe making it nutritionally of good value (Blandino *et al.*, 2003).

2.5.2 OSHIKUNDU

This is non alcoholic fermented drink which is very popular in the Northern, Central and Kavango regions of Namibia where the land is suitable for pearl millet and sorghum farming (Shapi and Cheikhyoussef, 2012). *Oshikundu* is popular among the Owambo communities in Northern Namibia who use it on daily basis. Brewing is usually done for household consumption but it is also done for income generation as it is sold. Traditionally, *oshikundu* is served to visitors as a sign of welcome and hospitality; it is also served during important ceremonies as a part of the tradition such as initiation of girls (Misihairabgwi and Cheikhyoussef, 2017).

Oshikundu is prepared and served on regular basis as well as during weddings and other important occasions and social interaction places. Pearl millet flour and sorghum flour are the main ingredients for production with addition of water. Sometimes pearl millet bran may be added to as an ingredient. Oshikundu is a highly perishable beverage and has approximately six hours of shelf life (Ashekele *et al.*, 2012).

Processing stages of traditional oshikundu production includes: boiled water is added to pearl millet flour with continuous stirring; this is followed by a second procedure involving mixing of sorghum malt, hot water and pearl millet flour and stirring continuously. Germinated and milled sorghum is added to the mixture after it has cooled to room temperature and then stirred well. This is the stage at which pearl millet bran might be added. Cold water is added depending on the required volume and consistency then pre-fermented portion is mixed to initiate the process of fermentation, and the blend is stored for up to 6 hrs under the shade for fermentation (Cheikhyoussef and Kahaka, 2012).

2.5.3 Kisra

Kisra (Aseeda or Aveda) is enjera-like product that is eaten throughout the Arabian Peninsula. The basic ingredients of kisra are sorghum or pearl millet flour which is fermented and made into dough. After kisra dough has completely fermented, it is baked on a hot plate into thin, flat sheets and it is usually consumed with different types of stews prepared from meat with vegetables. In kisra, *Lactobacillus sp.*, *Acetobacter sp.* and *S. Cerevisiae* are the main microorganisms' involved but it is believed that there are other microorganisms which may also be present although they have not been identified. Traditional methods of processing kisra such as fermentation, germination and baking have shown to have profound effect on the contents of vitamin B1, B2 and mineral. The mineral level of fermented kisra has not been significantly affected whereas fermentation increased riboflavin level and greatly decreased thiamine (Blandino *et al.*, 2003).

2.5.4 TO

To is a traditional staple food for many communities in many parts of Africa, especially below the Sahara desert. The grain is dehulled first and pounded using a mortar and a pestle to form flour. Water acidified with lemon juice or tamarind juice is used to cook the flour. The ratio of water to flour varies from community to community but is approximately 4:1. After cooking, the *To* is allowed to cool for about an hour before being served with sauce. The sauce is usually made from variety of ingredients such as tomatoes, chillies, cow pea leaves, cow peas, Amaranthus and other vegetables (Ratnavathi and Patil, 2013).

2.5.5 BOGOBE

Bogobe is a porridge like product eaten with meat or vegetables and can be fermented or non-fermented. It is fermented for about 24 hours to form a thin porridge and is known as *motogo wa ting* or *ting*. Fermentation is initiated by addition of pre-fermented portion that is prepared from small amount sorghum flour fermented for around 48 hr. Bogobe products has different names depending on the time of the day consumed, for example: when it is firm and not fermented it is called *mosokwane*. And whereas Ting is consumed in the morning and evening, *mosokwane* is consumed at lunch. Different types of *mosokwane* exist where sorghum flour is blended with a small quantity of wheat flour and sugar and then boiled to make porridge known as *mageu* (Ratnavathi and Patil, 2013).

2.5.6 OGI

Ogi is a popular Nigerian thick porridge consumed throughout in Nigeria. It is traditionally the first weaning food for children in Nigeria. *Ogi* is usually made from sorghum, fermented maize, millet or mashed rice. The stages of traditional *ogi* preparation include steeping which involves cleaning of the grains, soaking in water for 2 to 3 days, wet milling and sieving. This is usually followed by a souring phase which involves sedimentation of the filtrate for 12h to 2 days to obtain sour *ogi (*Apotiola, 2013).

2.5.7 TORTILLA

Traditional tortillas are indigenous to Central American countries and have often been consumed as stable bread or with a variety of meat and/or vegetable fillings as burritos, tacos, tamales, and enchiladas tortillas have successfully been made using triticale and sorghum in place of wheat or corn as flour components (Hayes, 2014).

Flour blends made from maize and sorghum to make tortilla is regarded by many as the best way in which sorghum will be utilized by Mexicans for food. Sorghum behaves similar to maize with reference to the rheological properties and quality of the dough and the final *tortilla.*

Tortilla made from sorghum has darker colour due to the tannins and phenols present in the sorghum grain. After nixtamalization the grains are ground to very fine flour to form dough. When making tortilla, a round press with a diameter of about 15cm is used and about 30g of the dough in the shape of a round ball. The ball is placed in the middle of the press between two pieces of nylon plastic and pressed very gently to make the round tortilla which is then baked on a hot pan until completely cooked (Ratnavathi and Patil, 2013).

2.6 NUTRITIONAL COMPOSITION OF SORGHUM

Sorghum (*Sorghum bicolor*) is a staple food crop for many resource poor communities particularly in ASAL regions. Sorghum is used as food for human consumption and animal feed, alcohol production and also important industrial ingredient (Awika and Rooney, 2004). Sorghum is an excellent source of carbohydrate and energy like any other cereal, it contains no gluten hence have a great potential in the gluten-free market where recently the frequency of Celiac Disease (CD), which is an immunological response to gluten intolerance is increasing. Sorghum grain has phenolic compounds like flavonoids (Kulamarva *et al.,* 2009) which have been reported to prevent the growth of tumour.

Sorghum utilization could be beneficial to diabetic people because hydrolyzed sorghum starches (in to sugars) are released slowly compared to other cereal crops (Kulamarva *et al.,* 2009). Studies indicate that a mature sorghum grain contains about 10% embryo, 8% bran, or pericarp and the endosperm constitutes more than 80% of the grain depending on the environmental growth conditions, genetic background and state of maturity (Kulamarva *et al.,* 2009).

Starch constitutes the highest percentage (averagely 69.5 %.) of the sorghum grain like any other cereal since carbohydrate is stored in starch form (Table 2.1). sorghum in particular and cereals in general, arabinoxylans or pentosans have very important role during bread manufacturing and have a renown effect on the water absorption, starch retrogradation and the general characteristics of the dough. Although sorghum flour has similar quantity of starch as other cereals such as wheat, it has less α-amylase enzyme and amylolytic activities compared to wheat flour (Kulamarva *et al.,* 2009). After starch, proteins are the most important component of sorghum grains. The amount of protein in sorghum varies and depends on genetic variety and environmental growth factors. The protein content of sorghum is proven to change with the changes in its amino acid composition (Kulamarva *et al.*, 2009). The amount of protein composition in sorghum is similar to that of other cereals like maize and wheat. The consumer acceptability and preference of sorghum products is influenced by the higher fiber content and poor digestibility of nutrients in sorghum products.

Sorghum contains good amount of minerals that has different bioavailability ranging from lower than 1 percent for some forms of iron, to more than 90 percent for Na and K. but sorghum grain has lower amounts of Phosphorous, potassium, Magnesium, Calcium, Sodium, Zinc, Iron, Manganese, and Copper when compared with barley and rye (Ragaee *et al*., 2006). The mineral composition of sorghum grain is influenced by both genetic variety and environmental factors (Zhao *et al*., 2009; Hussain *et al*., 2010; Zhang *et al*., 2010) and the interaction of environmental conditions and the genotype makes it difficult for the development of enhanced variety for a crop in a specified environment (Mgonja *et al*., 2008). The macro and micro nutrient constituents of sorghum breeder varieties differ greatly over a wide range of environmental conditions; however, there are some genotypes that show consistent trends in macro-and-micro nutrient composition (Ng'uni *et al*., 2011).

Studies indicate that sorghum grain is rich in vitamin B-complex which plays an important role in body energy metabolism. Sorghum has high energy content and good supply of vitamin B-complex which is a perfect combination for energy utilization. Some of the main vitamins containing in sorghum grain include: thiamin, riboflavin, niacin, pantothenate, and vitamin B6. For young children whose ages range between 1 and 9 years, consumption of sorghum provides them 26-47% of the World health organizations' RNI recommendations for vitamin B_1, 16-28% for vitamin B_2, 24-49% for vitamin B_3, 31-63% for vitamin B_5, and 118 to 59% for vitamin B6 (Lindsay, 2010).

Table 2.1 Nutritional content of sorghum whole kernel and its fractions

Kernel fraction	% of kernel weight	Protein[b] (%)	Mineral (%)	Lipid (%)	Starch (%)	Niacin (mg/100 g)	Riboflavin (mg/100 g)	Pyridoxin (mg/100 g)
Whole kernel	100	12.3	1.67	3.6	73.8	4.5	0.13	0.47
Endosperm	82.3	12.3	0.37	0.6	82.5	4.4	0.09	0.40
		(80)	(20)	(13)	(94)	(76)	(50)	(76)
Germ	9.8	18.9	10.4	28.1	13.4	8.1	0.39	0.72
		(15)	(69)	(76)	(20)	(17)	(28)	(16)
Bran	7.9	6.7	2.0	4.9	34.6	4.4	0.40	0.44
		(43)	(11)	(11)	(4)	(7)	(22)	(8)

[a]Values in parentheses represent percentage of whole kernel value; and [b]N × 6.25.

Source: Kulamarva 2009

However, sorghum grain is low in protein content, while the essential amino acids lysine, threonine, and tryptophan are limited. Hence, if sorghum were to be used to produce products singly, it would be necessary to find an accessible, yet high quality source of nutrients, including protein, to complement it (Awobusuyi, 2020). Thus, using starch sources such as maize, oat, barley and wheat combined with sources of protein such as peas or beans can increase the nutritional quality of snack products (Patil *et al.*, 2016).

Sorghum grain, on the other hand, has low protein content, and the important amino acids threonine, tryptophan, and lysine are limited. Therefore, when sorghum is used to produce products singly, a readily available, high-quality supply of nutrients, including protein, would be required to supplement it (Awobusuyi, 2020). Thus, combining carbohydrate sources like wheat, barley, oat, and maize with protein sources like beans or peas can improve the nutritional quality of snack foods (Patil *et al*., 2016).

Cereal grains provide considerable amounts of minerals, fibre and vitamins in addition to providing energy; however they are deficient in the crucial amino acid lysine. As a result, diets based solely on cereal grains cannot guarantee nutritional security (Igbabul *et al*. 2015). Legumes, on the other hand, are low cost protein sources that are high in lysine but low in sulphur-containing amino acids like cysteine and methionine. However, they have antinutritional components that limit their utilization.

Despite this, they continue to play an important role in increasing the protein content of cereal-based products. It has been found that products made from blends of cereals and legumes have a higher nutritional and calorific content than products made just from cereals or legumes alone. Combining cereals and legumes improves the protein and energy content. This is a critical approach to malnutrition in Africa, because most African diets consist mostly of cereals as staple food. The importance of such crops in reducing malnutrition is critical (Igbabul *et al*., 2015).

2.7 PIGEON PEA

Pigeon pea (*Cajanus cajan* (L.) is the third most important legume in Kenya after bean (*Phaseolus vulgaris*) and cowpea (Mergeai *et al.*, 2001). Pigeon pea is drought-tolerant protein rich food grain legume which has multiple uses. The crop provides numerous benefits to asset-less poor farmers such as protein source, animal feed, fuel and fencing material as well as improving soil fertility due to nitrogen fixing and control of soil erosion (Mergeai *et al.*, 2001).

Pigeon peas (*Cajanus cajan*) is well adapted to semi-arid climate conditions and can also grow in a variety of different agro-ecological zones. It forms an important part of the farming systems of the small scale farmers in many parts of the developing countries. In terms of production and area of cultivation, pigeon pea is ranked sixth after beans, pea and duck peas (Fasoyiro *et al.*, 2005).

Due to the global climate change, droughts are becoming common and arid and semi arid areas are expanding, pigeon peas will therefore be very crucial tool in managing food insecurity and nutritional situation in many parts of Africa. Pigeon pea is one of the few crops that can produce even during dry seasons where many other grains dry (Mutegi and Zingore, 2014).

One of the most effective methods to address protein energy malnutrition in under developed countries is fortification of cereal grains with legumes. Pigeon pea flour has high level of protein, iron and phosphorus and has been proven to be suitable source of protein supplementation with cereal grains (Marete, 2015). Due to its high nutritional quality, pigeon peas has been recommended and effectively used in school feeding programs as well as vulnerable sections of the populations in the developing countries. Pigeon pea presents a main source of diet and income to many farmers in the ASAL regions where other grains fail (Ojwang *et al.*, 2016). Pigeon pea is consumed in the marginalized regions as the main diet as well as to supplement with the cereal foods (Ojwang *et al.*, 2016). It is consumed in many forms and is reported that it has various medicinal properties beside its nutritional value. This is due to the presence of polyphenols and flavonoids (Saxena *et al.*, 2010).

Some pigeon pea varieties are used mainly as vegetable but are grown under same agronomical conditions only that the pods are harvested before they get to the ripening stage (Ojwang *et al.*, 2016). After harvesting, pigeon peas are unshelled manually and sold to the consumers in different quantities although sometimes it is sold with the shell depending on the target market (Shiferaw *et al*., 2008).

2.7.1 Nutritional value of pigeon peas

Legumes are reported to be the main source of proteins in the developing countries especially in marginalized areas where rainfall is minimal. Among the legumes family, pigeon pea plays a key role in the diets of rain-fed agricultural communities (Saxena *et al*., 2010). The pigeon pea seed consists of 85 percent cotyledon, 14% seed coat, and 1 percent embryo. Pigeon peas have good amount of protein, carbohydrates, minerals and vitamins. The protein content of pigeon peas is reported to range from 20% to 22% carbohydrate from 51.45% to 58.8%, Crude fibre between 1.2 – 8.1% and fat between 0.6 -3.8% (Talari and Shakappa, 2018).

Starch and non-starch fractions are the major components of carbohydrates of pigeon pea consisting of significant amount of α-galactosides. The carbohydrate fractions of pigeon peas include available carbohydrate fractions which are digested in the small intestine and unavailable carbohydrates which are not digested in the small intestine such as oligosaccharides, resistant starch, non-cellulosic polysaccharides, pectins, hemicelluloses, and cellulose (Cummings, 2007). The unavailable carbohydrates of pigeon pea like fructans and raffinose family oligosaccharides (RFOs) are the major water soluble carbohydrates which adversely affect bioavailability of certain vital nutrients (Talari and Shakappa, 2018).

Table 2.2 Proximate composition of pigeon peas

Proximate	**Oke, (2014)**	**Eltayeb *et al*. (2010)**	**Olalekan & Bosede, (2010)**	**Adamu, (2013)**	**Kunyunga *et al*. (2013)**

Moisture	11.20	8.0	8.45±0.95	0.24	11.27±0.04
protein	22.40	21.0	24.46±0.32	30.53	17.95±0.06
fat	2.74	1.7	4.78±0.22	3.68	2.77±0.57
Carbohydrate	48.19	63.6	56.63±0.48	50.08	57.45±0.04
Fibre	7.25	2.5	1.10±0.10	5.54	6.98±0.08
Ash	8.22	3.2	4.58±0.40	9.93	3.58±0.21

Source: Talari and Shakappa 2018.

2.7.1.1 Amino acid profile of pigeon peas

Generally, the amino acids methionine and cystine which are sulphur containing amino acids are found in low quantity in pulses. Pigeon pea seeds have high amounts of the amino acids lysine, leucine, aspartic acid, glutamic acid and arginine and are the main source of essential amino acids when consumed with cereals and other sulphur containing amino acids (Ade-Omowaye *et al.*, 2015). In a study, it has been reported that pigeon pea have similar nutritional quality as soybean and may be used in place of soybean without impacting rabbit performance (Adamu and Oyetunde, 2013). The best substitution combination is achieved when the ratio by weight of cereals to legume is about 7:3 (Sharma and Verma, 2011). Methionine and cystine are found in pigeon peas at around 1% in the embryo and the seed cotyledon whereas calcium is found in the coat and also in the embryo (Saxena *et al.*, 2010).

Table 2.3 Amino acid profiles of pigeon pea

Amino acid	Akande *et al.*,(2010) (g/ 16gN)	Nwokolo,(1987) (g/ 100g)	Kunyanga *et al.*, (2013) (g/ 100g)	Ade-Omowaye*et al.* (2015) (g/ kg)
Lysine	7.79	7.4	0.25	14.77
Histidine	3.66	5.0	0.66	7.93

Arginine	5.86	6.9	1.11	13.51
Aspartic acid	11.56	9.9	1.84	22.55
Threonine	3.12	3.7	0.72	8.25
Serine	3.59	4.9	0.99	1.42
Glutamic acid	9.23	19.7	3.14	43.31
Proline	3.17	4.8	0.85	1.44
Glycine	3.07	4.2	0.69	7.85
Alanine	3.79	4.6	0.91	9.72
Cystine	1.19	0.8	0.24	5.47
Valine	5.85	4.4	1.09	8.67
Methionine	1.19	1.1	0.23	2.65
Isoleucine	3.47	3.7	0.64	7.71
Leucine	6.78	7.8	1.38	16.48
Tyrosine	2.63	2.9	0.47	5.52
Phenylalanine	6.15	8.9	1.69	22.19
Tryptophan	ND	-	0.15	-

Source: Talari and Shakappa 2018

2.7.1.2 Fatty acid profile of pigeon peas

Palmitic acid is the most abundant saturated fatty acid in pigeon pea, accounting for up to 25% of the total in the neutral fats, up to 30% in the phospholipids and 40% of the glycolipids (Talari and Shakappa, 2018). In Southwest Nigeria, a study was conducted to determine the nutritional value of nine underutilized legumes. Linoleic acid was found to be the most abundant polyunsaturated fatty acid (PUFA) in pigeon pea (C18:2) (Ade-Omowaye *et al*., 2015). Caprylic, lauric, oleic and eicosanoic acids occurred but in small amount only. Short chain fatty acids are reported to be present in higher amount in starch derived from pigeon peas. Indian food composition tables reported the palmitic acid content of pigeon pea as 236, oleic acid was 78.55; stearic acid was 40.95 mg/100g respectively (Longvah *et al*., 2017).

2.7.1.3 Vitamins and minerals

Pigeon pea provides good amount of water soluble vitamins, like B1, B2, and B3 etc. Pigeon pea was found to contain the highest amount of Vitamin C among all the vegetables with 569 mg/100g. Vitamin C content of pigeon peas is three folds more than the amount in peppers and is able to provide up to 94% of the Vitamin C RDI and when compared to other pulses, pigeon pea has been found to contain a high carotenoid level of 364.3 g/100g (Ellong *et al*., 2015). Indian food composition tables reported that pigeon pea has thiamine content of 0.74 , vitamin B_2 0.15, pantothenic acid 1.56, Pyridoxine 0.42, vitamin B_7 0.65, folates 229 mg/ 100g (Longvah *et al*., 2017). There quantities of lutein and zeaxanthin levels in pigeon pea have not been researched adequately. Minerals such as P, Mg, Fe, Ca, S, and K are abundant in pigeon pea, but sodium is low (Kunyanga *et al*., 2013). Average nitrogen level ranges from 1.95 to 3.33% and 2.24% to 3.17%, Ca amount between 0.25% and 0.37%, and 0.26% to 0.51% and P content between 0.56 % to 0.72 % and 0.58% - 0.80% in varieties of pigeon pea (Sangle, 2015). Indian food composition tables found that the Ca content of pigeon pea is 1.39, Cu 1.32, and Fe 5.37 mg/100g (Longvah *et al*., 2017).

2.7.1.3 Prebiotic and health benefits of pigeon peas

Prebiotics are more recent concept compared to probiotics, and are dietary compounds that can selectively induce the growth of beneficial components of the indigenous gut microorganisms, like lactobacilli and bifidobacteria. Prebiotics are finding increased interest and application into the food sector recently (Blatchford *et al*., 2013).

Fermentation of carbohydrates supplies the energy required for the growth and development of the gut microbiota. In several researches, prebiotics have been shown to help with weight control by enhancing microbial balance, reducing adiposity, and improving mucosal integrity with decreased inflammation (John *et al*., 2012).

Various systems have been involved in the relationship between gut microbiota, increased fatty acid digestion, and storage of fat calories (Mallappa *et al*., 2012). Prebiotics can be used to regulate the microbiota of the gastrointestinal tract, which plays an important role in the physiology of obesity. A diet that contains high amount of un-metabolized carbohydrates resulted in significant weight loss and associated basic alterations in the gut flora in obese children (Zhang *et al*., 2015). Another study found that prebiotic fiber intake for sixteen weeks increased bifidobacterial abundance in overweight and obese children, proving that prebiotic fiber is a possible therapy option for body fat reduction through gut microbiota modification (Nicolucci *et al*., 2015).

The prebiotic potential of red gram raffinose oligosaccharides has recently been proven in an animal model. The prebiotic potential of red gram oligosaccharides was discovered to have a hypolipidemic effect, lowering blood glucose levels, improving HDL, and lowering LDL. This fresh body of evidence may be sufficient to support the pigeon pea's prebiotic potential (Talari and Shakappa, 2018).

Because of phytochemicals and bioactive substances that have key roles in humans, the nutritional components of pigeon pea are commonly considered necessary for human nutrition (Talari and Shakappa, 2018). Cajanus cajan leaves have traditionally been used to treat jaundice by the Rabha tribe. They have also been described as effective for the treatment of smallpox, chicken pox, measles, and as an astringent mouthwash by indigenous people in North East India (Sarma *et al*., 2015). Sickle cell anemia can be controlled with the use of pigeon peas. Many Sickle Cell Disease patients in India use pigeon pea for successful erythrocyte control in Chhattisgarh (Verma, 2015).

In a survey, pigeon pea plant was identified as a traditional medicinal plant used in Northern and South-Eastern Ivory Coast for the treatment of anemia (Kone, 2011).

Pigeon pea contains anti-ulcer properties as well (Mansoor, 2015). Diet and lifestyle strategies are recommended by the European Society of Hypertension as a foundation for hypertension prevention and therapy. Both water concentrations of pigeon pea that are fermented by bacteria and *bacillus subtilis* have been shown to improve both systolic and diastolic blood pressure in hypertensive rats (Lee *et al*., 2015).

2.8 RTE BREAKFAST CEREALS

Ready to eat (RTE) breakfast cereals are products processed from different cereal grains which can be consumed without any further cooking. Because of their ease of preparation, diversity, and nutritious quality, ready to eat breakfast cereals usually have a stable shelf life and are light in weight. They are preferred by customers of all ages (Asif, 2011).

Breakfast cereal is undisputable important product in the modern life in the world where urbanization is growing fast and on top of that people are getting more health conscious. Now, breakfast cereals give variety of choices of whole grain diet options and meet the consumer demands for the whole society regardless of the age group. Cereal grains are rich in nutritional components like carbohydrates, fibre, fat, phenolics and antioxidants, vitamins and minerals which have been reported to have health benefits such as reduction of the risk of cancer. These protective substances are reported to be removed during grain processing such as refining because they are found in the germ or the bran (Janvekar, 2010)

For a long time now, breakfast cereals have been perceived to have very important role to contribute a balanced diet (McKevith, 2010). Guidelines regarding on diets noted that breakfast cereals especially whole grain breakfast cereals are key source of important nutrients (N.H.M.R.C. Australia, 2013). Breakfast cereals are rich in antioxidant components apart from being rich source of minerals and vitamins (Ryan *et al.,* 2011) and phytoestrogens (Kuhnle *et al.,* 2009) and are undeniably the most outstanding source of whole grain (Devlin *et al.,* 2013). People who usually eat breakfast cereals have high milk intake ration and stand high chance of meeting their RNI especially dietary fibre, vitamin B, folic acid, Ca, Fe, Mg and Zn (Williams, 2014)

In most cases, the nutritional value of the breakfast cereals is achieved through fortification. Consumption of breakfast cereal is said to be associated with low fat intake. Evidences are emerging to indicate that eating breakfast cereal leads to a better mental wellbeing, improved intellectual working and diminished danger of high blood pressure however more conclusive research is required to be done before any conclusion is drawn (Williams, 2014). In general, breakfast cereals form very important base in the diet of the modern society. They are cheap, have high nutrient content, convenient product and can be suggested as a healthy form of balanced diet. The regular eating of breakfast cereals can assist to provide enough nutrient intakes and may even help in preventing or reducing the risk of overweight, cardiovascular or diabetes.

Malnutrition resulting from lack of protein is thought to be the main nutritional issue facing in most of the under developed countries in the world. Pulses have high protein content and essential amino acids such as lysine although sulphur containing amino acids like methionine and cystein are limiting. Apart from that, cereal products are known to have low protein content and are deficient in lysine but have sufficient amount of sulphur containing amino acids. This makes the pulses the ideal protein to fortify it with cereal grains to produce a product of well-balanced amino acids. In developing countries, legume proteins are cheaper source of proteins compared to animal proteins which are more expensive (Gbenyi *et al.*, 2016).

2.10 GAPS IN KNOWLEDGE

Sorghum is a promising cereal grain that can be used in the fight against hunger as well as spark income generation and employment opportunities for small scale farmers and the country in general especially for the communities residing in ASAL and marginalized regions. This potential has not been exploited significantly. There is need for increased research on sorghum products like development of new sorghum based products with high nutrient dense. Sorghum can also be an effective tool to reduce the impact of the increasing global climate change especially for poor and vulnerable farmers.

There is limited information on production of flakes and breakfast cereal products from sorghum while it is possible to develop high nutrient dense products from sorghum grains using suitable processing techniques. In this study, attempts were therefore made to develop ready to eat breakfast cereal from sorghum and pigeon pea blends through drum drying.

2.11 THESIS LAYOUT

CHAPTER ONE: GENERAL INTRODUCTION.

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: UTILIZATION AND PROCESSING OF SORGHUM BY SMALL HOLDER FARMERS AND FARMER GROUPS IN DROUGHT PRONE AGRO-ECOLOGICAL ZONES OF KENYA

CHAPTER FOUR: EFFECTS OF PROCESSING ON NUTRITIONAL QUALITY AND ANTINUTRITIONAL COMPOSITION OF READY TO EAT BREAKFAST CEREAL DEVELOPED FROM SORGHUM-PIGEON PEAS BLENDS

CHAPTER FIVE: MICROBIAL AND KEEPING QUALITY OF A READY TO EAT BREAKFAST CEREAL DEVELOPED FROM SORGHUM-PIGEON PEAS BLENDS

CHAPTER SIX: GENERAL CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 3: UTILIZATION AND PROCESSING OF SORGHUM BY SMALL HOLDER FARMERS AND FARMER GROUPS IN DROUGHT PRONE AGRO-ECOLOGICAL ZONES OF KENYA

3.1 ABSTRACT

Sorghum is an under-utilized crop and one of the most important cereal crops in semi-arid tropics. In Kenya, sorghum is grown in the often drought prone marginal agricultural areas of Eastern, Nyanza and Coast regions with many biotic and abiotic constraints that reduce its productivity. It is typically grown by small-scale, resource-poor farmers and mainly used for home consumption. The study was designed to assess the current utilization and processing of sorghum by small holder farmers and farmer groups in drought prone agro-ecological zones of Kenya. Makueni County, a representative of drought prone agro-ecological zones was purposively selected since sorghum is highly cultivated, and the region has organized formally registered farmer groups and is also easily accessible. Key informant interviews (20), household survey questionnaires (300), and focus group discussions (12) with the small holder farmers were conducted to gather data on sorghum production, challenges in production, consumption, and utilization, processing technology and market access. The farmers' average sorghum farming experience was found to be 8.2 years. The age of the farmer was positively correlated with their experience in the production of sorghum. Level of education was another factor that had direct impact in sorghum production with those who had lower levels of education having significantly ($P<0.05$) higher number of years of involvement in sorghum farming. 46% of the interviewed farmers were male whereas 54% were female with majority (92.3%) of the farmers being married. The main uses of sorghum include: Stiff porridge (*ugali*) (35.2%), thin porridge (*uji*) (42.6%), fried dough (*mandazi*) (3.1%), flat bread (chapatti) (2.6%), *githeri* (sorghum mixed with

legumes) (11.5%), beverage (sorghum tea) (1.2%) and other uses such as preparation of sorghum cake (3.8%). Female farmers reported significantly ($P<0.05$) higher utilization level (59%) with more diversified products compared to their male counterparts. The greatest challenges that hinders utilization and limits processing of sorghum and value addition were lack of markets (12.3%), low volumes of production due to low productivity (3.5%), lack of capital (4.6%), pest and diseases (38.2%), lack of equipment (24.6%) and lack of processing knowledge (16.8%.). The study recommends that more farmers training on sorghum value addition should be conducted as well as creating awareness on sorghum products utilization and linking the products to the markets

Keywords: Sorghum products, Utilization, Processing, Small Holder Farmers, Farmer Groups.

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3.2 INTRODUCTION

Sorghum is one of the most important cereal crops in the ASAL regions of Africa where it is mainly used for human consumption and as animal feed. The crop is a staple food crop for large populations living in India and semi-arid tropics of Africa. Nearly all the sorghum produce in these regions is used directly as human food (Kulamarva, 2009). The use of sorghum as human food in the United States and Japan is rising due to its use in snacks and cookies (Gbenyi, 2016). In many African countries, various sorghum products are available, including instant infant porridge, puffed or popped grains and flaked RTE breakfast cereals.

In West Africa, un-germinated sorghum is usually used to prepare 'to' porridge and 'ogi'. Malted sorghum is used in the preparation of local beer called 'dolo' which is cloudy and opaque with reddish colour. Infant soft porridges and non-fermented beverages are also prepared from malted sorghum (Dicko *et al.*, 2006). *Injera* is traditional pancake-like flat bread prepared in Ethiopia which is made from fermented sorghum while *Kisra* is Sudanese flat bread which is made from fermented sorghum dough (Gbenyi, 2016). Sorghum utilization could be helpful to curb the food security problems facing many regions of Asia and Africa because sorghum is a drought tolerant crop that can easily withstands the harsh climatic conditions in those regions. Sorghum is one of the major sources of energy and proteins in African and Asian countries (Chávez *et al.*, 2018).

Sorghum is an under-utilized crop and one of the most important cereal crops in semi-arid tropics (Muui *et al.*, 2013; Jacob *et al.*, 2013). Sorghum is grown for subsistence in Kenya, in the regions which usually experience recurrent droughts including Eastern, Coast, and Nyanza regions (Muui *et al.*, 2013). Many people regard sorghum to be a crop for the vulnerable and poor people in the ASAL regions and some farmers prefer to grow maize even in areas where it does not do well. Consequently, there is recurrent crop failure leading to increased food insecurity (Dicko *et al.*, 2006; Orr *et al.*, 2016). A broad range of naturally occurring biotic and abiotic constraints including poor soil fertility, water scarcity, crop pests, diseases, weeds, birds and high temperatures are well known to reduce the productivity of sorghum. This leads to low efficiencies of input use, suppressed crop output and reduced food security (Strange and Scott, 2005; Gregory *et al.*, 2005).

Most farmers in Eastern Kenya grow sorghum for home consumption along with legumes such as green grams, pigeon pea and cowpea and cereals like maize. Very few farmers grow sorghum for income generation (Muui *et al*., 2013). Sorghum is seen by most farmers as a less valuable cash crop, therefore they do not invest in its production. This is common traditional view in most African cultures where sorghum is regarded as a poor man's crop (Kagwiria *et al*., 2019).

The increasing crop failures of the common crops preferred by farmers in the arid and semi-arid areas like maize and beans, has also increased the need for farmers to shift crop choices to more drought tolerant ones, including varieties that are resistant to drought and diseases (Khan *et al.*, 2014; Hadebe *et al.*, 2016). Kagwiria and others (2019) reported that farmers in Makueni County owned more land, but they allocated less than one hectare for sorghum production and as a result the sorghum production was low.

In the arid and semi-arid regions, sorghum is a good crop option since it gives farmers an opportunity to produce and harvest from the otherwise unproductive lands using the limited inputs they have. Therefore it forms an important livelihood crop for the communities who experience crop failures (Oyier *et al.*, 2016). Sorghum grain is a staple food crop for many people living in the semi-arid tropics. It is an ideal crop for the rural communities facing food insecurity and has good storage properties. A diverse range of products have been developed by different local communities based on traditional processing technologies although commercialization of the products is yet to be achieved in most regions (Oyier *et al.,* 2016, Okuthe *et al.*, 2013). Therefore the main objective of this study was to assess the current situation on utilization and processing of sorghum by smallholder farmer/groups in drought prone agro-ecological zones of Kenya.

3.3 METHODOLOGY

3.3.1 Study Design

The research design employed in this study was cross-sectional consisting semi-structured questionnaire, focus group discussions, direct visual observations, and key informant interviews to get information from the study subjects.

3.3.2 Sampling procedure/protocol

The sampling procedure employed in this research was purposive sampling technique to identify farmers growing sorghum who could provide relevant information about the research topic.

3.3.3 Sample size determination

The study population comprised of sorghum growing households and targeted the farmers who had grown sorghum in at least the last three cropping season. A sample size of 300 farmers was selected using the formula of Fischer et al., 1991):

$$n = \frac{z^2pq}{d^2}$$

Where;

n= the desired sample size (assuming the population is greater than 10000)

z= the standard normal deviation, set at 1.96, which corresponds to 95% confidence interval

p=proportion in the target population to have particular characteristic and in this study, the proportion was calculated with the assumption that 74% of the farmers in the study area grow sorghum which was obtained from pretested questionnaires, sampling errors of 5% and 95% confidence interval was also assumed. (Ören and Biçkes, 2011; Rodriguez del Aguila and Gonzalez-Ramirez, 2013)

q= 1-p

d= degree of accuracy desired, here set at 0.05, corresponding to the 1.96

$$\text{Hence, } n = \frac{1.96^2 \times 0.74 \times (1-0.74)}{0.05^2} \approx 296 \text{ farmers}$$

3.3.4 Study Setting

The study was conducted in Makueni County, a representative of drought prone areas situated in agro-ecological zone in Kenya where sorghum is a widely cultivated crop and the region has organized formally registered farmer groups

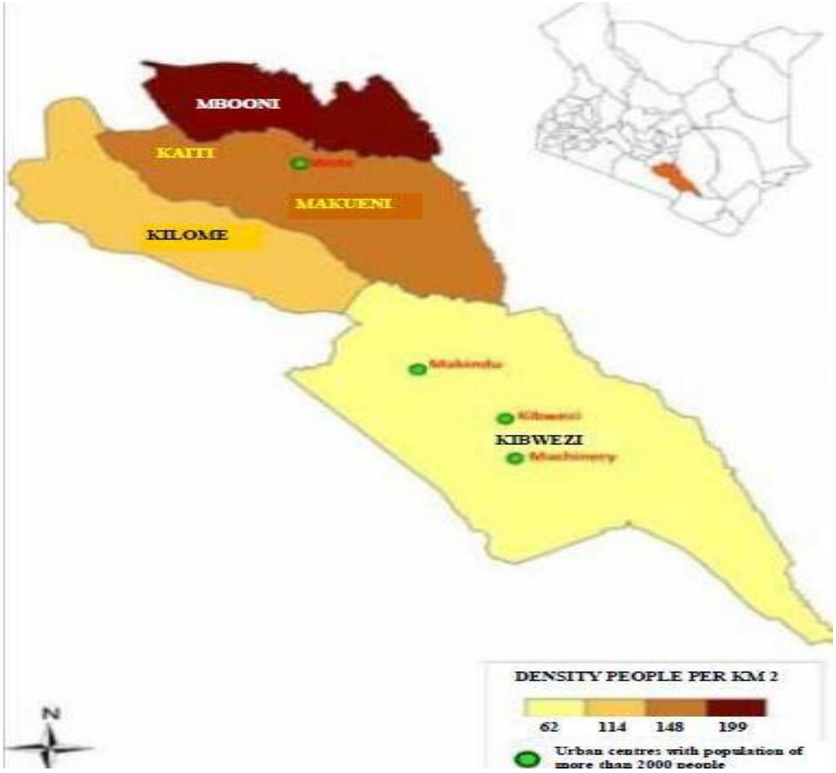


Figure 3.1 Map of Kenya showing the study area

The locations where the study was conducted included: Kaiti Sub County wards of Kee, Kilungu, Ilima and Ukia. Makueni Sub County: wards included Muvau, Kathonzweni, Mavindini, Kitise/Kithuki, Wote and Mbitini. Kibwezi West Sub County: wards Makindu, Kikumbulyu North, Kikumbulyu South, Nguumo, Masumba and Emali. The study was conducted in March and April 2019.

3.3.5 Methods of data collection

3.3.5.1 Household surveys

300 individual farmers were randomly selected for the household surveys targeting the farmers who had grown sorghum in at least the last three cropping seasons. The interviews were conducted by local field assistants. A previously pretested semi-structured questionnaire was used as a guide to gather the information (Appendix 3). The selected households were interviewed on a variety of issues, including sorghum

production, challenges in production, consumption and utilization, processing technology and market access. The interviews were administered using questionnaires designed and pre-tested in the field by trained enumerators using the local languages.

3.3.5.2 KEY INFORMANT INTERVIEWS (KII)

Key informant interviews were conducted with 20 people comprising of government extension officers, farmers' group leaders, grain millers and sorghum farmers who have been active in the sorghum sub-sector. These individuals were selected with the help of the district extension officers and on the basis that they interact with the farmers frequently. The interviews of the key informants were conducted individually, to avoid influences from other informants (Appendix 2).

3.3.5.3 FOCUS GROUP DISCUSSIONS (FGDs)

Eight focus group discussions were conducted mainly with the farmer groups and some of the farmers selected by the group leaders on the basis of their experience in sorghum farming. Many of the farmers in the study area are organized into Common Interest Groups (CIGs) such as farmer groups or self-help groups. These groups are registered with the Ministry responsible for Social Services. Agricultural development aid and projects as well as extension services by the government and development organizations are delivered through these groups and are therefore obvious avenues for agriculture and nutrition change and information flows. The focus group discussion membership constituted 11 to 15 participants with attempts to balance gender of group members and Swahili language was the main language of communication since most of the farmers could not understand English. Where necessary, the questions were interpreted with the help of local field assistants for better understanding (Appendix 1).

3.3.6 Data quality control

The questionnaire was validated through pre-testing. The research assistants were closely supervised by the principal investigator during the pre-testing and throughout the survey period.

After data entry into the computer, frequencies were run for each variable to check for outliers that may have occurred due to errors during data entry and also check for consistency of responses between questions.

3.3.7 Statistical Analysis

The data collected were subjected to Analysis of Variance (ANOVA) using SPSS version 2.0 for Windows and effects declared significant at 5% level. Least Significance Difference was used to separate means.

3.8 RESULTS AND DISCUSSION

3.8.1 Demographic Characteristics of the Farmers

The socio-demographic characteristics of the farmers are summarized in Table 3.1. Of all the farmers who were interviewed, 46.0% of them were male whereas 54.0% were female. Majority (92.3%) of the farmers were married. The number of female farmers (54.0%) was more than that of male farmers (46.0%) which mean women are more involved in sorghum farming than men. More women were found to be involved in farming than men probably due to the fact that women are usually left behind at home to take care of the farming activities as men look for extra way of earnings to sustain the family needs since the farming activities are not solely enough to sustain the family. This finding was in agreement with that of Muui and othrers (2013) and Ogeto and others (2013) who found that the number of female farmers were more than that of males. Similarly, Marangu and othrers (2014) and Okuthe and othrers (2013) also found that more than a half of the interviewed farmers were female.

More than half of the farmers (51.3%) have completed primary education while only a quarter (25%) has completed secondary. Those who indicated that they have completed tertiary education were 9.4% while 13.4% of the interviewed farmers have dropped out of school at either primary or secondary school. Roughly 1% of the farmers did not go to school at all. The literacy level among the farmers is still low indicating that most of the farmers do farming activities on experimental basis. This could be based on the fact that those who have completed their basic education look for white collar jobs rather than farming. Chepng'etich and othrers (2015) found that almost half (46%) of all the farmers captured in a survey done in Makueni and Machakos Counties, terminated their formal education at primary level while 14% of the household heads have not attended any formal school at all. Noel (2015) found that in Tanzania, majority (79.75%) of the farmers have acquired primary education. Omoro (2013) also reported that most of the farmers were not well educated with 74% of the male farmers having not gone past primary level while 72% of the female respondents have not gone past primary education. Similar findings were also reported by Muui and othrers (2013) and Ogeto and others (2013).

Table 3.1 Socio-demographic characteristics of sorghum farmers

Demographic characteristics	Percentage
Gender	
Male	46.0
Female	54.0
Marital status	
Single	7.7
Married	92.3
Level of education	
Completed primary	51.3
Completed secondary	25.0
Completed tertiary	9.4
Dropped out in any of the above levels	13.4
Did not go to school	0.9

3.4.2 Sorghum Production

The farmers' average sorghum farming experience was found to be 8.2 years. The age of the farmer was positively correlated with their experience in the production of sorghum. Level of education was another factor that had direct impact in sorghum production with those who had lower levels of education having significantly ($P<0.05$) higher number of years of involvement in sorghum farming (Figure 3.2). Similar findings were reported by Chepng'etich and othrers (2015) who found that up to 61% of the farmers in Makindu, Makueni County had more than five years of sorghum farming experience. Koome and Wanjohi (2017) also reported that majority of the sorghum farmers in Giaki location, Meru County have not less than 6 years of experience in the sector. And in Zimbabwe, Musara and others (2019) reported that most farmers had an average 15 years farming experience.

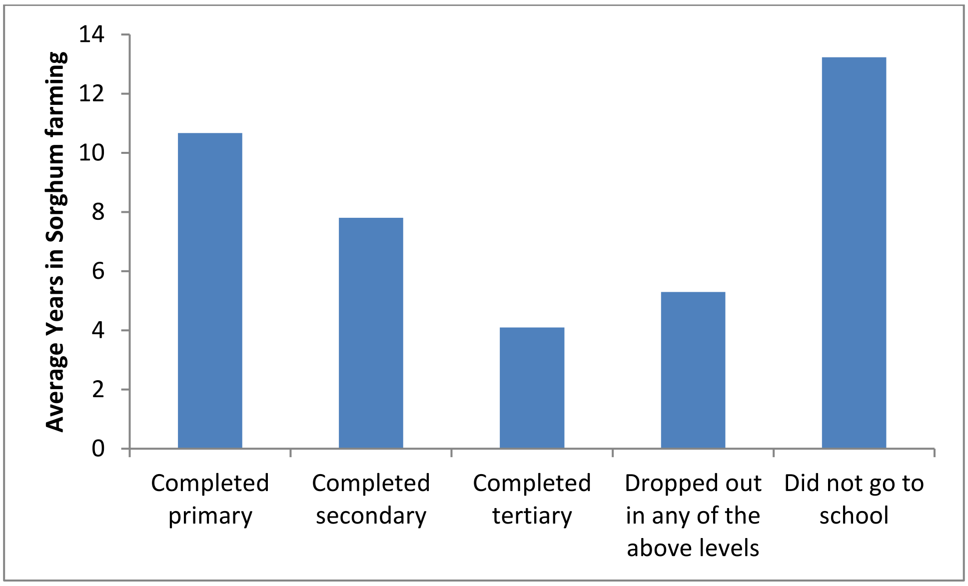


Figure 3.2 Years spent in sorghum farming based on the level of education

The sorghum sector in the study site is dominated by small scale and subsistent farmers with a mean average quantity of sorghum harvested during a high season ranging between 270 kg ha^{-1} to 3150 kg ha^{-1} while in a low season, the harvest was between less than 100 kg ha^{-1} to 305 kg ha^{-1}. Most of the farmers (53%) indicated that they harvest roughly 1t ha^{-1} in a season. Marangu and others (2014) found that sorghum productivity in Eastern Kenya ranged from 216 kg/acre to 501 kg/acre. Another study by Kagwiria and othrers (2019) reported that sorghum grain yield in Makueni was low with most of the farmers harvesting between 151-250 kg ha-1. Muui and othrers (2013), on the other hand found that sorghum yield in Eastern Kenya ranged from 1.0 to 3.5 t ha^{-1}. According to the statistics of the Food and Agriculture organization in 2014-2015, sorghum production in Kenya was inadequate (Oyier *et al.*, 2016).

Elsewhere, Akinseye and others (2020) reported that rainfall and temperature could be limiting environmental factors for sorghum productivity in semi-arid areas. Mundia and others (2019) also reported that globally, sorghum still remains below its yield potential

The farmers see sorghum as less cash crop and majority of them (76.4%) in the study area produced sorghum primarily for their own consumption. The other main objective of growing sorghum was to use it as animal feed (14.8%) while 3.8% of the farmers interviewed indicated that they produced sorghum to sell. Other purposes of sorghum production (5%) were production of alcoholic drinks and fodder production. Kagwiria and othrers (2019) indicated that 85.6% of the farmers in Makueni grow sorghum for their own consumption, 12.2% for animal feed and 2.7% for sale while Muui and othrers (2013) also reported that farmers in Eastern Kenya grow sorghum as a source of food in the household. The study is also in agreement with the findings of Kaminski and others (2013) who found that in Mali, sorghum is largely used for home consumption with only about 30% of production marketed in local and urban markets.

3.4.3 Market Access

Sorghum marketing is low with only about 23.6% of the crop marketed. The main buyers (46.5%) of sorghum are local buyers who usually come for the produce at the farm gate. Other main buyers of sorghum are brokers (middle men) (23.8%) who collect the produce at the farm gate and paid the farmers immediately and in cash, except in some cases where the farmer knows the broker in person in which case the broker was given the produce on credit. Farmers also believed that brokers sell sorghum to EABL as well as some local buyers who they said they buy sorghum on behalf of EABL. Other notable buyers' were wholesalers (14.5%) and retailers (15.2%) as shown in Figure 3.3 Male farmers were found to sell significantly ($P<0.05$) higher volume of products than female farmers owing to the fact that men are more aggressive and have higher market access opportunities compared to female. Level of education was another factor that had direct impact on sorghum marketing where those with higher level of education selling significantly ($P<0.05$) higher volumes of sorghum.

Similar findings were reported by Marangu and othrers (2014) who found that farmers sold sorghum grains to key buyers who included brokers or middlemen (67%) consumer of other farmer (16%) rural assemblers (13%) urban grain traders (4%). Elsewhere, Deribe and Kassa (2020) found that wholesalers account for the largest proportion (36.6%) of sorghum trading in Ethiopia. Mwadalu and Mwangi, (2013) also reported that sorghum marketing and trading is low due to poor marketing channels and that only 30% of the domestic production is marketed. Similarly, Mundia and others (2019), Musara and others (2019) and Kirimi (2013) all reported that sorghum trading is limited and that the crop has no reliable markets

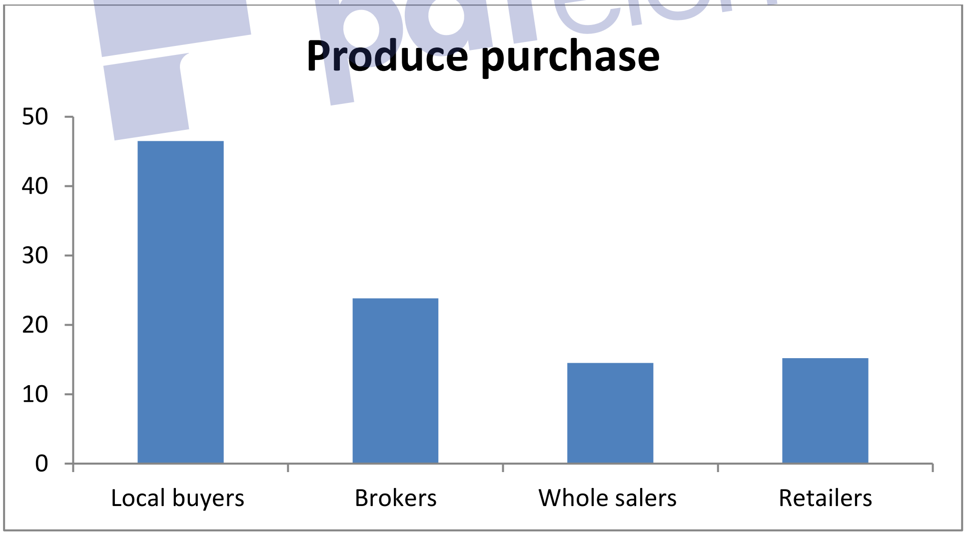


Figure 3.3 Purchase of sorghum by different buyers.

3.4.4 Intercropping of Sorghum with other crops

Most of the farmers (52.2%) practiced mixed farming where they intercropped sorghum with other crops. The main crops intercropped with sorghum were maize, cowpeas, pigeon peas, green grams, beans, and finger millet (Table 3.2). Previous studies by Marangu and othrers (2014), Kagwiria and othrers (2019) and Muui and othrers (2013) all reported that farmers intercropped sorghum with other crops mainly maize, pigeon peas, green grams, beans, cow peas and millet. Mbwika and others (2011), reported that intercropping is a dominant sorghum cropping system which is highly associated with farm risk minimization

Table 3.2 Crops intercropped with sorghum

Crop	Percentage (%)
Maize (*Zea mays*)	21.2
Cowpea (*Vigna unguiculata*)	47.7
Green gram (*Vigna radiate*)	10.2
Pigeon peas (*Cajanus cajan*)	11.5
Beans (*Phaseolus vulgaris*)	6.6
Finger millet (*Eleusine coracana*)	2.9

3.4.5 Challenges in Sorghum Production and Processing

The greatest challenges that hinder utilization and limits processing of sorghum and value addition were lack of markets (12.3%), low volumes of production due to low productivity (3.5%) and lack of capital (4.6%). Pest and diseases (38.2%) were sited to be the greatest challenge while birds were noted to be the most notorious sorghum pest by the farmers. Lack of equipments (24.6%) and lack of processing knowledge (16.8%) were the other major challenges that prevent successful processing and utilization of sorghum. Previous studies by Muui and others (2013), and Mwadalu and Mwangi, (2013) have reported similar findings that the main constraints in sorghum production were lack of funds to purchase farm inputs, pest and disease and inadequate rainfall. In addition, they sited lack of seeds, low fertilizer application, and lack of extension services as other notable challenges in sorghum production.

Okuthe and others (2013) found that the major constrains facing sorghum farmers include variable rainfall, bird damage, striga weed, disease problems and insect pest damages while Deribe and Kassa (2020) reported that in Ethiopia, 33% of the agro-processors are not aware of any food recipe that could be manufactured from the sorghum grain and that there is less diversified sorghum products while there was poor consumer knowledge on food values of sorghum. Similarly, Ouedraogo and others (2017) reported that In Burkina Faso, drought (85.6%) is the most important abiotic constraint for sorghum production

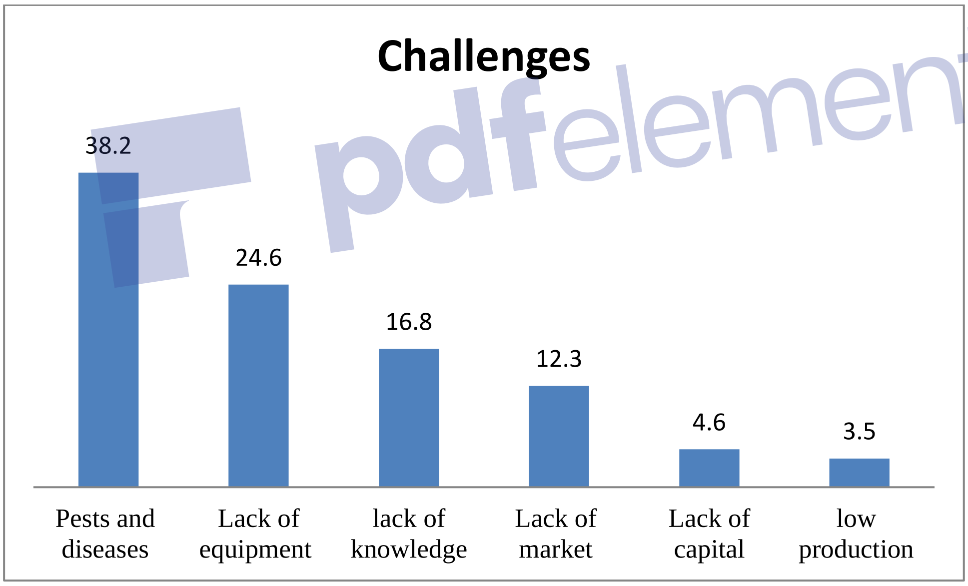


Figure 3.4 Challenges in sorghum production and processing

3.4.6 Sorghum Products

The most important uses of sorghum were preparing of *ugali* (stiff porridge) and *uji* (thin porridge). A great proportion of the farmers (42.6%) indicated that they use sorghum to prepare *uji* (thin porridge), 35.2%of the respondents said they prepared *ugali* (stiff porridge) from sorghum while 11.5% prepared *Githeri* from sorghum

(sorghum mixed with legumes). Other food products made included *Mandazi* (fried dough) (3.1%), chapatti (flat bread) (2.6%), tea or beverage (1.2%), and other uses (3.8%) such as preparation of sorghum cake. Some farmer groups make sorghum cake and sorghum tea where they sold these products at local markets especially during special occasions and functions. During preparation of chapatti (flat bread), cake and *mandazi* (fried dough), sorghum flour is mixed with small amount (up to 30%) of wheat flour to help spreading of the dough. *Ugali* (stiff porridge), *githeri* (sorghum mixed with legume) and *uji* (porridge) were used as main dishes which are prepared almost on daily basis while other products like cakes and the beverage were less frequently used and made only during functions and special occasions.

Previous study conducted by Marangu and others (2014) found that the most important uses for sorghum flour were for preparation of porridge (*uji*) (50%) and *ugali* (stiff porridge) (37%) while other uses included preparation of alcoholic drinks (4%), chapatti (flat bread) (7%), cake (1%) and as animal feed (2%). Similar findings were also reported by Kavoi and others (2013) who found that the main sorghum products made by the farmers were porridge, sorghum cake, '*Musandi'* (sorghum mixed with cowpea), sorghum chapatti (flat bread) and sorghum *Mandazi* (fried dough). Elsewhere Deribe and Kassa (2020) reported that in Ethiopia, the higher volume of sorghum is traditionally utilized for making *enjera*, porridge and traditional drinks while Noel (2015) reported that in Tanzania the use of sorghum include stiff porridge i.e. (*Ugali*) (87.25%) followed by animal feed (80.87%) porridge (57.39%), while few responses have been observed on uses such as local brew (36.82%) non alcoholic drinks (23.77%), other uses (35.36%), and fried products (2.32%). Buah and others (2010) also reported that in Ghana sorghum is used primarily to prepare local foods such as thick porridge (*tuo*) and thin porridge (*koko*) and any other dietary functions

Female farmers realized significant amount of sorghum utilization (59%) in all uses compared to their male counterparts and the reason behind this is attributed to the fact that food preparation is usually carried out by females in most of the communities. Similarly, Ogeto and others (2013) found that women are more involved in sorghum production than men.

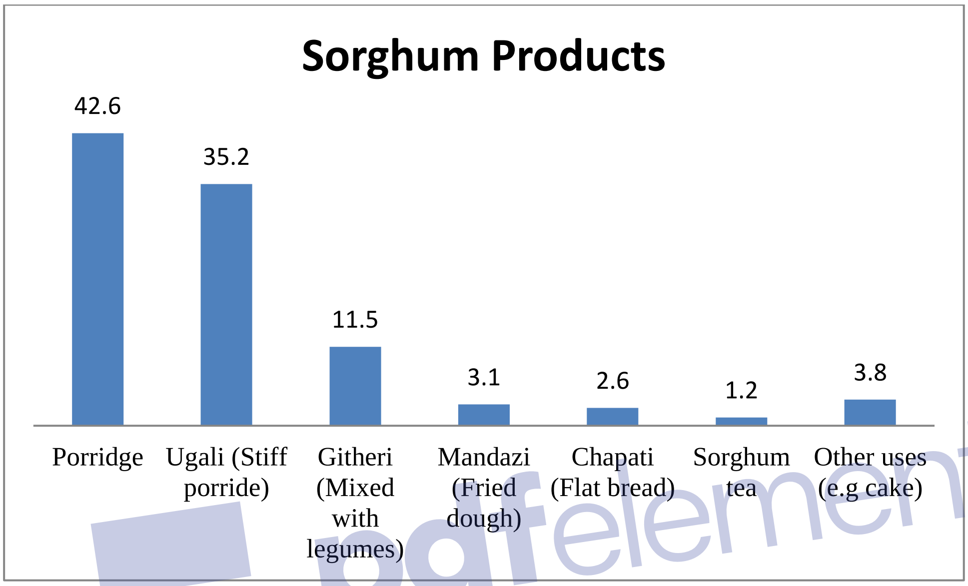


Figure 3.5 Products Processed from sorghum grain

3.4.6 Processing Technology

Grinding was the main technique used in processing of sorghum to make various products. 84.5% of the farmers indicated that they used grinding as the major technique in sorghum processing which is usually done at commercial mills. Some farmers (15.5%) said they used other forms of grinding including mortar and pestle to process sorghum in to various products. The most preferred processing technique was, however, grinding using grain milling machines (43.9%). This is because the farmers believed that it is fast, cheap, less physical and fast processing technique.

Similar findings were reported by Laswai and others (2008) who reported that processing of sorghum still relied on the rudimentary technology of pestle and mortar unlike other cereals. Marangu and others (2014) reported similar findings where they reported that the major sorghum processing activities were milling sorghum grain alone (38%), followed by blending or mixing with maize, pearl millet, cassava, cowpea, green gram or wheat for milling (36%), wet milling (15%) and dehulling (6%). Kaminski and others (2013) also found that apart from milling, there is little processing of sorghum in Mali. Nthoiwa and others (2013) reported that in Botswana, primary milling is the main sorghum processing activity with very limited value-added processing.

Table 3.3 Methods of sorghum processing

Technique	Proportion (%)
Processing technique of the products(n=385)	
Not processed	**0.3**
Grinding	**84.5**
Dehulling	**6.2**
Baking	**2.2**
Fermentation	**3.1**
Boiling	**3.7**

Products made from sorghum are mainly used for home consumption with only 18.6% of the farmers indicating that they sold the products at the local markets, while the majority (81.4%) of the farmers reported that they consumed the products at home. Of those who sold their products, their main buyers were local buyers (89.6%). The products sold include sorghum cake, sorghum tea (beverage), porridge, mandazi (fried dough) and githeri (sorghum mixed with legumes). The farmers prepare products to sell mainly at functions although some take it to the local markets such as Kathonzweni. Visitors who come to the functions also buy some of the processed sorghum products.

Marangu and others (2014) found that farmers sold sorghum flour to mainly consumer of other farmer (60%) and rural assemblers (40%). There was no ready and reliable market for the processed products from sorghum where the famers could take their products to sell therefore, apart from sorghum grain and flour, trading of other sorghum products is very much limited. Similarly, Deribe and Kassa (2020) reported that in Ethiopia, small-sized agribusiness firms use sorghum to make *enjera*. Musara and others (2019) reported that sorghum has no reliable markets while Kaminski and others (2013) reported that sorghum is largely self-consumed with only about 30 percent of production marketed in local and urban markets.

The product quality was also low as there was no standard processing technique followed. The farmers had also no adequate training on how to process such products for commercial purposes. Processing of sorghum grains in to good quality products is also not easy especially for the small scale resource poor farmers who also lack the scientific and technological know-how of cereal processing. The findings were in agreements with those of Deribe and Kassa (2020) reported that sorghum products possess poor consumer taste and perceptions and that this remains to be the major barrier as foresighted by the agro-processing firms. Similarly, Mundia and others (2019) found that sorghum is difficult to process into food-quality form with traditional reputation as a coarse grain used primarily as animal feed and dubbed as ‘the poor man’s food’, reserved for low income populations.

Majority of the farmers (73.7%) transported their products to the market or selling point using human labour. Some (13.5%) of the farmers used motorbikes, vehicles (4.9%) and animals (2.1%) to transport products to the selling point while the rest (5.8%) did not transport their products at all as shown in figure 3.6 below. Since there was no ready market for the processed products, the products were transported during special occasions and functions while the study discovered that there were some farmers who transported some products to the nearby markets on market days or to schools to target children for sorghum cookies and cake. Orr and others (2013) found that most farmers used donkeys (their own or borrowed) to transport sorghum to the market or collection centres while those who live near the market or the collection centers, women carried the sorghum on their backs. Chepng'etich and others (2015) also reported that the most commonly available and used means of transport was motorcycles although a motor vehicle was available once or twice a week only during the open market days.

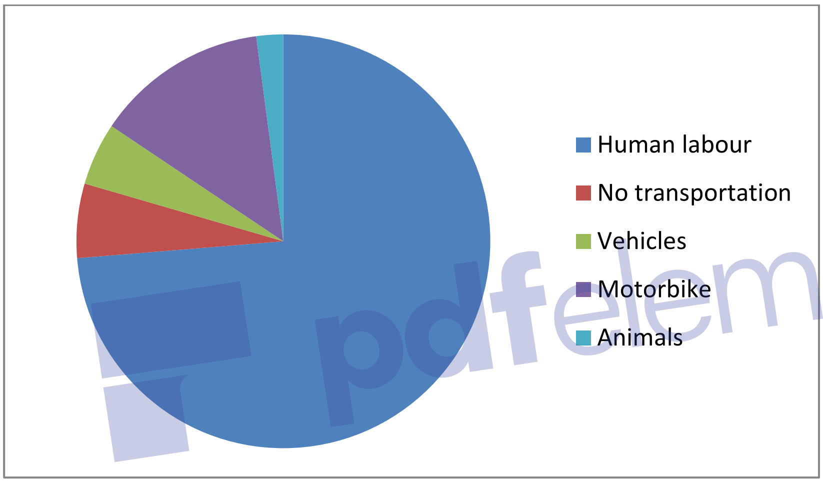


Figure 3.6 Transportation of products to the point of sale

About 73.1% of the farmers interviewed were aware of the existence of sorghum products in the market. The main commercial products that most of the farmers were aware of were sorghum beer and flour. In terms of market solutions for sorghum-based products, 41.5% of the farmers suggested creation of awareness of sorghum products in the market and 21.1% suggested adoption of new technology in sorghum products processing while 18.9%, 16.7% and 1.9% preferred the use of improved sorghum varieties, creation of new marketing channels and proper storage respectively as the best ways of improving utilization of sorghum products.

Similar findings were reported by Deribe and Kassa (2020) found that 33% of the agro-processors in Ethiopia are not aware of any food recipe that could be manufactured from the sorghum grain. Similarly, general awareness seems to be the worst for some sorghum processed products. Kleih and others (2000) also reported that poor sorghum product quality and customer awareness/psychology discourages its use. Kagwiria and others (2019) also found that there is need to increase commercialization and mechanization of the sorghum production process and recommended strengthening of farmer groups and increasing their capacity through trainings. Kavoi and others (2014) also reported that adoption of improved technologies and innovations in the Eastern region has been minimal

Table 3.4 Improving utilization and consumption of sorghum products

Suggested Solutions by farmers	Proportion (%)
Awareness creation in markets	41.5
Adoption of new technology for sorghum products processing	21.1
Improved sorghum varieties	18.9
Creation of new marketing channels	16.7

Proper storage	1.9

Commercially processed sorghum products were viewed as source of food and nutrition by about 61.5% of the farmers whereas 11.2% believed that it is the best way to create income from sorghum farming. About 1.5% of the farmers said that they believed processed sorghum products have medicinal value while the rest (25.8%) attached no positive value to sorghum based products. Orr and others (2013) found that 25% of the respondents used sorghum as food security crop while around 11% of them used it as a cash income crop. Ratnavathi and Patil, (2013) also reported that sorghum is utilized as a food in different countries, India and Africa and its nutritional value and health benefits obtained from sorghum. On the other hand, Kagwiria and others (2019) reported that most farmers consider sorghum as a less important cash crop and hence they do not invest in its production

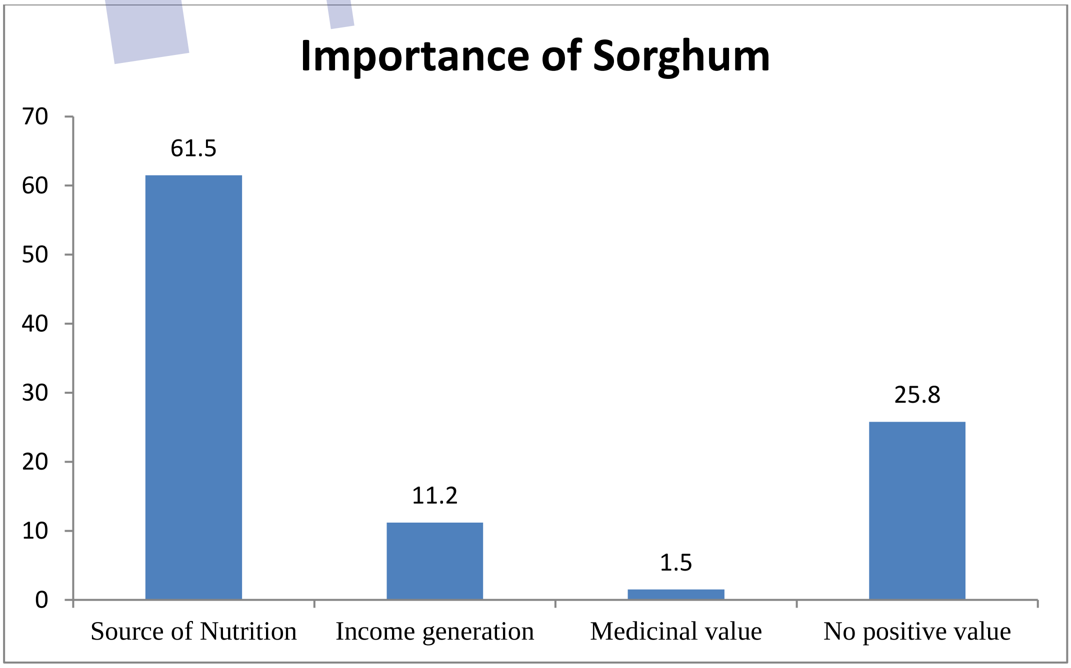


Figure 3.7 Farmers perceived importance of sorghum

3.5 Conclusions

Sorghum production in the county is well below its potential and is dominated by small scale subsistent farmers. Farmers also practice intercropping of sorghum with other crops for crop diversification and farm risk minimization. The main products made from sorghum are *Ugali* and porridge, but there are other important products made from sorghum including sorghum cake, beverage or tea, mandazi and chapatti. Milling is the main activity associated with sorghum processing which is mainly done at the poshomills. The main product from grain milling is flour which is made in to different products. Hand pounding with mortar and pestle is the primary processing technique used for milling sorghum by traditional households. The flour produced in traditional households mainly goes to self-consumption within the producing household.

CHAPTER 4: EFFECTS OF PROCESSING ON NUTRITIONAL QUALITY AND ANTINUTRITIONAL COMPOSITION OF READY TO EAT BREAKFAST CEREAL DEVELOPED FROM SORGHUM-PIGEON PEAS BLENDS

4.1 ABSTRACT

Sorghum has a high agronomic potential even under adverse tropical conditions. The crop sustains the lives of the poorest rural people and will continue to do so in the foreseeable future. However, the utilization of sorghum and its products is well below its potential. Ready to eat (RTE) breakfast flakes were developed by blending flours of sorghum and pigeon peas. The effect of fermentation, dehulling and malting techniques on nutritional, antinutritional and sensory quality of the formulated flakes were determined and the processes optimized. Dehulling and fermentation of the samples showed the highest protein content of 13.94%. Malted and fermented samples had 13.45% protein content. The untreated wholegrain sorghum samples had the lowest protein content of 11.31%. Malting and fermentation had significantly ($P<0.05$) increased the protein content (11.3% and 13.6% respectively). The protein content increased progressively with increase in the ratio of the pigeon peas. The energy content ranged from 358.60 Kcal/100g to 385.20 Kcal/100g with no significant difference among the treatments. Increase in the ratio of pigeon peas reduced the energy content. Malting and fermentation was found to increase the mineral content while dehulling reduced the mineral content. Dehulling followed by fermentation was found to be the most effective technique in reducing total phenolics, tannins and phytates with 50%, 19% and 57% reduction respectively. Untreated wholegrain sorghum samples showed the highest antinutritional contents with 0.36, 55.67 and 3.81mg/100g total phenolics, tannins and phytate content respectively. Malted samples scored highest in all sensory attributes while dehulling came second recording highest in colour and overall acceptability of 3.92. Samples formulated from 100% untreated whole grain sorghum were also acceptable (3.56). Dehulling followed by fermentation was the most effective treatment in reducing antinutritional content while malting was found to be the best treatment regarding nutritional and sensory quality with 11%, 12% and 4.5% increase in protein, fat and fibre contents respectively. Malting, decorticating and fermentation are simple and inexpensive processing techniques that can be used to improve the nutritional quality of sorghum based products while at the same time solving the problem of anti nutritional factors in sorghum.

Key words: Sorghum Breakfast Flakes, Antinutrients, Malting, Fermentation, Dehulling.

4.2 INTRODUCTION

Sorghum is an important cereal crop worldwide and is native to Africa. Sorghum is utilized as both food and animal feed. Most sorghum varieties are heat and drought tolerant which makes it the ideal crop in arid and semi-arid regions, where the crop is one of the staples for poor and rural people (Adeyeye, 2016). Despite the potential of sorghum and its important and outstanding agronomic attributes, its use for food worldwide is limited (Girard and Awika, 2018). Sorghum is used as a staple food crop mainly in ASAL regions of Africa and to a less extent in parts of India and Central America. The increased interest in diversification of food products, healthy eating and alternative food ingredients has sparked increased interest in utilization of sorghum in different parts of the world (Girard and Awika, 2018).

There are a diversity of traditional products processed from sorghum including but not limited to: fermented and unfermented products like bread, porridges, cakes, biscuits, cookies, cereal extracts, malted alcoholic and non-alcoholic drinks (Ogbonna *et al.*, 2012). Despite sorghum grain containing good array of nutrients, sorghum based products are nutritionally and organoleptically considered inferior. This has largely been associated to the presence of anti-nutrients such as phytates, polyphenols, tannins and trypsin inhibitor which tend to bind the nutrients into complexes making them nutritionally unavailable (Ogbonna *et al.*, 2012).

Several methods of processing have been employed to improve the nutritional and organoleptic characteristics of cereal based food products and at the same time eliminate or reduce the anti-nutritional contents to safe levels so that the bioavailability of the micro-nutrients in the food is improved (Mbaeyi and Onweluzo, 2010) such techniques include: fermentation, malting, dehulling, flaking, puffing and extrusion cooking among others.

Although cereal grains have been staple food for many people over the years, it has been discovered that they are poor in protein contents both in terms of quality and quantity. The amino acids lysine and tryptophan has been considered limiting in cereals and this has limited the utilization of cereals as a single food (Filli, 2017). The best alternative is therefore complimenting cereals with a protein source such as legumes.

In terms of tonnage, pigeon peas accounts about 5% of worlds legumes production and is one of the important legumes in Kenya's ASAL regions (Marete *et al*., 2016). Like sorghum, pigeon pea can grow and tolerate unfavourable environmental conditions such as poor soils and drought (Mahenge, 2018). The crop has good amount of protein, fibre, vitamins, and minerals. It therefore makes the perfect march with sorghum to make highly nutritious product from the two crops.

Malting, fermentation and dehulling are simple and inexpensive techniques that can be used to enhance the nutritional quality of complimentary food products. Fermentation and malting has been proven to increase sorghum protein content and improve flour digestibility while dehulling of grains reduces anti-nutrients drastically (Marete *et al*., 2016; Okporo *et al*., 2016).

Development of breakfast flakes from sorghum-pigeon pea blends using fermentation, malting and dehulling as processing methods can be useful means to address food security issues in the ASAL regions of Kenya. There is limited research information on sorghum breakfast cereals while most of the farmers possess little information on the processing techniques of both sorghum and pigeon peas (Marete *et al*., 2016). The aim of this is study was therefore, to determine the effect of processing techniques and formulation ratios on the nutritional, anti-nutritional and sensory characteristics of sorghum-pigeon pea flakes.

4.3 MATERIALS AND METHODS

4.3.1 Sample Collection and Preparation

Sorghum and pigeon pea grains were purchased from authorized grain suppliers in Nairobi. The cleaning, grading and the product development were done at the pilot plant of the Department of Food Science Nutrition and Technology, Faculty of Agriculture, Collage of Agriculture and Veterinary Sciences, University of Nairobi. The samples were cleaned manually to remove foreign materials, broken pieces, insect parts, and infected grains. The grains were then washed with tap water to remove dust and mud and then dried to 12% moisture. Other ingredients were also purchased from authorized suppliers in Nairobi.

4.3.2 Experimental Design

The experimental design employed in this study was a 6 by 3 factorial design. The study examined the effect of two processing techniques of ready to eat cereal flakes on the nutritional, anti-nutrient, and sensory quality. The product treatment or preparation method included (dehulled, dehulled and fermented, malted, malted and fermented, whole grain, whole grain and fermented) and the formulation ratios of the two grains sorghum: pigeon pea (100:0, 80:20 and 60:40). The formulations were done according to the methods developed by Kinyua and others, (2016), Tope, (2014) and Mbaeyi, (2010). Using all combinations of these factors, a total of 18 samples of ready to eat cereal flakes were formulated and analyzed for their proximate composition, anti-nutritional content, mineral composition, and sensory characteristics. The experiment was done in duplicates.

4.3.3 Product Formulation and Treatments

4.3.3.1 Preparation of whole grain sorghum flour

2 kg of sorghum grains were cleaned manually to remove foreign contaminants. The grains were then washed with water to clean from dust and adherent impurities and

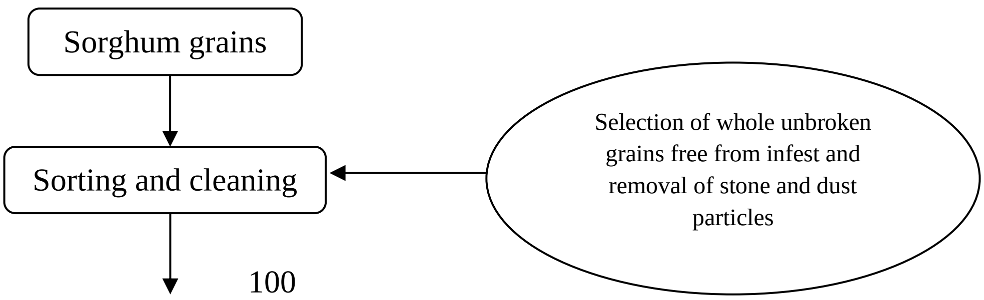
oven dried at 105°C to 12% moisture. The grain were then milled using a commercial hammer mill to obtain flour that can be sieved through 0.3mm sieve size and packed in air tight containers for storage before using in product formulation.

4.3.3.2 Preparation of decorticated sorghum flour

About 2kg of decorticated (dehulled) sorghum grains were purchased from an authorized cereal supplier in Nairobi and hand cleaned to remove visible impurities such as stones, husk, and chaff. The grain was then washed with tap water and oven dried at 105°C to 12% moisture. The clean decorticated sorghum grains were then milled using commercial hammer miller to pass through 0.3 mm sieve screen and packaged in air-tight container for storage.

4.3.3.3 Preparation of malted sorghum flour

Sorghum grains were first cleaned, graded and soaked for 12 hours in tap water (1:2 W: V). After soaking, the grains were drained and germinated by spreading out on a tray and covered with a cloth. Water was sprinkled on the germinating grains after every 12 hours for four days. The germinated grains were dried in a cabinet drier at 65ºC for 5 hours. The rootlets of the sprouted grains were removed by hand through abrasion. The dried malted grains were then milled in to fine flour of 0.3mm sieve size and packaged in air tight packages for use in the product formulation. The following diagram shows the scheme of malted flour production.



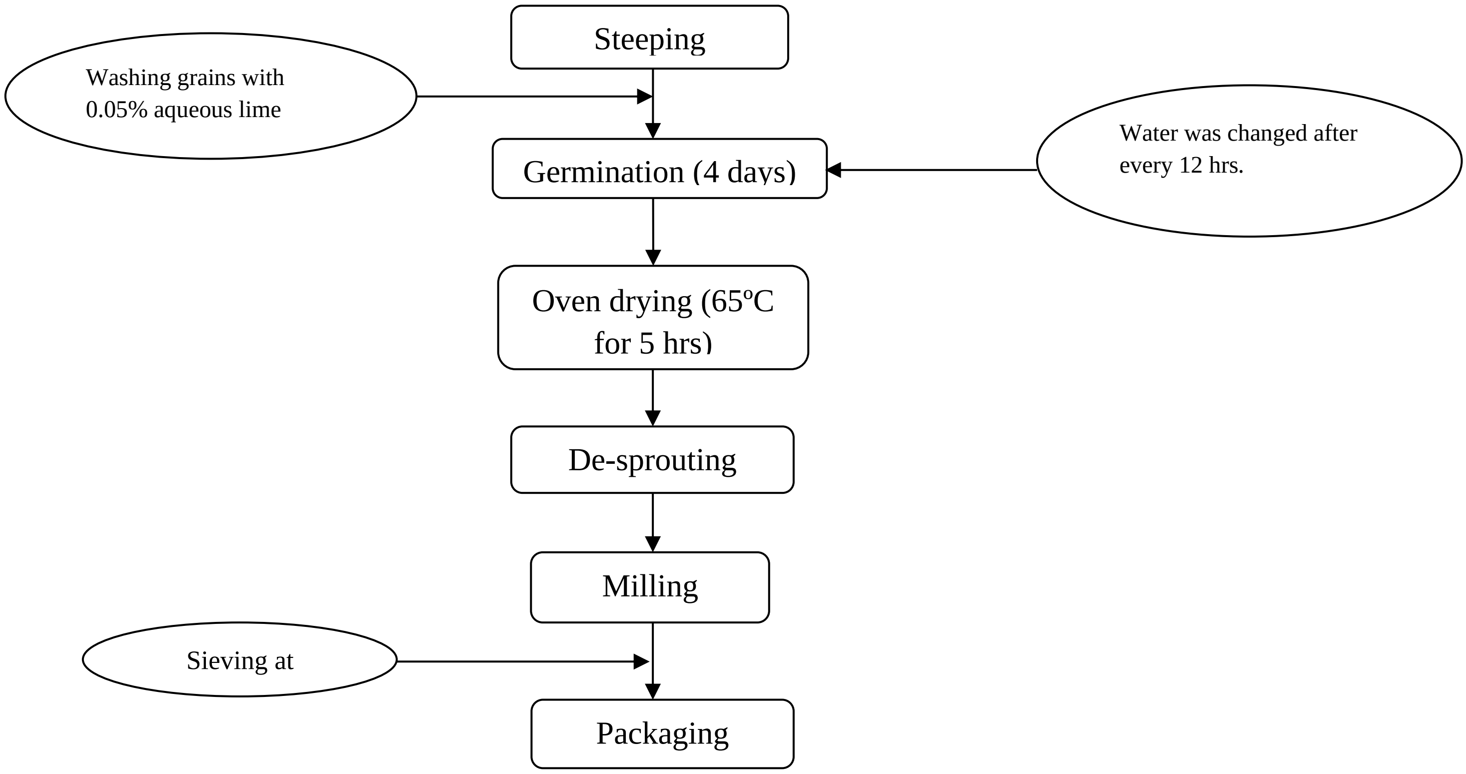


Figure 4.1 Production of Malted Sorghum Flour

4.3.3.4 Preparation of pigeon peas flour

Pigeon pea grains were sorted to remove insect infested grains, broken pieces and other foreign materials. The grains were then washed thoroughly and oven dried at 70ºC for 5 hours. The dried grains were then milled using commercial hammer mills to obtain fine flour of 0.3 mm sieve size and then stored in airtight containers for storage.

4.3.3.5 Preparation of fermented flours

Pre-fermented portions of fermented sorghum flour were prepared from 500g of fine malted sorghum flour, dehulled sorghum flour and whole grain sorghum flour. To prepare the portions, 500g of fine sorghum flours was mixed with 1liter of water (1:2 w/v) to form a thick paste which was then put in a container and then incubated at 37ºC for 24 hours. To start the fermentation process spontaneously, the pre-fermented portions were used to prepare a larger amount of fermented flours.

In each treatment (malting, dehulling and whole grain), 120g of the pre-fermented portions were mixed with 500g of fine flour and 600ml of water. The thick paste dough formed was then left to ferment at room temperature (25ºC) for 24 hours. The dough was then transferred to perforated metal trays and spread into a thin layer. The trays were then put into a cabinet drier at 75°C for 8 hours. The dried materials were then cooled before breaking into small pieces which were then milled using hammer miller to obtain fine fermented flours named malted and fermented, dehulled and fermented and whole grain fermented accordingly.

4.3.3.6 Processing of the sorghum-pigeon peas flakes

The flakes were prepared using the flours formulated. 500g of the prepared flour (69.4%) was mixed with 600ml of water, sugar 80g (11.1%), cooking oil 30ml (4.2%), salt 10g (1.4%) and milk powder 100g (13.95). the thick dough obtained was flaked using steam heated drum drier. About 200g of the paste was put on the surface of the rotating drum drier and spread to a uniform thickness of about 0.6mm. The product was flaked at 140°C for 10 minutes until a golden brown sheet was formed. The sheet was then collected in clean metal trays to cool before cutting into smaller pieces of about 5mm by 5mm which were then packaged in airtight packages.

The drum drier used was Single drum drier for drying (APV-Mitchell (Dryers) Ltd., Carlisle, England) with Diameter 12 in. (0.30A8 m) Total surface area = 0.2797 m^2 Length 11.5 in. (0.2921 m) Effective drying surface - 79.3% (0.2217 m^2).

Table 4.1 Typical operational data on preparation of sorghum-pigeon peas flakes

Drum drier speed	1.43 rpm
Steam pressure (gauge pressure)	4.08 kg/cm^2 (4.0 bar)
Steam temperature	140°C
Drying time	10 min

4.3.4 Analytical methods

4.3.4.1 Chemical composition

4.3.4.1.1 Determination of Moisture content

The AOAC standard method 950.46 (AOAC, 2005) was used. Approximately 5g of the sample was weighed in aluminum made dish which was placed in an oven at 105ºC for approximately 5 hours. Cooling followed and both the dish and the residue were weighed. The difference in weight between the original fresh sample weight and the dried sample gave the moisture content. This was expressed as per cent moisture content.

4.3.4.1.2 Determination of Fat content

The soxhlet method according to AOAC Approved method 954.02 (AOAC, 2006) was used to determine the crude fat content of the products. 5g of pounded sample was accurately weighed into an extraction thimble containing cotton wool which was then transferred into the sohxlet extractor and extraction of the fat done in a tared flask for 8 hours using petroleum ether (B.P. 40-60ºC). Evaporation of the fat was done in a rotary evaporator. The drying of the residue was done in an air oven at 105ºC for about 1 hour and then weighed. Determination of the fat content was done and values expressed in form of percentage of the sample dry matter content

4.3.4.1.3 Determination of Protein content

The approved AOAC (2006) Kjeldahl 992.15 method was used for crude protein determination. 0.5g of the sample was accurately weighed and placed in a Kjeldahl flask, folded in a nitrogen free filter paper. A catalyst tablet and sulphuric acid were carefully added to digest the sample in a fume chamber. Phenolphthalein was used as the end point indicator before the Kjeldahl flask was connected to a distillation unit. 40% NaOH solution was used for back titration against a 0.1N HCL solution. The standard conversion factor for Nitrogen into crude protein content of the sample was 6.25.

4.3.4.1.4 Fibre Determination

Method 978.10 of AOAC (2006) was used. 10g of sample was digested with 200 ml of boiling 0.225N Sulphuric acid in heating mantle for 30 minutes with condenser. After boiling, the contents were filtered through a fluted funnel and washed with boiling water to remove the acids. It was then boiled with preheated 200 ml of 0.313 NaOH for 30 minutes in heating mantle with condenser. The sample was again filtered and washed in fluted funnel. The material was then dried, weighed and then ashed in the furnace at 540˚C. Subtraction of ash weight from weight of acid, alkali treated sample gave weight of crude fibre.

$$\text{Crude fiber (\%)} \quad \frac{\text{Weight of crude fiber}}{\text{Weight of sample taken}} \times 100$$

4.3.4.1.5 Determination of ash content

The standard AOAC (2006) Method 942.05 was used. Charred samples were placed in dishes followed by heating for 6 hours at 525ºC till the ash become white in colour. The weight of the obtained ash was divided by the weight of the sample and expressed in percentage.

4.3.4.2 Determination of anti-nutritional content

Raw sorghum grains were dried in hot air oven at 50ºC for 6 hours and then milled using laboratory mill (hammer mill, type DFH48, No. 282521/UPM 6000, Sitzerland) and sieved (0.1mm) to obtain fine flour for further analysis. The extraction and analysis were done as follows

4.3.4.2.1 Total Phenolic Content

Total phenolics were extracted by taking 1g of defatted flour with 10ml of 100%, 80% and 50% methanol and 70% acetone acidified with 1% conc.HCL in ultrasonic bath (Bandelin Sonorex RK-514 H Berlin Germany) for 30 min. After centrifugation, all the supernatants were pooled and made up to known volume of 50ml.

The extract were then purified by treating with 1g of PVPP at 0ºC for 30min and then the contents were purified again by using a solid phase cartridge (SPC) (Strata-x-33 um polymeric sorbent, 8B S100-FCH-S, from Phenomenex USA). The total free phenolics were eluted with 10ml of 50% and 100% methanol and used for estimation by using Folin-Ciocalteu reagent (Singleton *et al.*, 1999). The absorbance was measured at 765nm with UV-Vis Spectrometer (Perkin-Elmer, Lambda 35, USA). Based on the standard curve prepared with (+) catechin hydrate (20-100µg), the amount of total free phenolics in the extract was calculated in grams sample on dry matter basis.

4.3.4.2.2 Analysis of phytic acid

1 g of defatted flour was added to 10 ml of 2.4% HCl and incubated for 10 min in ultra-sonic bath. Then the contents were centrifuged at 13,000 x g for 5 min and the supernatant is collected. Similarly, the residues were re-extracted twice and all the supernatants were pooled together and made up to a known volume of 50ml with distilled water. The extract was then purified by using an anionic-exchange column chromatography (0.7 cm x 15 cm) containing 0.5 g of anion-exchange resin (100–200 mesh, chloride form; AG1-X4, Bio-Rad Co., CA, USA) and phytic acid was eluted with 2M HCl. The extract was frozen at – 80 °C for overnight and dried in lyophilier (Virtis Freezemobile 25 EL, New York) for 8 h and finally the residue was weighed and the total dry yield of extract is calculated. The extract was re-dissolved in distilled water at the ratio of one milligram of extract per milliliter of solvent and used for further analysis. Phytic acid was quantified according to Latta & Eskin method (1980). The partially purified extract (500 µl) was diluted to 2.5 ml with distilled water and 1 ml of Wade reagent (0.03% $FeCl_3.6H_2O$ and 0.3% sulfosalicylic acid) was added. The contents were vortexed and centrifuged at 3500 x g for 5 min and the absorbance of the supernatant was measured at 500 nm using a UV-Vis Spectrometer (Perkin-Elmer, Lambda 35, USA). The phytic acid content was calculated by using the standard curve prepared with synthetic phytic acid and expressed as g/100 g on dry weight basis.

4.3.4.2.3 Analysis of tannins

The tannins were extracted from the flours by taking 1 g of defatted flour sequentially with 100%, 90%, 80%, and 70% acetone solutions acidified with 1% conc. HCl. After centrifugation, all the supernatants were pooled together and made up to a known volume with acetone. Then the extract was purified by using Sephadex LH-20 column chromatography (96 x 1.6 cm) with acetone water (50:50, v/v) as a solvent. After collecting 20 fractions (5 ml each), the active fractions were identified and pooled together and used for quantification by using modified vanillin-HCL in methanol method (Price *et al.*, 1978). The aliquot (100 µl) was taken in a test tube and treated with 3 ml of 4% vanillin and 5 ml of 70% HCl. After standing for 12 min at room temperature, the contents were mixed well and the absorbance was measured at 500 nm in a UV-Visible Spectrophotometer (Perkin-Elmer, Lambda 35). The standard curve was prepared by taking different concentrations of tannic acid and the level of tannins were calculated as g tannic acid equivalents per 100g flour.

4.3.5 Sensory Evaluation

Sensory evaluation was done using a panel of 30 semi-trained judges who were familiar with cereal products (Appendix 4). The key attributes to be focused by the panellist were colour, physical appearance, aroma (odour), texture (mouth-feel), Chewability and overall acceptability of the product. Coding was done using four digits to enable subjective and independent judgment. Water was provided for rinsing the mouth in between the samples. The 5 point hedonic scale was used to evaluate the acceptability of the developed products (Barbosa-Canovas 2009).

4.3.6 Statistical Analysis

All data collected was done in duplicates. The data was analyzed using two ways ANOVA and Fisher's unprotected LSD for multiple mean comparisons. The data obtained was subjected to statistical analysis using Genstat software version 15.0 at $P<0.05$ significance level. Sensory analysis was also done using Genstat software version 15.0 at $P<0.05$ significance level and Fisher's unprotected LSD for multiple mean comparisons to study the difference between means.

4.4 RESULTS AND DISCUSSIONS

4.4.1 Chemical composition of the formulated sorghum-pigeon pea flakes

4.4.1.1 Moisture Content

Moisture content of the flakes did not show any regular pattern with minimum moisture content of 4.08% and maximum of 7.26% (Table 4.2). The moisture content of the flakes was well within the KEBS standards of max 7.5 for flaked products (KENYA STANDARD Breakfast cereals -Specification', 2010). The table below shows the moisture content of the product. There was no significant difference in the moisture content of the samples at $P<0.05$.

Table 4.2 Effects of processing on moisture content of the formulated sorghum-pigeon peas flakes (g/100g)

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	6.27±3.63[a]	5.15±1.45[a]	5.77±1.95[a]	5.73±2.02[a]

Dehulled and fermented	6.18±3.77[a]	6.42±0.86[a]	4.08±1.45[a]	5.56±2.18[a]
Malted	6.33±3.00[a]	4.89±2.93[a]	6.76±3.66[a]	5.99±2.64[a]
Malted and fermented	6.87±0.59[a]	7.26±0.94[a]	5.83±2.16[a]	6.65±1.27[a]
Whole Grain	6.31±1.28[a]	7.20±2.00[a]	6.60±2.29[a]	6.70±1.53[a]
Whole grain fermented	7.25±1.59[a]	5.62±2.46[a]	5.94±0.72[a]	6.27±1.55[a]
Average	6.53±1.97[a]	6.09±1.73[a]	5.83±1.88[a]	
LSD	4.77			

*Values are Means ±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

The treatments did not show a particular trend in moisture with the samples made from 100% whole grain sorghum showing the highest moisture content while dehulled, malted and fermented samples showed reduced moisture content (Table 4.2). Malted samples recorded decreased moisture content which showed that the absorption of moisture in the malted samples reduce during malting than the raw sample which had higher moisture content. Nwosu and others (2013) reported that malting has reduced the moisture content of pigeon pea samples. A study by Carvalho and others, (2012) found moisture content of 6.7% for broken rice and bean extruded breakfast meal. Elsewhere, the study by Carvalho and others, (2012) noted that other studies reported moisture content of breakfast cereals containing corn flour and soybeans meal, with 5.11% and 3.74%, respectively. FAO, (2012) suggested that flakes should have moisture content of bellow 7%. Fermentation has generally led to the reduction of the moisture content of the final product except for the malted and fermented samples where the moisture content has increased (Table 4.2). Similar results were reported by

(Tope, 2014) who found decrease in moisture content with increase in fermentation time of sorghum-beniseed blends

The moisture content decreased as the levels of pigeon peas addition increased which may be because of the increase in protein content. This is important in shelf life since products with lower moisture content have better keeping quality. Similar results were found by Simwaka and others, (2017) who reported that polar amino acid residues of proteins have affinity for water molecules and Agu and others, (2015) who also found decrease in moisture content of acha-soy breakfast cereal flour due to increase in protein content and attributed this to fact that protein has more affinity to moisture than carbohydrate. Similarly, Patil and others,(2017) found reduction in moisture content of extrudates due to increase in legume incorporation. Rehman and others, (2016) also reported that increase in protein due to legume incorporation resulted reduction of moisture content.

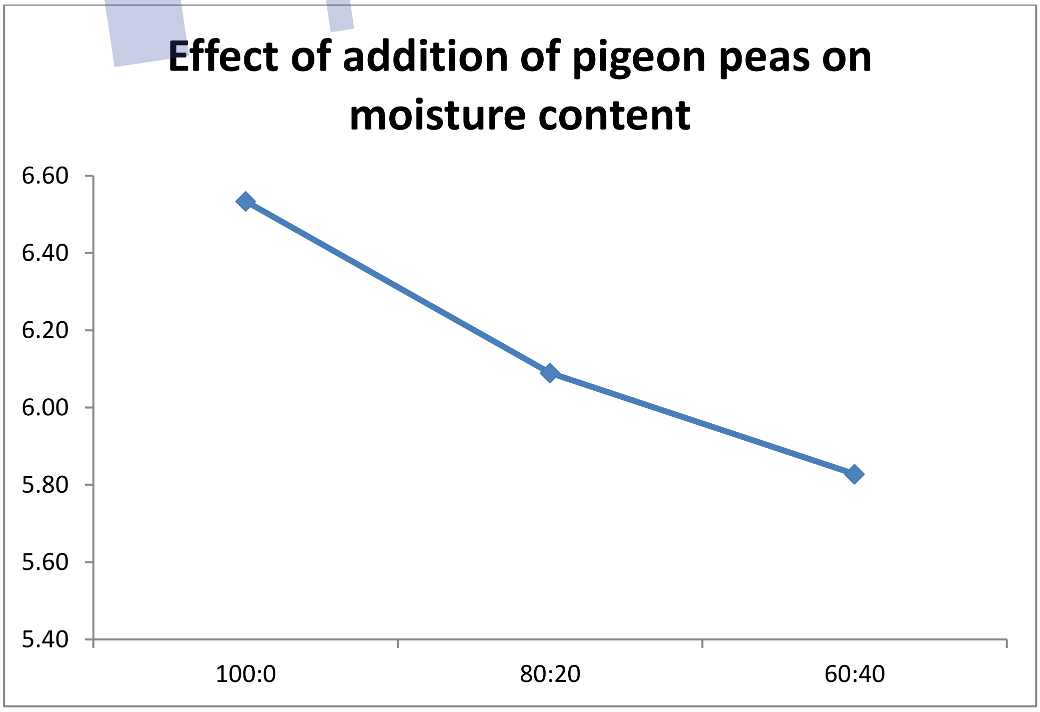


Figure 4.2 Effect of addition of pigeon peas on moisture content of the final product

4.4.1.2 Protein content

The protein content increased progressively with the increase in the proportion of pigeon peas (Fig 4.3). The interaction between the treatments (malting and fermentation) had a significant ($P<0.05$) effect on the protein content. Samples made from 100% sorghum grains had the lowest protein content while those that contained 40% pigeon peas recorded the highest protein content. The protein content of the final product ranged from 10.07% to 15.34% (Table 4.3). Dehulled samples had higher protein content than whole grain samples which could be attributed to that the seed coat contained less protein. Similar results were reported by Rababah and others, (2017), and Makinde and Akinoso, (2013) who found that raw sesame seeds contained less protein than dehulled seeds. This could also be attributed to the removal of anti-nutrients that prevent the availability of proteins that are concentrated in the seed coats. Elsewhere Wang, (2008), Mang and others, (2016) and Jonathan, and Adeyeye, (2015) found that dehulled seeds had higher protein content than whole un-dehulled grains.

Table 4.3 Protein content of the formulated sorghum-pigeon pea flakes (g/100g)

Treatments	**Sorghum/pigeon pea Blended formulation ratios**			**Average**
	Formulation 100:0	**Formulation 80:20**	**Formulation 60:40**	
Dehulled	11.07 ± 0.68^{abc}	11.42 ± 1.36^{abcd}	12.13 ± 1.12^{abcdef}	11.54 ± 0.97^{ab}
Dehulled and fermented	12.09 ± 0.74^{abcdef}	14.39 ± 0.74^{fgh}	15.34 ± 0.56^{h}	13.94 ± 1.59^{c}
Malted	10.69 ± 2.06^{ab}	12.95 ± 0.74^{bcdefgh}	14.12 ± 2.43^{efgh}	12.59 ± 2.14^{abc}

Malted and fermented	12.02 ± 0.28^{abcdef}	13.48 ± 0.38^{cdefgh}	14.86 ± 0.53^{gh}	13.45 ± 1.31^{c}
Whole Grain	10.07 ± 2.32^{a}	11.25 ± 0.29^{abc}	12.60 ± 1.30^{bcdefg}	11.31 ± 1.65^{a}
Whole grain fermented	12.57 ± 0.73^{bcdefg}	11.95 ± 0.54^{abcde}	13.85 ± 0.27^{defgh}	12.79 ± 0.97^{bc}
Average	11.42 ± 1.36^{a}	12.57 ± 1.31^{b}	13.82 ± 1.51^{c}	
LSD	2.44			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Malting had significantly (P<0.05) increased the protein content of the flakes (from 11.31 to 12.59, (Table 4.3) and this could be due to the synthesis of proteins during germination as well as the breakdown of tannin-protein complexes. The findings are in accordance with the findings of Mbaeyi, (2005) who also found that sprouting has increased the protein content of sorghum-pigeon pea composite flour. Similarly, Nwosu and others, (2013), Chaturvedi (2015), Dewar, (2003), Mbaeyi, (2005), Osman, (2011), Mugendi and Njagi, (2010) and Otutu and others, (2014) indicated increase in protein content due to malting.

The obtained data also showed a significant (P < 0.05) change in protein content of the final product (Table 4.3) due to fermentation which could be attributed to the loss of dry matter mainly carbohydrates during fermentation. Similar results were reported by Osman, (2011), Nkhata and others, (2018) and Simwaka and others, (2017) who reported reduction of protein content as a result of fermentation. Abdelseed and others, (2011) reported that fermentation improves protein content only slightly which could be due to the loss of dry matter mainly carbohydrates. Offia and others, (2017) found that fermentation did not cause significant changes (P>0.05) in protein contents for maize and soybean flours.

Increase in pigeon peas proportion has significantly increased the protein content of the final product with the 60:40 (sorghum/pigeon pea) treatments having the highest protein content (Fig 4.3). This is due to the fact that pigeon pea has higher protein content than sorghum. This is consistent with the finding of Mohammed and others 2017), Elhag, (2009), Toum, (2009), Mbaeyi, (2005) and Balasubramanian and others, (2012) who reported an increase in protein content due to addition of legumes to cereal grains. Similarly, Patil and others, (2017) also reported increase in protein content of wheat based snacks due to incorporation of legumes.

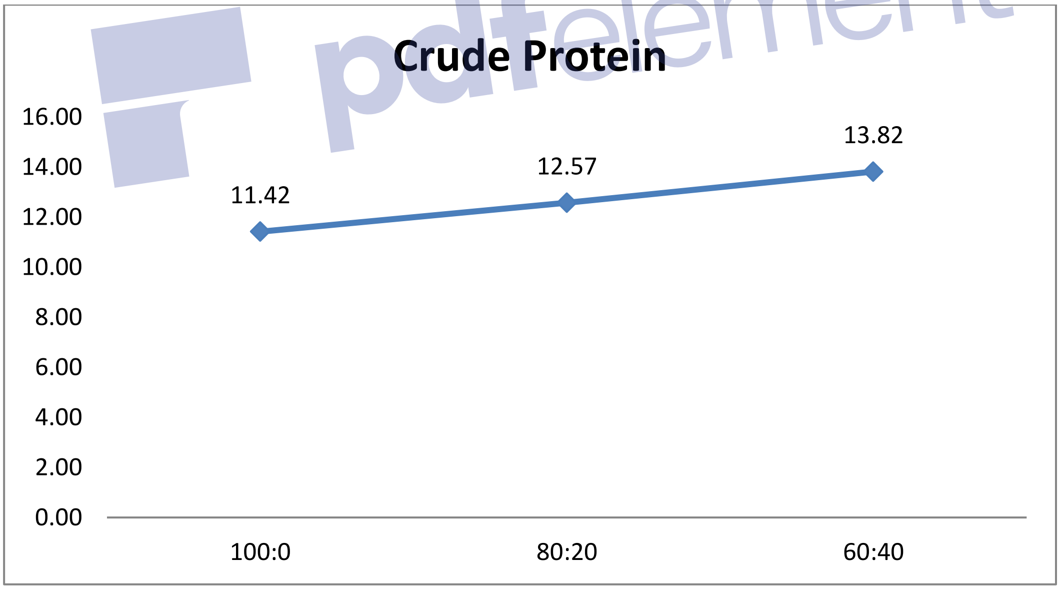


Figure 4.3 Effect of different levels of pigeon peas addition to sorghum on protein content of the formulated sorghum-pigeon peas flakes

4.4.1.3 Fat content

The fat content of the product did not show any particular trend ranging from 3.45% to 5.98% (Table 4.4). the fat content of the final flakes was well within the limits of KEBS requirements for breakfast cereal (flaked/puffed) of 8% max (KEBS Breakfast cereals -Specification, 2011). There was a significance difference (P<0.05) in the fat content of the final product. The final fat content may have been affected by the addition of vegetable oil as an ingredient during formulation of the flakes.

Table 4.4 Fat content of the formulated sorghum-pigeon pea flakes (g/100g)

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	5.98±1.28d[e]	5.08±0.55[abcde]	3.74±0.04[abc]	4.93±1.19[a]
Dehulled and fermented	4.28±0.52[abcd]	4.97±0.06[abcde]	5.21±0.41[bcde]	4.82±0.52[a]
Malted	5.51±0.27[de]	3.56±0.75[ab]	4.05±0.06[abcd]	4.37±0.98[a]
Malted and fermented	5.13±1.04[abcde]	3.45±1.36[a]	5.05±0.10[abcde]	4.54±1.14[a]
Whole Grain	5.67±1.77[de]	4.84±0.78[abcde]	4.21±0.78[abcd]	4.91±1.14[a]

Whole grain fermented	5.67±0.35[de]	4.64±1.03[abcde]	5.26±0.27[cde]	5.19±0.68[a]
Average	5.37±5.37[b]	4.42±4.42[a]	4.59±4.59[a]	
LSD	1.68			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Dehulling has increased the fat content slightly possibly due to the loss of the hulls which contain less fat and concentration of endosperm. Similar findings were reported by Anuradhaand others, (2016) and Pal and others, (2016) who found that dehulling has significantly increased the lipid content. Malting has slightly reduced the fat content which could be due to the activities of lipolytic enzymes during malting. Fat acts as a source of energy during germination. The finding was in agreement with that of Nkhata and others, (2018), Simwakaand others, (2017), Mbaeyi, (2005), Mohammed and others, (2017) and Ogbonna and others, (2012) who reported a decrease in fat content due to malting. The reduction in fat content could also be due to processing like drying, milling and flaking which are all done after malting.

Fermentation was found not to significantly affect the fat content of the final product although there was an insignificant increase, which was in consistent with the findings of Osman, (2011) who did not observe any significant change in crude fat content of sorghum after natural lactic acid fermentation for 4 days. Ongol and others, (2013) and Thuita, (2010), also reported similar results. Some yeast species responsible for fermentation may contribute to fat synthesis hence lead to the increased fat content noted.

The samples made from a 100% sorghum grains showed significantly higher crude fat content than the pigeon peas incorporated samples with the 80:20 (sorghum: pigeon peas) treatment showing the lowest content while the 60:40 (sorghum: pigeon peas) treatment showed slight increase again but there was no significance difference in fat content between the two samples. Sorghum has higher fat content than pigeon peas which is the reason why the fat content decreased at higher pigeon pea substitution level. Similar results were reported by Toum, (2009) who found that the fat content of sorghum flour decreased upon supplementation with 50% and 33.3% of white beans. In another study, Balasubramanian and others, (2012) reported comparatively lower fat content for sorghum at 15% incorporation level of legumes. Mbaeyi, (2005) reported that sorghum has higher crude fat content than pigeon peas while Mugendi and Njagi (2010) reported that legumes generally contain low fat contents of 1-2% except chickpea, soybean and peanut.

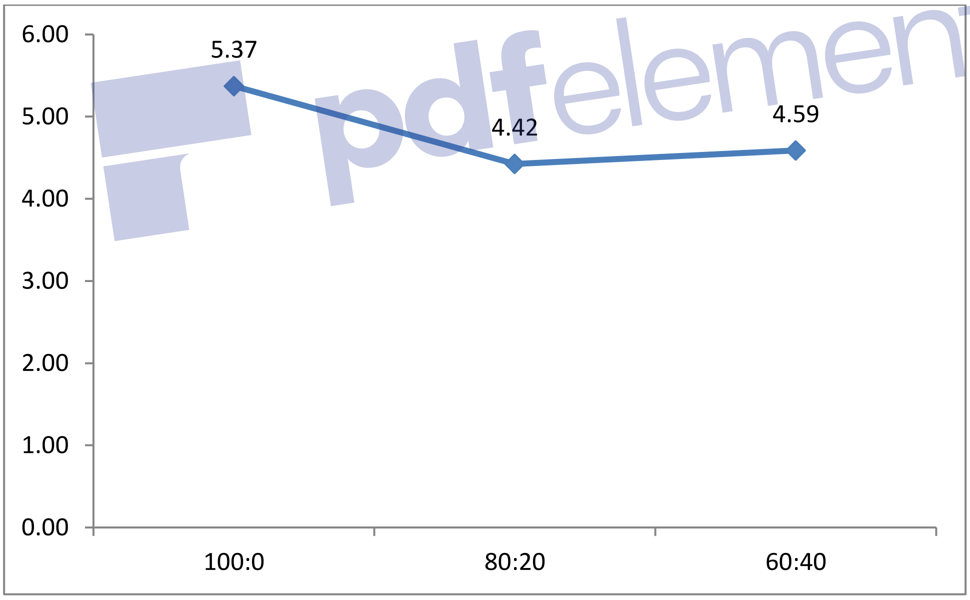


Figure 4.4 Effect of different levels of pigeon peas addition to sorghum on fat content of the formulated sorghum-pigeon peas flakes

4.4.1.4 Fibre content

The fibre content ranged from 3.53% to 5.97% which represented a significant difference at $P<0.05$ (Table 4.5). The fibre content was higher than the findings of

Chavan and others, (2015) who found fibre content of 2.14-3.12% for sorghum flakes. Carvalho and others, (2012) reported that fibre content of (>3 g.100 g–1) makes product a source of fibre. The fibre content was comparable to the findings of Marete, (2015) for sorghum-pigeon pea flour blends for ready to eat complementary food product (4.5% max). Carvalho and others, (2012) found fibre content of 3.71g/100g for extruded breakfast meal formulated with broken rice and bean flour.

Table 4.5 Fibre content of the formulated sorghum-pigeon pea flakes (g/100g)

Treatments	**Sorghum/pigeon pea blended formulation ratios**			**Average**
	Formulation 100:0	**Formulation 80:20**	**Formulation 60:40**	
Dehulled	4.43±0.79^{ab}	4.59±0.56^{ab}	4.49±1.34^{ab}	4.50±0.74^{a}
Dehulled and fermented	4.04±0.52^{ab}	3.87±0.31^{ab}	3.53±0.39^{a}	3.82±0.40^{a}
Malted	5.97±0.07^{b}	4.55±1.75^{ab}	4.79±1.97^{ab}	5.10±1.36^{a}
Malted and fermented	4.53±0.72^{ab}	4.61±0.29^{ab}	4.79±1.10^{ab}	4.65±0.62^{a}
Whole Grain	4.38±0.65^{ab}	5.10±0.72^{ab}	5.15±2.48^{ab}	4.88±1.25^{a}
Whole grain fermented	3.87±0.74^{ab}	3.82±1.12^{ab}	3.98±0.30^{ab}	3.89±0.62^{a}
Average	4.54±0.85^{a}	4.42±0.84^{a}	4.46±1.24^{a}	
LSD	2.27			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Dehulling has reduced the fibre content which may be due to the removal of the outer coverings or husk which is rich in fibre. In most of the grains, the higher percentage of the fibre is found in the outer covering which is removed during dehulling. Similar findings were reported by Rababah and others, (2017) who reported lower fibre content in dehulled sesame seed. Mugendi and Njagi, (2010), Suri and others, (2017) and Akinjayeju and Ajayi, (2011) also reported reduction of fibre due to dehulling. Similarly Wang, (2008) found that removal of seed coat significantly reduced crude fibre content.

Malting has slightly increased the fibre content of the final product. This increase could be attributed to increase in building of bran and dry matter during germination. Malting or germination leads to increase in the cellular structure of the plant. Banusha and Vasantharuba, (2013) attributed the gradual increase in crude fibre content to the synthesis of structural carbohydrates such as cellulose and hemicelluloses. Similar findings were also reported by Ogbonna and others, (2012) and Joshi and Varma, (2016). Chavan and others, (2015) who reported that sorghum flakes had 3.12% crude fibre while the study pointed out that the fibre content in the sorghum flakes showed lower value than the grain itself due to the loss during processing.

Fermentation has reduced the fibre content of the final flakes which could be attributed to the utilization and breakdown of the fibre by microorganisms causing fermentation. It could also be due to enzymatic breakdown of fibre by lactic acid bacteria during fermentation. Similar results were reported by Jood and others, (2012), Tope, (2014), Ojokoh and Bello, (2014), and Ogodo and others, (2019) who reported reduced fibre content due to fermentation. Ojokoh and Bello, (2014) also reported that fermentation has reduced the fibre content of millet-soybean blends. Elsewhere, Ogodo and others, (2018) found reduction of fibre content with increase in fermentation time.

The fibre content of the final product decreased as the level of pigeon peas addition increased (Fig 4.5) from 4.54 to 4.42 and then increased to 4.46 but generally decreased slightly. Similar findings were reported by Toum, (2009) who found that the fibre content of sorghum flour increased when supplemented with 50% white beans and decreased when supplemented with 33.3%. similarly, Mbaeyi, (2005) found the fibre content of a breakfast cereal made from sorghum and pigeon peas has increased as the levels pigeon peas increased. Elsewhere, Balasubramanian and others, (2012) reported that legume incorporation did not significantly change the fibre content of sorghum and wheat flour extrudates.

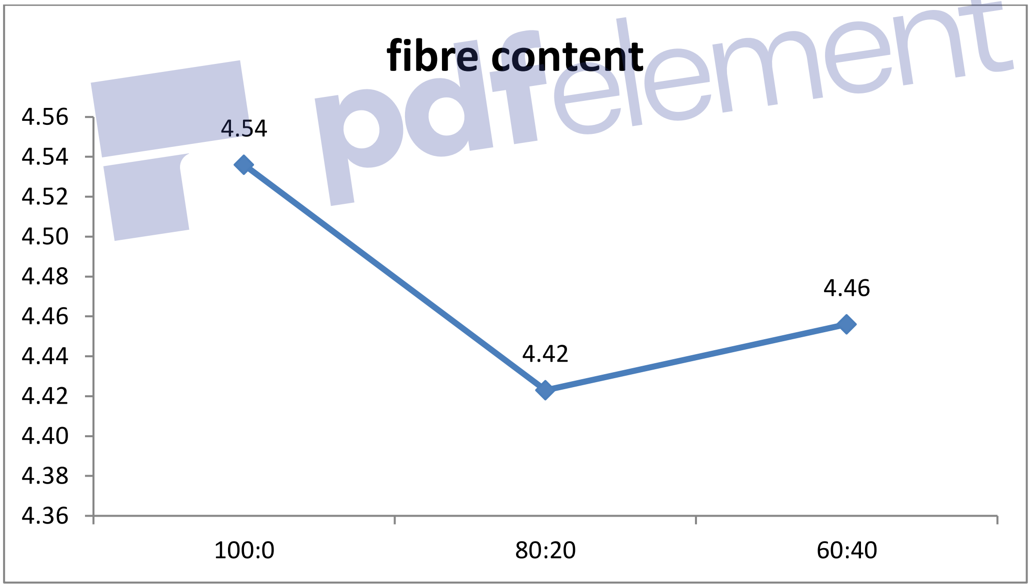


Figure 4.5 Effect of different levels of pigeon peas addition to sorghum on fibre content of the formulated sorghum-pigeon peas flakes

4.4.1.5 Total Minerals

The total mineral content ranged from 2.32% to 3.35% (Table 4.6). The total mineral content was below the maximum total ash limit by KEBS for breakfast cereals which is 6% max. Mahenge, (2018) reported that flour samples should have maximum 5% total mineral content.

Table 4.6 Total mineral content of the formulated sorghum-pigeon pea flakes (g/100g)

Treatments	Sorghum/pigeon pea blended formulation ratios Formulation 100:0	Formulation 80:20	Formulation 60:40	Average
Dehulled	2.46±0.17[a]	2.48±0.41[a]	2.67±0.66[a]	2.53±0.37[ab]
Dehulled and fermented	2.32±0.75[a]	2.44±0.65[a]	2.62±0.40[a]	2.46±0.50[a]
Malted	3.35±0.63[a]	3.09±0.66[a]	3.10±0.52[a]	3.18±0.49[b]
Malted and fermented	2.79±0.13[a]	2.79±0.32[a]	2.70±0.89[a]	2.76±0.43[ab]
Whole Grain	2.94±0.24[a]	2.89±0.08[a]	3.07±1.21[a]	2.96±0.56[ab]
Whole grain fermented	2.81±0.13[a]	2.70±0.37[a]	2.74±0.69[a]	2.75±0.36[ab]

Average	2.78±0.47[a]	2.73±0.41[a]	2.81±0.61[a]
LSD	1.21		

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Dehulling has slightly decreased the total mineral content which may be due to the removal of the hulls from the whole grain which may contain some minerals. The hulls contain great amount of the mineral element of the grains. Rababah and others, (2017) and Makinde and Akinoso, (2013) found that dehulled grains had lower mineral content than raw whole grains of sesame seeds. Similar findings were also reported by Akinjayeju and Ajayi, (2011), Mang and others, (2016) and Adebooye and Singh, (2007) who reported reduced value of total mineral due to dehulling. The total mineral content decreased during fermentation but the decrease was not significant. The decrease may be due to leaching of minerals during fermentation and utilization of some of the minerals by the fermenting microorganisms. Simwaka and others, (2017) indicated that leaching of soluble minerals into water during fermentation might have contributed to decrease in total mineral content. Elsewhere, Offiah and others, (2017) also reported that fermentation decreased the total mineral content of fermented soybean flour. Similarly, Tope, (2014) found that fermentation has reduced the total mineral content of sorghum-beniseed blends.

Malting has increased the total mineral content although the increase was not significant (P<0.05) this may be due to the synthesis of mineral elements during germination. During germination, anti-nutritional compounds are enzymatically broken down which may otherwise bind minerals making them available. Otutu and others, (2014), Hingade and others,(2018), Ogbonna and others, (2012), Abioye and others, (2018) and Menasra and others, (2018) all reported that germination has slightly increased the total mineral content. Banusha and Vasantharuba, (2013) reported that the total mineral content of un-germinated seeds was similar to that of germinated seeds.

The total mineral content decreased upon incorporation of 20% pigeon peas to sorghum and increased steadily at 40% pigeon pea incorporation. Pigeon pea has roughly higher ash content than sorghum which could be the reason why at higher substitution levels of pigeon peas, the total minerals increased. Mbaeyi, (2005) found that addition of pigeon to sorghum in production and evaluation of breakfast cereal using pigeon-pea and sorghum has led to increase in the total mineral content. Similar findings were reported by Toum, (2009) who found that the total mineral content of sorghum flour supplemented with 50% white beans increased while supplementation with 33.3% decreased the total mineral content. Balasubramanian and others,(2012) also reported decrease in total mineral content sorghum upon 15% incorporation of legumes.

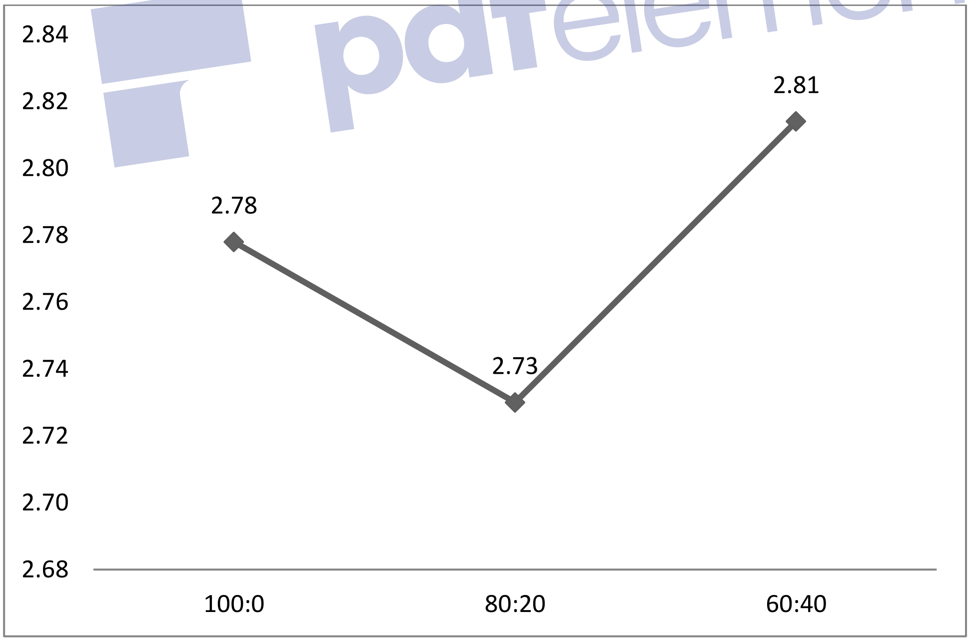


Figure 4.6 Effect of different levels of pigeon peas addition to sorghum on the ash content of the formulated sorghum-pigeon pea flakes

4.4.1.5 Potassium content (Kmg/100g)

The potassium content of the formulated sorghum-pigeon peas flakes ranged from 452.10mg/100g to 803.9mg/100g (Table 4.7). There was a significant difference ($P<0.05$) in the potassium content among the samples. The whole grain samples showed lower potassium content compared to fermented and malted samples while dehulled samples had the lowest potassium content. Malting and fermentation had significant ($P<0.05$) impact on the potassium content of the formulated sorghum pigeon peas flakes.

Table 4.7 Potassium content in mg per 100g of the formulated sorghum-pigeon pea flakes

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	452.10±53.73^{a}	504.20±79.54^{a}	513.30±89.28^{a}	489.90±65.64^{a}
Dehulled and fermented	683.30±66.84^{cde}	568.70±141.68^{abc}	756.80±79.87^{e}	669.60±115.66^{d}
Malted	472.00±55.48^{a}	575.90±83.48^{abcd}	710.60±76.43^{de}	586.20±120.97^{bc}
Malted and fermented	732.40±5.06^{e}	590.50±30.62^{abcd}	803.90±64.19^{e}	709.00±102.27^{d}

Whole Grain	455.80±54.17^{a}	557.60±5.44^{abc}	513.60±24.47^{a}	509.00±52.89^{ab}
Whole grain fermented	532.90±13.80^{ab}	665.80±37.45^{bcde}	739.70±80.62^{e}	646.10±102.00^{cd}
Average	554.70±122.50^{a}	577.10±75.90^{a}	673.00±132.60^{b}	
LSD	140.70			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Fermentation and malting have significantly (P<0.05) increased the potassium content of the final flakes. This could possibly be due to the leaching and reduction of the anti-nutritional factors binding the minerals by the process treatments. Anti-nutritional factors are greatly reduced and broken down during malting and fermentation. Similar findings were reported by Assohoun and others, (2013) who reported that fermentation has increased potassium content. Udeh and Duodu, (2018) and Nkhata and others, (2018) also found that malting had significantly increased potassium content of sorghum. Ogbonna and others, (2012) reported that steeping and germination increased the potassium content by 29.55%.

Dehulling has reduced the potassium content of the final product since the removed hulls may contain some of the minerals. Rababah and others, (2017) reported that dehulling has reduced the potassium content of sesame seeds compared to raw seeds. Similar results were also reported by Makinde and Akinoso, (2013) who found that sesame hulls contained higher amount of potassium than the grain. Adebooye and Singh (2007) reported 7.4% loss of potassium due to decortications.

Addition of pigeon peas up to 40% increased potassium content of the final product. Pigeon peas contain significantly higher amounts of potassium compared to sorghum leading to the observed increase in potassium due to increase in pigeon peas. Similar findings were reported by (Mahenge, 2018) who found that the potassium content of extruded instant white sorghum-pigeon peas gruel flour has increased as the levels of pigeon peas addition was increased. Abioyeand others, (2018) also reported that the potassium content increased with increase in substitution of African yam bean.

4.4.1.5 Zinc content (Zn mg/100g)

The zinc content ranged between 4.60mg/100g to 7.26mg/100g (Table 4.8). On average, whole grain sorghum treatment had the highest zinc content compared to the dehulled and malted samples. There was no significant (P<0.05) difference in the zinc content of the final products.

Table 4.8 Zinc content in mg per 100g of the formulated sorghum-pigeon pea flakes

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	5.03±0.49^{a}	4.60±0.16^{a}	7.26±3.10^{a}	5.63±1.90^{a}
Dehulled and fermented	5.16±0.94^{a}	4.71±0.42^{a}	7.13±3.29^{a}	5.66±1.92^{a}
Malted	5.40±0.93^{a}	5.17±0.31^{a}	5.37±0.34^{a}	5.32±0.48^{a}
Malted and fermented	6.14±1.52^{a}	5.52±2.00^{a}	5.62±0.41^{a}	5.76±1.18^{a}
Whole Grain	5.87±1.97^{a}	5.41±0.52^{a}	6.78±0.18^{a}	6.02±1.11^{a}

Whole grain fermented	6.69±0.60^{a}	5.87±0.17^{a}	6.41±0.85^{a}	6.32±0.60^{a}
Average	5.71±1.07^{ab}	5.21±0.80^{a}	6.43±1.59^{b}	
LSD	2.91			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Fermentation has increased slightly the zinc level while both dehulling and malting has led to slight decrease in the zinc content. Malting reduced zinc content which may be due to utilization of minerals during germination process. It could also be due to the leaching out of minerals during steeping and germination. Similar findings were reported by Obilana, (2014) who reported that malting had significantly decreased the zinc content of malted pearl millet.

Reduction of zinc content of the dehulled samples could be attributed to the removal of the hull which may contain some minerals since most of the minerals are found on the hulls. This finding was in agreement with that of Makinde and Akinoso, (2013) who reported that dehulling of sesame seeds has led to reduced zinc content. Adebooye and Singh, (2007) reported 16.5% loss of zinc due to dehulling. Makinde and Akinoso, (2013) also found reduction of zinc through dehulling.

Fermentation reduces anti-nutrients which bind the minerals and this could be a possible reason for the increase in the zinc content of the final product. Asres and others, (2018) reported that fermentation had significantly (P<0.05) increased the zinc contents of fermented wheat and teff. Similar results have also been reported by Mohite and others, (2013), Chikwendu and others, (2014) and Buta and Emire, (2015) who found that the zinc content increased after fermentation which could be due to reduction of phytates and anti-nutrients. Assohoun and others, (2013) also found that fermentation increased zinc content

Pigeon peas incorporation at 40% level has steadily increased the zinc content of the final product since pigeon peas contain higher amount of zinc compared to sorghum. Similarly, Mahenge, (2018) found that increase in the levels of pigeon peas increased the zinc content of extruded instant white sorghum-pigeon peas gruel flour. Egbujie and Okoye, (2019) also reported that the zinc contents of a complementary food made from sorghum, African yam bean and crayfish increased significantly ($p<0.05$) with increase in substitution with African yam bean and crayfish flour.

4.4.1.6 Carbohydrate content

The carbohydrate content of the formulated sorghum-pigeon peas flakes ranged from 66.77% to 71.28%. There was no significant difference ($P<0.05$) in carbohydrate content among all the samples (Table 4.9). The carbohydrate content was comparable to the findings of Mahenge, (2018) for extruded instant white sorghum-pigeon peas gruel flour.

Table 4.9 Carbohydrate content of the formulated sorghum-pigeon peas flakes (g/100g)

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	69.79±0.71[a]	71.28±3.52[a]	71.20±0.11[a]	70.76±1.77[a]
Dehulled and fermented	71.09±2.73[a]	67.91±0.27[a]	69.23±0.49[a]	69.41±1.90[a]
Malted	68.15±6.03[a]	70.96±1.83[a]	67.18±3.54[a]	68.76±3.68[a]

Malted and fermented	68.66 ± 2.20^{a}	68.42 ± 0.84^{a}	66.77 ± 0.47^{a}	67.95 ± 1.41^{a}
Whole Grain	70.63 ± 3.71^{a}	68.72 ± 1.73^{a}	68.37 ± 0.67^{a}	69.24 ± 2.15^{a}
Whole grain fermented	67.85 ± 0.34^{a}	71.28 ± 5.52^{a}	68.23 ± 1.71^{a}	69.12 ± 3.09^{a}
Average	69.36 ± 2.72^{a}	69.76 ± 2.61^{a}	68.50 ± 1.95^{a}	
LSD	5.63			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Fermentation caused a slight decrease in the carbohydrate content although the decrease was not significant (P<0.05), this may be due to the utilization of carbohydrates by microorganisms causing fermentation as source of energy. the findings were in agreement with that of Simwaka and others, (2017), Osman, (2011), Nkhata and others, (2018), Menasra and others, (2018) and Tope, (2014) who all reported that fermentation has decreased the carbohydrate content. Similar findings were also reported by Offiah and others, (2017), Mohammed and others, (2017) and Ogodo and others, (2019) who also found that fermentation has led to the reduction of carbohydrates.

Dehulled samples recorded increase in carbohydrate content which could be attributed to the removal of the hulls which bind nutrients hence its removal leads to increase in nutritional value of the grains. Similar findings were reported by Mang and others, (2016) who attributed the carbohydrate increase to the complexation of carbohydrates by tannins and polyphenols present in the hull. Chavan and others, (2015), Jonathan and Adeyeye, (2015) also found increase of carbohydrate by dehulling.

Malting has also caused slight but insignificant decrease in the carbohydrate content, this could be due to the enzymatic breakdown of carbohydrates into simple sugars through activation of endogenous enzymes such as α-amylase during germination. Similar findings were reported by Menasra and others, (2018) and Nkhata and others, (2018). Elsewhere, Nwosu and others, (2013), Otutu and others, (2014) and Ogbonna and others, (2012) also reported decrease in carbohydrate content due to malting.

The carbohydrate content has decreased as the levels of pigeon peas addition increased which could be attributed to the increased protein content since pigeon peas contain significantly higher protein content than sorghum. Similar findings were reported by Mahenge, (2018) who reported that legumes addition reduces carbohydrate content of cereal based formulation. Toum, (2009) also reported that supplementation of sorghum flour with white beans at 50% and 33.3% has decreased the carbohydrate content of the resulting composite flour. Mbaeyi, (2005) found that pigeon pea has lower carbohydrate content than sorghum while Offiah and others, (2016) also found that blending of African yam beans with maize led to decrease in carbohydrate.

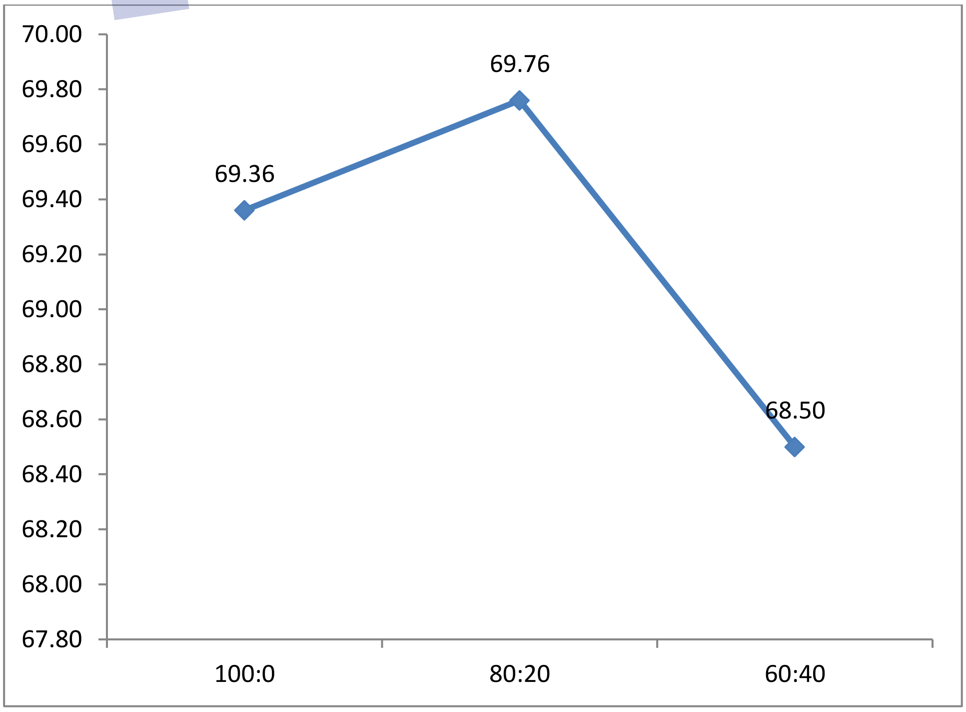


Figure 4.7 Effect of different levels of pigeon peas addition to sorghum on carbohydrate content of the formulated sorghum-pigeon pea flakes

4.4.1.7 Energy content

The energy content of the final product ranged from 358.60 Kcal/100g to 385.20 Kcal/100g and there was no significant effect among the treatments on the energy content of the final product (Table 4.10).

Table 4.10 Energy content of the formulated sorghum-pigeon pea flakes (Kcal/100g)

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	377.30±17.04^{ab}	376.60±3.68^{ab}	367.00±5.23^{ab}	373.60±9.63^{a}
Dehulled and fermented	371.30±18.58^{ab}	373.90±2.37^{ab}	385.20±7.88^{b}	376.80±11.23^{a}
Malted	364.90±13.48^{ab}	367.70±11.09^{ab}	361.60±4.93^{a}	364.80±8.55^{a}
Malted and fermented	368.90±0.61^{ab}	358.60±10.41^{a}	372.00±1.15^{ab}	366.50±7.81a
Whole Grain	373.80±10.38^{ab}	363.40±15.07^{a}	361.80±9.52^{a}	366.40±10.92^{a}

Whole grain fermented	372.60±1.13[ab]	374.60±10.63[ab]	375.70±8.17[ab]	374.30±6.17[a]
Average	371.50±10.03[a]	369.10±9.99[a]	370.50±9.97[a]	
LSD	20.95			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Dehulling has led to increase in energy content of the final flakes formulated. Hulls contain higher amounts of anti-nutrients which bind the nutrients hence its removal improves the nutritional content of the product. Similar findings were reported by Mera-zúñiga and others,(2019) who found that dehulling has led to increase in the value of the metabolizable energy.

Malted samples recorded slightly lower but insignificant energy content compared to the whole grain and fermented samples. During germination, there is breakdown of carbohydrates into simple sugars which may lead to the reduction in the final energy content. Obilana, (2014) found that malting had no effect on the energy content of malted pearl millet.

Fermentation has led to increase in energy content of the final product which could be due to the reduction of anti-nutritional contents such as tannins and phenolic compounds. Similar findings were reported by Offiah and others, (2017) who reported that fermentation has led to increase in energy content of fermented soybean flour compared to non-fermented flour while fermentation has reduced the energy content of fermented maize flour. Elsewhere, Assohoun and others, (2013) reported that energy content remained unchanged after fermentation.

On average, samples formulated from 100% sorghum grains had the highest energy content followed by the 60:40 formulations which may be due to the increase in the protein content. Similar findings were reported by Mbaeyi, (2005) who found that energy content increased as the levels of pigeon pea addition has been increased. Similarly, Toum, (2009) reported that the energy content of sorghum flour supplemented with white beans has decreased when supplemented with 50% and 33.3%. Egbujie and Okoye, (2019) also reported that the energy content of a complimentary food made from sorghum, African yam bean and crayfish flours decreased with increase with substitutions of African yam bean and crayfish.

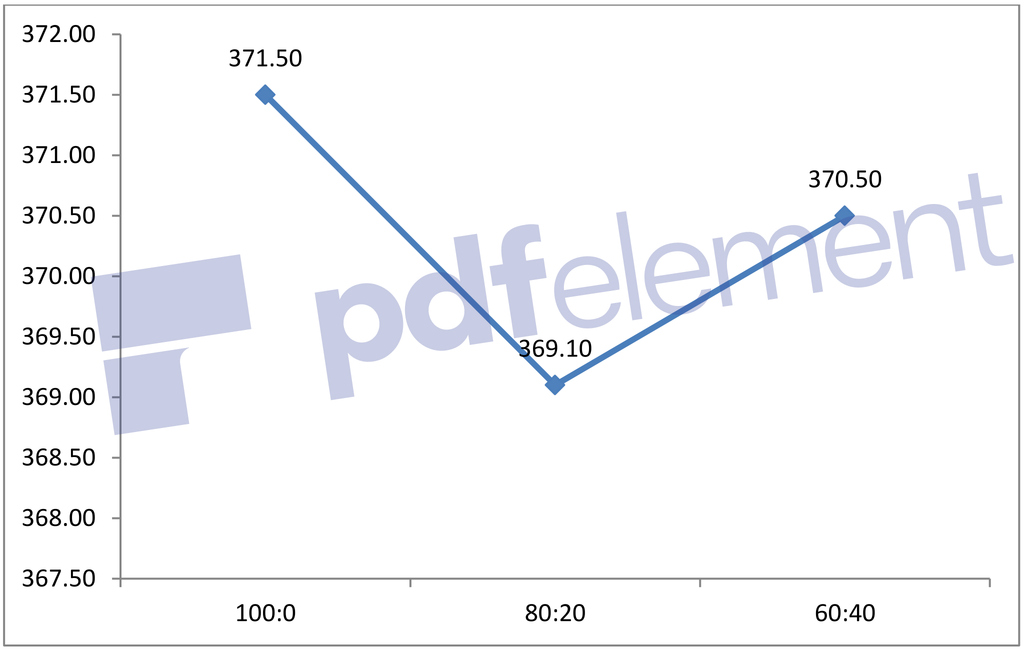


Figure 4.8 Effect of different levels of pigeon peas addition to sorghum on energy content of the formulated sorghum-pigeon peas flakes

4.4.2 Anti-nutritional Analysis

4.4.2.1Total Phenolic Content

The total free phenolics of the formulated flakes ranged from 0.15% to 0.39%. The results of the total free phenolics are presented in table 4.11. The total phenolic content found in this study were within the range of the findings reported by Chiremba, (2009) who reported 0.41 g gallic acid equivalents and Sorour and others, (2017) who also reported 178.28 mg gallic acid equivalent (GAE)/100g.

Table 4.11 Total free phenolic content of the formulated sorghum-pigeon peas flakes

Treatments	**Sorghum/pigeon pea blended formulation ratios**			**Average**
	Formulation 100:0	**Formulation 80:20**	**Formulation 60:40**	
Dehulled	0.26 ± 0.01^{cd}	0.21 ± 0.02^{b}	0.18 ± 0.03^{ab}	0.21 ± 0.04^{b}
Dehulled and fermented	0.22 ± 0.04^{bc}	0.19 ± 0.01^{ab}	0.15 ± 0.04^{a}	0.18 ± 0.04^{a}
Malted	0.35 ± 0.01^{ghij}	0.35 ± 0.01^{ghij}	0.31 ± 0.02^{efg}	0.33 ± 0.03^{cd}
Malted and fermented	0.38 ± 0.01^{ij}	0.28 ± 0.04^{def}	0.28 ± 0.02^{de}	0.31 ± 0.05^{c}
Whole Grain	0.39 ± 0.01^{j}	0.36 ± 0.04^{hij}	0.33 ± 0.02^{fgh}	0.36 ± 0.03^{d}
Whole grain fermented	0.37 ± 0.01^{hij}	0.36 ± 0.04^{hij}	0.33 ± 0.01^{ghi}	0.35 ± 0.03^{d}
Average	0.32 ± 0.07^{c}	0.29 ± 0.08^{b}	0.26 ± 0.08^{a}	

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

All the treatments, dehulling, malting and fermentation have decreased the total phenolic contents. Hulls are known to contain appreciable amount of anti-nutrients. Dehulling significantly reduced the total phenolic content while the most effective treatment for the reduction of the total pheonlic content was dehulling followed by fermentation. The results were in agreement with the findings of Chiremba, (2009), Kundgol and others, (2013), Bagdi and others, (2011) and Akinjayeju and Ajayi, (2011) who reported that dehulling has reduced phenolic content. Anton and others, (2008) reported that the highest concentration of phenolic content in pinto and navy beans occurred in the seed coat.

Malting has also reduced the total free phenolics from 0.36% to 0.33% possibly due to the activation of endogenous enzymes which hydrolyse the antinutrients. Similar findings were reported by Nwosu and others, (2013), Abioye, (2019), Eshraq and others, (2016), Obilana, (2014) and Phattayakorn and others, (2016) who reported that germination has reduces total phenolic contents. Malting may also reduce phenolic content through leaching of water soluble compounds during steeping and germination.

Fermentation is also found to cause reduction in the phenolic content of the final products. Fermentation activates endogenous enzymes which breakdown the anti-nutritional compounds leading to its reduction. These findings were in agreement with those of Álvarez and others, (2017), López and others, (2018) and Adebo and Medina-Meza, (2020) who all found reduction of total phenolics due to fermentation. Tian and others, (2019) reported that cereal fermentation has increased phenolic content of grains except for sorghum.

The phenolic contents were found to be inversely related to the levels of pigeon peas substitution with sorghum as there was a decrease in the phenolic content as the levels of the pigeon peas increased. This could be attributed to the fact that pigeon peas contain fewer amounts of total phenolic content compared to sorghum. Similar findings were reported by Agbajeand others, (2017) who reported that the anti-nutrients were reduced by the increased addition of defatted soybean flour to complementary food produced from malted red sorghum and defatted soybean flour blend. Shah and others, (2017) also reported reduction of total phenolic contents of flat bread made from maize-asparagus bean composite flour as the level of beans increased.

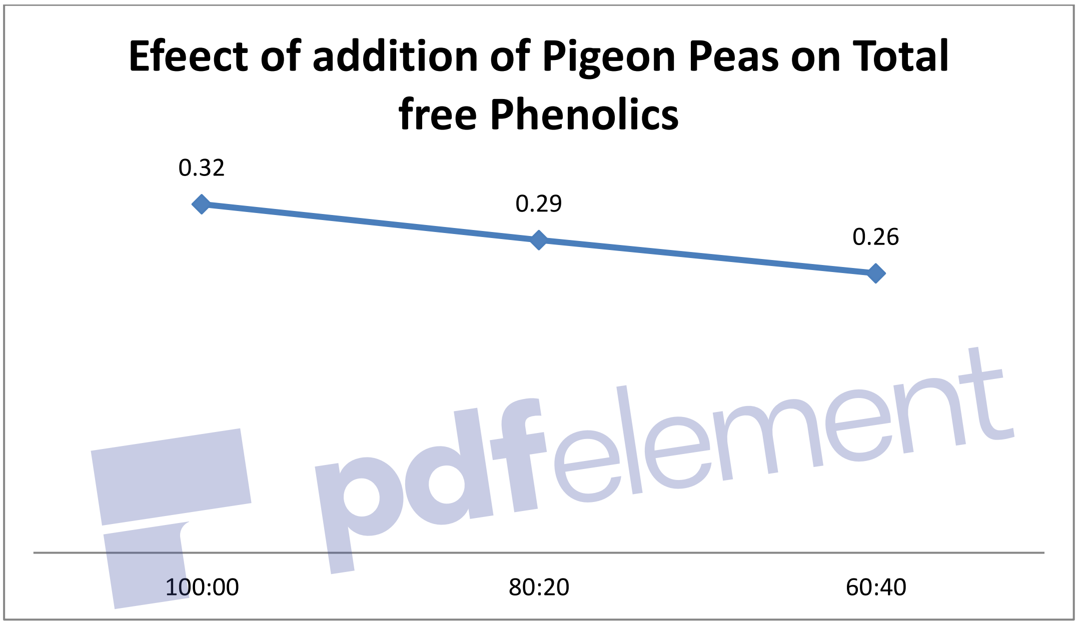


Figure 4.9 Effect of different levels of pigeon peas addition to sorghum on total free phenolics content of the formulated sorghum-pigeon peas flakes

4.4.2.2 Phytate Content (mg/100g)

The phytate content of the formulated flakes ranged from 43.58mg/100g to 58.73mg/100 (Table 4.12). The results were within the limits of the findings of Marete and others, (2016) and Marete, (2015).

Table 4.12 Phytate content of the formulated sorghum-pigeon peas flakes

Treatments	Sorghum/pigeon pea blended ratios Formulation 100:0	Formulation 80:20	Formulation 60:40	Average
Dehulled	55.02 ± 0.04^{def}	49.03 ± 4.37^{abcde}	47.90 ± 0.52^{abcd}	50.65 ± 3.95^{bc}
Dehulled and fermented	46.61 ± 4.02^{abc}	44.37 ± 5.76^{b}	43.58 ± 3.25^{a}	44.85 ± 3.74^{a}
Malted	52.75 ± 4.84^{cdef}	50.36 ± 6.75^{abcde}	49.97 ± 0.09^{abcde}	51.03 ± 3.95^{bcd}
Malted and fermented	48.31 ± 3.57^{abcde}	47.23 ± 3.18^{abcd}	46.03 ± 0.50^{abc}	47.20 ± 2.38^{ab}
Whole Grain	58.73 ± 0.06^{f}	56.11 ± 4.55^{ef}	52.18 ± 3.66^{bcdef}	55.67 ± 3.94^{cd}
Whole grain fermented	54.84 ± 3.60^{def}	54.05 ± 6.89^{cdef}	49.79 ± 2.32^{abcde}	52.89 ± 4.37^{d}
Average	52.71 ± 4.96^{b}	50.19 ± 5.75^{ab}	48.24 ± 3.37^{a}	

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Dehulling has greatly reduced the phytate content of the flakes which could be due to the removal of the outer covering which contains appreciable quantity of the anti-nutrients such the phytate. Similar findings were reported by Makinde and Akinoso, (2013) who reported that dehulling sesame seeds greatly reduced the phytate content. Kundgol and others, (2013), Nakitto and others, (2015), Akinjayeju and Ajayi (2011), Osunbitan and others, (2015) and Joshi and Varma, (2016) also reported reduction of phytates through dehulling.

Malting has also reduced the phytate content of the flakes possibly due to the leaching of phytates during steeping as well as activation of phytase enzymes which causes hydrolysis of phytic acid to inorganic phosphate and inositol during germination. The findings were in agreement with those of Onyango and others, (2013), Abioye, (2019), Joshi and Varma, (2016) and Hussain and others, (2011) who also reported reduction of phytates during germination. Similarly, Makinde and Akinoso, (2013) reported that germination caused significant reduction in phytate content compared to the other process treatments. Nakitto and others, (2015) found that germination reduced phytate content due to enzymatic hydrolysis of phytic acid.

Fermentation was also found to reduce the phytate content of the flakes which could be due to the hydrolysis of the anti-nutrient complexes through enzymatic activation during fermentation. Similarly Krishnan and Meera, (2018), Sherrif, (2017), Chikwendu and others, (2014), Ojokoh and Bello, (2014), Valdez-González and others, (2018) and Onwurafor and others, (2014) all reported that fermentation reduced the phytate content. Onyango and others, (2013) found that fermentation caused reduction of phytates by 20-21% with 2 days of fermentation while Osman, (2011) reported 51.9% reduction of phytate due to fermentation.

Increase in the addition of pigeon peas has drastically decreased the phytic acid content of the flakes due to the fact that pigeon peas contain lower levels of phytic acid content than sorghum. Similar findings were reported by Marete and others, (2016). Agbaje and others, (2017) reported that increase in the addition of pigeon peas to a complementary food produced from malted red sorghum and defatted soybean flour blend caused a reduction in phytate content. Toum, (2009) found that supplementation of sorghum with white bean has reduced the phytic acid content of the final product.

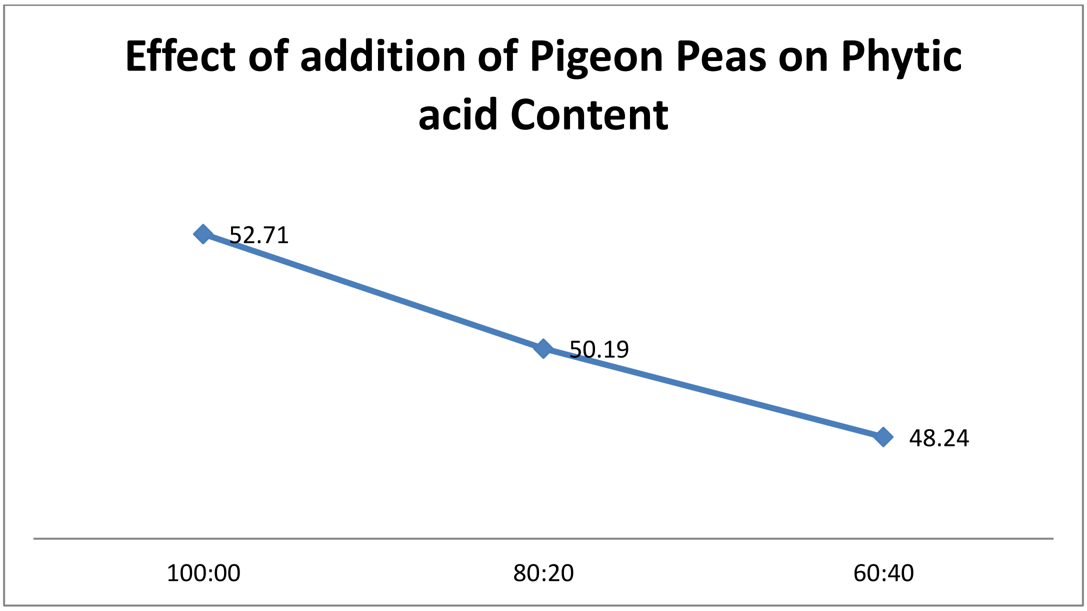


Figure 4.10 Effect of different levels of pigeon peas addition to sorghum on the phytic acid content of the formulated sorghum-pigeon peas flakes

4.4.2.3 Tannin Content (mg/100g)

The tannin content of the formulated flakes ranged from 0.97mg/100g to 3.84mg/100g (Table 4.13). The results were within the limits of those reported by Marete and others, (2016) and Marete, (2015).

Table 4.13 Tannin content of the formulated sorghum-pigeon peas flakes

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
Dehulled	$2.44±0.18^{b}$	$2.36±0.03^{b}$	$2.32±0.18^{b}$	$2.37±0.13^{b}$
Dehulled and fermented	$1.02±0.01^{a}$	$1.01±0.06^{a}$	$0.97±0.02^{a}$	$1.00±0.04^{a}$
Malted	$3.78±0.04^{g}$	$3.72±0.03^{fg}$	$3.70±0.00^{fg}$	$3.73±0.04^{e}$
Malted and fermented	$3.50±0.28^{ef}$	$3.38±0.07^{de}$	$3.20±0.02^{d}$	$3.36±0.19^{d}$
Whole Grain	$3.84±0.01^{g}$	$3.82±0.02^{g}$	$3.77±0.02^{g}$	$3.81±0.03^{e}$
Whole grain fermented	$3.51±0.09^{ef}$	$3.15±0.23^{d}$	$2.82±0.20^{c}$	$3.16±0.34^{c}$
Average	$3.01±1.05^{c}$	$2.90±1.02^{b}$	$2.80±1.00^{a}$	
LSD	0.25			

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Dehulling, malting and fermentation has all significantly (P<0.05) reduced the tannin content of the flakes. Dehulling removes the outer covering of the grain where the tannins are concentrated therefore reducing the tannin content of the dehulled samples. Malting reduces tannins through leaching out during steeping as well as enzymatic degradation which greatly reduces the tannin content of the final product. Fermentation also causes reduction in the tannin content of the final product through enzymatic degradation of the tannin complexes during fermentation.

Joshi and Varma, (2016), Valdez-González and others, (2018) and Nakitto and others, (2015) reported reduction of tannins due to dehulling. Osunbitan and others, (2015) found that dehulling has significantly reduced the tannin content of beans due to the concentration of tannins in the seed coat.

Ojokoh and Bello, (2014), Valdez-González and others, (2018), Sherrif, (2017) and Chikwendu and others, (2014) reported that fermentation has significantly reduced the tannin content. Banjarbaru, (2016) also found that fermentation has reduced the tannin content of *Crataeva nurvala* flower.

Eshraq and others, (2016), Joshi and Varma, (2016), Abioye, (2019), Nakitto and others, (2015), Obilana, (2014) and Modgil and Sood, (2017) reported that germination has led to the reduction of tannin content. Hussain and others, (2011) found that germination has significantly reduced the tannin content of mung beans and wheat. Kanensi and others, (2011) reported that the tannin level of amaranth grains have been reduced to low levels that it could not be detected after germination.

Increase in the addition of pigeon peas levels has been found to significantly reduce the tannin content of the formulated flakes. This could be attributed that pigeon peas contain lower levels of tannins than sorghum. Similar findings were reported by Toum, (2009) who found that the tannin levels decreased after sorghum flour was supplemented with white beans. Agbajeand others, (2017) reported that antinutrients decreased as the levels of defatted soybean flour addition to malted red sorghum increased. Marete and others, (2016) found that food formulated with 1:1 sorghum pigeon peas has the least tannin content. Similarly, Lawan and others, (2018) reported similar findings.

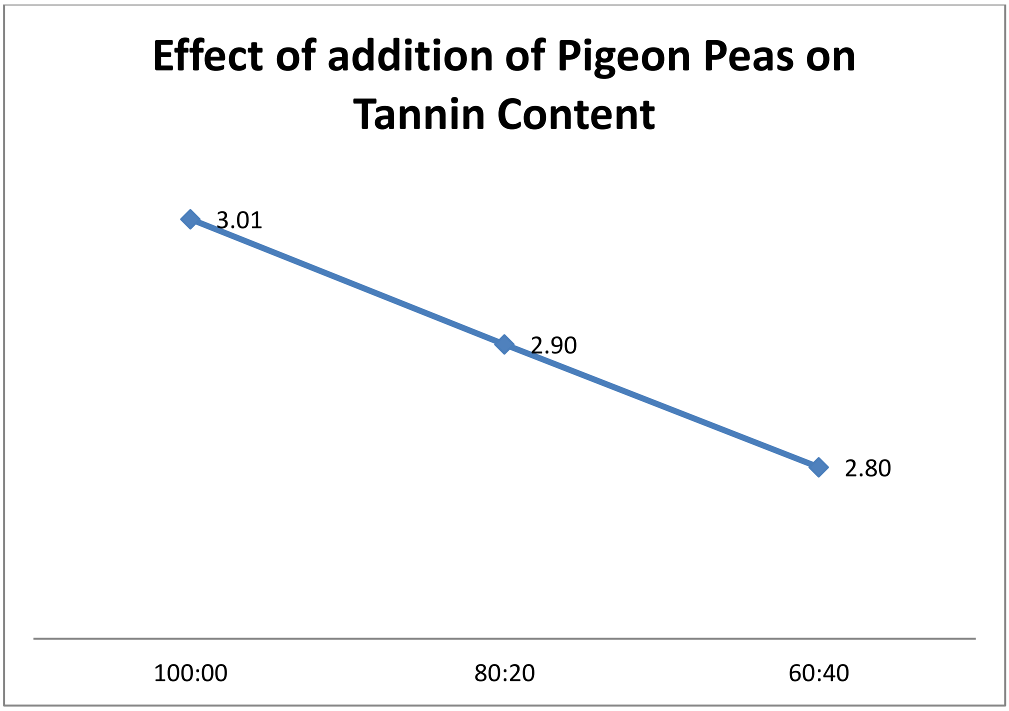


Figure 4.11 Effect of different levels of pigeon peas addition to sorghum on the tannin content of the formulated sorghum-pigeon peas flakes

4.4.2 Sensory evaluation

Tables 4.14, 4.15 and 4.16 show the sensory evaluation results of the formulated flakes. The malted samples scored highest in all attributes except chewability and colour, recording overall acceptability of 4.19. Dehulling came second recording highest in colour and overall acceptability of 3.92. Samples formulated from 100% whole grain sorghum were also acceptable with overall acceptability score of 3.56 recording lowest in taste with 3.41 score. The colour of a food product has an effect on the general acceptance of the product thus increase in pigeon peas concentration improved the appearance through reduction of the sorghum dark colour. There was a significant difference ($P<0.05$) in all the attributes among the samples except in the physical appearance.

Table 4.14 Sensory attributes (Physical appearance, colour and odour) of the formulated sorghum-pigeon peas flakes

Treatments	Sorghum/pigeon pea blended formulation ratios			Average
	Formulation 100:0	Formulation 80:20	Formulation 60:40	
		Physical appearance		
Dehulled	4.00±0.79^{a}	4.13±0.78^{a}	3.83±0.99^{a}	3.99±0.85^{a}
Malting	3.90±1.13^{a}	4.10±0.96^{a}	4.07±0.87^{a}	4.02±0.98^{a}
Whole Grain	3.83±0.87^{a}	3.83±1.18^{a}	3.67±1.03^{a}	3.78±1.03^{a}
Average	3.91±0.93^{a}	4.02±0.98^{a}	3.86±0.97^{a}	
		Colour		
Dehulled	4.03±0.81^{ab}	4.20±0.89^{b}	3.70±1.21^{a}	3.98±0.99^{a}
Malting	4.03±0.85^{ab}	3.67±0.96^{a}	4.20±0.85^{b}	3.97±0.91^{a}
Whole Grain	3.73±1.01^{a}	3.80±1.03^{ab}	4.10±0.88^{ab}	3.88±0.98^{a}
Average	3.93±0.90^{a}	3.89±0.98^{a}	4.00±1.01^{a}	
		Odour		
Dehulled	3.60±0.86^{a}	4.20±0.81^{c}	3.47±1.07^{a}	3.76±0.96^{a}
Malting	4.13±0.73^{bc}	4.30±0.75^{c}	4.13±0.82^{bc}	4.19±0.76^{b}
Whole Grain	3.73±1.01^{bc}	4.13±0.86^{bc}	3.77±0.86^{bc}	3.88±0.92^{a}
Average	3.82±0.89^{a}	4.21±0.80^{b}	3.79±0.95^{a}	

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different ($P<0.05$)

Table 4.15 Sensory attributes (taste, chewability and texture) of the formulated sorghum-pigeon peas flakes

Treatments	Formulation 100:0	Formulation 80:20	Formulation 60:40	Average
		Taste		
Dehulled	3.13 ± 1.22^{bc}	4.63 ± 0.56^{f}	3.00 ± 1.23^{b}	3.59 ± 1.28^{a}
Malting	4.47 ± 0.82^{ef}	3.83 ± 0.79^{d}	3.60 ± 1.16^{cd}	3.97 ± 1.00^{b}
Whole Grain	4.00 ± 1.02^{de}	3.80 ± 1.10^{d}	2.43 ± 1.10^{a}	3.41 ± 1.27^{a}
Average	3.87 ± 1.16^{b}	4.09 ± 0.92^{b}	3.01 ± 1.25^{a}	
Treatments		**Chewability**		
Dehulled	3.50 ± 0.97^{ab}	4.37 ± 0.76^{d}	3.50 ± 1.20^{ab}	3.79 ± 1.06^{b}
Malting	3.73 ± 0.98^{bc}	3.80 ± 0.96^{bc}	4.07 ± 0.69^{cd}	3.38 ± 0.90^{a}
Whole Grain	3.20 ± 1.19^{a}	3.83 ± 0.87^{bc}	3.10 ± 1.16^{a}	3.87 ± 1.10^{b}
Average	3.48 ± 1.06^{a}	4.00 ± 0.90^{b}	3.56 ± 1.10^{a}	
Treatments		**Texture**		
Dehulled	3.70 ± 0.92^{ab}	4.33 ± 0.80^{c}	3.63 ± 1.10^{ab}	3.89 ± 0.99^{b}
Malting	4.07 ± 1.01^{bc}	3.83 ± 0.87^{b}	4.03 ± 0.85^{bc}	3.98 ± 0.91^{b}
Whole Grain	3.63 ± 1.07^{ab}	3.90 ± 0.84^{bc}	3.27 ± 0.98^{a}	3.60 ± 0.99^{a}
Average	3.80 ± 1.01^{ab}	4.02 ± 0.86^{b}	3.64 ± 1.02^{a}	

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different ($P<0.05$)

Table 4.16 The overall acceptability of the formulated sorghum-pigeon peas flakes

Treatments	Formulation 100:0	Formulation 80:20	Formulation 60:40	Average
Treatments		**Overall acceptability**		
Dehulled	3.77±1.01^{bcd}	4.53±0.57^{f}	3.47±1.17^{ab}	3.92±1.04^{b}
Malting	4.30±0.79^{ef}	4.17±0.75^{def}	4.10±0.76^{cde}	4.19±0.76^{c}
Whole Grain	3.70±0.84^{bc}	3.80±0.89^{bcd}	3.17±1.09^{a}	3.56±0.97^{a}
Average	3.92±0.91^{b}	4.17±0.80^{c}	3.58±1.08^{a}	

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Malting improved sensory attributes which could be due to starch being hydrolyzed which increased the sugar content of the product leading to improved flavour. Similar findings were reported by Umar and others, (2013) and Yusufu, (2018). Egbujie and Okoye, (2019) also reported that a complimentary food produced from 100% malted sorghum flour had significantly (p<0.05) the highest scores for colour, taste, flavour and overall acceptability compared to the test samples in all the parameters evaluated. Oluwole and others, (2012) also found that soy-malt beverage containing soymilk and Maize malt was highly acceptable. Elsewhere, Akoma and others, (2006) reported that kunun-zaki (beverage) produced by the addition of ground malted rice to millet was the most preferred sample in terms of aroma and taste

Dehulling has also improved sensory attributes especially the colour and all the dehulled samples were acceptable to the sensory panellist with average overall acceptability of 3.92. During dehulling, the outer covering causing dark colour of the product is removed which greatly enhances the colour and the sensory attributes in general. Akinjayeju and Olayinka, (2011) found that products prepared from dehulled seeds were more acceptable to panellists in almost all parameters compared to that prepared from un-dehulled samples. Saleh and others, (2013) also reported that dehulling improves sensory attributes.

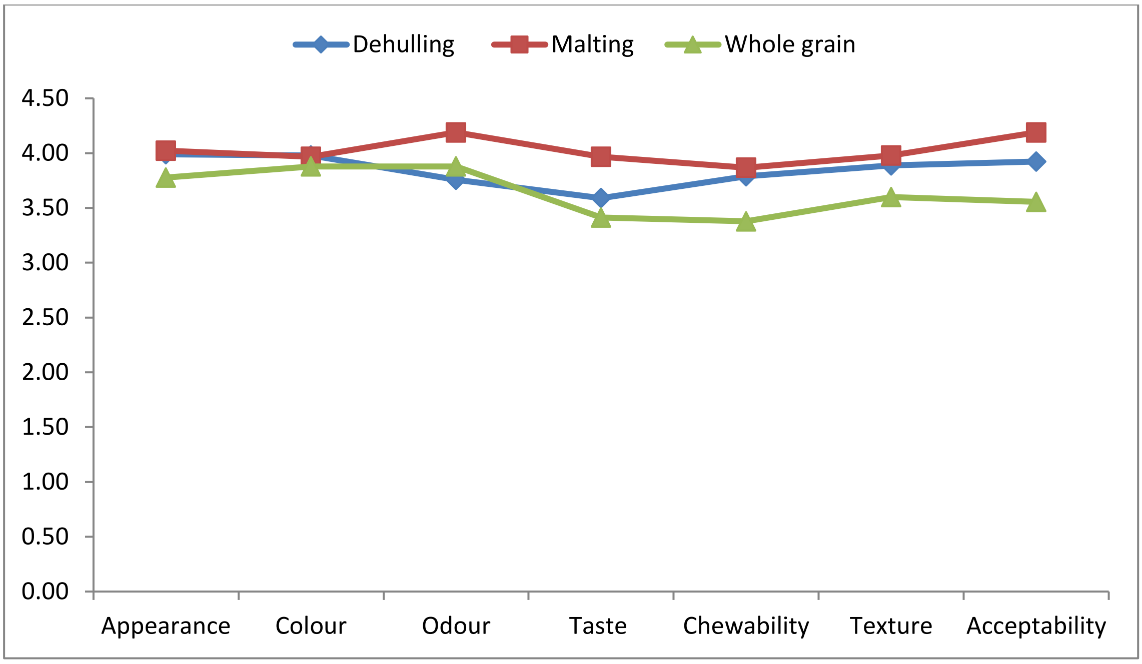


Figure 4.12 Effect of processing (wholegrain, dehulling and malting) on the sensory attributes of the formulated sorghum-pigeon peas flakes

80:20 sorghum pigeon formulation recorded best in all attributes with overall acceptability of 4.17. For colour, the 60:40 treatments scored best with score of 4.00 but there was no significant difference among the treatments on colour. Increase in sorghum concentration reduced the colour acceptability this was due to the fact that consumers prefer lighter colours than dark colours. Julien and others, (2016) reported that the consumers favoured sorghum and millet foods with lighter colours than darker ones. Mkandawire and others, (2015) reported that breakfast cereals made from extruded whole grain sorghum had been rated 'like slightly' hence was acceptable.

The treatments had significant ($P<0.05$) effect on the overall acceptability of the final product with the 80:20 sorghum pigeon peas formulation being the best followed by 100:0 and 60:40 scoring lowest. Mbaeyi and Onweluzo, (2010) found that Pre-gelatinized sorghum flour and pigeon peas at the ratio of 60:40 was most preferred probably due to the improved texture, taste, aroma and colour while Egbujie and Okoye,

(2019) found that increase in the substitution of African yam bean and crayfish has decreased the acceptability of complimentary food made from sorghum, African yam bean and crayfish. Increase in pigeon peas levels results in better acceptability in colour of the developed flakes due to the lighter colour of pigeon peas compared to sorghum and this was right up to 80:20 substitution level. As the substitution increased to 60:40, it affected the physical appearance as this sample recorded lowest in both physical appearance and overall acceptability. This could be attributed to the increase in protein content which leads to darker colour as a result of Millard reaction due to relatively higher lysine content. Similar results were reported by Rehman and others, (2016) who reported that increase in protein content resulted in more colour darkness due to Millard reaction and caremelization. Offiah and others, (2016) also found that addition of African yam beans to maize did not adversely affect the sensory characteristics of the tortillas made from the blends. Adeyeye, (2016) reported that increase in the levels of sorghum substitution in wheat flour cookies affected the colour, taste and texture of the product above 35% substitution of wheat flour with sorghum flour.

4.4.2 Conclusion

High quality and acceptable breakfast cereal can be developed from locally available sorghum and pigeon peas grains. Incorporation of pigeon peas with sorghum improved the nutritional characteristics and caused remarkable changes in the protein content of the product. Thus, pigeon pea (legume) incorporation shows a promising trend for protein rich breakfast cereal production and could be effective in producing high energy dense sorghum based food products.

Simple and inexpensive processing techniques such as malting, decorticating and fermentation can be used to improve the nutritional quality of sorghum based products while at the same time solving the problem of anti nutritional factors in sorghum.

CHAPTER 5: MICROBIAL AND KEEPING QUALITY OF A READY TO EAT BREAKFAST CEREAL DEVELOPED FROM SORGHUM-PIGEON PEAS BLENDS

5.1 ABSTRACT

Cereal based breakfast products such flakes, bread, and muesli are consumed by numerous people because they are an important source of macro- and micro-nutrients for both adults and children. The shelf life of a product is highly dependent on the type of packaging material used and the environmental conditions around the product. This study aimed at the assessment of the storage stability of flaked breakfast cereal prepared by blending sorghum and pigeon peas in different proportions. Samples of the formulated product were packaged using two different packaging materials-laminated kraft paper and retortable pouch (stand up pouch) and incubated at 55^{o}C for 12 days. During storage, changes in microbial content (TVC, yeast and molds, *E.coli* and *Salmonella*), moisture content, free fatty acids (FFA) and peroxide value (PV) were analyzed after every three days for a period of 12 days. The microbial growth indicated an increasing trend throughout the storage period showing lower growth in the standup pouches compared to the laminated kraft paper. TVC showed average growth rate of 3.8% in the stand up pouches compared to the kraft paper which had growth rate of 5.06%. Similarly, Yeast and molds showed lower growth rate of 3.69% than the kraft packaged samples (3.82%). The moisture content declined too as the storage days advanced with the samples stored in the stand up pouches showing lower average moisture change (4.78%) compared to the kraft paper (5.24%) indicating the moisture loss was minimal in the stand up pouches hence longer shelf life. The FFA and PV both showed an increasing trend as the storage time progressed. Samples stored in the retortable pouches showed slightly lower increase in both the FFA and PV values

compared to the laminated kraft paper. This is suggesting that lipid oxidation and rancidity was lower in the retortable pouches meaning the product would have stayed longer in the pouch than in the kraft paper. The results indicated that the product had estimated shelf life of 9 months as some critical quality parameters were exceeded after the 9th day. Laminated kraft paper was found to the least suitable for packaging of sorghum-pigeon pea flakes because of essential quality changes of samples during their storage compared to the retortable pouch.

Key words: Sorghum/pigeon pea breakfast cereal, storability, microbial quality, free fatty acids, peroxide value.

5.2 INTRODUCTION

Sorghum has great potential to provide food security in the arid and semi-arid regions, where majority of the cereal crops fail or produce little yield. It is considered to be one of the most important cereal crops in those regions (Kange *et al.*, 2014). Sorghum is a drought tolerant cereal crop and is used as an important food crop in many parts of Kenya where maize production fails or produces little yield. This is because sorghum can withstand erratic rainfall, pests and diseases. Sorghum is predicted to continue to be an important food crop around the world and especially draught prone areas with high temperatures where sorghum is better adapted than other cereals (Okuthe *et al.*, 2013).

Because of the presence of anti-nutritional factors such as tannins and phytates, sorghum has poor organoleptic properties and decreased protein digestibility. However, adequate processing techniques such as malting, dehulling and fermentation can solve the issues of antinutritional factors in sorghum (Tope, 2014).

The protein quality of cereals such as sorghum can be improved by supplementing with locally available legumes such as pigeon pea which is a good source of protein and lysine, although often limiting in sulphur containing amino acids through mutual complementation of their individual amino acids (Marete, 2015). To increase the consumption and utilization of sorghum, diversification and production of new products from the grain is highly important. Therefore of great importance, is the possibility of developing low cost breakfast cereal form locally available raw materials that provides necessary nutrients required by the body.

Recently, the consumption of breakfast cereals and related products have increased steadily throughout the world earning a big share in the food market (Carvalho *et al.*, 2012). Ready to eat (RTE) cereal products rank as one of the best choices available as part of a nutritious breakfast. Owing to their ease of preparation, ready to eat cereals foster independence, this ensures that kids and teens can be responsible for their own breakfast or snacks (Mbaeyi and Uchendu, 2016).

The quality of breakfast cereals depends not only on their original condition, but also on the degree of manufacturing and storage changes. Foods are exposed to a vast variety of environmental factors during storage and distribution. Several reaction mechanisms that can lead to food deteriorations can be caused by environmental factors such as temperature, humidity, oxygen and light. As a result of these processes, foods can be changed to such a degree that they are either rejected by the consumer or become harmful to the individual who consumes them (Macedo *et al.*, 2011).

Many cereal products and snack foods contain lipids and are dry. These products have water activity below 0.6 which makes them stable against microbial growth however, chemical and enzymatic reactions can occur resulting in deterioration of the product. Moisture content has great impact on the physical properties of the product, stability and microbial growth (Macedo *et al.*, 2011). Breakfast cereals contain fat either added or within the grain used to formulate the product and this may therefore make them susceptible to lipid oxidation, resulting in formation of off-flavours during storage. During packaging of food products, the impact of oxygen pressure and humidity on the oxidative stability of snacks and cereal products is of great concern which may be crucial in the selection of the initial headspace gas composition, initial product water activity and gas and water vapour permeability of the packaging material (Nkubana and Dusabumuremyi, 2019).

The use of packaging in the food production is an essential part of food processing and it is very common to use packaging in the food supply chain. Generally, cereal products are usually packaged in paper or polyethylene packaging materials (Senhofa *et al.*, 2015). Two different material types can be used to combine for packaging materials of cereal flakes, the first being intended for product safety and the other for easy use by the customer. Significant advances in food packaging technologies have developed a way of suppressing microbial growth and shielding food from external microbial contamination (Cutter, 2002). Packaging materials have been primarily designed to prevent food degradation resulting from changes caused by air, moisture or pH exposure, while preserving sensory properties (Senhofa *et al.*, 2015). The aim of this study was to evaluate microbial and keeping quality changes of ready to eat breakfast cereal developed from sorghum-pigeon peas blends under different packaging materials.

5.3 MATERIALS AND METHODS

5.3.1 Sample Collection and Preparation

Sorghum and pigeon pea grains were purchased from authorized grain suppliers in Nairobi. The cleaning, grading and the product development were done at the pilot plant of the Department of Food Science Nutrition and Technology, Faculty of Agriculture, Collage of Agriculture and Veterinary Sciences, University of Nairobi. The samples were cleaned manually to remove foreign materials, broken pieces, insect parts and infected grains. The grains were then washed with tap water to remove dust and mud and then dried to 12% moisture. Other ingredients were also purchased from authorized suppliers in Nairobi.

5.3.2 Experimental Design

Experimental design is as has been illustrated in chapter 4 section 4.3.2 in page 97.

5.3.3 Product Formulation and Treatments

5.3.3.1 Preparation of whole grain sorghum flour

2 kg of sorghum grains were cleaned manually to remove foreign contaminants. The grains were then washed with water to clean from dust and adherent impurities and oven dried at 105°C to 12% moisture. The grain were then milled using a commercial hammer mill to obtain flour that can be sieved through 0.3mm sieve size and packed in air tight containers for storage before using in product formulation.

5.3.3.2 Preparation of decorticated sorghum flour

About 2kg of decorticated (dehulled) sorghum grains were purchased from an authorized cereal supplier in Nairobi and hand cleaned to remove visible impurities such as stones, husk and chaff. The grain was then washed with tap water and oven dried at 105°C to 12% moisture. The clean decorticated sorghum grains were then milled using commercial hammer miller to pass through 0.3 mm sieve screen and packaged in air-tight container for storage.

5.3.3.3 Preparation of malted sorghum flour

Sorghum grains were first cleaned, graded and soaked for 12 hours in tap water (1:2 W: V). After soaking, the grains were drained and germinated by spreading out on a tray and covered with a cloth. Water was sprinkled on the germinating grains after every 12hours for four days. The germinated grains were dried in a cabinet drier at 65ºC for 5 hours. The rootlets of the sprouted grains were removed by hand through abrasion. The dried malted grains were then milled in to fine flour of 0.3mm sieve size and packaged in air tight packages for use in the product formulation. The following diagram shows the scheme of malted flour production

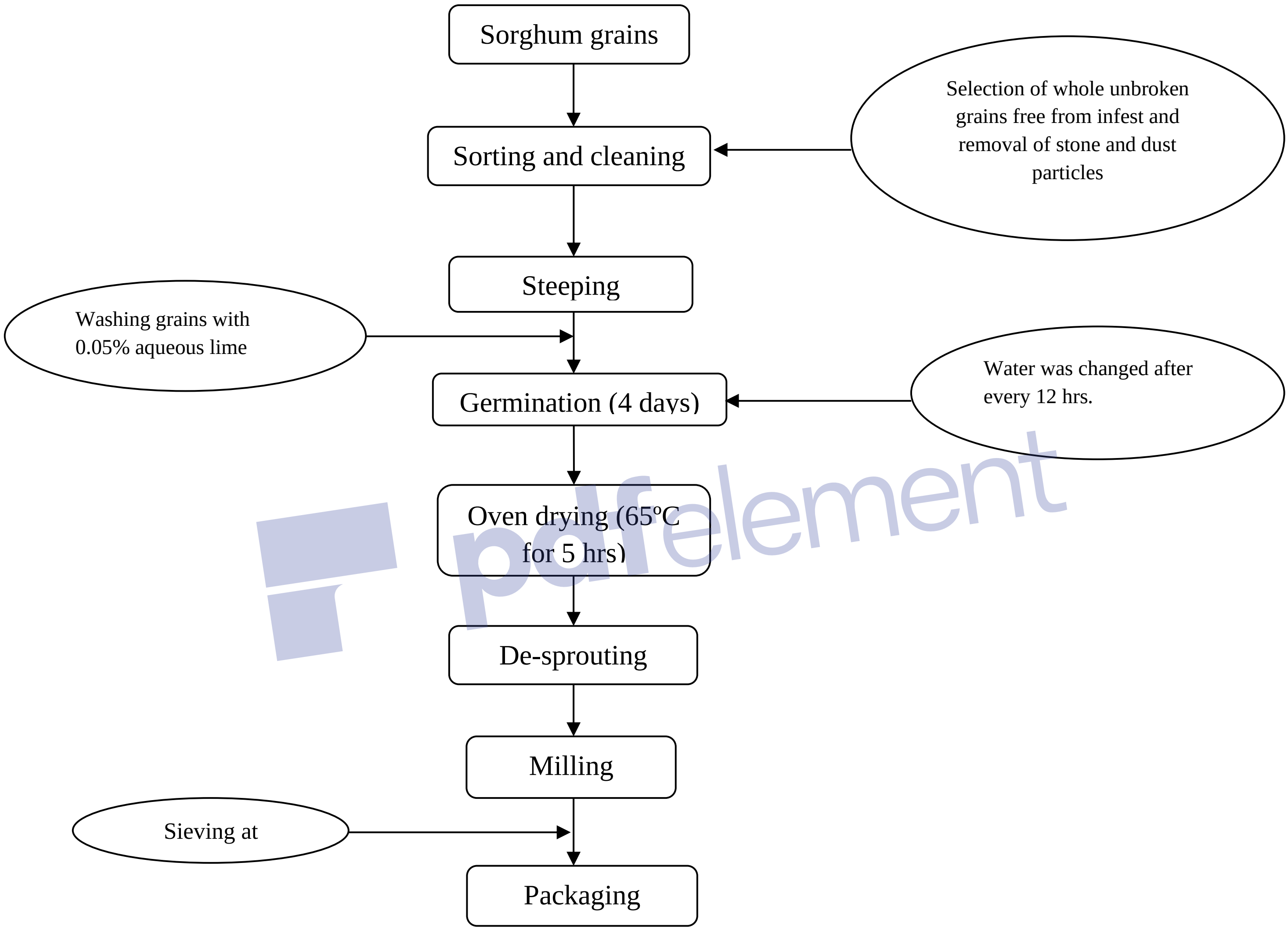


Figure 5.13 Production of Malted Sorghum Flour

5.3.3.4 Preparation of pigeon peas flour

Pigeon pea grains were sorted to remove insect infested grains, broken pieces and other foreign materials. The grains were then washed thoroughly and oven dried at 70°C for

5 hours. The dried grains were then milled using commercial hammer mills to obtain fine flour of 0.3 mm sieve size and then stored in airtight containers for storage.

5.3.3.5 Preparation of fermented flours

Pre-fermented portions of fermented sorghum flour were prepared from 500g of fine malted sorghum flour, dehulled sorghum flour and whole grain sorghum flour. To prepare the portions, 500g of fine sorghum flours was mixed with 1liter of water (1:2 w/v) to form a thick paste which was then put in a container and then incubated at 37ºC for 24 hours. To start the fermentation process spontaneously, the pre-fermented portions were used to prepare a larger amount of fermented flours.

In each treatment (malting, dehulling and whole grain), 120g of the pre-fermented portions were mixed with 500g of fine flour and 600ml of water. The thick paste dough formed was then left to ferment at room temperature (25ºC) for 24 hours. The dough was then transferred to perforated metal trays and spread into a thin layer. The trays were then put into a cabinet drier at 75°C for 8 hours. The dried materials were then cooled before breaking into small pieces which were then milled using hammer miller to obtain fine fermented flours named malted and fermented, dehulled and fermented and whole grain fermented accordingly.

5.3.3.6 Processing of the sorghum-pigeon peas flakes

The product processing is as has been illustrated in chapter 4 section 4.3.3.6 and table 4.1

5.3.4 Analytical methods

The RTE cereal flakes were analyzed for various microorganisms to evaluate the microbiological profile of the formulated product in order to estimate the overall keeping quality and general hygiene. The microbiological tests were conducted for a period of 12 days for proper comparison with the normal RTE breakfast cereals and flaked products in the commercial market. The objective was to get an accurate estimation of the products microbial quality and shelf-life in relation to the conventional RTE cereal flakes in the market. The tests were conducted after every 3 days for 12days throughout the incubated storage period.

5.3.4.1 Microbial Analysis

The RTE flakes were analyzed for various microorganisms to determine the microbial profile so as to predict the general hygiene and overall keeping quality. *Escherichia coli* were analyzed as hygiene indicator especially for faecal contamination. Total viable count (TVC) was analyzed as indicator of overall microbial quality of the processed flakes. The microbiological analysis was performed to determine the time period for detectable changes in microbial quality during storage.

5.3.4.1.1 Determination of Escherichia coli

E. coli was enumerated Based on ISO method 16649-2:2001(ISO 2001). 10g of the sample was homogenized in 90ml peptone water. Decimal serial dilutions of the homogenized solution in sterile peptone water were prepared and plated in duplicate on the selective agar media. Blue green colonies for *E. coli* were expected to form and counted after 48 hours of incubation at 40^{o}C. The number of colony forming units (CFU) of presumptive *E.coli* per gram of sample was calculated as Log CFU g^{-1}.

5.3.4.1.2 Determination of total viable counts (TVC)

ISO method 4833:2003 (ISO 2003) was used for the total viable count (TVC) enumeration. Duplicate plates containing plate count agar was used in the process. Incubation was done at 37^{o}C for 24 hours after which microbial counts were expressed as numbers of cfu/g of the sample.

5.3.4.1.3 Determination of Yeasts and Molds

ISO method 21527-1:2008(en) was used. Potato Dextrose agar (PDA) was used to enumerate yeasts and molds using pour plating method. Incubation of the plates was done for 5 days at 25±1 °C. The sum total of CFU of presumptive yeast and molds per gram of sample was calculated.

5.3.4.1.4 Determination of *Salmonella*

The ISO method 6579:2002 (ISO 2002) was used for enumeration of *Salmonella* species. 25g of sample were homogenized with peptone water and incubated at 37±1^{o}C for 18±2 hours. The inoculums were shifted to Rappaport- Vassiliadis broth and selenite cysteine broth from the pre- enrichment broth and incubation done at 41.5±1^{o}C and 37±1^{o}C for 24 hours for selective enrichment. A loopful of the selective enrichment was streaked onto two solid selective media: Brilliant green agar (BGA) and xylose lysine desoxycholate agar (XLD). XLD agar was incubated at 37±1^{o}C and observed after 24±3 hours for typical *Salmonella* transparent red halo and a black centre.

5.3.4.2 Accelerated shelf life analysis

Accelerated shelf life testing according to the method of Fu and Labuza, (1997) with slight modification was used to test the shelf life of the developed flakes. The developed products were packed in two different types of packaging materials and then stored at 55^{o}C in an incubator for 12 days (1day=1month). Physicochemical and microbiological characteristics were used to quantify the quality of the developed product during the storage time. The packaging materials used were retort pouches and laminated craft paper.

5.3.4.2.1 Determination of peroxide value

The method (AOAC, 2008 – Method 965.33) was used to determine the peroxide value of the samples. Approximately 5g of the sample was weighed into a dry 250ml stoppered conical flask. 30ml of the mixture glacial acetic acid: chloroform (3:1) was added and the fat dissolved by careful swirling. 0.5ml of fresh saturated aqueous potassium iodide solution was added and the flask stoppered. The contents were shaken for 1 minute and the flask placed in darkness for 1 minute. 30ml of distilled water was added and mixed well with the flask contents. Titration of the iodine with 0.002M or 0.01M sodium thiosulphate solution using 1% starch solution as an indicator then followed. A reagent blank determination (V0) was carried out using 0.5ml of 0.01M thiosulphate solution.

5.3.4.2.2 Determination of free fatty acids value

The free fatty acids were determined based on (ISO 660:2009 method). Twenty five millimetres of diethyl ether and 25ml of ethanol were mixed. The solution was neutralized with 0.1N sodium hydroxide solution. About 5g of the sample was weighed and placed into the neutral solution and then titrated with 0.1N Sodium Hydroxide solution. Phenolphthalein was used as indicator. Free fatty acids were expressed as the g of sodium hydroxide required to neutralize free acid in 100g of sample.

5.3.5 Statistical Analysis

All data collected was done in duplicates. The data was analyzed using two ways ANOVA and Fisher's unprotected LSD for multiple mean comparisons. The data obtained was subjected to statistical analysis using Genstat software version 15.0 at $P<0.05$ significance level. Packaging effect was also done using Genstat software version 15.0 at $P<0.05$ significance level and Fisher's unprotected LSD for multiple mean comparisons to study the difference between means.

5.4 RESULTS AND DISCUSSIONS

5.4.1 Effect of packaging and storage time on the microbial quality of formulated sorghum-pigeon peas breakfast cereals

5.4.1.1 Effect of packaging and storage time on TVC of formulated sorghum-pigeon peas breakfast cereals

Total viable counts showed an increase from log 0.95 to log 6.41 for stand up pouches and log 2.97 to log 6.94 for laminated kraft paper during the entire accelerated storage period from day 1 to 12 days. Samples stored in retortable pouches showed slower growth of TVC compared to those in laminated kraft paper suggesting that the product could have longer shelf life in retortable pouches than the laminated kraft paper. Figure 5.2 and 5.3 shows the changes in the TVC content of the formulated breakfast cereal product packed in a retortable pouch and laminated kraft paper for comparison.

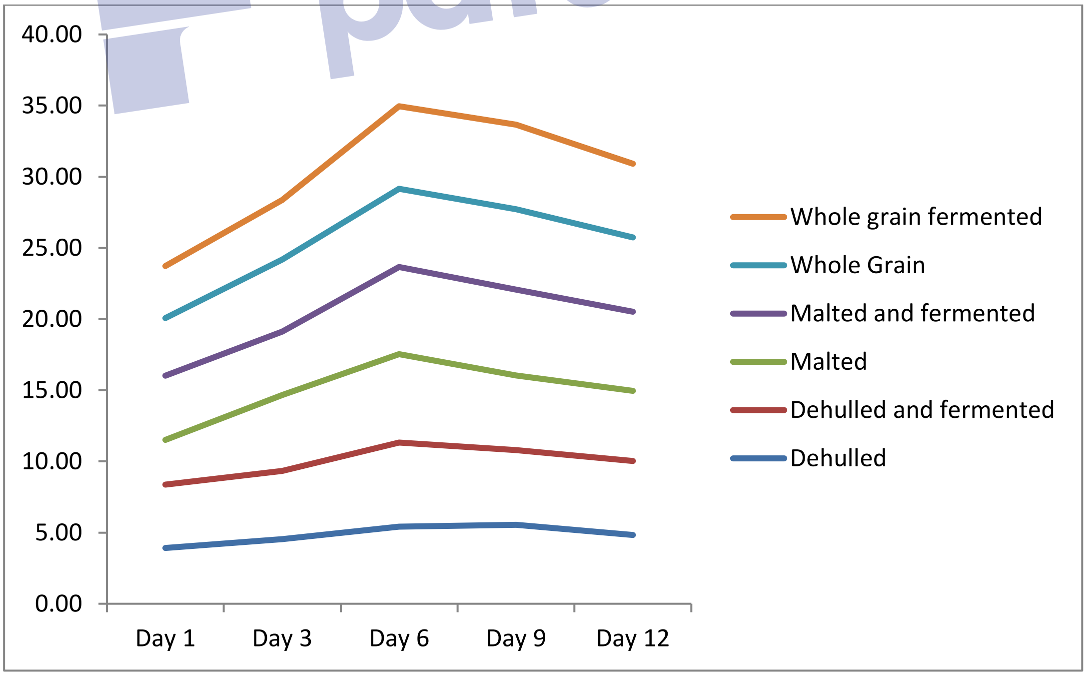


Figure 5.1 Changes in the TVC content of the formulated sorghum pigeon peas breakfast cereals packaged in laminated kraft paper

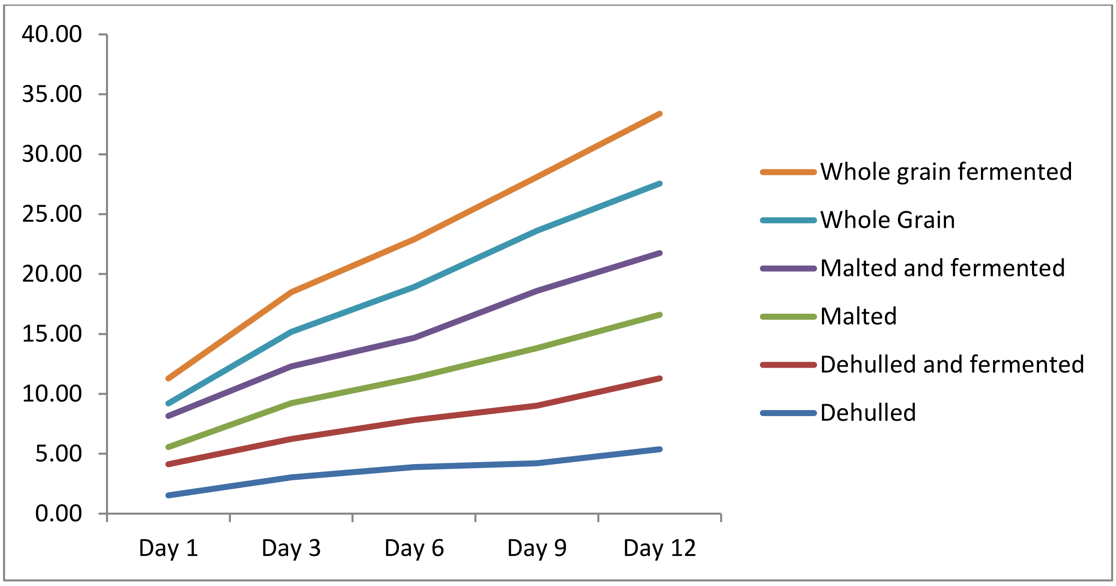


Figure 5.2 Changes in the TVC content of the formulated sorghum pigeon peas breakfast cereals packaged in retortable pouches

5.4.1.2 Effect of packaging and storage time on yeasts and mold of formulated sorghum-pigeon peas breakfast cereals

Yeast and molds ranged from log 0.27 to log 5.81 for the retortable pouches and log 0.32 to log 7.60 from day 1 to day 12 of the accelerated shelf life. Samples stored in retortable pouches showed slower growth of yeast and molds compared to those in laminated kraft paper suggesting that the retortable pouches did not favour the growth of the yeast and molds during the storage period hence the product could have longer shelf life in retortable pouches than the laminated kraft paper. Yeast and molds could not be detected on day one of accelerated shelf life for samples stored in retortable pouches. Figures 5.4 and 5.5 shows the changes in the yeast and molds content of the formulated breakfast cereal product packed in a retortable pouch and laminated kraft paper for comparison.

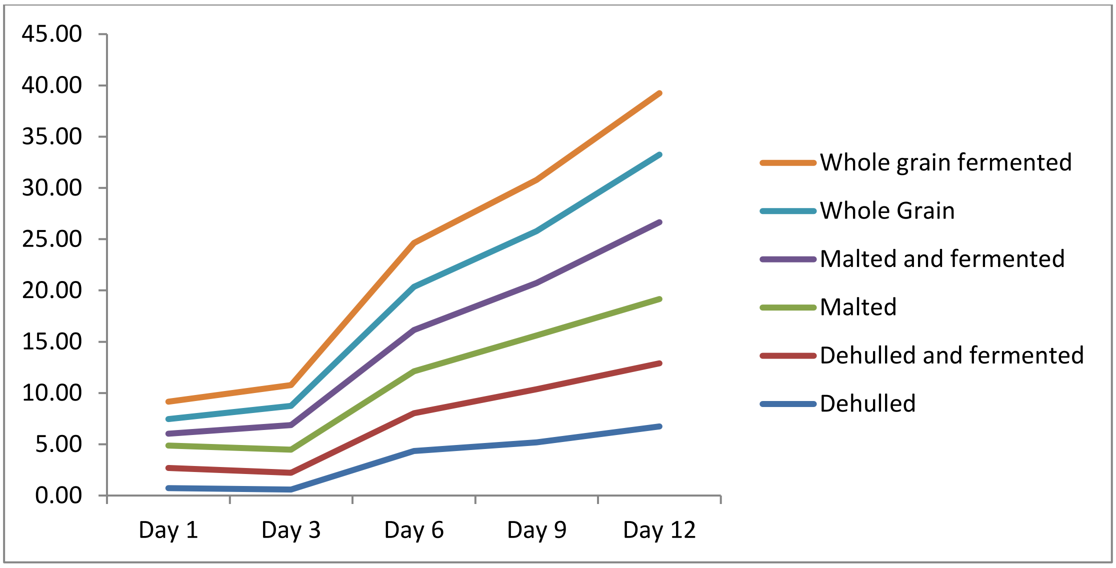


Figure 5.3 Changes in the Yeast and Molds content of the formulated sorghum pigeon peas breakfast cereals packaged in laminated kraft paper

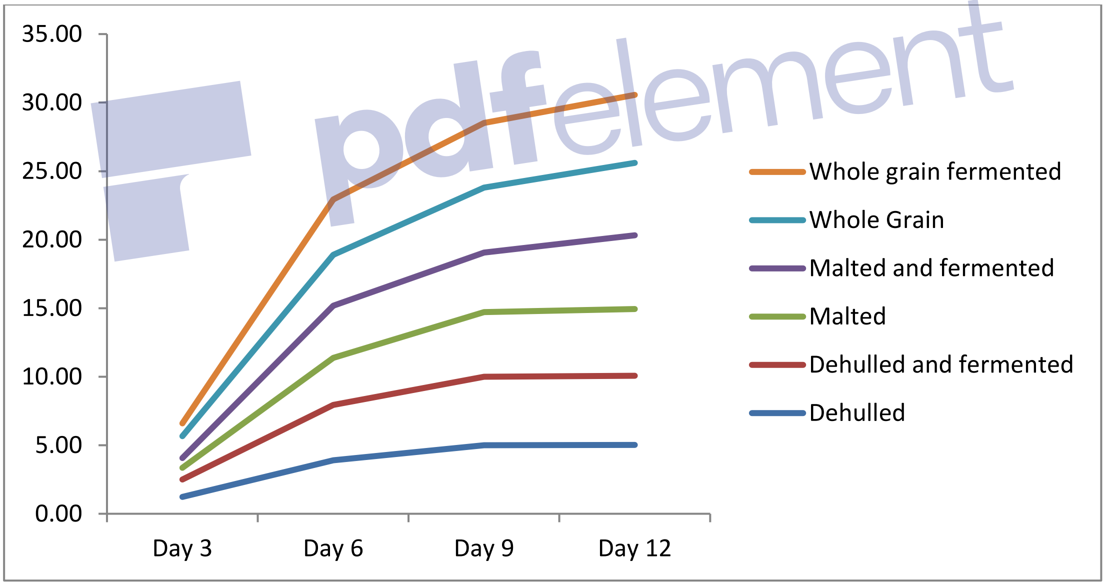


Figure 5.4 Changes in the Yeast and Molds content of the formulated sorghum pigeon peas breakfast cereals packaged in retortable pouches

Generally, packaging did not have a significant difference (*p*>0.05) in the total viable count and yeast and molds count. Microbial growth was higher from the first day to the sixth day of the accelerated storage compared to the ninth and twelfth days where the growth slowed down. This could be attributed to the fact that the water activity of the product reduced as the storage time advanced due to moisture loss. The product was kept at 55°C in the entire storage period; therefore, some microorganisms could also be destroyed at that temperature with prolonged time of storage leading to the slowed microbial growth noted in the ninth and twelfth days of storage. But, generally microbial growth gradually increased throughout the storage period (Bello *et al.*, 2018), (Mohamed *et al*., 2017).

In both packaging systems the values were within the range specified for ready to eat breakfast cereal products by Kenya bureau of standards (KEBS) up to 9th day of accelerated storage. According to Kenya bureau of standards (KEBS) (KS 523-2: 2015) the legal limits for TVC, yeasts and moulds are 6.0 log10cfu/g, 50 col.per gram, maximum, respectively. *Escherichia coli* and *Salmonella* were not detected throughout the storage period for all the samples which was also in compliance with KEBS requirement which states that both *Escherichia coli* and *Salmonella* should be absent from breakfast cereal products (KS 523-2: 2015).

Increase in the microbial content during the storage may have been resulted by the presence of air in the packaged product and diffusion of air in and out of the packaging material. Similar findings were reported by Senhofa and others,(2015) who stated that both TVC and yeast and molds of muslei product increased during storage regardless of the type of packaging used. Similar results were also reported by Agu and others, (2015). Retortable pouches recorded lower microbial growth compared to the laminated kraft paper since they are less permeable to air hence low microflora development (Senhofa *et al.*, 2015).

Although the product was heat treated and processed under high care of hygiene quality, microbial growth still occurred. This could possibly be due to the fact that the microbial characteristic of the grains has develops in the field before harvest or under storage before processing. Similar findings were reported by Kaukovirta-Norja and others, (2004). Sample treatments of dehulling, germination and fermentation presented a significant *(p*>0.05) difference in the microbial content of the final product. On average, fermented samples were found to have slightly higher microbial content compared to the other treatments (Figure 5.2 and 5.3). Similar findings were reported by Marko and others, (2014) who found increase in the fermentation time led to the increase of the number of bacteria. Ogodo and others, (2019) also reported similar results. The product was flaked through drum drying at 140°C for 10 which could have killed most of the microorganisms present and hence eliminated the effect of product treatments on the microbial quality of the final product.

5.4.2 Effect of packaging and storage time on the chemical quality of the developed sorghum-pigeon peas breakfast cereal

5.4.2.1 Moisture

The moisture content ranged from 3.82% to 6.55% for samples packaged in retortable pouches (Table 5.2) and 3.52% to 6.18% for samples packed in laminated kraft paper (table 5.1). Packaging had no significant ($p > 0.05$) effect on moisture content of the product. In both packaging conditions, moisture content showed a declining trend throughout the accelerated storage time. Decrease in moisture content works against microbial growth although it may bring chemical changes essential to consumer acceptability of the product. Products packaged in retortable pouches had higher moisture content than product packed in laminated kraft paper indicating that the retortable pouches had less moisture loss during storage than the laminated kraft paper.

Table 5.1 Moisture content of the formulated products packaged in laminated Kraft paper

Treatment	Substitution level	Day 1	Day 3	Day 6	Day 9	Day 12
Dehulled	100:00	5.92±0.09[bc]	5.68±0.04[ab]	5.56±0.01[bc]	5.31±0.06[abc]	5.28±0.10[abc]
	60:40	5.44±2.25[abc]	5.25±2.23[ab]	5.10±2.21[abc]	4.97±2.19[abc]	4.78±2.20[abc]
	80:20	5.11±0.95[abc]	5.03±0.88[ab]	4.92±0.89[abc]	4.78±0.86[abc]	4.73±0.83[abc]
Dehulled and fermented	100:00	4.28±0.10[ab]	4.11±0.16[a]	3.96±0.24[ab]	3.79±0.19[ab]	3.66±0.09[ab]
	60:40	4.74±0.13[abc]	4.70±0.11[ab]	4.61±0.10[abc]	4.51±0.15[abc]	4.39±0.00[abc]
	80:20	5.66±0.94[abc]	5.63±0.89[ab]	5.54±0.98[bc]	5.44±1.03[bc]	5.40±1.05[bc]
Malted	100:00	5.26±0.61[abc]	5.19±0.56[ab]	5.10±0.51[abc]	5.08±0.54[abc]	4.99±0.48[abc]
	60:40	5.06±0.79[abc]	4.90±0.89[ab]	4.74±1.04[abc]	4.56±0.92[abc]	4.51±1.00[abc]
	80:20	4.78±0.57[abc]	4.57±0.63[ab]	4.43±0.70[abc]	4.30±0.69[abc]	4.22±0.60[abc]
Malted and fermented	100:00	4.71±0.86[abc]	4.67±0.87[ab]	4.58±0.84[abc]	4.39±0.90[abc]	4.29±0.86[abc]
	60:40	5.35±0.06[abc]	5.31±0.02[ab]	5.16±0.06[abc]	5.10±0.11[abc]	4.91±0.13[abc]
	80:20	4.02±0.03[a]	3.94±0.09[ab]	3.67±0.10[abc]	3.57±0.04[a]	3.54±0.05[a]

Whole Grain	100:00	4.51±0.70^{abc}	4.33±0.78^{ab}	4.07±0.80^{ab}	3.87±0.78^{ab}	3.52±0.73^{a}
	60:40	6.18±1.16^{c}	6.09±1.13^{b}	5.92±1.09^{c}	5.68±1.06^{c}	5.50±0.99^{c}
	80:20	5.13±1.57^{abc}	4.92±1.58^{ab}	4.73±1.62^{abc}	4.47±1.50^{abc}	4.19±1.52^{abc}
Whole grain fermented	100:00	4.88±0.07^{abc}	4.78±0.01^{ab}	4.55±0.07^{abc}	4.44±0.06^{abc}	4.28±0.08^{abc}
	60:40	4.98±0.33^{abc}	4.90±0.33^{ab}	4.73±0.39^{abc}	4.67±0.30^{abc}	4.56±0.36^{abc}
	80:20	5.03±0.06^{abc}	4.60±0.30^{ab}	4.57±0.29^{abc}	4.48±0.17^{abc}	4.39±0.21^{abc}

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Table 5.2 Moisture content of the formulated product packaged in retortable Pouches

Treatment	Substitution level	Day 1	Day 3	Day 6	Day 9	Day 12
Dehulled	100:00	5.43±1.54^{a}	5.14±4.47^{a}	4.91±1.58^{a}	4.73±1.62^{a}	4.34±1.43^{a}
	60:40	5.61±1.44^{a}	5.25±4.71^{a}	4.96±1.64^{a}	4.73±1.63^{a}	4.53±1.72^{a}
	80:20	6.25±2.80^{a}	6.11±4.75^{a}	5.88±2.78^{a}	5.63±2.77^{a}	5.41±2.79^{a}
Dehulled and fermented	100:00	5.76±0.93^{a}	5.41±4.97^{a}	5.18±0.76^{a}	5.00±0.57^{a}	4.73±0.84^{a}
	60:40	5.18±0.18^{a}	4.97±5.12^{a}	4.63±0.03^{a}	4.40±0.08^{a}	4.33±0.11^{a}
	80:20	6.55±2.41^{a}	6.36±5.14^{a}	6.21±2.50^{a}	5.83±2.40^{a}	5.77±2.42^{a}
Malted	100:00	5.29±0.51^{a}	4.75±5.25^{a}	4.59±0.05^{a}	4.49±0.14^{a}	4.30±0.32^{a}
	60:40	4.64±0.71^{a}	4.47±5.41^{a}	4.07±0.86^{a}	3.90±0.87^{a}	3.82±0.80^{a}
	80:20	5.60±0.46^{a}	5.12±5.44^{a}	4.85±0.53^{a}	4.71±0.54^{a}	4.65±0.54^{a}
Malted and fermented	100:00	6.32±1.50^{a}	6.03±5.58^{a}	5.72±1.58^{a}	5.51±1.44^{a}	5.32±1.68^{a}
	60:40	6.25±1.10^{a}	6.00±5.66^{a}	5.86±0.95^{a}	5.66±1.05^{a}	5.50±1.17^{a}
	80:20	5.72±0.86^{a}	5.44±5.66^{a}	5.14±0.84^{a}	4.98±0.95^{a}	4.74±0.61^{a}

Whole Grain	100:00	5.00±1.29[a]	4.71±5.68[a]	4.47±1.37[a]	4.25±1.35[a]	4.23±1.34[a]
	60:40	6.11±0.30[a]	5.89±5.89[a]	5.64±0.42[a]	5.38±0.38[a]	5.10±0.32[a]
	80:20	5.81±1.55[a]	5.68±6.00[a]	5.28±1.73[a]	5.18±1.71[a]	5.13±1.66[a]
Whole grain fermented	100:00	5.69±2.25[a]	5.58±6.03[a]	5.31±2.26[a]	5.19±2.31[a]	4.84±2.38[a]
	60:40	6.06±2.02[a]	5.66±6.11[a]	5.43±1.82[a]	5.18±1.80[a]	5.06±1.95[a]
	80:20	5.93±0.62[a]	5.66±6.36[a]	5.33±0.65[a]	5.08±0.65[a]	4.79±0.74[a]

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different (P<0.05)

Both sample treatment and level of pigeon pea substitution with sorghum showed no significant ($p > 0.05$) effect on the moisture content of the product during storage. All samples recorded reduced moisture content at the end of the storage period. Similar findings were reported by Senhofa and others, (2015). Nkubana and Dusabumuremyi, (2019) reported decrease in moisture content of extruded products.

On average, fermented samples exhibited slightly higher moisture content throughout the storage period. During fermentation water is added to facilitate the fermentation process and this might have led to increased moisture content of the fermented samples. Similar findings were reported by Ojokoh and Bello, (2014) who reported increase of moisture content by fermentation process.

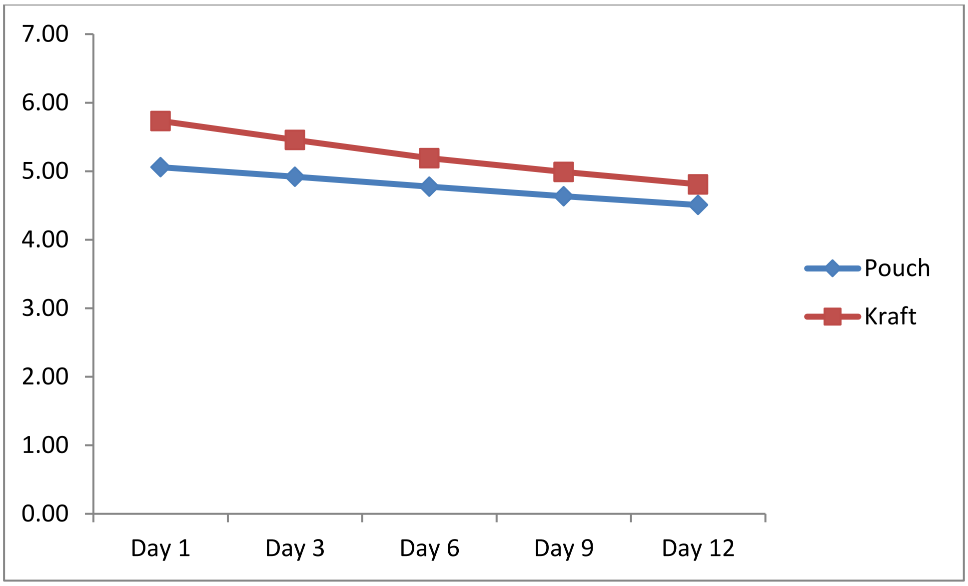


Figure 5.5 Changes in the moisture content of the formulated sorghum pigeon peas breakfast cereals during the storage period.

The moisture content was safe for the product storage as it was not high enough to cause product deterioration and microbial growth since lower moisture content affords the product longer shelf life. Jonathan and Adeyeye, (2015) reported similar findings. The findings are also in agreement with those of Kince others, (2018) who reported that a moisture content of 10% to 12% is sufficient to provide appropriate quality for dry cereal product during their storage. The moisture content of the product packed in the pouch was higher compared to the laminated kraft paper due to the low permeability of the pouch material to water vapour which prevented the loss of moisture during the accelerated storage. The findings were in agreement with the findings of Kruma others, (2018). Senhofa others, (2015) found higher water loss in muslei products stored in paper bag (56%) and paper tube (51%) compared to doypack (stand up pouch).

5.4.2.2 Free Fatty acids (%)

Free fatty acid value ranged from 0.65% to 4.31% for samples packed in retortable pouches (Table 5.4) and 0.51% to 3.72% for samples packed in laminated kraft papers

(Table 5.3). Free fatty acids could not be detected on day one of accelerated storage for samples packaged in retortable pouches and there was a significant *(p*>0.05) increase in free fatty acid content as the storage time advanced probably due to lipolysis.

Table 5.3 Free fatty acid content of the formulated product packaged in laminated Kraft paper

Treatment	Substitution level	Day 1	Day 3	Day 6	Day 9	Day 12
Dehulled	100:00	ND	2.05±0.69^{cde}	2.95±0.21^{d}	3.60±0.11^{bc}	3.67±0.25^{de}
	60:40	0.97±0.26^{bc}	2.86±0.15^{f}	2.76±0.80^{cd}	3.32±0.55^{bc}	3.36±0.66^{bcde}
	80:20	ND	2.49±0.06^{ef}	2.74±0.12^{cd}	3.64±0.62^{bc}	3.53±0.58^{cde}
Dehulled and fermented	100:00	ND	1.05±0.29^{a}	1.47±0.44^{a}	2.41±0.37^{ab}	3.01±0.11^{abcde}
	60:40	1.12±0.18^{c}	1.89±0.25^{bcde}	2.03±0.55^{abcd}	2.83±1.58^{abc}	2.72±0.30^{abc}
	80:20	1.08±0.15^{c}	1.98±0.25^{bcde}	2.05±0.16^{abcd}	2.68±0.59^{abc}	2.90±0.79^{abcde}
Malted	100:00	ND	2.19±0.33^{cdef}	2.95±0.40^{d}	3.72±0.25^{c}	3.71±0.71^{e}
	60:40	1.04±0.15^{bc}	2.37±0.42^{def}	2.19±0.05^{abcd}	3.10±0.01^{bc}	3.29±0.50^{bcde}
	80:20	0.68±0.23^{bc}	1.66±0.69^{abcd}	2.55±0.54^{bcd}	2.92±0.45^{abc}	2.93±0.63^{abcde}

Malted and fermented	100:00	0.51±0.05^{ab}	1.87±0.34^{bcde}	2.43±0.60^{abcd}	2.57±0.04^{abc}	2.73±0.57^{abcd}
	60:40	0.74±0.22^{bc}	1.98±0.19^{bcde}	2.92±0.06^{cd}	3.24±0.11^{bd}	3.33±0.01^{bcde}
	80:20	0.64±0.39^{bc}	1.60±0.06^{abc}	2.51±0.67^{abcd}	3.24±0.12^{abc}	2.99±0.08^{abcde}
Whole Grain	100:00	ND	1.76±0.19^{abcd}	2.25±0.76^{abcd}	1.74±0.96^{a}	2.21±0.48^{a}
	60:40	0.76±0.17^{bc}	2.50±0.23^{ef}	2.14±0.87^{abcd}	2.92±0.12^{abc}	2.70±0.26^{abc}
	80:20	0.84±0.51^{bc}	1.61±0.24^{abc}	2.51±0.26^{abcd}	3.14±0.48^{bc}	3.20±0.09^{bcde}
Whole grain fermented	100:00	0.62±0.21^{bc}	1.76±0.05^{abcd}	2.24±0.57^{abcd}	2.44±0.11^{ab}	3.03±0.25^{abcde}
	60:40	0.70±0.61^{bc}	1.33±0.40^{ab}	1.56±0.57^{ab}	2.66±0.79^{abc}	3.11±0.16^{abcde}
	80:20	0.89±0.08^{bc}	1.67±0.39^{abcd}	1.86±0.36^{abc}	2.54±0.64^{abc}	2.44±0.44^{ab}

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different ($P<0.05$)

ND=not detected

Table 5. 4. Free fatty acid content of the formulated product packaged in Pouch

Treatment	Substitution level	Day 3	Day 6	Day 9	Day 12
Dehulled	100:00	2.00±0.54^{d}	3.20±1.10^{f}	4.31±0.74^{d}	2.63±0.10^{bcd}
	60:40	1.97±0.44^{d}	2.02±0.30^{cde}	2.39±0.18^{abc}	2.36±0.59^{abcd}
	80:20	2.05±0.25^{d}	2.53±0.11^{ef}	3.78±0.56^{cd}	3.35±0.15^{d}
Dehulled and fermented	100:00	0.65±0.48^{a}	0.91±0.35^{a}	1.66±1.22^{ab}	2.60±0.63^{abcd}
	60:40	1.42±0.58^{abcd}	1.92±0.40^{bcde}	3.06±2.68^{bcd}	2.74±1.04^{cd}
	80:20	1.48±0.52^{bcd}	1.95±0.01^{cde}	2.54±0.11^{abcd}	1.32±0.06^{a}
Malted	100:00	1.67±0.08^{cd}	1.92±0.20^{bcde}	3.11±0.93^{bcd}	2.84±0.30^{cd}
	60:40	1.77±0.57^{cd}	2.38±0.19^{e}	2.68±0.33^{abcd}	2.27±0.06^{abcd}
	80:20	1.11±0.22^{abc}	1.50±0.15^{abcd}	1.51±0.13^{a}	1.34±0.08^{ab}

Malted and fermented	100:00	1.02±0.13^{abc}	1.42±0.01^{abcd}	1.80±0.37^{ab}	1.42±0.59^{ab}
	60:40	1.41±0.02^{abcd}	2.47±0.27^{ef}	3.28±0.40^{bcd}	2.36±0.26^{abcd}
	80:20	0.98±0.67^{abc}	1.16±0.25^{a}	2.58±1.38^{abcd}	2.12±0.66^{abcd}
Whole Grain	100:00	0.70±0.27^{ab}	0.86±0.18^{a}	1.15±0.13^{ab}	1.69±0.51^{abc}
	60:40	0.98±0.11^{abc}	1.19±0.06^{ab}	2.16±0.37^{abc}	2.00±0.43^{abc}
	80:20	1.11±0.17^{abc}	1.50±0.32^{abcd}	2.89±0.68^{abcd}	2.08±0.16^{abcd}
Whole grain fermented	100:00	1.35±0.53^{abcd}	2.15±0.44^{de}	1.75±0.56^{ab}	1.93±1.50^{abc}
	60:40	0.83±0.31^{ab}	1.36±0.29^{abc}	2.66±0.79	2.13±0.45^{abcd}
	80:20	1.95±0.03^{d}	2.01±0.15^{cde}	1.99±0.57^{abc}	1.93±1.09^{abc}

*Values are Means±sd. Superscripts abc Indicates that means along the same row with similar superscripts are not significantly different ($P<0.05$)

Retortable pouches recorded lower free fatty acid values compared to the laminated kraft paper suggesting that fat oxidation is lower (indicated by the lower FFA) in retortable pouches which could result in longer keeping quality of the product.

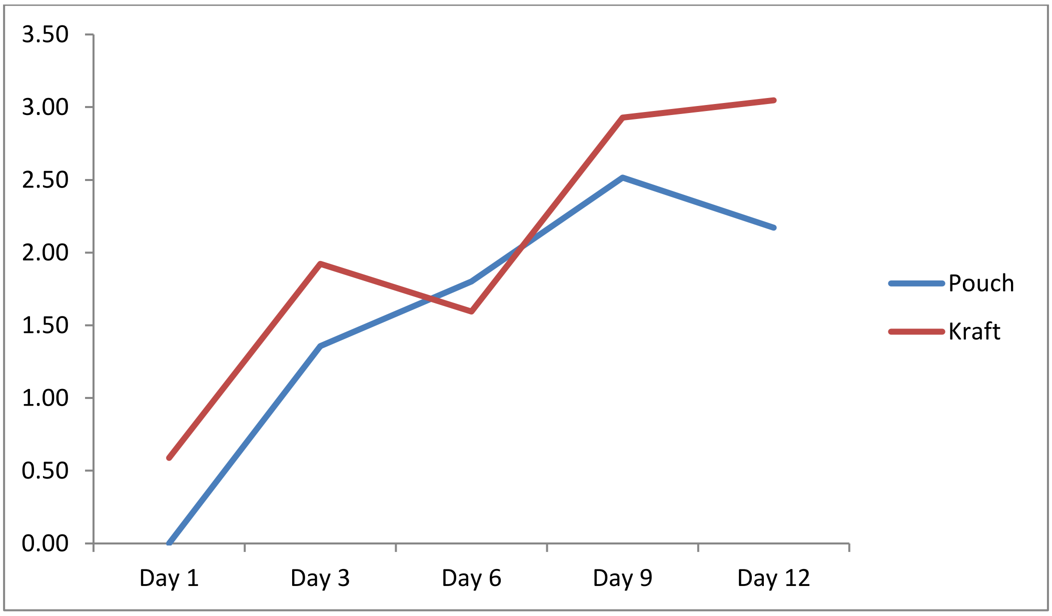


Figure 5.6 Changes in the free fatty acid content of the formulated sorghum pigeon peas breakfast cereals during the storage period

There was increase in free fatty acid content throughout the storage period regardless of the type of package used. This implies that there was slow but continuous fat oxidation of the product during the storage period. Similar findings were reported by Fastnaught and others, (2006), Zbikowska and Rutkowska, (2011) and Szafrańska, (2015). Kruma and others, (2018) reported decrease in the fat content of breakfast cereals packaged in stand up pouches and stored for six months which they attributed to be caused by fat oxidation during storage.

Free fatty acids result from the hydrolysis of fat present in the product which may be hydrolytic and is induced by moisture, or it can be oxidative hydrolysis which is catalyzed by presence of oxygen at high temperature. At elevated temperatures, long fatty acids may be broken in to smaller portions through fat hydrolysis which may increase the free fatty acids in the product. Increase in the amount of FFA content in the product leads to rancidity and production of off flavours reducing the quality and shelf stability of the stored product (Nkubana and Dusabumuremyi, 2019). Despite increasing progressively during the entire storage period, the free fatty acids (FFA) did not exceed the FFA limit of 100 mg KOH/100 g db (Szafrańska, 2015).

5.4.2.3 Peroxide value

The peroxide value was not detected on day one of storage in both packaging materials and showed progressive increase from day three onwards. Similarly, Werikhe and others, (2019) reported that at the beginning of shelf life of foods peroxide values are low. Packaging did not cause significant ($p > 0.05$) difference in the peroxide value of the product during storage. Samples packed in retortable pouches had lower peroxide values compared to those in laminated kraft papers.

Peroxide values increased significantly (p>0.05) throughout the storage period with fluctuating values showing no sign of stabilizing regardless of the type of packaging used. Peroxide value is usually low at the beginning of shelf life of the product (Mathi, 2016) but increases progressively due to the breakdown of long chain fatty acids in to smaller portions which increases the accumulation of primary oxidation products (measured by PV). Peroxide value is an indication of fat peroxidation causing rancidity leading to product spoilage. Products with higher fat content have relatively higher peroxide value (Balasubramanian *et al.*, 2014), (Mathi, 2016).

Products packed in retortable pouches had lower peroxide values throughout the accelerated storage period compared to the laminated kraft packed products although the difference was not significant ($p<0.05$). This is attributed to the lack of penetration of enough oxygen to initiate peroxidation reactions through the packaging material. Similar findings were reported by Sharma and others, (2017).

At the end of the storage, malting showed the highest mean peroxide value compared to the other treatments (dehulling, fermentation and whole grain). This is due to the malting conditions such as germination temperature, soaking and germination processes which may cause lipid degradation leading to increased peroxide value. Similar findings were reported by Balasubramanian and others, (2014) who found that significant ($p<0.05$) increase in lipase activity resulting from induction of enzyme activity due to initiation of seed germination during soaking. Özcanand others, (2018) also reported that malting conditions affect lipid degradation.

The rate of increase of PV was higher up to the sixth day of storage and lower in the ninth and twelfth day. Similarly, Zbikowska and Rutkowska, (2011) reported increase in PV in the first three weeks of storage of cookies and then the oxidation process slowed down. In both packaging systems, the peroxide value levels were within the recommended values >10meq/Kg (Gichau *et al*., 2019) up to the 9th day of accelerated shelf life.

5.5 CONCLUSION

The results indicated that laminated kraft paper bags were the least suitable for packaging of sorghum-pigeon pea breakfast cereal because of essential quality changes of the product during their storage. The study found that lipid oxidation causing product deterioration can be minimized though proper packaging of the product. Lack of proper hygiene quality of the raw material before processing, during processing and during storage can have profound effect on the shelf life of the product.

The product is predicted to have 9 months of stable shelf life since the quality parameters were within the standard limits up to the 9th day of accelerated shelf life extrapolated to 9 months (1 day = 1 month). After the 9th day of accelerated storage, microbial content and peroxide value exceeded the critical limits therefore the product was deemed to be expired.

CHAPTER SIX: GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The study has found that commercial sorghum products are limited and is mainly in the form of flour. The main products made from sorghum are Ugali and porridge, but there are other important products made from sorghum including sorghum cake, beverage or tea, mandazi and chapatti which can easily be commercialized. Milling is the main activity associated with sorghum processing which is mainly done at the poshomills.

The study showed the possibility of combination of sorghum with pigeon peas in different ratios so as to improve the nutrients composition and therefore increase the utilization of sorghum. Sorghum and pigeon peas combination can therefore be used to successfully formulate nutritious and highly acceptable breakfast cereals. Usually, cereals perform better when combined with legumes such that the formulations in which pigeon peas were added had better nutritional composition than the control plain sorghum in all formulation. The combinations made at 60:40 sorghum-pigeon peas, had the best nutrient qualities especially protein.

This study includes the effects of dehulling, malting, and fermentation and evaluation of quality parameters of processed breakfast flakes made from sorghum pigeon peas blends. From the study result it is clear that, dehulling, malting and fermentation do have positive effects on the proximate composition, anti-nutritional contents, and sensory quality of the formulated flakes. Malting, decorticating and fermentation are simple and inexpensive processing techniques that can be used to improve the nutritional quality of sorghum based products while at the same time solving the problem of anti nutritional factors in sorghum.

Therefore it may be nutritionally interesting to use these processing techniques to develop nutritionally acceptable sorghum based products. This study also evolved that the sensory quality of the processed flakes was found to be enhanced by malting and dehulling.

6.2 Recommendations

Creation of awareness among the farmers and the country at large on sorghum products consumption is vital in promotion and streamlining of sorghum potential markets. Training of farmers on sorghum value addition and also providing them with basic equipments to start with processing will in great way help the livelihood of many households who rely on the grain. The biggest fear among the farmers is the lack of market for their produce and this may be one of the reasons why the farmers opt for maize farming while in some instances sorghum yields are better.

It is also recommended use of other locally available and protein rich legumes such as pigeon peas to formulate sorghum based breakfast cereals so as to raise the level of protein content. By doing so it will increase the market of sorghum based products.

Adoption of extrusion cooking technology when preparing sorghum based products is recommended. This is because, the extrudates produced are easy to prepare and have good microbiological quality, and therefore they are safe products. Also, the antinutritional factors are reduced which results to increase the bio availability of nutrients in sorghum and its based products and therefore increase the sorghum utilization.

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APPENDICES

APPENDIX 1: FOCUS GROUP DISCUSSION GUIDE

Introduction: this survey intends to assess the current situation on utilization and processing of sorghum by small holder farmers/groups in Makueni

Guiding questions

- What products do you make from sorghum?
- How are these products prepared?
- What equipments are used to prepare the product?
- Who is the end user of the product?
- What are the challenges encountered in preparation of the product?
- How often are sorghum products consumed?
- How much of the household income goes to sorghum as food?
- What are the general challenges faced by sorghum farmers
- What do you think you can do to improve those products?
- What are the opportunities of sorghum products in the near future?
- What are the obstacles and challenges in sorghum products?

APPENDIX 2 Key informant interview

Name of Key in formant ________________________

Position/ Designation __________________________________

Contacts ____

Interviewer's name _______________________________

Date of Interview ______________________________________

Place ____

- Give us brief introduction about sorghum farming in the county
- What are the general challenges faced by sorghum farmers in the county?
- What proportion of the population in the county would you say depend on sorghum farming?
- List down all products that are made from sorghum
- How are these products prepared?
- What equipments are used to make those products?
- What proportion of the harvested sorghum grains is consumed at the household?
- How much of the sorghum produced is processed locally?
- Are there processed sorghum products in the market?
- What do you think can be done to improve sorghum products?
- What are the opportunities of sorghum products in the near future?
- What are the obstacles and challenges in sorghum products?
- Of all the things we've discussed today, what would you say are the most important issues you would like to express about sorghum farming and its products?

- What is your general recommendation?

APPENDIX 3 House hold questionnaire

Household survey questionnaire for assessment of current situation on utilization and processing of sorghum by small holder farmers/groups

Processor/HH name (optional):________________________________

Age ____________________

Gender 1.Male 2. Female

Marital status 1.Single2. Married 3.Widow

Education level _________________________

Years in sorghum farming _____________Date of interview ________

Processor/HH phone no:_______________ County______________

Name of Enumerator: ________________________Village _____________

Enumerator phone number: ___________________________

1) Which crops do you grow?

2) Which is your preferred crop? Tick appropriately.

3) How many sacks do you harvest per season?

   a. High

      i. (90kg bags)

      ii. (50kg bag)

   b. Low

      i. (90kg bags) (50kg bags)

4) What are the main challenges you face in sorghum farming?

5) How much of what you produce do you consume at home?

6) How much of what you produce do you sell?

7) At what price do you sell per bag? Who are the main buyers (market) who buy from you?

8) What products do you make from sorghum at home?

9) How are those products processed?

10) What are the equipments used in processing the product?

11) What are the raw materials used in production of the product?

12) Do you sell those products (yes/no)? If yes who are the main buyers?

13) How do you transport the product to the market?

14) How much do you sell per kg of the processed product?

15) What other products do you know that can be made from sorghum?

16) Are there products made from sorghum in the market?

17) In your view what do you think should be done to improve sorghum products?

18) After harvesting, how do you store the grains?

19) What are the major causes of losses during storage?

20) What are the estimated losses in percentage of sorghum grains?

21) What is your view on commercially processed sorghum products?

APPENDIX 4 SENSORY EVALUATION OF BREAKFAST FLAKES

Sheet number …………………………………………

Date ………/………../………

COLOUR AND PHYSICAL APPEARANCE

You are provided with coded samples of cereal flakes. Without tasting them, score your liking of the colour and physical appearance of each on the basis of the evaluation chart shown below:

Sample code	Colour	Physical appearance
DCF64		
DCG37		
M1000		
G8020		
G1000		
M4060		
M2080		
FG82		
FG100		

Now taste the products one at a time in any order and for each product score your liking of the taste, aroma (odour), texture (mouthfeel), Chewability and overall acceptance of each on the basis of the evaluation chart shown below**.** Score each attribute using the scale provided at the bottom of the page and record the score of your response in the appropriate space on the grid provided.

Attribute **Sample code**	**Odour**	**Taste**	**Chewability**	**Texture**	**Overall acceptability**
DCF64					
DCG37					
M1000					
G8020					
G1000					
M4060					
M2080					
FG82					
FG100					

Scale

1……………………………………….dislike extremely

2……………………………………….dislike moderately

3……………………………………….neither like nor dislike

4………………………………………..like moderately

5………………………………………..like extremely

Comments