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**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
CENTER FOR FOOD SCIENCE AND NUTRITION**

**NUTRITIONAL QUALITY AND ACCEPTABILITY OF EXTRUDED WEANING
FOODS BASED ON PEANUT, LOW-TANNIN SORGHUM AND SOYBEANS**

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Food Science and Nutrition.

BY

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July, 2014

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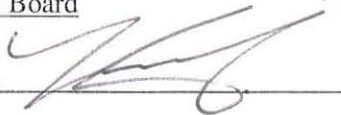
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Acknowledgement

First of all, I strongly yearn to give my glory to the almighty God through his son, Jesus Christ as nothing could have been true without him.

Secondly, there are many people without whom this thesis could never have been written. I will however, want to thank the most prominent individuals.

I would like to give my gratitude to my advisors Ato Kelbesa Urga and Ato Tilahun Bekele who had been guiding me in any case of my work, supporting and encouraging me to be strong enough and for their excellent and valuable discussion early from the beginning in developing my proposal till this time.

I need to present my thanks to the EHNRI (Ethiopian Health and Nutrition Research Institute), Melkassa Agricultural Research Center, Worer Agricultural Research Center and pawi Agricultural Research Center for allowing me to take all the samples needed for this particular study.

I would like to give my deepest gratitude to my husband, my mother and my sister who stood by my side and giving every support so that I can successfully finish this research.

Last but not least, I wish to thank all the staff members of Food Science and Nutrition center of Addis Ababa University for helping me in my effort to be fruitful.

ABSTRACT

The aim of this present study was to produce low cost energy dense and good protein quality complementary food with improved micronutrient bioavailability from low tannin sorghum, peanut and soybean using extrusion processing. The experiment had two levels of treatments: blends I and II. Blend I was composed of sorghum -peanut flours (SP); while blend II had sorghum –soya bean flours (SY). During formulation nine composite blends were formed. That is each peanut and soya bean flours were added to low tannin white sorghum at levels of 0%,10%,15%,20%, and 40% respectively and submitted to extrusion cooking . The blends were extruded using twin screw extruder(Model Clextral , BC-21 No 194,Firminy,France) at 15% moisture content, 120°C barrel temperature and at the screw speed of 150rpm fitted with 9mm die nozzle diameter. The resulting extrudates were analyzed for proximate , mineral (calcium, iron ,zinc and phosphorous) composition , anti-nutrients (phytate and condensed tannin content) ,functional characteristics .The bioavailability of minerals(molar ratio of calcium, Iron ,and zinc) and sensory properties(color, taste, aroma, texture and overall acceptability) were also determined. The evaluated functional characteristics were water and oil absorption capacity, bulk density, viscosity, expansion ratio and specific length . With the increase in the level of peanut and soya bean the results of proximate , mineral composition and functional properties showed significant($P<0.05$) decrease in fiber , and carbohydrates content for both SP and SY extrudates but the moisture ,ash, protein , fat, Calcium , phosphorous and bulk density contents were significantly ($p<0.05$) increased as peanut and soya bean proportion increases. However, the results of other functional and physical properties :- water and oil absorption capacity, ,expansion ratio, specific length and viscosity decreased significantly($p<0.05$) as the increase in the level of peanut and soya bean flours . The investigated result of the effect of extrusion cooking shows extrusion cooking does not have significantly ($p>0.05$) effect on the content of protein. Meanwhile, the moisture and Fe composition increased significantly ($p<0.05$) and the ash, fat, fiber, carbohydrates, phosphorous, zinc and anti-nutrients composition decreases significantly($p<0.05$)after extrusion. Phytate level was reduced by (35%) for both SP and SY extrudates. While the condensed tannin level was reduced (60.8-73.68%) and (59.9-61.3%) for extruded SP and SY samples respectively as the result, the bioavailability of Zn and Ca were increased after extrusion. The produced extrudates were expanded due to pre-gelatinization of the extrudates .hence their water absorption capacity, bulk density and viscosity results were reduced .The sensory analysis results of all SP and SY indicates, except taste result of SP and the color rating result of SY extrudates ,all the other rating results(taste ,colour ,aroma ,texture and overall acceptability) reduced significantly($p<0.05$) with the increase of (10-40%) peanut and soya bean proportions respectively. Based on the overall ranking using protein , energy ,Calcium/Phosphorous ratio and sensory attributes indices, it could be concluded that ESY2(80% sorghum,20% soyabean) extrudate were nutritionally superior, functionally appropriate and organoleptically acceptable. The result indicated that ESY2 formulations had compositions and properties comparable to those of cerelac hence having good potential for use as complementary food.

LIST OF ABBREVIATIONS

AMDR.....	Acceptable Macronutrient Distribution Range
ANOVA.....	Analysis of Variance
AOAC.....	Association of Official Analytical Chemists
CT.....	Condensed Tannin
DWB.....	Dry Weight Basis
FAO.....	Food and Agricultural Organization
HT.....	Hydrolysable Tannins
HTST.....	High Temperature Short Time
IOM.....	Institute of Medicine
IVPD.....	In Vitro Protein Digestibility
NPU.....	Net Protein Utilization
PDCAAS.....	Protein Digestibility Corrected Amino acid
PEM.....	Protein Energy Malnutrition
PER.....	Protein Efficiency Ratio
PPC.....	Peanut Protein Concentration
RDA.....	Recommended Daily Allowance
RTE.....	Ready to Eat
SP.....	Sorghum-Peanut
SSA.....	Sub-Saharan African Countries
SY.....	Sorghum-Soybean
UK.....	United Kingdom
USAID.....	United State Agency for International Development
WAC.....	Water Absorption Capacity
WFP.....	World Food Program
WHO.....	World Health Organization
WHP.....	World Health Program

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CHAPTER ONE

1.1. INTRODUCTION

Complementary feeding is a gradual process that the infant becomes accustomed to the adult diet. Based on world health organization, Complementary foods should be given to the baby at about the age of six months. At six months most babies start to need extra food in addition to breast milk; because they grow fast and breast milk is no longer enough to support their growth (Srivastava, 2002). Despite the efforts of national and international agencies, private relief organizations, scientists and others, protein-energy malnutrition (PEM) remains a severe world health problem. Infants and pre-school children with greater energy and protein requirements per body weight than adults are especially prone to the devastating effects of malnutrition on physical and mental development (Munroe and Crim, 1980; Cravioto and Delicardie, 1976).

Breast milk, even from a less than well-nourished mother, usually provides an adequate source of energy, protein, and other essential nutrients for a growing infant from birth to approximately four months of age (Brown, 1978). Thereafter, nutritionally appropriate complementary foods must be available to at least partially replace mother's milk during the complementary feeding process. Once weaned from the breast, the infant is totally dependent on complementary foods to provide the nutrients he or she needs. An infant's dependence on complementary foods lasts until they make a complete transition to an "adult" diet. This may take several months to a year or longer

The children between the age of 4 months and 2-3 years are suffering from malnutrition because they are neither getting mothers' milk nor the supplementary foods. To combat this situation, soybean based complementary food may be an alternative. A normally growing child doubles its birth weight by the time it is six months old and triples its birth weight by the time it is one year. A rapid growth and tissue build up is very necessary during this period and unless proper type of protein rich foods are provided during this period, protein malnutrition and under nutrition will develop, which when unattended will lead to kwashiorkor (Jon and Webb, 1964).

Many complementary foods are primarily composed of cereal grains and/or legumes which are in chronically short supply in some countries. Complementary foods based on starchy plant materials may meet the energy but not the protein requirements of a growing child. Traditional

complementary foods also tend to be bulky (high volume/unit weight) and a young child may have difficulty eating large enough quantities to meet their energy and protein requirements. Young children tolerate soft food especially well and for this reason mothers typically dilute complementary food mixtures with water. Children subsisting on thin watery gruels can be expected to have low intakes of energy, protein and other nutrients (Cameron and Hofvander, 1976). The addition of fats and oils has been recommended as a way of increasing the energy density of complementary foods. However, it is often difficult to incorporate significant quantities of fat or oil into foods. Physical separation or drainage of much of the fat from the food material often occurs before the food can actually be eaten (deep-fat frying).

This study was conducted in order to formulate extruded complementary foods from peanut, low tannin sorghum and soybean, to analyze the composition of raw and extruded materials, to determine the effect of processing parameters (extrusion cooking) on composition of the complementary food and to evaluate the sensory attributes of weaning food.

1.2. Statement of the problem

Childhood malnutrition is very common in developing countries (Plahar and Hoyle, 1991; FAO, 2004). This is because infants at this stage of development require higher energy and proteins in their diet so as to meet increasing demand for metabolism. The nutritional status of children less than 5 years of age is of particular concern, since the early years of life represent the period for optimal growth and development (Prechulek *et al.*, 1999). Their nutritional well-being reflects household, community and national investments in family health thereby contributing both directly and indirectly to overall country development and in particular, development of human resource (Central Bureau of Statistic, 1999).

Malnutrition contributes directly or indirectly to more than 60% of ten million child deaths each year (WHO, 2002). It has been reported that over 226 million children below 5 years old are stunted, 67 million are wasted and 183 million weight less than they should for their age (UNICEF, 1998). The prevalence of malnutrition increases dramatically from the age of 6 - 18 months as a result of poor feeding practices and low purchasing power that characterized many homes. Diets in developing countries are frequently deficient in macronutrients (protein, carbohydrates and fat) leading to protein-energy malnutrition and micronutrients (electrolytes, minerals and vitamins)

leading to specific micronutrient deficiencies or both (Brabin and Coulter, 2003; Millward and Jackson, 2004).

In order to solve this nutrition problem Fashakin *et al.*(1986) have formulated nut-ogi (a mixture of corn gruel and peanut). Akinrele and Edwards(1989) formulated soya-ogi (corn gruel plus soya bean). Sanjum and Rashim (2011) formulated supplementary foods based on wheat, soyabean concentrate and green gram flours. Salve *et al.*, (2011)were also developed complementary foods based on wheat flour, soyabean flour and chick pea flour by fortifying with skimmed milk powder. In the above products that used animal products such as milk the products will not be low cost so that cannot be able to solve nutritional problem of children of the developing countries .In another study complementary food were developed by Yewelsew Abebe *et al.*,(2006) using corn ,Kocho and legume seeds, the protein content of this product is less than the recommended value of the protein content. There was also complementary food developed based on Moringa olifera and pop corn by Ijarotimi and Oluwalana (2013), however, the products does not satisfy the recommended calorific content.

The traditional weaning foods could be improved by combining locally available foods that complement each other in such a way that new pattern of amino acids created by this combination is similar to that recommended for infants (Fashakin *et al.*, 1986)

1.3. Significance of the study

Preparation of complementary foods from cereals and legumes have gained a great deal of attention recently. Complementary foods based on cereals and legumes are of special interest since it gives infants and pre-school children quite enough amount of energy and proteins including essential amino acids and hence to ameliorate protein energy malnutrition (PEM) in infants. This particular research on the nutritional quality and acceptability of extruded weaning foods from peanut, low-tannin sorghum and soybean will also provide a formulation that can be used by various food industries for the preparation of weaning foods to meet the nutritional needs of growing children.

1.4. Objectives of the study

General objectives of the study

To formulate nutritional and acceptable extruded complementary foods based on peanuts, low tannin sorghum and soybeans.

Specific objectives of the study

To formulate and evaluate nutritional quality of extruded complementary foods

To compare the nutritional value of the formulated products with the recommended dietary guide line and to the standard infant food (Cerelac)

To evaluate anti-nutritional factors and functional properties

To study the sensory quality and to recommend nutritional and acceptable product

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Complementary Foods

Complementary feeding is the process of gradual introduction semi-solid or solid foods to the breast or formula-fed child to meet extra nutritional needs for rapid growth and development (Eschleman, 1991). Most urban and rural poor women in Africa breast-feed from 18 to 24 months. Most Ghanaian mothers start complementary feeding by the third month of life (Armar, 1989). A few mothers, however, start after one month. Based on interviews with breast-feeding African mothers, Armar & Wheeler (1991) have reported that the main complementary food for infants up to six month of age was a traditional fermented maize porridge (koko).

From six months onwards, the infants are given the family diet with complementary breast feeding. The family foods on which the infant are weaned include dishes made from cereal, starchy tubers, legumes, and vegetables. These indicate that there is early supplementation with solid food or early weaning. Although the majority of women start complementary feeding to their infants at the age of three to four months, a few begin within the first two months of life (WHO, 2002).

2.2. The Production Process and the Preparation of Weaning Foods

2.2.1. The Production Process

The production process of weaning foods consists of 5 steps:

Storage of ingredients/raw materials

Cleaning

Roasting

Grinding and Mixing

Packaging.

In addition to these steps, storage and distribution of the weaning food is important.

A. Storage of the raw materials

If raw materials or ingredients are purchased in small quantities one would not need much storage capacity. Because of price-fluctuations it would then be difficult to produce and sell the product for the same price all-year-round. Raw materials could also be purchased in large quantities when prices are low, immediately after the harvest period. This does however mean that there must be enough space to store the raw materials in a clean and safe manner.

In tropical climates, it is essential to store stocks in a clean and safe manner, to prevent perishing and loss. Usually, large plastic bags/bales are used for storage, but also empty oil drums can be used. Oil-seeds, such as peanuts, cannot be purchased early because much of its nutritive substances are lost during storage and aflatoxin (a toxin) can develop. To prevent this, regular testing must be done, by using the salted-water-boiling technique.

B. Cleaning

Cleaning of the ingredient ensures that the ultimate quality of the product is good and that it remains so. The product is checked by hand or simple techniques such as sieving can be used to remove dirt, stones and the like.

C. Roasting

Roasting of the raw materials is very important for the following reasons:

- It reduces the cooking time of the pulses and oil seeds in the end product, and consequently, the preparation time and fuel costs;
- It improves the safety of the product, especially by killing the bacteria and other micro-organisms;
- It prolongs the storage time to about 6 months by inactivating the anti-nutritional factors (natural toxins), which are also present in bitter cassava and soya beans;
- It improves the taste and digestibility of the product.

D. Grinding and Mixing

After roasting, the product must be cooled before mixing the ingredients in the right proportions, which is dependent on the products used and the chosen recipe. After mixing, the ingredients must then be grounded. Experience has learned that groups of people usually make use of a mill that is already in use in the village or town, for example, by a baker, miller or agricultural co-operative. If this is not possible, one can also grind or pound the ingredients by hand.

E. Packaging

Packaging of small-scale produced weaning food is usually done by hand, therefore proper hygiene is essential. It is useful to have a sealer to immediately vacuum seal the packet. But this does mean that electricity is required. If no sealer is available, then the plastic packing can be melted and sealed using a candle.

The choice of packaging material depends on:

- a. What is locally available;
- b. The storage time, and;
- c. The distribution channels.

Polyethylene 0.5 mm thick is the preferred choice; usually double packaging, i.e. two bags, one inside the other. An advantage is that it keeps it fresh for a longer time. The production costs will however be a little higher.

Another advantage of double packaging is that a label can be placed between the two plastic bags with at least. The label should at least contain: trade name; product information; shelf-life of the product; instructions for preparation and use (they need to be clear enough to for people who cannot read or speak another language).

The label should also clearly state that the weaning food should be given in addition to breast-feeding up to two years of age, and that weaning food is not a substitute for mother's milk.

For commercial sales and customer relations the packaging must be recognizable and attractive. If packaging the weaning food in small quantities is difficult, for instance, either because packing

material is not readily available, or because there is little demand for it, then the required quantity can be measured off into the customer's canister or tin. Here, it is vital that these persons are well instructed about the importance of hygiene when storing and preparing the weaning food at home. Weaning food must always be cooked thoroughly!

2.2.2. Preparation

As mentioned in the above, information will need to be gathered on the local eating habits and the ingredients/raw materials that are locally available. To do this the following questions need to be answered:

Will the target group accept the weaning food?

With regard to taste and image, what are the wishes and opinions of the target group?

What do people associate with the product; do they or do they not see it as having a healthy image?

What are the religious or other cultural beliefs of the target group concerning (a child's) food?

The answers to these questions together with the availability of the various ingredients can then be used to compile a recipe for the production of the weaning food. The answers to the questions will also help formulate the guidelines for the information about the product.

Weaning food usually consists of a mixture of one type of grain, a pulse and an oil seed. Before starting the production of weaning food, it would be useful for the organizers and fellow workers to visit similar projects to exchange experiences and ideas.

It is necessary that the production and sale of the weaning food fits in with the local activities on nutrition and health care education. Therefore, you have to seek co-operation locally with health care workers, women's groups, the local government and perhaps even pharmacies and hospitals or health care posts. In some cases you could seek contact with international organizations. Depending on the local situation it may be possible that the international organizations buy a portion of the distribution, and subsidize or distribute it free-of-charge in the health sector and/or at information sessions.

2.2.3. Hygiene and safe preparation of weaning foods

In spite of improving epidemiological knowledge in relation to child health, the challenge of promoting the survival and quality of life of infants and children in most parts of the developing world remains an abiding public health problem. There is also limited research in to the causes of food poisoning caused by infant weaning foods, mainly because of failure to recognize food poisoning as a major cause of infant diarrhea. Specific research in to the microbiological quality of infant weaning foods has focused on less developed countries where kitchen facilities and levels of hygiene fall below western standards and this is often reflected in the microbiological quality and safety of the food (Onweluzo and Nwabugwu, 2009)

2.3. Nutritional composition and energy density of weaning foods

Complementary foods should be varied and include adequate quantities of meat, poultry, fish or egg, as well as vitamin A-rich fruits and vegetables every day. Where this is not possible, the use of fortified complementary foods, vitamins and mineral supplements may be necessary to ensure adequacy of particular nutrient intakes. As infants grow, the consistency of complementary foods should change from semi-solid to solid foods and the variety of foods offered should increase. By eight months, infants can eat 'finger foods' and by 12 months, most children can eat the same types of food as the rest of the family (WHO/UNICEF, 1998).

Dietary reference intakes published by the Institute of Medicine, USA shows that the diets of infants and young children in most populations in low-income countries are consistently deficient in some nutrients, including iron, zinc and vitamin B6 (Daelmans and Saadeh , 2003). Cereals have low content of proteins and fat while legumes are low in fat. Weaning foods from plant sources are also high in anti-nutrient contents which decrease nutrient bioavailability (Eschleman, 1991). The bulkiness of traditional weaning foods and the presence of high concentration of crude fiber and absorption inhibitors (anti-nutritional factors like phytic acid and tannin) are major factors reducing their nutritional benefits.

Foods are rarely modified at the house hold level to increase nutrient density to meet the needs of infants. Traditional infant foods made of cereals or tubers may be low in several nutrients including protein, vitamin A, zinc and iron; these nutrients are of special importance due to their impact on

physical and cognitive development (Huffman & Martin, 1994). Generally, foods eaten in developing countries contain high levels of carbohydrates with very low or no proteins due to the high cost of protein rich foods and some traditional beliefs about feeding infants with protein foods.

2.4. Complementary food problems in Africa and its solution

Foods eaten in developing countries contain high levels of carbohydrate with very low or no proteins due to the high cost of protein rich foods. Legumes such as soybean, groundnut and cowpea are rich in quality protein, oil and minerals. Their lysine content complements this amino acid deficiency in cereal while the methionine in cereal complements its deficiency in the legumes. Therefore, blends of legume and cereal give high-quality protein complementary mixtures. In order to combat PEM efficiently, a low-cost weaning food that is high in protein and dense in energy is a desirable substitute for expensive imported weaning food. Soybean is increasingly being used as a high source of protein to upgrade the protein level of both adult and weaning diets (Olusola *et.al*, 2009).

2.4.1. Ethiopian experience

Faffa is an Ethiopian variety of protein rich infant food. Unfortunately tryptophan and methionine are limiting amino acids, and results indicate that Fafa does not have the expected biological value for children. Although in Ethiopian village a marked improvement occurred in nutritional status of children enrolled in an applied nutrition program which included supplementary food distribution, health supervision and nutrition advice, protein rich weaning foods, such as Fafa, Superamine, and others, should not be considered equal in nutritional value to milk-based formula. Precautions should be taken to guarantee that such weaning foods are used as supplements only and that the basic diet is a mixed diet based not only on vegetables, but containing animal protein as well (Jelliffe, 1968)

2.5. Complementary Food Formulation

The first solid food and the most popular weaning food is a thin cereal gruel, which is called by different names depending on the type of cereals of the African countries. For example, koko in Ghana, Ogi, prepared from maize or sorghum (couscous ogi), is a popular weaning food in Sierra

Leone. Legumes are rarely used for weaning and are introduced much late (after six months of age) because of the problems of indigestibility, flatulence, and diarrhoea associated with their use.

Apart from protein and energy, weaning diets of infants in developing countries require more calcium, vitamin A and D, iron and some important trace elements. These can be obtained by combining the local staples presently available in the country. Combination of commonly used cereals with inexpensive plant protein sources like legumes can be used. Cereals are deficient in lysine but have sufficient sulphur containing amino acids which are limited in legumes whereas legumes are rich in lysine. The effects of the supplementation are highly beneficial, since nutritive value of the product is also improved (Amankwah, *et al*, 2009).

2.6. Nutritional aspects of Food Extrusion

2.6.1. Extrusion Process Technology

Deterioration of nutritional quality, owing to high temperature, is a challenging problem in most traditional cooking methods. Extrusion cooking is preferable to other food-processing techniques in terms of continuous process with high productivity and significant nutrient retention, owing to the high temperature and short time required (Guy, 2001). Extrusion cooking is a high-temperature, short-time process in which moistened, expansive, starchy and/or proteinaceous food materials are sterilized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions (Castells *et al.*, 2005). This technology has some unique positive features compared with other heat processes, because the material is subjected to intense mechanical shear. It is able to break the covalent bonds in biopolymers, and the intense structural disruption and mixing facilitate the modification of functional properties of food ingredients and/or texturizing them (Carvalho & Mitchell, 2000). In addition, the extrusion process denatures undesirable enzymes; inactivates some antinutritional factors (trypsin inhibitors, haemagglutinins, tannins and phytates); sterilizes the finished product; and retains natural colours and flavours of foods (Bhandari *et al.*, 2001).

Extrusion systems are able to process highly viscous materials that are difficult or impossible to handle using conventional methods. The ability of extrusion systems to carry out a series of unit operations simultaneously and continuously gives rise to savings in labour costs, floor space costs

and energy costs whilst increasing productivity. Besides processing advantages, extrusion cooking also can induce some beneficial nutritional and chemical changes in foods (Camire, 2002). The process has found numerous applications, including increasing numbers of ready-to-eat cereals; salty and sweet snacks; co-extruded snacks; indirect expanded products; croutons for soups and salads; an expanding array of dry pet foods and fish foods; textured meat-like materials from defatted high-protein flours; nutritious precooked food mixtures for infant feeding; and confectionery products (Eastman *et al.*, 2001).

Prevention or reduction of nutrient destruction, together with improvements in starch or protein digestibility, is clearly of importance in most extrusion applications. Reviews of various chemical changes affecting the nutritional quality of food during extrusion cooking have been published by Camire *et al.* (1990)

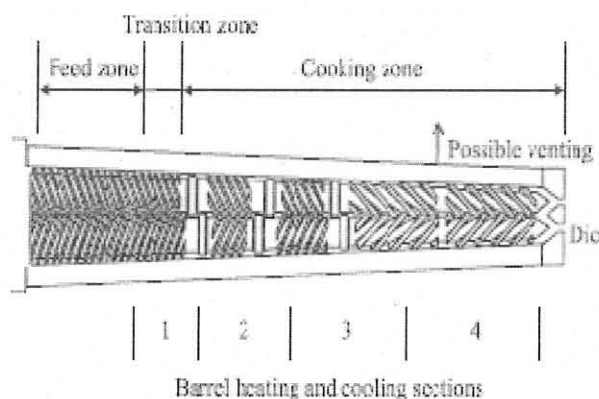


Fig. 1. Screw configuration of Twin-screw Extruder

2.6.2. Nutritional changes due to extrusion

A. Protein

Among the process variables, the feed ratio has the maximum effect on protein digestibility, followed by process temperature in the extrusion of fish-wheat flour blend. Tripling the ratio of fish

to wheat increases the digestibility of the extrudates by 2–4% (Bhattacharya *et al.*, 1988; Camire *et al.*, 1990). Increase in extrusion temperature (100–140°C) enhances the degree of inactivation of protease inhibitors in wheat flour, and consequently, the protein digestibility values are increased. Extrusion, even at 140°C, does not have any adverse effect on protein digestibility, which might be attributed to the lesser residence time of food dough within the extruder. The effect of other process variables, such as length to diameter ratio and screw speed on protein digestibility values appears to be insignificant (Bhattacharya *et al.*, 1988).

An advantage of extrusion cooking is the destruction of anti-nutritional factors, especially trypsin inhibitors, haemagglutinins, tannins and phytates, all of which inhibit protein digestibility (Armour *et al.*, 1998; Alonso *et al.*, 1998, 2000a). The destruction of trypsin inhibitors increases with extrusion temperature and moisture content. At constant temperature, inactivation increases with increasing product residence time and moisture content. The highest protein quality (as measured by protein efficiency ratio), corrected for a value for casein of 2.5 is 2.15 in extruded soy flour, obtained at a barrel temperature of 153°C, 20% moisture and 2 min residence time, coinciding with 89% reduction of trypsin inhibitors. Extrusion (300-r.p.m. screw speed, 27-kg h⁻¹ feed rate, 5/32 inches die size and 93–97°C outlet temperature) causes complete destruction of trypsin inhibitor activity in extruded blends of broken rice and wheat bran containing up to 20% wheat bran (Singh *et al.*, 2000). However, in blends containing bran beyond 20%, the inactivation of trypsin inhibitor decreases from 92 to 60% (Singh *et al.*, 2000). In another study, without preconditioning prior to extrusion cooking a temperature of 143°C, at 15–30% moisture and residence time of 0.5–2 min, produced a product of maximum protein efficiency ratio, despite the finding that only 57% of trypsin inhibitors are destroyed. An increase in feed rate, with similar process conditions, has been reported to result in less destruction of trypsin inhibitors, presumably because of reduced residence time.

Lectin (haemagglutinating) activity is relatively heat resistant. An aqueous heat treatment, at 60 or 70°C for up to 90 min, does not alter the lectin activity in soybeans. Lectin activity is reduced, but not abolished by heating at 80 or 90°C. However, as found with kidney bean (Grant *et al.*, 1982, 1994), the lectin activity in the fully imbibed seed could be completely abolished by heating them for 5 min at 100°C. Extrusion has been shown to be very effective in reducing or eliminating lectin

activity in legume flour (Alonso *et al.*, 2000a, b). Thus, extrusion cooking is more effective in reducing or eliminating lectin activity as compared with traditional aqueous heat treatment.

The enzyme hydrolysis of protein is improved after extrusion cooking as a result of the inactivation of antitrypsin activity in extruded snacks. The higher susceptibility of protein to pepsin, as compared with trypsin, further suggested the presence of antitrypsin activity. The improvement in pepsin hydrolysis might be the result of the denaturation of proteins during extrusion cooking, rendering them more susceptible to pepsin activity. This suggests that extrusion considerably improved the nutritive value of proteins (Singh *et al.*, 2000).

B. Carbohydrates

Carbohydrates range from simple sugars to more complex molecules, like starch and fibre. The effects of extrusion on each of these components will be discussed.

C. Sugar

Sugars, such as fructose, sucrose and lactose, are a great source of quick energy. They provide sweetness and are involved in numerous chemical reactions during extrusion. Control of sugars during extrusion is critical for nutritional and sensory quality of the products. Extrusion conditions and feed materials must be selected carefully to produce desired results. For example, a weaning food should be highly digestible, yet a snack for obese adults should contain little digestible material (Camire, 2001).

Several researchers have reported sugar losses in extrusion. In the preparation of protein-enriched biscuits, 2–20% of the sucrose was lost during extrusion at 170–210⁰C mass temperature and 13% feed moisture (Noguchi *et al.*, 1982; Camire *et al.*, 1990). It may be explained based on the conversion of sucrose into glucose and fructose (reducing sugars), and loss of these reducing sugars during Maillard reactions with proteins.

Oligosaccharides (raffinose and stachyose) can induce flatulence and therefore, impair the nutritional utilization of grain legumes (Omuetti and Morton, 1996). Raffinose and stachyose decreased significantly in extruded high-starch fractions of pinto beans (Borejszo and Khan, 1992). Extruded snacks, based on corn and soy contained lower levels of both stachyose and raffinose

compared with unextruded soy grits and flour, but values were not corrected for the 50–60% corn present (Omueti and Morton, 1996). The destruction of these flatulence-causing oligosaccharides might improve the nutritional quality of extruded legume products.

D. Starch

Starchy cereals and tubers provide the bulk of calories consumed by most people, particularly those living in less-developed nations. Thus studies of extrusion effects on starch are significant. Humans and other monogastric species cannot easily digest ungelatinised starch. Extrusion cooking is unique because gelatinization occurs at much lower moisture levels (12–22%) than is necessary in other forms of food processes (Qu and Wang, 1994).

The branched structure of amylopectin makes it susceptible to shear. Both amylose and amylopectin molecules might decrease in molecular weight. Larger amylopectin molecules in cereals flour had the greatest molecular weight reductions (Politz *et al.*, 1994a). Low die temperature (160 vs. 185°C) and feed moisture (16 vs. 20%) significantly reduced the average starch molecular weight in cereals flour, but protein content of flour was not an important factor (Politz *et al.*, 1994b). Screw configuration can be designed to minimize or maximize starch breakdown (Gautam and Choudhoury, 1999).

During extrusion, the formation of amylose–lipid complex is evident. The extent of amylose–lipid complex formation is dependent upon both starch and lipid type present in a food. Monoglycerides and free fatty acids are more likely to form complexes than are triglycerides, when added to high-amylose starch (Bhatnagar and Hanna, 1994). Low feed moisture (19%) and barrel temperature (110–140°C) induced the greatest amount of complex formation between stearic acid and normal cornstarch, with 25% amylose (Bhatnagar and Hanna, 1994). High viscosity and longer residence time may favor complex formation.

E. Dietary Fiber

Fiber is a term used to describe many food components. The American Association of Cereal Chemists (2001) coined the following description of dietary fibre: “Dietary fibre is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes

polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibres promote beneficial physiological effects including laxation, and/ or blood cholesterol attenuation, and/or blood glucose attenuation.”

Extrusion reduces the molecular weight of pectin and hemicellulose molecules, resulting in increased water solubility of sugar beet pulp fibre (Ralet *et al.*, 1991). Ferulic acid, a phenolic acid normally associated with plant cell walls, was also recovered from the soluble sugar beet fraction. Smaller fragments may be soluble in aqueous ethanol, which is used for extraction steps in enzymatic-gravimetric and enzymatic-chemical methods of fibre analysis.

Many factors influence fibre solubility. Acid and alkaline treatment, prior to extrusion, increased the soluble fibre slightly in corn bran (Ning *et al.*, 1991). Grinding doubled the soluble fibre of pea hulls to 8% (dry basis), but all the extruded hulls contained over 10% soluble fibre (Ralet *et al.*, 1993).

Insignificant changes in dietary fibre content were reported in both untreated and twin-screw extruded wheat flour and whole-wheat meal at 161–180⁰C mass temperature, 15% feed moisture and 150–200-r.p.m. screw speed (Varo *et al.*, 1983). No significant change was found in dietary fibre content when wheat was extruded under milder conditions, but the fibre present became slightly more soluble (Siljestrom *et al.*, 1986). On the other hand, an increase in dietary fibre content of wheat flours with increasing product temperature (150–200⁰C) was reported. The increase may be the result of the glucans, present both in the soluble and insoluble dietary fibre fractions, indicating starch alterations.

Extrusion cooking increased the total dietary fibre of barley flours. The total dietary fibre increase in waxy barley was the result of an increase in soluble dietary fibre. For regular barley flour, the increase in both insoluble dietary fibre and soluble dietary fibre contributed to the increased total dietary fibre content (Vasanthan *et al.*, 2002). The change in dietary fibre profile during extrusion of barley flour may be attributed, primarily, to a shift from insoluble dietary fibre to soluble dietary fibre, and the formation of resistant starch and enzyme-resistant indigestible glucans formed by transglycosidation.

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F. Lipids

The class of chemical compounds known as lipids is a heterogeneous group of nonpolar materials, including glycerides, phospholipids, sterols and waxes. Although many types of lipids occur in foods, the triglycerides are the most common. A triglyceride consists of three fatty acid molecules esterified to one glycerol molecule. Although lipids serve as a concentrated form of energy, excess dietary lipid consumption is associated with chronic illnesses, such as heart disease, cancer and obesity (Camire, 2001).

During the extrusion of foods, native lipids might be present within the raw materials or added to the ingredients. Cereals, such as wheat and corn are typically low (2%) in oils, although oats may contain up to 10% oil. The oil is concentrated in the bran and germ portions of the seed kernel, and is removed during milling to improve storage stability. Oilseeds, such as soybeans and cottonseed may contain up to 50% by total seed weight as oil. Oilseed flours used in extrusion may be full fat or partially or wholly defatted.

Extrusion of high-fat materials is generally not advisable, especially in the case of expanded products, as lipid levels over 5–6% impair extruder performance (Camire, 2000a). Torque is decreased because the lipid reduces slip within the barrel, and often product expansion is poor because insufficient pressure is developed during extrusion. Lipid is released from cells owing to the high temperature and physical disruption of plant cell walls. At the same time, small lipid levels (<5%) facilitate steady extrusion and improve the texture. A decrease in extractable fat after extrusion cooking has been found with an average of 40% of the original recovered in extruded maize, by using different solvents (Nierle *et al.*, 1980). Some lipid might be lost at the die as free oil, but this situation only occurs with high-fat materials, such as whole soy. Another explanation for the lower lipid level is the formation of complexes with amylose or protein (Camire, 2000a).

High levels of free fatty acids in foods create a number of problems. Increased levels of free fatty acid produce off flavours and affect the storage quality of foods (Camire *et al.*, 1990). Free fatty acids are produced in foods from hydrolysis of triglycerides, mainly because of lipase enzymes and high temperatures. The extrusion process can prevent free fatty acid release by denaturing hydrolytic enzymes (Camire *et al.*, 1990). Lipid oxidation has negative impact on sensory and nutritional qualities of foods and feeds. It probably does not take place during extrusion owing to

the very short residence time. However, rancidity is a concern for extruded products during storage. On the other hand, extrusion denatures enzymes that can promote oxidation, and lipids held within starch are less susceptible to oxidation. Compounds produced by Maillard reactions can also act as antioxidants.

G. Vitamins

The daily vitamin intakes might be small compared with other nutrients, but the small quantities consumed are crucial to good health because of the role of vitamins as coenzymes in metabolism. The increase in the consumption of extruded infant foods and similar products, which may form the basis of an individual's diet, has focused concern on the effects of extrusion on the recovery of vitamins and minerals that are added prior to extrusion.

As vitamins differ greatly in chemical structure and composition, their stability during extrusion is also variable. The extent of degradation depends on various parameters during food processing and storage, e.g. moisture, temperature, light, oxygen, time and pH. This subject is addressed in reviews on nutritional changes during extrusion (Camire *et al.*, 1990; Camire, 1998) and in a review of vitamin retention by Killeit (1994). Minimizing temperature and shear within the extruder protects most vitamins.

Among the lipid-soluble vitamins, vitamins D and K are fairly stable. Vitamins A and E and their related compounds – carotenoids and tocopherols, respectively, are not stable in the presence of oxygen and heat (Killeit, 1994). Thermal degradation appears to be the major factor contributing to *b*-carotene losses during extrusion. Higher barrel temperatures (200°C compared with 125°C) reduce all *trans*-*b*-carotene in wheat flour by over 50% (Guzman-Tello and Cheftel, 1990).

Pham & Del Rosario (1986) began to assess the effects of high temperature, short-time extrusion cooking on vitamin stability using mathematical models. Thiamine has been investigated most frequently, followed by riboflavin, ascorbic acid and vitamin A. Very few studies dealt with other B-complex vitamins or vitamin E.

Ascorbic acid (vitamin C) is also sensitive to heat and oxidation. This vitamin decreased when extruded at a higher barrel temperature at fairly low (10%) moisture (Andersson and Hedlund, 1990). Blueberry concentrate appeared to protect 1% added vitamin C in an extruded breakfast

cereal compared with a product containing just corn, sucrose and ascorbic acid (Chaovanalikit, 1999). When ascorbic acid was added to cassava starch to increase starch conversion, retention of over 50% occurred at levels of 0.4–1.0% addition (Sriburi and Hill, 2000).

In summary, the retention of vitamins in extrusion cooking decreases with increasing temperature, screw speed and specific energy input. It also decreases with decreasing moisture, feed rate and die diameter. Depending on the vitamin concerned, considerable degradation can occur, especially in products with high sensory appeal. The following options for the nutritional enrichment of extruded products with vitamins are possible.

The usage of specific vitamin compounds or forms of application with improve stability;

Addition of extra amount to compensate for losses during extrusion and storage;

Post extrusion application, e.g. by dusting, enrobing, spraying, coating or filling together with other ingredients;

H. Minerals

Although mineral elements represent a minor portion of the composition of foods, they play major roles in food chemistry and nutrition. Minerals are solid, crystalline, chemical elements that cannot be decomposed or synthesized by ordinary chemical reactions. Minerals are classified as macro- and micro-minerals. Macro-minerals include calcium, phosphorous, sodium, potassium and chloride. Of these, calcium and phosphorus are needed in large amounts, while the rest are needed in smaller amounts. Micro minerals include magnesium, manganese, zinc, iron, copper, molybdenum, selenium, iodine, cobalt and chromium, which are needed in minute amounts.

Phosphorus, in the form of phosphates, is commonly added during food processing; however, iron and calcium are the mineral elements typically added to foods for improving nutritional value (Camire *et al.*, 1990). Metals, particularly iron (Fe), copper (Cu), magnesium (Mg), and calcium (Ca), act as catalysts for enzymes. Iron is essential for the prevention of anaemia, and calcium is necessary for bone health (Camire *et al.*, 1990). Depending upon the product and the population for which it is intended, other minerals may be added at fortification or enrichment levels.

Extrusion cooking generally affects macromolecules. Smaller molecules may be impacted upon by either the extrusion process itself or by changes in larger molecules, which in turn affect other compounds present in the food. Despite the importance of minerals for health, relatively few studies have examined mineral stability during extrusion because they are stable in other food processes (Camire *et al.*, 1990). Minerals are heat stable and unlikely to become lost in the steam distillate at the die.

Extrusion can improve the absorption of minerals by reducing other factors that inhibit absorption. Phytate may form insoluble complexes with minerals and eventually affect mineral absorption adversely (Alonso *et al.*, 2001). Extrusion hydrolyses phytate to release phosphate molecules. Extrusion of peas and kidney beans resulted in phytate hydrolysis, which explains the higher availability of minerals after processing (high temperature extrusion) (Alonso *et al.*, 2001).

Extrusion reduces phytate levels in wheat flour, but not in legumes, at low extrusion temperature (Lombardi-Boccia *et al.*, 1991). Boiled legumes and ones extruded under high-shear conditions had less dialysable iron than samples extruded under low-shear conditions (Ummadi *et al.*, 1995); although phytic acid was lower under all processing conditions, total phytate was not affected. Thus, processing conditions play an important role in the reduction of phytate in legumes.

Mineral absorption could be altered by fibre components. Cellulose, lignin and some hemicelluloses affect the mobility of the gastrointestinal tract and interfere with the absorption of minerals. Extrusion processing (high temperature) might have reorganized dietary fibre components, changing their chelating properties. Moreover, it must be taken into consideration that complex agents, present in foodstuffs, such as phytate may interact with fibre, modifying the mineral availability (Alonso *et al.*, 2000a, b).

2.7. Overview of Peanut, Sorghum and Soybean

2.7.1. Overview of Sorghum

Sorghum is a staple food in many African countries and contains reasonable amount of protein, ash, oil and fiber (Drich and Pran, 1987), however, is deficient in essential amino acid content, particularly with respect to lysine.

Pelembe *et al.* (2002) reported that, in Africa, due to deforestation by utilization of wood for fuel, there is a great need for pre-cooked foods. High-Temperature, Short-Time (HTST) extrusion cooking could be used to produce sorghum-based foods of high nutritional quality and in a ready-to-eat form. According to Brennan (2006), there are many benefits to using extruders to process food materials.

Sorghum is an excellent source of energy, mainly in the form of complex carbohydrate. Complex carbohydrate (fibers, starches) is usually slowly digested and therefore provides satiety and delayed hunger. Sorghum is the fifth most important cereal in world production, being exceeded by wheat, rice, maize and barley in that order (FAO, 2005). Sorghum is found to contain many anti-nutritional factors such as, tannins, phytic acid, proteinase inhibitors and cyanogenic glycosides. Tannins are members of the naturally occurring active nutrients known as polyphenols. Tannins are reported to interact with proteins (both enzymes and non-enzyme proteins) to form tannin protein complexes resulting in inhibition of digestive enzymes (Almamary *et al.*, 2002).

Grain sorghum (*Sorghum bicolor* L. Moench) is an important basic food in many parts of Africa and Asia; it is widely grown in the semiarid regions because of its drought tolerance. Grain sorghum contains more fat than wheat, rice and cassava and about the same percent of protein as other grains.

Micronutrients in Sorghum

Iron and zinc are two of the four micronutrients (iron, zinc, iodine and vitamin A) identified by the Committee on Micronutrient Deficiencies (1998) as limiting in developing countries. Sorghum is an excellent source of both iron and zinc, even when calculated at 10% bioavailability for iron and moderate bioavailability for zinc.

Sorghum is rich in B-complex vitamins. The B-complex vitamins play key roles in energy metabolism. Sorghum's high-energy content and ready supply of B-complex vitamins are a perfect combination for energy utilization. Sorghum is rich in thiamin, riboflavin, niacin, pantothenate, and vitamin B-6. For children ages 1-9 years, sorghum provides 47 to 26% of the WHO RNI recommendations for thiamin, 28 to 16% for riboflavin, 49 to 24% for niacin, 63 to 31% for pantothenate, and 118 to 59% for vitamin B-6. Sorghum provides eleven essential nutrients in the good to excellent category, nine of which are micronutrients.

Evaluating foods in forms as eaten is the most reliable approach for determining bioavailability. Iron, zinc and copper content and extractable iron, zinc and copper in sorghum flour and as eaten in fermented bread (injera) were analyzed by Mohammed *et al.* (2010). They reported the iron, zinc and copper content for sorghum flour as 2.24 mg/100 g, 0.75 mg/100 g and 0.61 mg/100 g and the extractable iron, zinc and copper as 34%, 52% and 34% respectively. For the fermented injera on a dry basis, the iron, zinc and copper content amounts were 3.95 mg/100 g, 0.64 mg/100 g and 0.61 mg/100 g and the extractable amounts were 34%, 62% and 38% respectively. These data are specific for the Tabat sorghum variety (Mohammed *et al.* 2010). Other varieties may show different mineral levels and bioavailability due to variety, geographic region cultivated and other methods of processing. However, Mohammed *et al.* (2010) finds that fermentation may increase mineral bioavailability is useful in countries where fermented foods are widely eaten.

Carbohydrates in Sorghum

For the first time in 2002, the Food and Nutrition Board (2002) of the Institute of Medicine (IOM) published Recommendations for all macronutrients. The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate, protein and fat were determined as a percent of total kilocalories needed to maintain body weight. The AMDR for carbohydrate was set at 45 to 65% of kilocalories for ages from one year to > 70 years. This is particularly relevant to sorghum with its 75% carbohydrate content. The minimum amount of carbohydrate of 130 grams (520 kilocalories) per day was recommended for both children and adults, as this amount is needed to produce glucose, primarily for brain function.

Protein in Sorghum

There are questions regarding the percent of protein requirements that are met by sorghum due to varying protein digestibility values derived by varying methods. Upon wet cooking, sorghum protein digestibilities range from 36.4 to 74% as reported by Henley *et al.* (2010). Arguing that a pepsin digestion model was preferred, Mertz *et al.* (1984) reported digestibility values up to 79% for decorticated/extruded sorghum (variety 954062). Researchers disagree regarding the best model for determining protein digestibility for sorghum since some say that rat models are not suitable for evaluating sorghum for human nutrition. For food label protein claims, the U.S. Food and Drug Administration (FDA) requires true digestibility studies using rats for determination of protein

quality via Protein Digestibility Corrected Amino Acid Score (PDCAAS) (Henley and Kuster, 1994).

Research, both in breeding and processing is ongoing to improve the bioavailability of lysine, the limiting amino acid in all grains, and the amino acid in grains that determines their PDCAAS. Fermented foods are popular in many African countries thus Mohammed *et al.* (2010) evaluated the nutritional effects of processing sorghum flour into injera, a popular fermented bread. Mohammed *et al.* (2010) analyzed amino acids and conducted in vitro (pepsin) protein digestibility during injera processing and found that fermentation improved both. Dietary diversity (and adequate kilocalories); such as the addition of pulses or beans to grain-based diets insures adequate protein. Sorghum with its carbohydrate/high-energy value and high amounts of B-complex vitamins helps insure that its inherent protein and other dietary protein is spared and used for protein's needed functions.

2.7.2. Overview of Soybean

The soybean is originated in Eastern Asia, probably in north and central China. Soya beans grows well on almost all types of soil, with the exception of deep sands with poor water retention. It is believed that cultivated varieties were introduced into Korea and later into Japan some 2000 years ago. Soybeans have been grown as a food crop for thousands of years in China and other countries of East and South East Asia and constitute to this day, an important component of the traditional popular diet in these regions. Soybean entered to Ethiopia 50 years ago. Till now there have been a number of studies conducted on different soybean varieties. Through the studies it has been determined suitable conditions and places for the growth of the bean, suitable plantation periods and methods of production, and productive varieties are well known (Fouzia, 2009)

Soybean is an annual crop, fairly easy to grow, that produces more protein and oil. It is a versatile food plant that used in its various forms, is capable of supplying most nutrients. Soybean protein quality has been the subject of intense investigation for several decades due to soybean's increasing importance as human food resource (Yemer Assefa, 2008)

According to De Ruiter (1974), the use of soy flour in composite flours is emphasized and is quite understandable with regard to the worldwide cultivation of soybean, its protein content and

nutritional protein quality. The addition of soy flour to that of sorghum, maize, peanut and wheat will overcome their deficiency of some nutritional composite like the essential amino acid lysine.

2.7.3. Overview of Peanut

The peanut (*Arachis hypogaeae* L.) also known as groundnut, earthnut, monkeynut, Manilanut and ground bean is the world's fourth most important source of edible vegetable oil and third most important source of vegetable protein (Lusas, 1979).

2.7.3.1. Peanut Protein Production

Peanuts are grown and consumed in many countries in different continents as revealed by the worldwide production data. Peanut is a native of South America and is grown on 20 million hectares in about 80 countries in the world. India is the largest producer of peanut in the world averaging about 6 million tons annually. China followed by the United States and countries in Africa are next in order of importance so far as peanut production is concerned.

Crude protein content of whole seed peanuts ranges between 22 and 30% (Pancholy *et al.*, 1978). Peanut proteins are consumed in the form of various foods as discussed below. Although peanuts are more popular for their oil content, processing of peanuts for oil extraction yields protein rich co-product which could also be used for human consumption.

2.7.3.2. Food uses of Peanut

Among the major oil seed crops, peanut has some specific important advantages as it can be used in many food forms. With simple roasting and grinding process, peanuts can be converted into a variety of quality food products. Among the peanut eating people of the world, roasting and salting is the most preferred way of eating. Of the various ready-to-eat (RTE) foods of peanuts, roasted nuts are the most popular ones. About 60% of the peanuts harvested outside the United States are crushed and used for oil extraction while 70% of the United States crop is used for food purposes (Pancholy *et al.*, 1978). In the United States, nearly 52% of the domestic edible peanut crop is used for peanut butter spreads, 23% for salted peanuts and 21% for confectionery (Evans, 1982). Peanuts are sold fresh as a vegetable, canned, frozen, and roasted in the shell, toasted and salted, used in

more than 50% confections are bakery products and are ground into butter for use in more than 100 recipes (Woodroof, 1983).

Results of a recent survey in some African countries indicated that peanuts were commonly used in the form of various food items such as roasted, ground (or paste), peanut oil, boiled or raw, the most commonly utilized form is the roasted peanut followed by peanut paste (Rubico *et al.*, 1987). Extruded products of peanut meal and legume flour are also becoming popular as human foods in some African countries (Singh, 1985).

2.7.3.3. Peanut Fortified Foods and Sensory Quality

In recent years, more efforts have been made to develop cereals and legumes-based foods using peanuts. From consumption viewpoint, the pleasant aroma, nutty flavor and desirable texture of the raw and roasted nuts are the unique features of peanuts that place them above all other edible grain legumes. Different combinations and concentrations of peanut in a mixed product influence the sensory quality of the product. According to Khan *et al.* (1975), peanut protein concentrates (PPC) higher than 10% reduced loaf volume of bread significantly compared to that of bread baked with other protein sources. Abdel *et al.* (1980) reported that 10% of peanut, 30% sweet potato, and 15% soybean flours in combination with wheat flour produced acceptable cake. Further, they noticed that laboratory prepared flours containing 15% of peanut, soybean and sweet potato in place of wheat flour also did not affect the cake quality (Abdel *et al.*, 1980). The industrially processed oil seed proteins and isolates including that of peanut were found suitable for baking properties (Khan and Lawhom, 1980).

A cake-type recipe was prepared by using cowpea-wheat and peanut meal (30%) untoasted and it was concluded that peanut of cowpea meal was suitable for inclusion in such doughnuts but reduction of meal particle size and inclusion of soy flour to reduce fat absorption during frying were recommended (Mc Walters, 1982). While describing methods of producing a slurry from peanuts and crop foods such as soybeans or peas, it was reported that heating of slurry followed by rapid cooling prevented damage to protein content and produced desirable flavor of peanut for various food formulations (Hanis, 1982). Confections with peanuts have been the subject of several studies in the past. Riedel (1982) described recipes using roasted peanuts which can be made and sold throughout the year including peanut cubes or bars, peanut crunch and coated peanuts.

Manufacture of soft-panned confectionery products with particular reference to soft-panned ground fruits was described as a typical example (Anon, 1983). A chocolate-flavored shake-type beverage containing 84% whey and 8% peanuts has been developed by soaking peanuts in sodium bicarbonate solution overnight to develop desirable flavor before being incorporated into whey slurry (Nolan, 1983).

The development of cereal-based foods using peanut has received considerable attention in the recent years. Khalil *et al.* (1983) conducted organoleptic evaluation of wheat bread supplemented with peanut flour and found that bread containing 20% peanut flour was best with respect to organoleptic properties. Axer (1984) obtained comparable sensory evaluation results on almonds and peanut butter for 8 bakery formulations. The development of neutral flavored high stability peanut paste for use as an extender to bakery and marzipan products was reported by Black (1985). Maize extrudates were prepared with improved structure by addition of finely comminuted peanuts (Bhavanisankar *et al.*, 1987). Temperature and moisture of the extrusion process greatly influenced the texturization and sensory quality of peanut products (Aboagye and Stanley, 1987). Lil and Chang (1987) studied the relationship between texture and chemical components of peanuts after precooking and found that cooking improved texture and shear press, but values declined on longer cooking. Peanut supplemented Chinese type noodles were prepared from blends of durum wheat flour and partially defatted peanut flour and it was observed that replacement up to 15% of wheat flour with peanut flour resulted in noodles with acceptable sensory qualities (Chompreeda *et al.*, 1987). Further, addition of peanut most favorably affected the flavor of porridge and nshima, two traditional Zambian corn based cereal dishes (Ashraf, 1988).

2.7.3.4. Nutritive Value of Peanut-Fortified Foods

Like other grain legumes, the nutritive value of peanut proteins is also a function of its protein content, amino acid composition, and protein digestibility. As reported above, protein content of peanuts ranges between 15.4 and 30.2% showing a large variation which is greatly influenced by genotypes and environments. Peanut flour which is most commonly used for fortification contains protein ranging from 47 to 55% with mean being 50 % (Mc walters, 1982) . Protein isolates and protein concentrates contain higher amount of proteins depending on the methods of preparation. Peanut protein concentrates had crude protein 70.2% but it had an unbalanced amino acid pattern

and was deficient in lysine, threonine, methionine and tryptophan. Peanut proteins are generally considered to be of low nutritional quality because several of the essential amino acids are present in limited amounts, e.g., lysine, tryptophan, threonine and sulfur containing.

Fortification of cereals with legumes has resulted in improving the nutritional quality of human dietary proteins. Khalil *et al* (1983) observed that PER and net protein utilization (NPU) of wheat breads were significantly increased due to supplementation with peanut flour. Ory and Conkerton reported that muffins made of wheat and peanut flours contained 33-40% protein and can serve as a high-protein snack foods or bakery items. Data presented on the characteristics of peanut flours used in protein fortification have revealed considerable improvement in protein quality of three Nigerian foods: chin-chin, puff-puff and akara (Reber *et al.*, 1983). Per value of sorghum flour when supplemented with cowpea soy flour and peanut flour was 2.37 comparable with casein protein and essential amino acid patterns comparable with FAO values (Okeiyi and Futrell, 1983).

In another study, children fed with peanut fortified millet and rice diets experienced greater height and weight growth, greater arm and chest development and higher hemoglobin concentration levels than control children who were not fed these diets. By using chicks as test animals' nutritional evaluation of bread-enriched with peanut proteins revealed that peanut flour improved the protein quality and was as good a substitute as peanut protein isolate or peanut protein concentrate (Taha *et al.*, 1986). The nitrogen balance of 6 adult human subjects fed on maize bread alone and bread supplemented with 20% peanut flour was significantly improved with supplementation suggesting that fortification of maize bread with peanut flour will enhance the nutritive value of maize bread for adult human subjects. When fed with food product of maize and peanut mixtures (Epa-Ogi), children gained more weight than the control diet indicating the better protein quality of the product studied (Afolabi *et al.*, 1988). In vitro protein digestibility (IVPD) of wheat flour was 30% and it increased to 40% when supplemented with peanut meal showing a considerable improvement in protein digestibility (Brule and Savoie, 1988). A considerable improvement in protein, lysine and IVPD of sorghum-based kisra, fermented unleavened bread, was observed when it was supplemented with peanut flour (Ahmed *et al.*, 1987).

2.8. Overview of Anti nutritional Factors of Sorghum, Peanut and Soya bean

Anti-nutritional factors are naturally occurring compounds that are classified under a broad group of secondary metabolites. They include saponins, tannins, flavonoids, alkaloids, trypsin (protease) inhibitors, oxalates, phytates, haemagglutinins (lectins), cyanogenic glycosides etc. Felix and Mello (2000) defined anti-nutritional factors in two senses: firstly, compounds that present in human or animal foods which cause anti-nutritional effects and anti-physiological effects such as impaired reproductive function or reduced immune competence; secondly, substances which reduce feed intake in animals. Panhwar (2005) revealed that anti-nutritional factors also known as anti-nutrients which are poisonous substances that can be found in most food and able to limit the nutrient available to the body. A complementary food made from cereals and legumes is often low in mineral content and contains significant quantities of mineral absorption inhibitors(anti-nutrient) such as phytic acid and condensed tannins .Some of these plant chemicals have been shown to be deleterious to health or evidently advantageous to human and animal health if consumed at appropriate amounts (Sugano *et al.*, 1993).

Being an Antinutritional factor (ANF) is not an intrinsic characteristic of a compound but depends upon the digestive process of the ingesting animal (Kumar, 1992). For example, trypsin inhibitors, which are ANFs for monogastric animals, do not exert adverse effects in ruminants because they are degraded in the rumen (Cheeke and Shull, 1985).

2.8.1. Phytic acid

Phytic acid (inositol hexaphosphate or IP6) is an organic acid found in plant materials(Heldt, 1997). It is primarily found in seeds, it provides energy for plant growth and stores phosphorus .Phytic acid (PA) is the primary storage compound of phosphorus in seeds accounting for up to 80% of the total seed phosphorus and contributing as much as 1.5% to the seed dry weight .Phytic acid combines with some essential elements to form insoluble salts called phytate. Phytates reduces the availability of many minerals like calcium, magnesium, iron and zinc. That is the negatively charged phosphate in PA strongly binds or chelates to metallic cations of Ca, Fe, K, Mg, Mn and Zn making them insoluble and thus unavailable as nutritional factors to non-ruminant animals. This mineral-phytic acid complex, phytate, is either insoluble or difficult to hydrolyze during digestion.

Phytic acid inhibits absorption of minerals by humans and other monogastric animals in a dose-dependent manner. The phytate also decreases the activity of enzymes (pepsin, trypsin and amylase) as well as availability of protein, amino acids, starch and energy (Sebastian *et al.*, 1998; Ravindran *et al.*, 2000). The ability of phytate to form complexes with these mineral can make the mineral content of a food inadequate especially for children (Ilelaboye and Pikuda, 2009).

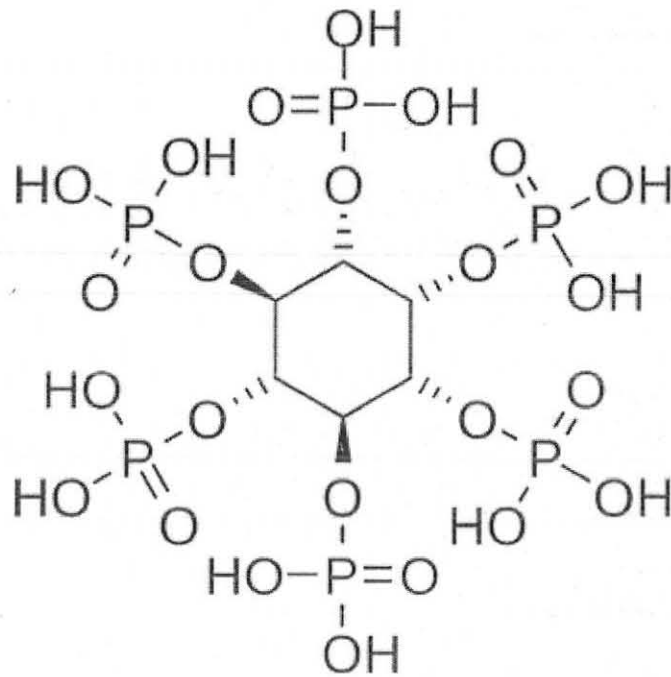


Fig.2. Structure of Phytate

Sanberg (1991) reported that the minimum amount of phytate to cause negative effect on iron and zinc absorption were 10-50 mg per meal. Thereby, anemia and other mineral deficiency disorders are common in regions where the diet is primarily a vegetarian. Phytate mainly accumulates in protein storage vacuoles as globoids, predominantly located in the aleurone layer of cereals .

Soybeans and peanut contain a high level of phytic acid, which has many effects including acting as an antioxidant and a chelating agent. The beneficial claims for phytic acid include reducing cancer, minimizing diabetes, and reducing inflammation. It is estimated that two-thirds of the phosphorus in soybean is bound as phytate and unless freed is mostly unavailable to animals. Phytic acid is present in soybean and most soybean products at level 1-1.5g/100g of the dry matter.

2.8.2. Condensed Tannin

Tannins are polyphenolic compounds, which are widely distributed in plants. They can be classified as condensed or hydrolyzable tannins. They are the oligomeric higher molecular weight polyphenolic compounds occurring naturally in plants. Due to their binding ability with protein and carbohydrates, tannins can inhibit digestive enzymes and reduce the bioavailability of different proteins (Muhammad *et al.*, 2009).

Condensed tannins are nutritionally important since they bind to and reduce the bio-availability of minerals, proteins and digestive enzymes by forming complexes that are not readily digestible (Aletor, 1993a). They also cause a bitter taste to the grains making them unpalatable and reduced growth rate (Roeder, 1995).

Tannin also inhibits the activity of some enzymes and, therefore, adversely influences protein digestibility and cellulose break down. Condensed tannins (CTs) occur in sorghum varieties that have a pigmented testa (Waniska and Rooney, 2000). Red sorghum genetically has higher condensed tannin compared to white sorghum. The levels of tannins in these sorghums range from 700 to 2 200 mg/100 g (Gu *et al.*, 2004; Awika *et al.*, 2003 a). Sorghums without the pigmented testa layer do not contain condensed tannins but often have high levels of flavonoids depending upon the variety (Dykes *et al.*, 2005).

Most of the tannins in soybean are condensed tannins, formed by polymerization of flavan-3-ols or flavan-3, 4-diols. The amount of tannins in plant depends on the variety, the degree of maturation and extraction method, and varies from 0.2 to 3% of defatted soybean meal (Erkihun Massresha, 2011).

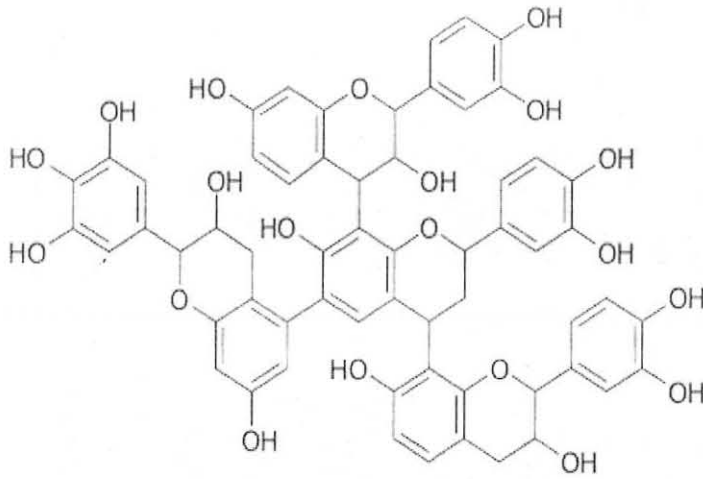


Fig.3. Structure of condensed tannin.

Some of the tannins in soybean exist in insoluble forms. Erkihun Massresha (2011) measured the content of insoluble-bound tannins in soy bean hulls and concluded that their insolubility may be due to polymerization as well as to the formation of insoluble complexes with the fiber and protein fractions of the seed.

2.8.3. Processing Methods for Reduction of Anti-nutrients

A number of processing methods and treatment conditions are convenient to remove or inactivate ANFs in legume seeds. The net effect of processing techniques is increasing the nutritive value; remove flatulent causing components; improve the flavor and increase overall acceptance through the reduction/removal of antinutrients (Monari, 1993).

a. Soaking

Soaking cereal and most legumes in water can result in passive diffusion of water-soluble Na, K, or Mg - phytate, which can then be removed by decanting the water. The extent of the phytate reduction depends on the species, pH, and length and conditions of soaking. A simple soaking procedure appropriate for rural subsistence households has been developed that can reportedly

reduce the phytate content of unrefined soybean by 50%. This is important because several recent in vivo isotope studies in adults and infants have reported improvements in absorption of iron, zinc, and calcium in cereal-based foods prepared with a reduced phytate content. Some polyphenols and oxalates that inhibit iron and calcium absorption, respectively, may also be lost by soaking (Ologhobo and Fetuga, 1984).

b. Dehulling

Dehulling is one of the physical treatments to remove the soybean hulls (coats) that contain unwanted substances such as tannins and high-lignin fibers present in the hull. The hulls, therefore, should be removed to reduce off-flavour. The preparation of beans for processing is important to achieve good hull removal. This step is critical for manufacture of high-protein dehulled soy meal. However, the complete separation of the hulls from the meal of the soybean during processing is unlikely. Dehulled soybean is produced by dry method or wet method. Dry method involves heating the cleaned whole soybeans in oven or a dry saucepan and splitting the beans then removing the hulls from the cotyledons. The wet method involves soaking the whole beans in water for some times and removing the hulls manually and drying the cotyledons (Christine and Rosalind, 2007).

c. Roasting

Roasting consists of dry heat to the seed material by conduction or convection and heat radiations. In conduction equipments heating can be indirect through a granular medium, or direct through a metallic surface heated with a burner or electric resistances. In convection equipments, like drum-drier, the seeds are heated by hot air, and infrared radiations generated by a gas-fired burner. Residence time can be adjusted from 1 to 10 minutes as a function of the slope of the drum (Yemer Assefa, 2008).

Roasting methods involve the treatment of soybean with a temperature varying between 110 to 170°C. In any case, a uniform treatment must be sought, thus avoiding a situation in which the core of some of the particles remains raw whilst the outer layer of others has been over processed. It is important to divide the different beans up into size categories before roasting in order to prevent the overheating of the smallest ones. Roasting has a significant impact on the overall quality of grain and the final product (Mridula *et al.*, 2007).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Experiment Location

The experiment on the extrusion process was conducted in Food Process and Technology Department's laboratory, Faculty of Engineering, Bahir Dar University. Analysis of raw material and products for proximate composition, antinutritional factors of extrudates, physical and functional properties was done at center for food science and nutrition laboratory, Addis Ababa university .Determination of crude fiber , mineral composition and sensory analysis was conducted in the Ethiopian Health & Nutrition Research Institute(EHNRI) Laboratoy, Viscosity of semi-solid porridges were measured at Hawassa University ;School of Nutrition ,Food Science and Post – Harvest technology Department.

3.2. Materials

Peanuts, low tannin sorghum and soybeans for blend formulations and extrusion were obtained from different Agricultural Research Station of Ethiopia. Condensed tannin-low sorghum local "Teshale" variety, which was white in color was obtained from Melkassa Agricultural Research Center (MARC) ,Peanut of "Worer 961" variety from Worer Agricultural Research Center (Awash melka) and Soybean of "Belesa 95" variety from Pawi Agricultural Research Center (Gojam).

3.3. Sample Preparation

3.3.1. Sorghum flour preparation

The sorghum grains were cleaned by removing extraneous materials such as chaff and stones, after which the bad grains were removed by sorting. In order to remove the bran, about 20% water was added to temper the grain to the moisture content of 16% (Taylor and Dewar, 2001).Then the grains was mechanically dehulled using mortar and pestle to remove the bran. The dehulled sorghum then sun dried ,winnowed manually to separate the bran, finally milled using a stone mill .The flour was then sifted to pass through 480 μ m test sieve , sealed in polyethylene bag and store at room temperature .

3.3.2 Peanut flour preparation

The peanut seeds were cleaned by removing extraneous materials such as stones and also bad grains. Then the seeds were light roasted, dehulled and finally grounded in a mill.

3.3.2. Soya bean flour preparation

The seeds of soybean were cleaned manually to remove broken seeds and other extraneous materials such as stones and bad grains. Then the seeds were light roasted, dehulled and finally grounded in a mill.

Fig.4 Flow diagram for the preparation of extruded weaning foods from blends of sorghum and soybean (soya bean was added to sorghum at 0%,10%,15%,20% and 40%).

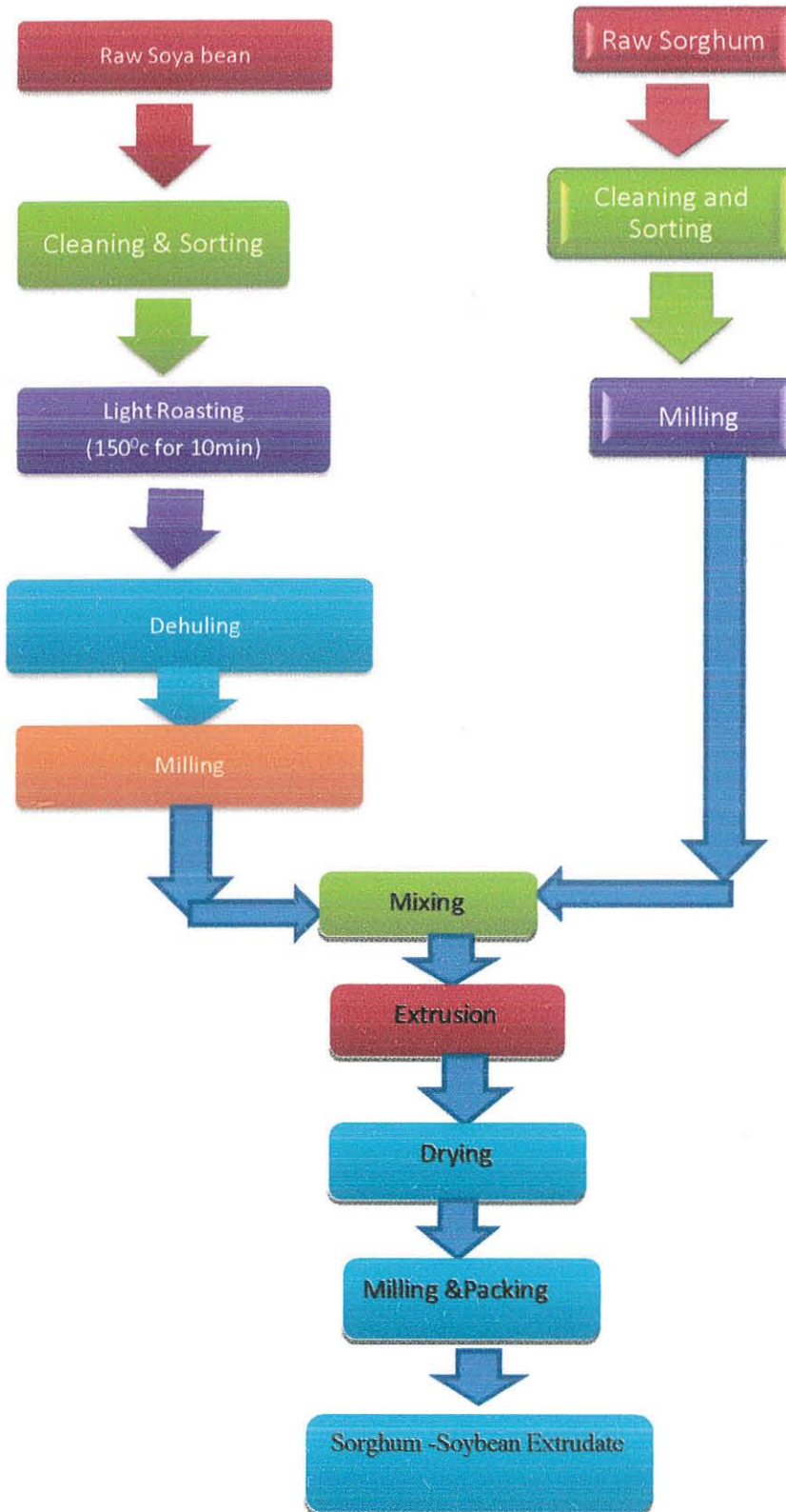
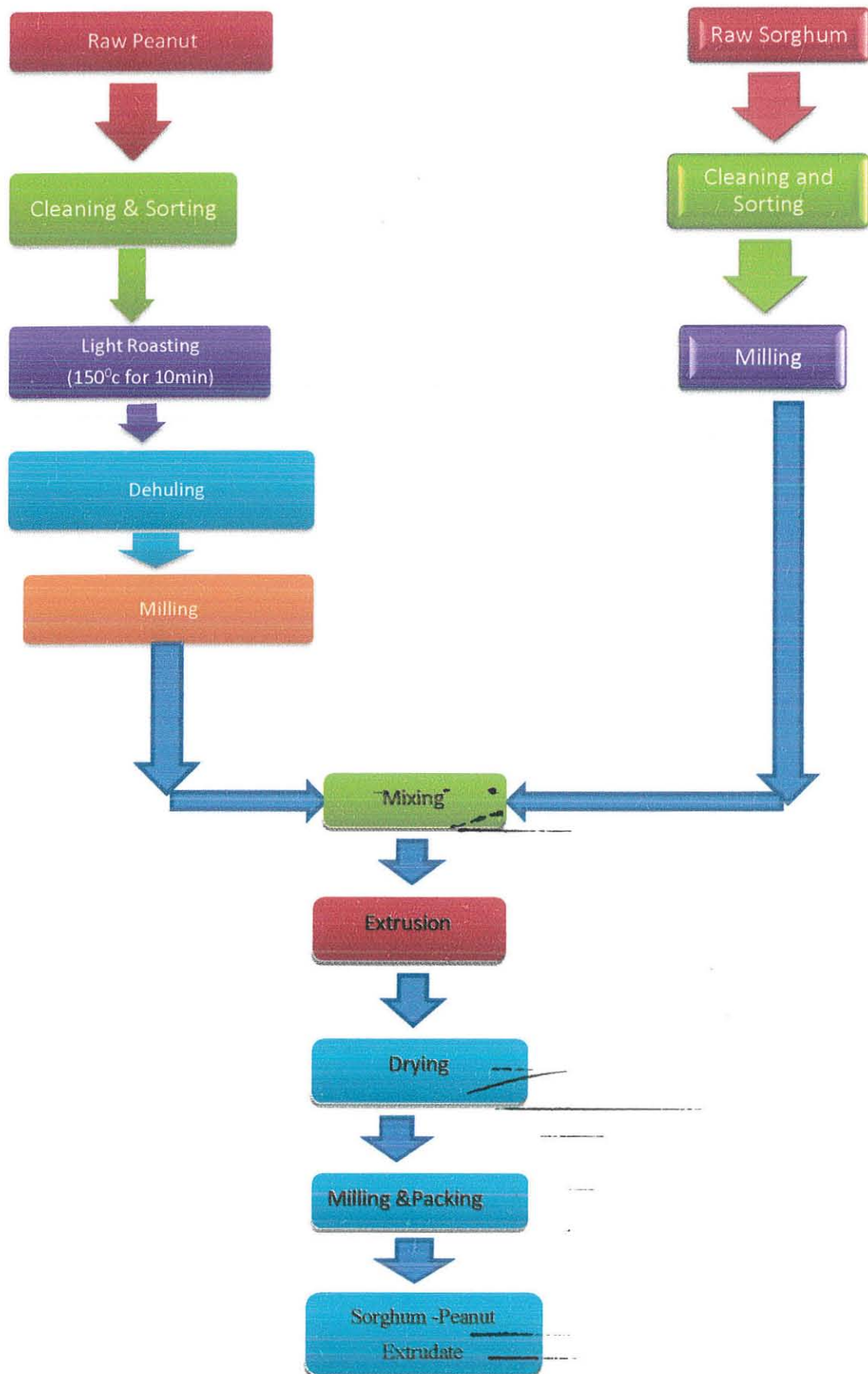


Fig.5. The Flow diagram for the preparation of extruded weaning foods from blends of sorghum and peanut (peanut was added to sorghum at 0%,10%,15%,20% and 40%).



3.4. Formulation of complementary foods

Formulation of flours of sorghum-peanut and sorghum –soya bean was done based on the nutritional requirements of older infants and young children according to (CODEX CAC/GL 08, 1991): Codex alimentarius: Guidelines on formulated supplementary foods for older infants and young children.

This experiment had two levels of treatments: blends I and II. Blend I was composed of sorghum –peanut flours (SP); while blend II had sorghum–soya bean flours (SY). During formulation nine products were formed. Peanut flour were added to low tannin sorghum at the level 0%,10%,15%,20% and 40%. Similarly soya bean were also added to sorghum at the level 0%,10%,15%,20% and 40%. During extrusion cooking each blend was extruded in three replications.

Table 1: Mixing formulation of non –extruded and extruded blends of sorghum with peanut

Sample code	Formulation ratio (% w/w)
NSP1	Non-extruded blends of (Sorghum: 60%, Peanut: 40%)
NSP2	Non-extruded blends of (Sorghum : 80%, Peanut:20%)
NSP3	Non-extruded blends of (Sorghum: 85%, Peanut:15%)
NSP4	Non-extruded blends of (Sorghum: 90%, Peanut: 10%)
NSOR	Non-extruded blends of (Sorghum: 100%, Peanut:0%)
ESP1	Extruded blends of (Sorghum: 60%, Peanut: 40%)
ESP2	Extruded blends of (Sorghum: 80%, Peanut:20%)
ESP3	Extruded blends of (Sorghum: 85%, Peanut: 15%)
ESP4	Extruded blends of (Sorghum: 90%, Peanut: 10%)
ESOR	Extruded blends of (Sorghum:100%, Peanut:0%)

Table 2: Mixing formulation of non-extruded and extruded blends of sorghum with Soybean

Sample code	Formulation ratio (% w/w)
NSY1	Non-extruded blends of (Sorghum: 60%, Soya bean:40%)
NSY2	Non-extruded blends of (Sorghum:80%, Soya bean :20%)
NSY3	Non-extruded blends of (Sorghum: 85%, Soya bean :15%)
NSY4	Non-extruded blends of (Sorghum: 90%, Soya bean : 10%)
NSOR	Non-extruded blends of (Sorghum: 100%, Soya bean: 0%)
ESY1	Extruded blends of (Sorghum: 60%, Soya bean: 40%)
ESY2	Extruded blends of (Sorghum: 80% Soya bean: 20%)
ESY3	Extruded blends of (Sorghum: 85%, Soya bean: 15%)
ESY4	Extruded blends of (Sorghum: 90% Soya bean: 10%)
ESOR	Extruded blends of (Sorghum: 100%, Soya bean: 0%)

3.5. Extrusion cooking process

3.5.1. Extrusion cooking machine

The extrusion cooking process was performed using a pilot scale co-rotating twin screw food extrusion cooker (model Clextal, BC-21 N0 194, Firminy, France). The barrel has 25mm diameter screws with 300mm useful length. The flour were fed in to the extruder inlet by volumetric feeder type KMV-KT20. Water was injected in to the extruder by positive displacement pump (type Clextal DKM). At the end of the extruder, a die plate with a circular hole of 2mm diameter was fixed. The temperature of the three zones of the extruder and of the product before entering the die can be controlled by Eurotherm controller (Eurotherm Ltd. Worthing, UK) and read on separate control panel board.

3.5.2. Equipment Setting and Extrusion Cooking Process

Prior to the main extrusion cooking process, the necessary calibration and adjustment of the material feed rate and water flow rate was performed. First the extruder screw was started 'ON' at screw speed of 120 rpm, then water was pumped in to the barrel by setting the barrel temperature around 70 °C to minimize material loss till the required barrel temperature of 120°C was achieved. Next, the material feeding was started at the flour rate of 51.8 g/min and moisture feed rate 8.55

g/min. As the dough appeared at the die, the barrel temperature was increased to 120⁰C, and water flow rate was adjusted till the required flow rate attained. Extrusion cooking of sorghum-peanut and sorghum-soya bean formulations were carried out at 15% moisture level, at the 120⁰c barrel temperature and at the screw speed of 150 rpm. Sample products were extruded as straight rope for ten seconds interval. After cooling of the samples for 30 minutes measurement of weight, length and diameter of extrudates takes place. Finally, samples were sealed in moisture proof polyethylene bags and stored at room temperature until ready for analysis and consumer acceptability tests.



Fig.6.The extrusion cooking machine



Fig.7. Extruded products.

3.6. Analytical methods

3.6.1. Proximate composition analysis of Extruded Weaning Foods

Samples of extruded weaning foods were developed and analyzed for moisture, protein, carbohydrates, fat, crude fiber and ash following standard methods.

3.6.1.1. Determination of moisture content

Moisture of the products were determined according to (AOAC, 2000) using the official method 925.09. A clean dried and covered flat aluminum dish was weighed and 5g of the sample was transferred to the dish. The dish then placed in the oven at 105⁰C for 3h and cooled in desiccators and re-weighed. Then, the moisture content was estimated by the formula:-

Moisture content [%] = (weight of fresh sample-weight of dry sample)×100/ (weight of fresh sample)

3.6.1.2. Determination of crude protein

Protein content was determined according to (AOAC, 2000) using the official method 979.09. In the digestion flask containing 0.5 g of sample and 6 ml of acid mixture (conc. Sulphuric acid) 3.5ml of 30% hydrogen peroxide will be added .As soon as the violent reaction stops, add 3g of catalyst mixture (K₂SO₄ and CuSO₄) then expose to 370 °C for four hours in order to allow digestion. Then, distillation was took place by adding 25 ml of 40% NaOH and using 25 ml of 4% boric acid that contains indicator as a trapping solution. Finally, the distillate was titrated with standardized 0.1N hydrochloric acid to a reddish color. Then, crude protein content was estimated using the formula:-

$$\text{Total nitrogen} = \frac{((V_2 - V_1) * N * 14.007 * 100)}{W}$$

Where,

V₂ = Volume in ml of standard hydrochloric acid solution used in the titration for the test material.

V₁ = Volume in ml of standard hydrochloric acid solution used in the titration for the blank determination.

N = Normality hydrochloric acid of ,14=Eq wt of Nitrogen

W = Weight in grams of the test material.

Conversion factors of sorghum, peanut and soya bean were 6.25,5.46 and 5.71 respectively (FAO/WHO,1973).

Crude protein (%)=total nitrogen(%)*conversion factor of the seed

3.6.1.3. Determination of crude fat

A clean and dried thimble containing 2 g of dried sample and covered with fat free cotton at the bottom and top was placed in the extraction chamber and 50ml of diethyl ether was added to the

extraction flask .Crude fat was determined by extracting a sample in diethyl ether in soxhlet extractor. The extraction was took place for at 3h according to (AOAC, 2000) official method 450.1. Then the extraction flask with its content placed in drying oven at 92°c for 30 minutes. The crude fat content was determined by the formula:-

$$\text{Weight of fat (Wf)} = \text{Wa} - \text{Wb}$$

Where:

Wa = Weight of extraction flask after extraction.

Wb = Weight of extraction flask before extraction.

$$\text{Crude fat content [g/100]} = (\text{Wf} \times 100 / \text{Wd})$$

Where:

Wd = weight of fresh sample.

3.6.1.4. Determination of crude fiber

Crude fiber analysis was conducted using the method of (AOAC, 2000) official method 962.09 , 1.5g weighed sample was transferred into a 600 ml beaker and 200 ml 1.25% sulfuric acid was added and boiled for 30 min. Recording was took place by placing a watch glass over the mouth of the beaker. After 30 min heating by gently keeping the level constant with distilled water, 20 ml 28% KOH was added and again boiled gently for further 30 min. Subsequently, washing was conducted with 1% sulfuric acid and NaOH solution. Then, it was filtered and dried in the electric oven at 130 °C for 2h. Furthermore, it was cooled at room temperature for 30 min in a desiccator and weighed, then it was transferred to crucible to muffle furnace for 30 min ashing at 550°C. Finally, it was cooled again in a desiccators and re-weighed. The crude fiber content was determined by using the formula:-

$$\text{Crude fiber content [(g/100)]} = [(w1 - w2) * 100 / w3]$$

Where,

w1 = Crucible weight after drying

w2 = Crucible weight after ashing

w3 = Dry weight

3.6.1.5. Determination of total ash

About 2.50g of fresh sample in duplicate was placed in dish. Dish was placed on a hot plate under a fume-hood and the temperature was slowly increased until smoking ceases and the samples become thoroughly charred. Then the dishes with sample were placed in muffle furnace at 550°C for 5 hours and cooled in desiccator for 1 hrs and weighing it, the ash content was determined by (AOAC, 2000) using the official method 923.03 and applying a simple formula:-

$$\text{Total ash [\%]} = \left[\frac{(w_2 - w)}{(w_1 - w)} \right] * 100$$

Where:

w = Weight in grams of empty dish

w1 = Weight in grams of the dish plus the dried test material

w2 = Weight in grams of the dish plus ash

3.6.1.6. Determination of total carbohydrates

Total carbohydrate content of the samples including crude fiber were determined by subtraction of the above tested parameters from 100% as described by Filli et al (2013).

$$\text{Total carbohydrates [\%]} = 100 - [\% \text{Moisture} + \% \text{Protein} + \% \text{Fat} + \% \text{Ash} + \text{fiber\%}]$$

3.6.1.7. Energy value calculation (Calorific value)

Energy value (calorific value) was quantified using an indirect calculation method. The three groups of nutrients, which provide the body with energy, are carbohydrates, fats and proteins (Nguyen *et al.*, 2007). One gram of carbohydrate (C) will be assumed/ to give 15.71KJ energy; one gram of fat (F) 37.71KJ energy and one gram of protein (P) 16.76KJ. Therefore, the determination of calorific value (KJ/100g) of the samples were determined according to Osborne and Voogt

(1978). The energy values for one gram of the three groups of nutrients which provides the body with energy were calculated by using specific values of Atwater factors for protein, fat, and total carbohydrate .

Energy value = (P* 16.76) + (F* 37.71) + (C* 15.71) in KJ/100g of the sample

Where;

P = Protein content (%).

F = Fat content (%).

C = Available total carbohydrate (%).

3.6.1.8.Mineral analysis

Determination of Zinc, Calcium and Iron

Zinc, calcium and Iron were determined using atomic absorption method of Osborne & Voogt (1978). The ash that was obtained after dry ashing at 550⁰C was treated with 7 ml of 6N HCl to wet it completely and 15 ml of 3N HCl were added and the dish was heated on the hot plate until the solution just boils. Then, it was cooled and filtered. Ten(10 ml) of 3N HCl was added to the dish and heated until the solution just boils. Finally, it was cooled and filtered into the graduated flask. A 2.5ml of 10% Lanthanum chloride was added to analyze calcium. Then the solution was cool and dilute to the mark (50ml)with deionized water, and a blank was prepared by taking the same procedure as the sample .The content of calcium, iron and zinc were determined by using atomic absorption spectrophotometer after calibrating the AAS with standard . Reading was taken from the graph which depicted the metal concentrations that correspond to the absorption or emission values of the samples and the blank. The metal contents were calculated by using the formula:-

Metal content [(mg/100g)] = [(((A-B)*V)/10W)]

Where,

W = Weight of sample in (g)

V = Volume of extract (ml)

A = Concentration of sample solution ($\mu\text{g/ml}$)

B = Concentration of blank solution ($\mu\text{g/ml}$)

Determination of phosphorous

Ashes were obtained from dry ashing then dissolve the ashes with 20% HCL, free of iron and wash it continuously with deionized water in 100ml volumetric flask .Then take 1ml of clear extract and dilute it to 100ml with deionized water .After that add in to a test tube 5ml duplicate of the sample dilution 0.5ml molybdate and vortex and 0.2ml Aminonaphtholesulphonic acid and mix .Then add 5ml duplicate of standard and treat as in the above steps. Finally read the absorbance of standard, blank and sample at 660 nm spectrophotometer (Fiske and Subbarow, 1925)

Calculation

$$\text{Phosphorus in mg/100gm} = \frac{(A_s - A_B) * \text{dilution factor} * \text{extracted volume} * 100}{\text{Slope} * \text{weight of sample} * 1000}$$

Where,

A_s = absorbance of sample

A_B = absorbance of blank

Slope = getting from the calibration curve.

3.6.1.9.Determination of some anti-nutritional factors

Phytic Acid Analysis

Phytic acid was determined by using the method of Latta & Eskin (1980) as modified by Vaintraub & Lapteva (1988). Dried sample of 5 mg was extracted with 100 ml 2.4% HCl for 1h at an ambient temperature and centrifuged (3000 rpm/30min). The supernatant was used for phytate estimation. One (1 ml) of Wade reagent (containing 0.03% solution of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and 0.3% of

selfosalicilic acid in water) was added to 3 ml of the sample solution and centrifuged. The absorbance at 500 nm was read using spectrophotometer. The phytate concentration was calculated from the difference between the absorbance of the control and that of assayed sample. The concentration of phytate was calculated using phytic acid standard curve and results were expressed as of phytic acids in mg/100g fresh weight.

Calculation: Phytic acid in mg/100g=(absorbance-intercept)3/(slope \times ρ \times wt .of sample \times 10),

Where, ρ is density

Condensed Tannins Analysis

Tannin was determined by the modified Vanillin assay Burns (1971). The sample that weighed 1.0000g was extracted with 10 ml of 1% HCl in methanol for 24 hour at room temperature with mechanical shaking. After 24hours of mechanical shaking the solution was centrifuged at 1000rpm for 5 minutes then 1 ml of supernatant was taken and mixed with 5ml of vanillin -HCl reagent (prepared by combining equal volume of 8% concentrated HCl in methanol and 4%Vanillin in methanol).Then read the absorbance at 500nm using spectrophotometer. The tannin concentration were found after getting the absorbance of the sample and standard solution. D-catechin was used as a standard for condensed tannin determination. A standard curve was made from absorbance versus concentration. Finally, the tannin contents were calculated.

Values of tannins were expressed in milligram of D-catechin equivalent per 100 gram of sample.

Tannin in mg/100g= (absorbance-intercept)/(slope*density*weight of sample*10)

Phytate: mineral molar ratios

The millimoles of phytic acid and iron were calculated by dividing the milligrams of phytic acid by 660.0 (atomic weight of phytate ion) and the milligrams of 55.8 (atomic weight of iron). The molar ratio was then calculated by dividing millimoles of phytic acid by millimoles of iron. The millimoles zinc was calculated by dividing the milligrams of zinc by 65.4 (atomic weight of zinc). The molar ratio was then calculated by dividing millimoles of phytic acid by millimoles of zinc. Similarly, millimole of calcium was calculated by dividing the milligrams of calcium by 40.0 (atomic weight of calcium). Phytate \times calcium/zinc millimolar ratio was obtained (mg of

phytate/molecular weight of phytate) (mg of calcium/molecular weight of calcium)/(mg of zinc/molecular weight of zinc) divided by 100 (Bains *et al.*, 2011).

3.6.2. Determination of functional properties

3.6.2.1. Water absorption capacity (WAC)

The WAC which gives an indication of the amount of water available for gelatinization was determined according to methods of Beuchat (1977). One (1g) of each samples were measured and mixed with 10ml of distilled water and vortex for 1 min and then centrifuged at 3000 rpm for 45min. The volume of the supernatant was recorded in a 10 ml graduated cylinder and used for determinations of water absorption; WAC was expressed as the weight of water bound by 1g dry flour.

Water absorption capacity = $(V_1 - V_2)P / \text{Weight of sample}$

Where:

V1 = is the initial volume of water used

V2 = is the vol. remaining (not absorbed)

P = is the density of water (1.0 g/cm³)

3.6.2.2. Oil Absorption capacity

Oil absorption capacity was determined according to the methods of Chau and Huang (2003). One g of each sample flours were measured and mixed with 10 ml of oil (pure soybean oil). The mixture was stirred for 30 min at room temperature. After sample was centrifuged at 2500 rpm for 30 min, the supernatant was transferred to a graduated cylinder of 10 ml, where the volume was measured. Oil absorption capacity was expressed as the weight of oil bound by 1g dry flour. The density of the oil was determined too. The volume of oil absorbed was multiplied by the density of the oil to determine the weight of oil so absorbed.

Oil absorption capacity = $(V_1 - V_2) P / \text{Weight of sample}$

Where:

V = Initial volume of oil used 1

V = Volume remaining (not absorbed) 2

P = density of the oil used

Density of oil was taken as 0.925g/ml.

3.6.2.3. Determination of viscosity

The paste viscosity was measured using a Brookfield Viscometer (Model DVII Rheometer V2.0RV; Middleboro Massachusetts, USA). The amount of flour and water used to prepare semi-solid porridge with the right consistency for infant food from sorghum-peanut and sorghum-soya bean were different (Filli *et al.*, 2010). The Sorghum-peanut products were prepared by mixing 20g of flour with 80ml of water. However, the sorghum-soya bean products were prepared from by mixing 25g of flour with 75ml of water. The semi-solid porridges was placed in water bath maintained at 45°C then they were poured in to the viscometer beaker. The viscosity was measured at 45°C (in centipoises, cP) using spindle number 7 at 60 revolution per minute (RPM). within 10 minutes the average of the maximum and the minimum viscosity reading was recorded (Mbata *et al.*, 2009).

3.6.3. Determination of Extrusion Product Characteristics.

3.6.3.1. Expansion ratio (Radial expansion ratio)

Sample products were extruded as straight rope for ten seconds interval. Length was measured by pocket size steel tape. The diameter of the extrudate was measured by caliper. Weight was measured by digital balance. The mean value of length (4 times), weight (4 times) and diameter (10 times) were recorded. The expansion ratio (diametric) was determined as the ratio of the diameter of the extrudate to the diameter of the die hole (Laike Kebede, 2006).

3.6.3.2. Specific length

Specific length (cm/g) relates extruded product length to its weight and measures the axial expansion of extrudates. Specific length of the extruded products depends on barrel temperature, screw speed and feed moisture content (Laike Kebede, 2006).

3.6.3.3. Bulk density (BD) of the extrudates

Bulk density (g/cm³) is determined by filling a container of known volume with a sample followed by weighing. This was important for obtaining the proper fill weight for the package volume (Okaka and potter, 1979).

3.6.4. Sensory Evaluation

Developed products (porridges) were evaluated for their acceptability by ten (10) semi trained panelists. These sensory evaluations were conducted at the Ethiopian Health & Nutrition Research Institute (EHNRI). The porridges were served to the panelists in white cups at about 45°C. The panelists were asked to rank the porridge on the basis of color, taste, aroma, texture and overall acceptability using a nine point hedonic scale as listed on (Appendix), (where 1 = dislike extremely and 9 = like extremely). Overall acceptability of the samples was also rated on same scale with 9 = extremely acceptable and 1 = extremely unacceptable (Inyang and Idoko, 2006).

3.6.5. Selection criteria for determining optimal complementary food

A ranking system using four nutritional criteria, i.e., protein content, energy value, calcium: phosphorous ratio and sensory attributes, was devised to determine the optimal blend combination according to the method modified by Griffith *et al.* (1998).

3.6.6. Statistical Analysis

The data were analyzed using SPSS/PC+ Version 20 statistical software. Statistical parameters were estimated using analysis of variance. Differences between means were evaluated by the least significant difference test and significance was accepted at $P < 0.05$.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. The Proximate and Functional Property Result of Raw Sample Flours

The results of chemical composition analysis of the raw materials sorghum, soybean and peanut are presented in Table 3. Components other than moisture contents are expressed on dry basis. There was a significant ($P<0.05$) difference in the values of moisture, protein, fat, ash, fibre, carbohydrate, energy and on minerals (calcium, iron, zinc and phosphorous) and in anti-nutrients composition such as phytic acid and tannin. There was also significant ($P<0.05$) difference in the values of the functional properties such as bulk density, water and oil absorption capacities.

4.1.1. Raw sorghum flour

Proximate analysis of sorghum whose variety called Teshale Shows that the protein contents on a dry basis were 11.76% (Table 3) which is within the range (9.5%-12.9%) reported by Shimelis and Dawit (2012). In this study the crude fat contents 4.92% was. Similarly, Noha *et al.* (2011) have obtained 4.2% of the crude fat contents during their investigation. The crude fat content is related to the energy content of the flour. The ash content were (1.71%) and also similar to the result (1.75%) reported by Ibid (2011). This sorghum had crude fiber content of (2.61%), this result agreed with that of (2.64 g/100 g) reported by Shimelis and Dawit (2012). The moisture content was 4.23% which is below 10% and this low moisture content extends shelf life of flours (Kikafunda *et al.*, 2006). Flour moisture is typically an indication of flour quality and has an impact on functionality in specific products.

The mineral composition of sorghum shown on the (Table 4) indicates the amount of calcium, iron, zinc and phosphorous was 36.65%, 8.02%, 2.48% and 319.1% respectively. The presented result of calcium, zinc and phosphorous was analogous to the result (37.1mg/100g, 2.40mg/100g and 318.57mg/g) reported by Shegro *et al.* (2012). Likewise Tizazu (2011) have obtained (8.21%) of the iron content during his investigation.

The phytate and tannin content was 126.68% and 64% respectively (Table 5). The result of phytate is like to the phytate content of white sorghum (125.2mg/100g) reported by Ochanda *et*

al. (2010).The result of tannin was within in the range of tannin free sorghum(50 mg/100g-380mg/100g) similar to the report of Joseph and Lloyd (2004).

The results of bulk density, water absorption capacity and oil absorption capacity were (0.82g/ml, 2.00ml/g and 0.90ml/g respectively (Table 6). The result of bulk density resembles the result (0.75g/ml) and (0.73g/ml) reported by Sing *et al.* (2012) and Ocheme and Mikailu (2011) respectively. However Phattanakulkaewmorie *et al.*, (2011) ; Shimelis and Dawit (2012) reported the water absorption capacity of sorghum (1.1ml/g) and (2.8ml/g) respectively. The result of oil absorption capacity is in agreement with (1.1ml/g) reported by Shimelis and Dawit (2012).

4.1.2. Raw Peanut Flour

Proximate analysis of peanut whose variety called Werer 961 (Table 3) shows that the moisture content was (1.64%),Similarly Ejigui *et al.* (2005) have reported that the moisture content of 1.45%, However, Ayoola *et al.* (2012) also reported the moisture content of peanut 1.07% which is less than the current study.

The moisture content is low, this makes the shelf-life to be long and contribute to the stability of peanut. The content of crude protein was (26.38%), correspondingly Abdulrahman (2013) and Ingale and Shrivastava (2011) obtained the crude protein content of (27.93%) and (25.20%) respectively.

The value of fat was (49.94%) Likewise Abdulrahman (2013) and Nepote, (2008), have reported the fat content of peanut was within the range(50 % -55%) and (47.94%) respectively. The ash content was (2.47%). Analogously Abdulrahman (2013) and Ejigui (2005) reported (2.3%) and (2.45%) for the ash content of peanut.

The amount of crude fibre was 6.25%, Correspondingly Batal *et al* (2005) have reported (8.3%) which was higher than current study. The result of carbohydrates was (12.54%) and this result is within the range (9.5% -19.0 %) reported by Guy (2009).

The content of calcium, Iron, Zinc and Phosphorous content presented on (Table 4) were 121.77mg/100g, 2.49mg/100g, 2.89mg/100g and 394.16mg/100g respectively. The result of calcium and iron was within the range (44mg/100g -134 mg/ 100g) and (0.2 mg/100g -3.7

mg/100g) respectively, as reported by Guy (2009). On the other hand Abdualrahman (2013) obtained the zinc content of soya bean (3.7mg/100g) which was higher than the current result. The phosphorus contents obtained for the studied peanut varieties was alike to the result (396.25mg/100g) reported by Guy (2009).

The anti-nutritional composition (Table 5) shows it contains Phytate (416mg/100g) and tannin (31.7mg/100g). Correspondingly Inuwa et al. (2011) and Megat *et al.* (2012) obtained (418 mg/100g) and (32.69mg/100g) to the result of Phytate and tannin respectively. Bulk density, water absorption capacities and oil absorption capacities were found on (Table 7) was (1.00g/ml, 1.31ml/g and 1.23ml/g). However, Juliana and zhergxing (2008) obtained the bulk density of peanut (0.41g/ml) during their investigation. The difference in values may be due to their difference in fat content because peanut analyzed by Juliana and zhergxing (2008) was defatted and peanut analyzed in this study which is the variety called Werer 961 was full fat.

Bulk density signifies the behavior of the products in dry mixes and is an indication of porosity of the products, so the result varies with the fineness of the flour particles (Balogun and Oltridoye). The higher result of peanut (Werer 961) obtained was probably due to high fat content, so the flour occupies small volume and consequently the bulk density will be higher (Mohamed *et al.*, 2009). Zain & Ooi (1992) obtained the results of water absorption capacities and oil absorption capacities of peanut as (0.9ml/g and 0.7ml/g) respectively which was less than the current study. The energy content is (606.83%), However Abdualrahman (2013) obtained (601.856 kcal) for the energy content of peanut.

4.1.3. Raw soya bean flour

It is evident from Table 3 that the moisture content of soybean was (3.80%). Similarly Odumodu (2010) have reported (3.7%) for the moisture content of soya bean. However Edema *et al.* (2005) reported the moisture content of soya bean (6.11%) which was higher than the result of current study. The difference in values may be due to the processing methods. The flours in this study were obtained after roasting the soya beans, and this might reduce the moisture content of the samples by driving off most of the moisture due to the application of heat during roasting. The content of crude protein was (39.14%), Similarly Eshun (2012) reported the crude protein content of (39.25%) during his investigation.

The fat content was (25.69%) , likewise Odumodu (2010) reported the fat content of soya bean (25.97 %) during his investigation. The fiber content was (4.8%), Correspondingly DOASL (2006) reported (4.90%) for the fiber content of soya bean. Presented results of ash and carbohydrates were (4.95% and 22.11%) respectively. Analogously Agunbiade(2011) obtained (4.52%) for the ash content of soyabean . The energy content was (477.96kcal/100g), Similarly Eshun(2012) reported (473.62kCal/100g) for the energy content of soya bean .

It is evident from the Table 4 that amount of calcium, iron, zinc and phosphorous found in soya bean were (349.29mg/100g, 11.16mg/100g,3.89mg/100g and 543.40mg/100g) respectively. Teresa (2011) reported (262mg/100g) for the calcium content of soya bean during his investigation which was less than the current study. Correspondingly DOASL (2006) and Guy (2009) reported the iron and phosphorous contents of soya bean were (12.2mg/100g) and within the range (400.42 mg/100g - 601.20 mg/100g) respectively. It is evident from the Table 5 that the phytate and tannin contents were 278.7mg/100g and 36.20mg/100g respectively. Likewise Joyce and Patience (2004) and Odumodu (2010) reported the value of phytate and tannin were (280.37mg/100g) and (34.92 mg/100g) respectively during their investigation. As it is shown on Table 6 the results of bulk density, water absorption capacity and oil absorption capacity of soya bean were (0.81g/ml,2.5ml/g and 1.44ml/g respectively).Similarly Deshpande (1982) and Liu (1997) reported the water absorption capacity and oil absorption capacity of soya bean was (2.4ml/g) and (1.43ml/g) respectively, However Maha *et al*, (2012) also reported oil absorption capacity of soya bean (1.6ml/gm) which was higher than the current study

4.2. Proximate compositions of non - extruded and extruded blends of sorghum-peanut and sorghum- Soya bean samples.

4.2.1. Moisture content

The moisture content values located on (Table 3) were ranged between (7.46%-8.98%),(4.11%-8.49%) and (6.36%) for sorghum- peanut, sorghum- soybean and the control samples respectively. The moisture contents were within the acceptable range with low mean moisture contents which fulfills the Protein Advisory Group Recommendations (1972). Moisture content should be between 5% to10% and they are required for convenient packaging and transport of products (Oduro *et al*, 2007). The moisture content of formulated weaning foods were significantly ($P \leq 0.05$) lower than

11.3% (the levels in commercial weaning food or cerelac) . Therefore, moisture contents of both formulated sorghum-peanut and sorghum-soya bean extrudates were within the recommended critical values (Munasinghe *et al.* ,2013).

4.2.2. Total ash content

The ash contents result of the extruded blends of sorghum-peanut, sorghum-soya bean and the control samples shown on (Table 3) were ranged between (1.33%-1.91%), (1.87%-3.19%) and (1.10 respectively. The sorghum-soya bean sample had significantly ($p < 0.05$) highest ash content than the extruded sorghum-peanut and control samples.

The study shows ash content of extrudates increased significantly ($p < 0.05$) with increasing level of peanut and soybean in the blends of sorghum-peanut and sorghum-soya bean samples respectively. This is due to higher amount ash found in the peanut and soybean than sorghum. Ash gives an indication of inorganic elements that are present in a food as minerals. The results of ash content of the extrudates shows ESP1 from Sorghum-Peanut extrudates and all the samples of extruded blends of Sorghum – Soya bean does not differ ($p > 0.05$) significantly. However the original ash content of the remaining samples of Sorghum-Peanut extruded blends and the control decreased ($p < 0.05$) significantly.

The ash content of formulated weaning foods were significantly ($P \leq 0.05$) lower than the results of commercial weaning food. But ash contents were the same ($P \leq 0.05$) between the formulated diets. Acceptable ash content of weaning foods which given by the Protein Advisory Group recommendations (1972) should not exceed 5%. Formulated foods studied in the current study were within this limit as well. (Munasinghe *et al.*, 2013).

4.2.3. Crude Protein Content

The protein contents result of the extruded blends of sorghum-Peanut, sorghum-soya bean and the control samples are shown in (Table 4). The results were ranged between (11.17%-16.38%), (12.75%-22.05%) and (11.25%) for extruded sorghum-peanut, extruded sorghum-soya bean and control samples respectively. The extruded Sorghum-soya bean samples had significantly ($p < 0.05$) highest protein content than the extruded Sorghum-peanut and the

control samples. As expected, there was significant difference ($p < 0.05$) amongst the extruded samples.

The protein content of the extrudates increased proportionally with the amount of peanut and soybeans increase in the formulation. Ojinnaka *et al.* (2013) and Okoye *et al.* (2010) reported protein content increased with increased quantities of the soybean flour addition or African yam bean addition on sorghum based complementary food development. Similar observation was also made in a research study by Adebayo *et al.* (2011) which showed an increase in the protein content with corresponding increase in the proportion of bambara flour supplementation in complementary food production from ofada rice flour blend). The protein content of the following formulated weaning foods (ESP1, ESY1, ESY2) were significantly higher than ($P \leq 0.05$) the levels in commercial weaning food (cerelac) and the protein content of ESY3 equal to the level in commercial weaning food (cerelac).

A minimum protein content of 15% is required for maximum complementation of amino acids in foods and for growth. Thus all the above formulations whose protein value contain 15% and above were satisfied the protein demand for complementary foods for older infants and young children according to Codex Alimentarius Commission (CODEX CAC/GL 08.1991). According to Wickramanayake (1996) the high lysine content of legumes improve the nutritional quality of cereals by complementing the limiting amino acids. Sulphur containing amino acids such as methionine are limiting in legumes and relatively high in cereals whereas lysine is limiting in cereals and high in legumes. Comparing the result of the protein composition of the raw SP blend and SY blend with their extrudates indicates except ESP1, ESP4 from sorghum- peanut and ESY4 from sorghum- soya bean there was no significant ($p > 0.05$) change in the level of protein between raw blends and their extrudate which is similar to study reported by Catootjie *et al.* (2011). This study also shows there was a significant ($p < 0.05$) decrease in the content of proteins, for all those sorghum peanut extrudates with lower extrudates moisture content. Fischer (2004) observed that moisture content of the wheat flour affected the mode and the nature of the protein polymerization.

Extrusion cooking is a process that combines shear, pressure and temperature that leads to intra and inter molecular rearrangements between starch, protein and fiber components. At the higher moisture content specific mechanical energy is lower, because water acts as a lubricant, the material

in the extruder becomes more flexible, friction during extrusion is also reduced and this lowers the duration of exposure of the feed to thermal energy that is due to increased screw speed which resulted in an increase in the protein content .however at lower moisture content residence time of extrudates is higher due to low screw speed and this results for more thermal energy absorption by the feed which will cause a subsequent decrease of protein (Olapade and Aworh., 2012). Similar reduction of protein content after extrusion was reported by Anuonye *et al.*,(2009).

The protein content of the extrudate decreased during extrusion cooking , due to exposure of the chemical constituents of the feed material to high temperature, high shear and high pressure and these brings denaturation of extrudate protein. The thermo-mechanical action during extrusion brings gelatinization of starch, denaturation of protein and inactivation of enzymes, microbes and anti-nutritional factors. There was a remarkable decrease in the protein content of the meat analogue samples as the barrel temperature increase. During extrusion, peptides of proteins massively undergo unfolding and/or aggregation and this releases low molecular weight peptides protein (Leszek, 2011). Extrusion cooking, generally randomly disrupt the disulphide and linear linkages of peptides attributed to reductions in nitrogen content as an effect of the formation of isopeptide bonds between amine groups of lysine and amide groups of asparagines or glutamine, accompanied by the release of ammonia and these leads for decreased protein content. Yaqoub *et al.* (2008) observed similar finding on protein denaturation due to heating leading to transamination and deamination reactions and hence reduction in amino acids .

4.2.4. Crude fat content

The fat contents result of the extruded blends of sorghum- peanut, sorghum-soya bean and the control samples are shown in(Table 3). The results were ranged between (7.3%-18.36%),(4.42%-10.5%) and (1.25%) for extruded sorghum-peanut, extruded sorghum-soya bean and control samples respectively. The extruded sorghum-peanut samples had significantly ($p<0.05$) highest fat content than the extruded sorghum-soya bean and the control samples.

As expected, there was significant difference ($p<0.05$) amongst the extruded samples. The fat content of the extrudates increased proportionally with the amount of peanut and soybeans increase in the formulation. Except the result(18.36%) for ESP1 and the result (10.5%) for (ESY1) of sorghum- peanut and sorghum- soybean extrudates respectively ,the remaining SP and SY

extrudates fat content were lower than the fat value (10.5%) of the commercial weaning food (cerelac). The fat content of a food sample can affect its shelf stability.

This is because fat can undergo oxidative deterioration, which leads to rancidification and spoilage. Hence, a food sample with high fat content is more liable to spoilage than one with a lower fat content (Amankwah *et al.*, 2009). Protein Advisory group (1972) recommends fat content of a weaning food should be not more than 10% due to oxidative deterioration. In the current study, soybean and peanut were used as the fat suppliers.

Soy bean oil agree with the recommendations of (FAO/WHO, 1998) that vegetable oils can be included in foods meant for infants and children, which will not only increase the energy density, but also be a carrier for fat soluble vitamins and provide essential fatty acids. Soybean and cereals contain unsaturated fats which does not increase the cholesterol in the blood hence can be recommended for children (Munasinghe *et al.*, (2013).

The fat content of extrudates significantly increased ($p < 0.05$) with increasing level of peanut and soybean (Table 3). However there was a significant ($P < 0.05$) decrease in the fat content of the both extruded blends of sorghum- soybean and sorghum- peanut extrudates after extrusion. Similar reduction of fat were reported by Nierle *et al.*(1980). The reduction of fat content during extrusion cooking can, in part, be attributed to its volatilization, degradation of fat due to high temperature inside the screw channel, or to physical loss as droplets which were not recovered couple with shear effect of extruder screw pressure extrusion of dough against the die small nozzle and other process interaction(Nwabueze, 2006).

The presence of starch and proteins in the raw material is also conducive to the formation of starch lipid and lipid-protein complexes (Guzman *et al.*, 1992). Leszek, (2011) stated that the loss in lipid can be attributed to starch-lipid and protein-lipid complex formations which confer resistant to some lipid extraction techniques.

Therefore, fatty acids in the material may form complexes with amylose making it more difficult to extract crude fat for quantification. As reported by Schoenlechner and Berghofe (2000) all the extruded samples, notable complexing of fats was recorded, as well as a distinct reduction in the content of free fats, extracted by hexane. Free lipids are defined as those that can be extracted with petroleum ether or hexane at room temperature, whereas the bound lipids are extractable with

water-saturated butanol or chloroform-methanol mixtures (Schoenlechner and Berghofe, 2000). Ho and Izzo (1992) reported similar finding on lipid binding due to interactions with starch and protein macromolecules in extrusion cooking of cornmeal.

Table 3. Proximate composition of non extruded and extruded blends.

	Type	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	CHO* (%)	Energy kcal/100g
Ratio	Sorghum	4.23 ± 0.20 ^c	1.71 ± 0.10 ^a	11.76 ± 0.69 ^a	4.92 ± 0.07 ^a	2.61 ± 0.15 ^a	74.08 ± 0.64 ^c	389.97±1.19 ^a
	Soybean	3.80 ± 0.07 ^b	4.95 ± 0.10 ^c	39.14 ± 0.39 ^c	25.69 ± 0.57 ^b	4.80 ± 0.17 ^b	22.11 ± 0.22 ^b	477.96±0.98 ^b
	Peanut	1.64 ± 0.03 ^a	2.47 ± 0.44 ^b	26.38 ± 0.57 ^b	49.94 ± 0.55 ^c	6.25 ± 0.26 ^c	12.54 ± 0.47 ^a	606.83±1.01 ^c
Non extrude	NSP1	3.14±0.22 ^a	2.14±0.10 ^e	17.74±0.79 ^e	22.92±0.56 ⁱ	4.13±0.15 ^f	49.60±2.20 ^a	476.75±1.05 ⁱ
	NSP2	3.75±0.49 ^{ab}	1.94±0.11 ^{de}	14.83±1.10 ^c	13.93±0.20 ^b	3.39±0.30 ^e	62.20±0.24 ^c	433.43±0.35 ^b
	NSP3	3.80±0.24 ^{ab}	1.88±0.02 ^{de}	14.71±0.11 ^{bc}	11.67±0.10 ^f	3.20±0.20 ^e	65.31±0.20 ^{de}	422.60±0.25 ^f
	NSP4	3.97±0.29 ^{ab}	1.83±0.06 ^{de}	13.39±0.20 ^b	9.39±0.19 ^e	3.01±0.08 ^{de}	68.39±0.39 ^f	411.70±1.20 ^e
	NSOR	4.23±0.22 ^b	1.71±0.19 ^{cd}	11.97±1.00 ^a	4.89±0.07 ^b	2.65±0.11 ^{cd}	74.55±0.98 ^h	390.09±1.00 ^b
	NSY1	3.85±0.12 ^a	3.02±0.05 ^f	22.47±0.89 ^e	13.31±0.44 ^b	3.54±0.42 ^e	53.15±1.17 ^a	425.11±1.89 ^d
	NSY2	4.02±0.24 ^a	2.44±0.41 ^e	17.29±0.41 ^d	9.17±0.53 ^e	3.06±0.09 ^d	64.41±1.63 ^b	407.25±1.08 ^{bcd}
	NSY3	4.12±0.13 ^a	2.19±0.17 ^{cde}	16.24±0.62 ^{cd}	8.15±0.47 ^d	2.94±0.08 ^{cd}	66.44±0.99 ^b	403.15±1.95 ^{bcd}
	NSY4	4.13±0.18 ^a	2.17±0.32 ^{cde}	15.46±0.69 ^c	7.07±0.39 ^c	2.85±0.11 ^{cc}	69.20±1.29 ^c	402.88±1.96 ^{bcd}
	NSOR	4.23±0.22 ^a	1.71±0.19 ^b	11.97±1.00 ^{ab}	4.89±0.07 ^b	2.65±0.11 ^c	74.55±0.98 ^d	390.09±1.00 ^{abc}
Extruded	ESP1	7.46±0.21 ^d	1.91±0.19 ^{de}	16.38±0.30 ^d	18.36±0.06 ^h	2.29±0.29 ^{bc}	53.60±0.29 ^b	445.15±0.09 ^h
	ESP2	8.67±1.13 ^e	1.44±0.09 ^{bc}	14.03±0.09 ^{bc}	9.69±0.30 ^e	1.41±0.40 ^a	64.63±0.09 ^d	401.85±1.02 ^d
	ESP3	8.98±0.39 ^e	1.49±0.40 ^{bc}	13.64±0.39 ^{bc}	7.79±0.20 ^d	1.31±0.18 ^a	66.78±0.34 ^e	391.83±0.19 ^c
	ESP4	8.58±0.40 ^e	1.33±0.13 ^{ab}	11.17±1.03 ^a	7.30±0.29 ^c	1.31±0.11 ^a	69.97±0.01 ^b	391.62±1.00 ^c
	ESOR	6.36±0.34 ^c	1.10±0.10 ^a	11.25±1.02 ^a	1.25±0.11 ^a	2.25±0.04 ^b	77.79±1.02 ⁱ	367.32±1.02
	ESY1	8.49±0.45 ^c	3.19±0.33 ^f	22.05±0.71 ^e	10.50±0.68 ^f	2.18±0.20 ^b	52.90±1.17 ^a	397.04±1.00 ^{bcd}
	ESY2	6.28±0.44 ^b	2.37±0.19 ^{de}	16.34±0.72 ^{cd}	9.09±0.52 ^e	1.90±0.27 ^b	64.60±1.67 ^b	403.09±1.98 ^{bcd}
	ESY3	4.11±0.08 ^a	1.97±0.05 ^{bcd}	15.05±0.16 ^c	7.09±0.46 ^c	1.29±0.11 ^a	70.54±1.75 ^c	405.48±2.02 ^{bcd}
ESY4	8.43±0.57 ^c	1.87±0.13 ^{bc}	12.75±0.39 ^b	4.42±0.59 ^b	1.28±0.24 ^a	71.31±1.04 ^c	374.61±1.49 ^{ab}	
Cerelac		11.3	3.2	15.8	10.5	2.1	68.4	432
RV (g/100g)		<5	<3	>15	10-25	<5	64	400-425

Source for RV (recommended values):*(CODEX CAC/GL 08. 1991): Codex alimentarius: Guidelines on formulated supplementary foods for old infants and young children. Values are means of two duplicates ± SD. Values in the same column with different superscripts for each type of analysis are significantly different (P<0.05) . Sample code as in Table 1 and Table

4.2.5. Crude fiber content

The fiber content were ranged between (1.31%-2.29),(1.28%-2.18%) and (2.25%) for sorghum-peanut, sorghum-soya bean and the control samples respectively.

The crude fiber content of the following (ESP2, ESP3, ESP4 ,ESY2, ESY3 and ESY4) formulated weaning foods were significantly ($P \leq 0.05$) lower than the results of commercial weaning food (cerelac) which was (2.1%). However the other (ESP1, ESY1 and the control samples contain close similar fiber content to of commercial weaning food (cerelac). Acceptable fiber content of weaning foods should not exceed 5% according to the Protein Advisory Group Recommendations (1972). When the fiber content is high it decreases the digestibility of the particular food. The crude fiber contents of both the sorghum-peanut and sorghum-soya bean extrudates were within this acceptable range. The dietary fiber fractions of all this weaning foods were comparatively low due to the incorporation of de-hulled legumes and decorticated sorghum (Ghasemzadeh and Ghavide, 2011).

From the study it was found that peanut and soybean proportion had significant ($p < 0.05$) effect on fiber content of the products (Table 3). Increasing the level of peanut and soybean results in a significant increase ($p < 0.05$) in fiber content of extrudates. On the other hand the result for the proximate composition of fiber in raw flour blend and the corresponding blended extrudates shows the fiber content of extrudates decreased significantly ($p < 0.05$) after extrusion. Anguita *et al.* (2006) reported similar findings of reduction of fiber content after extrusion. The changes observed in this work could be attributed to alterations in fibers structures because extrusion processing have reorganised dietary fibre components and changing their chelating properties. As with starch, large fragments of fiber molecules may be sheared off during extrusion (Leszek, 2011). That is, there might be a shift in form from insoluble dietary fibers to soluble dietary fibers and the formations of resistant starch and enzyme-resistant indigestible glucans formed by transglycosidation (Anguita *et al.*, 2006). As stated by Omohimi *et al.* (2013) the insoluble and soluble fibers are redistributed after extrusion, producing thermomechanical transformation that will not appear in a proximal determination of crude fiber due to the techniques low sensitivity.

The reduction in the fibre contents of the extrudates observed in this study is an advantageous for the following reasons. In terms of digestibility, to increase bioavailability of minerals and to decrease bulk density. High fiber content lowers mineral absorption because cellulose, lignin and some hemicelluloses affect the mobility of the gastrointestinal tract and interfere with the absorption of minerals and high fiber content can also decreased expansion ratio and increased bulk density of the product. Fiber does have significant ($p < 0.05$) effect on product structure and texture, it does not expand but acts as a solid filler diluting the expanding starch ingredient in the mix. The bulk density of product thus increased with increasing fiber content (Ryu, 2004). The effect of fiber on bulk density has been reported previous by Chulaluck *et al.* (2008).

4.2.6. Total carbohydrate content

The carbohydrate contents result of the extruded blends of sorghum-peanut, sorghum-soyabean and the control samples were ranged between (53.60%-69.97%), (52.90%-71.31%) and (77.80%) for extruded sorghum-peanut, extruded sorghum-soya bean and control samples respectively. The control sample had significantly ($p < 0.05$) highest carbohydrate content than the extruded sorghum-peanut and sorghum-soya bean samples.

Due to lower content of carbohydrate in peanut and soybean the carbohydrate content of the raw blends decreased significantly ($p < 0.05$) with the amount of peanut and soybeans increase in the formulation. Comparing the chemical composition of the raw blended sorghum-soybean, raw blended sorghum-peanut and control with their extrudates shows carbohydrate content of the raw and extruded blend of sorghum and soybean does not have significant ($p > 0.05$) difference except ESY3 extrudate who shows significant ($p < 0.05$) increase in carbohydrate content (Anuonye *et al.*, 2010). However, for the sorghum-peanut blend and the control sample except ESP3 extrudate, all the other extrudates carbohydrate content increased significantly ($p < 0.05$). These increases in carbohydrate content could be attributed to the effect of intense mechanical shearing during the extrusion processes. Mechanical shearing can bring about mechanical breakage of bonds holding down some carbohydrate materials within the matrix.

As this shearing intensifies coupled with a higher temperature, some hitherto unavailable carbohydrate materials are released into the matrix. In essence extrusion may predigest starch depending on the composition of the feed material and operating conditions (Omohimi *et al.*, 2013). The carbohydrate content of the following (ESY1, ESY2 and control) formulated weaning foods were significantly ($P \leq 0.05$) lower than the levels in commercial weaning food. The commercial product has shown the highest mean carbohydrate content and this is because of its lower crude protein and crude fat contents. In this study sorghum was used as the main carbohydrate supplier which helped to maintain the carbohydrate content over 65% as the recommendations made by Protein Advisory Group (1972).

4.2.7. Energy value

The result of the value of energy were ranged between (391.62 kcal/100g-445.15kcal/100g), (374.61kcal/100g-405.48kcal/100g) and (367kcal/100g) for extruded blends of Sorghum-Peanut, Sorghum – Soya bean and the control samples respectively. The sorghum-peanut extrudate had significantly ($p < 0.05$) highest energy content than the extruded sorghum-soya bean and control samples. Due to higher content of energy in peanut and soybean, the value of energy increased significantly ($p < 0.05$) with the amount of peanut and soybeans increase in the formulation.

Nutritionally, the energy values of the experimental food samples found within (400kcal/100g - 425kcal/100g) met the FAO/WHO (1991) specification guidelines for the young child complementary food formulations. Except the energy value of ESP1 (60% sorghum, 40%peanut) the other sorghum-peanut and sorghum-soya bean extrudates energy amount is lower than the energy composition of the commercial weaning food (cerelac) 432kcal/100g. The energy value of the non-extruded flour blend and the extrudate were not significantly ($p < 0.05$) different from each other. However, the energy values of the extrudates were higher compared to the flour blend numerically. This can be attributed to gelatinization of starch during extrusion cooking reduced the oxalate, phytate and trypsin inhibitor.

4.3. Mineral Content of Non- Extruded and Extruded Blends

The Minerals content of both sorghum - peanut and sorghum- soya bean blends before and after extrusion are presented in (Table 4) zinc, iron, calcium and phosphorus content have been determined.

The value of calcium were ranged between (46.03mg/100g-69.08mg/100g),(67.30mg/100g-160.11mg/100g) and (36.39mg/100g) for extruded blends of sorghum-peanut, sorghum-soya bean and the control samples respectively .The sorghum-soya bean sample had significantly ($p<0.05$) highest content than the extruded sorghum-peanut and the control samples. The iron content of extrudates increased significantly ($p<0.05$) after extrusion and were ranged between (6.65mg/100g-11.7mg/100g),(6.5mg/100g-14.19mg/100g) and(9.82mg/100g) for extruded blends of sorghum-peanut , sorghum-soya bean and the control samples respectively. The zinc content were ranged between (1,61mg/100g-2.75mg/100g),(1.91mg/100g-3.23mg/100g) and (2.23mg/100) .Finally the values of phosphorous were ranged (188.2mg/100g-297mg/100g),(209mg/100g-329mg/100g) and (274mg/100g)for extruded blends of sorghum-peanut , sorghum-soya bean and the control samples respectively .

The extrudates had higher values for mineral composition than individual raw samples blends. This shows that fortification had Improved the nutritional value of extrudates and also this increase has been attributed to screw wear in the extruder(Anuonye *et al.*, 2009). The variation in mineral content of formulated food samples with that of cerelac (a commercial formula) could be due to the enrichment of the cerelac product with essential mineral during production.

Table 4. Mineral content of non-extruded and extruded blends.

	Type	Ca in mg/100g	Fe in mg/100g	Zn in mg/100g	P in mg/100g
Ratio	Sorghum	36.65 ± 0.07 ^a	8.02 ± 0.06 ^b	2.48 ± 0.03 ^a	335.08 ± 0.8 ^b
	Soybean	349.29 ± 0.09 ^c	11.16 ± 0.06 ^c	3.89 ± 0.04 ^c	396.57 ± 1.14 ^a
	Peanut	121.77 ± 0.07 ^b	2.49 ± 0.04 ^a	2.89 ± 0.03 ^b	394.16 ± 0.91 ^a
N.extruded	NSP1	70.69 ± 0.09 ^j	5.8 ± 0.04 ^a	2.65 ± 0.03 ^h	358 ± 2.82 ^a
	NSP2	53.67 ± 0.07 ^h	6.9 ± 0.04 ^c	2.57 ± 0.03 ^g	346.89 ± 2.67 ^b
	NSP3	49.42 ± 0.08 ^f	7.19 ± 0.06 ^d	2.54 ± 0.03 ^{fg}	343.93 ± 2.3 ^c
	NSP4	45.16 ± 0.09 ^c	7.46 ± 0.05 ^e	2.52 ± 0.03 ^{ef}	340.98 ± 1.10 ^d
	NSOR	36.65 ± 0.08 ^b	8.02 ± 0.06 ^f	2.48 ± 0.03 ^e	335.08 ± 0.25 ^e
	NSY1	161.70 ± 0.09 ^j	9.27 ± 0.05 ^g	3.04 ± 0.04 ^h	359.66 ± 1.07 ^a
	NSY2	99.30 ± 0.09 ^g	8.64 ± 0.05 ^f	2.76 ± 0.03 ^g	347.37 ± 1.23 ^b
	NSY3	83.54 ± 0.08 ^e	8.49 ± 0.05 ^e	2.69 ± 0.03 ^f	345 ± 1.55 ^c
	NSY4	67.91 ± 0.08 ^d	8.33 ± 0.05 ^d	2.62 ± 0.03 ^e	341.22 ± 1.58 ^d
	NSOR	36.65 ± 0.08 ^b	8.02 ± 0.06 ^c	2.48 ± 0.03 ^d	335.08 ± 1.66 ^c
Extruded	ESP1	69.08 ± 0.08 ⁱ	6.65 ± 0.05 ^b	2.75 ± 0.03 ⁱ	297 ± 1.69 ^h
	ESP2	52.71 ± 0.10 ^g	6.92 ± 0.06 ^c	1.92 ± 0.02 ^c	188.2 ± 1.13 ^g
	ESP3	48.28 ± 0.08 ^e	8.93 ± 0.06 ^g	1.84 ± 0.02 ^b	297.2 ± 1.41 ^h
	ESP4	46.03 ± 0.07 ^d	11.70 ± 0.06 ⁱ	1.61 ± 0.02 ^a	263.4 ± 0.84 ⁱ
	ESOR	36.39 ± 0.09 ^a	9.82 ± 0.06 ^h	2.23 ± 0.03 ^d	274.74 ± 1.27 ^j
	ESY1	160.11 ± 0.11 ⁱ	14.19 ± 0.06 ^j	3.23 ± 0.04 ⁱ	429.3 ± 1.55 ^f
	ESY2	100.93 ± 0.08 ^h	12.52 ± 0.06 ⁱ	2.47 ± 0.03 ^d	247.6 ± 0.98 ^g
	ESY3	84.57 ± 0.07 ^f	7.51 ± 0.04 ^b	2.12 ± 0.03 ^b	284.6 ± 2.26 ^h
	ESY4	67.30 ± 0.07 ^c	6.5 ± 0.04 ^a	1.91 ± 0.02 ^a	209.4 ± 3.11 ⁱ
	ESOR	36.39 ± 0.09 ^a	9.82 ± 0.06 ^h	2.23 ± 0.03 ^c	274.74 ± 2.71 ^j
Cerelac		600	7.5	5.0	400
RV(mg/100g)		500	16	3.2	456

Source for RV (recommended values): *(CODEX CAC/GL 08. 1991): Codex alimentarius: Guidelines on formulated supplementary foods for old infants and young children.

Values are means of two duplicates ± SD. Values in the same column with different superscripts for each type of analysis are significantly different (P<0.05) . Sample code as in Table 1 and Table 2.

Minerals content before and after extrusion was significantly ($p < 0.05$) different for both extrudates that is there is significant ($p < 0.05$) increase in iron content and there was significant ($p < 0.05$) reduction on the content of calcium, zinc and phosphorous. The increase in content of Iron in the blend is due processing and it is most likely to the result of the wear of metallic pieces, mainly screws, of the extruder (Alonso *et al.*, 2001).

4.4. Anti-Nutritional Factors of Non- Extruded and Extruded Blends

4.4.1. Condensed tannin content

The result of the study indicates extrusion process significantly ($P < 0.05$) reduced tannin content by (60.8%-73.68%), (59.9%-61.3%) and (70.6%) for extruded sorghum-peanut, extruded sorghum-soya bean blend and for the control sample respectively. The result observed in this study is comparable to the report of Anuonye and Ndaceko (2012) showing (61.22%) reduction in level of condensed tannin in extrudates formed from blend of pigeon pea and unripe plaintain.

The effect of extrusion on tannin was also studied by El-hady and Habiba (2003) and Alonso *et al.* (1998) and they have reported significant reduction in tannin content after extruding legume seeds and the effects of extrusion and conventional processing methods on protein and on reduction of anti-nutritional factors such as tannin. Tannins might form insoluble complexes with divalent ions in the gastrointestinal tract, thereby lowering their bioavailability, it form insoluble complexes with proteins and digestive enzymes thereby decreasing the digestibility of proteins (Uzoehina, 2007), it also decrease palatability, cause damage to intestinal tract, and enhance carcinogenesis (Makkar and Becker, 1996).

The increase in mineral absorption, observed after extrusion, could be due the effect extrusion temperature which affects the molecular structure of condensed tannins. This chemical modification may alter tannins' solubility or chemical reactivity (Barroga *et al.*, 1985) or brings the destruction of tannin. Changes in the tannin content after thermal treatment might result in the binding of tannin with other organic materials present (Alonso *et al.*, 2001). The decrease in the level of tannin compounds after extrusion is therefore related to thermal decarboxylation and polymerization. Reduced tannin content in the extrudate means increased bioavailability of macromolecules notably,

proteins; increased palatability; reduced pathogenesis of cancer development and reduced damage to intestinal tract (Makker and Becker, 1996; Uzoechina, 2007).

Table 5. Phytic acid and condensed tannin concentration of non extruded and extruded blends .

	Type	Phytate in mg/100g	Tannin in mg/100g
Ratio	Sorghum	126.68±0.04	64.00±0.04
	Soybean	278.73±0.05	36.20±0.03
	Peanut	416.00±0.05	31.70±0.03
Non extruded	NSP1	242.40±0.04 ^j	51.08±0.04 ^f
	NSP2	184.54±0.04 ⁱ	57.54±0.04 ^g
	NSP3	170.07±0.06 ^h	59.15±0.03 ^h
	NSP4	155.61±0.04 ^g	60.77±0.04 ⁱ
	NSOR	126.68±0.05 ^e	64.00±0.04 ^j
	NSY1	187.49±0.03 ^j	52.88±0.04 ^f
	NSY2	157.08±0.05 ⁱ	58.44±0.04 ^g
	NSY3	149.47±0.04 ^h	59.83±0.03 ^h
	NSY4	141.80±0.04 ^g	61.22±0.04 ⁱ
	NSOR	126.68±0.05 ^f	64.00±0.04 ^j
Extruded	ESP1	153.68±0.03 ^f	20.02±0.03 ^c
	ESP2	119.04±0.04 ^d	19.33±0.03 ^d
	ESP3	110.88±0.05 ^c	18.21±0.03 ^b
	ESP4	100.52±0.04 ^b	16.71±0.03 ^a
	ESOR	82.35±0.03 ^a	18.81±0.03 ^c
	ESY1	121.49±0.04 ^e	21.20±0.03 ^b
	ESY2	101.00±0.04 ^d	22.96±0.03 ^c
	ESY3	98.22±0.03 ^c	23.15±0.03 ^d
	ESY4	91.30±0.03 ^b	24.30±0.03 ^c
	ESOR	82.35±0.03 ^a	18.81±0.03 ^a

Values are means of two duplicates ± SD. Values in the same column with different superscripts for each type of analysis are significantly different (P<0.05) . Sample code as in Table 1.

4.4.2. Phytate content

Increasing the level of supplementation of peanut and soyabean from 0% to 40% caused a significant (p<0.05) increase in phytate content of both sorghum-peanut and sorghum-soyabean extrudates. Extrusion cooking significantly (p<0.05) reduced the phytate level by 35% for both blends of Sorghum-Peanut and Sorghum-Soya bean extrudates and the control sample. Anderson *et al.* (1990) and Alonso *et al.* (2001) were reported similar finding on the amount of phytic acid

reduction which was within the range (13–35%) and (34%–38%) after extrusion of a wheat bran–starch–gluten mix and extrusion of kidney beans respectively.

This result is also comparable to the results showing (34.9%) and (38.7%) reduction of phytic acid level on extruded soy flour and in the extruded blend of soya bean, African bread fruit and yellow corn extrudates with a concomitant increase in the inositol tetrakisphosphate and inositol pentakisphosphate contents as reported by Hamza *et al.* (2012) and Nwabueze (2006) respectively.

It would be expected that lowering level of phytate should enhance the bioavailability of minerals because phytate may form insoluble complexes with minerals and eventually affect mineral absorption (Anuonye *et al.* 2009). As reported by Alonso *et al.* (2001) extrusion of peas and kidney beans resulted in phytate hydrolysis, which explains the higher availability of minerals after processing.

This reduction may be due to the hydrolysis and heat destruction of some molecules of inositol hexaphosphate to penta, tetra and triphosphate. That is during extrusion cooking inositol hexaphosphate could have been hydrolyzed to lower molecular weight forms, which is in agreement with the work of Alonso *et al.* (2000), who have reported a significant reduction in phytic acid content in beans submitted to extrusion cooking. The report of Ejigui *et al.* (2005) about effect of extrusion using high performance liquid chromatography (HPLC), revealed that during extrusion, some molecules of inositol hexaphosphate were hydrolysed to penta-, tetra and triphosphates.

4.5. Calculation of molar ratios of phytate:zinc, phytate:iron, phytate:calcium and [Calcium]/[Phytate]: zinc.

This study shows extrusion cooking enhances apparent absorption of most minerals. This increased absorption can be explained by the positive effect of extrusion in the reduction of antinutritional factors (phytates and condensed tannins). The molar ratios of phytate: zinc, iron and calcium and the calcium /phosphorous ratio to predict their bioavailability are shown in Table 6.

Phytate: Zinc Molar Ratio is used to estimate the likely absorption of zinc from a diet. The result of phytate:zinc molar ratio were ranged between (5.51 mol/kg -6.18 mol/kg), (3.72 mol/kg -4.73 mol/kg)and(3.65 mol/kg) for Sorghum-Peanut , sorghum-soya bean and for control sample respectively. Phytate:zinc molar ratios of sorghum-peanut and sorghum-soyabean increased significantly as the increasing level of peanut and soya bean except ESY1 and ESY2 who had the same value to that of the control(100:0).The phytate :zinc molar ratio results of both SP and SY were below 15 mol/KG(the critical value) indicating they are all bioavailble .Diets with a phytate: zinc molar ratio greater than 15 mol/KG have relatively low zinc bio-availability, those with phytate: zinc molar ratios between 5mol/KG and 15mol/KG have medium zinc bio-availability and those with a phytate: zinc molar ratio less than 5 have relatively good zinc bio-availability .The result of phytate:zinc molar ratio shows medium zinc bio-availability for sorghum peanut extrudates, good zinc bio-availability for sorghum soybean extrudates and the control sample (Tizazu *et al .*, 2011).

Table 6. Relationship between phytate and bioavailability of selected minerals (Zinc, Iron and Calcium) (Molar ratio) and Ca/P ratio of extruded blends

Extrudate	Ratio	Phytate : Zn	Phytate : Fe	Phytate : Ca	(Ca) (Phytate) : Zn	Ca/P
SP	ESP1	5.51±0.20 ^c	1.94±0.10 ^c	0.13±0.02 ^c	0.09±0.02 ^{bc}	0.23±0.00 ^a
	ESP2	6.14±0.13 ^d	1.45±0.10 ^d	0.14±0.10 ^c	0.08±0.01 ^{bc}	0.28±0.00 ^a
	ESP3	5.97±0.53 ^d	1.04±0.04 ^b	0.14±0.02 ^c	0.07±0.02 ^b	0.16±0.00 ^b
	ESP4	6.18±0.10 ^d	0.72±0.03 ^a	0.13±0.02 ^c	0.07±0.01 ^b	0.18±0.00 ^{bc}
SY	ESY1	3.72±0.30 ^a	0.72±0.02 ^a	0.04±0.01 ^a	0.15±0.02 ^d	0.38±0.12 ^d
	ESY2	4.05±0.05 ^a	0.68±0.03 ^a	0.06±0.02 ^{ab}	0.13±0.02 ^d	0.43±0.08 ^e
	ESY3	4.59±0.19 ^b	1.10±0.04 ^{bc}	0.07±0.01 ^{ab}	0.10±0.01 ^c	0.29±0.14 ^{af}
	ESY4	4.73±0.23 ^b	1.18±0.09 ^c	0.08±0.02 ^b	0.08±0.01 ^{bc}	0.32±0.05 ^{ag}
Sorghum	ESOR	3.65±0.10 ^a	0.71±0.02 ^a	0.14±0.03 ^c	0.03±0.01 ^a	0.12±0.01 ^{bh}
*Critical value		>15.0	>1.0	>0.24	>0.5	>1

Values are means of two duplicates ± SD. Values in the same column with different superscripts for each type of analysis are significantly different (P<0.05). Sample code as in Table 1 and 2.

*Sources for critical values: Phytate: calcium > 0.24 (Morris & Ellis, 1985), Phytate: iron > 1 (Hallberg *et al.*, 1989), Phytate :zinc >15 (Adeyeye *et al.*,2000; Turnlund *et al.*,1984; Morris & Ellis, 1989), Phytate : calcium/zinc > 0.5(Ellis *et al.*,1987; Akindahunsi & Oboh, 1999).

SP= (Sorghum-Peanut blend of porridge),SY=(Sorghum-Soybean blend porridge) and SOR=(sorghum alone or control).

Phytate: Iron Molar Ratio were ranged between (0.72 mol/kg -1.94mol/kg), (0.72mol/kg-1.18mol/kg) and(0.71mol/kg) for sorghum-peanut ,sorghum-soybean and for control sample respectively. Phytate: iron molar ratios of sorghum-peanut and sorghum-soya bean extrudates increased significantly as the increasing level of peanut and soya bean except ESP4,ESY1 and ESY2 who had the same value to that of the control(100:0).The result indicates bioavailability of iron decreased as the increase of peanut and soya bean ,except those results who had the same phytate :iron molar ratio to that of the control sample. Phytate: iron molar ratios >1 are regarded as indicative of poor iron bioavailability.

Phytate: Calcium Molar Ratio values were ranged between (0.13 mol/kg -0.14mol/kg), (0.04 mol/kg -0.08 mol/kg and (0.14 mol/kg) for sorghum-peanut, sorghum-soya bean and the control samples respectively. Increasing peanut flour level did not show a significant effect ($p>0.05$) on phytate: calcium molar ratio of extrudates. However, in the sorghum-soya bean blends the result of their phytate: calcium molar ratio decreased as the increase of soyabean level. The calcium: phytate molar ratio >0.24 is indicative of unfavorable for calcium absorption therefore all the extrudates of sorghum peanut and sorghum soya blends analyzed in this study exhibited calcium: phytate molar ratios less than 0.24, which indicated that calcium is available for absorption from such diets.

[Ca][phytate]/[Zn] molar ratio ratio values were ranged between(0.07 mol/kg -0.09mol/kg), (0.08 mol/kg -0.15mol/kg) and (0.03 mol/kg) for sorghum-peanut ,sorghum-soyabean and the control samples respectively. The result of [Ca][phytate]/[Zn] molar increased as the increase of peanut and soyabean in the extrudates . High calcium levels in foods can promote the phytate-induced decrease in zinc bio-availability when the [calcium]x[phytate]:[zinc] millimolar ratio is > 0.5 . The [Ca][phytate]/[Zn] molar ratio results of both Sorghum-Peanut and Sorghum-soyabean extrudates were below this critical value (0.5) which indicates the possible contribution of calcium in the complementary foods in exacerbating the low bio-availability of zinc and iron due to phytate is probably minimal (Adetuyi and Adelabu, 2011).

4.6. Calcium/phosphorous ratio

Calcium/phosphorous ratio were ranged between (0.16mg/100g-0.28mg/100g), (0.29mg/100g-0.43mg/100g) and (0.12mg/100g) for sorghum-peanut ,sorghum-soyabean and for control sample respectively. The result of this observation indicated that the formulated food samples would serve

as poor sources of minerals such as calcium and phosphorous, which are considered essential for bone and teeth formation and development in children. The food products containing a Ca/P ratio of >1.0 is rated good, while <0.5 is rated poor (Nieman *et al.*, 1992).

4.7. Determination of product property

4.7.1. Water Absorption Capacity (WAC)

Water absorption capacity indicates the volume of water required to form gruel with suitable consistency for infant feeding (Onweluzo and Nwabugwu, 2009). Water absorption capacity depends on the availability of the hydrophilic groups to bind water molecules and the gel forming ability of the macromolecules.

The results of the water absorption capacity of the extruded blends of Sorghum-Peanut, Sorghum-Soyabean and the control samples are shown in Table 7. The result of water absorption' capacity ranged between (3.01ml/g-3.80ml/g),(1.65ml/g-3.20ml/g) and (1.65ml/g) for extruded Sorghum-Peanut, extruded Sorghum-soyabean and control samples respectively.

The extruded Sorghum-Peanut samples had significantly ($p<0.05$) highest water absorption capacity than the extruded Sorghum- Soyabean and the control sample. Increased supplementation of peanut and soybean to sorghum from 10% to 40% shows significant ($p<0.05$) reduction in water absorption capacity.

Low values of water absorption indicates almost intact starch granules while high values are attributed to protein denaturation, starch gelatinization and swelling of the crude fiber. Damaged /transformed starches has the ability for high water absorption to form paste at room temperature by mechanism of gelatinization (Nwabueze, 2006).

As reported by Mbofung *et al.* (2006), Butt and Batool (2010) the ability of flour to absorb water have a significant correlation with the respective content of hydrophilic constituent of carbohydrate and protein respectively. Protein has both hydrophilic and hydrophobic properties, and so can interact with water in foods. Carbohydrates have also been reported to influence water absorption capacity of foods (Adejuyitan, 2009). According to the result of this study; although peanut and soybean have high content of protein than sorghum, their protein had lower hydration capacity.

This may be due to complex formation of carbohydrates to protein and also to fat during extrusion so that the amount of free carbohydrate left to undergo gelatinization will be lower or to the protein denaturation during extrusion cooking that results in loss of hydration capacity (Fernandez *et al.*, 2004).

The other probability for reduction of water absorption capacity at the higher content of peanut and soya bean is their high fat content; As reported by Lin *et al.* (1997) higher fat content during extrusion reduces considerably the level of starch gelatinization, due to drop off of the barrel temperature caused by the oily effect and due to complex formation fat to starch. Similar results were also recorded by Singh *et al.* (2007) and Filli, *et al.* (2010). The report of Filli *et al.* (2010) indicates the reduction of water absorption capacity by addition of pea in the extrusion of rice and addition of soybean to millet respectively. When the lipid content is high in the flour, the water absorption decreases because lipids block the polar sites of the proteins attenuating the absorption of water.

Harper (1981) reported similar findings on lower water absorption capacity of extruded products from rice flour and 20% fish mince is possibly due to incomplete gelatinization because of higher concentration of protein. Santosa *et al.* (2008) stated that the fat content of raw material influences the chemical properties of the extrudates because fat could form complex with other compounds such as starch. During extrusion process, amylose can inhibit degradation of fat molecule, thus it will affect the expansion of starch granule, resulting in gelatinization difficulty in extrusion process and end product development (Cai and Diosady, 1993).

Therefore water absorption capacity (WAC) can be influenced by chemical components and depends on availability of hydrophilic groups which bind water molecules and on the gel forming capacity of macromolecules. Hence more sorghum, less peanut and Soya bean results for more starch in the blended extrudate and more water absorption due to the occurrence of more damaged or gelatinized starch.

These gelatinized starches are sites for water absorption due to the presence of many exposed hydroxyl groups on the molecules, which were available for water binding (Milan *et al.*, 2000).

The WAC result of all sorghum-peanut extrudates and the sorghum-soybean extrudates except ESY1 were significantly ($P < 0.05$) higher than the water absorption capacity result (2.31 ml/g) of

the commercial weaning food (cerelac). The lower water absorption capacity of the extrudates suggests that they would be useful functional ingredients in complementary food formulation because desirable for making thinner gruels (Ghasemzadeh and Ghavide, 2011). Munasinghe *et al.* (2013) observed high fat, high protein, low carbohydrate content of weaning food corresponds to the reduced WAC. When starch content is high as in commercial weaning food then the water binding capacity also high because starch absorbs more water (Griffith *et al.*, 1998).

4.7.2. Oil Absorption Capacity (OAC)

Results obtained for OAC (Table 7) showed that the oil absorption capacity of the extruded blends of sorghum-peanut, sorghum-soyabean and the control samples were within the range (0.16ml/g-0.39ml/g), (0.27ml/g-0.73ml/g) and (0.37ml/g) for extruded sorghum-peanut, extruded sorghum-soyabean and control samples respectively. Supplementation of peanut and soybean from 10% to 40% to sorghum results significant ($p < 0.05$) reduction in oil absorption capacity. The extruded sorghum-soyabean samples had significantly ($p < 0.05$) highest oil absorption capacity than the extruded sorghum-peanut and the control. Oil absorption capacity is one of the indicators of extrudate quality. The high oil absorption capacity makes the flours suitable in facilitating enhancement in flavor and mouth feel when used in food preparations.

Similarly, Nwabueze (2006) has recorded that the reduction of OAC on addition of soya bean to African bread fruit. The differences in oil absorption capacity between the extruded sorghum-peanut and sorghum-soyabean samples might be due to the presence of more non-polar amino acids in sorghum-soya bean than in sorghum-peanut.

This higher protein content in soybean than peanut may result for the exposition of more hydrophobic amino acid groups during extrusion. On the other hand the presence of high fat in peanut lowered oil absorption capacity.

The reduction of OAC by high fat composition on foods is reported by Doherty *et al.* (1982) says oil and starch mixture influence physical characteristics of starch because oil can form a complex with amylose that inhibits starch granule swelling. The report of Hassan and Abou-Arab (1993) have explained that OAC is mainly attributed to the physical entrapment of oil and is related to number of non-polar side chains on protein that binds hydrocarbon chains on fatty acids.

4.7.3. BULK DENSITY (BD)

Bulk density is an index of extent of puffing. It considers expansion of extrudate in all direction and it measures how much expansion has occurred as a result of extrusion or the total volume of the extrudates. The extrudates having lower expansion showed higher density and vice versa. This inverse relationship between expansion ratio and density of extrudates has been earlier reported by Chulaluck *et al.* (2008). The heat developed during extrusion can increase the temperature of the moisture above the boiling point so that when the extrudate exits from the die, a part of the moisture would quickly flash-off as steam and result in an expanded structure with large alveoli and low bulk density (Wang and Ballington, 2007). From this study it was found that increasing peanut and soybean content results significant ($p < 0.05$) increase in bulk density for both sorghum-peanut and sorghum-soya bean extrudates.

For higher peanut and soybean content which containing more protein and fat decreased expansion ratio and increased bulk density of the product as shown in (Table 7). Results obtained for bulk density showed that the bulk density of the extruded blends of sorghum-peanut, sorghum-soya bean and the control samples were ranged between (0.91g/ml-0.71g/ml), (0.8g/ml-0.62ml/g) and (0.49g/ml) respectively.

According to the BD result of this study the value of BD was significantly ($p < 0.05$) highest on those extruded blends containing high amount of soy and peanut flour. The bulk density of extruded blend of sorghum-peanut was significantly ($p < 0.05$) higher than the extruded sorghum-soybean and the control. This might be due to the higher content of protein and fat on these extrudates that could influence density by forming oil-starch and protein-starch complex. Similar Zhu *et al.* (2010) observed the reduction of bulk density in the presence of high amount of protein and fat.

As reported by Bhattacharya *et al.* (1982) oil and starch mixture influence physical characteristics of starch because oil can form a complex with amylose that inhibit starch granule swelling and gelatinization. Seker (2005) also reported that, protein-starch interactions could decrease the free expansion of amylopectin chains and inhibit the release of water vapor, thus limiting expansion and increasing density. The report of Hernandez-Nava *et al.* (2011) on the result of Bulk density values

during the extrusion of blended banana and lentil extrudates also indicates decrease in BD due to higher starch gelatinization.

The bulk density result obtained for the formulated weaning foods ESY2,ESY3,ESY4 and the control sample were relatively comparable to the results of commercial weaning food(cerelac) 0.56g/ml. The high bulk (low nutrient density) of cereal weaning porridges is a major cause of infant malnutrition in Africa. High bulk limits the caloric and nutrient intake per feed per child because infants are unable to consume enough to satisfy their energy and nutrient requirements (Omueti *et al.*, 2009).Nutritionally, lower bulk density promotes easy digestibility of food products, particularly among children with immature digestive system (Osundahunsi and Aworh, 2002)

Table 7. Bulk density, water absorption, oil absorption capacity, expansion ratio, specific length and viscosity of extruded blends.

Extrudate	Ratio	Bulk density (g/ml)	Expansion ratio (cm/cm)	Specific length (cm/g)	Water absorption capacity(ml /g)	Oil absorption capacity(ml /g)	Viscosity (cP)
SP	ESP1	0.91±0.01 ^g	0.90±0.01 ^a	1.14±0.02 ^a	3.01±0.02 ^d	0.16±0.01 ^a	1150±2.00 ^c
	ESP2	0.80±0.01 ^f	1.12±0.02 ^b	1.46±0.03 ^c	3.30±0.02 ^f	0.17±0.01 ^a	1216±2.00 ^d
	ESP3	0.77±0.02 ^e	1.58±0.02 ^e	1.83±0.03 ^e	3.60±0.02 ^g	0.19±0.01 ^a	1263±2.00 ^e
	ESP4	0.71±0.01 ^d	1.74±0.02 ^g	2.06±0.02 ^f	3.80±0.03 ^h	0.39±0.02 ^c	1300±2.00 ^f
SY	ESY1	0.80±0.02 ^f	1.26±0.02 ^c	1.22±0.02 ^b	1.65±0.04 ^a	0.27±0.02 ^b	66.70±1.39 ^{ai}
	ESY2	0.68±0.01 ^c	1.54±0.03 ^d	1.72±0.02 ^d	2.40±0.03 ^b	0.38±0.01 ^c	500±2.00 ^b
	ESY3	0.64±0.01 ^b	1.68±0.03 ^f	2.31±0.01 ^g	2.90±0.02 ^c	0.63±0.02 ^d	2400±2.00 ^g
	ESY4	0.62±0.02 ^b	1.99±0.03 ^h	2.32±0.02 ^g	3.20±0.03 ^e	0.73±0.03 ^e	3118±2.10 ^h
Sorghum	ESOR	0.49±0.01 ^a	2.32±0.02 ⁱ	2.42±0.03 ^h	1.65±0.03 ^a	0.37±0.02 ^c	3923±2.51 ⁱ
Cerelac		0.56g/ml	Nd	Nd	2.31ml/g	Nd	(2250cP)

Values are means of two duplicates ± SD. Values in the same column with different superscripts for each type of analysis are significantly different (P<0.05). sample code as in Table 1 and 2. Viscosity of extruded blends at a temperature of 45⁰C.

SP= (Sorghum-Peanut blend of), SY=(Sorghum-Soybean blend) and SOR=(sorghum alone or control). Nd=(not determined)

4.7.4. EXPANSION RATIO (Radial expansion ratio)

Expansion phenomena are dependent on the viscous and elastic properties of melted dough or expansion of extruded starch-based materials depends on the degree of starch gelatinization (Baladran-Quintana *et al.*, 1998). When extrusion cooked melt exits the die, they suddenly go from high pressure to atmospheric pressure. This pressure drop causes a flash-off of internal moisture and the water vapour pressure, which is nucleated to form bubbles in the molten extrudate, allows the expansion of the melt. The rapid release of pressure as the food emerges from the die causes instantaneous expansion of steam and gas in the material to form low-density products. Bulk density has been linked with the expansion ratio in describing the degree of puffing in extrudates (Emmanuel *et al.*, 2010).

Results obtained for Expansion ratio (Table 7) shows that the result of the Expansion ratio of extruded blends of sorghum-peanut, sorghum-soybean and the control samples were within the range(0.9-1.74),(1.26-1.99) and (2.32) for extruded sorghum- peanut, extruded sorghum- soya bean and control samples respectively. According to the expansion ratio result of this study the value of expansion ratio was significantly($p < 0.05$) highest on those extruded blends containing high amount of sorghum flour. Abd El-Hady *et al.* (2002) reported highly expanded products are obtained with high starch content, whereas the expansion of extruded starch-based materials depends on the degree of starch gelatinization. The starch and some proteins play an important role on structure formation of the extrusion-cooked products. During extrusion cooking starch granules are disrupted, melted, swelled and gelatinized. Starch conversion leads to the loss of crystalline structure to form an amorphous phase, This helps to retain the gases released during the expansion process at the extruder die, enabling the formation of expanded foam structures (El-Samahy *et al.*, 2007).

Comparing the expansion ratio of sorghum-peanut, sorghum-soybean and the control sample indicates, the expansion ratio of the control sample was significantly ($p < 0.05$) higher than the extruded sorghum- peanut and the extruded sorghum- soya beans blends respectively. This result indicates, protein levels had a marked impact on the expansion of extrudates. Similar results have been observed by other investigators Micheal *et al.* (2003) who found that, as fish muscle replaced starch in the feed, gelatinization and expansion of the extrudates decreased.

It was proposed that the protein enclosed available starch, thereby limiting its expansion. Zhu *et al.* (2010) observed starch–protein interactions limit gelatinization and expansion of extrudates and reported that during extrusion, protein–starch interactions could decrease the free expansion of amylopectin chains and inhibit the release of water vapor, thus limiting expansion and increasing density. It was proposed that the protein enclosed available starch, thereby limiting its expansion.

Similarly Asare *et al.* (2004) have reported that the addition of proteins to a starch system does interfere with expansion in the case of addition of protein to rice and when cowpea was added to maize respectively. This decrease of ER may be due to the reduction of free starch. Density of extrudates increased with bean flour addition. There is solid evidence in the literature that as high-fibre, high-protein materials are added to starch-based extruded products, density is expected to increase (Onwulata *et al.*, 2001; Veronica *et al.*, 2006). In this study bulk density was inversely correlated with expansion ratio based on the same rationale. Gujska and Khan (1991) suggested that the degree of expansion affects the density, fragility and overall texture of extruded products (Alex *et al.*, 2009).

Comparing the expansion ratio results of sorghum-peanut and Sorghum-soyabean indicates the values are significantly ($p < 0.05$) different and also expansion ratio results of sorghum-soyabean were relatively higher than Sorghum-Peanut. The reduction of ER in Sorghum-Peanut blends might be due to higher amount of fat content in Sorghum-Peanut than Sorghum-soyabean. Alonso *et al.* (2001) observed highest expansion and least bulk density value due to lower fat content in different maize cultivars.

That is higher fat content during extrusion reduces considerably the level of starch gelatinization, due to drop off of the barrel temperature caused by the oily effect. Fat also diminish starch alteration during extrusion by avoiding harsh mechanical collapse of the starch granules by rotating screw and preventing water from being absorbed by starch. High fat would reduce friction between the dough and the screw/ barrel, and have a negative impact on the starch gelatinization thereby reducing the product's expansion (Emmanuel *et al.*, 2010). Decrease starch alteration/gelatinization eventually results in decreased expansion (Lin *et al.*, 1997) and Alonso *et al.* (2001). Similarly Singh *et al.* (2007) reported a puffer extrudate by decreasing the lipid content in the feed mix.

4.7.5. Specific Length

Results obtained (Table 7) showed that the specific length of the extruded blends of sorghum-peanut, sorghum-soya bean and the control samples were within the range (1.14cm/gm-2.06cm/gm), (1.22cm/gm-2.32cm/gm) and (2.42cm/gm) for extruded sorghum-peanut, extruded sorghum-soya bean and control samples respectively. Increase in peanut and soybean to sorghum results significant ($p < 0.05$) reduction in specific length. The specific length result of the control sample was significantly ($p < 0.05$) higher than the specific length result of both Sorghum-Peanut and Sorghum-soya bean.

This might be due to higher starch, lower protein and lower fat content of the control sample relative to Sorghum-Peanut and Sorghum-Soya bean. This is because protein and fat decreased or delayed starch gelatinization. As it was stated under results and discussion part of expansion ratio, it was proposed that the protein enclosed available starch, fat diminish starch alteration during extrusion by avoiding harsh mechanical collapse of the starch granules by rotating screw and preventing water from being absorbed by starch.

Abd El-Hady *et al.* (2002) and El-Samahy *et al.* (2007) reported that highly expanded products are obtained with high starch content, whereas the expansion of extruded starch-based materials depends on the degree of starch gelatinization.

High fat content during extrusion can also reduce considerably the level of starch gelatinization, due to drop off of the barrel temperature caused by the oily effect thereby limiting its expansion, resulting in an increased bulk density. Singh *et al.* (2006b) reported that Specific Length was highly affected by moisture content and temperature of feed. Comparing the specific length result of Sorghum-Peanut and Sorghum-Soya bean indicates, the extruded sorghum soybean samples had significantly ($p < 0.05$) highest specific length than the extruded sorghum-peanut. This might be due to higher fat content of peanut than soya bean.

During extrusion higher fat and protein content lowers the gelatinization of starch thereby reduce its both radial and longitudinal expansion ratios. Similar result showing the reduction of the specific length were recorded during extrusion of different variety of soybeans by Fouzia (2009). Hsieh *et al.* (1993) also explained extrudate specific length is related to the expansion volume. The more the

extrudates expanded in either the axial or radial direction, the less dense they become indicating a higher proportion of starch gelatinization (Laike Kebede, 2006).

4.7.6. Viscosity measurement of extruded blends

The viscosity of a paste depends on to a large extent on the degree of gelatinization of the starch granules and the rate of molecular breakdown. Filli *et al.* (2010) have reported that extrusion induced starch dextrinization resulted in reduction of viscosity in gruels and a concomitant increase in caloric and nutrient density.

It has been indicated that the viscosity of the extruded blends of sorghum-peanut, sorghum-soya bean and the control samples were ranged between (1150cP-1300cP), (66.7cP-3118cP) and (3923cP) for extruded blend of Sorghum-Peanut, extruded Sorghum-Soyabean and control samples respectively. The proportion of flour and water used during viscosity analysis was (20%:80%), (25%:75) and (10%:90%) for Sorghum-Peanut, Sorghum-soya bean and the control samples respectively. The spindle number of the viscometer used was "7" for all extrudates.

The reading was undertaken at 45°C (Francis *et al.*, 2013). According to the viscosity result of this study the value of viscosity increased significantly ($p < 0.05$) as the amount of sorghum increased. The result indicates the control sample was highly viscous than extruded blend of sorghum-peanut and extruded sorghum-soybean. Increase in the amount of soybean and peanut flour significantly ($p < 0.05$) decrease the viscosity of extrudates. The higher amount of soya bean and peanut results for the occurrence of higher level of protein and fat.

This reduction in viscosity due to increasing soybean and peanut may be attributed to; the high level of oil from the soybean and peanut flour, denaturation of the protein, as well as the starch-protein interactions that produce structures with lower capacity for interaction with water and consequently low viscosity. Filli *et al.* (2013) observed Peanut fortification reduced the viscosity peak of sorghum flour because high amount of oil decreased the shear effect as a result of lubrication in the metering zone. Similar result were reported by Lampart-Sczapa *et al.* (2006) and Guha *et al.* (1998) indicating the lower results for the viscosity of extruded materials due to their lower water absorption capacity, which was attributed to the modification of the conformation of the proteins that is many of the covalent bonds that stabilize the secondary structure are

destroyed and new bonds can be form between the subunits enabling the formation of starch-lipid and starch protein complex, as well as retrograded amylase .

Even though many published gruel viscosity data are available. Due to lack of standardized viscosity measurement procedure, comparisons and interpretations of the different viscosity results is difficult. However, comparing the result of viscosity, the amount of flour and water used for making porridge indicates that the extruded Sorghum-Peanut blends are with high bulk (low nutrient density) than Sorghum-soya bean blends.

Because in order to make semi solid porridge the amount of water used in Sorghum-Peanut was (80%) which was higher than the amount of water used by Sorghum-soya bean which was (75%) . This excessive dilution with water, to reduce the viscosity and to make appropriate for infant feeding leads for energy and nutrient thinning, that is, the reduction of energy and nutrient densities. Cereal-based complementary foods from non –extruded ingredients form a relatively high viscous porridge. The high bulk (low nutrient density) of cereal weaning porridges is a major cause of infant malnutrition in Africa, since it limits nutrient intake (Da *et al.*, 1982). Therefore the reduced viscosity of protein rich extrudates of Sorghum-Peanut and Sorghum-Soya bean could be useful for infant feeding.

The result indicates except ESY4 (3118cP) and the control sample (3923cP) the results of viscosity of the remaining extrudates was significantly ($p<0.05$) lower than the viscosity value (2250cP) of commercial weaning food (cerelac) and were considered as suitable to satisfy the recommended criteria of infant foods (Philip *et al.*, 2007). Similarly Filli (2013) has reported that, reduced viscosity of protein rich sorghum – cowpea extrudate could be very beneficial for infant feeding.

4.8. Sensory results for acceptance of extruded blends test

4.8.1. Appearance (Color)

Color is an important quality indicator of a food system that could affect consumer acceptance. The mean panelists rating of the sensory attributes of the Sorghum-Peanut, sorghum-soya bean and control are shown in (Table 8). Color rating of sorghum-peanut, sorghum-soya bean and control

was significantly ($P < 0.05$) different and the values ranged from (2.7-6.7), (6.6-8) and (5.9) respectively.

The sorghum-peanut extrudate color ratings result increased with peanut ratio decrease. The reason for lower rating on higher level of peanut may probably be due to unattractive darker color of the samples, as a result of higher percentage of fat.

However, the Sorghum-soya bean color ratings increased with soya bean ratio increase. The reason for higher rating on higher soya bean content may probably be due to attractive yellow colour of the samples, as a result of higher percentage of soya bean. The result of colour rating of the control sample was comparable to the result of higher colour rating result of sorghum-peanut extrudate and the lower colour rating result of sorghum-soya bean extrudates.

4.8.2. TASTE

Taste rating of Sorghum-Peanut, Sorghum-Soya bean and control was significantly ($P < 0.05$) different and the values ranged from (4.5 -5.9), (1.6-5.6) and (5.1) respectively. There was no significant difference ($P < 0.05$) on taste rating between the different Sorghum-Peanut ratio and the control sample. But the taste rating result of Sorghum-soya bean indicates there was significant difference ($P < 0.05$) between the different Sorghum-Soya bean ratios. The Sorghum-Soya bean taste rating decreased with soybean increase. The reason for lower rating on higher Soya bean content may probably be due to unwanted taste of soya bean by many people.

4.8.3. AROMA

The aroma rating result of some of sorghum-peanut, sorghum-soya bean and control was significantly ($P < 0.05$) different and the values ranged from (5.7-7.2), (2.6-5.4) and (6.9) respectively. The sorghum-peanut blends had higher rating compared to the sorghum-soya bean and control ($P < 0.05$). The sorghum-peanut aroma rating results increased with the increase of peanut ratio. The reason for higher rating on higher level of peanut may probably be due to the attractive aroma of the samples, as a result of higher percentage of peanut. However, the sorghum-soya bean aroma ratings increased with the decrease of soya bean ratio. The reason for higher rating on lower soya bean content may probably be due to the presence of unwanted or

unattractive aroma of the samples, as a result of higher percentage of soyabean . The result of aroma rating of the control sample was comparable to the result of higher aroma rating result of sorghum-peanut and the lower colour rating result of sorghum-soya bean.

4.8.4. TEXTURE

The texture rating result of some of Sorghum-Peanut, sorghum-soya bean and control was significantly ($P < 0.05$) different and the values ranged from (5.1-6.7) ,(2.9-7.0) and (5.7) respectively. The texture rating results increased with the decrease of peanut and soya bean ratios respectively The result of texture rating result of the control sample was comparable to the result of higher texture rating result of sorghum-peanut.

4.8.5. Overall Acceptability

The overall acceptability result of some of sorghum-peanut, sorghum-soya bean and control was significantly ($P < 0.05$) different and the values ranged from (4.9-6.4), (2.5-6.2) and (5.8) respectively.). The overall acceptability value of sorghum-peanut was higher ($P < 0.05$) than the sorghum-soya bean and the control. There was no significant ($p > 0.05$) difference within sorghum-peanut blended samples except ESP1. However the overall acceptability result of sorghum-soya bean increased with the decrease of soybean ratio.

The overall acceptability result of ESP2, from sorghum-peanut blends was rated higher than the others. sorghum-peanut and sorghum-soya bean blends containing 40% of peanut and soybean was the less preferred samples on taste, texture and on overall acceptability result while extrudates from 100% sorghum flour had relatively highly acceptance for all sensory parameters scored.

Table 8. Sensory results for acceptance test

Extrudate	Ratio	Color	Taste	Aroma	Texture	Overall acceptability
SP	ESP1	2.7±1.25 ^a	4.5±1.90a	7.2±0.63 ^c	5.1±1.44 ^a	4.9±1.52 ^a
	ESP2	4.3±1.25 ^b	5.9±1.66a	6.2±0.91 ^{abc}	6.1±1.28 ^{ab}	6.4±0.96 ^b
	ESP3	4.4±1.71 ^b	5.6±1.71a	5.7±1.82 ^a	6.3±0.94 ^b	6.0±1.15 ^b
	ESP4	6.7±0.67 ^c	5.0±1.15a	6.0±0.81 ^{ab}	6.7±0.67 ^b	6.1±0.87 ^b
SY	ESY1	8.0±0.81 ^c	1.6±0.69a	2.6±0.96 ^a	2.9±1.52a	2.5±0.85 ^a
	ESY2	7.5±0.84 ^{bc}	3.0±1.05 ^b	3.5±1.51 ^{ab}	5.0±1.88 ^b	4.8±1.81 ^b
	ESY3	7.1±0.74 ^{bc}	4.9±1.44 ^c	4.2±1.87 ^{bc}	6.3±0.67 ^{cd}	5.6±1.17 ^{bc}
	ESY4	6.6±0.96 ^{ab}	5.6±1.42 ^c	5.4±1.50 ^c	7.0±0.66 ^d	6.2±0.92 ^c
SOR	ESOR	5.9±1.37 ^a	5.1±1.45 ^c	6.9±1.28 ^d	5.7±1.05 ^{bc}	5.8±1.03 ^{bc}

Higher values indicate greater preference. Values are means of two duplicates \pm SD. Values in the same column with different superscripts for each type of analysis are significantly different ($P < 0.05$). Sample code as in Table 1 and 2.

SP= (Sorghum-Peanut blend of porridge), SY=(Sorghum-Soybean blend porridge) and SOR=(sorghum alone or control).

4.9. Criteria for Determining Optimal Weaning Food

A ranking system using three nutritional criteria, i.e., protein content, energy value, calcium/phosphorous ratio and sensory attributes, was devised to determine the optimal blend combination according to the modified method of Griffith *et al.* (1998); Ijarotimi and Keshinro (2012). Based on the relative importance and interrelationship of those criteria, ranking was reported on an equal weight basis. The weighting of those criteria as to relative importance produced identical conclusive results. The nine extrudates were ranked from 1 (best) to 9 (worst) to objectively determine the choice weaning blend.

The blend yielding the lowest score was considered to possess the most suitable nutritional characteristics. The ESY2 (80% sorghum,20% soya bean)had the lowest ranking score . Therefore, the ESY2sample was concluded to possess the most desirable nutritional profile among the formulated food samples.

Table 9. Ranking of formulated complementary foods

	Parameters	Protein	Energy	Ca/P	Sensory	Total
SP	ESP1	3	1	6	7	17
	ESP2	5	4	5	1	15
	ESP3	6	6	8	4	24
	ESP4	9	7	7	3	26
SY	ESY1	1	5	2	9	17
	ESY2	2	3	1	8	14
	ESY3	4	2	4	6	16
	ESY4	7	8	3	2	20
SOR	ESOR	8	9	9	5	31

Sample code as in Table 1 and 2. SP= (Sorghum-Peanut blend), SY=(Sorghum-Soybean blend).SOR=(sorghum alone or control).

CHAPTER FIVE

CONCLUSION

This study aimed at formulating low cost precooked (ready to eat), energy dense and good protein quality complementary foods with improved micronutrient bioavailability from low tannin sorghum, peanut and soya bean. During formulation nine products were formed. Peanut flour were added to low tannin sorghum at the level 0%,10%,15%,20% and 40%. Similarly, soya bean were also added to sorghum at the level 0%,10%,15%,20% and 40%.

The blends were extruded using twin screw extruder (Clextral, BC-21 NO. 194, Firminy, France) at 15% moisture content, 120⁰c barrel temperature and with the screw speed of 150 rpm fitted with 9mm die nozzle diameter.

Proportion of peanut and soya bean were found to have significant effect on chemical and physical properties of product. The crude protein ,fat ,ash ,energy, calcium and phosphorous content of extrudates were significantly increased while the carbohydrate , fiber, Iron and zinc decreased with increase in the level of peanut and soya bean flour to sorghum .

Increasing peanut and soya bean had also significant effect on anti-nutritional factors (condensed tannin and phytate) composition, physical and functional properties of extrudates. The phytate composition of both sorghum-peanut and sorghum-soya bean were significantly increased and the tannin content decreased significantly with increase of peanut and soya bean. Except the result of bulk density, all the results functional properties such as; water absorption capacity, oil absorption capacity, viscosity, expansion ratio and specific length decreased significantly with increase in the level of peanut and soya bean.

Comparing the results of non- extruded and extruded blends indicates, extrusion cooking does not significantly affect the content of protein. However the moisture and iron content increased and the fat, fiber, ash, carbohydrate, phosphorous, zinc ,and anti-nutrients composition decreased significantly in both extrudates of sorghum-peanut and sorghum-soya bean after extrusion.

Extrusion cooking reduces the content of tannin and phytate level. The phytate content of both sorghum-peanut and sorghum-soya bean extrudates reduced (35%) after extrusion. Moreover, the

level of tannin reduced by (60.8 - 73.68%),(59.9 - 61.3%) and (70.6%)for extruded sorghum-peanut, sorghum soya bean and control samples respectively. This reduction of phytate enhances the bioavailability of zinc and calcium in all sorghum-peanut and sorghum-soya bean extrudates. Nonetheless the bioavailability result of iron was poor except the following extrudates ;ESP4(90% sorghum,10% peanut),ESY1(60% sorghum, 40% soya bean),ESY2(80% sorghum, 20 %soya bean).

Even though the relative inhibitory effect of the phytates were overcome, the reduction in phytates due to this extrusion processing was not enough to compensate for the rather low iron and zinc content of the complementary foods.

During extrusion cooking the products were expanded. This expansion results for the pre-gelatinized product with lower water absorption capacity. Therefore this cooking process improves the low energy density of infant porridge by reducing the bulkiness and viscosity of extrudates.

The nine point hedonic scale sensory analysis result of sorghum-peanut and sorghum-soyabean indicates except taste rating result of sorghum-peanut and colour rating result of sorghum-soyabean, all the other results of sensory attributes(taste, colour, aroma, texture and overall acceptability)reduced significantly with the increase of(10-40%) peanut and soya bean respectively.

This study revealed that sorghum –peanut and sorghum-soya bean blends could be used to produce nutritious ready to eat food products for infants and young children. The blends were extruded to provide pre-cooked food that could be reconstituted at 45⁰C as a semi–solid porridge, eliminating prolonged cooking and degradation of heat labile nutrients.

From the nine formulated extruded products of sorghum-peanut and sorghum-Soybean the ESY2 (80% sorghum, 20%soyabean) product is recommended as the best weaning foods which can contribute to the alleviation of protein –energy malnutrition.

ESY2 (80% sorghum, 20%soya bean) is nutritionally superior, functionally appropriate and organoleptically acceptable based on overall ranking using protein, energy, calcium/phosphorous ratio and sensory attributes. The recommended ESY2 blends have similar proximate composition and functional properties to that of cerelac .

This ESY2 formulas were produced from low cost cereals (sorghum) and legume (soya bean), hence it will become inexpensive and could make a great contribution in food security for solving problems associated with protein energy malnutrition facing infants and young children in sub-Saharan region and other developing countries including Ethiopia.

CHAPTER SIX

RECOMMENDATIONS

It is recommended that other researchers should conduct the analysis on essential amino acids (lysine and tryptophan).

It is also recommended for researchers to conduct other more functional properties such as emulsion activity and stability; foaming capacity and stability; and water solubility index.

It is better to design small and industrial scale de hulling machine in order to keep the high nutritive value of soybean.

Sweeteners and flavorings need to be incorporated to improve the acceptability of the products more by infants and young children.

It is recommended other preprocessing methods should be used in order to reduce more anti nutritional factors and to increase the bioavailability of minerals.

Since the extruded blends did not meet the recommended micronutrients (minerals) requirements for infants and children, fortification with appropriate micronutrients or micronutrient-dense foodstuffs will be necessary.

Further study on sorghum-soybean blend ESP2(80%Sorghum,20%soyabean) is highly recommended so as to decrease the viscosity of the gruel and overall acceptability by the panelists because it is already recommended as nutritionally superior, functionally appropriate and organoleptically acceptable based on overall ranking using protein, energy , calcium/phosphorous ratio and sensory attributes.

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APPENDICES

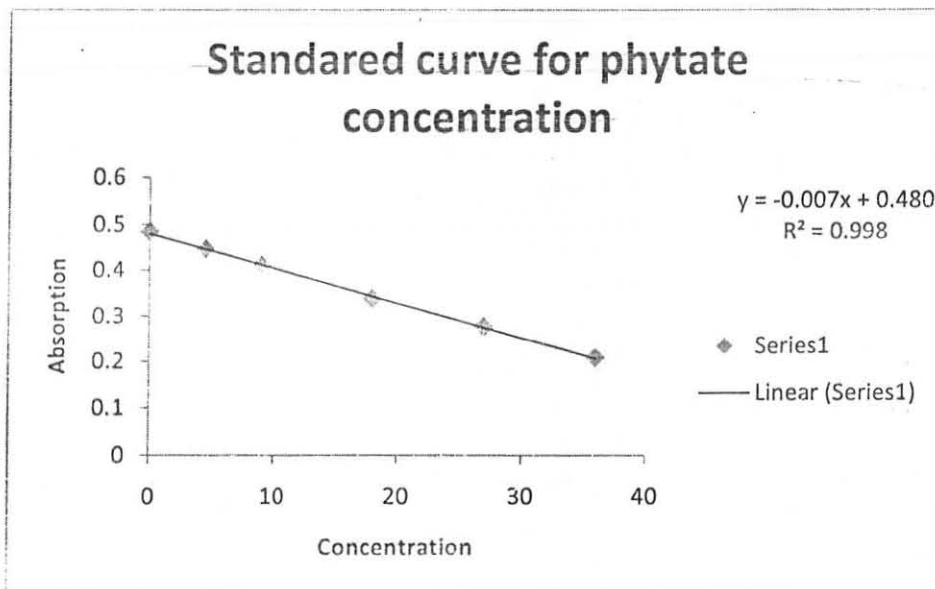
Appendix 1

Sensory evaluation score card using nine point Hedonic scale

Panelist code/name: _____ sample code: _____ date: _____

Sensory perception (score)	Sensory quality attributes					Overall acceptability
	Appearance	Color	Taste	Odor	Texture	Hedonic scale
1=dislike extremely						1=Extremely unacceptable
2=dislike very much						2=very much unacceptable
3=dislike moderately						3=moderately unacceptable
4=dislike slightly						4=Slightly unacceptable
5=neither like nor dislike						5=neither acceptable nor Unacceptable
6=like slightly						6=Slightly acceptable
7=like moderately						7=moderately acceptable
8=like very much						8=highly acceptable
9=like extremely						9=Extremely acceptable

Concentration mg/ml	Absorbance
12	0.0815
24	0.163
36	0.2435
48	0.3145
60	0.388



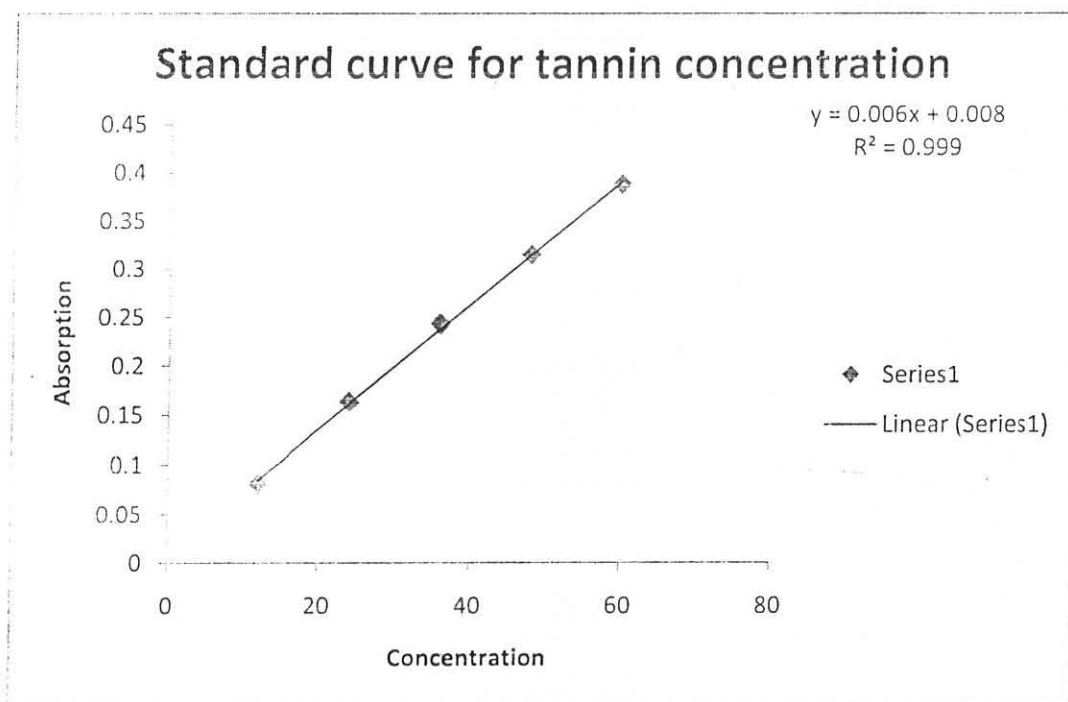
APPENDICES

Appendix : Standard curve

Table A.1 Standard curve for phytate

Concentration mg/ml	Absorbance
0	0.4855
4.5	0.446
9	0.41
18	0.338
27	0.2765
36	0.2085

Table A.2 Standard curve for tannin




I BETELHEM TESHOME, hereby declare that:

- (a) This thesis has been written by me and that it is a record of my original research work and has not been presented for a degree in any other University.
 - (b) All sources of materials used for the thesis have been acknowledged.
-

Name: Betelhem Teshome

GSR/1085/04

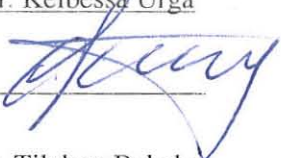
Signature: 

Place: Addis Ababa, Ethiopia

Date of submission: July, 2014

The thesis has been submitted for examination with my approval as university advisor

Name: Mr. Kelbessa Urga

Signature: 

Name: Mr. Tilahun Bekele

Signature: 