EVALUATION OF NUTRITIONAL QUALITY, PHYSICOCHEMICAL PROPERTIES AND SENSORY ATTRIBUTES OF FOUR SOYBEAN VARIETIES GROWN IN WESTERN KENYA

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MAY, 2015

DECLARATION

DECLARATION BY THE CANDIDATE

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DEDICATION

This work is dedicated to my parents, the Right Rev. Hezekiah Ageng'o and Mama Mary Muhonja for their dedication, support and guidance that inspired me to excel in academics from my early school days.

To my wife Irine Cherutich and daughters' Kate Muhonja and Charlotte Blessed for their support as well as enduring my absence when I was pursuing my studies.

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May the Almighty God bless you all.

ABSTRACT

Protein nutrition is important for human health because its deficiency leads to major public health problems such as Protein Energy Malnutrition. Soybean an excellent and cheap source of high quality protein has been introduced into developing countries for improved health and food security, but end use qualities may reduce its utilization. The main objective of this study was to evaluate the nutritional quality, physicochemical properties and sensory characteristics of four soybean varieties grown in Western Kenya. The physical characteristics of colour, grain size, hydration and swelling capacities and the cooking times were determined. The proximate analyses including moisture, crude protein, crude oil and ash were conducted using AOAC International approved methods. Protein nutritional quality was determined using male weanling albino rats for the indices of net protein retention, food efficiency, apparent and true protein digestibilities and faecal weight. The soybeans' amino acid efficiency was evaluated using Protein digestibility corrected amino acid score. Sensory evaluation was conducted using a descriptive panel to characterize the four soybean varieties and a consumer panel for acceptability using a 9 point hedonic scale. The four soybean varieties had physical characteristics that ranged from pale yellow to yellow colours. Variety SB 132 had the highest length and width of 8.35 mm and 6.69 mm respectively, shortest cooking time of 128.33 minutes and best hydration and swelling capacities of 0.26 g/seed and 0.46 ml/seed, respectively. Variety SB 132 was also highest in proximate composition for the raw, roasted and boiled samples in crude protein at 40.18 g/100 g, 40.60 g/100 g and 36.71 g/100 g, fat at 23.00 g/100 g, 23.17 g/100 g and 21.83 g/100 g and energy at 1864.73 kJ, 1949.12 kJ and 1866.36 kJ, respectively. The raw soybean had the ash content between 7.83 g/100 g in SB 25 and SB 132 to 8.17 g/100 g in SB 30. Boiling reduced the ash content in comparison to the raw and roasted samples. Soybean diet SB 132 had the highest protein nutritional quality with the best protein retention of 6.29 g, Apparent Protein digestibility of 89.13%, True Protein Digestibility of 96.48%, weight gain of 5.50 g and a Net Protein Retention Ratio of 4.70. All the four soybean varieties had high amino acid profiles with a Protein digestibility Corrected Amino Acid Score of 1.0. Principal Component Analysis (PCA) revealed that of the 90% variation showed by the 26 attributes, 70% were due to the varieties and 16% due to physical characteristics. Soybean variety SB 132 was associated with positive characteristics of sweet and oily flavour, roasted soybean and sweet aromas and splitting surface by the descriptive sensory panel and the highest consumer liking rating on total quality of 7.42 in appearance, aroma, flavour and texture attributes. Soybean variety SB 132 is the most superior in digestibility, physicochemical properties, sensory characteristics and consumer acceptability and the study recommends its promotion as a food crop in Western Kenya and other developing countries for the management of Protein Energy Malnutrition and for food security.

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LIST OF ABBREVIATIONS

AOAC	-	Association of Official Analytical Chemists’
APD	-	Apparent protein digestibility
ASA	-	American Soybean Association
CIAT	-	Centro Internacional Agricultura Tropicale
CRD	-	Complete Randomized Design
FAO	-	Food and Agriculture Organization
FER	-	Food efficiency ratio
IITA	-	International Institute of Tropical Agriculture
MDG	-	Millennium development Goals
NPRR	-	Net protein retention ratio
NRC	-	National Research Council
PDCAAS	-	Protein Digestibility Corrected Amino Acid Score
PEM	-	Protein Energy Malnutrition
RCBD	-	Randomized Complete Block Design
TGx	-	Tropical Grain Crosses
TPD	-	True protein digestibility
TSBF	-	Tropical Soil Biology and Fertility Institute
UNICEF	-	United Nations Child Educational Fund
VLIR – UOS	-	Vlaamse Interuniversitaire Raad-University Development Cooperation
WHO	-	World health Organization

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CHAPTER ONE

INTRODUCTION

1.1: Background of the study

Protein nutrition is important for human health because its deficiency leads to major public health problems such as Protein Energy Malnutrition (PEM) (Muller and Krawinkel, 2005). According to the United Nations International Children's Emergency Fund (UNICEF), PEM is currently one of the most widespread nutrition related health problems globally and in 2011 alone, 2.3 million Children died because they did not get the nourishment they needed (UNICEF, 2013). Protein which is one of three major macronutrients is an important source of calories and serves as the structural component of muscle and other tissues, hormones, enzymes and haemoglobin (Hoffman and Falvo, 2004). Protein quality in food varies greatly and is dependent on the amino acid composition and digestibility (Cromwell, 2013).

Protein foods are either from plant or animal sources. Animal protein sources such as meat, milk and eggs are high quality because they contain all indispensable amino acids and have high digestibility (Hoffman and Falvo, 2004). However, they are unaffordable for most people in developing countries, who live below the poverty line (Muller and Krawinkel, 2005). Therefore, plants supply about 65% of the of the world's edible proteins, because they are cheaper, though the quality is poorer (Young and Pellet, 1994). Legumes and cereal grains are the most important sources of plant proteins in the context of human protein nutrition (Duranti, 2006). Legumes including many varieties of beans and peas have high protein content compared to other plant proteins. In addition, it has been established that compositing legume proteins with those from cereal and root crops has a complementation effect producing complete and well balanced amino acid profiles that meet human physiological requirements (Duranti, 2006).

Soybean (*Glycine max* (L) Merril), among legumes is unique because it is an important source of high quality but inexpensive protein and oil. It has an average protein content of 40% (IITA, 2009) and is a good source of all indispensable amino acids (Karr-Lilienthal et. al., 2006) and a standard against which other protein sources are compared (Britzman, 2006). Soybean is an excellent source of energy and fatty acids, potassium and vitamins such as choline, folic acid, riboflavin, niacin, pantothenic acid and thiamine (Swick, 2007). Soybean proteins have high lysine content and digestibility (Serrem, de Kock, Oelofse and Taylor, 2011). Studies have shown that soy protein reduces body weight and fat mass (Velasquez and Bhathena, 2007; Mikkelsen, Toubro, and Astrup, 2000), reduces the risk of heart disease, osteoporosis and certain forms of cancer (Erdman, 2000). A Soybean diet is also good for individuals with Type 2 diabetes (Mateos-Aparicio, Cuenca, Villanueva-Suarez and Zapata-Revilla, 2008).

The use of soybean has been promoted in most of the developing countries in Africa and Asia (Chianu et al., 2008) as a cheap source of protein (Messina, 1999) for poor populations. However, varietal differences and environmental conditions elicit differences in end use qualities such as nutrient composition, physical characteristics and flavour of soybeans and products made from them (Lee and Choung, 2011). This in turn may influence consumer acceptability and therefore reduce utilization of such beans as a cheap protein source. In Western Kenya where different varieties of soybean have been introduced, differences such as grain sizes, maturity periods and cooking time were noted among varieties that affected their utilization (Mahasi, Mukalama, Mursoy, Mbehero and Vanlauwe, 2011). It is important to establish the quality characteristics of such beans in order to identify those with positive end use qualities to enhance optimal utilization by such populations. Therefore, the aim of the study was to determine the nutritional quality, physicochemical properties and sensory characteristics of four soybean varieties grown in Western Kenya by VLIR – UOS project.

1.2: Problem statement

Many countries have made great strides to improve their food and nutrition situation, but hunger and malnutrition remain a serious problem especially in third world countries like Kenya (FAO, 2007). Malnutrition is a serious public health problem that has been linked to a substantial increase in the risk of mortality and morbidity (Blossner and de Onis, 2005). Globally, protein energy malnutrition (PEM) continues to be a major health burden in developing countries and the most important risk factor for illnesses and death especially among young children (Muller and Krawinkel, 2005). The World Health Organization estimates that about 60% of all deaths, occurring among children aged less than five years in developing countries, could be attributed to malnutrition (Faruque et al., 2008), hence the increasing demand for proteins with balance in indispensable amino acids and high digestibility. However, due to poverty, many households do not have adequate income to buy and consume protein rich foods from animal sources. In Western Kenya, poverty levels are extremely high. An estimated 31.5% of the households may be classified as hardcore poor in terms of their energy and protein intake requirements, non-food expenditures per capita and value of liquid assets (Place, Hebinck and Omosa, 2003). Plants may therefore provide a potential source of direct protein for human consumption. Soybean among plants is regarded as the richest, cheapest and easiest source of best quality proteins and fat (Rani, Grewal and Khetarpaul, 2008). Different soybean varieties have been introduced and promoted in Western Kenya with the farmers liking varieties such as SB 132 squire and SB 19 due to their expressed desire of having high yielding, early maturing and rust resistant varieties. The Ministry of Agriculture through Kenya Plant Health Inspectorate Services has also supported the growth of Hill, Black Hawk, EAI 3600, Nyala and Gazelle varieties (Mahasi et al., 2011). However, because of limited information available on soybean nutritional quality and physicochemical properties, there has been poor human utilization of these crops in different food formulations at household level (Chianu, 2009) with up to about 80% of soybean being consumed by the livestock industry (MOA, 2006). Therefore, this study was designed to establish an understanding of the nutritional quality, physicochemical properties and sensory characteristics of four selected soybean varieties grown in Western Kenya farming systems by VLIR – UOS project to promote human utilization of those with optimum end use characteristics. This would enhance food and nutritional security among households in this region.

1.3: Objectives

1.3.1: Broad objective

To determine the nutritional quality, physicochemical properties and sensory characteristics of four soybean varieties grown in Western Kenya

1.3.2: Specific objectives

1. To determine the physicochemical properties of four soybean varieties grown in Western Kenya

2. To determine protein digestibility of four soybean varieties grown in Western Kenya using a rat bioassay
3. To evaluate the sensory characteristics of four soybean varieties grown in Western Kenya

1.4: Hypothesis

1. H_0 There are no significant differences in the physicochemical properties among the four soybean varieties grown in Western Kenya
2. H_0 There are no significant differences in protein digestibility among the four soybean varieties grown in Western Kenya
3. H_0 There are no significant differences in sensory characteristics among four soybean varieties grown in Western Kenya

1.5: Significance of the study

The results obtained in this study are an important tool to the health workers and nutritionists in helping individuals meet their dietary requirements for protein as well as a source of vital information to the plant breeders to produce suitable soybean cultivar for human consumption with considerations of protein, fatty acids, sugar contents, suitable grain size, clear hilum and shorter cooking time. The results are also important information to the food industries on the nutrition quality, physicochemical and sensory characteristic of the soybean cultivars to obtain products with better functional, nutritional and sensory qualities for human consumption and to the consumers (Community) as the information obtained from this study has an actual impact on the lives of resource-poor families, thus giving consideration to soybean utilization at household levels.

CHAPTER TWO

LITERATURE REVIEW

2.1: Soybean history

The sufficiency of human diet depends a lot on the availability of adequate nutrient from plants consumed directly or indirectly (Bruulsema, Heffer, Welch, Cakmak and Moran, 2012). There are about 7,000 plant species being used worldwide as food, but only 30 crop species feed the world. These provide about 95% of global plant derived energy and protein intake (Schmidt and Wei, 2006).

Legumes are plants that belong to the family *Leguminosae*, which includes all types of beans, peas, peanuts, alfalfa as well as clover among others and serve as food for a large number of people (Akinjayeju and Francis, 2008). The seeds of many legumes are an important food staples worldwide because they are rich in oil and provide protein, almost two to three times higher than that of cereals (Van Heerden and Schonfeldt, 2004). Beans are often called "poor man's meat" or "the protein tablet" because they are an inexpensive source of high-quality protein (McMahon, 2008).

Soybean (*Glycine max* (L.) Merill) is a leguminous crop that grows in tropical, sub-tropical and temperate climate (IIAT, 2009). Soybean is the fourth highest grain (267 million tons per annum) produced worldwide after maize (*Zea mays* L.), wheat (*Triticum aestevum* L.) and rice (*Oryza sativa* L.) with 857, 655 and 469 million tons each, respectively (USDA, 2013). Approximately half of the world's soybean is produced in developing countries and the other half in the developed ones (Schoote, 2012). It is an important source of high quality but inexpensive protein and oil (IITA, 2009). Soybean is a multipurpose crop grown for industrial oil production and human food, while its' by products can be used as livestock feed and more recently, as a source of bio-energy (Myaka, Kirenga and Malema, 2005). The crop for that reason, has the potential to improve food security, alleviate poverty in rural areas, protect the environment and increase incomes through increased productivity and value addition (Mathu, Nandokha, Riungu, Matere, and Bendera, 2009)

The earliest recorded history of soybean consumption as reported by Shurtleff and Aoyagi (1994) dates back to the 3rd Century in China, but the interest in soybeans reemerged in the late 1970's and has continued to rise after diminished consumption during the 2nd World war. Soybean has been esteemed in the Orient for centuries and was considered one of the sacred crops of ancient Chinese (McMahon, 2008). Soybean cultivation in Africa started in the late 1800s, although little is known of the countries to which it was first introduced. However, the rapid rise of interest in soybeans and soy foods in Africa, paralleling the new interest worldwide started about 1973 (Fennel, 1996).

2.2: Consumer concerns about soybean

Consumer awareness is important in creating an environment for consumers to develop product familiarity and the ability to evaluate different alternatives available for satisfying wants. According to Zellner (1991), consumers prefer those foods with which they are familiar rather than those they are unfamiliar. As such, food neophobia as well as the halo effect of colour and appearance has been reported to influence consumers' food selection and consumption behaviour (Wszelaki et al., 2005). Likewise, soybean used directly for human consumption must have certain special characteristics that are adored by consumers and include light-coloured seed coat, large grain size, best taste and reduction of the unpleasant beany odours (Destro et al., 2013).

A great number of people have accepted and consumed soybean products because of its high nutritive value (Ugwu and Nwoke, 2011). Despite this significant nutritional composition, soybean consumption in the normal diets has been faced with a number of constraints. These include poor cooking knowledge for home consumption, longer cooking time and non-availability of processing equipment to decrease hard labour of manual processing (CIAT, 2006). Beniwal, Yadav and Goel (2013) conducted a study on the perceived constraints of consumers regarding soybean consumption and found that the non-cooperative attitude of family members to consume soybean, lack of readiness to accept additional responsibility of soy processing and prevalence of certain misconceptions regarding soybean were major constraints affecting consumers' choice to utilize soybean in their diets. Similarly, Winham and Hutchins (2011) who assessed the perceptions of flatulence from bean consumption among adults reported that many consumers also avoid eating beans because they fear that excessive intestinal gas or flatulence may result.

2.3: Utilization of soybeans

Since the ancient times in Asia, soybeans have been consumed in hundreds of ways. Examples of soy products include soy sauce a dark brown liquid obtained from a fermented mixture of soybeans and wheat with a salty taste and sharp savory flavour and soy tofu produced from precipitated soybean in the form of a curd, resembling a soft white cheese or a very firm yogurt (Li and Hsieh, 2004). Other products include edamame made from immature soybeans and used as an ingredient in salad and natto which is a traditional Japanese soy food made by fermenting soybean with strains of *Bacillus subtillis* (Shigeki et al., 2008). Soybean sprouts which contain substantial amounts of good protein and much higher amounts of various vitamins have always been popular in the east (He and Chen, 2013).

In recent times, several soybean products have been introduced into the market in a variety of flavours, textures, fat content and nutritional qualities (Jooyandeh, 2011). Textured soy proteins have been made to resemble beef, pork, seafood or poultry in structure and appearance when hydrated and used in many types of fibrous foods (Endres, 2001). Soybean can also be made into numerous fermented and unfermented dishes (Hassan, 2013) including good quality oil to which triglycerides are the major component (Dixit, Antony, Sharma and Tiwari, 2011). The oil then can be used for the production of a number of edible kitchen and salad oils, printing ink and biodiesel (Singh, 2010). In a review, Endres (2001) reports that soy proteins are being utilized in the production of infant cereals, baby foods and are milk protein replacers, binders, emulsifiers, meat flavour enhancers, brine ingredients, and meat analogues. Soybean flour is also useful in gravies, sauces, soups and stews. Consequently, soybean meal has gained popularity due to its high concentration of protein and the excellent profile of highly digestible amino acids such as lysine, tryptophan, threonine, isoleucine, and valine, which are seriously deficient in corn, grain sorghum, and other cereal grains (Cromwell, 1999).

2.4: Effect of climate on quality of soybeans

Documented evidence shows that soybean seed composition varies with environmental factors, especially during the seed filling period when accumulation of the seed chemical components occurs (Carrera et al., 2011). Some researchers have reported findings on the effects of temperature on soybean seed. For instance, in reference to amino acid, Karr‑Lilienthal, Grieshop, Spears and Fahey-Junior (2005) conducted a study on the amino acid, carbohydrate, and fat composition of soybean meals and reported that essential, nonessential, and total amino acid contents of soybean were lower in northern zones of the United States, which are cooler than central and southern zones. A similarly study by Cromwell (2013), reported that soybean varieties from the United States on high-pro and low-pro soy meal were superior in amino acid content and estimated digestibility and that the amount of selenium in soybean meal is highly dependent on the area where the soybeans were produced. Carrera et al (2011) in their study on the amino acid composition of soybean seeds as affected by climatic variables further established that the amino acid composition of soybean grains were strongly affected by environmental factors such as the average daily mean air temperature, cumulative solar radiation, precipitation and daily evapotranspiration rates. In a different study Kumar, Rani, Solanki and Hussain (2006) evaluating the influence of growing environment on the biochemical composition and physical characteristics of soybean seed concluded that the protein concentration in soybean was positively associated with mean temperatures during the developmental period.

On examination of the effect of drought on the nutrient composition of soybean, Anuonye (2011) found that though growing soybeans under limited rainfall conditions reduced their physical sizes and moisture content, it improved foaming and emulsion capacities and fat content and the amino acid profile elucidating nutritional superiority of the drought samples over the rain fed samples. Lee and Choung (2011) also found differences in the protein and oil contents of soybean depending on varieties and genotypes that were grown in different countries. In addition Arslanoglu, Aytac and Oner, (2011) also concluded that environmental conditions had the greatest effect on the oil and protein content in soybean seeds.

Several studies have also reported higher variability of the nutrient levels in soybeans based on multi environmental conditions. For example, In reference to soy meal, negative response of some amino acids to even more favourable environmental conditions, such as higher solar radiation and water availability, have been reported to contribute to a decline in protein concentration levels in the soybean seeds (Carrera et al., 2011). This is a result of accumulation of relatively higher oil content in seeds. Further changes in the global climate related parameters such as temperature, precipitation, soil moisture and sea level are anticipated to continue to alter soybean crop productivity through changes in genetics and nutritional quality (Cure and Acock, 2004). Soybean has the ability to adapt to a wide range of climate and unique chemical composition on an average dry matter basis (Schoote, 2012).

2.5: Nutrient composition of soybeans

Soybean is an important vegetable crop, which provides both protein and oil and is utilized both for human and animal consumption as well as for industrial purposes (Hartman, West and Herman, 2011). Soybeans are the most highly nutritious legume seeds, and rival milk and meat in food value. Thus, it is very important for vegetarians and vegans due to the nutritional value that it offers (Hassan, 2013). Soybeans are composed of protein, oil, soluble carbohydrate, insoluble carbohydrate and moisture (ASA, 2003). A study by Liu (2004) on soybeans as a powerhouse of nutrients and phytochemicals reported that soybeans are rich in minerals especially calcium, potassium, magnesium, iron, zinc and copper. Also, Toda and Ono (2007) assessing the effect of components extracted from okara on the physicochemical properties of soymilk and tofu texture acknowledged that soybean is an excellent source of vitamins such as thiamine, riboflavin and niacin. Raw soybean is one of the richest sources of folates (Rader, Weaver and Angyal, 2000). Soybeans are also sources of several secondary metabolites that include isoflavones, saponins, phytic acid and goitrogens (Tavakolan, Alkharouf, Khan and Natarajan, 2013).

Soybean protein has unique physicochemical properties, making it suitable for various human and animal food uses. It is approximately 92-100% digestible in humans (Riaz, 1999). Protein digestibility is an index of protein quality, an indication that the proteins cannot be utilized unless they are digested. Soybean has an average protein content of 40% (IITA, 2009) and is a good source of all indispensable amino acids (Karr-Lilienthal et. al., 2006) and a standard against which other protein sources are compared (Britzman, 2006). Soybean protein is comprised of two storage globulins, 11S glycinin and 7S β-conglycinin (Liu, 1997). These proteins contain all amino acids essential to human nutrition, which makes soy products almost equivalent to animal sources in protein quality but with less saturated fat and no cholesterol. Soybean proteins have high lysine content (Serrem et al., 2011), a relatively high solubility in water, does not have glutenin and also the highest source of natural dietary fiber (Sipos, 1994). Soybean also contains the biologically active protein components hemagglutinin, trypsin inhibitors, α-amylase and lipoxygenases (Liu, 1997).

Soybean oil contains about 21% of the mono-unsaturated oleate (Hammond, Johnson, Caiping, Tong, and White, 2005). The oil adds to the energy value of the soybean (Britzman, 2006). Crude soybean oil contains about 1.9 ppm of Vitamin K1 or phylloquinone (Piironen, Koivu, Tammisalo and Mattila, 1997). This vitamin plays a role in blood coagulation and bone metabolism. Soybean fat stands out for its high content of polyunsaturated fatty acids (linoleic and linolenic acids), considerable amounts of unsaturated fatty acids (oleic acid) and moderate amounts of the saturated fatty acids (palmitic acid and stearic acid) (Messina, 1997).

Total carbohydrate content of soybean is about 30% made of 10-13% soluble carbohydrates (Schoote, 2012). Soybean has very little starch and a large portion of saccharides, cellulose and non-starch polysaccharides and with the exception of sucrose, much of the carbohydrate is undigested in the monogastric animal and passes into the hindgut where some of it serves as substrate for the gastro intestinal microflora (Swick, 2007). Soybeans are good source of several dietary fibre, micronutrients, phytochemicals and isoflavones (Messina, 1999). The fiber content comes primarily from the hulls that are added back to the meal during processing. The maximum moisture content in soybean should be 12% as higher moisture content tends to dilute the nutritional value of the soybean meal (Britzman, 2006). It should also be understood that those proteins in soybean that acts as anti-nutritional factors such as trypsin inhibitors, chymotrypsin inhibitors and α - amylase inhibitors are destroyed by simple cooking and may only course problems when the soybeans are consumed raw or when they are insufficiently cooked (Burssens et al., 2011).

Table 2.1: Nutrient composition of soybean per 100 g

Nutrient	Unit	Value per 100 g
Proximates		
Water	G	5.16
Energy	kJ	1816
Protein	G	37.80
Total lipid (fat)	G	20.65
Ash	G	4.46
Carbohydrate, by difference	G	31.93
Fiber, total dietary	G	9.6
Minerals		
Calcium, Ca	Mg	206
Iron, Fe	Mg	6.37
Magnesium, Mg	Mg	429
Phosphorus, P	Mg	494
Potassium, K	Mg	2515
Sodium, Na	Mg	13
Zinc, Zn	Mg	3.92
Copper, Cu	Mg	2.92
Manganese, Mn	Mg	2.28
Selenium, Se	Mg	7.5
Vitamins		
Thiamin	Mg	0.58
Riboflavin	Mg	1.16
Niacin	Mg	4.32
Pantothenic acid	Mg	1.59
Vitamin B-6	Mg	0.46
Folate, total	Mg	345
Folate, food	Mg	345
Folate, DFE	Mg	345
Vitamin B-12	Mg	0.00
Vitamin A, RAE	Mg	6
Vitamin A,	IU	120
Lipids		
Fatty acids, total saturated	G	2.99
Fatty acids, total monounsaturated	G	4.56
Fatty acids, total polyunsaturated	G	11.66
Cholesterol	Mg	0

Adapted from USDA National Nutrient Database for Standard Reference Release 26 (USDA, 2013)

Table 2.2: Amino acid composition (g/100 g) of soybean, meat, egg and milk

Nutrient	Soybeans	Meat	Egg	Milk
Indispensable amino acids				
Histidine	0.93	0.46	1.21	0.17
Isoleucine	1.68	0.67	2.45	0.34
Leucine	2.81	1.04	4.18	0.59
Methionine	0.47	1.31	1.50	0.16
Phenylalanine	1.31	0.61	2.55	0.28
Threonine	1.50	0.58	2.14	0.27
Tryptophan	0.50	0.09	0.78	0.08
Valine	1.72	0.69	3.01	0.45
Dispensable amino acids				
Alanine	1.63	0.79	2.72	0.27
Arginine	2.68	0.87	3.09	0.20
Aspartic acid	4.34	1.13	5.05	0.33
Cystine	0.56	0.07	1.08	0.04
Glutamic acid	6.69	2.02	6.43	1.02
Glycine	1.60	0.68	1.63	0.04
Lysine	2.30	1.03	3.36	0.51
Proline	2.02	0.76	1.84	0.58
Serine	2.002	0.495	3.797	0.492
Tyrosine	1.306	0.521	1.994	0.281

Adapted from the USDA National Nutrient Database for Standard Reference Release 26 (USDA, 2013)

2.6: Influence of soybean on human health

There is a strong link between good nutrition and good health prompting advice for healthy diets that may promote health and longevity. This is dependent on daily consumption of at least three servings of fruits or vegetables and variation of foods to include items derived from diverse plants belonging to different botanical families (Thompson et al., 1999). Soybean products have been designated as one of the world's healthiest foods owing to them being excellent sources of high quality protein and non-fish sources of omega-3 fatty acids, essential for various body functions (Sena and Seica, 2011).

Burrington (2000) noted that soy proteins are high in the amino acids contents, which apart from increasing the protein quality also stimulate the liver to remove cholesterol from the blood and are also rich in antioxidants that have a wide range of anti-aging and disease prevention properties. Following a study on soy protein and cardiovascular diseases, Erdman (2000) suggests that consumption of soy protein in place of animal protein may provide cardiovascular benefits, modify the risk factors for heart diseases and prevents diabetes. Similarly, Velasquez and Bhathena (2007) in a review reported that soy protein is an important component of soybeans and provides ample amounts of all the indispensible amino acids plus several other macronutrients responsible for the reduction of body weight and fat mass in addition to reducing plasma lipids. Similarly, Stadler, Bakhit and Holshouser (2009) observed that soy protein intake also leads to increased calcium absorption, since calcium from soybean is utilized better than calcium in food supplements.

Soybean contains approximately 20% crude fat which consists of triglycerides, phospholipids, unsaponified lipids and free fatty acids (Burssens et al., 2011). The principal fatty acid in soybeans is majorly of the unsaturated types, oleic and linoleic acids. Unlike the saturated fat in animals, these fats are suitable for reducing heart diseases, which may be provoked by excessive intake of cholesterol from animal fat (Kolapo, 2011). In an assessment on soybean as a food or remedy Barbalho and Farinazzi-Machado (2011) reported that both the monounsaturated and polyunsaturated fatty acids in soybean have health benefits especially in reducing cell membrane fluidity, modifying prostaglandin metabolism, changing platelet aggregation and other vascular functions.

Soybean also contains isoflavones, which are phenolic compounds that belong to phytochemicals called phytoestrogens in soybeans because they exhibit estrogenic effects. They are phytonutrients working as antioxidants to protect human cells from oxidative damage of normal cells (Stadler et al., 2009). Thus, isoflavones are believed to have potential benefits in reducing the risk of age-related and hormone-related diseases, such as cancer, menopausal symptoms, cardiovascular disease, and osteoporosis (Chun et al., 2007). It is also accepted that a high fibre diet, particularly soluble fibre, is useful in controlling plasma glucose concentration in diabetics. For that reason, soybean fibre is useful because of its insulin-moderated effect that improves blood glucose levels (Chandalia et al., 2000). The dietary fibre also reduces or delays the absorption of carbohydrates and increases faecal excretion of bile acid that causes low absorption of fat (Jenkins et al., 2003).

As mentioned by Cromwell, (2013) soybean like any other oilseeds has some amount of anti nutritional factors such as trypsin inhibitors, phytic acid, oligosaccharides, antigenic and lectins that inhibit the activities of the digestive enzyme leading to poor digestibility. These antinutritional factors bind to trypsinogen and chymotrypsinogen preventing conversion into their active forms, limiting protein digestibility (Dozier and Hess, 2011). Therefore, to eliminate these digestive enzyme inhibitors, soybean should be properly heated (Khan, 2009).

2.7: Soybean and the management of protein energy malnutrition

Protein energy malnutrition (PEM) first recognized in the 20th Century, is by far the most fatal form of malnutrition with infants and young children being most susceptible to its characteristic growth impairment because of their high energy and protein needs (WHO, 2003). According to Muller and Krawinkel (2005) PEM is a range of pathological conditions arising from a deficiency of protein and energy. It is defined by measurements that fall below minus two standard deviations of the normal weight for age (underweight), height for age (stunting) and weight for height (wasting). PEM generally occurs during the crucial transitional phase when infants are being weaned from liquid to semi-solid or fully adult foods. During this period, because of their rapid growth, children need nutritionally balanced, calorie-dense supplementary foods in addition to mother's milk (WHO, 2000). PEM is a serious problem for people whose diets consist mainly of cereal or starchy food (Subhashree and Patel, 2013).

The Sub-Saharan Africa still remains the most troubled geographical area having by far the highest rate of child mortality with under-nutrition being the main underlying factor for up to half of all deaths of children under five (UNICEF, 2008). PEM has been considered a problem in developing countries where growing populations and lack of agricultural development and productivity has resulted in a limited supply of high-quality protein for average persons (Riaz, 1999). Considering the fact that in many developing nations, cereal based foods are widely utilized as food and as dietary staples for adults and weaning foods for infants (Osungbaro, 2009), recent research has been directed towards developing legumes including soybeans for the Sub Saharan Africa region. This has been in the realization that soybean not only provides the needed protein but also improves the nutritional status and enhances socio-economic growth of the people (Anuonye, 2011).

One significant way to curb the global menace of PEM has been through fortification of foods of plant origin. Food fortification is broadly aimed at allowing all people to obtain from their diet energy, macronutrients and micronutrients that they need to enjoy a healthy and productive life (Lutter and Rivera, 2003). In the developing countries, it is worth noting that legumes have been reported as an important source of protein and in some cases oil (Adelakun, Duodu, Buys and Olanipekun, 2013). Among the legumes, soybean stands out with protein of high lysine content and digestibility (Serrem et al., 2011). Thus, fortification of staple cereals with soybean can help improve their nutritive value and aid in alleviating PEM in the developing world (de Pee and Bloem, 2008). Soybean protein both complements the amino acid profile of cereal protein and is a cheap source of protein. The soy bean has considerable potential to improve the nutritional status of large populations of people who depend on cereal-based diets (Riaz, 1999).

As explained earlier a number of foods can be made from soybean (Jooyandeh, 2011). Combining with a variety of foods increases nutritive value and makes them ideal both as a staple and as a weaning food. Soy-milk as well as a combination of soya-beans with maize pap "soyogi," have been found to be valuable in the management of malnutrition (Abiodun, 1991). Fortified blended foods, such as corn/soy blend and wheat/soy blend are some of the appropriate food commodities used among poor populations in the management and alleviation of PEM (de Pee and Bloem, 2008). As a matter of concern, all the initiatives aimed at improving nutrition should consider ways of improving both maternal and child nutrition as a prerequisite for achieving millennium development goals (MDG 4) which focus on reducing child malnutrition and MDG 5 for reducing child mortality (UNICEF, 2012).

2.8: Physical characteristics of soybeans

2.8.1: Soybean seed structure

Soybean seed coat can be described as thin or thick depending on the cell arrangements and composition. Those varieties that have thick seed coats have been linked to having higher lipid contents (Sathe and Deshpande, 2003). Seed coats help in the regulation of water absorption into the radicle, hypocotyl and cotyledon through its inner barrier that prevents the destruction of the seed tissues at the beginning of water imbibition (Koizumi et al., 2008). Soybean seed coat also contains several polyphenolic compounds, which include phenolic acids, tannins, and flavonoids (Paiva, 2000) as well as calcium and iron (Sathe and Deshpande, 2003). As such, the seed coat plays an important role in providing defense to the seed cotyledons to the effects of the external environment (Reyes-Moreno and Paredes-Lopes, 1993).

The bean seed has two cotyledons with parenchyma cells (Sathe and Deshpande, 2003) that perform the duty of storing nutrients for the seed (Kabeya and Sakai, 2003). The two cotyledons are both bound together by a cell wall and middle lamella that has substantial amounts of non-starchy polysaccharides and pectin that supposedly has a role in the cooking quality of beans (Reyes-Moreno and Paredes-Lopes, 1993). The seed cotyledon cell walls contain proteins, carbohydrates, cellulose, hemicellulose, pectin and lignin with the hilum and the micropyle found on the external parts of the seed, having an influence on water imbibitions in the seed (Sathe and Deshpande, 2003).

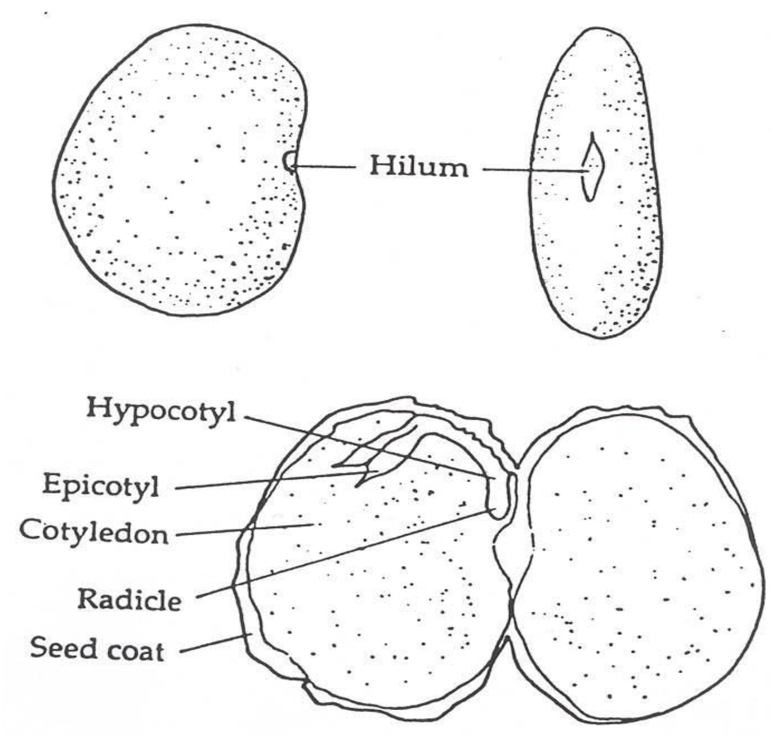

Figure 2.1: Whole grain and cross-section of a soybean grain (Adapted from Hardman and Gunslous (1994).

2.8.2: Soybean grain sizes

The average raw soybean grain size can be evaluated based on the weight of 100 grains randomly sampled for length, width and thickness (Kibar and Ozturk, 2008). Grain sizes are an important quality characteristic for food type soybean depending on the type of utilization. Thus, small grain sizes (weight of 100 grains of 7–10 g) are more suitable for natto and soybean sprouts, whereas large grain sizes (weight of 100 grains of 20 - 30 g) are recommended for tofu (da Silva, Carrao-Panizzi and Prudencio, 2009). Vello (1992), classified soybean into two types: grain type and food type. The grain-type, which has average-size seeds and seedless mass of 10 to 19 grams, is cultivated mainly to supply oil and bran. The food type, have been further divided into two categories: those of small seeds, with 100-seed mass inferior to 10 grams, consumed in “natto” (fermented soybean) or sprouts and those of large seeds, with 100-seed mass equal or greater than 20 grams, being utilized as mature grains in the form of soybean sweet (dark tegument) or salad (light-colored tegument), as tofu (cheese), misso (paste) or extract (milk). In addition, green pods with large seeds are consumed as edamame.

According to Faye, Fulton, Ibro, Dushwaha and Lowenberg-DeBoer (2004) who assessed ways to develop cowpea market opportunities in West Africa, consumers are willing to pay a higher price for legumes that are larger in size. Studies have also been carried out on seed sizes in relation to the cooking time of legumes. For example, Olapade, Okafor, Ozumba and Olatunji (2002) reported that conduction is anticipated to be the primary mode of heat transfer within cowpea seeds. Therefore, smaller seeds receive heat faster in the interior during cooking. On the contrary, Demooy B. and Demooy C. (1990) concluded that smaller cowpea seeds required the longest cooking time. As such, there are conflicting views on the dependence of cooking time on seed size.

2.8.3: Hydration and swelling capacity

Hydration process involves soaking of soybean seeds in water until maximum mass is reached while swelling is the process that leads to maximum increase in volume and weight that starch undergoes when allowed to freely swell in water (Ruales, Valencia and Nair, 1993). Seeds of grain legumes used for human food require hydration to prepare for cooking and eating since the imbibition of water by bean seeds leads to the softening of the seed coat, cotyledon and starch gelatinization (Golonka, Dryzek and Kluza, 2002). Thus, the hydration capacity is dependent on the ease of water absorption through the seed coat to the cotyledon (Del Valle, Stanley and Bourne, 1992). If the bean cell wall is rigid, swelling and dispersion of starch during cooking is inhibited, rendering the cooked product hard in texture (Wang, Daun and Malcomson, 2003).

Water absorption capacity is also associated with the type and amount of protein present in the bean (Mwasaru, Muhammad, Bakar and Man, 1999). Hence, at the initial stages of bean cotyledons imbibitions, water is very fast absorbed by the grains and bound to its solid matrix. The amount of bound water is mainly determined by hydration of storage substances that are abundant in cotyledons; hence hydration of the cotyledon structure evokes reduction of the surface and interior tension and loosening structure of the seeds (Golonka et al., 2002). In addition, Bayram, Oner and Kaya (2004) exploring the factors that influence soaking on the dimensions and colour of soybean, concluded that soaking soybeans prior to cooking will help in eliminating toxic substances that are found in the raw seed.

2.8.4: Seed colour

According to Yang et al. (2010) performing genetic analysis of seed coat and flower colours in soybean observed that soybeans exhibit natural variation in seed coat colour based on the differences on their anthocyanin pigments in their respective tissues. These differences in the seed coat colours can be considered to be a reflection of the mutation that affects enzymes at different steps of the anthocyanin biosynthetic pathway. Similarly, in a review on the quality of soybean and its food products, Gandhi (2009) noted that there are two classes of soybeans, those with yellow or green seed coats, and a mixed variety. It can therefore be concluded that a majority of the soybean cultivars that are grown and consumed worldwide at present have yellow, white or colourless seed coats, whereas the majority of known accessions of the wild progenitor have black or, rarely, brown seed coats (Yang et al., 2010).

Soybean seed coat colour is a characteristic of consumers liking. Thus, Negri, Floridi and Montanari (2001), who analyzed consumer demand focused on visible characteristics of raw seeds, found that coloured seeds are more favoured by consumers and that many consumers are attracted to white seeds because they do not tint the colour of cooking water that is often served with beans. Visible characteristics of raw seeds are however, not a reliable measure for cooking quality. Legumes with similar appearance may have significantly different cooking properties. In addition to visible characteristics, legumes with good overall flavour are given higher ratings by sensory panelists (Taylor and Roberts 2004).

2.8.5: Cooking time

Cooking time is described as the time required for beans to reach the cooked texture that is considered acceptable by the consumers (Moscoso, Bourne and Hood, 1984). Cooking time is a main consideration used to evaluate the cooking quality of legumes. Cooking times of beans may vary widely due to the hydration capacity during soaking (Shimelis and Rakshit, 2005) as well as varietal differences in soybean. Beans that require longer cooking time are less preferred by consumers compared to the fast cooking beans, due to their hard texture. In addition to their longer cooking times, the nutritive value of protein is also reduced (Wang et al., 2003). Hence, for those seeds, which are hard to cook, it has been reported that the use of soluble salt solution may help reduce their cooking time (Onwuka and Okala, 2003).

Different methods have been used to measure legume cooking time, but no universal method has been established (Wang et al. 2003). The reported methods involve the Mattson bean cooker and Instrumental texture analysis, which provides objective data but can be costly and time consuming (Yeung, 2007). As suggested by Faye et al. (2004) consumers are willing to pay between 0.7% and 1.2% above the usual price for a one minute reduction in cooking time. Therefore, a method that will efficiently determine the cooking time of legumes is highly beneficial.

The Mattson bean cooker developed by Jackson and Varriano-Marston (Jackson and Varriano-Marston, 1981) measures cooking time by evaluating the time required for each of 25 beans to reach a level of softness. Time is recorded as each weighted plunger punctures a bean while cooking in boiling water. Proctor and Watts (1987) showed that cooking time of navy beans determined by sensory evaluation was reproduced using a Mattson bean cooker at 92% cooked point. Existing cooking methods for legumes do not evaluate sufficient samples in one trial. Methods typically include materials and procedures that allow for evaluation of only a few samples and their characteristics at a time. Cooking more than one sample typically involves boiling in separate cooking containers (Negri et al 2001). This involves the time-consuming task of staggering the start of the cooking time in order for all samples to cook for the same amount of time.

2.9: Protein digestibility

2.9.1: In vivo digestibility

According to Fenerci and Sener (2005) for digestibility studies and studies related to finding the feeding values of foodstuff, the most popular method to be used should be the in vivo method. They further said that, this experimental method may be very slow, expensive and time consuming, because the digestion speed may vary depending on the animal species, food type, quantity and the prevailing temperatures. Hence such studies require the use of smaller animals because they are known to digest their food in a shorter time compared to bigger ones. Fenerci and Sener (2005) further added that food digestibility can be determined in two ways. Direct measurement method by weighing food ingredients going to the digestive system and extracted by faeces and the measurement of the food ratio and indicator material in diets and faeces of the animal.

As described by FAO/WHO (1991), rat growth assays have been widely used to predict protein quality in foods, but the only problem with such assays is the higher requirements of rats for some amino acids compared to humans. Nevertheless, it should be understood that the nutritive value of a protein depends upon its capacity to provide nitrogen and amino acids in adequate amounts to meet the requirements of an organism (FAO/WHO, 1991). Thus, the modern concepts of protein synthesis require that all amino acids should be available at the same time. This is determined by the bioavailability of amino acids from proteins during their digestion in vivo by enzymes of the gastro intestinal tract (Raghunath and Rao, 1984).

Akimov and Bezuglov (2012) recommend that evaluation of protein stability in the digestive tract is important to help evaluate food quality during food processing of digestibility, allergenicity and stability of protein. Thus, the process clearly shows the normal protein digestion across the digestive tract that begins with pepsin cleavage in stomach and proceeding through trypsin and chymotrypsin digestion in intestinal lumen, and finally involving cleavage by intestinal surface and intracellular proteases. Protein quality measurements evaluate the protein relative to human requirements. Since protein value is related primarily to the amino acid content relative to human amino acid needs. Both amino acid composition and digestibility measurements are considered necessary to accurately predict the protein quality of foods for human diets (FAO/WHO, 1991).

Digestibility studies using rats and soybean have been conducted by various scholars. For Instance, loss of a weight by a rat group fed on raw samples of the soybean in a study by Giami (2002) was attributed to the presence of toxic components such as growth inhibitors in the raw seeds. The rat groups that were fed on boiled soybeans in the same study gained more weight than those fed on autoclaved diets. Baskaran, Malleshi, Jayaprakashan and Lokesh (1999) also evaluated eight different diets based on popped cereals and legumes using a rat bioassay and reported that there were no significant differences among the supplementary diets and that all the eight diets were nutritionally and biologically adequate. In another study Serrem et al. (2011) used a rat bioassay to evaluate protein nutritional quality of soy fortified sorghum biscuits and concluded that their high Protein Efficiency Ratio (PER) indicated that they had considerable potential as a supplementary food for young children to alleviate PEM.

2.9.2: Protein Digestibility Corrected Amino Acid Score (PDCAAS)

PDCAAS is a method of evaluating the protein quality based on both the amino acid requirements of humans and their ability to digest it (FAO/WHO, 1991). According to Schaafsma (2000) PDCAAS is based on comparison of the concentration of the first limiting essential amino acid in the test protein with the concentration of that amino acid in a reference (scoring) pattern. Using the PDCAAS method, the protein quality rankings are determined by comparing the amino acid profile of the specific food protein against a standard amino acid profile with the highest possible score being a 1.0. This score means, after digestion of the protein, it provides per unit of protein 100 percent or more of the indispensable amino acids required (Schaafsma, 2000).

Protein quality measurement should evaluate the protein relative to human requirements. Since protein value is related primarily to the amino acid content relative to human amino acid needs, the primary criterion for judging any food protein should be its essential amino acid content relative to human amino acid requirements (FAO/WHO, 1991). Thus, PDCAAS takes into consideration the amino acid profile, digestibility and ability to supply indispensable amino acids in the amounts required for human needs (Kannan, Nielsen and Mason, 2001).

2.10: Sensory evaluation

Product quality, particularly that related to flavour, affects food purchasing and consumption decisions (Farmakalidis, 1999). Real or perceived quality shortfalls shape consumer's desire to eat food and food products and food sensory attributes drive immediate and future consumption (Shepherd, 1997). Adoption of healthy diets can be affected by concerns about poor food quality (Bowman, Lino, Gerrior and Basiotis, 1998), since consumers emphasize sensory experiences such as appearance, texture, aroma and taste with the pleasure derived from consumption as an important motivator in eating (Westenhoefer and Pudel, 1993).

Sensory evaluation is a scientific discipline used to evoke measure, analyze, and interpret reactions to characteristics of foods and materials perceived by the senses of sight, smell, taste, touch and hearing (Lawless and Heymann, 2010). These include food appearance, odour, taste, feel in the mouth and sound (Gramatina, Zagorska, Straumite, and Sarvi, 2012). Food companies regularly use sensory tests, such as descriptive analysis and consumer affective tests, to study ingredient effects, processing variables and storage changes (Stone and Sidel, 1993). Hence, sensory analysis provides marketers with an understanding of product quality and evaluation of product reformulations from a consumer perspective.

The primary goal of sensory evaluation is to conduct valid and reliable tests to produce data which is important and can be used to make sound decisions about a food product (Meilgaard, Civille and Carr, 1999). In this case, a well trained descriptive panel can be used to analyze and detect quality problems at the same time, using a preference test to gain insight into what might be influencing the consumer preferences (Dzung, Dzuan and Tu, 2004). Human subjects have been used as instruments in descriptive tests, where the panelists are screened, selected (approximately 6-15 people), and then trained (Meilgaard et al., 1999). After an extensive training, the panel is used to evaluate the overall flavour quality and the intensity of individual off-flavours (Hammond et al., 2005).

Sensory quality in soybean is an ongoing problem where sensory research often labels soybean as having characteristics of beany, bitter, grassy and astringent flavours (Chang and Stone, 1990). A study by Solina, Baumgartner, Johnson and Whitfield

(2005) showed that soybean had the beany and grassy flavours, which unacceptable and can limit the application of soybean proteins in food fortification.

2.11: Soybean promotion in Western Kenya

Soybean has been promoted by various organizations over the years but still remains a minor crop in the farming systems throughout Kenya (CIAT, 2006). The major reasons attributed to this are labourious methods of thermal processing, which is not only time consuming, but also expensive in terms of cooking fuel used, the strong beany flavour, lack of sufficient knowledge in the preparation of soybean as well as lack of broad-based awareness of the nutritional value of soybean in comparison to other beans (Chianu et al., 2008). As a consequence, soybean has never become part of the traditional diet among Kenyans. Based on this knowledge TSBF-CIAT had broadened the exposure of rural households to soybean in Western Kenya (CIAT, 2006). They developed and tried multipurpose soybean varieties specifically the TGx series that are characterized by high promiscuous nodulation hence referred to as 'dual-purpose' because they not only produce grains like the traditional varieties but also have properties (poverty alleviation, income generation, and soil fertility among others) that are highly desirable in Kenya (Chianu et al., 2008).

According to Coulibaly et al. (2009), like most of the food crops grown in Africa, the production of soybean is mainly rain-fed and generally grown by small-scale farmers on small land areas and in various mixed cropping systems, usually with little or no input. Hence creation of more awareness about soybean is of enormous potential to improve the dietary quality as well as correcting the unfounded myths that have contributed to making soybean a minor crop in the farming systems of Western Kenya

(CIAT, 2006). Soybean has the potential to provide majority of low-income populations with the main nutritious source of high and inexpensive protein (Coulibaly et al., 2009).

Production of soybeans in Kenya and in particular Western Kenya is low compared to the rest of the world (Chianu et al., 2009). This low productivity is a problem because Kenya needs more soybeans to improve human nutrition. Promotion of higher-yielding varieties of soybean with higher nutritional quality will enhance the availability and utilization of nutrients in the usual diets as one approach to improve nutritional status of the populations in Western Kenya whose diets are often bulky, monotonous and are mainly cereal based (Vilakati, 2009). Such diets have poor nutrient contributions to the body due to the presence of phytic acid which inhibit the bioavailability of some nutrients (Davidsson, Galan, Hercberg and Hurrell, 1997), therefore, exacerbating the effects of PEM that has been found to be a major problem facing households due to extreme poverty levels (UNICEF, 1998). It has been demonstrated that soybean is the best alternative and an affordable source of protein for the low-income consumer (Chianu et al., 2008).

Summary of literature and gaps in knowledge

Based on the available information on nutrient composition of soybean including the amino acid profile, human consumption of soybean and soybean products can be promoted because of the positive effect on nutritional enhancement on different fortified food products. Documented evidence shows no doubt that Malnutrition is one of the major health challenges in Africa. It manifests in the form of PEM and Macro and Micro Nutrient Malnutrition. Utilization of soybean is healthier owing to its invaluable nutritive and health benefits. High variability levels on nutrients in soybeans based on multi environmental conditions have also been observed in all individual amino acid compositions (Carrera et al., 2011).

The current study strives to fill the gap between soybean attributes as a food crop and its utilization in solving the challenges of protein energy malnutrition as well as food insecurity to bring about food security in Sub-Saharan Africa where all indicators of hunger are worsening. As such to adopt a food, its properties must appeal to the consumer for nutritional efficacy and maximum utilization. Thus there is a need to complement sensory, physicochemical and nutrient properties to identify the soybean varieties with optimal end use qualities in order to influence their adoption as a food of choice by people in Western Kenya.

CHAPTER THREE

MATERIALS AND METHODS

3.1: Materials

Four soybean grain varieties, SB 19, SB 25, SB 30 and SB 132, were obtained from Centro Internacional Agricultura Tropicale (CIAT), Maseno, Kenya. The grains had been grown in Siaya and Busia Counties of Western Kenya, planted during the short rains of September to December and the long rains of March to June growing seasons of the year 2012 - 2013.

In addition, for the rat study, skimmed milk powder “Miksi” (Promasidor Kenya Ltd, Nairobi, Kenya) was used as the control. Other components included in the diet were mineral and vitamin mixtures “Amilyte” (Ultravetis East Africa Ltd, Nairobi Kenya), wheat bran (locally milled), white sugar (Mumias Sugar Company Ltd, Mumias – Kenya), corn flour “Zesta” (Trufoods (K) Ltd, Nairobi, Kenya) and corn oil “Elianto”, (Bidco Oil Refineries, Thika, Kenya).

3.2: Experimental design

The physicochemical experiments were performed in triplicate and the average values used for the purpose of the study data. The physicochemical experiment had 5 physical and 6 chemical treatments with the following factors: Grain size, hydration capacity, swelling capacity, colour and cooking time for physical analysis and Moisture content, crude protein, crude fat, ash, energy contents and carbohydrate contents for proximate analysis.

The digestibility study was performed based on a Completely Randomized Design (CRD). Rats were randomly assigned into 6 groups of 4 rats each based on their weights. The evaluated diets were made from four different soybean varieties, a maintenance diet and skimmed milk powder as a control diet. The rats formed the replicates while the different diets were the treatments.

The Descriptive sensory evaluation was based on a Randomized Complete Block Design (RCBD) that involved the assessment of boiled samples of the four different soybean varieties as the treatment which were randomized and replicated thrice with evaluators as the blocks.

The consumer acceptability also considered the use of a CRD approach. Randomized number codes were assigned to the boiled soybean samples for blinding purposes with the sample arrangements on the trays randomized for each panelist. The evaluation process was also randomized with the evaluators coming to the evaluation room at random to evaluate the samples for acceptability purposes.

3.3: Processing soy grains

Grains were cleaned to remove extraneous material and sundried for two consecutive days to protect from insects and mould. Each of the four varieties of soybeans was subjected to different processing techniques depending on their intended use in the study. The first group was soaked in distilled water for 24 hours, boiled and solar dried after draining off the water. The second group was roasted in an oven at 120^0C for 30 minutes. The third group was not subjected to any treatment and was left as raw grains. The three groups' soybeans were milled into flour using a commercial hammer mill (Powerline, BM-35, Kirloskar, India) with a 2 mm diameter mesh sieve. The fourth group which was not subjected to any treatment was retained as unprocessed grain. All the milled and the unprocessed soybean samples were stored in airtight plastic containers at room temperature until required for use.

3.4: Physical analyses

3.4.1: Grain size

One hundred soybeans were randomly selected from each of the four soybean varieties and two principle dimensions, length and width measured using a vernier caliper as described by Nithiyanantham, Siddhuraju and Francis (2013). The length was defined as the distance from the tip cap to kernel crown and the width as the widest point taken parallel to the face of the kernel.

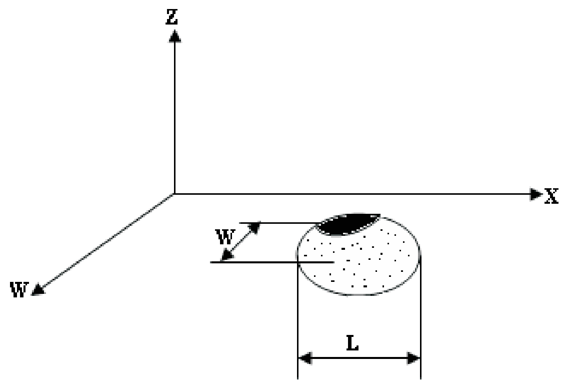

Figure 3.1: Grain length and width measurements

Key:

W - Width/width plain

L - Length

Z - Plain of the height

X - Plain of the length

3.4.2: Hydration capacity

A 20 g sample from each of the soybean varieties was soaked in 60 ml deionised water for 24 hours at 22 ^{0}C using a 100 ml measuring cylinder. After soaking, the water was drained and the soybeans dried with Whiteman No. 1 filter paper as described by Shimelis and Rakshit (2005). The hydrated beans were weighed again to determine the increase in mass and the hydration capacity was calculated as described by Adebowale, Adeyemi and Oshodi (2005).

Hydration Capacity in (g/seed)

(W2 - W1) / N

Where W1 = weight of seeds before soaking;

W2 = weight of soaked seeds;

N = number of seeds

3.4.3: Swelling capacity

A 20 g sample from each of the soybean varieties was soaked in triplicate in 60 ml deionised water for 24 hours at 22 ^{0}C using a 100 ml measuring cylinder. After soaking, the water was drained and the soybeans dried with Whiteman No. 1 filter paper as described by Shimelis and Rakshit (2005). Swelling capacity was measured by calculating the difference in volume of seeds before and after soaking as described by Adebowale et al. (2005).

Swelling capacity in (ml/seed)

(V2 - V1) / N

Where V1 = volume of seeds before soaking;

V2 = volume of soaked seeds;

N = number of seeds

3.4.4: Colour

Soybean seed coat colour was evaluated on dry conditions using a Munsell's colour chart. A total of ten (10) soybeans grains from each variety were evaluated against the colours of the Munsell's colour chart to determine the hue of the different soybean varieties.

3.4.5: Cooking time

Cooking time was determined by the method developed by Jackson and Varriano-Marston (Jackson and Varriano-Marston, 1981) using a Mattson bean cooking device (locally made) with modifications. Soybean seeds were first soaked in water for 12 hours before being cooked to eliminate the toxic substances in raw beans and decrease the cooking time (Bayram et al., 2004). For each treatment, 25 soybean seeds were positioned in the perforated saddles of the bean cooker. The piercing tip of each 90 g rod was placed in contact with the surface of the soybean. The rack was then placed into a cooking saucepan filled with 2 litres of distilled boiling water and cooked. When soybeans were sufficiently tender, the plunger penetrated through the cooked soybean and dropped a short distance of about 4 cm from the top through the hole in the saddle. Cooking time was recorded when the 23^{rd} rod (92% of the rods) drop (Proctor and Watts, 1987).

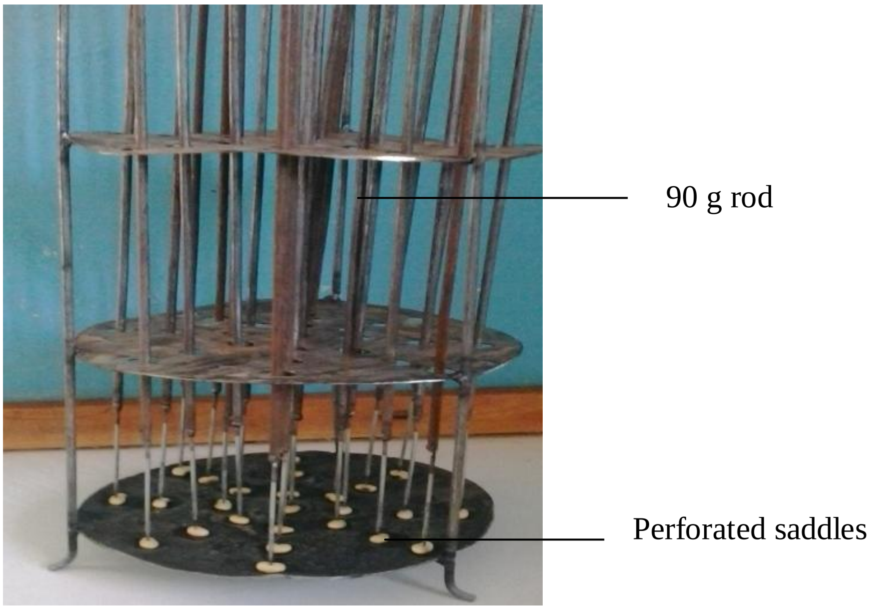

Figure 3.2: Mattson Bean Cooker (Source: Author, 2014)

3.5: Proximate analyses

3.5.1: Moisture Content

Moisture content was determined using an oven (Model UNB 300 Schutzart, by Memmert GmbH & Co. KG, Germany) drying procedure (AOAC International, 1995), Method 925.09. About 2 g of the sample was oven dried at 105 ^{0}C for 3.5 hours. The sample was then cooled and weighed. The moisture content of the sample was expressed as a percentage of the initial weight of the sample using the following formula:

$$\%\ \text{Moisture content} = \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Weight of wet sample}}\ \text{x}\ 100$$

3.5.2: Crude Protein

Crude protein was determined by the microKjeldahl method (AOAC International, 1995) Method 992.23. A sample of 0.3 g of each of the flours was digested in a heating block (Model DK series 20 digester unit, 115 V / 50 - 60 Hz, Manufactured by VELP Scientifica Srl, Milano Italy) at 370-400^{0}C for about 60-90 minutes or until the contents became clear. In 0.2 ml of the digested sample, 5ml of a previously prepared N1 mixture was added and allowed to stand for about 15 minutes before 5ml of N2 was added. The mixture was allowed to stand for one hour during which it developed a blue color whose absorbance was read off a spectrophotometer (Spectronic 21D AKIU®, Milton Roy, Germany) at 650 nm. The absorbance values were used to read off the %N from a graph plotted using standards (Okalebo, Gathua, and Woomer, 2002). The %N in the sample was calculated using the formula:

$$\%\ \text{Nitrogen} = \frac{(\text{a} - \text{b})\text{x v x } 100}{1000 \text{ x w x al x } 1000}$$

Where

a = Concentration of N in the solution

b = Concentration of N in the blank

v = Total volume at the end of analysis procedure

w = Weight of the dried sample and

al = Aliquot of the solution taken.

The crude protein was then attained by multiplying the % nitrogen by a factor (6.25).

3.5.3: Crude Fat

Crude fat content was determined using the Soxhlet extraction method (AOAC International, 1995) Method 920.29. Samples of 2 g were weighed into a thimble and oil was extracted using petroleum ether as solvent for 8 hrs. The extract was oven-dried at 105 ^{0}C for about 30 minutes, cooled in desiccators, and weighed. The oil content was determined using the following formula:

$$\% \text{ Crude fat} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \text{ x } 100$$

3.5.4: Ash content

Ash was determined using (AOAC International, 1995) Method 923.03. Samples of 2 g of the food sample were burned at 350 – 600^{0}C for 6 hours in a muffle furnace (Carbolite 530 2 AU, Bamford, Sheffield, England) to constant weight. The samples were cooled in desiccators and weighed. Ash content was determined using the following formula:

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

3.5.5: Energy content

Energy content was determined by multiplying the mean values of crude protein, crude fat and total carbohydrate by Atwater factors of 16.736kJ, 37.656kJ and 16.736kJ respectively. Results were presented as kilojoules per 100 g sample (FAO, 2003).

3.5.6: Carbohydrate content

Carbohydrate content was determined by subtracting the sum of weights of protein, lipid, ash and moisture from the total wet matter basis (FAO, 2003).

$$(CH_2O)_n = 100 - \{\text{Protein } (\%) + \text{ Lipid } (\%) + \text{ Ash } (\%) + \text{ Moisture } (\%)\}$$

3.6: Protein nutritional quality – Rat bioassay

3.6.1: Animals and housing

Twenty four (24) weanling male albino rats of between 5 to 7 weeks old were obtained from the zoology department of the University of Eldoret, Kenya. The initial weight of the rats was between 94 g and 145 g. They were housed in individual cages with wire bottomed screens to separate the faecal materials. An alternating 12-hour light/dark cycle with mean temperature of between 22^{0}C and 25^{0}C and humidity conditions of between 40% and 60% was maintained. The rats' maintenance was conducted in accordance with the US National Research Council Guide for the Care and Use of Laboratory Animals (NRC, 2011).

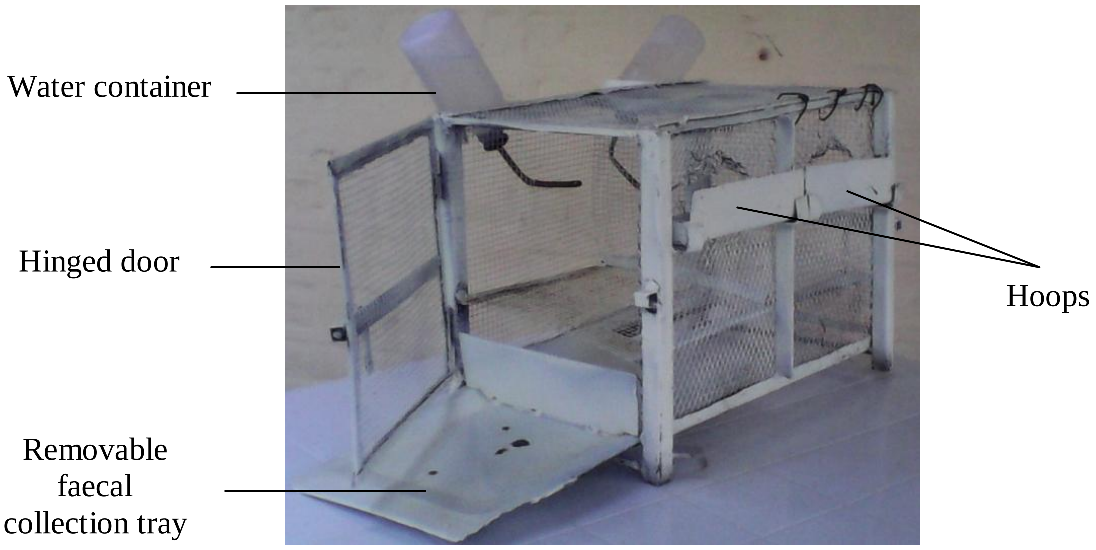

Figure 3.3: Rat cage (Source: Author, 2014)

3.6.2: Diet formulation

Formulation of the diet was done according to AOAC International (2000), method 960.48 with modifications. A total of six diets were prepared and used in the study (Table 3.1). The first four diets were prepared from the flour obtained after boiling, drying and milling of soybean varieties SB 19, SB 25, SB 30 and SB 132. Based on their proximate composition (Table 3.2), the diets were made isonitrogenous by adjusting their protein contents to 10%. The fifth was the control/reference diet

(Skimmed milk powder) that was prepared according to the procedure described by Chapman, Castillo and Campbell (1959). The sixth was the protein free diet that was used to determine the endogenous nitrogen excretion. The diets were also made to supply adequate nutrients by incorporating (1%) vitamin, (1%) cellulose and (5%) minerals. The soybean and powdered milk were incorporated into the basal (protein-free) diet at the expense of the sucrose: corn starch mixture of 50:50 to bring the diet composition to 100%. The fat content in all the diets was adjusted to 9% using corn oil.

To prepare each of the diets, all the dry ingredients were mixed thoroughly for 10 minutes using a Kenwood food mixer (Kenwood chef KMC200, Kenwood Co. Ltd, United Kingdom) operated at medium speed to ensure even distribution. Oil was then added and the diets mixed again for 10 minutes. Each diet was then packed in a separate zip lock plastic bag and stored at 4^0C in a refrigerator. Before feeding, the calculated amount of dry feed for a diet per day for each rat was mixed with 5 g of distilled water to wet the feed to make it easier for the rats to consume

3.6.3: Acclimatization

The rats were acclimatized for an initial period of 4 days from 27th February to 2nd March 2014 and during this times the rats were fed on standardized laboratory irradiated rat pellets (Hindustan Animal Feeds, Gujarat, India) provided on a ratio of 1:1 with the formulated diets for the first 3 days (27th February to 1st of March 2014). This was meant to provide each rat with a 15 g daily meal. On the last day of acclimatization (2nd of March 2014) the rats were put on the formulated diets that went all through to the digestibility period of the study.

Table 3.1: Proximate composition of the four soybean varieties used to calculate the diets

Diet	Protein (%)	Fat (%)	Moisture (%)	Ash (%)	Carbohydrate (%)
SB 19	35.2	17.8	10.2	5.3	31.5
SB 25	35.5	18.7	10.5	5.2	30.2
SB 30	34.6	17.5	11.0	5.2	31.8
SB 132	36.7	21.8	10.2	5.3	26.0

Table 3.2: Formulation of Experimental diets

Ingredients	Diet composition (g)					
	SB 19	SB 25	SB 30	SB 132	Protein free diet	Skimmed milk powder
SB 19	284.4	0	0	0	0	0
SB 25	0	282	0	0	0	0
SB 30	0	0	289.44	0	0	0
SB 132	0	0	0	272.4	0	0
Skimmed milk powder	0	0	0	0	0	333.3
Corn oil	90	90	90	90	90	90
Mineral mix	50	50	50	50	50	50
Vitamin mix	10	10	10	10	10	10
Cellulose	10	10	10	10	10	10
Sucrose	277.8	279	275.28	283.80	420	253.35
Corn flour	277.8	279	275.28	283.80	420	253.35
	1000	1000	1000	1000	1000	1000

Skimmed milk powder (Miksi, by promasidor (Kenya) Ltd, Nairobi), mineral and vitamin mixtures (Amilyte, Manufactured by Ultravetis east Africa Ltd, Nairobi Kenya), wheat bran (locally milled), sucrose (Mumias Sugar Company Ltd, Mumias – Kenya), corn flour (Zesta, Manufactured by Trufoods (K) Ltd, Nairobi Kenya) and corn oil (Elianto, Manufactured by Bidco oil refineries, Thika Kenya).

3.6.4: Digestibility study

Rats were grouped by Complete Randomized Design into six (6) groups based on the rat's weights with the mean weight per group not differing by more than 8 g. This was caused by the wide variation in rat weights as there was a shortage from the supplier. The first four groups were fed on diets made from different varieties of soybean. The fifth group was on a protein-free diet and the sixth group was fed on the control/reference diet (Skimmed milk powder) with each rat being provided 15 g of the diet ad libitum on a daily basis during the study period. Foods that remained on the feeding trays at the end of the day was collected and weighed to determine the amount of food that had been consumed. Clean water was provided during the entire study period. Protein digestibility study lasted for 5 days from 3rd to 7th March 2014, of which faeces from each rat was collected in polyethylene bags on a daily basis and frozen at – 20^{0} C until required. Each rat's daily records for food consumption and weight gain or loss were recorded and used to calculate the net protein retention ratio (NPRR), food efficiency ratio (FER), food intake, protein intake and body weight gain or loss.

3.6.5: Faecal analyses

The total faeces from each rat were collected and dried overnight at 100^{0} C in an air circulation oven, weighed and ground using laboratory mortar and pestle. Faeces from each group of four rats fed the same diet were pooled. Nitrogen in the faeces was determined by microKjeldahl method (AOAC International, 1995) Method 984.13 (Chapter 3 section 3.4.2). The faecal material of the rat group that was fed the protein free diet was used to calculate the endogenous nitrogen losses. Apparent protein digestibility (APD), faecal protein and true protein digestibility (TPD) were computed from the faecal nitrogen and nitrogen intake of the test diet.

The following protein quality indices were calculated from the data collected (WHO 2007).

$$\text{Net Protein Retention Ratio (NPRR)} = \frac{\text{g of weight gain} + \text{g of wgt loss in PFD}}{\text{g of protein consumed}}$$

$$\text{Food Efieciency Ratio (FER)} = \frac{\text{g of weight gain}}{\text{g of food consumed}}$$

$$\text{Apparent Protein (N) Digestibility (\%)} = \frac{\text{I} - \text{F x 100}}{\text{I}}$$

$$\text{True Protein (N) Digestibility (\%)} = \frac{\text{I} - (\text{F} - \text{F}_\text{O})\text{ x 100}}{\text{I}}$$

$$\text{Faecal Protein (\%)} = \frac{\text{F} - \text{F}_\text{O}\text{ x 100}}{\text{I}}$$

Where I = Nitrogen intake of the test diet

F = Faecal nitrogen loss on the test diet

F_0 = Faecal nitrogen loss on a protein-free diet

3.6.6: Protein Digestibility Corrected Amino Acid Score (PDCAAS) determination

The PDCAAS is the official method for predicting protein quality for food based on human amino acid requirements (WHO 2007). The parameters considered are essential amino acid profile of the test protein and ability to supply the amino acid in sufficient quantity. Indispensable amino acid profiles for the soybean were obtained from USDA (2013). In this study, amino acid composition data for the test product and true digestibility values were used to compute the PDCAAS using the following equation (WHO 2007):

$$\text{Amino acid score} = \frac{\text{mg of amino acids in 1 g test protein}}{\text{mg of amino acid in requirement pattern}}$$

Amino acid scores for 9 indispensable amino acids, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, tryptophan and Valine were computed using a human pattern for amino acid requirements for (1 to 2), (3 to 10), (11 to 14), (15 to 18) and 18 and above years (WHO 2007).

3.7: Sensory evaluation

3.7.1: Descriptive Sensory Analysis

Preparation of soy bean samples

The four soybean varieties SB 19, SB 25, SB 30 and SB 132 were soaked in 700 ml distilled water for 12 hours in plastic containers, then later cooked in boiling water with no salt added for 3 hour. Each of the samples was cooked separately in a cooking saucepan of the same size on a two-plate cooking stove.

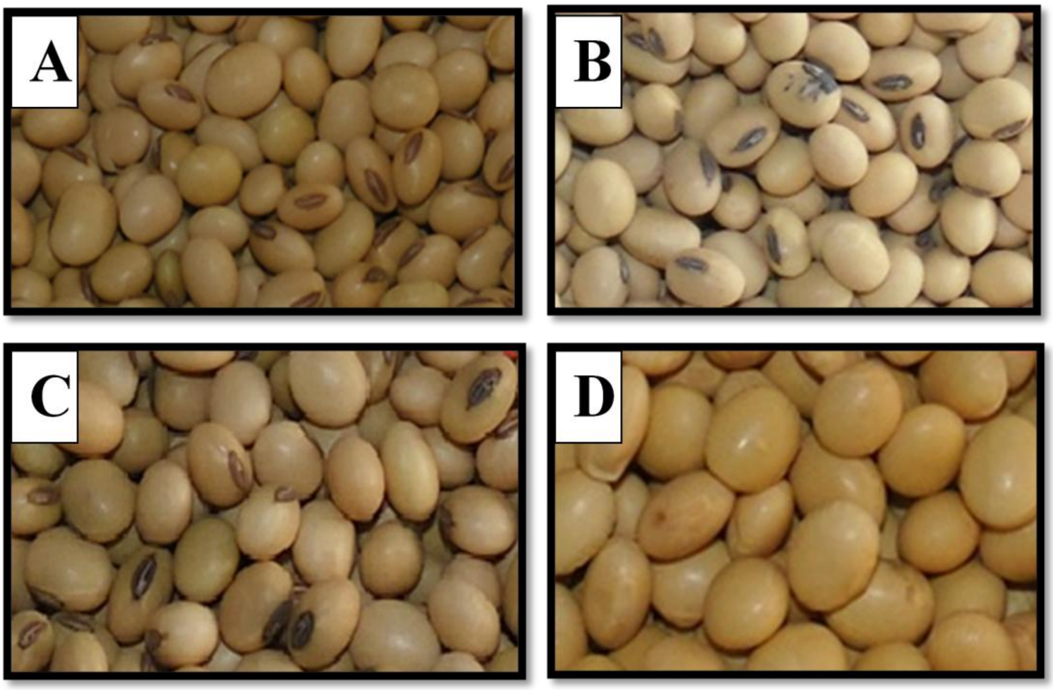

Figure 3.4: A – Soybean variety SB 19, B – Soybean variety SB 25, C – Soybean variety SB 30 and D – Soybean Variety SB 132 (Source: Author, 2014)

Recruitment and screening of panelists

Students of the University of Eldoret who normally consumed beans and did not suffer from food allergies were invited to apply for a descriptive sensory panel through an advertisement, phone calls and email. Forty two (42) individuals who responded attended an orientation session and were subjected to three different screening tests to determine their sensory acquity. The tests included identification of the basic tastes, sweet, sour, bitter, salt and umami as described by Lawless and Heyman (2010), an aroma identification test and a test to identify differences in sensory attributes that described taste, aroma, flavour and appearance of boiled beans. The four varieties of beans evaluated were soybean, red kidney beans, and two local varieties, njahi and nyayo. The final panel selected constituted four males and six females, aged between 20 and 26 years. Before the tasting exercise, the panelists filled in a consent form that informed them about the nature of the samples they would evaluate.

Training of the Panel

The panelists were trained for 8 sessions with each session taking 2 hours per day over a period of 2 weeks. The generic descriptive method described by Einstein (1991) was used to perform the descriptive sensory profiling of the four soybean varieties. During the training, the panelists described the differences that existed among samples and food items were used as references to clarify sensory attributes (Table 3.3). Panelist agreement was evaluated through several tests during the training. The panelists generated and reached consensus for 26 descriptive terminologies that were grouped under appearance, aroma/smell, flavour, texture and after taste, with their definitions and references standards to anchor the scale ends (Table 3.3).

Figure 3.5: Descriptive panel training session (Source: Author, 2014)

Evaluation of soybean samples

The evaluations were carried out by the panelists for 2 days after the training in three sessions each lasting 45 minutes. The panelists evaluated all samples in triplicate during the two days with two sessions being performed on day one and one session on day two. Each panelist received four samples of soybeans on a white tray, with each presented in a glass ramekin covered with cling film, a tooth pick, a serviette, carrot slices and a plastic tumbler filled with distilled water for cleansing the palate between tasting of the samples. They were also provided with Table 3.3, the attributes and their definitions and had access to the reference foods throughout the evaluation. Each sample was labeled with random three digit codes and the order of sample presentation was randomized over the panel. The evaluation session was conducted at the research room in the foods laboratory of the University of Eldoret. Panelists were seated at individual stations where they could not see each other. The 26 descriptors were used to rate the four samples on a 10-point graphic rating scale to measure the intensity of the individual attributes. Results were entered manually in the ballot (Apendix 4).

Figure 3.6: Descriptive panel tray set up (Source: Author, 2014)

Table 3.3: Descriptive sensory attributes and their definitions

DESCRIPTORS	DEFINITION	REFERENCE	RATING SCALE
Appearance			
Surface colour intensity	Colour intensity ranging from light yellow/beige to dark yellow/beige	Munsell's colour chart	Not light = 0 Very light = 10
Glossiness of seed coat	The degree to which there is shine or luster emanating from the seed coat	Cooked soybean not coated with oil = 0 Cooked soybean coated with oil = 10	Not glossy = 0 Very glossy = 10
Dark eye	Intensity of darkness associated with the eye of the bean	Cooked white eyed bean = 0 Cooked black eyed bean = 10	Not dark = 0 Very dark = 10
Wrinkled seed coat	The degree to which wrinkling of the cooked seed coat is perceived by the eye	Raw soybeans = 0 Raw uncooked soybeans soaked for 30 minutes to wrinkling = 10	Not wrinkled = 0 Very wrinkled = 10
Small size	Overall proportion of cooked soybeans	Uncooked green grams= 0 Uncooked broad beans = 10	Not small = 0 Very small = 10
Splitting surface	Visual assessment of the number of soybeans that were transversely or longitudinally cracked after cooking	Cooked un-split soybeans 100% = 0 Cooked and split soybean 100% = 10	Not splitting = 0 Extreme splitting = 10
Seed coat peeling	Visual assessment of the extent to which the seed coat peeled during cooking	Cooked bean with seed coat not peeled = 0 Cooked bean and seed coat peeled 100% = 10	Not peeling = 0 Extreme peeling = 10
Smooth surface	Absence of any particles, lamps or bumps on the soybean	Soaked wrinkled soybeans = 0 Uncooked soybean = 10	Not smooth = 0 Very smooth = 10
Aroma/smell Roasted soybeans	Intensity of aroma associated with roasted soybeans	Unroasted soybean = 0 Soybeans roasted at 180^0C for 30 minutes=10	No roasted soybean aroma = 0 Intense roasted soybean aroma=10
Beany	Intensity of aromatic characteristics of soybeans and other legumes	Njahe = 0 Green beans slightly boiled-10 mins in pre-heated water = 10	No beany aroma = 0 Intense beany aroma =10
Sweet	Intensity of aroma associated with sugars	Distilled water without sucrose = 0 5% Sucrose in distilled water = 10	No sweet aroma = 0 Intense sweet aroma = 10
Flavour			
Oily	Intensity of flavour associated with vegetable or mineral oil	Un-oiled boiled soybeans = 0 Cooked soybean coated with oil = 10	No oily flavour = 0 Intense oily flavour = 10

Cont. Table: 3.3.

DESCRIPTORS	DEFINITION	REFERENCE	RATING SCALE
Bland	Degree of mild sensation of taste	Cooked Njahe = 0 Stiff maize mill porridge (ugali) = 10	No bland flavour = 0 Intense bland flavour = 10
Sweet	Fundamental taste sensation elicited by sugars	Distilled water without sucrose = 0 5% sucrose solution = 10	No sweet flavour = 0 Intense sweet flavour =10
Starchy	Intensity of flavour associated with cooked Irish potatoes	Cooked Fresh peas = 0 Cooked Irish potatoes = 10	No starch flavour = 0 Intense starch flavour = 10
Boiled arrow root	Intensity of flavour associated with cooked arrow roots	Cooked Njahe = 0 Arrow roots boiled for 30 minutes = 10	No boiled arrow root aroma = 0 Intense boiled arrow root = 10
Beany	Intensity of flavour characteristics associated with soybeans and other legumes	Dry Maize soaked overnight and boiled for 45 min = 0 Green beans slightly boiled for 10 minutes in pre-heated water = 10	No beany flavour = 0 Intense beany flavour = 10
Texture			
Graininess	Degree to which a sample contains smaller particles forming in the mouth during mastication	Boiled Fresh beans = 0 Maize flour roasted with very slight oiling for 30 minutes = 10	Not grainy = 0 Very grainy = 10
Smoothness	Degree of absence of perception of any lumps, bumps on the soybean surface	Soaked wrinkled soybeans = 0 Uncooked soybeans = 10	Not smooth = 0 Very smooth = 10
Chewiness	It is the number of chews at 1 chew per second needed to masticate the sample to a consistency suitable for swallowing	Cooked Irish potatoes = 0 Dry Maize soaked overnight and boiled for 45 minutes = 10	Not chewy = 0 Very chewy = 10
Hardness	Force required to compress soybeans between molar teeth	Cooked Irish potatoes = 0 Dried maize boiled slightly for 10 min = 10	Not hard = 0 Very hard = 10
Slippery	Degree to which the soybeans slides over the tongues	Cooked wrinkled soybean = 0 African spinach cooked = 10	Not slippery = 0 Very slippery = 10
After taste			
Graininess	Degree to which a sample contains smaller particles that form in the mouth during mastication	Boiled Fresh beans = 0 Maize flour roasted with very slight oiling for 30minutes =10	Not grainy = 0 Very grainy = 10

Cont. Table: 3.3.

DESCRIPTORS	DEFINITION	REFERENCE	RATING SCALE
Beany	Intensity of flavour characteristics associated with soybeans and other legumes	Dry Maize soaked overnight and boiled for 45 min = 0 Green beans slightly boiled for 10 minutes in pre-heated water = 10	No beany flavour = 0 Intense beany flavour = 10
Boiled arrow root	Intensity of flavour associated with cooked arrow roots	Cooked Njahe = 0 Arrow roots boiled for 30 minutes = 10	No boiled arrow root flavour = 0 Intense boiled arrow root flavour = 10
Seed coat residue	The degree to which the seed coat remains in the mouth after swallowing.	Irish potatoes cooked and mashed = 0 Dry Maize soaked overnight and boiled for 45 min = 0	No seed coat residue = 0 Intense seed coat residue = 10

Soy cooking oil (Amel Trading Company, Kenya)

3.7.2: Consumer evaluation

Sample preparation

The soybean samples used in the consumer panel were prepared in the same way as those for the descriptive panel (Chapter 3 section 3.7.1).

Recruitment and screening

Consumers were recruited through an advertisement put at the University of Eldoret, Kenya to select a sample of 50 consumers among the staff and student population. Those who responded to the advert were asked to fill in a consent form informing them about the samples and to ascertain their personal commitment in participating in the consumer panel to evaluate the four varieties of soybean and only those who indicated their liking for beans and were not allergic to any foods were allowed to participate. At the end, a random sample of twenty two males and twenty eight females, aged between 20 and 37 years was selected.

Evaluation session

Each consumer was provided with four samples of different soybean varieties, a carrot and a glass of distilled water to cleanse their palates before and in between the tasting. The consumers were asked to rate their degree of liking for appearance, aroma, flavour colour and texture on a nine-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike and 9 = like extremely. The minimum value of 1 denoted not intense or not much and the maximum point of 9 denoted very intense or very much (Larmond, 1977). After the evaluation of the soybeans the consumers were asked to fill out a questionnaire about their nutrition knowledge, consumption habits and preference for soybeans. Each session lasted 45 minutes.

3.8: Data analysis

All the laboratory analyses were performed in triplicate and the results presented as mean values. Significant differences between the physicochemical properties and sensory characteristics of different soybean varieties were evaluated with one-way analysis of variance (ANOVA). All means were compared using Fischer's least significant difference test. Principal Component Analysis (PCA) (correlation matrix) of the significant sensory attributes was performed. Box and whisker plots were used to illustrate consumer hedonic score distribution for the soybean cooked samples. The digestibility values for each diet were statistically analyzed using linear model procedures and the significant differences were considered. Significant differences were considered at $P < 0.05$.

3.9: Ethical Considerations

An informed consent of the panelist and consumers was sought before involving them in the study. Maintenance of animals was conducted in accordance with the US National Research Council Guide for the Care and Use of Laboratory Animals (NRC, 2011).

CHAPTER FOUR

RESULTS

4.1: Physical properties of the soybean varieties grown in Western Kenya

The results for the physical characteristics of colour, grain size, cooking time, hydration and swelling capacities determined for the four soybean varieties are shown in Table 4.1.

The colours of the four varieties of soybeans as determined by the Munsell's colour chart were of varying shades of yellow. SB 19 and SB 25 were pale yellow with a chroma of 4, while SB 132 and SB 30 were yellow with a chroma of 6 (Table 4.1).

Grain sizes among the beans were significantly different. Lengths ranged from 6.76 mm in SB 19 to 8.35 mm in SB 132 while the width was 5.89 mm in SB 19 to 6.69 mm in SB 132 (Table 4.1). The percentage difference between the largest and the smallest grain sizes among the soybean varieties was 19% length and 12 % width.

The cooking times also varied among the four soybean varieties as seen in Table 4.1. Soybean variety 132 with cooking time of 128.33 minutes had the shortest cooking time, while SB30 cooked in the longest time of 195.33 minutes, a difference of 34%.

The hydration capacities among the four soybean varieties were significantly different (Table 4.1). The soybean variety with the highest hydration capacity was SB 132 at 0.26 g/seed and the lowest was SB 19 at 0.13 g/seed. The distinction between the two was 50%.

The swelling capacities among the soybean varieties also differed. SB132 with the highest swelling capacity of 0.46 ml/seed had a 54% difference from SB19 the lowest of 0.21 ml/seed (Table 4.1).

Table 4.1: Physical characteristics of four soybean varieties grown in Western Kenya.

Variety	Seed coat colour				Grain sizes		Cooking times (Minutes)	Hydration capacity (g/seed)	Swelling capacity (ml/seed)
	Colour name	Chroma	Hue	Value	L[1](mm)	W[2](mm)			
SB19	Pale yellow	4	2.5Y	8	$6.76^{d}\pm0.36$	$5.89^{d}\pm0.38$	$173.67^{b}\pm0.58$	$0.13^{d}\pm0.00$	$0.21^{d}\pm0.01$
SB25	Pale yellow	4	2.5Y	8	$7.69^{b}\pm0.46$	$6.38^{b}\pm0.52$	$160.67^{c}\pm0.58$	$0.23^{b}\pm0.00$	$0.40^{b}\pm0.01$
SB30	Yellow	6	2.5Y	8	$7.03^{c}\pm0.41$	$6.17^{c}\pm0.41$	$195.33^{a}\pm0.58$	$0.15^{c}\pm0.00$	$0.26^{c}\pm0.01$
SB132	Yellow	6	2.5Y	8	$8.35^{a}\pm0.49$	$6.69^{a}\pm0.48$	$128.33^{d}\pm0.58$	$0.26^{a}\pm0.00$	$0.46^{a}\pm0.01$

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at ($p<0.05$) as assessed by Least Significant Difference.
[1]Length
[2]Width

4.2 Proximate composition

Crude protein content was significantly higher in soybean variety SB 132 both for the raw, roasted and boiled samples at 40.18 g/100 g, 40.60 g/100 g and 36.71 g/100 g respectively and significantly lower in SB 30 for both raw, roasted and boiled samples at 37.41 g/100 g, 37.46 g/100 g and 34.55 g/100 g respectively (Table 4.2). The percentage differences in the raw, roasted and boiled samples were 7%, 8% and 6% respectively.

The fat content among the four soybean varieties ranged between 17.50 g/100 g, 18.33 g/100 g, 18.83 g/100 g in SB 30 and 21.83 g/100 g, 23.00 g/100 g, 23.17 g/100 g in SB 132, with a 20%, 25% and 19% difference in the boiled, raw and roasted samples respectively (Table 4.2).

Moisture content in the soybeans was significantly different between the raw and heat treated samples. The moisture content in raw soybean was significantly high in SB 25 and 132 (9.50 g/100 g) and significantly low in SB 19 (8.83 g/100 g). Roasting significantly lowered the moisture content to between 4.67 g/100 g in SB 30 and 132 to 5.33 g/100 g in SB 19 whereas boiling raised the moisture content to between 10.17 g/100 g in SB 19 and 132 to 11.00 g/100 g in SB 30 (Table 4.2). The percentage differences among the raw, roasted and boiled samples were 7%, 12% and 8% respectively.

The ash (mineral) content of soybeans reduced when the samples were subjected to boiling treatment. The raw soybean had an ash content of between 7.83 g/100 g in SB 25 and SB 132 to 8.17 g/100 g in SB 30, roasted between 7.83 g/100 g in SB 25 and

132 to 8.13 g/100 g in SB 30 and boiled ranged from 5.17 g/100 g in SB 25 and 30 to 5.33 g/100 g in SB 19 and 132 (Table 4.2). A 4%, 4% and 3% difference in the raw, roasted and boiled samples respectively.

Table 4.2: The proximate compositions of four varieties of raw, roasted and boiled soybean grown in western Kenya

Treatment	Variety	Protein	Oil	Moisture	Ash	Carbohydrate[1]	Energy (kJ)[2]
Raw	SB 19	38.82[c]±0.08	19.50[b]±0.50	8.83[a]±0.76	8.01[a]±0.50	24.84[b]±0.65	1799.71[b]±27.62
	SB 25	39.62[b]±0.04	19.67[b]±0.29	9.50[a]±0.50	7.83[a]±0.76	23.38[b]±1.29	1795.06[b]±17.12
	SB 30	37.41[d]±0.06	18.33[c]±0.29	9.00[a]±0.50	8.17[a]±0.29	27.09[a]±0.86	1769.71[b]±3.62
	SB 132	40.18[a]±0.04	23.00[a]±0.50	9.50[a]±0.50	7.83[a]±0.29	19.49[c]±0.61	1864.73[a]±11.52
Roasted	SB 19	38.86[c]±0.04	19.33[cb]±0.29	5.33[a]±0.29	8.01[a]±0.29	28.47[b]±0.61	1854.73[c]±10.32
	SB 25	39.64[b]±0.16	19.47[b]±0.29	4.83[ba]±0.29	7.83[a]±0.76	28.23[b]±0.81	1869.04[b]±15.13
	SB 30	37.46[d]±0.04	18.83[c]±0.29	4.67[b]±0.29	8.13[a]±0.29	30.91[a]±0.54	1853.30[cb]±10.32
	SB 132	40.60[a]±0.30	23.17[a]±0.29	4.67[b]±0.29	7.83[a]±0.29	23.73[c]±0.57	1949.12[a]±6.04
Boiled	SB 19	35.16[c]±0.06	17.83[c]±0.29	10.17[b]±0.29	5.33[a]±0.29	31.51[a]±0.25	1787.20[b]±6.04
	SB 25	35.45[b]±0.13	18.67[b]±0.29	10.50[ba]±0.50	5.17[a]±0.29	30.21[b]±0.89	1801.92[b]±15.13
	SB 30	34.55[d]±0.10	17.50[c]±0.50	11.00[a]±0.50	5.17[a]±0.29	31.78[a]±0.84	1769.08[c]±6.72
	SB 132	36.71[a]±0.10	21.83[a]±0.29	10.17[b]±0.29	5.33[a]±0.29	25.96[c]±0.20	1866.36[a]±6.04

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at ($p<0.05$) as assessed by Least Significant Difference

[1]Carbohydrate was obtained by differences $\{100 - \{\text{Protein}\ (\%) + \text{Lipid}\ (\%) + \text{Ash}\ (\%) + \text{Moisture}\ (\%)\}$

[2]Energy was calculated from the Atwater factor of (carbohydrate, fat and protein in kJ)

Carbohydrate content was significantly higher in soybean variety SB 30 with 27.09 g/100 g, 30.91 g/100 g and 31.78 g/100 g and significantly lower in SB 132 with 19.49 g/100 g, 23.73 g/100 g and 25.96 g/100 g respectively in the raw, roasted and boiled samples. Carbohydrate content of the boiled samples was significantly different and ranged between 25.96 g/100 g to 31.78 g/100 g (Table 4.2) with a difference of 18% in the carbohydrate content.

Energy content was significantly higher in soybean variety SB 132 (1864.73 kJ, 1949.12 kJ and 1866.36 kJ) for the raw, roasted and boiled soybean samples and significantly lower in soybean variety SB 30 (1769.71 kJ, 1853.30 kJ and 1769.08 kJ) for raw, roasted and boiled soybean samples, a 5% difference between the boiled samples of SB 30 and 132. Energy content in soybean varieties SB 19 (raw, 1799.71 kJ, roasted, 1854.73 kJ and boiled, 1787.20 kJ) and SB 25 (1795.06 kJ, 1869.04 kJ and 1801.92 kJ) for raw, roasted and boiled soybean samples respectively were significantly higher than SB 30 but slightly lower than that in soybean variety SB 132 (Table 4.2).

4.3: Protein digestibility

The food intake, protein intake, faecal volume, faecal protein and protein retained were determined and the results are as presented in Table 4.3. The food intake was lowest in the rat group that was fed on the protein free diet (52.00 g) compared to the group that were fed on the control diet (64.50 g), a 19% difference (Table 4.3). The highest food intake was observed in the rat group that was fed on soybean diet SB 25 (65.75 g) which was not significantly different from the group fed on soybean diet SB 132 (65.50 g).

Table 4.3: Food and protein intake and faecal weight, faecal protein and protein retention

Diets	Food intake (g)	Protein intake (g)	Faecal weight (g)	Faecal protein		Protein retention (g)
				(g)	(%)	
SB19	$62.25^{b}\pm3.69$	$6.23^{b}\pm0.37$	$2.36^{d}\pm0.21$	$0.26^{c}\pm0.02$	$4.11^{c}\pm0.04$	$5.97^{b}\pm0.35$
SB25	$65.75^{a}\pm1.50$	$6.58^{a}\pm0.15$	$3.18^{b}\pm0.39$	$0.31^{b}\pm0.01$	$4.63^{b}\pm0.10$	$6.27^{ba}\pm0.14$
SB30	$65.25^{ba}\pm2.06$	$6.53^{ba}\pm0.21$	$3.95^{a}\pm0.20$	$0.36^{a}\pm0.01$	$5.45^{a}\pm0.01$	$6.17^{ba}\pm0.19$
SB132	$65.50^{a}\pm2.08$	$6.55^{a}\pm0.21$	$2.98^{bc}\pm0.02$	$0.26^{c}\pm0.01$	$4.08^{c}\pm0.02$	$6.29^{a}\pm0.20$
SMP	$64.50^{ba}\pm1.73$	$6.45^{ba}\pm0.17$	$2.80^{c}\pm0.11$	$0.23^{d}\pm0.01$	$3.59^{d}\pm0.12$	$6.22^{ba}\pm0.17$
PFD	$52.00^{c}\pm0.82$	$0.00^{c}\pm0.00$	$0.73^{e}\pm0.04$	$0.00^{e}\pm0.00$	$2.71^{e}\pm0.07$	$0.00^{c}\pm0.00$

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at ($p<0.05$) as assessed by Least Significant Difference.
SMP – Skimmed Milk Powder
PFD – Protein Free Diet

The percentage differences observed between the highest and the lowest food intake was 21%. Among the soybean diets, the lowest food intake by the group fed on the SB 19 diet (62.25 g) with a 5% difference in the intake levels compared to the highest food intake. The average daily food intake per rat fed on control diet and those fed on protein free diet was approximately 12.9 g and 10.4 g diet/day, respectively.

Protein intake was least in the rat group that was fed on the protein free diet (0.00 g) and highest among the rat groups fed on the soybean diet SB 25 (6.58 g), a 100% difference in the protein intake levels. The intake also varied between the protein free diet and the control diet (6.45 g). In consideration to the soybean diets, there was a 5% difference in the protein intake levels between soybean diet SB 25 (6.58 g) that provided the highest protein intake levels and soybean diet SB 19 (6.23 g) that provided the lowest protein intake levels (Table 4.3).

The faecal weight was highest for the rat group that was fed on soybean diet SB 30 (3.95 g) which was 29% and 82% higher than the groups fed on the control diet (2.80 g) and protein free diet (0.73 g), respectively. The lowest faecal weight was realized by the rat group fed on the protein free diet, which was 4 times less than the group fed on the control diet. Comparing the soybean varieties, there were significant differences in the faecal weight produced by rats fed on diets containing the different varieties with the highest SB 30 (3.95 g) and the lowest, SB 19 (2.36 g), a 40% difference as indicated in table 4.3.

The faecal protein expressed as a percentage of the nitrogen output from the diet was significantly different among all the diets tested in the present investigation. The faecal protein of the control diet (3.59%) was 25% higher than that lowest produced faecal protein by the rat group fed on protein free diet (2.71%). The highest faecal protein was observed among the rats fed on soybean diet SB 30 (5.45%) that produced a 34% and 50% higher faecal protein than the control and the protein free diet respectively. In relation to the soybean diets, the rat group that was fed on SB 132 diet produced the lowest faecal volume (4.08%), 34% lower than the SB 30 diet that produced the highest faecal protein and 12% higher than the faecal protein produced by the control diet (Table 4.3).

Protein retention was higher in the soybean diet SB 132 (6.29 g) and lower in the protein free diet (0.00 g). Among the soybean diet SB 19 had the lowest retention rate of 5.97 g (Table 4.3). There was a 5% difference in the retention rate between SB 19 and SB 132.

4.4: Evaluation of protein nutritional quality

The indices of protein quality for the four soybean varieties grown in Western Kenya were determined and results are presented in Table 4.4.

The food efficiency ratio (FER) in the present investigation was in the range of -0.105 for the rats group fed on the protein free diet and 0.090 for the group fed on the control diet. The FER for the SB 132 diet was equivalent to 94% compared to the control diet. Comparing the FER amongst the rat group fed on the soybean diet, FER was highest in the SB 132 diet (0.085) and lowest in SB 30 diet, (0.038), a 55% difference (Table 4.4).

Table 4.4 shows that the Apparent Protein Digestibility (APD) levels in the control and soybean diets were all high at 84% and above with only slight differences between the diets. The APD in soybean diet SB 132 (89.13%) was higher than that of the control (88.06%) and protein free diet (0.00%) by 1.2% and 100% respectively.

The true protein digestibility (TPD) value was higher in the control diet (97.17%) compared to the rest of the diets evaluated in the present study. The TPD value of the control diet was 0.7% higher than that the SB 132 diet (96.48%) which was the highest among the soybean diets and 100% higher than the protein-free diet (0.00%). Similarly, soybean diet SB 30 (92.12%) had the lowest TPD value among the soybean diets which was 5% lower than SB 132. There were a 0.7% differences in the TPD value between the control diet and the soybean diets SB 132 and a 100% difference between the control diet and the protein free diet (Table 4.4).

Mean weight loss of -5.25 g was observed in the rat group that was fed on the protein free diet which was about 191% total weight loss in comparison to the rats group that was fed on the control diet. There was a significant difference in the weight gain among the rats groups that were fed on the different soybean diets with the SB 132 diet achieving the highest weight gain of 5.50 g and diet SB 30 (2.50 g) the least weight gain, a 55% difference in (Table 4.4). There was a non - significant difference in the weight gain between the rat groups fed on the control diet (5.75 g) and SB 132 (5.50 g), respectively.

Table 4.4: Indices of protein quality for the four soybean varieties grown in Western Kenya

Indices of protein quality	SB 19	SB 25	SB 30	SB 132	Skimmed milk powder	Protein free diet
Food efficiency ratio	0.060^{bc}±0.02	0.061^{bac}±0.02	0.038^{c}±0.01	0.085^{ba}±0.02	0.090^{a}±0.01	- 0.105^{d}±0.02
Apparent protein digestibility (%)	88.37^{b}±0.04	87.40^{c}±0.32	84.21^{d}±0.07	89.13^{a}±0.07	88.06^{b}±0.49	0.00^{e}±0.00
True protein digestibility (%)	96.14^{b}±0.15	94.85^{c}±0.47	92.12^{d}±0.14	96.48^{b}±0.10	97.17^{a}±0.68	0.00^{e}±0.00
Body weight gain/loss (g)	3.75^{bc}±0.96	4.25^{ba}±1.50	2.50^{c}±0.58	5.50^{a}±1.29	5.75^{a}±0.96	- 5.25^{d}±0.96
Net protein retention ratio	2.90^{bc}±0.85	3.45^{ba}±1.60	1.69^{c}±0.65	4.70^{a}±1.38	4.93^{a}±1.07	0.00^{d}±0.00

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p<0.05$) as assessed by Least Significant Difference.

The Net Protein retention ratio (NPRR) varied among the soybean diets with soybean diet SB 132 having the highest NPRR of 4.70 and diet SB 30 having the lowest NPRR of 1.69. This was a 64% difference between variety SB 30 and SB 132. The NPRR also varied between the control diet (4.93) and the protein free diet (0.00). The highest NPRR in the present investigation was by the control which was not significantly different from the SB 132 and lowest in the protein free die (Table 4.4).

4.5: Protein Digestibility Corrected Amino Acid Score (PDCAAS)

Table 4.5 shows the quantities of the indispensable amino acids in the skimmed milk powder (control diet) and the four soybean diets relative to the WHO (2007) reference pattern for 1 to 2, 3 to 10, 11 to 14, 15 to 18 and 18 and above years. The PDCAAS index reflects the estimated ability for the food products to meet the protein needs for an individual. The ages 1 to 2, 3 to 10, 11 to 14, 15 to 18 and 18 and above years amino acid scoring pattern is recommended by WHO (2007) for judging protein quality. The skimmed milk powder (control diet) had a PDCASS of 1.0 which indicated that it is an effective food product to meet an individual's protein needs. On the other hand, soybean diets were not deficient in any of the indispensable amino acid with respect to the requirements of the ages.

Table 4.5: Comparison of amino acid composition (mg/g protein) of diet protein sources with WHO requirement pattern for children, adolescents and adults

Amino acids	**USAD, 2013**					**FAO, 2011**				
	SMP	**SB 19**	**SB 25**	**SB 30**	**SB 132**	**1-2 yrs**	**3-10 yrs**	**11-14 yrs**	**15-18 yrs**	**≥18 yrs**
Histidine	27.13	24.6	24.6	24.6	24.6	18	16	16	16	15
Isoleucine	60.51	44.3	44.3	44.3	44.3	31	30	30	30	30
Leucine	97.95	74.4	74.4	74.4	74.4	63	61	61	60	59
Lysine	79.31	60.8	60.8	60.8	60.8	52	48	48	47	45
Methionine + Cysteine	34.32	27.04	27.04	27.04	27.04	25	23	23	23	22
Phenylalanine + Tyrosine	96.58	82.22	82.22	82.22	82.22	46	41	41	40	38
Threonine	45.13	39.68	39.68	39.68	39.68	27	25	25	24	23
Tryptophan	14.10	13.28	13.28	13.28	13.28	7	6.6	6.6	6.3	6.0
Valine	66.92	45.61	45.61	45.61	45.61	41	40	40	40	39
Protein content	**36.16**	**37.80**	**37.80**	**37.80**	**37.80**					
Total	**558.11**	**449.73**	**449.73**	**449.73**	**449.73**	**310**	**290.6**	**290.6**	**286.3**	**277**
TPD (%)	97.17	96.48	94.85	92.12	96.48					
Limiting AA (1 -2yrs)	None	None	None	None	None					
Limiting AA (3 -10yrs)	None	None	None	None	None					
Limiting AA (11 -14yrs)	None	None	None	None	None					
Limiting AA (15 -18yrs)	None	None	None	None	None					
Limiting AA (≥18 yrs)	None	None	None	None	None					
Lysine Score (1- 2yrs)	1.53	1.17	1.17	1.17	1.17					
Lysine Score (3 -10yrs)	1.64	1.27	1.27	1.27	1.27					
Lysine Score (11-14yrs)	1.65	1.27	1.27	1.27	1.27					
Lysine Score (15-18yrs)	1.68	1.29	1.29	1.29	1.29					
Lysine Score (≥18 yrs)	1.76	1.35	1.35	1.35	1.35					
PDCAAS (1-2 yrs)	1.0	1.0	1.0	1.0	1.0					
PDCAAS (3-10 yrs)	1.0	1.0	1.0	1.0	1.0					
PDCAAS (11 -14 yrs)	1.0	1.0	1.0	1.0	1.0					
PDCAAS (15 -18 yrs)	1.0	1.0	1.0	1.0	1.0					
PDCAAS (≥18 yrs)	1.0	1.0	1.0	1.0	1.0					

Indispensible amino acid scores were obtained from the USDA (2013). Amino acid reference pattern for children, adolescents and adults (FAO, 2011)
Skimmed milk powder "Miksi" (Promasidor Kenya Ltd, Nairobi, Kenya)

4.6: Descriptive sensory analysis

Analysis of variance F-values of the four soybean varieties profile data of the 26 attributes scored by the descriptive sensory panel all showed significant differences ($p<0.05$) among the soybean varieties and the attributes (Table 4.6). The data were further analyzed by principal component analysis (PCA) to determine the systematic variation and underlying relationships among the physical characteristics and sensory attributes of soybean varieties. The first two principal components explained 90% of the total variation (Figure 4.1).

Table 4.6: Mean score for sensory attributes of the four soybean varieties as evaluated by the trained descriptive sensory panel (n=11)

ATTRIBUTES	SB 19	SB 25	SB 30	SB 132	F VALUE
Appearance					
Surface colour intensity	$6.82^{a}\pm0.85$	$7.36^{b}\pm0.65$	$6.55^{a}\pm0.79$	$8.36^{c}\pm0.78$	35.66**
Glossiness of seed coat	$3.45^{b}\pm0.67$	$6.91^{a}\pm0.91$	$6.85^{a}\pm0.85$	$6.82^{a}\pm0.73$	150.77**
Presence of dark eye	$6.09^{b}\pm0.80$	$7.36^{a}\pm1.25$	$7.36^{a}\pm1.52$	$0.64^{c}\pm0.49$	286.70**
Wrinkled seed coat	$1.73^{b}\pm0.76$	$2.58^{a}\pm0.50$	$2.73^{a}\pm1.15$	$6.09^{c}\pm0.91$	163.21**
Small size	$6.73^{d}\pm0.63$	$4.45^{b}\pm0.79$	$5.36^{c}\pm0.65$	$2.55^{a}\pm0.51$	238.29**
Splitting surface	$1.09^{c}\pm0.68$	$0.55^{a}\pm.051$	$0.12^{b}\pm0.33$	$0.55^{a}\pm0.51$	19.28**
Seed coat peeling	$1.88^{b}\pm1.02$	$2.97^{c}\pm0.85$	$1.36^{a}\pm0.82$	$6.18^{d}\pm1.04$	174.66**
smooth surface	$7.61^{a}\pm0.79$	$7.58^{a}\pm0.66$	$7.64^{a}\pm0.65$	$6.70^{b}\pm0.92$	11.74**
Aroma/Smell					
Roasted soybean aroma	$6.67^{a}\pm0.82$	$6.94^{a}\pm0.70$	$3.79^{b}\pm0.78$	$6.06^{c}\pm0.93$	102.34**
Beany aroma	$5.97^{a}\pm0.73$	$6.06^{a}\pm0.90$	$6.91^{a}\pm0.88$	$4.00^{b}\pm0.75$	74.86**
Sweet aroma	$5.21^{c}\pm0.86$	$4.58^{b}\pm0.61$	$3.67^{a}\pm0.60$	$6.58^{d}\pm0.61$	107.10**
Flavour					
Oily flavor	$5.27^{a}\pm0.67$	$5.36^{a}\pm0.60$	$4.24^{b}\pm0.83$	$6.18^{c}\pm0.77$	39.75**
Bland flavor	$5.82^{c}\pm0.88$	$3.18^{b}\pm0.68$	$6.58^{d}\pm0.87$	$2.21^{a}\pm0.82$	214.47**
Sweet flavor	$3.79^{b}\pm0.78$	$4.21^{c}\pm0.82$	$3.00^{a}\pm0.87$	$6.88^{d}\pm0.86$	135.08**
Starchy flavor	$4.12^{b}\pm0.82$	$5.79^{a}\pm0.96$	$5.76^{a}\pm0.79$	$5.82^{a}\pm0.77$	32.62**
Boiled arrow root flavor	$2.21^{a}\pm0.78$	$2.18^{a}\pm1.04$	$2.33^{a}\pm0.96$	$3.00^{b}\pm0.90$	5.69**
Beany flavor	$6.15^{a}\pm0.83$	$6.58^{a}\pm1.12$	$6.55^{a}\pm1.35$	$4.36^{b}\pm0.70$	34.10**
Texture					
Grainy texture	$3.52^{c}\pm0.51$	$3.94^{a}\pm0.90$	$3.94^{a}\pm0.61$	$2.36^{b}\pm0.74$	36.79**
Smooth texture	$6.76^{a}\pm0.75$	$7.27^{b}\pm1.01$	$7.06^{ab}\pm0.75$	$6.36^{c}\pm0.60$	8.21**
Chewy texture	$5.67^{a}\pm0.65$	$3.09^{c}\pm0.95$	$5.73^{a}\pm0.91$	$2.61^{b}\pm0.56$	147.70**
Hard texture	$5.64^{a}\pm0.78$	$3.09^{c}\pm0.91$	$5.55^{a}\pm1.00$	$2.00^{b}\pm0.87$	135.57**
Slippery texture	$2.85^{a}\pm0.83$	$4.94^{c}\pm0.93$	$3.30^{b}\pm0.77$	$6.12^{d}\pm0.86$	103.79**
Aftertaste					
Grainy residue in the mouth	$4.12^{a}\pm0.86$	$4.06^{a}\pm0.79$	$4.73^{c}\pm0.80$	$2.30^{b}\pm0.68$	58.38**
Beany flavor	$6.70^{a}\pm0.77$	$6.61^{a}\pm1.22$	$6.24^{a}\pm1.35$	$4.09^{b}\pm0.80$	43.73**
Boiled arrow root flavour	$1.91^{a}\pm0.91$	$2.15^{a}\pm0.80$	$2.00^{a}\pm0.90$	$3.18^{b}\pm0.64$	17.08**
Seedcoat residue in the mouth	$4.76^{c}\pm0.71$	$2.85^{b}\pm0.91$	$5.73^{d}\pm0.88$	$2.00^{a}\pm0.79$	142.22**

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p<0.05$) as assed by Fischer's least significant test. ** Significantly different at ($p<0.05$)

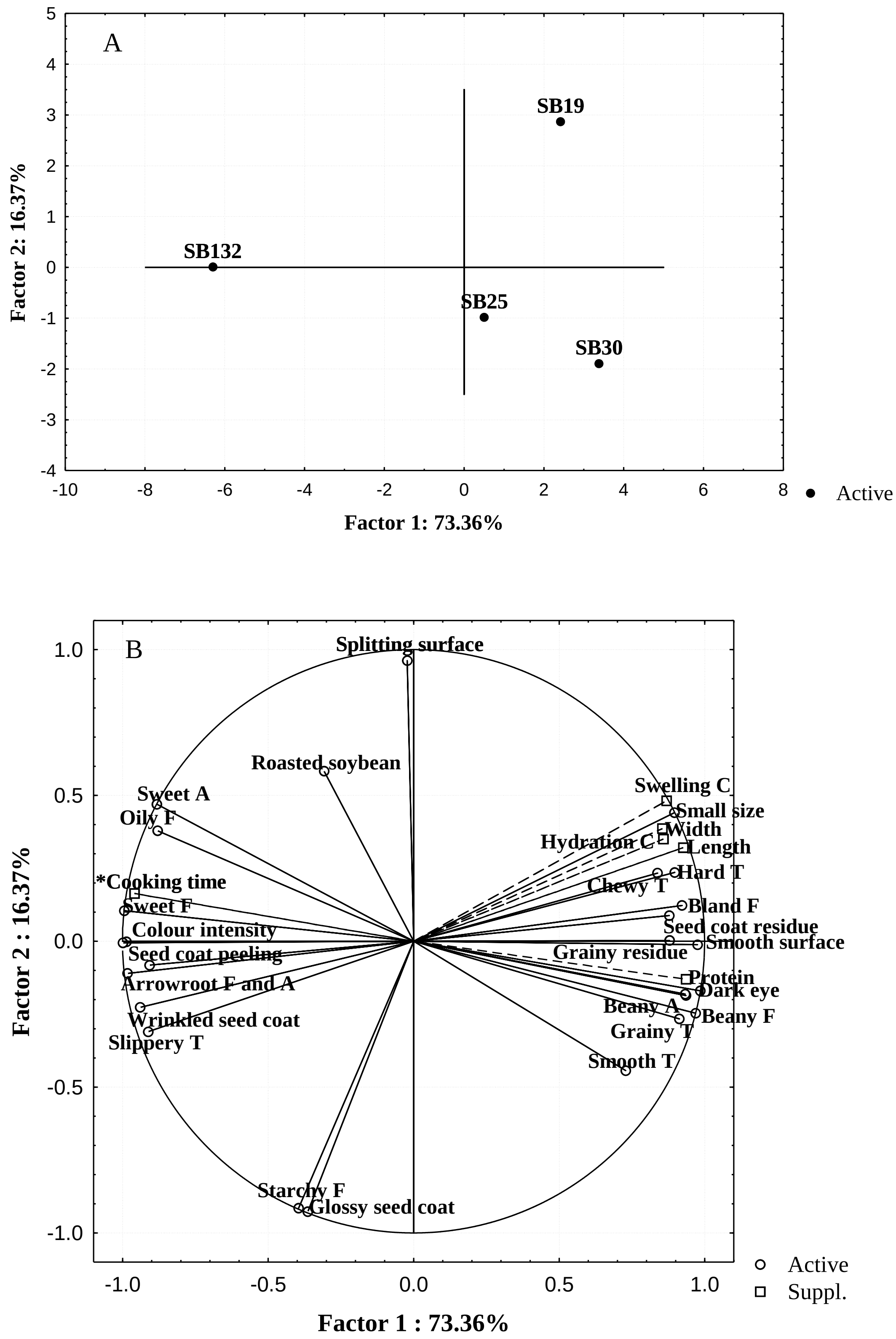

Figure 4.1: Principal component analysis (Correlation matrix) of the four soybean varieties. (4.1a) Plot of the first two principal component scores of soybean varieties. (4.1b) Plot of the first two principal loading projections of the sensory attributes A = Aroma, F = Flavour, T = Texture

Figure 4.1a shows the first two principal component scores of the four soybean varieties. PC1 explained 73% of the variation and separated the soybeans according to varieties with SB 19, SB 25 and SB 30 to the right and SB 132 to the left. PC2 accounted for 16% of the total variation and separated soybeans according to size with soybean varieties SB 19 and SB 132 at the top and SB 25 and SB 30 at the bottom.

The attribute loading for the first two principal components (Figure 4.1b), shows the relationship between the sensory attributes and the physical characteristics of the four soybean varieties. Soybean variety SB 132 was associated with the cooking time, sweet flavour and aroma, oily flavour, roasted soybean aroma and splitting surface which were negatively correlated with seed coat residue, grainy residue, beany flavour and aroma, bland flavour, chewy texture, hard texture, grainy and smooth surface. All these characteristics were negatively correlated with seed coat peeling, arrow root flavour and aroma, wrinkled seed coat, slippery texture, starchy flavour and glossy seed coat. Soybean varieties SB 19, SB 25 and SB 30 were associated with seed coat residue, grainy residue, beany flavour and aroma, bland flavour, chewy texture, hard texture, grainy and smooth surface.

4.7: Consumer acceptability of soybeans

There was a significant difference in consumer acceptance of the different soybean varieties. The soybean samples presented to consumers were rated on a 9 point hedonic rating scale where those rated towards 9 were the most preferred and those rated towards 1 were the least preferred. Results for the evaluation of the liking of four sensory attributes by 50 consumers are shown in Table 4.7.

Fifty consumers evaluated their liking of the four soybean varieties for the sensory attributes of appearance, smell, flavour and texture. In terms of the appearance, soybean variety SB 132 was liked most, SB 30 was the least liked by the consumers. The consumers considered SB 19 and SB 25 similar in appearance.

Table 4.7: Consumer perception (N=50) of sensory attributes for four varieties of soy beans grown in Western Kenya

Attributes	SB 19	SB 25	SB 30	SB 132
Appearance	$7.08^{b}\pm1.21$	$7.00^{b}\pm1.43$	$5.80^{a}\pm1.64$	$7.84^{c}\pm0.93$
Smell/Aroma	$6.54^{ab}\pm1.20$	$6.60^{bc}\pm1.28$	$6.02^{a}\pm1.72$	$7.10^{c}\pm1.25$
Flavour	$5.74^{a}\pm1.34$	$5.92^{a}\pm1.64$	$5.52^{a}\pm1.69$	$7.28^{b}\pm1.07$
Texture	$5.14^{a}\pm1.76$	$5.22^{a}\pm1.90$	$4.82^{a}\pm1.80$	$7.44^{b}\pm1.31$

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p<0.05$) as assessed by Fisher’s Least Significant Difference; 1 = disliked extremely and 9 = liked extremely.

The aroma of cooked soybean differed significantly among varieties. The aroma of Soybean variety SB 132 was the most liked and SB 30 was the least preferred in aroma. For the attribute of flavour, SB 132 was again significantly different from the rest of the varieties and was liked best by consumers. The consumers’ ratings for soybean varieties SB 19, SB 25 and SB 30 showed that they had similar flavour. In consideration of the texture attribute, soybean variety SB 132 was significantly different from the rest of the varieties and was the most liked by the consumers. Likewise, consumer texture liking for soybean varieties SB 19, SB 25 and SB 30 were not significantly different.

Figure 4.2: Shows the mean rating for the total score of liking for the four varieties of soybean by 50 consumers. There were significant differences in the total scores among the four soybean varieties. SB132 had the highest rating and was liked 40% more than SB30 which had the lowest score of 5.54. SB 19 and SB 25 which had similar total scores were liked 20% less than SB30 and 11% more than SB 19, the least liked. Figure 4.2 also shows the distribution along the bar line of the graph which explains agreement among the consumers. The shortest distribution of scores along the bar graphs for this study is an indication that generally there was agreement among the consumers over the scores for soybean variety SB132.

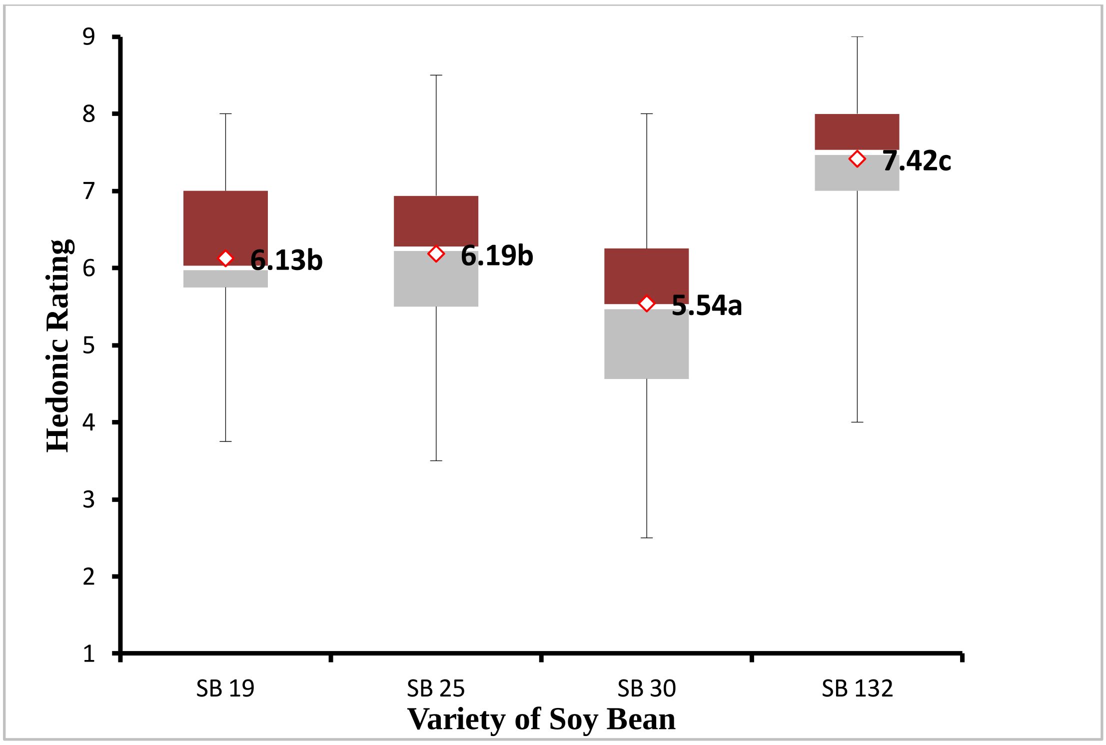

Figure 4.2: Total quality ratings by consumers (n=50) for four varieties of soy bean from western Kenya

^{abc} = Mean values with different letter superscripts differ significantly at ($P<0.05$). The higher percentile is the lighter shaded area and the bottom represents the value above which 75% of the ratings fell. The lower percentile is the darker shaded area and the top represents the value above which 25% of the ratings fell. The border between the two shaded areas is the median where 50% of the values fell above and 50% below. Hedonic rating scale, 1=dislike extremely, 5= neither like nor dislike, 9= like extremely.

4.8: Consumer knowledge on health and nutritional benefits of soybeans

The results for the consumer knowledge on health and nutritional benefits of soybeans are shown in Table 4.8 (A and B). The scores for reasons why consumers eat soybean and products made from soybean was 10%, 24% and 66% for religious belief, cultural and health issues respectively. The number of times a week that the consumers ate soybean and products made from soybean also varied from 6% (1- 2 days), 29% (3- 4 days) and 18% (5 – 7 days). All the consumers (100%) agreed that soybean products were safe for human use and 86% also agreed that soy diet is an adequate source of protein and energy for human health. A small percentage (14%) of the consumers was undecided about this.

Table 4.8 (a): Consumer knowledge about soybeans

	Scale	Score (%)
Reasons for eating soybean and products made from soybean	Religious beliefs	10
	Cultural issue	24
	Health issues	66
How often in a week do you eat soybean and products made from soybean	1 – 2 days	6
	3 – 4 days	58
	5 – 7 days	36
Are soybean and products made from soybean safe for human consumption	Yes	100
	No	0
	Undecided	0
Is soy diet adequate source of protein and energy for human health	Yes	86
	No	0
	Undecided	14

Table 4.8 (b): Health and nutritional benefits of soybeans

	Consumer preferences
Characteristics that consumers like in soybeans	Bright colour Bigger sizes Sweet flavour
Characteristics that consumers do not like about soybeans	Beany flavour Hard – to – cook characteristic
Reasons for advising a friend/friends to use soybean and products made from soybean	Good protein source A source of low saturated fat and complex carbohydrate Good source of dietary fibre

CHAPTER FIVE

DISCUSSION

5.1: Physical properties of the soybean varieties grown in Western Kenya

Results from the evaluation of seed coat colours for the four varieties of soybean in this study showed that they had different shades of yellow. The colours were yellow in SB 132 and SB 30 and pale yellow for SB 25 and SB 19 (Table 4.1). Differences in seed coat colour in soybean are caused by deposition of various anthocyanin pigments (Yang et al., 2010). Most commercial and consumer grown soybean varieties have a yellow colour (Todd and Vodkin, 1993). Also, it is possible that variation in soybean seed coat colour in the present study may have been due to genetic as well as environmental variability (Benitez et al., 2004). Colour is important because it affects soybean acceptability for human nutrition. In their review, Destro et al. (2013) reported resistance to consumption of light coloured soybeans promoted to alleviate malnutrition by a population used to the common bean which is dark. Additionally, processing of the beans for value addition such as protein and oil extraction may be affected by dark coloured beans.

The soybean grain sizes with reference to length and width of the four varieties were varied, ranging from 6.76 to 8.35 mm and 5.89 to 6.69 mm, respectively (Table 4.1). The variations may have arisen from the differences among soybean genotypes coupled by other environment factors within the areas where the seeds were grown (Burton and Wilcox, 1987). Similar findings have been reported by other researchers. For example, results from a study by Nwakonobi and Idike (2003) were comparable to the current study with dimensions of 6.36 mm to 7.94 mm in length and 5.45 mm to 6.18 mm in width for soybean grains. Giami (2002) also reported similar grain ranges for length but smaller widths of 3.8 mm to 4.5 mm. These researchers attributed the differences to variations in the plants area of origin, geographical sources and soil fertility. Large legume seed size is a characteristic that significantly influences the consumers' willingness to accept certain varieties over the others (Obatolu and Osho, 2006).

The cooking times in the present study varied among the four soybean varieties and were in the range between 128.33 and 195.33 minutes (Table 4.1). Variations in the cooking times might have been influenced by the differences in cultivar and the harvesting seasons (Vieira, Cabral and Paula (1997). The cooking times may also have been affected by hydration capacity of the seeds during soaking (Shimelis and Rakshit, 2005). In their study, Rocha-Guzman et al (2013) found cooking times in soybean of between 108 and 255 minutes and attributed these differences to the variations in the harvesting seasons and the cultural practices performed on the soybeans. Khetarpaul, Garg and Goyal (2004) reported that a cooking time of up to three hours (180 minutes) is sufficient for production of a soybean food product. The present study also found similar cooking times for all except for the SB 30 variety. Soybean variety SB 132 require the least cooking time, which is useful for saving fuel energy and should be preferred (Shimelis and Rackshit, 2005) whereas variety SB 30 showed the hard-to-cook characteristics responsible for undesirable texture and changes in colour and flavour and which limit their utilization in human diets (Nkunda, Mugisha and Muzuri, 2011). Extended cooking times also cause minerals, vitamins and proteins loss (da Silva et al. 2009). Determination of the cooking time in legumes is important in ensuring grain acceptability for human consumption, inactivation of the antinutritional factors and improving protein digestibility (Destro et al., 2013).

The hydration capacity was significantly different among the four soybean varieties in this study ranging from 0.13 to 0.26 g/seed. SB 132 had the highest hydration capacity (Table 4.1). The differences may have been brought about by seed coat variation among genotypes which is the main factor in controlling water imbibitions (Wilson, Resurrection, Hauck and Murphy, 1998). Previous studies have reported similar results. For example, Yimer (2008) reported a variation in the hydration capacity with a range of between 0.16 g/seed and 0.17 g/seed. Rani et al. (2008) also reported hydration capacity of 0.13 g/seed in some soybean varieties. These researchers attributed the differences in the hydration capacity to the ease of water absorption through the seed coat to the cotyledon. The hydration property of soybean is an important factor in the thermal processing of soybeans into various soy foods as well as in assessing the cooking time of soybean (Berrios, Swanson and Cheong, 1999).

Swelling capacity among the four soybean varieties evaluated in the present research significantly varied depending on the varieties with a range of between 0.21 and 0.46 ml/seed (Table 4.1). The differences in the swelling capacity might have been attributed to genotype variations that affected the rate at which water is absorbed in the grain (Golonka et al., 2002). Earlier, Tizazu and Emire, (2010) noted differences in the swelling capacity among some legume varieties obtained from different environments and attributed the differences to variation in the seed weight. Swelling in beans represents a degree with which the internal structure of starch is acted upon by water, thus an important factor to be considered when processing soybean into various soy foods (Alpaslan and Hayta, 2002).

5.2: Proximate composition of soybean varieties grown in Western Kenya

All the four soybean varieties had significantly high protein content (37 - 40 g/100 g) as indicated in Table 4.2. The protein content for soybean in this study is consistent with the USDA (2013) values of 37 g/100 g and 40 g/100 g by IITA (2009). Other researchers have determined the protein content of soybean and found similar results. For example, Eshun (2012) reported values between 36.94% and 40.01% while values of 35% to 40% were reported by Dixit et al. (2011). The variation in protein content among the four samples may have been caused by the differences in soybean variety. According to Burton and Wilcox (1987) differences in soybean genotypes and environmental variations affect soybean seed composition. Protein composition of soybean is important as the bean is being promoted for use in developing countries and western Kenya as a cheap source of protein to alleviate PEM (Riaz, 1999). It is utilized for growth, repair and maintenance of the human body (Qayyum, 2012).

The crude fat content of the four soybean varieties were significantly high (18 g/100 g to 23 g/100 g) as shown in Table 4.2 and were in agreement with 18 g/100 g reported by Anuonye (2011), but higher than the 20 g/100 g values of the USDA (2013). Variations in fat content among the varieties might have been attributed to varietal as well as environmental differences (Qayyum, 2012). Other researchers have determined the fat content in soybean and reported similar results. For instance, Arslanoglu et al. (2011) reported that fat content in soybean ranged from 20.42 to 22.04 g/100 g and 21 to 28.10 g/100 g was also reported by Rani et al. (2008). These researchers attributed the differences in soybean fat content to the interaction between the genetic structure and environmental factors. Fat composition of soybean is an important ingredient used to provide most of the energy in the body in the form of fatty acids as the plant is promoted in the management of cellular imbalance between the supply of nutrients and energy for the body's demand of growth, maintenance and specific functions (Donnen et al., 1996)

All the four soybean varieties had significantly high moisture content of 8.83 g/100 g to 9.50 g/100 g (Table 4.2). The moisture content of the soybean varieties selected for the present study were not significantly different among varieties and were consistent with the moisture contents of 8.60 g/100 g to 10.10 g/100 g for different soybean cultivars reported by Rani et al. (2008), but higher than the 5.16 g/100 g (USDA, 2013). It might be assumed that the non - significant differences observed in the moisture content of the soybean varieties evaluated in the present research would have been due to the uniformity of their storage environment (Taiwo, 1998). Moisture in soybeans is a measure of its water content and an important factor in evaluation of quality preservation and resistance to deterioration. As such, the moisture contents must be known in order to determine the nutritive value of soybeans (Eshun, 2009).

Ash content of the four soybean varieties was significantly high (7.83 g/100 g to 8.17 g/100 g) as indicated in Table 4.2. The ash content was not significantly different among the soybean varieties selected for the present investigation. Ash content among varieties was higher than the values of 4.46 g/100 g reported by the USDA (2013) and 5.73 g/100 g to 5.88 g/100 g reported by Yimer (2008) who attributed the non significant difference of the ash content among the soybean varieties of the present study to the uniformity in the mineral content among the varieties. Ash is the inorganic residue remaining after the organic material has been burnt off (Kirk and Sawyer, 1991). The total ash content of a food gives an idea of the amount of mineral elements that are present in that food sample (Eshun, 2009). Mineral elements are vital for the overall mental and physical well-being, body building and control of other body processes (Tull, 1996).

All the four soybean varieties had significantly low carbohydrate contents of between 19.49 g/100 g and 27.09 g/100g (Table 4.2) which were lower than 31g/100 g to 35 g/100 g values reported by USDA (2013). The generally low carbohydrate content in soybeans is due to storage of the energy as oil/fat (USDA, 2013). Additional differences may be a result of varying carbohydrate: oil ratios among the soybean varieties resulting from genotypic differences (da Silva et al., 2009). Some of the previous studies that have assessed the carbohydrate content in soybean have reported results that contrast with this investigation. For instance, Khan (2009) found carbohydrate content of soybean to range from 28.23 to 34.26 g/100 g while values of 27.05 to 31.28 g/100 g were reported by Ramadan (2012). These authors attributed the differences to the variations of protein and fat content of different soybean varieties. Carbohydrate is considered important energy source and acts as a ‘protein sparer’, so that the protein can be used for its primary functions rather than as a source of energy (Tull, 1996).

Energy value of soybean variety SB 132 was significantly different from that of the other three varieties (Table 4.2). The variation in the energy value was perhaps due to the beans larger surface area making it highest in protein and fat content compared to the other three varieties. In an earlier study by Eshun (2009) energy value in soybean was 1714.31 kJ. This finding is lower than that reported in the present study for all the four variety of soybean. A high dietary energy is important for sparing protein for body building and repairing body tissues avoiding diversion to provide energy (Stipanuk, 2006).

5.3: Effects of thermal processing on the proximate composition of soybean varieties grown in Western Kenya

The study established that the protein content in soybeans was reduced when they were thermally processed by boiling compared to the raw soybeans while roasting had no effect compared to the raw samples (Table 4.2). The reduction in protein content in relation to thermal treatment might have been due to solubilization and leaching out of the nitrogenous substances in the cooking medium Osman (2004). A similar study by Adeyeye (2010) found progressive reduction in the crude protein content from raw to cooked samples. Sharma, Goyal and Barwal (2013) also reported significant decrease in protein content when soybeans were boiled.

The fat content among the soybean varieties reduced when they were thermally processed by boiling while roasting had no effect compared to the raw samples (Table 4.2). Reduction due to boiling may be attributed to diffusion of fat into the cooking media (Hefnawy, 2011). Roasting on the other hand, may have maintained the stability of the fat content in soybeans due to the interactions between the sugars, amino acids, and lipids facilitated by the roasting process (Boge, Boylston and Wilson, 2009). A study by Sharma et al (2013) also found that boiling significantly decreased the oil content in soybean. Fat content both for thermal processed and raw soybean samples in this study were within the FAO/WHO (1994) recommended range of 10 g to 25 g oil per 100 g of food for young children.

Moisture content of the four soybean varieties evaluated in the present research reduced when they were thermally processed by roasting and increased due to the boiling processes compared to the raw samples (Table 4.2). Roasting subjected the grains to high and dry temperature that drew away moisture through evaporation (Biswas, Sana, Badal, and Huque, 2001; Eshun 2012) while boiling improved the hydration capacity and water absorption into the grains leading to increased moisture content (Sharma et al., 2013; Boge et al. 2009). In another study, Yeung (2007) found that boiling increased soybean moisture through absorption from the cooking medium (Yeung, 2007). The very low moisture content registered by roasted samples indicates that the grains can be better preserved by roasting (Ndidi et al., 2014).

Ash contents of the soybean were reduced by the thermal process of boiling when compared to the raw soybean as indicated in Table 4.2. Boiling might have caused a reduction of the ash due to an enhanced permeability of the seed coat when moist heat was applied leaching the minerals into the boiling water (Mariod et al., 2012). These results compare favourably with those reported by Ramadan (2012) who found a reduction in the ash content of soybean in processing and cooking. Khatoon and Prakash (2006) noted that the cooking processes reduced ash content by 7 to 13% in comparison to the raw seeds. Similarly, greater loss of ash content of up to about 50% as a result of seeds cooking was also obtained by Pysz, Biezanowska and Pisulewski (2001).

Carbohydrate content of the four soybean varieties increased significantly by the thermal treatments of boiling and roasting as shown in Table 4.2. The increase in carbohydrate content might have been due to the thermal effect that caused the granules to break down and then softened the cellulose making starch more available (Ndidi et al. 2014). A previous study by Sharma et al. (2013) also noted that thermal treatment enhanced the carbohydrate content in soybean seeds in relation to the raw samples.

The energy value obtained in the present study for the four soybean varieties with the thermal treatments of roasting was high compared to the raw and boiled samples (Table 4.2). The difference in the energy content might have been affected by the protein and carbohydrate contents of the roasted soybean (Seena, Sridhar, Arun and Young, 2006). The energy contents of the roasted as well as the boiled and raw samples of all the four soybean varieties in the present study met the recommended minimum value of 1674 kJ/100 g for food for young children (FAO/WHO, 1994).

5.4: Protein digestibility

Food intake of the protein free diet was less by 19% compared to the control and soybean diets (Table 4.3). Differences in the food intake among different rat groups might have been influenced by the nutrient quality of each diet. Food consumed in greater quantities than the other must have been more palatable (Erlanson-Albertsson, 2005). The low food intake may be due to the presence of unpalatable components and deficiencies in certain indispensible amino acids, minerals and vitamins, leading to nutrient imbalance (Porres et al., 2002). Following similar studies, Mosha and Bennink (2004) attributed suppressed food intake to an imbalance of dietary protein.

While Serrem et al. (2011) concluded that high food intake is influenced by the type and quantity of protein in a diet.

Protein intake of soybean diet SB 19 was 3.4% less compared to the control diet. Similarly, diets SB 25 and 132 were 2%, respectively higher than the control diet (Table 4.3). Protein intake is critical for growth such that its deficiency leads to a reduction in growth, muscular wasting, emaciation and even death (Serrem et al., 2011). Protein intake is believed to be influenced by the quantity, availability and nature of the indispensible amino acids present in the diet (Khan, 2009).

The faecal weight of the rat group fed on soybean diet SB 30 was 29%, 40%, 19% and 25% higher than control diet and soybean diets SB 19, SB 25 and SB 132 respectively (Table 4.3). High faecal bulk may be explained by a large amount of unabsorbed residue in the diet that elicits more faecal excretion. Serrem et al. (2011) attributed higher faecal weights to the effects of enzyme – resistant starch and thermal processing of the test foods in diets. Similarly, diets may differ in their potential to increase fecal weights even when they contain identical amounts of total dietary fibre (Ranhotra, Gelroth, Glaser and Rag, 1991).

Faecal protein among the rats fed on the soybean diets was high in diet SB 30 and low in diet SB 19 and SB 132, and the control diet, showing that the latter three retained higher quantities of protein (Table 4.3). The higher faecal protein excretion in soybean diet SB 30 shows that less protein was absorbed. Also, it could be a result of increased microbial activity in the intestine, utilizing indigestible carbohydrates and proteins from the beans substrate (Serrem et. al., 2011). Higher retention may be due to lower levels of anti-nutritional factors, hence more digestible protein increasing the protein retained (Fang, 2013). It has also been suggested by Karalazos (2007) that there is a positive effect with increased dietary lipid in improving protein retention.

5.5: Protein nutritional quality

Food Efficiency Ratio (FER) of the protein free diet was negative. A higher FER was observed among the rats that were fed on the control diet which was 6% greater than that of soybean diet SB 132 (Table 4.4). A lower FER value of the protein free diet might have resulted from a lower food intake and weight loss (Baskaran et al., 1999). Similarly, a higher FER was perhaps due to high food intake levels (Serrem et al., 2011). Previously, Baskaran et al. (1999) established that there was a higher FER value among rats that were fed on the control diet. A higher FER is an important quality attribute of the supplementary foods with high dietary bulk (Serrem et al., 2011).

Apparent protein digestibility (APD) of the control and soybean diet were high (84% and above) with only slight difference between the diets (Table 4.4). This might have been due to the ability of the protein in the control and soybean diets to meet the metabolic demand for amino acids (Boye, Wijesinha-Bettoni and Burlingame, 2012). Studies have assessed APD values and reported results similar to those of the present study. For example, Fang (2013) reported APD values in the range of 63.4% and 95.4% in soybean. Similarly, Siccardi (2006) found out APD values of between 89.9% and 96.9% in soybean that compared well with those reported in soybean diet SB 132.

True Protein Digestibility (TPD) value was highest for the control diet but with only slight variation from the soybean diets (Table 4.4). The TPD value in the control and the soybean diet may be attributed to the presence of substantial quantities of essential amino acids in the diets (Khan, 2009). A previous study by Jackson (2009) reported TPD for legumes and control diet of between 62.6 to 98.1%, respectively. The TPD value observed in the present investigation shows that the soybean varieties had high protein digestibility, an indication that they can be used to improve the protein quality of diets to fulfill nutritional requirements for growth and maintenance.

Weight gain was high in the rats fed on the control diet which was similar to that of the rats fed on soybean diet SB 132 while the rats fed on the protein free diet lost weight. Among the soybean diets, the least weight gain was observed in the rat group fed on diet SB 30 (Table 4.4). The increased weight gain of rats fed on a positive nitrogen balanced diet might have been due to a more highly digestible protein that promoted a higher weight gain in the test animals (Fang, 2013) while the drastic weight loss in the rats fed on the basal diet was due to the inadequacy in quality and quantity of the dietary protein (Serrem et al., 2011). Mosha and Bennink (2004) noted that rats fed on a maize meal only diet lost weight. Similarly, Serrem et al. (2011) also reported that rats fed on 100% sorghum biscuits did not gain weight during the 5 days of a digestibility study.

Net protein retention ratio (NPRR) of the control diet and soybean diet SB 132 were quite similar (Table 4.4). The proteins from skimmed milk powder and soybean diets performed better and as such were reflected in the positive weight gain response of the test animals. An earlier study by Qayyum (2012) has reported NPRR values of

2.21 to 3.48 among different legume varieties. The NPRR is an indicator of protein quality that takes into account the weight loss of the rats on the protein free diet in contrast to the protein efficiency ratio (FAO/WHO, 1991).

5.6: Protein Digestibility Corrected Amino Acid Score (PDCAAS)

Performance of the skimmed milk powder (Control diet) and soybean diets in the present study have shown that they probably have indispensable amino acid pattern considered adequate (Table 4.5) based on the scoring pattern recommended for judging protein quality in children, adolescents and adults (FAO/WHO, 1991). Other researchers have also conducted similar studies on legumes and used PDCAAS index to provide information about the potential of plant protein sources. For example, Singh, Kumar, Sabapathy and Bawa (2008) reported acceptable PDCAAS values of 0.92 for soybean protein isolate and 0.99 for soybean protein concentrate. Messina (1999) also noted that PDCAAS of legumes imparts reasonably good protein with improved digestibility.

5.7: Descriptive sensory analysis

The descriptive panelists evaluated four soybean varieties and associated varieties SB 19, SB 25 and SB 30 with the beany flavour and aroma characteristics that are thought to have affected their acceptability levels (Figure 4.1b). This objectionable flavour and aroma in soybean might be linked to the presence of high proportion of unsaturated fatty acids, particularly linolenic acid in the soybean oil fraction or the abundant presence of lipoxygenases in the beans (Maestri, Labuckas and Guzman, 2000). The SB 19, SB 25 and SB 30 varieties of soybean were positively correlated with each other in their association to the grainy, chewy and hard texture characteristics. These may be attributed to the effect of starch granules in the soybeans that are encapsulated by hydrophobic cross linkages which restricts swelling solubility and mobility of the polymer molecules thus affecting their mechanical attrition or cooking (Chiu and Solarek, 2009). The same three varieties when evaluated by the panelists also had a characteristic feature of seed coat residues that remained in the mouth. This feature was positively correlated with the characteristic hard textured. The seed coat residue in the mouth might have been attributed to the harder seed coat that took longer time to disintegrate during chewing (Mkanda, Minnaar and de Kock, 2007).

Variety SB 132 scored high for sweet, oily, roasted soybean, arrow root flavour and aroma which were positively correlated with wrinkled seed coat, slippery texture, glossy seed coat and starchy flavour. All these characteristics were negatively correlated with smooth texture, grainy texture and beany flavour and aroma. Roasted soybean aroma and flavour in variety SB 132 may have been developed from the maillard reaction as a result of thermal treatment. Previously, Serrem et al. (2011) reported the development of roasted soybean flavour in the thermal treated sorghum biscuits with defatted soybean flour replacement of 50%. This variety also ranked highest in the characteristic of splitting surface. This may have been influenced by the differences in physicochemical properties of legumes that may perhaps have contributed to splitting of beans during cooking (Mkanda et al., 2007).

5.8: Consumer acceptability of soybean

Appearance attributes

Many of the consumers liked the appearance of soybean variety SB 132 (Table 4.7). This may have perhaps been due to the influence of its superior physical characteristics of appealing seed coat colour and large grain size in comparison to the other varieties (Obatolu and Osho, 2006). Earlier research by Negri et al. (2001) has examined consumer demand and noted that they focus on visible characteristics of raw seeds and for culinary purposes, the beans that are liked are bigger sizes without the dark eye.

Flavour and Aroma attributes

Soybean flavour and aroma are the main limiting factor affecting soybean acceptability. In the present investigation, a higher number of consumers liked the flavour and aroma of soybean variety SB 132 (Table 4.7). This acceptable flavour in soybean variety SB 132 might have been due to the characteristic sweet flavour of the Isomalto-oligosaccharides which are glucose oligomers that occur in soy as natural constituent of honey responsible for sweet flavours (White and Hoban, 1959). Equally, the acceptable aroma perhaps was also facilitated by the better cooking quality of the variety, thus improved the aroma characteristics (Krinsky, 2005). On the other hand, varieties SB 19, SB 25 and SB 30 were rated low by consumer in their acceptability score. This might have been due to the presence of high levels of off-flavours in the varieties that was perhaps facilitated by an increase in the concentration of genistein and daidzein that increases due to hydrolytic action of β-glucosidase on glucosidic isoflavone precursors (Matsuura, Obata and Fukushima, 1989). The concentration of isoflavone compounds in the seed is influenced by genetics and environmental factors (Wang and Murphy, 1994).

Textural attributes

The texture attributes of the soybean variety SB 132 was the most acceptable by many consumers in relation to varieties SB 19, SB 25 and SB 30 (Table 4.7). This might have been influenced by cooking that imparted a softer texture to the variety as compared to the rest of the varieties evaluated (Mkanda et al., 2007). Texture attributes of soybeans have been previously studied in relation to consumer acceptance. For instance, Song, An, and Kim (2003) found that consumers preferred soybeans which had a soft texture.

5.9: Consumer knowledge on health and nutritional benefits of soybeans

The general acceptability of soybean showed no specific formula and there was also no formula that was generally rejected (Table 4.8 A and B). From the consumer information it can be reported that soybean have played an important role in the traditional diets of many regions and have traditionally been an important part of the diets of many cultures, as well as forming part of a delicacy in many people’s diets due to their perceived health benefits.

A bigger number of the consumers indicated that they consumed soybean and products made from soybeans between a period of 3 - 4 days and 5 - 7 days in a week. All the consumers were in agreement that soybean and soybean products are safe for human use. Similarly, a larger number of consumers indicated that soybean and products made from soybean were adequate sources of protein and energy for human health.

Some of the characteristics that the consumers liked about the soybeans were the sensory attributes of perceived brighter seed coat colour, big size seeds and sweet flavour while the beany flavour and hard - to - cook characteristics were the attribute that the consumers did not like about soybean. Most of the consumers admitted that they would advice their friends to use soybean and products made from soybeans for the reasons that soybeans are high in protein, low in saturated fat, and high in complex carbohydrates and a source of dietary fibre.

5.10: General discussion

Colour was evaluated using a Munsell's colour chart that creates a rational to describe colour using hue, value and chroma. This method was adopted for since it described colour and not the visible wavelength of colour. Similarly, grains sizes were determined by the use of a vernier caliper (Nithiyanantham et al., 2013) a procedures that allows for easier determination of the grain dimension of length and width. Hydration and swelling capacities were checked by soaking the seed in distilled water for a period of 24 hours (Shimelis and Rakshit, 2005) at room temperature. Soaking for 24 hours seemed too long as some of the seed samples showed signs of foaming, an indication of the onset of fermentation. Thus consideration should be made on the soaking temperature (Mkanda et al., 2007). Equally, cooking time of the four soybean varieties was evaluated by the procedures developed by Jackson and Varriano-Marston (Jackson and Varriano-Marston, 1981). However, the results from different studies that have used the Mattson bean cooker to determine cooking times cannot be easily compared because of the variations in the harvesting seasons and the cultural practices performed on the soybeans (Rocha-Guzman et al., 2013).

The total dietary fiber was obtained from the USDA (2013) value, a method that varied from the other such as enzyme digestion (Baskara et al., 1999) and the AOAC international procedures. This procedure was opted for to avoid the difficulty involved in sourcing for the apparatus required in performing the total dietary fibre tests.

In the evaluation of the protein quality using a rat bioassay, past studies have recommended the use of casein diet as a reference protein (Serrem et al., 2011). The present investigation adopted the use of skimmed milk powder as control diet (Chapman et al., 1959). Since the casein diet would have not been sourced for from the local companies.

The study assumption was that soybean varieties grown in western Kenya have differences in nutritional, physicochemical and sensory properties due to varietal and environmental differences even though the environmental conditions influencing nutritional components of the soybean may have not be ascertained. Similarly, lack of human models for use in this kind of study could produce data that is inconsistent with that obtained from human models.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATION

6.1: Conclusions

1. The cooking time and the physical characteristics in terms of grain size, hydration and swelling capacities are highest in soybean variety SB 132 increasing its potential for human utilization due to better culinary characteristics.
2. Soybean SB 132 has the highest nutrient density in terms of protein, fat and energy making it the most concentrated among the varieties in nutrients for prevention of Protein Energy Malnutrition
3. All the four selected soybean varieties have superior protein quality with high Apparent and True Digestibilities and Protein Digestibility Corrected Amino Acid Scores of above 1.0 and can supply protein comparable to animal source to individuals of all age groups in Western Kenya.
4. Soybean variety SB 132 which is associated with the sweet flavour and aroma, oily flavour, roasted soybean aroma and splitting surface, attributes which are positive for culinary characteristics and is the most liked by consumers in terms of appearance, aroma, flavour and texture. Thus, has a high potential of being adopted for human consumption in Western Kenya to alleviate PEM.

6.2: Recommendations

1. In selection of soybean varieties to be released from agricultural research centers, attention should be given to sensory and consumer acceptability on the varieties.

2. Plant breeders and nutritionist should be able to promote soybean variety SB 132 as a food crop variety since it has the best consumer quality characteristics and the potential for use as a protein source for the management of PEM
3. Food processing Industries should utilize soybean varieties SB 19, 25 and 30, due to their physical characteristics, to fortify other foods with low protein quality e.g. maize flour, sorghum flour, cassava flour, potato flour.

6.3: Suggestions for further research

1. There is need for further research to find innovative solutions for the negative characteristics such as beany flavour and enhance the positive attributes like sweet flavour and shorter cooking time through selecting lines for human consumption.
2. Research should also be conducted on the nutritive value by animal assays at least after every two years, to check and compare the quality of soybean.

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APPENDICES

APPENDIX I: Application form for serving in a trained sensory panel

APPLICATION FORM FOR SERVING IN A TRAINED SENSORY PANEL

1. Full name and surname ---
2. Your residential address? ---

----

3. Telephone or mobile cell No. ---
4. E-mail address --
5. Your age? --

6. Are you?	Male	Female
7. Your occupation or main activity during 17th March 2014 to 4th April 2014 (e.g. student, technician etc.)?		
8. Are a registered University of Eldoret student?	Yes	No
If yes , course and year of study and hours you are available		
9. Are you a University of Eldoret staff member?	Yes	No
If yes, state the time and day of the week you are available		

10. Please evaluate your ability to read, speak and write English on the following scale:

Poor ☐ Fair ☐ Average ☐ Good ☐ Excellent☐

11. Are you allergic to anything?	Yes	No
If yes, give details.		
12. Please specify any specific food product/s that you prefer not to consume.		
13. Do you smoke?	Yes	No
If Yes, how many cigarettes a day?		
14. Will you be available for the taste panel as explained during the introduction session on 17th March 2014 to 4th	Yes	No

April 2014		
15. Have you ever been on any sensory evaluation panel?	Yes	No
If yes, where/when/to evaluate what?		
19. Will you be able to attend the screening sessions on:		
Wednesday: 18 March 2014	Yes	No
20. If you are available for the screening sessions, which of the following time/s would be suitable.		
10:00 – 11:00 Hours	Yes	No
13:00 – 14:00 Hours	Yes	No
21 In not more than 20 words, write down why you think we should choose you for our sensory panel		

I declare that the information furnished above is correct and true to the best of my knowledge.

Signature Date

APPENDIX II: Sensory evaluation consent form

SENSORY PANELIST CONSENT FORM

Sensory evaluation of soybeans

Thank you for your willingness to potentially participate in a sensory evaluation project at the Department of Family and Consumer Sciences, University of Eldoret.

Date of Participation: ……………………………………………..

Voluntary Nature of Participation: I understand that participation in this project is completely voluntary and I do not have to participate in this sensory project if I do not agree to participate hence I can withdraw my participation at any time.

Risks to the individual: I understand that I will evaluate different varieties of soybean grains using descriptive sensory evaluation. I note that people who are allergic to soybeans should avoid these products.

Medical Liability: I understand that no financial compensation will be paid to me in connection with any physical injury or injury in the unlikely event of physical injury or illness as a direct or indirect result of my participation in this sensory project.

Confidentiality: participants are not required to reveal any confidential information. All responses to questions will be treated in a confidential manner. Responses to sensory questions via the evaluation form are tracked using numbers only. These numbers are not in any way related to the participant's name.

If you have any questions about this sensory project, contact Fredrick Agengo. Department of Family and Consumer Sciences, University of Eldoret at 0722 – 267536.

I HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE SENSORY PROJECT AND I AM PREPARED TO PARTICIPATE IN THIS PROJECT.

Participant's Signature Date

Participant's Name *please print clearly*

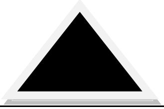
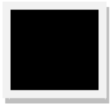
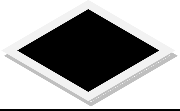
Sensory Panel Leader Signature Date

APPENDIX III: Descriptive Sensory Evaluation

SCREENING TESTS
TEST 1

Name: ______________________________ Date:................................

Identify the taste on each of the papers

TEST 2

Name: ______________________________ Date: ....

Identify the following flavours by smelling. Enter the code of the sample you have identified against the flavour.

Perceived flavour	**Code**
Lemon favour	
Caramel flavour	
Almond flavour	
Pineapple flavour	
Chocolate flavour	
Orange flavour	

TEST 3

Name: ______________________________ Date: ....

You are provided with five samples of beans. Please take a sip of water before you start tasting and in between tasting the different samples. Using your own terms, show how the beans are different in taste, flavour, texture and appearance.

	743	**692**	**508**	**455**	**122**
TASTE					
FLAVOUR					
TEXTURE					
APPEARANCE					

APPENDIX IV: Descriptive panel evaluation sheet

WELCOME TO THIS TASTING SESSION

DEPARTMENT OF FAMILY AND CONSUMER SCIENCES

UNIVERSITY OF ELDORET

PANELIST CODE …………..

PANELIST NAME ……………………………………………

ENTER TRAY NO. ……………………………………………..

Instructions

You are provided with four (4) samples of soy bean. Please taste the samples in the order presented from left to right. Take a sip of water and eat a piece of carrot before you start tasting and in between tasting the different samples. Circle the relevant bar on the scale provided for each attribute.

Question 1:

Look at the sample **…………………………..** and rate the following appearance descriptors

Surface colour intensity

Not light — **Very light**

Glossiness of seed coat

Not glossy — **Very glossy**

Presence of dark eye

No dark eye — **Very dark eye**

Wrinkled seed coat

Not wrinkled — **Very wrinkled**

Small size

Not small — **Very small**

Splitting surface

Not splitting — **Extremely splitting**

Seed coat peeling

No peeling — **Extremely peeling**

Smooth surface

Not smooth — **Very smooth**

Question 2:

Smell sample ………using short sniffs and rate the intensity of the following aroma descriptors

Roasted soybean aroma

No roasted soybean — **Intense roasted soybean**

Beany aroma

No beany aroma **Intense beany aroma**

Sweet aroma

No sweet **Intense sweet**

Question 3:
Taste sample ………………and rate the intensity of the following flavour descriptors

Oily flavour

No oily flavour **Intense oily flavour**

Bland flavour

No bland **Intense bland**

Sweet flavour

No sweet flavour **Intense sweet**

Starchy flavour

No starch flavour **Intense starch flavour**

Boiled arrow root flavour

No boiled arrow root **Intense boiled arrow root**

Beany flavour

No beany flavour **Intense beany flavour**

Question 4:
Taste sample **…………….**and rate the intensity of the following texture descriptors

Grainy texture

Not grainy **Very grainy**

Smooth texture

Not smooth **Very smooth**

Chewy texture

Not chewy **Very chewy**

Hard texture

Not hard **Very hard**

Slippery texture

Not slippery **Very slippery**

Question 5:

After swallowing the soybeans, rate the after taste of the sample ………………………….

Grainy residue in the mouth

No grainy **Very grainy**

Beany flavour

No beany **Intense beany**

Boiled arrow root flavour

No boiled arrow root **Intense boiled arrow root**

Seed coat residue in the mouth

No seed coat residue **Intense seed coat residue**

Any other Comments:

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………

Instructions

REMEMBER to take a sip of water and eat a piece of carrot before you start tasting

APPENDIX V: Consumer acceptability sheet

WELCOME TO THIS BEANS TASTING SESSION
DEPARTMENT OF FAMILY AND CONSUMER SCIENCES
SCHOOL OF AGRICULTURE AND BIOTECHNOLOGY
UNIVERSITY OF ELDORET

Age: ………………………………
Gender: …………………………...
Tray Number: …………………….

PART A - Instructions

You are provided with four (4) samples of soy bean. Please taste the samples in the order presented from left to right. Take a sip of water before you start tasting and in between tasting the different samples. Indicate your liking or disliking by placing a check mark at the relevant bar on the scale provided for each attribute.

Sample No.																
Scale	**Appearance**	**Smell**	**Flavour**	**Texture**	**Appearance**	**Smell**	**Flavour**	**Texture**	**Appearance**	**Smell**	**Flavour**	**Texture**	**Appearance**	**Smell**	**Flavour**	**Texture**
Like extremely																
Like very much																
Like moderately																
Like slightly																
Neither like nor dislike																
Dislike slightly																
Dislike moderately																
Dislike very much																
Dislike extremely																

Comments:……
………
………

PART – 2: Questionnaire

Welcome!

My names are Fredrick Agengo, a student at University of Eldoret currently pursuing a Masters Degree in Community Nutrition, I am interested in collecting data related to your knowledge about soybean and soybean products use as well as the health benefits related to their use. This data is for academic purposes and not for any other reasons. Your responses will help to promote the improvements in the utilization of soybean foods as well as forming part of a large education program towards developing soy behaviour that is geared towards promoting nutritional security. Anything you tell us will be confidential and the survey will take about ten minutes of your time.

Instructions for answering the questions

Tick in the appropriate box corresponding to the respondents answer to each of the questions.

Demographic data:

1. Gender

   [ ] Male [ ] Female
2. What is your age bracket?

   [ ] Below 18 yrs [ ] 18 - 24 yrs [ ] 24 - 30 yrs

   [ ] 31 - 40 years [ ] 41 and above
3. What is the highest level of education you have attained?

   [ ] Primary [ ] O' Level [ ] Tertiary

   [ ] University

   Others (Specify) ....
4. Occupation?

   ....

Knowledge on health and nutritional benefits of soybeans

1. Do you eat soybean and products made of soybeans

   [ ] Yes [ ] No
2. If Yes, What are your reasons for eating soybean and products made from soybean

[ ] Religious beliefs [ ] Cultural issues [ ] Health issues

Others (specify)……………………………………………………………………………

……………………………………………………………………………………

3. If no, why not ………………………………………………………………………

4. How often in a week do you eat soybeans and products made from soybeans

   [ ] 1 – 2 days [ ] 3 – 4 Days [ ] 5 – 7 Days

5. Are soybeans and products made from soybeans safe for human consumption?

   [ ] Yes [ ] No

6. Do you consider diet of soybean an adequate source of protein and energy for human health?

   [ ] Yes [ ] No

7. Would you replace animal sourced protein foods with soybean in your diet

   [ ] Yes [ ] No

8. In your use of soybeans have you noted any differences among the types.

   [ ] Yes [ ] No

9. If yes, what are some of these characteristics differences?

   ……………………………………………………………………………………

   ……..…………………………………………………………………………..

   ……………………………………………………………………………………

10. What characteristics do you like about soybeans?

    ……………………………………………………………………………………

    ……………………………………………………………………………………

11. What characteristics do you not like about soybeans?

    ……………………………………………………………………………………

    ……………………………………………………………………………………

12. Can you advice a friend/friends to use soybean and soybean products?

    [ ] Yes [ ] No

13. If Yes, why? ………………………………………………………………………

14. If No, why not? ……………………………………………………………………

15. Any other view on the use of soybeans and soybean products?

    ……………………………………………………………………………………

    ……………………………………………………………………………………

Thank you.