Sensory and nutritional quality of an extruded sorghum and cowpea blend as a complementary food for school age children

By

Nosihle Princess Dlamini

Dissertation

Submitted in partial fulfilment of requirements for the degree

MSc Food Science

In the

Department of Food Science

Faculty of Natural and Agricultural Sciences

University of Pretoria

Republic of South Africa

June 2016

DECLARATION

I declare that the dissertation herewith submitted for the degree MSc Food Science at the University of Pretoria, has not been previously submitted by me for a degree at any other university or institution of higher education.

Nosihle Princess Dlamini

Date: 06/06/2016

DEDICATION

This dissertation is dedicated to God the enabler of dreams for making this possible. It is also dedicated to my family for the great support and motivation.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and acknowledgements to the following people for their support and assistance with this research:

My supervisor Prof J. R. N. Taylor, for the giving me the opportunity to carry out this work, his excellent guidance and wisdom, constructive criticism, challenging ideas and motivation throughout the course of the work. My co-supervisor Prof H. L. de Kock, for her support, positive criticism and her valuable contribution towards this research;

I am grateful to Howard Buffet Foundation through Norman Borlaug Institute of Texan A & M University for a Masters Scholarship;

I wish to thank Prof M. N. Emmambux for his invaluable advice and support on extrusion, Prof E. Buys, Prof K. G. Duodu and Dr J. Kruger for their help and advice at different stages of my research;

I would also like to express my sincere gratitude to Dr Janet Taylor for the emotional support and motherly care.

My special gratitude extended to the other academic and non-academic staff and fellow postgraduate students of the department of Food Science, University of Pretoria for their support in fulfilling this research;

My family and friends for their prayers and support in various ways;

Above all, to God who made it all possible.

ABSTRACT

Sensory and nutritional quality of an extruded sorghum and cowpea blend as a complementary food for school age children

By

Nosihle Princess Dlamini

Supervisor: Prof. J. R. N. Taylor

Co supervisor: Prof. H. L. de Kock

Protein-energy malnutrition (PEM) is a major problem in sub–Saharan Africa, which is predominant in children and women. Poverty is the underlying cause. Children rely on cereal staples like sorghum for nutrient supply. However, sorghum is limiting on indispensable amino acid lysine and has poor protein digestibility, compromising its protein quality. Cowpeas are major subsistence crops in sub-Saharan Africa due to their tolerance to harsh climatic conditions and notable protein quality. Snacks are widely consumed by school-going children during break lunches and convenient, palatable, ready-to-eat and have long-shelf life. Therefore sorghum-cowpea snack blends have potential to address PEM. Hence, objectives of the study were to develop and evaluate the effects of compositing sorghum with cowpea on nutrient quality and sensory properties of snack blends.

Ready-to-eat sorghum-cowpea expanded snacks were produced using a twin screw extruder. Snacks were made from 0, 25 and 50% ratios of wholegrain cowpea flour (Glenda variety) to commercial decorticated red non-tannin sorghum flour and 1% salt. The nutritional and sensory characteristics of snacks were investigated in terms of proximate and nutrient composition, protein digestibility, lysine content, mineral content and bioaccessibility and descriptive sensory analysis coupled with instrumental texture (breaking force) and colour analyses.

Inclusion of cowpea significantly improved nutrient composition of the snacks. A 30 g packet of composite snacks would provide 4-5 g protein which is 15-31% of the protein daily requirement for school-age children. Cowpea inclusion significantly increased lysine by 97% of daily requirement for school-age children. The sorghum-cowpea blend snacks had some

16% improved *in-vitro* protein digestibility. Hence, the calculated Protein Digestibility Corrected Amino Acid Scores of the blend snacks was more than double that of the sorghum only snacks. Mineral contents of snacks were improved on cowpea inclusion. However, phytate content increased also, decreasing the bioaccessibility of the minerals.

Conversely, inclusion of cowpea flour darkened the colour and increased dark specks in the snacks. Snack hardness was similarly rated by panellists and the instrumental texture analysis. Beany, cocoa, burnt, boiled and roasted nut flavours with metallic aftertaste were highly perceived in the 50:50 blend. Salt addition affected salty flavour only.

Inclusion of cowpeas in extruded cereal snack formulations has the potential to address PEM in school-going children in sub-Saharan Africa because it substantially improves the protein content and quality of the snacks. Although inclusion of 50% cowpea gave the highest nutritional quality, it resulted in a beany flavour and metallic aftertaste. These may require masking through commercial flavouring for consumer acceptability.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1. INTRODUCTION

Protein-Energy malnutrition (PEM) is defined as a range of pathological conditions arising from lack, in varying proportions, of proteins and calories, occurring most frequently in infants, young children, pregnant and lactating women and commonly associated with infections (Roulet, 1994; Muscaritoli et al., 2009; FAO, IFAD and WFP, 2015). The prevalence of PEM in the sub-Saharan Africa region is still a major problem and poverty is identified as the underlying cause. PEM is associated with the low socio-economic status that leads to reliance on cereal staples as a major source of nutrients.

In sub-Saharan Africa, sorghum is a major food crop because of its drought tolerance (Taylor et al., 2006) and it is a good source of energy and antioxidants (Duodu et al., 2003). However, sorghum has poor protein quality because the main storage proteins (prolamins) are deficient in the essential amino acid lysine (Taylor et al., 2006). In addition to that, the nutritional value of sorghum protein is significantly reduced when the grain is wet cooked for example, in the making of porridge (Duodu et al., 2003). The reliance of people on sorghum in sub-Saharan Africa probably makes them prone to PEM.

Cowpeas are a vital component of diets in the developing countries of Africa as a valuable source of protein to complement cereals (Phillips et al., 2003). They are also a very good source of dietary fibre, vitamins and minerals (Uzogara and Ofuya, 1992). Although cowpeas are rich in lysine, they are deficient in sulphur containing amino acid (Phillips et al., 2003). Furthermore, the consumption of cowpeas is limited by the lack of convenient food applications and physiological effects.

This nutritional composition makes the cowpeas complementary to the sorghum cereal (Egoulenty and Aworh, 2003) and hence novel nutritious products can be made from the combination of the two products. This would also optimize the use of these grains and at the same time, address the issue of malnutrition.

A number of new innovative products like biscuits, beverages and extruded snacks (Pelembe et al., 2002; Serrem, 2010; Anyango et al., 2011) to mention but a few, have been developed to produce low-cost, complementary, ready to eat and convenient foods from sorghum and legume blends. Snacks are ready to eat, convenient and widely consumed by people of all ages. In addition, composite cereal-legume extruded snacks are a potential substitute for the less nutritious snacks consumed widely by school-going children as nutrition is not a deciding factor in their food choice. Hence, the aim of this study was to produce a nutritious snack blend from sorghum and cowpeas that can be used as a complementary snack for school-age children. Extrusion cooking, a multi-variable unit operation that combines mixing, shearing, cooking, puffing and drying in a continuous process is widely used to manufacture snack foods (Devi et al., 2013). Furthermore, as opposed to wet cooking, the extrusion of sorghum flours has shown an improvement in sorghum protein solubility and functionality (Devi et al., 2013).

Compositing sorghum with cowpea can improve the nutritional value of extruded snacks. School-going children are major consumers of snacks during school breaks and lunches. This is mainly because of their affordability and convenience. The use of the extrusion technology in the production of the snacks from sorghum-cowpea composites could enhance better nutrient retention and nutrient quality, more especially the proteins (Singh et al., 2007). This could in turn ensure a production of sorghum based snacks of high nutritional quality and convenience whilst at the same time addressing PEM in school-going children.

2. LITERATURE REVIEW

This chapter discusses the potential application of extrusion cooking of sorghum and cowpeas in making composite snacks to alleviate protein-energy malnutrition (PEM). The issues addressed are the protein quality of sorghum and cowpeas in relation to children's nutritional requirements, malnutrition and protein-energy malnutrition prevalence in Africa, strategies for meeting the dietary needs of children, ready-to-eat technologies, extrusion cooking technology and its effects on nutrients. The study also reviews the role of snacks in the diet and quality aspects of extruded snacks in relation to their sensory properties.

2.1 Sorghum

2.1.1 Sorghum production and distribution in Africa

Sorghum serves as the main staple and the only viable grain crop for many of the world's most people who live in the semi-arid tropics where droughts cause frequent failures of other crops (ICRISAT, 2009). It is ranked the world's fifth most important cereal grain by acreage after wheat, maize, rice and barley (FAOSTAT3, 2015). Sorghum is also a major cereal crop cultivated in Africa whereby it is the second most important cereal in the tonnage perspective (FAOSTAT3, 2015). Africa produced about 20 million tons of sorghum annually in the past decade, which is a third of the global production. Africa's production has been increasing steadily such that now it is approximately 25 million tonnes (FAOSTAT3, 2015). Nigeria is the leading producer of sorghum and produces some 6.7 million tonnes which is approximately 25% of Africa's total production (FAOSTAT3, 2015).

2.1.2 Sorghum nutrient composition

Table 2.1 shows the nutrient composition of sorghum grain. The main component in sorghum grain is starch which is 75-79% of the grain weight. It generally comprises 70-80% amylopectin and 20-30% amylose (Waniska et al., 2004). The pericarp and germ in sorghum are rich in minerals, namely iron, zinc, potassium and phosphorus, dietary fibre, B vitamins and essential fatty acids (linoleic acid 49%, oleic 31%, palmitic 14%, linolenic 2.7% and stearic 2.1%) (Table 2.1) (FAO, 1995; USDA, 2014). Henley et al. (2010) considered that sorghum is an excellent source of iron and zinc when calculated at 10% bioavailability for iron and moderate bioavailability for zinc. Sorghum is also rich in B-complex vitamins which are essential for energy metabolism (USDA, 2014). The combination of the high energy content and B-complex vitamins is ideal for the energy utilization in the body (WHO/ FAO/ UNU, 2007).

Table 2.1: The nutrient composition of sorghum (per 100 g edible portion) and the percent of required nutrient intake (RNI) of children provided by the portion

Nutrients	**Unit**	**USDA (2014)**[b]	**% RNI** [a]
Protein	g	9.55	43-92
Carbohydrate	g	75	nd
Energy	kJ	1436	21-34
Fat	g	3.43	nd
Ash	g	Nd	nd
Total dietary fibre	g	6.7	nd
Minerals			
Calcium	mg	13	4-6
Iron	mg	3.5	49-73
Magnesium	mg	128	190-366
Phosphorus	mg	255	nd
Potassium	mg	361	nd
Sodium	mg	1	nd
Zinc*	mg	1.78	28-38
Copper*	mg	0.28	92
Manganese	mg	1.32	245
Selenium	mg	nd	<1
Vitamins			
Thiamin	mg	0.44	26-47
Riboflavin	mg	0.07	16-28
Niacin	mg	3.71	24-49
Pantothenate	mg	0.41	31-63
Vitamin B-6	mg	0.29	59-118
Folate	mg	nd	<1
Vitamin A	IU	<50	<1
Vitamin E	mg-ATE	0.5	<1

[a]Adapted from: WHO/ FAO/ UNU (2007) based on the required nutrient intake for children aged 3 to 9 years
[b]USDA Nutritional Value Database (2014);
*Food and Nutrition Board of the National Academy of Sciences (2001)
nd: no data

2.1.3 Sorghum proteins and amino acids

Protein is the second largest chemical component of the sorghum grain (Serna-Saldivar and Rooney, 1995).The protein content in sorghum ranges from 7-15% depending on the sorghum cultivar and environmental factors. As identified by Taylor and Schüssler (1986), sorghum grain has four protein fractions, namely the alcohol-soluble prolamins located in the endosperm, alkali-soluble glutelins also in the endosperm and the water-soluble albumins and globulins in the germ (FAO, 1995). The prolamins in sorghum are known as kafirins (Shewry et al., 1995) and comprise about 50-70 % of the grain protein (Duodu et al., 2003). Kafirins are of low protein quality as they are deficient in lysine (Table 2.2) but rich in leucine, proline and glutamine (Duodu et al., 2002). Kafirins are also protease resistant which reduces the nutritional quality of the sorghum proteins (Duodu et al., 2003). The globulins and albumins are much richer in lysine than the prolamins (Taylor and Schüssler, 1986). However, these fractions are predominant in the germ and pericarp which are removed on processing by milling, thereby substantially reducing the lysine content (Taylor, 2003).

Table 2.2: Approximate amino acid composition of sorghum protein (g/100g protein)

Amino acid	**Sorghum**[a]	**WHO Amino Acid requirement**[b]
Histidine	2.2	1.6
Isoleucine	3.8	3.1
Leucine	13.2	6.1
Lysine	2.0	4.8
Methionine + cystine	1.5	2.4
Phenylalanine + tyrosine	4.8	4.0
Threonine	3.1	2.5
Tryptophan	1.1	0.7
Valine	5.0	4.0

[a]USDA (2014);

[b]The pattern is based on the essential amino acid requirements of 3 to 10 year old children (WHO/ FAO/ UNU, 2007)

2.1.4 Sorghum utilization and effects of processing on nutritional quality

Many different food products are prepared with sorghum depending on the country and region. FAO and ICRISAT (1996) grouped sorghum traditional foods into four categories, namely flatbreads, porridges, boiled products and snacks. The common traditional foods in sub-Saharan Africa are thin porridge (gruel), thick porridge (fermented and unfermented); flat unleavened fermented bread like injera and unfermented bread such as chapatti (Anyango, 2009). Taylor and Emmambux (2008) also discussed some main foods from sorghum thin porridges, e.g. uji and ogi (Africa), stiff porridge e.g. tô (West Africa), couscous (Sahel region), injera (Ethopia), nasha and kisra (Sudan), traditional beers e.g. dolo and burukutu (West Africa) and baked products (USA, Japan, Africa).

In the production of these products, sorghum undergoes milling. During milling, the germ and the pericarp are usually removed yet they contain a significant proportion of lysine in the grain (Taylor and Schüssler, 1986). Hence, protein quality is reduced (Serna–Saldivar and Rooney, 1995) but the level of destruction is dependent on the milling process used (Kebakile et al., 2007). Decortication, an abrasive removal of the outer layers of the grain greatly reduces the nutritional quality of the sorghum grain as the lysine rich protein, minerals, B vitamins and dietary fibre concentrated parts are removed (Serna-Saldivar et al., 1994).

Wet cooking with water is a widely used method for cooking the thin and thick porridges. Wet cooking has been found to cause a reduction in protein digestibility in sorghum (Duodu et al., 2003). Protein digestibility reductions of 48% and 34% in whole condensed non-tannin red and white varieties were found. Also, Hamaker et al. (1986) observed about 20% reduction in protein digestibility in whole condensed non tannin sorghum. Hamaker et al. (1987) proposed two theories to explain the reason why kafirin digestibility was reduced on cooking. Firstly, it was proposed that kafirin proteins might form high molecular weight polymers bound by intermolecular disulphide bonds which may be less susceptible to digestion compared to the lower molecular weight protein units in the raw flour. Secondly, it was proposed that toughening of the outer edge of the kafirin protein bodies due to the formation of disulphide bonds or the formation of disulphide bound protein coat surrounding the protein body, making the protein bodies inaccessible for attack by the proteolytic enzymes.

Hassan and El Tinay (1995) found fermentation to increase the *in vitro protein digestibility* (IVPD) of tannin sorghums by up to 15%. Furthermore, Taylor and Taylor (2002) found up to 85% increase in protein digestibility. They suggested that higher protein content allowed more protein exposure to pepsin which resulted in the higher IVPD.

2.2 Cowpeas

2.2.1 Cowpea production and distribution

Cowpeas are one of the most widely adapted, versatile and nutritious grain legumes (Ehlers and Hall, 1997). It is a drought-resistant grain crop that is important for food and providing income to millions of the rural and urban poor in sub-Saharan Africa (Coulibaly et al., 2009). Cowpeas are important for food security for the poor people as it can be grown in dry areas where most staples like cereals do not grow effectively. World cowpea production is about 5.7 million tonnes with Africa producing 5.4 million tonnes, 95% of the global production in 2013 (FAOSTAT, 2015). In Africa cowpeas are widely grown in West and Central Africa (Singh et al., 2003; Coulibaly et al., 2009). Nigeria is the world's largest producer of cowpeas followed by Niger (FAOSTAT, 2015). In Africa, cowpeas are generally grown intercropped or in succession with maize, cassava, groundnuts, sorghum or pearl millet (Ehlers and Hall, 1997).

2.2.2 Cowpea nutrient composition

Table 2.3 shows the nutrient composition of cowpeas. The protein of cowpeas is located in the cotyledons, whereas the minerals are concentrated on the seed coat (Adebooye and Singh, 2007). Where decortication is applied, significant losses of the minerals can be experienced. Adebooye and Singh (2007) found a reduction in calcium of 29.1%, iron of 16.1%, manganese of 6.2%, magnesium of 16.5%, zinc of 16.5%, potassium of 7.4% and copper of 24.1% in two varieties of cowpeas. There were no significant effects on the protein content and amino acid profile of the cowpeas.

Cowpeas contain up to 18% oligosaccharides, raffinose, stachyose and verbascose (Ofuya and Akhidue, 2006). These oligosaccharides cause flatulence in people but they are beneficial as they can shorten transit time and promote growth of bifidobacteria (Onyenekwe et al., 2000; Ofuya and Akhidue, 2006).

Table 2.3: The nutrient composition of cowpea (per 100 g edible portion) and the percent required nutrient intake (RNI) for children (3 to 9 years) provided by the portion

Nutrients	**Unit**	**USDA (2014)**[b]	**% RNI** [a]
Protein	g	23.5	43-92
Carbohydrate	g	60	nd
Energy	kJ	1406	21-34
Fat	g	1.26	nd
Ash	g	3.24	nd
Total dietary fibre	g	10.6	nd
Minerals			
Calcium	mg	110	4-6
Iron	mg	8.3	49-73
Magnesium	mg	184	190-366
Phosphorus	mg	424	nd
Potassium	mg	1112	nd
Sodium	mg	16.2	nd
Zinc*	mg	3.4	28-38
Copper*	mg	0.8	92
Manganese	mg	1.53	
Selenium	mg	9.0	
Vitamins			
Thiamin	mg	0.9	26-47
Riboflavin	mg	0.2	16-28
Niacin	mg	2	24-49
Pantothenate	mg	1.5	31-63
Vitamin B-6	mg	0.35	59-118
Folate	mg	633	<1
Vitamin A	IU	50	1
Vitamin E	mg-ATE	0.5	<1
Vitamin K	mg	5	

[a]Adapted from: WHO/ FAO /UNU (2007) based on the required nutrient intake for children aged 3 to 9 years
[b]USDA (2014); nd= no data
*Food and Nutrition Board of the National Academy of Sciences (2001)

2.2.3 Cowpea protein and amino acids

The protein in cowpea is mainly globulins which are rich in lysine the first limiting amino acid in plant-based diets, glutamic acid and aspartic acid (Table 2.4). However, they are low in sulphur containing amino acids (Hallén et al., 2004). Globulins are the major protein fraction (Chan and Phillips, 1994; Freitas et al., 2004). Globulins are classified as 7S (vicilin) and 11S (legumins) according to their sedimentation coefficients (Duranti, 2006). The differences between vicilin and legumin are based on the structure and molecular weight of the proteins. Sathe et al. (2002) found that vicilin was a trimeric, glycosylated and a low molecular weight protein of approximately 150 to 180 kDa compared to the hexameric, nonglycosylated and high molecular weight of approximately 400 to 500 kDa legumin.

Table 2.4: Approximate amino acid composition of cowpea protein (g/100 g protein)

Amino acid	Cowpea[a]	WHO Amino Acid requirement[b]
Histidine	3.1	1.6
Isoleucine	4.0	3.1
Leucine	7.8	6.1
Lysine	6.8	4.8
Methionine + cystine	1.4	2.4
Phenylalanine + tyrosine	5.8	4.1
Threonine	3.8	2.5
Tryptophan	1.2	0.7
Valine	4.7	4.0

[a]Adapted from : USDA (2014);

[b]The pattern is based on the essential amino acid requirements of 3 to 10 year old children, WHO/ FAO/ UNU (2007)

2.2.4 Cowpea utilization and the effects of processing on nutritional quality

Cowpeas are primarily produced for human consumption in sub-Saharan Africa but it is also used as animal feed, a raw material for processing and green manure to improve soil fertility (Singh et al., 2003; Singh et al., 2011). For human consumption, the grains are the principal form (Ehlers and Hall, 1997) but the leaves are also used. The fresh leaves (Eastern Africa), fresh green pods (Asia and Carribean) and the fresh seeds (Senegal and southern USA) are eaten like vegetables (Ehlers and Hall, 1997). The green seeds are roasted to make snacks (like roasted nuts) and in soups when still green and tender, whereas when dried they can be used for stews and soups as well (Onyenekwe et al., 2000). The seeds can also be ground into flour that can be pressed into deep-fried cakes called "akara balls" or steamed cakes known as "moin-moin" (Taiwo, 1998; Kerr et al., 2001). The plant stems and leaves can be used to feed livestock and can be dried and kept for when the fodder is scarce (Singh et al., 2003). In addition to feed, cowpea plants also help in stabilising the soil and as a thick shade covering for the soil which preserves moisture. Moreover, as cowpea fixes nitrogen in the soil, it makes it more conducive for cultivation of other vegetables and staple crops (Singh et al., 2003).

Despite its high protein content, the use of cowpeas as food has been somewhat limited by the presence of indigestible oligosaccharides, particularly raffinose and stachyose (Onyenekwe et al., 2000). The oligosaccharides can be fermented by intestinal anaerobic microorganisms to produce flatulence (intestinal gas) (Ofuya and Akhidue, 2006). Moreover, antinutritional factors such as phytates and trypsin inhibitors which are responsible for reducing the digestibility of proteins by inhibiting protease activity and also lectins are found in cowpeas (Hallén et al., 2004).

Processing of cowpea grains is necessary to transform the grains not only to palatable food products but to also improve the functionality of the flours (Prinyawiwatkul et al., 1997). Traditional methods of processing cowpeas used at household level enhance the bioavailability of micronutrients (Hotz and Gibson, 2007). Thermal processing and processing technologies such as soaking, fermentation and germination have long been used.

Thermal processing can destroy certain antinutritional factors which results in improved bioavailability of micronutrients (Hotz and Gibson, 2007). However, it is not clear as to whether phytates are degraded by thermal treatments. Boiling and blanching have been shown to moderately reduce phytic acid (Hotz and Gibson, 2007). Cooking has also been shown to reduce oligosaccharides in cowpeas by 46 -50% and the mechanism is suspected to be by leaching since these oligosaccharides are heat stable (Onyenekwe et al., 2000).

In legumes, phytates are associated with the protein bodies (Reddy, 2002). Soaking reduces phytate levels (Lestienne et al., 2005). Soaking has also been found to reduce polyphenols and oxalates that inhibit iron and calcium absorption (Hotz and Gibson, 2007). Lestienne et al. (2005) found about 17-28% reduction in phytate in whole cowpea seeds after soaking for 24 hours at 30^{o}C. Oligosaccharides like stachyose and raffinose are also reduced by soaking. Onyenekwe et al. (2000) found a reduction of about 40% after soaking cowpea seeds for 16 hours.

Traditional fermentation induces phytate hydrolysis through the action of microbiological phytase enzymes which hydrolyze phytate to lower inositol phosphates (Hotz and Gibson, 2007). These resultant lower inositol phosphates do not have adverse effects on zinc and iron absorption. Fermentation also improves protein digestibility and quality in terms of amino acid composition and vitamin B content (Hotz and Gibson, 2007). In addition, fermentation also improves the microbial safety and keeping quality of the grain food product (Griffith et al., 1998). The end products of such fermentations are low molecular weight organic acids which have the potential to enhance iron and zinc absorption through the formation of soluble ligands while simultaneously generating a low pH that optimises the activity of endogenous phytase from cereal or legume flours (Hotz and Gibson, 2007).

Germination of cowpeas, apart from improving the protein content, was found to reduce phytate and other anti-nutritional factors (Khatoon and Prakash, 2004). Germination increases the activity of endogenous phytase activity in cereals and legumes through the activation of intrinsic phytase, *de novo* synthesis or both (Hotz and Gibson, 2007). The rate of phytate hydrolysis varies with the extent germination, moisture content, pH, temperature (optimal range 45-57^{o}C), solubility of phytate and presence of certain inhibitors. Additionally, germination has also been found to also reduce certain tannins and polyphenols in legumes and sorghum as a result of formation of polyphenol complexes with proteins and the gradual degradation of oligosaccharides which may facilitate iron absorption (Hotz and Gibson, 2007). Germinated grains can be used in composite weaning foods to increase the nutrient density and protein digestibility (Griffith et al., 1998). It can improve the nutritional quantity of legumes before they are incorporated into legume supplemented products such as cereal-legume composites. The improvement is a result of an increase in free essential amino acids and available vitamins and partial hydrolysis of starch (Onyenekwe et al., 2000).

2.3 Malnutrition

Malnutrition can be loosely translated as “bad feeding.” Bad feeding can be either too much or too little (FAO, IFAD and WFP, 2015). “Too much” intake of food is normally termed over-nutrition. This is a condition whereby more nutrients, especially macronutrients are consumed than required by the body. Over-nutrition often results in obesity and chronic cardiovascular diseases (FAO, IFAD and WFP, 2015). This condition was not an issue until recently in most developing countries. However, this has now become great concern as it contributes to the double burden (overnutrition and undernutrition) of malnutrition that these countries are facing. On the contrary, under-nutrition is whereby the body receives an inadequate amount of nutrients, which adversely affects growth and development functions (Whitney and Rolfes, 2013). This has long been known as a major nutritional problem in developing countries (FAO, IFAD and WFP, 2015).

Poverty in developing countries has been identified as the underlying cause of malnutrition and its determinants (Duncan, 2001; Sachs and McArthur, 2005). Poverty results in inadequate food intake which causes nutrient deficiencies. These deficiencies are explained as an insufficient supply of macro- and micronutrients that results in under-nutrition (Whitney and Rolfes, 2013). Micronutrients include vitamins and minerals. These are essential for regular growth and development of the body although required only in minute quantities (Sultan et al., 2014).

An inadequate supply of macro-nutrients, particularly carbohydrates and proteins results in Protein-Energy Malnutrition (PEM). Schofield and Ashworth (1996) defined PEM as a multi deficiency state that entails a range of clinical conditions. The severe conditions are marasmus, kwashiorkor and marasmic-kwashiorkor. In slight contrast, Muller and Krawinkel (2005) described PEM as an imbalance between nutrient supply and requirements, with children and women at child-bearing age being the most vulnerable groups.

Malnutrition greatly reduces physical growth and development (Brabin and Coulter, 2003). It also adversely affects mental development and increases the risk of diseases in children. In sub-Saharan Africa, an estimated 18% in Eastern Africa, 15% in Middle Africa, 12% in Southern Africa and 20% in Western Africa of children is underweight (FAO, IFAD and WFP, 2015). Whitney and Rolfes (2013) reported one child in six globally, to be born underweight, and one in four becoming underweight by the age of five. Malnutrition is also responsible for 75% of the deaths of children worldwide whereby an estimation of five children die every minute (Whitney and Rolfes, 2013). Some 220 million people in sub-Saharan Africa are affected by malnutrition (FAO, IFAD and WFP, 2015). This results in the vicious cycle of malnutrition and diseases. Death then becomes one of the consequences (FAO, IFAD and WFP, 2015).

Acute malnutrition which can be described as recent severe food deprivation is indicated by underweight which is characterised by wasting (Brabin and Coulter, 2003). Wasting is described as the loss or depletion of muscle and fat tissue in the body resulting in weight loss and folding skin (FAO, IFAD and WFP, 2015). An estimated 10% children under the age of five worldwide is affected by wasting (Whitney and Rolfes, 2013). Chronic malnutrition which can be described as long-term food deprivation was indicated by a short height for age, which is characterised as stunting. Stunting remains a challenging problem among children under five in many sub-Saharan African countries (Figure 2.1) (FAO, IFAD and WFP, 2015).

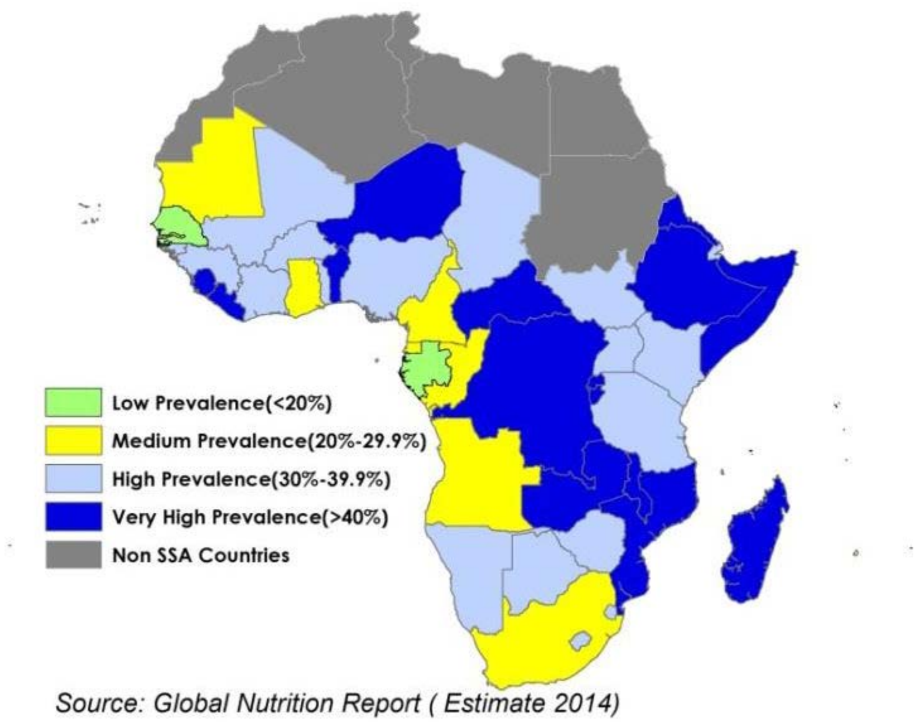


Figure 2.1: Prevalence of stunting in children under the age of 5 in sub-Saharan Africa (FAO, IFAD and WFP, 2015)

According to Brabin and Coulter (2003), wasting and stunting are indicative of an inadequacy in nutrients necessary to perform specific functions in the body. These nutrients could be protein, energy and /or micronutrients. Micronutrient deficiencies are sometimes called the Hidden Hunger as they are not obvious but damaging to the affected person (Sultan et al., 2014). Deficiency in minerals like iron, iodine, calcium and zinc can result in a number of diseases for example anaemia and goitre and disorders like growth retardation and brain disorders. In developing countries iron, iodine, zinc and vitamin A deficiencies are still major public health problems (Diaz et al., 2003). Preschool children and women of child bearing age are the most vulnerable groups for micronutrient malnutrition (Sultan et al., 2014) and for macronutrient malnutrition (FAO, IFAD and WFP, 2015).

2.4 Nutrient needs of school age children (3-10 years)

Protein and carbohydrates are the major macronutrients of concern with regard to the prevention of PEM. Carbohydrates are the main source of the energy and critical in proper blood sugar control (FAO/ WHO/ UNU, 2007). Energy requirement is defined as the amount of food energy needed to balance energy expenditure in order to maintain body size, composition and a level necessary and desirable physical activity consistent with long term good health (Otten et al., 2006; FAO/ WHO/ UNU, 2007). The average daily energy intake and requirement of children aged 3-10 years is between 4393 and 8700 kJ per day (Table 2.5). These estimates are based on the physical activity of the age group with considerations to the sedentary and the very active.

Proteins are necessary for proper growth and repair of cells and muscles as well as development of red blood cells. Inadequate supply of these macronutrients causes malnutrition in children, which results in difficulty in learning, fatigue, dizziness and weakness when observed over a short period of time (Brabin and Coulter, 2003). The required protein intake for children aged 3-10 years is between 13 and 34 g (Otten et al., 2006; FAO/ WHO/ UNU, 2007).

Table 2.5: Recommended Dietary Allowances (RDAs) for selected nutrients for children

Nutrient	**Unit**	**1-3years[a]**	**4-6 years[a]**	**7-10 years[b]**
Energy	kJ	4393	7100	8700
Protein	g	13	30	34
Calcium	mg	500	800	1 000
Iron	mg	7	10	8
Zinc	mg	3	10	8

[a] Adapted from WHO/ UNU/ FAO (2007)
[b]Institute of Medicine, (2004)

Protein intake has two major components: that for total nitrogen and that for indispensable amino acids (WHO/ FAO/ UNU, 2007). This means that a diet could be deficient in quantity or quality of protein. The frequent lack in quality of the protein of people's diets in sub-Saharan Africa is mainly due to the high dependency on cereal foods, which are lysine deficient (FAO, IFAD and WFP, 2015). On the contrary, legumes are widely available in the region and provide a richer source of protein (Ofuya and Akhidue, 2006). Furthermore, legumes are much rich in lysine than cereals. However, the use of legumes is limited by lack of innovative ways of processing because they take a long time to be cooked (Hallén et al., 2004).

Micronutrients are needed in small quantities in the body (Sultan et al., 2014). However, micronutrients are essential for good health. A deficiency can result in serious health problems (FAO, IFAD and WFP, 2015). Micronutrient deficiencies impair cognitive development and lower resistance to disease in children and adults (UNICEF, 2004). They increase morbidity and mortality risk of both mothers and infants from birth to early childhood. Micronutrient deficiencies also impair immunity and increase susceptibility to infectious diseases and mortality particularly amongst the vulnerable groups such as children and pregnant women. In adults, physical ability and economic productivity is greatly reduced by this lack (FAO, 2011).

Calcium is essential for development of strong bones and teeth. It is also vital for cell signalling, blood clotting, muscle contraction and nerve function (Sultan et al., 2014). The deficiency of calcium may result in osteoporosis, weak bones and teeth (FAO, IFAD and WFP, 2015). Since calcium is very important for the skeletal structure, it is important that children get sufficient amount. Children less than 3 years of age require 500 mg, 800 mg for children between 4 and 6 years and 1000 mg of calcium for children between 7 and 10 years (Institute of Medicine, 2004; FAO/ WHO/ UNU, 2007).

Iron serves as a carrier of oxygen to the tissues from the lungs through haemoglobin, as a transport medium for electrons within the cells and as an integrated part of important enzyme systems in various tissues (FAO, IFAD and WFP, 2015). Iron deficiency often results in anaemia and inadequate development of the brain and other tissues such as muscles. The highest prevalence of iron deficiency is found in infants, children, adolescents and women of childbearing age, especially pregnant women (FAO, IFAD and WFP, 2015). Children between the 3 and 10 years of age need 7-10 mg of iron per day (Table 2.5).

Zinc is an essential component for enzymes in the body and stabilises the molecular structure of cellular components and membranes (FAO, IFAD and WFP, 2015). Severe zinc deficiency may result in growth retardation and increased susceptibility to infections caused by defects in the immune system. Children that are less than 10 years of age need up to 10 mg of zinc daily (WHO/ FAO/ UNU, 2007).

2.5 Strategies for meeting the nutrient requirements of children

Brown (1991) and Khanum et al. (1994) described some of the strategies that have been developed to combat severe malnutrition in children. These strategies target weight gain and the correction of the nutrient deficiencies. They include the use of ready-to-use therapeutic foods, for example a paste made of peanut butter fortified with vitamins and minerals and a water-based F100 milk which was made for rehydration and electrolyte balance. These were used as medication for severely malnourished children. The paste was used for the children who can still eat food. Therefore small portions of the nutrient dense paste were fed to the children until the target weight was reached for the child’s age. The milk was intended for infants less than six months and severely malnourished children who were not able to take in solid food. The milk formula was fortified with micronutrients that will rehabilitate a severely malnourished child in a short time.

These therapeutic intervention strategies dealt with limiting the problem of malnutrition at an advanced stage in a short term. This has shown that solving malnutrition is not a simple task but requires a range of consistent approaches (Bhutta et al., 2008). The approaches include food-fortification, food supplementation, dietary diversification, food compositing, and biofortification through conventional breeding or genetic modification (GM) of staple crops.

In this study, a sorghum-cowpea extruded snack blend is investigated with the vision and potential of providing the necessary nutrients and enhancing nutrient intake in school-age children that are between 3 and 10 years.

2.5.1 Food fortification

Fortification refers to the addition of one or more nutrients in small amount to food with the aim of improving the nutrient status of that particular nutrient in the population that it is intended for (van Lieshout and West, 2004). The nutrient(s) added to the food can be normally present or not in the food but the main purpose is prevention or correction of a verified deficiency of that nutrient in a specific population (FAO, 2011). Fortification has been used for several years by countries wishing to reduce nutritional deficiencies most commonly of iron, iodine and vitamin A which are a major problem (FAO, 2011; Sultan et al., 2014). Cereals are major fortification vehicles of iron. This is because cereals are the crucial component in the diet in most developing countries. Fortification has been found to be better than other strategies because it requires little change in people's dietary habits and has been identified as the most economic method (Pinero et al., 2003). However, fortification requires a centralized food processing infrastructure, technical expertise and government oversight which are not available in rural areas of developing countries (Miller and Welch, 2013). It is a particularly effective way of tackling deficiencies in densely populated areas where it reaches a large number of consumers through retail purchase of foods.

2.5.2 Food supplementation

Supplementation is a short term approach used to alleviate nutrient deficiencies over a specific period of time (Van Lieshout and West, 2004). Supplementation helps to meet immediate deficits of vulnerable groups (FAO, 2011). Supplements are usually given in a form of a capsule, tablet and/ or injection highly concentrated with the vitamin or mineral that is deficient (FAO, 2014). Supplements can be used as a contingency when fortification seems to be too slow and then subsequently supported with a long term suitable and sustainable strategy. Supplementation is more suitable for a small population and is feasible for women when attending ante- and post-natal clinics because of the cost of effectively implementing supplementation (FAO, 2011).

2.5.3 Dietary diversification

Dietary diversification is explained by Ruel and Levine (2000) as a food-based strategy with an aim of increasing the availability, access, production, bioavailability and consumption of foods that are rich sources of the essential nutrients. This strategy is not heavily reliant on government support but mainly on community sensitisations. It is based on cultivation of vegetable gardens, use of indigenous foods, and proper food preparation, preservation, processing and storage (Tumwet et al., 2005).

2.5.4 Food Compositing

Composites are prepared by mixing or blending different components of food at a predetermined ratio (Duodu and Minnaar, 2011). Most composites are in flour or powder form. In such cases, flours from cereals, roots, tubers and/ or legumes are mixed to form the composite. Cereal-legume compositing is the most practical way of improving the protein quality of cereal foods which are staples and major source of food for the people living in Sub-Saharan Africa (Devi et al., 2013). This is because legumes are protein rich relative to cereals and generally provide a better content of amino acids, particularly lysine. Foods prepared from these composites normally have the following benefits: 1) overall increase in protein content as opposed to that of the cereal only, and 2) better amino acid balance due to the contribution of lysine by the legume and methionine by the cereals (Duodu and Minnaar, 2011).

Compositing cereal with legumes does not only affect the nutritional quality of composites, but also influences the functional, sensory and physicochemical qualities of the final food product. In addition to the compositing, the processing of the flours to form the composites can also have an effect on the sensory and physicochemical properties (Duodu and Minnaar, 2011). The ratio of the flours in the composites is also influential on the physical, sensory and nutritional characteristics of the final product. This in turn, can affect the consumer acceptability of the product.

2.5.5 Biofortification

Biofortification refers to the development of micronutrient-dense staple crops using the best traditional breeding practices and modern biotechnology (Nestel et al., 2006). Biofortification enables the efficient production of plant-based foods with high micronutrient concentration and bioavailability in their edible tissues (Carvalho and Vasconcelos, 2013). The major goal of a biofortification programme is to increase the density and bioavailability of micronutrients in staple crops (Carvalho and Vasconcelos, 2013). Biofortification of food crops is facilitated in three major strategies: 1) Agronomic biofortification whereby mineral elements with good mobility in the soil and plant are used (White and Broadley, 2005), 2) Conventional plant breeding which enhances the micronutrient concentrations of both minerals and vitamins in edible parts of plant tissues (Carvalho and Vasconcelos, 2013) and 3) Genetic engineering which is an alternative for increasing the concentration of and bioavailability of micronutrients in edible crop tissues in the absence of sufficient genotypic variation for the desired trait within the species (Mayer et al., 2008).

Biofortification can be effective in reducing the problem of malnutrition as part of a strategy that includes dietary diversification, supplementation, fortification and other aspects (FAO, 2014). Moreover, biofortification is viable for reaching out to rural areas where fortification is not possible (FAO, 2011). For example, biofortification of rice with provitamin A in India.

2.6 Ready-to-eat (RTE) food technologies

RTE technologies promote the use of local foods by transforming them to readily usable food products (FAO, 2014). They can provide convenience at relative low cost. RTE technologies are widely used in the production of breakfast cereals, expanded snacks and texturised vegetable protein (Singh et al., 2007). They involve thermal treatment with the addition of variable amounts of water and drying to produce a shelf-stable product (Mangala et al., 1999). RTE technologies have three major principles, namely: starch gelatinization which melts the starch and then prevents crumbling of the product; texture addition whereby the product is made crispy after expansion, and inactivation of anti-nutrients especially trypsin inhibitors in RTE legume products (Soukoulis and Aprea, 2012). RTE technologies include wet cooking, roller drying and flaking, popping and puffing, micronisation and extrusion (Kulp, 2000; Bellido et al., 2003; Ushukumari et al., 2004; Hoke et al., 2005; Mishra et al., 2014). These technologies are described briefly and extrusion cooking will be discussed in detail.

2.6.1 Wet cooking

Raw materials which may be whole grain or whole endosperm are cooked at atmospheric pressure or under pressure in a batch or continuous process (Kulp, 2000). The major drawbacks of wet cooking are energy inefficiency as water has to be heated and then removed to dry the product (Kulp, 2000). Also, often it is a batch process which makes it inefficient. Wet cooking can promote formation of disulphide-bonded protein polymers, for example in sorghum (Hamaker et al., 1986). Wet cooking of sorghum can also reduce protein digestibility, which is a drawback (Duodu et al., 2003). This may be due to the formation of disulphide bonded protein polymers, bringing about change in the secondary structure of sorghum (Hamaker et al., 1986).

2.6.2 Roller drying and flaking

Material for roller flaking is often pre-cooked by wet cooking, steaming, micronisation or extrusion (Ushukumari et al., 2004). The material is then squeezed between a pair of steel rolls in a continuous process. The rolls are heated with steam or electrically thus pregelatinizing the starch so that melted starch acts as glue (Mangala et al., 1999). To produce good flakes, the material has to be pre-moistened and allowed to stand for moisture to equilibrate in a process called tempering (Ushakumari et al., 2004).

2.6.3 Popping

Popping is a dry thermal treatment (Mishra et al., 2014). It is, for example, the final step in producing cornflakes and rice krispies. The material is passed through an oven at a very high temperature of about 300^{o}C for about 30 seconds in a continuous process (Mishra et al., 2014). The water in the material is instantaneously turned into steam. The escaping steam expands the starch granules and hence the product giving characteristic blisters on the surface, for example of cornflakes and holes in rice krispies. Complete drying also makes the product crispier (Nath and Chattopadhyay, 2007).

As popping is an explosive process it results in fragmentation of the cell walls of the vitreous endosperm of cereals such as maize and sorghum (Mishra et al., 2014). This was shown to improve the accessibility of protein components within the endosperm to enzymes resulting in better protein digestibility of popped compared to wet cooked sorghum (Parker et al., 1999). Apart from enhancing protein and carbohydrate digestibility, popping has been found to enhance the appearance, colour, taste and aroma of grains such as finger millet (Mangala et al., 1999).

2.6.4 Gun and oven puffing

Puffing is used to produce products such as puffed wheat, rice puffs for snacks and instant sorghum porridges. It is a low moisture cooking process. The whole grain and a little water or steam is put in a pressure vessel and heated up to 220^{o}C under pressure (Hoke et al., 2005). A trip valve is released and water is instantaneously turned into steam which then causes the starch granules to explode thus expanding the product. Puffed cereals readily absorb water because of the high porosity of the starch matrix responsible for the rapid hydration of the puffed cereals and the predominance of capillary water absorption (Lai and Cheng, 2004). High water uptake is a good characteristic in the manufacture of RTE cereals.

2.6.5 Micronisation

Micronisation is a continuous process of cooking dry grains with infrared radiation (Bellido et al., 2003). It involves intense heat treatment which cooks the food in a short exposure time by electromagnetic radiation in the infrared region of the spectrum. In the process, rapid heating at the surface leads to cracking, which allows rapid water penetration when the product is being cooked (Žilić et al., 2010). This leads to some starch melting and some starch granule expansion as a result of vaporisation of water (Batham et al., 2013). Micronisation also reduces microbial activity, inactivates enzymes, increases digestibility of food products. Further, it creates rapid cooking products from legumes such as lentils and cowpeas (Arntfield et al., 1997; Cenkowski and Sosulski, 1997) and beans (Bellido et al., 2003). Mwangela et al. (2006) showed that micronisation reduces cooking time. Micronisation also increases starch gelatinization in lentils and barley (Arntfield et al., 1997; Fasina et al., 1999). Furthermore, micronisation results in protein denaturation in cereals and legumes and the denaturation is more pronounced with the water- and salt-soluble proteins, albumins and globulins (Zheng et al., 1998).

2.7 Extrusion cooking

Extrusion cooking is a process that combines several unit operations, including mixing, cooking, kneading, shearing, shaping and forming (Riaz, 2013). An extruder is used to facilitate the aforementioned operations (Figure 2.2). An extruder is a device that speeds up shaping and restructuring of the food ingredients (Riaz, 2012). Extruders can be classified according to the method of operation as cold extruders or extruder cookers and according to the method of construction as single- or twin-screw extruders. The principles of operation are similar for all types (Riaz, 2013).

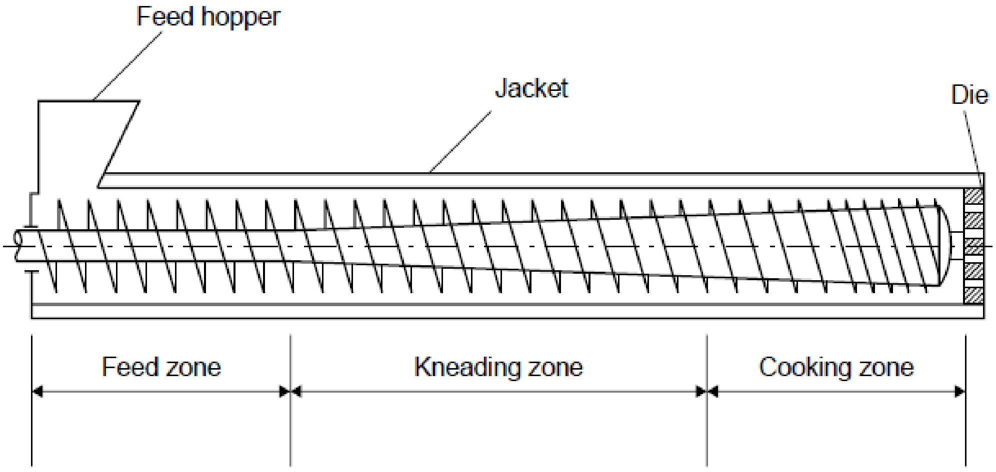


Figure 2.2 An illustration of a single-screw extruder operation (Riaz, 2013)

The feed material enters through feed hopper then conveyed by the screw inside the barrel. During the conveying, the screw compresses and shears and/ or kneads the feed to transform it to a semi-solid plasticized mass (Riaz, 2013). In extrusion cookers, food is heated by a steam-jacketed barrel and/or by a steam heated screw. The barrel in a cooking extruder can be divided into three parts based on their function. These are feeding, kneading and cooking zones as illustrated in Figure 2.2. The feeding zone mixes, moistens and heats the granular material fed in to obtain a compressed uniform mass (Lewicki, 2004). The kneading zone compresses, with some shearing and heating about 100^{o}C and above to produce a hot melted, viscous and plasticized material. In the cooking zone the mass is further compressed, sheared and heated. In this zone there is a substantial change in the pressure flow of the barrel which results in a highly sheared mass (Lewicki, 2004). The cooking temperatures in the cooking zone are high but mostly dependent on the product type. Compression in the barrel can be achieved by increasing the diameter of the screw and decreasing the screw pitch, using a tapered barrel with a constant or decreasing screw pitch, or placing restriction in the screw flights.

Extrusion of foods is dependent on the following variables: feed moisture, feed composition, feed particle size, feed rate, barrel temperature, screw speed, screw configuration, and die geometry (Meng et al., 2010). These variables coupled with material properties determine the degree of macromolecular transformations during the extrusion process, which in turn affect the rheological properties of the food melt in the extruder and, consequently, the product characteristics of extrudates. Temperature, mixing mechanism, moisture content and residence time distribution are mainly responsible for a certain physical state of the extrudate and the quality attributes of final product in extrusion cooking. For example, texture is often dependant on extrudate viscosity (Moscicki and van Zuilichem, 2011). Extrusion cooking exposes food molecules to heat and shear force causing chemical reactions that change the component structure of the food. These changes include gelatinization of starch and denaturation, realignment and cross-linking of protein (Björck and Asp, 1983; Singh et al., 2007). Such changes affect the physical, chemical, nutritional and sensory properties of the end product.

2.7.1 Effects of extrusion cooking on proteins

Singh et al. (2007) noted that the protein digestibility of extrudates is higher than non-extruded products because of denaturation of the proteins and inactivation of anti-nutritional factors that impair digestion. The denaturation of the proteins exposes enzyme active sites. Extrusion cooking inactivates the trypsin inhibitor through the high temperature and mechanical shear. These cause intense structural deformation and denaturation which change the protein configuration, thus inactivating the trypsin inhibitor activity (Devi et al., 2013). Nwabueze (2007) observed a reduction of trypsin inhibitor activity by 88 to 91% in products from corn (maize)-soy blends. Moreover, extrusion cooking has been shown to improve protein digestibility of common beans, which was attributed to the reduction or elimination of the anti-nutrients by thermal treatment (Alonso et al., 2000). Phytates are known to interact with protein to form complexes which increases the degree of cross-linking (Reddy et al., 1985). The cross-linking decreases the solubility of proteins making the protein complexes less susceptible to proteolytic enzyme.

Proteins are denatured when subjected to extrusion cooking. The combination of temperature and shear weakens the bonds which stabilize the tertiary and quaternary structures of protein (Singh et al., 2007). During extrusion, protein molecules unfold and align themselves in the direction of material flow towards the die as shown in Figure 2.3 (Day and Swanson, 2013). The unfolding of the proteins exposes amino acids that were folded in, so they can react with reducing sugars and other food components.

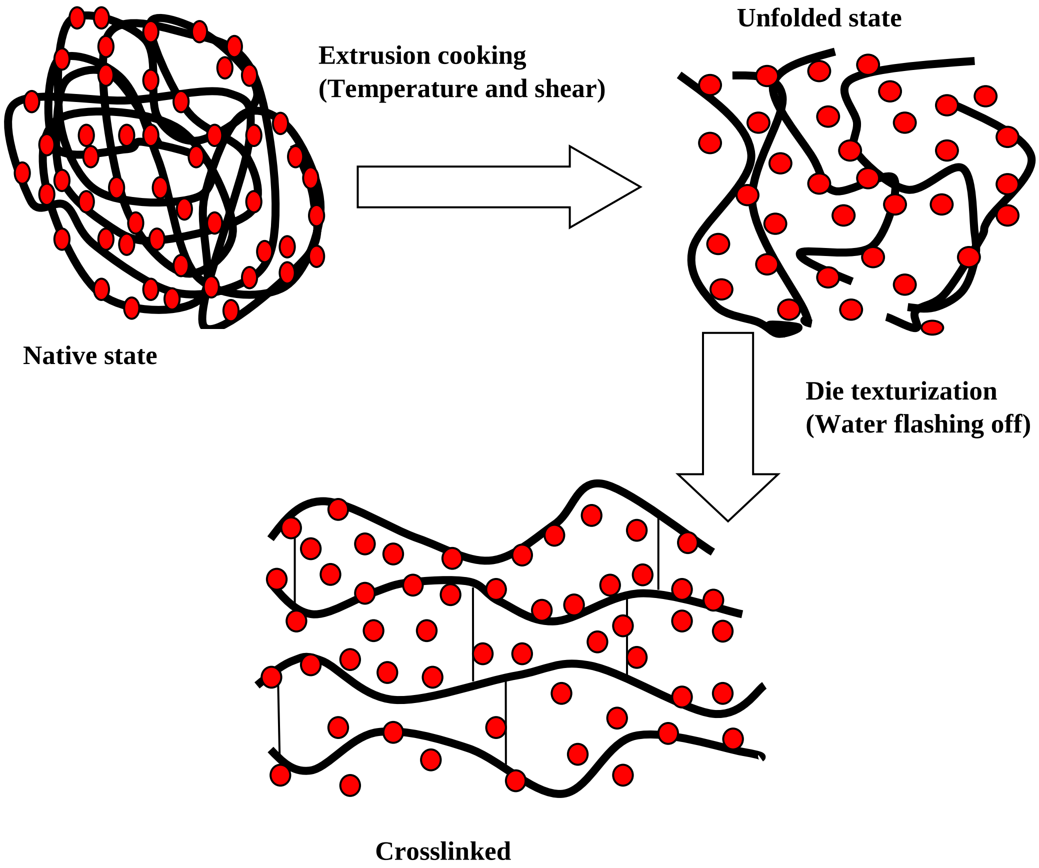


Figure 2.3: Schematic diagram of a protein molecule unfolding, aligning with the flow in the extruder barrel. Circles represent amino acid residues and straight lines represent disulphide bridges (Riaz, 2006).

Extrusion cooking involves high temperature in combination with low water content, a favourable condition for Maillard reaction (Björck and Asp, 1983). Lysine is the most reactive protein-bound amino acid due to its free ϵ-amino group. In addition to lysine, Camire (1991) and Iwe et al. (2001) noted that arginine, tryptophan, cysteine and histidine are also vulnerable to the reaction.

Reduction in the availability of lysine during processing can be divided into three phases (Björck and Asp, 1983). The first follows first order kinetics and is rapid. The second phase is the transition zone. In this phase, increases in available lysine occur with increase in processing time. The last phase after short recovery stabilizes the available lysine levels with no further losses of lysine.

During extrusion cooking, reducing sugars may be formed by hydrolysis of starch and dietary fibre fragments with sucrose thus increasing Maillard activity (Singh et al., 2007). Lysine retention during extrusion cooking is strongly influenced by process temperature. High feed moisture content significantly improves retention. Improved lysine retention at higher moisture content can be explained by the law of mass action since water is produced in the reversible phase of Maillard reaction. Lysine retention has been found to be enhanced by an increase in screw speed which reduced the resident time in the barrel of the product and the reduction in die diameter (Iwe et al., 2001).

2.7.2 Effects of extrusion cooking on starch

Starch is regarded as the most important component in the extrusion process (Pérez-Navarrete et al., 2008). Starch composition and content affect the expansion and texture of extrudates. Cooking and gelatinization of starch increases its susceptibility to amylase hydrolysis, mainly due to hydration of starch granules and partial solubilisation of starch molecules (Cheftel, 1986). Despite the low water content during extrusion, complete gelatinization is usually possible. The susceptibility of cereal starches to α-amylase hydrolysis has been found to increase two-fold with increasing extrusion temperature (Akdogan, 1999). In vitro digestibility of extruded rice starch was found to be comparatively higher than that of raw material because of physical disruption of the granule structure in combination with gelatinization (Hagenimana et al., 2006). Particle size is one factor that appears to influence the rate of the α-amylase in vitro digestion. The starch digestibility of legumes such as common beans also increases after extrusion (Alonso et al., 2000).

2.7.3 Effects of extrusion cooking on dietary fibre

Dietary fibre mainly comprises non-starch polysaccharides and lignin that are resistant to digestive enzymes (Björck and Asp, 1983). Degradation may occur in processes that involve shear. Degradation of fibre is inversely proportional to the size of the fibre particles. Disruption and homogenization of bran particles by the intense mechanical treatment during extrusion cooking were suggested by Singh et al. (2007) to render dietary fibre more available for fermentation. Severe extrusion cooking conditions can cause an apparent increase in dietary fibre due to the formation of amylase resistant starch fractions (Cheftel, 1986).

2.8 Sensory properties of extruded cereal-legume composites

Legume composites have a lower expansion ratio than materials with lower protein content like cereals (Devi et al., 2013; Olapade and Aworh, 2012). Texture analyses conducted on cowpea composites have shown that the lower expansion results in a harder product. In a study by Olapade and Aworh (2012), expanded snacks made from acha (fonio) and cowpea composites had a lower expansion ratio than typical puffed, light and crispy snacks. This was found to be due to polymers formed by the protein matrix which limit expansion and the type of starch available from the acha. Composite extrudates have a low moisture content. The low moisture content correlates with the crunchy texture (Olapade and Aworh, 2012; Filli et. al., 2013) and shelf-stability. Snacks with low moisture are also generally light and crispy (Filli et al., 2013).

Legumes have been associated with a beany flavour (Olapade and Aworh, 2012). The beany flavour was a character of most of the products made from sorghum-legume composites (Pelembe et al., 2002; Anyango, 2009; Serrem et al., 2011). This beany flavour is attributed to the action of lipoxygenase enzyme which catalyses the formation of carbonyl compounds, which are known to have a pungent smell (Björck and Asp, 1983).

Cereal-legume composite products, due to their high protein contents, have been associated with a darker colour. In a study by Hallén et al. (2004), bread had a progressively darker colour with an increase in cowpea content. Serrem et al. (2011) observed a darker colour in the composite biscuits. This darkening is attributed to an increased Maillard reaction taking place during baking or processing because of the high lysine content of the cowpeas (Ilo and Berghofer, 2003). Lysine is very reactive because of the ϵ-amino group which make it prone to such degradative reactions (Iwe et al., 2001).

2.9 Role of snacks in the diet

Snacking has increased enormously in recent years more especially with life getting busier and parents not having time to prepare home cooked meals (Henry-Unaeze and Ibe, 2013). Snack foods were found by Shukla (1994) to contribute largely to the diet of many individuals particularly children and can influence overall nutrition. This is attributed to the changes in lifestyle and eating patterns (Priyanka et al., 2012). The most widely consumed snacks are made from cereals due to their good expansion characteristics (Meng et al., 2010). Consumers appreciate snacks that have a good taste, smell, mouthfeel and nutrition value (Priyanka et al., 2012). Extrusion cooking has made it possible for food manufacturers to meet these demands of consumers. This process enables different shapes, texture, colour, and appearances with minimal changes to the machine and at a reasonable cost (Riaz, 2006). However, most expanded snacks are made from maize or other cereal flour or starches that are low in protein and have low nutritional value (Iqbal et al., 2006).

The use of high protein ingredients like whey proteins, soy flour and soy protein isolate (Chaiyakul et al., 2009; Devi et al., 2013) and legumes like common beans and cowpeas (Alonso et al., 2001; Filli and Nkama, 2007; Anton et al., 2009; Kumar et al., 2010) have been studied to enhance the protein content and quality of extruded snacks. Compositing cereals with legumes have proved to be the most applicable way for enhancing the protein quality and addressing issues of PEM (FAO, 1996).

2.10 Extruded snack quality

Expansion is an important quality measure in extruded snacks that determines the textural properties (Moraru and Kokini, 2003). Expansion is dependent on the interaction of shear, temperature and moisture in the extruder. The increase in shear and control of energy distribution responses (melt temperature, torque and pressure) using screw configuration, speed and reverse screw elements determines the degree of puffing (Sokhey et al., 1994). Expansion is also dependent on the starch content and composition. Other components like protein, lipids, fibre and sugar can be considered as diluents (Moraru and Kokini, 2003). High amylose content results in hard and less expanded extrudates. However, for maximum expansion 50% amylopectin is required. High amylopectin content yields light, elastic and homogenous expanded textures (Mercier and Feillet, 1975). The lower degree of expansion obtained from high amylose flours is due to the alignment of the linear amylose chains in the shear field making it difficult to pull apart during expansion (Moraru and Kokini, 2003). At a given moisture content, amylopectin starches are not as hard as amylose starches which allow greater expansion (Kokini et al., 1992).

The addition of protein decreases the expansion ratio of extrudates. This was evident in studies by Li et al. (2005) and Veronica et al. (2006) whereby soy protein decreased the expansion ratio and increased the hardness in snacks. Similarly, Anton et al. (2009) found that an increase in level of bean flour resulted in a decrease in expansion. This was attributed to the decrease in starch, increase in protein concentration and the presence of fibre which interacts with the other components. Fibre on its own has the potential to rupture gas cell walls and preventing air bubbles from expanding to their optimal potential (Anton et al., 2009). Proteins reduce expansion by altering water distribution in the matrix and through their macromolecular structure and conformation, which affect the extensional properties of the extruded melts. Furthermore, proteins increase the number of sites for cross-linking which forms extensive networking through covalent and non-bonding interactions during extrusion resulting in compromised textural quality (Onwulata et al., 2001).

2.11 Conclusions

Research on the compositing of sorghum with cowpeas has focused mainly on the manufacture of traditional foods. This was successful in the nutritional and sensory aspects of the food products. However, these food products require a time allocation for sitting and consumption, whereas times have changed. Currently, everyone is so busy and there is hardly time allocation for meal preparation (Henry-Unaeze and Ibe, 2013). Preparation of traditional foods seems tedious and time consuming. In the case of school-going children, during breaks they need ready-to-eat, easy and conveniently packed snacks in lunch boxes that will be eaten without any confinement. The extruded snacks are ideal in such situations. However, it appears that the commercially available produced snacks are made from cereal grains only which compromises their nutritional quality. Therefore, extruded snacks made from sorghum-cowpea blends have potential to be nutritionally adequate and at the same time provide the convenience that parents and school children expect.

3. HYPOTHESES AND OBJECTIVES

3.1 Hypotheses

Extruded snacks made from sorghum and cowpea blends will have substantially improved nutritional quality, in terms of protein content and quality protein digestibility and mineral content than sorghum extruded snacks. This is because cowpeas contain 20-25% protein (USDA, 2014) and globulins which are high in lysine, the limiting amino acid in sorghum. The replacement of some of the less digestible sorghum kafirins (Duodu et al., 2003) by globulins will improve the protein digestibility of the blends. Furthermore, extrusion cooking enhances the reduction in protein digestibility of kafirins (Pelembe et al., 2002, Singh et al., 2007). Cowpeas are also known to be rich in mineral content which will increase the micronutrient bioaccessibility of the snack (Ofuya and Akhidue, 2006).

Extruded snacks made from sorghum and cowpea composites will have some altered sensory attributes compared to snacks made from sorghum only. Compositing cereal with legumes not only affects the nutritional quality of composites, but also influences the functional, sensory and physicochemical qualities of the final food product (Duodu and Minnaar, 2011). Legumes are associated with a beany flavour (Anyango, 2009) which will be imparted to the rest of the formulation. Lipoxygenase enzymes catalyse the formation of carbonyl compounds which are responsible for the pungent beany flavour (Boge et al., 2009). Composite snacks will also have a low expansion ratio, resulting in hardness which is due to additional protein that hardens the starch thereby hindering the starch expansion (Olapade and Aworh, 2012). Composited snacks will be darker than sorghum snacks because of the high protein content which favours Maillard reaction during processing (Ilo and Berghofer, 2003).

3.2 Objectives

1. To determine the effects of compositing sorghum with cowpeas on the protein–energy and micronutrients content and protein quality of the extruded snack blends as a means to address PEM in school going children.

2. To determine the effects of compositing sorghum with cowpea on the sensory properties (appearance, aroma, flavour, mouthfeel and texture) of the extruded snacks as these are detrimental to the snack acceptability to the consumers.

4. RESEARCH

Effects of compositing sorghum with cowpea on the chemical, nutrient quality and sensory properties of extruded snack blends

Abstract

Protein-energy malnutrition is a major problem in sub-Saharan Africa and predominant in children and women. Extruded snacks are made by a simple technology and are palatable, convenient and have a long shelf-life. Snacks were made from 100% red non-tannin sorghum and composites made from addition of 25% and 50% cowpea flour to the sorghum. In one treatment each blend was flavoured with 1% salt. The nutritional, instrumental and sensory properties of the snacks were evaluated. Inclusion of cowpeas increased the protein content of composites by 25% and 53%, respectively. The *in vitro* protein digestibility was increased to 92 and 51% for the multi-enzyme and pepsin assays respectively because of the soluble globular proteins in cowpeas. Lysine contents of composite snacks were 3.69 and 4.65 g/100 g protein. This contributed to the two fold increase in lysine scores. Moreover, calculated Protein Digestibility Corrected Amino Acid Scores of the composite snacks were increased by over 100% through cowpea inclusion. Mineral content of extruded snacks was slightly improved on cowpea addition. However, the presence of phytate in cowpeas increased the phyate: mineral ratio thereby decreasing mineral bioaccessibility. Instrumental colour and sensory analyses showed darkening of colour on addition of cowpeas. This was probably a result of Maillard reaction. The beany flavour also increased with cowpea ratio. This is of concern with regards to the acceptability of the composite snack. Masking of the flavour through commercial flavours is suggested. Texture analyses revealed that cowpea inclusion had no significant influence on the hardness of the snacks. The expansion ratio of snacks was increased on cowpea addition. This work shows that sorghum-cowpea snacks have potential to be used as a protein-rich complementary food to address PEM in school-age children.

4.1 Introduction

Snacks are ready-to-eat, convenient and widely consumed by people of all ages. They provide short-term satiety. Snacks are often manufactured using extrusion cooking technology. Extrusion cooking is defined as a multi-variable unit operation that combines mixing, shearing, cooking, puffing and drying in a continuous process (Devi et al., 2013). The extrusion of the snacks involves the use of cereal staples which produce the expanded extrudates that are generally flavoured and dried for desired sensory attributes that favours consumption. Sorghum is a cereal that can be used in the manufacture of expanded snacks. Sorghum is a major food crop because of its drought tolerance (Taylor et al., 2006) and providing a good source of energy and antioxidants (Duodu et al., 2003). However, sorghum has inferior protein quality because the main storage proteins (prolamins) are deficient in the indispensable amino acid lysine (Taylor et al., 2006).

Cowpeas are a vital component of diets in the developing countries of Africa as a valuable source of protein to complement cereals (Phillips et al., 2003). They are also a very good source of dietary fibre, vitamins and minerals (Uzogara and Ofuya, 1992). Although cowpeas are rich in lysine, they are deficient in sulphur containing amino acids (Phillips et al., 2003). Furthermore, the consumption of cowpea is limited by the lack of convenient food applications. The nutritional composition of cowpeas makes them complementary to the cereals such as sorghum (Egounlety and Aworh, 2003). Hence, nutritious snacks can be made from the combination of the two products. This would also optimize the use of these products and at the same time, help address the issue of malnutrition.

Compositing sorghum with cowpea can improve the nutritional value of extruded snacks. School-going children are major consumers of snacks during school breaks and lunches. This is because of their affordability and convenience. The use of extrusion technology in the production of the snacks from the composites enhances better nutrient retention and nutrient quality, more especially the proteins (Singh et al., 2007). This will in turn ensure a production of sorghum-based snacks of high nutritional quality and convenience whilst at the same time addressing PEM in school going children.

In the production of extruded snacks for school-going children, determining the sensory properties of these snacks is of utmost concern to ensure that the product delivers product wise and acceptable to consumers. This also enables survival in the market amongst other products. Sensory evaluation is defined as a scientific method that evokes, measures, analyses and interprets responses to products as perceived through the senses of sight, smell, taste, touch and hearing (Stone and Sidel, 2004). The colour, texture, aroma and flavour of the snacks are the major drivers for the acceptability of the snacks more especially to school-going children. This study aims to develop and characterise the extruded snacks in terms of colour, texture, aroma and flavour attributes and through quantitative descriptive sensory evaluation.

4.2 Materials and methods

100% sorghum or sorghum and cowpea flour (25% and 50%) with half a portion with 1% salt added

↓

Extrusion cooking (up to 150^{o}C, 350 rpm and 20% moisture) for each portion (non-salted and salted)

↓

Oven drying at 100^{o}C for 7 minutes and then cooling to room temperature

↓

Packing snacks in 35 x 40 mm ziplock bags for sensory evaluation.

↓

Descriptive sensory evaluation of the three different snack blends both salted and non-salted.

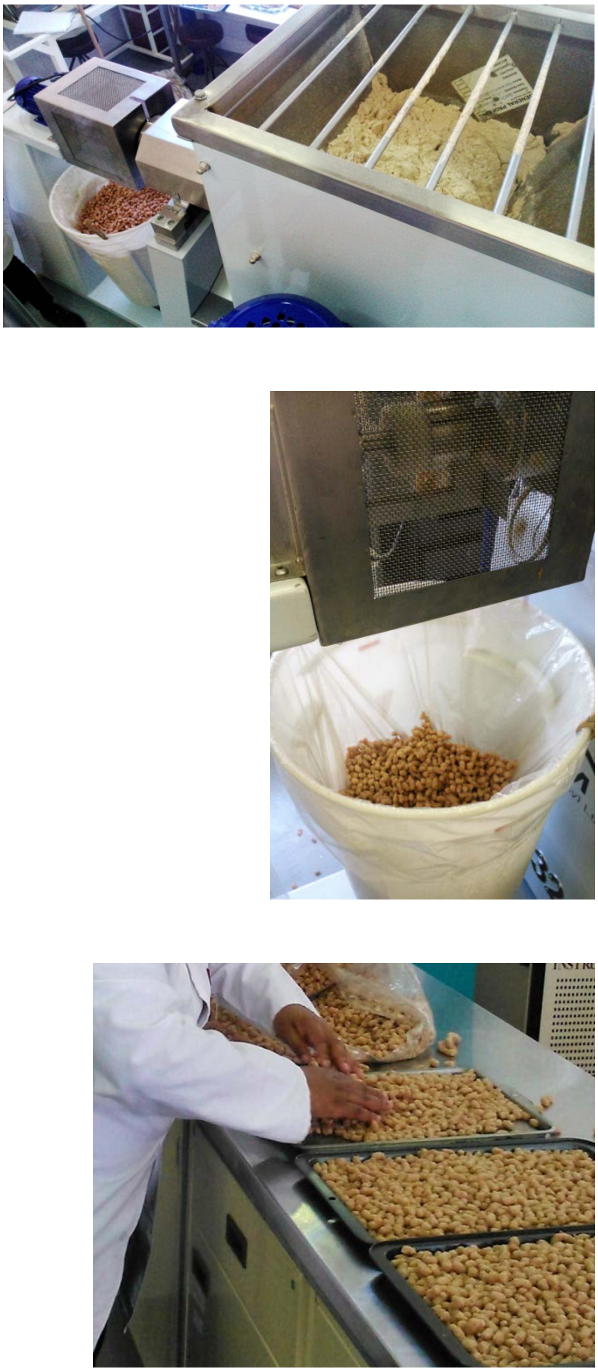


Figure 4.1: Flow diagram for preparation of extruded snack blends

Preparation of grain flours and composites

Cowpea grains of Glenda variety were used in the study. The cowpeas were a 2014 harvest from Potchefstroom, North-west Province, South Africa purchased at AGRICOL, Silverton Pretoria. Monati refined sorghum meal was used in the study. The sorghum meal was purchased at Foodcorp wholesale outlet in Randfontein, Gauteng Province. The meal was milled from decorticated red, non tannin sorghum grains.

The cowpea grains were cleaned first to remove stones and foreign materials and were then milled twice using an industrial hammer mill (Drotsky S1, Alberton, South Africa) fitted with a 1mm opening screen to give whole grain flour. The sorghum meal was also milled in the hammer mill using the same screen for uniform particle size (≤1mm) distribution in all the flours.

Composite meals were prepared by mixing sorghum and cowpea meals at ratios of 75:25 and 50:50 (w/w) in an industrial bowl mixer (Talsa, Mix 90 ST, Spain). The meals were mixed for 30 minutes at 15 minutes rotation intervals for homogeneity. A half portion of each ratio was salted with 1% salt (w/w) and mixed. The meals were then stored in closed plastic buckets at 5^{o}C prior to snack preparation.

4.2.1. Sample preparation

The meals were extruded using a co-rotating twin screw extrusion cooker (CFAM Technologies, model TX 32, Potchefstroom, South Africa). The three different compositions based on the sorghum cowpea ratio were extruded on different days. The 100% sorghum meal was extruded first, followed by salted 100% sorghum flour on the same day. The next session was for the 75:25 sorghum-cowpea ratio without salt then salted and lastly the 50:50 sorghum-cowpea ratio. The cooking temperatures ranged from 60^{o} to 150^{o}C (60, 80, 100, 110, 140 and 150^{o}C for zone 1,2,3,4 and 5, respectively) at 450 rpm screw speed. The machine dosing rate was approximately 2.8 L/hour. The feed rate was approximately 20 kg/hour. The extrudates were put into oven trays then dried in a convection oven (Unox, Italy) at 90^{o}C for 10 minutes, then packaged in plastic bags, stored in 20 L buckets tightly closed at 5^{o}C.

4.2.2 Proximate analyses

Moisture

The moisture content of the flours, their composites and milled snacks was determined by an oven drying method, the American Association of Cereal Chemists (AACC) International (2000) Method 44-15A. The samples were accurately weighed to approximately 2 g and dried in a forced draught oven at 103^{o}C for 3 hours.

Crude fibre

The crude fibre content of the snack powder was determined by a ceramic fibre filter method, AOAC (2000) Official method of analysis 962.09. The samples were digested in sulphuric acid and sodium hydroxide solutions then rinsed. The residue was then heated in a muffle furnace at 550^{o}C for 5 hours.

Crude fat

The crude fat was determined by a Soxhlet extraction method, AACC International (2000) Method 30-25. The samples were extracted with petroleum ether for 4 hours. The ether was then removed from the collection flask at low temperature volatilization. The residual fat was dried in a forced draught oven at 103^{o}C for 30 minutes.

Ash

The ash (mineral) content was determined according to AACC International (2000) Method 08-01. Two grams of milled samples were weighed into oven dried crucibles and charred. The charred samples were heated in a muffle oven at 550^{o}C for 5 hours.

Protein

Protein contents (N x 6.25) of the flours, composites and milled snacks were determined by a Dumas combustion method, the AACC International (2000) Method 46-30.

Carbohydrates

Total carbohydrate was calculated as the difference of:

$100 - (\%moisture + \%ash + \%crude\ fat + crude\ protein)$.

Energy

Energy content was calculated using the Atwater calorie conversion factors, based on the assumption that each gram of protein, fat and carbohydrate yield 17 kJ, 37 kJ and 17 kJ, respectively (FAO, 2003).

4.2.3 *In vitro* assays for protein quality

Pepsin protein digestibility

A pepsin digestion method based on that of Hamaker et al. (1987) was used. Samples were digested with porcine pepsin ≥250 units/ mg solids (P7000) (Sigma-Aldrich, St Louis, MO) for 2 hours at 37^{o}C. The soluble products of digestion were carefully pipetted off using a Pasteur pipette. The residue was then washed with distilled water, centrifuged and the resultant supernatant pipetted off again. The residues were dried at 100^{o}C overnight in a forced draft oven and the protein content of the residual material determined by Dumas combustion. *In-vitro* protein digestibility was calculated using the difference between the initial total weight of the protein and the residual weight of the protein after pepsin digestion, and expressed as percentage of the total protein.

Multienzyme protein digestibility

The multienzyme protein digestibility assay was based on that of Hsu et al. (1977). Aqueous protein suspension of samples was prepared by dissolving finely milled samples in distilled water. The sample suspensions pH was then adjusted to pH 8 using either 0.1M HCL and /or NaOH. A multienzyme solution prepared from bovine trypsin,13000-20000 BAEE units/mg protein (T03030, Sigma-Aldrich), chymotrypsin type II, 60 units/mg protein (C4129, Sigma-Aldrich) and protease XIV, 3.5 units/mg solids (P5747, Sigma-Aldrich) was then added to the adjusted suspensions and incubated in a water bath at 37^{o} C. The drop in pH of the solution was recorded over 10 minutes at 1 minute intervals. The *in vitro* protein digestibility was calculated using the regression equation of Hsu et al. (1977), which is

$Y = 210.46 - 18.10x$; where Y is the *in vitro* digestibility (%) and X is the pH of the sample suspension after 10 minutes of digestion.

4.2.4 Lysine content

The lysine content of samples was determined using the Pico-Tag method which is a reverse phase HPLC procedure (Bidlingmeyer et al., 1984). In this method, the lysine containing sample is put into a test tube with 6M HCL to yield free amino acids and hydrolysed for 22 hours at 110-115^{o}C. After hydrolyses the acid was evaporated in a flash evaporator and the sample derivatized. The resultant sample was then analysed by the reverse phase HPLC.

4.2.5 Protein Digestibility Corrected Amino Acid Score (PDCAAS)

PDCAAS is a standard measure of how well the protein can be used by the body and has been adopted as the official method for predicting protein quality of food based on human amino acid requirements (WHO/ FAO/ UNU, 2007). The PDCAAS was determined using the *in vitro* protein digestibility (Pepsin and Multienzyme methods), lysine content of extruded snacks and the lysine requirement pattern for children 3-10 years old. PDCAAS was computed using the following equations (WHO/ FAO/ UNU, 2007):

$$Amino\ acid\ score = \frac{mg\ of\ lysine\ in\ 1\ g\ test\ protein}{mg\ of\ lysine\ requirement\ pattern\ (3-10\ year\ olds)}$$

$$PDCAAS = in\ vitro\ protein\ digestibility \times lysine\ score$$

4.2.6 Minerals

The mineral contents of samples were determined according to Zasoki and Barau (1977). In this method, samples were digested in nitric-perchloric acid for an hour and digests were diluted by deionized water to 35 mL. The diluted digests were then filtrated using a filter paper (Whatman, ashless, grade 40). Zinc, Iron and calcium were determined for the extruded snacks as per the different ratios. The mineral content of the filtered samples was determined by applying Inductively Coupled Plasma- Optical Emission Spectrometry (ICP-OES).

4.2.7 Descriptive Sensory Evaluation

4.2.7.1 Panel selection

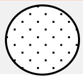
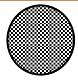
Fifteen panels were selected from the trained panel that evaluates for the Department of Food Science at the University of Pretoria. The panel was selected on the basis of committed availability for the sensory training and evaluation sessions in November 2014. The panel was required to be available twice in a week on Tuesdays and Thursdays for two hours per day. Twelve people were available and three were recruited from the panel that evaluates on Mondays and Wednesdays.

4.2.7.2 Panel training

The panel was trained for 4 hours in a week for 3 consecutive weeks on the sensory attributes of sorghum and cowpea related food products. Since this was a trained panel, sorghum extruded snacks were given to them to evaluate and propose descriptors that best described the snacks. The descriptors were written and the common descriptors were compiled for each extruded snack. Using consensus, the sensory attributes were discussed and approved. After the descriptors were decided on, the reference samples were prepared to depict the ends of the scale of each attribute. Each attribute was defined and with the help of the reference samples the scales were anchored.

The extruded snacks were packed in 65 x 80 mm ziplock type bags and coded with random 3 digit code and given to the panel in trays to evaluate. The panel was trained to start by evaluating the appearance of the snacks in the plastic ziplock bag. They opened the ziplock bag and smelled the product for aroma attributes. The snack was then taken out of the bag and rubbed against the tongue to determine roughness. The panel was then required to bite one snack with the front teeth for hardness and monitor the sound that comes with the breaking of the snack when crushed. From there, the flavour and the mouthfeel were evaluated during mastication. Lastly, the aftertaste was evaluated when the snack was swallowed. The panel undertook a trial session in the sensory laboratory. The Compusense Five®software (version 4.6 Compusense, Guelph, Ontario, Canada) was used to rate the attributes in the six snacks.

Table 4.1: The descriptors, their definitions and the references used in the evaluation of the extruded snacks

Attributes	Description	Reference
Appearance		
Colour intensity	Intensity of colour as observed by the eye.	1 9
Visible specks	Quantity of red or brown specks on the surface of the snack.	1  9 
Rough surface	A visual assessment of holes and grooves in the snack.	1= not rough (surface of a peanut cotyledon without skin) 9= very rough (more holes)
Aroma		
Overall aroma	The intensity of the aroma in the snack.	1= not intense 9 = very intense
Dried grass aroma	Intensity of aroma associated with dry brown grass wetted.	1= not detectable 9= intense (dried grass wetted)
Cooked cereal grain aroma	Intensity of aroma associated with cooked starchy cereal grains.	1= not detectable 9= intense (boiled rice)
Earthy aroma	Intensity of aroma associated with wet soil.	1= not detectable 9= intense (wet loam soil)
Woody aroma	Intensity of aroma associated with wet woods.	1=not detectable 9= intense (wet tree bark)
Cocoa aroma	Intensity of aroma associated with cocoa powder	1= not detectable 9= intense (nestle cocoa powder sniffed from the can)
Roasted cereal aroma	Intensity of the aroma associated with roasted cereals like maize.	1=not detectable 9= intense (roasted maize seeds)
Roasted nut aroma	Intensity of aroma associated with roasted nuts	1= not detectable 9= intense (roasted peanut)
Burnt nut aroma	Intensity of aroma associated with burning nuts on the shell.	1=not detectable 9= intense (burnt peanuts on the shell)
Sawdust aroma	Intensity of aroma associated with dry wood.	1= not detectable 9= intense (sawdust from gum tree)
Texture and flavour		
Roughness	The degree of abrasiveness of the snack surface when rubbed against the tongue.	1=not rough (Surface of a nut cotyledon) 9=very rough (Bokomo buttermilk rusks sides)
Hardness	The force required to cut through the snack when using the molars.	1=not hard (Beacon marshmallows) 9= very hard (buttermilk rusks)
Crunchiness/	The sound perceived when crushing one	1= not crunchy

crispness	unit of the snack by the molars	(marshmallow) 9= very crunchy (extruded maize snacks spicy beef flavour, Niknaks, Isando, South Africa)
Overall flavour intensity	The intensity of the snack flavour	1= not intense 9=very intense
Boiled nut flavour	The intensity of flavour associated with boiled nuts.	1= not nutty 9=very nutty (boiled peanuts)
Roasted nut flavour	The intensity of flavour associated with roasted nuts.	1= not nutty 9=very nutty (roasted peanuts)
Dried grass flavour	The intensity of flavour associated with wet dry grass.	1= not grassy 9=very grassy (wheat bix)
Starchy flavour	The intensity of flavour associated with starchy food.	1= not starchy 9=very starchy (white maize porridge)
Beany flavour	The intensity of flavour associated with beans or legumes.	1= not beany 9= very beany (boiled jugo/ bambara nuts)
Burnt nut flavour	The intensity of flavour associated with burnt nuts.	1= not detectable 9= very strong (burnt roasted peanuts)
Astringent	The intensity of flavour associated with the drying of the mouth.	1= not astringent 9=very astringent (five roses tea;6 teabags in 1L water)
Earthy flavour	The intensity of flavour associated with soil.	1=not earthy 9=very earthy (steamed brown mushroom)
Bitter	The intensity of flavour associated with bitterness.	1=not bitter 9=very bitter (cocoa powder)
Sweet	The intensity of flavour associated with sugar taste.	1=not sweet 9= very sweet (1 tbs sucrose dissolved in 200 mL water)
Sour	The intensity of flavour associated with acid.	1= not sour 9= very sour (clover plain yoghurt)
Salty	The intensity of flavour associated with sodium chloride.	1=not salty 9= Very salty (1 tbs dissolved in 200 mL water)
Cocoa flavour	The intensity of flavour associated with cocoa powder.	1= not detectable 9=very strong (tasted in powder form)
Woody flavour	The intensity of flavour associated with wet wood.	1= not woody 9=very woody
Rate of break down on the mouth	The speed at which three snacks are chewed and ready to be swallowed.	1= takes longer time 9=very fast (melt in the mouth)

Moisture absorption	The amount of saliva required to masticate the snack.	1=little moisture (moist) 9=more moisture (dry)
Doughiness	The rate at which the snack forms dough before swallowing.	1=not doughy 9=very doughy (lightly cooked bread)
Graininess	The amount of small grains residing in the mouth during mastication.	1=not grainy 9=very grainy (Sasko whole grain bread)
Aftertaste		
Astringent aftertaste	The dry feeling in the mouth after swallowing.	1=not astringent 9=very astringent
Bitter	The bitterness remaining after snacks have been swallowed.	1=not bitter 9=very bitter
Sour	The sour taste that remains in the mouth after swallowing.	1=not sour 9=very sour
Nutty	The nutty taste remaining in the mouth after swallowing.	1=not nutty 9=very nutty
Umami	The umami taste that lingers in the mouth after swallowing. Common to foods that contain monosodium glutamate.	1=not umami 9=very umami (meaty taste)
Metallic	The metallic taste that remains after swallowing	1=not metallic 9= very metallic (placing the keys in the tongue)

4.2.7.3 Sample evaluation

The samples (5 g) were placed into ziplock bags and coded using random 3 digit code and randomly served to the panel. The samples were served all at once. The snacks were placed in serving trays in the order they were to be evaluated. On the serving trays were the snacks with tray number, serviette and the polystyrene cup for water. Water was used as a pallet cleanser. The samples were served at 25^{o}C. They were served through the sensory lab booths and the ratings were done in the computers using the Compusense® Five software.

4.2.8 Instrumental colour analyses

The snacks were crushed into powder using an electric blender and the powder was decanted into transparent petri dishes. A Chroma meter CR-400 (Konika Minolta Sensing, Osaka, Japan) was used to measure L* (100 perfect lightness, 0 for black), a* (positive values for reddish colours and negative values for greenish ones) and b* (positive for yellowish colours and negative for the bluish ones) values. Chroma meter was first calibrated using a white tile before measurements were taken. Measurements were randomly taken at the surface of the petri dish along the circumference. Three readings were taken for each petri dish and values recorded. Five samples were observed for each composition and recorded.

4.2.9 Instrumental texture analyses

The texture analyses of the different extruded snacks (100% sorghum, 75:25 sorghum-cowpea and 50:50 sorghum-cowpea; salted and non-salted of each) were determined using the TA.TX2 type Texture Analyser (Stable Microsytems, Godalming, UK). The maximum compression force of extruded snacks was used to measure the hardness when cut through a blade. A vertical force was applied to the snack diameter at a crosshead pre-test speed of 1 mm/sec, test speed of 3 mm/sec, post-test speed of 10mm/sec and distance of 3 mm. The maximum peak force was recorded. Thirty samples were taken for each composition measurement. The higher the maximum peak forces the harder the snacks.

4.2.10 Expansion Ratio

Extrudate expansion ratio was determined using vernier callipers to measure the diameter of the extruded snacks in mm. The resultant diameter was divided by the die size of the extrusion cooker. A mean measurement of 20 snacks was taken for each blend flavour (i.e. salted and non-salted).

4.2.11 Statistical analysis

The effects of compositing sorghum with cowpea on the nutritional, sensory, chemical, colour and textural properties of snack blends were evaluated using multivariate Analysis of variance (ANOVA) based on a 5% level of significance. Statistica was used for data analyses (Statistica Version 10.0, Statsoft, Tulsa, Arizona). The significant differences between means were then compared using the Fisher's least significant difference (LSD) test.

4.3 Results and discussion

4.3.1. Proximate and chemical composition

Extrusion cooking considerably reduced the moisture content of the extruded snacks when compared to their corresponding flours (Table 4.3.1). The water reduction is presumably as a result of flashing off of moisture which took place during the expansion (150^{o}C) and oven drying (100^{o}C). The 50:50 sorghum-cowpea extruded snacks retained more moisture compared to the other formulations. The water retention can be attributed to the ability of the cowpea protein to hold moisture because of more binding sites available during extrusion which enhances protein unfolding (Camire, 1991).

Cowpea inclusion increased the fibre content of the composites progressively (Table 4.3.1). This was as a result of the high fibre content (10.6%) of cowpeas (USDA, 2014). It is worthy of note that the cowpea flour used in the study was whole grain cowpea flour. This could have contributed to the large increase in the fibre content. Extrusion cooking had no effect on the fibre content of the extrudates (Table 4.3.1).

The inclusion of cowpea flour greatly reduced the fat content of the composite flours. Sorghum flour had a higher fat content (2.4%) than the composites (2.2 and 1.6% respectively) (Table 4.3.1). This is because sorghum has a higher fat content (3.4%) than cowpeas (1.3%) (USDA, 2014). Extrusion cooking apparently reduced the fat content of the extruded snacks. This can be attributed to the formation of complexes with the fat during shearing in extrusion which would make the fat difficult to extract. Camire (1991) described a reduction in the extractability of fats and lipids after extrusion cooking with the method of extraction having a major effect on the content measured. Using non polar-solvents for extraction yielded less lipids as compared to using acid hydrolysis. In this present study solvent extraction was used, hence the apparent reduction in the fat content of extrudates. Additionally, some lipids may actually be lost through steam distillation when water flashes off during expansion of the extrudates out of the die (de Roos, 2006).

The inclusion of 50% cowpea significantly increased ash content of the flour (Table 4.3.1). This can be attributed to the high ash content in cowpeas (3.2%) (USDA, 2014). The ash content of extrudates was higher than that of raw flours, presumably as a result of the release of bound minerals during extrusion.

The sorghum-cowpea composites had higher protein content as compared to that of sorghum (Table 4.3.1). The increase in protein content was proportional to the amount of cowpea flour added. The 75:25 and 50:50 sorghum-cowpea ratios showed a 25% and 53% increase respectively. The increase is because cowpeas have much higher protein content (approximately 25%) than sorghum (approximately 9.6%) (USDA, 20l4). These findings are similar to those of Pelembe et al. (2002) where the protein content in extruded sorghum-cowpea composite instant porridge increased proportionally with percentage cowpea addition. Anyango et al. (2011) also found an increase of protein content of 57% in traditional sorghum foods that were composited with cowpea at a ratio of 70:30 sorghum-cowpeas. The extrudates had a higher protein content than the raw flours because they had lower moisture content than the flours (Table 4.3.1).

The daily protein requirements for children between the ages of 3 and 10 years increase from 13 to 34 grams (WHO/ FAO/ UNU, 2007). The composite snacks contained 13 and 16 g protein/ 100 g. Thus, a 30 g serving of 50:50 sorghum-cowpea extruded snacks would provide almost 15% of the daily protein requirement of children of 10 years.

The carbohydrate content decreased with addition of cowpea flour (Table 4.3.1). The decrease was proportional to the amount of cowpea flour added. Sorghum has more carbohydrates (75%) compared to that of cowpeas (60%) (USDA, 2014). The higher content of carbohydrates in sorghum is mainly provided by the starch. Starch is the main component in the sorghum grain and is about 75-79% of the grain weight (Waniska et al., 2004) and only about 45-48% in cowpeas (USDA, 2014).

Sorghum snacks had high energy levels because of the high fat content (3.4%) as compared to cowpeas (1.3%) (USDA, 2014). Fat is the major contributor to energy because one g fat is equivalent to 37 kJ whereas one g of carbohydrates or proteins is equivalent to only 17 kJ (FAO, 2003). Although the energy levels of sorghum snacks were significantly higher than that of the composites, the overall energy content of all the snacks was good. The energy requirement of children from ages 3 to 10 years ranges between 4393 and 8700 kJ per day (WHO/ FAO/ UNU, 2007). The consumption of a 30 g serving of the 50:50 sorghum-cowpea snacks would provide about 5 to 11% of the energy daily requirement depending on the child’s age.

Table 4.3.1: Effects of compositing sorghum with cowpea flour and extrusion cooking on the chemical composition (g/100 g) of raw flours and extrudates

Formulation	Raw/ Extrudate	Moisture	Crude fibre	Crude fat	Ash
100% Sorghum	Raw flour	$12.18^{d} \pm 0.04$	$1.04^{a} \pm 0.01$(1.18)	2.44^{d} ±0.06 (2.78)	$1.00^{a} \pm 0.00$ (1.14)
100% Sorghum	Extrudate	$5.51^{a} \pm 0.08$	$1.09^{a} \pm 0.05$ (1.15)	0.23^{a} ±0.04 (0.24)	$1.50^{b} \pm 0.00$ (1.59)
75:25 Sorghum-Cowpea	Raw flour	$11.89^{c} \pm 0.19$	$2.17^{b} \pm 0.06$ (2.46)	2.15^{c} ±0.03(2.58)	$1.00^{a} \pm 0.00$ (1.13)
75:25 Sorghum-Cowpea	Extrudate	$5.76^{a} \pm 0.04$	$2.06^{b} \pm 0.09$ (2.19)	0.29^{a} ±0.08(0.26)	$1.50^{b} \pm 0.00$ (1.59)
50:50 Sorghum-Cowpea	Raw flour	$11.73^{c} \pm 0.00$	$3.38^{c} \pm 0.03$ (3.83)	1.59^{b} ±0.19 (1.80)	$2.00^{c} \pm 0.00$ (2.27)
50:50 Sorghum-Cowpea	Extrudate	$6.18^{b} \pm 0.14$	$2.94^{c} \pm 0.04$ (3.13)	0.29^{a} ±0.01(0.21)	$2.00^{c} \pm 0.00$ (2.13)

Formulation	Raw/ Extrudate	Protein	Carbohydrates[1]	Energy[2] (kJ)
100% Sorghum	Raw flour	$9.72^{a} \pm 0.03$ (11.07)	$74.67^{a} \pm 0.05$ (85.03)	1525^{b} ±2
100% Sorghum	Extrudate	$10.70^{b} \pm 0.01$ (11.32)	$82.07^{b} \pm 0.13$ (86.86)	1585^{d} ±1
75:25 Sorghum-Cowpea	Raw flour	$12.17^{c} \pm 0.08$ (13.81)	$72.80^{c} \pm 0.30$ (82.62)	1524^{b} ±3
75:25 Sorghum-Cowpea	Extrudate	$13.27^{d} \pm 0.06$ (14.08)	$79.19^{d} \pm 0.18$ (84.03)	1583^{d} ±1
50:50 Sorghum-Cowpea	Raw flour	$14.84^{e} \pm 0.01$ (16.81)	$69.84^{e} \pm 0.21$ (79.12)	1498^{a} ±4
50:50 Sorghum-Cowpea	Extrudate	$16.34^{f} \pm 0.00$ (17.42)	$75.19^{f} \pm 0.16$ (80.14)	1567^{c} ±2

Mean values ± standard deviation with different letters in a column differ significantly at $p<0.05$;
Content on dry basis given in parentheses
n=2
[1]Calculated using the difference (100-(% moisture+ % ash + % fat +% protein))
[2]Calculated using the following conversion factors: protein 17 kJ/g, fat 37 kJ/g and carbohydrates 17 kJ/g.

4.3.2 Protein Quality

4.3.2.1 In vitro Protein digestibility

Table 4.3.2 shows that compositing sorghum with cowpea generally increased the *in vitro* protein digestibility (IVPD) of flours in both the multi-enzyme and pepsin methods. An approximately 9% increase for the 75:25 sorghum-cowpea ratio and about 15% increase for the 50:50 sorghum-cowpea composites was found using the multi-enzyme IVPD. The pepsin IVPD increase was rather greater, 25% and 41% for the 75:25 and 50:50 sorghum-cowpea ratios, respectively. The increase in IVPD can be attributed to the cowpea globulin proteins, which are aqueous soluble (Chan and Phillips, 1994) in comparison to the sorghum prolamin and glutelin proteins which are insoluble (Duodu et al., 2003). Similar increases in the IVPD of sorghum-cowpea composites were reported by Vilakati et al. (2015) with porridge and Anyango et al. (2011) with traditional African sorghum foods namely injera, ugali and uji.

Table 4.3.2: Effects of compositing sorghum with cowpea and extrusion on protein digestibility (%) using the multi-enzyme and pepsin methods

Formulation	Raw/Extrudate	Multi-enzyme (%)	Pepsin (%)
100% sorghum	Raw	79.64^{a}(0.45)	45.25^{b}(5.08)
100% sorghum	Extrudate	80.32^{a}(0.26)	34.85^{a}(3.33)
75:25 sorghum cowpea	Raw	87.28^{b}(0.26)	56.58^{c}(0.78)
75:25 sorghum cowpea	Extrudate	90.28^{c}(0.05)	48.45^{b}(1.17)
50:50 sorghum cowpea	Raw	91.36^{c}(0.27)	63.66^{d}(0.86)
50:50 sorghum cowpea	Extrudate	92.00^{c}(0.13)	51.02^{bc}(0.46)

Mean values with different letters in a column differ significantly at p<0.05; Standard deviation given in parentheses
n=3

Extrusion cooking resulted in little or no change in IVPD when using the multi-enzyme method, whereas the pepsin method gave 10, 8 and 12% point decrease in the IVPD for 100% sorghum, 75:25 and 50:50 sorghum-cowpea composites, respectively (Table 4.3.2). This difference is presumably due to Maillard reaction between amino groups and reducing sugars facilitated by extrusion. This Maillard reaction could result in the formation of low molecular weight nitrogenous reaction products which have antioxidant activity which can inhibit protein digestion (Oste and Sjödin, 1984). It is possible that the pepsin IVPD method was sensitive to the inhibitory effect of the Maillard reaction products as only one enzyme is used, unlike the multi-enzyme method (Vilakati et al., 2015). In addition, the pepsin IVPD method only estimates hydrolysis in the stomach (Boisen and Eggum, 1991) which gives the low IVPD. On the contrary, the multi-enzyme IVPD estimates hydrolysis in the stomach, small intestine and hind-gut of simple-stomach animals (Hsu et al., 1977). Therefore, more bonds will be hydrolysed by the multi-enzyme than the pepsin at the same time.

However, these results are contrary to the findings of Vilakati et al. (2015) who found high IVPD of extruded sorghum and micronized cowpea composites. The difference is probably because the cowpeas in this study were extruded and not micronized (infrared) heated whole which was the case in a study by Vilakati et al., (2015). Also, Singh et al. (2007), in a review, stated that extrusion cooking increases IVPD through protein denaturation and inactivation of enzyme inhibitors present in raw plant foods. Therefore, the high temperatures (above 100^{o}C) used in extrusion cooking were expected to some extent to enhance inactivation of protease inhibitors in the flour and increase protein digestibility. Although this was not the case, it is worthy of note that protein digestibility of extrudates is affected by a number of parameters and residence time in the barrel (Alonso et al., 2001). These influence the degree of protein denaturation and destruction of antinutritional factors and could have contributed to the different findings.

4.3.2.2 Lysine content and lysine scores

Lysine is well-known as the first limiting indispensable amino acid in cereals (WHO/ FAO/ UNU, 2007). As expected, sorghum had the lowest lysine content (Table 4.3.3). Inclusion of cowpeas substantially increased the lysine content of extrudates. The lysine content increase was 98% and 150% for 75:25 and 50:50 sorghum-cowpea ratio, respectively. The increase is due to the high protein lysine content (6.8%) of cowpeas compared to that of sorghum (2%) (USDA, 2014). The lysine requirement for children between 3-10 years is 4.8 g (WHO/ FAO/ UNU, 2007). Adding 50% cowpeas to the blend increased the lysine content to about 97% of the lysine daily requirement. A consumption of a 30 g 50:50 sorghum-cowpea blend would provide 29% of the daily requirement of lysine for a child aged between 3 and 10 years.

The sorghum lysine score of 0.39 for 3-10 year olds was far below the WHO/ FAO/ UNU (2007) score. A similar finding of 0.35 for extruded sorghum was found by Vilakati et al. (2015). Adding 25% cowpeas largely increased the scores (Table 4.3.3). The addition of 50% cowpeas significantly improved the scores to 0.97, essentially 1. Generally, lysine scores were increased by almost two folds on addition of cowpeas.

4.3.2.3 Protein Digestibility Corrected Amino Acid Score (PDCAAS)

As stated, PDCAAS is a standard measure of how well the protein in a food can be used by the body (WHO/ FAO/ UNU, 2007). The 100% sorghum formulation gave the lowest PDCAAS due to its low lysine content (Table 4.3.3). Generally, inclusion of cowpea increased the PDCAAS of the extruded snacks. The increase with the multi-enzyme IVPD was by 122% and 187% for the 75:25 and 50:50 sorghum-cowpea ratios, respectively. With the pepsin assay the increase was higher, 184% and 277% for the 75:25 and 50:50 sorghum-cowpea ratios. Similar increases in PDCAAS for sorghum-micronized cowpea porridge blends were found by Vilakati et al. (2015). Anyango et al. (2011) also found increases in PDCAAS after compositing traditional African sorghum foods with cowpea.

The WHO/ FAO/ UNU (2007) has recommended PDCAAS values of 0.72 and 0.79 as a reference for children less than 5 years and 4-10 years, respectively. The PDCAAS obtained for the 75:25 sorghum-cowpea composite snacks was slightly below the references when using multi-enzyme IVPD (Table 4.3.3). However, the 50:50 sorghum-cowpea composite in the multi-enzyme IVPD scored 8% higher than the reference for children 4-10 years old (0.79).

The pepsin assay gave the lowest PDCAAS values. The PDCAAS values of 0.14, 0.37 and 0.49 for the 100% sorghum, 75:25 and 50:50 sorghum-cowpea ratios were far lower than the recommended values of 0.72 and 0.79 for children up to ten years. This shows a limitation of the utilization of the sorghum protein due to inefficient digestion (WHO/ FAO/ UNU, 2007). This can be attributed to only limited hydrolysis of the protein by pepsin (Boisen and Eggum, 1991).

Table 4.3.3: Effects of inclusion of cowpeas on the Lysine content, amino acid score and Protein Digestibility Corrected Amino Acid Score (PDCAAS) of extruded snacks

						In-vitro Protein digestibility (%)[f] (from Table 4.3.2)		PDCAAS [g]	
Formulation	**Protein [a](g/100 g, dry basis)**	**Lysine [b] (g/100 g)**	**Lysine [c](g/100 g protein)**	**Lysine [d](mg/g, protein)**	**Lysine scores [e]**	**Multi-enzyme**	**Pepsin**	**Multi-enzyme**	**Pepsin**
100% Sorghum	11.3	0.21±0.00	1.86	18.6	0.39	80.3	34.9	0.31	0.14
75:25 Sorghum-Cowpea	14.1	0.52±0.01	3.69	36.9	0.77	90.3	48.5	0.70	0.37
50:50 Sorghum-Cowpea	17.4	0.81±0.03	4.65	46.5	0.97	92.0	51.0	0.89	0.49

[a] Mean values from Table 4.3.1
[b]Values are means ± standard deviation (n=2)
[c] Values calculated as follows: (100 g protein content x lysine content per 100 g)/ (protein content per 100 g sample)
[d] Values calculated as follows: (grams of lysine per 100 g protein) x (1000 mg)
[e] Lysine scores as follows :(mg of lysine in 1g protein)/ (mg of lysine requirement pattern); lysine requirement pattern is 48 for 3-10 year olds (WHO/ FAO/ UNU, 2007)
[f] Mean values from Table 4.3.2
[g] PDCAAS= Lysine score x IVPD

4.3.3 Mineral content

Compositing sorghum with cowpea did not significantly contribute to the iron content of the blends (Table 4.3.4). This was because the iron content of the cowpeas used in the research was low (5.2 mg/ 100 g) when compared to the USDA's National Nutrient Database value (8.3 mg/ 100 g) (USDA, 2014). The zinc content of composites was slightly increased by adding cowpea flour. Adding cowpea made a significant contribution to the zinc content of the snacks at a 50:50 sorghum-cowpea ratio. The increase in the zinc content can be attributed to the high zinc content of cowpeas (3.4 mg/100 g) compared to that of sorghum (1.78 mg/100 g) (USDA, 2014).

Inclusion of cowpea flour substantially contributed to the calcium content of the composites (Table 4.3.4). The calcium content in 100% sorghum was nearly doubled and tripled in the 75:25 and 50:50 sorghum-cowpea composites, respectively. This is because cowpeas had much higher calcium content (72 mg/100 g) compared to the 16 mg/100 g present in sorghum. An even much higher calcium content of 110 mg/100 g in cowpeas and a mere 13 mg/100 g in sorghum is given by the USDA National Nutrient Database (USDA, 2014). The differences in mineral contents between data can be attributed to the varieties used and the growth environment as they influence the chemical and nutritional composition of grains (Rooney and Serna-Saldivar, 2003).

The increase in mineral contents in the composites show the potential of the 50:50 blend to provide significant quantity of some essential minerals for school-going children. A 30 g serving of the 50:50 sorghum-cowpea snacks would provide 17% iron, 21% zinc and 2% calcium of the daily requirements for a 3 year old child (WHO/ FAO/ UNU, 2007).

Table 4.3.4: The effects of compositing sorghum with cowpea flour on mineral contents (mg/100 g)

Formulation	Iron	Zinc	Calcium
100 % Sorghum	3.35±0.70[a] (3.70)	1.49±0.06[a] (1.61)	16.21±2.74[a] (17.41)
75:25 Sorghum-Cowpea	3.93±0.61[a] (4.28)	1.66±0.09[a] (1.83)	29.86±2.54[b] (32.73)
50:50 Sorghum cowpea	4.05±1.19[a] (4.42)	2.13±0.16[b] (2.33)	45.29±6.27[c] (49.27)
*100 % Cowpea	5.21 (5.58)	2.47 (2.77)	72.59 (79.91)

[a] mean values with different letters differ significantly at p ≤0.05 ; ± standard deviation
Dry basis mean values in parentheses
n=4
*Calculated value from the formulation

However, the consumption of a 30 g portion of the snacks would not guarantee that the minerals would be readily available to the children. The presence of anti-nutritional factors like phytate in plant based food sources limits the utilization of such minerals in the body (Hallén et al., 2004). Legumes such as cowpeas have a higher phytate content than cereals such as sorghum (Kumar et al., 2010). This is shown by the increase in phytate content with the increase in cowpea ratio (Table 4.3.5).

The phytate: iron molar ratio decreased very slightly, but not significantly, with the increase in cowpea ratio (Table 4.3.5). The 21-23:1 ratios were very high. For improved bioaccessibility of iron, the phytate: iron ratio should be substantially less than 14:1 (FAO, 1992). Thus, the iron in the snacks was bound to the phytate rendering it largely unavailable.

The phytate: zinc molar ratios found in this study were also high (Table 4.3.5). However, they decreased as the cowpea content increased from 60:1 for sorghum to 49:1 for the 50:50 sorghum-cowpea ratio. The phytate: zinc ratios ranged from triple the reference (10-15) (Lestienne et al., 2005) which indicates low accessibility to about four times higher, meaning that the zinc was largely unavailable (FAO, 1992). The bioaccessibility of zinc declines at molar ratios above 10 and at ratios above 15, the absorption of zinc is less than 15% (FAO, 1992).

The phytate: calcium molar ratio for sorghum was 3:1 and decreased substantially with cowpea inclusion to 1:1 for the 50:50 sorghum-cowpea blend (Table 4.3.5). However, these molar ratios were higher than the ratio of 0.18 required for high accessibility (Gibson et al., 2010).

The combined phytate and calcium: zinc molar ratio increased with an increase in cowpea ratio, from 24:1 for sorghum only and 55:1 for the 50:50 sorghum-cowpea, which was double that of sorghum. These ratios were all less than 200, the reference for combined impacts of phytate and calcium on zinc (FAO, 1992). This means that the calcium had no influence on the bioaccessibility of zinc unlike phytates.

Table 4.3.5: Effects of phytate on the bioaccessibility of iron, zinc and calcium and the combination of phytate and calcium on the bioaccessibility of zinc

Formulation	Phytate (mg/ 100 g)	Phytate: Iron molar ratio	Phytate: Zinc molar ratio	Phytate: Calcium molar ratio	Phytate*Calcium: Zinc molar ratio
100% Sorghum	901*	23	60	3	24
75:25 Sorghum-Cowpea	977**	22	58	2	43
50:50 Sorghum-Cowpea	1053**	21	49	1	55

* Source: Vilakati (2016); value is for extruded sorghum
** Calculated using ratios; cowpea phytate value of 1206 mg/100 g and 901 mg/100g for sorghum.
Ratios obtained by dividing the phytate molar ratio by that of the minerals

4.3.4 Sensory characteristics

Inclusion of cowpea flour to the sorghum snacks brought about slight changes in a number of sensory attributes, whereas salt only affected the salty taste. The interaction of the cowpea and salt addition had no significant effect on the sensory attributes of the snacks.

4.3.4.1 Appearance

Compositing sorghum with cowpea changed the appearance attributes of the snacks (Table 4. 3.6). The inclusion of 50% cowpea flour had most effect on the appearance attributes of the extruded snacks (Table 4.3.6). The interaction of the sorghum cowpea ratio and addition of salt had no significant effect on appearance. The change in appearance attributes was evident with increase in the cowpea ratio. The snacks got progressively darker. This can be attributed to Maillard browning which could have been favoured by the high protein content and lysine content of cowpeas (Singh et al., 2007). Visible specks increased with an increase in the proportion of cowpeas. This was due to the black seed coats of the Glenda cowpeas used since the cowpea flour was whole grain. Also, the snack surface became rougher with the increase in the cowpea ratio. This can be attributed to the high fibre content (10.6%) contributed by the cowpeas (USDA, 2014). High dietary fibre results in extrudates with rough and uneven skin (Lue and Huff, 1991).

Table 4.3.6: Effects of compositing sorghum with cowpea, addition of salt and their interaction on the appearance of the extruded snacks

	Appearance		
Main Effects	**Colour intensity**	**Visible specks**	**Rough surface**
Sorghum cowpea ratio			
100% Sorghum	4.16[a](1.41)	5.25[a](1.43)	5.45[a](1.24)
75:25 Sorghum cowpea	4.49[a] (1.20)	5.88[b](1.20)	5.62[a](1.46)
50:50 Sorghum cowpea	5.12[b](1.62)	6.24[b](1.37)	6.13[b](1.49)
p value	**<0.01**	**<0.01**	**0.02**
Salts effects			
No salt	4.57[a](1.48)	5.74[a](1.40)	5.62[a](1.40)
Salted	4.60[a](1.47)	5.84[a](1.39)	5.84[a](1.45)
p value	**0.88**	**0.63**	**0.29**
Main effects interaction			
100% Sorghum No salt	4.24[a](1.65)	5.20[a] (1.56)	5.32[a] (1.21)
100% Sorghum Salted	4.08[a] (1.14)	5.30[a] (1.31)	5.57[a] (1.28)
75:25 Sorghum cowpea No salt	4.58[a](1.02)	5.99[a] (1.13)	5.68[a] (1.47)
75:25 Sorghum cowpea Salted	4.40[a] (1.36)	5.78[a] (1.27)	5.55[a] (1.48)
50:50 Sorghum cowpea No salt	4.89[a](1.64)	6.04[a] (1.36)	5.86[a] (1.49)
50:50 Sorghum cowpea Salted	5.34[a] (1.60)	6.44[a](1.38)	6.41[a] (1.45)
p value	**0.40**	**0.47**	**0.41**

Mean values with different letters in a column differ significantly at $p<0.05$; Standard deviation given in parentheses
n=30
Attribute Scale: 1= least perceived (not intense); 9= most perceived (very intense)

4.3.4.2 Aroma

The aroma of extruded snacks was not affected by adding cowpeas, salt or the combination of cowpeas and salt (Table 4.3.7). The aroma of the snacks was not intense. This can be attributed to the release of aroma compounds together with the steam when extruded snacks are forced out of the die during extrusion (Conti-Silva et al., 2012). Also, handling of the snacks after extrusion cooking could have led to loss of the aroma volatiles. For example, snacks were cooled and placed in trays for oven drying which could have led to loss of volatiles.

Table 4.3.7: Effects of compositing sorghum with cowpea, addition of salt and their interaction on the aroma of extruded the snacks

	Aroma Attributes				
Main Effects	**Overall aroma**	**Dried grass**	**Cooked cereal**	**Earthy aroma**	**Woody aroma**
Sorghum cowpea ratio					
100% Sorghum	4.45^{a}(1.58)	3.15^{a}(1.66)	4.36^{a}(1.67)	3.10^{a}(1.58)	3.04^{a}(1.47)
75:25 Sorghum cowpea	4.81^{ab}(1.57)	3.25^{a}(1.81)	4.42^{a}(1.77)	3.45^{a}(1.84)	3.15^{a}(1.55)
50:50 Sorghum cowpea	5.08^{b}(1.58)	2.99^{a}(1.62)	4.63^{a}(1.78)	3.42^{a}(1.88)	3.14^{a}(1.72)
p value	**0.09**	**0.71**	**0.67**	**0.51**	**0.91**
Salts effects					
No salt	4.82^{a}(1.60)	3.16^{a}(1.74)	4.50^{a}(1.63)	3.35^{a}(1.82)	3.20^{a}(1.63)
Salted	4.74^{a}(1.58)	3.09^{a}(1.66)	4.50^{a}(1.84)	3.29^{a}(1.72)	3.02^{a}(1.52)
p value	**0.76**	**0.79**	**0.83**	**0.82**	**0.43**
Main effects interaction					
100% Sorghum No salt	4.52^{a}(1.68)	3.15^{a}(1.73)	4.13^{a}(1.59)	3.16^{a}(1.68)	3.03^{a}(1.48)
100% Sorghum Salted	4.38^{a}(1.50)	3.15^{a}(1.62)	4.58^{a}(1.74)	3.05^{a}(1.51)	3.04^{a}(1.49)
75:25 Sorghum cowpea No salt	4.90^{a}(1.62)	3.36^{a}(1.93)	4.49^{a}(1.65)	3.48^{a}(1.96)	3.39^{a}(1.68)
75:25 Sorghum cowpea Salted	4.73^{a}(1.55)	3.14^{a}(1.73)	4.34^{a}(1.91)	3.42^{a}(1.75)	2.91^{a}(1.39)
50:50 Sorghum cowpea No salt	5.03^{a}(1.52)	2.98^{a}(1.59)	4.86^{a}(1.61)	3.43^{a}(1.87)	3.19^{a}(1.75)
50:50 Sorghum cowpea Salted	5.12^{a}(1.66)	3.00^{a}(1.69)	4.40^{a}(1.93)	3.41^{a}(1.92)	3.10^{a}(1.72)
p value	**0.89**	**0.92**	**0.35**	**0.99**	**0.67**

Table 4.3.7: Continued

Main Effects	**Cocoa aroma**	**Roasted cereal**	**Roasted nut**	**Burnt nut**	**Sawdust**
Sorghum cowpea ratio					
100% Sorghum	2.72[a](1.22)	4.17[a](1.66)	3.30[a](1.84)	3.03[a](2.00)	2.85[a](1.55)
75:25 Sorghum cowpea	2.73[a](1.49)	4.23[a](1.99)	3.65[a](1.81)	2.87[a](2.07)	2.85[a](1.43)
50:50 Sorghum cowpea	3.07[a](1.54)	4.44[a](1.97)	3.82[a](2.02)	3.21[a](1.98)	2.85[a](1.48)
p value	**0.31**	**0.70**	**0.32**	**0.67**	**0.99**
Salts effects					
No salt	2.96[a](1.46)	4.37[a](1.87)	3.72[a](1.81)	3.11[a](2.01)	2.84[a](1.50)
Salted	2.71[a](1.39)	4.19[a](1.89)	3.46[a](1.97)	2.96[a](2.02)	2.86[a](1.49)
p value	**0.25**	**0.52**	**0.35**	**0.62**	**0.95**
Main effects interaction					
100% Sorghum No salt	2.88[a](1.38)	4.12[a](1.59)	3.36[a](1.84)	3.24[a](2.19)	2.78[a](1.69)
100% Sorghum Salted	2.55[a](1.03)	4.22[a](1.75)	3.24[a](1.87)	2.83[a](1.81)	2.91[a](1.42)
75:25 Sorghum cowpea No salt	2.99[a](1.50)	4.54[a](1.98)	3.93[a](1.77)	2.90[a](1.90)	2.86[a](1.30)
75:25 Sorghum cowpea Salted	2.46[a](1.44)	3.91[a](1.97)	3.36[a](1.83)	2.85[a](2.09)	2.84[a](1.51)
50:50 Sorghum cowpea No salt	3.00[a](1.53)	4.46[a](2.05)	3.87[a](1.82)	3.20[a](1.97)	2.88[a](1.46)
50:50 Sorghum cowpea Salted	3.13[a](1.58)	4.42[a](1.93)	3.76[a](2.23)	3.21[a](2.19)	2.81[a](1.52)
p value	**0.43**	**0.52**	**0.76**	**0.83**	**0.93**

Mean values with different letters in a column differ significantly at $p<0.05$; Standard deviation given in parentheses; n=30

Attribute scale: 1= least perceived (not intense); 9=most perceived (very intense)

4.3.4.3 Texture

The addition of salt and its interaction with sorghum-cowpea ratio had no significant effects on the texture attributes of extruded snacks (Table 4.3.8). Compositing sorghum with cowpea specifically increased the roughness of extruded snacks as opposed to hardness and crunchiness. The roughness was more pronounced in the 50:50 sorghum-cowpea blended snacks than the 100% sorghum and 75:25 sorghum-cowpea blends. This can be attributed to the high fibre content. Fibre breaks bubbles during expansion (Lue and Huff, 1991). The burst bubbles causes holes in the surface of the snacks which have a cutting effect when rubbed against the tongue.

The snacks were rated similarly for hardness and crunchiness. The snacks with the higher level of cowpea flour were expected to be harder than the 100% sorghum snacks because of the high protein content which would lead to poor expansion and hardening of the snacks. Extrudates with high protein content were found to be hard when compared to that of low protein content (Singh et al., 2007). However, the snacks were similarly crunchy. This is significant as crunchiness in snacks is an important attributed related to the freshness quality of the snacks (Anton and Luciano, 2007).

Table 4.3.8: Effects of compositing sorghum with cowpea, addition of salt and the interaction thereof on the texture of extruded snacks

	Texture Attributes		
Main Effects	**Roughness**	**Hardness**	**Crunchiness**
Sorghum cowpea ratio			
100% Sorghum	5.19^{a}(1.69)	4.84^{a}(1.48)	6.52^{a}(1.40)
75:25 Sorghum cowpea	5.43^{a}(1.82)	4.82^{a}(1.54)	6.55^{a}(1.36)
50:50 Sorghum cowpea	6.16^{b}(1.55)	4.54^{a}(1.72)	6.69^{a}(1.22)
p value	**<0.01**	**0.51**	**0.77**
Salts effects			
No salt	5.42^{a}(1.70)	4.66^{a}(1.59)	6.63^{a}(1.23)
Salted	5.76^{a}(1.74)	4.80^{a}(1.59)	6.54^{a}(1.41)
p value	**0.17**	**0.57**	**0.65**
Main effects interaction			
100% Sorghum No salt	4.94^{a} (1.65)	4.92^{a} (1.40)	6.71^{a} (1.18)
100% Sorghum Salted	5.44^{abc} (1.71)	4.76^{a} (1.58)	6.33^{a} (1.59)
75:25 Sorghum cowpea No salt	5.27^{ab} (1.81)	4.66^{a} (1.51)	6.49^{a} (1.27)
75:25 Sorghum cowpea Salted	5.58^{abc} (1.85)	4.97^{a} (1.58)	6.62^{a} (1.46)
50:50 Sorghum cowpea No salt	6.05^{bc} (1.49)	4.41^{a} (1.81)	6.69^{a} (1.28)
50:50 Sorghum cowpea Salted	6.26^{c} (1.62)	4.66^{a} (1.63)	6.68^{a} (1.17)
p value	**0.89**	**0.68**	**0.55**

Mean values with different letters in a column differ significantly at $p<0.05$; Standard deviation given in parentheses

n=30

Attribute Scale: 1= least perceived (not intense); 9= most perceived (very intense)

4.3.4.4 Flavour

The inclusion of cowpeas had significant effects on some flavour attributes (Table 4.3.9). The addition of salt had no overall effect on the flavour of the snacks but had an effect on salty flavour ($p<0.01$). The interaction of sorghum-cowpea ratio and the addition of salt had no significant effects on most of the attributes but also affected the salty attribute. The flavour attributes affected by the addition of cowpeas were overall flavour, boiled nut, roasted nut, beany, burnt nut, earthy, salty and cocoa flavours. These attributes increased progressively with an increase in the cowpea ratio. Inclusion of 50% cowpea flour had more effect.

Overall flavour increased with an increase in cowpea ratio and the presence of salt. Boiled nut flavour was only perceived in the composite snacks, whereas the roasted nut flavour was perceived in sorghum snacks as well. Sweet and nutty flavours are positive attributes but are found in low intensities in sorghum foods. This is a problem in using sorghum grains as human food more especially for children (Brannan et al., 2001). Sweet and nutty flavour development can be attributed to Maillard reaction, and caramelisation when heating legumes in the extruder barrel (Sacchetti et al., 2004).

Dried grass flavour intensity was perceived similarly amongst the snacks which could be due to the sorghum flour as sorghum belongs to the grass family (Dillon et al., 2007). Starchy flavour was similarly perceived in all snacks. Starch is present in both the sorghum and cowpea.

Beany flavour increased with an increase in the cowpea ratio of the snacks. This flavour is associated with legumes. It is attributed to the action of lipoxygenase, which catalyzes the formation of odorous carbonyl compounds (pentyl furans) from components containing a cis-1,4-pentadiene system (Okaka and Potter 1979). The cocoa flavour which is associated with the cocoa bean flavour, was also perceived as expected. It increased with an increase in the cowpea ratio, confirming the correlation with the beany flavour.

The astringent and bitter tastes were similarly perceived amongst the different snacks. This might have been due to that both sorghum and cowpeas are rich in phenolic compounds, which contribute to the bitterness and astringency to food (Drewnoski and Gomez- Cameros, 2000).

The salty taste was perceived as expected. Salt addition had an effect on the perception of salty flavour (Table 4.3.9). The salt was perceived in all salted snacks in the different sorghum- cowpea ratios. The interaction of the sorghum-cowpea ratio and the presence of salt had an effect on the perception of the salty attribute. This was the only attribute affected by the interaction of the main effects. The salty flavour was intensified in combination with the 50% cowpea on the snacks.

Table 4.3.9: The effects of compositing sorghum with cowpea, addition of salt and the interaction on the flavour of the extruded snacks

	Flavour Attributes							
Main Effects	**Overall flavour**	**Boiled nut**	**Roasted nut**	**Dried grass**	**Starchy**	**Beany**	**Burnt nut**	**Astringent**
Sorghum cowpea ratio								
100% Sorghum	4.30^{a}(1.50)	3.20^{a}(1.53)	2.92^{a}(1.64)	2.79^{a}(1.57)	4.51^{a}(1.70)	2.77^{a}(1.55)	2.74^{a}(1.84)	3.47^{a}(1.93)
75:25 Sorghum cowpea	5.25^{b}(1.64)	4.41^{b}(1.70)	3.75^{b}(1.76)	3.42^{ab}(1.89)	4.66^{a}(1.73	4.80^{b}(2.00)	3.18^{a}(1.82)	3.36^{a}(1.88)
50:50 Sorghum cowpea	6.13^{c}(1.33)	4.97^{b}(1.75)	4.22^{b}(2.05)	3.50^{b}(1.96)	5.04^{a}(1.78)	5.94^{c}(1.60)	4.07^{b}(2.25)	3.39^{a}(1.89)
p value	**<0.01**	**<0.01**	**<0.01**	**0.07**	**0.23**	**<0.01**	**<0.01**	**0.94**
Salts effects								
No salt	5.01^{a}(1.79)	4.12^{a}(1.79)	3.53^{a}(1.89)	3.28^{a}(1.77)	4.69^{a}(1.73)	4.56^{a}(2.20)	3.36^{a}(2.04)	3.50^{a}(1.93)
Salted	5.44^{a}(1.50)	4.28^{a}(1.83)	3.74^{a}(1.91)	3.19^{a}(1.91)	4.79^{a}(1.76)	4.45^{a}(2.15)	3.30^{a}(2.06)	3.31^{a}(1.86)
p value	**0.06**	**0.48**	**0.43**	**0.76**	**0.71**	**0.67**	**0.84**	**0.49**
Main effects interaction								
100% Sorghum No salt	3.93^{a}(1.62)	2.93^{a}(1.49)	2.63^{a}(1.66)	2.88^{a}(1.71)	4.44^{a}(1.73)	2.88^{a}(1.77)	2.69^{a}(1.93)	3.67^{a} (2.03)
100% Sorghum Salted	4.67^{ab}(1.28)	3.46^{a}(1.54)	3.22^{ab}(1.59)	2.70^{a}(1.45)	4.59^{a}(1.69)	2.66^{a}(1.31)	2.79^{a}(1.77)	3.27^{a} (1.85)
75:25 Sorghum cowpea No salt	5.09^{b}(1.76)	4.50^{b}(1.53)	3.74^{bc}(1.77)	3.41^{a}(1.73)	4.56^{a}(1.75)	4.79^{b}(1.94)	3.25^{abc}(1.78)	3.43^{a} (1.92)
75:25 Sorghum cowpea Salted	5.41^{bc}(1.52)	4.33^{b}(1.88)	3.76^{bc}(1.79)	3.43^{a}(2.07)	4.76^{a}(1.74)	4.82^{b}(2.09)	3.11^{ab}(1.88)	3.28^{a} (1.88)
50:50 Sorghum cowpea No salt	6.01^{cd}(1.36)	4.89^{b}(1.76)	4.20^{c}(1.92)	3.54^{a}(1.85)	5.07^{a}(1.70)	6.01^{c}(1.65)	4.14^{c}(2.17)	3.40^{a} (1.89)
50:50 Sorghum cowpea Salted	6.24^{d}(1.30)	5.06^{b}(1.76)	4.24^{c}(1.21)	3.46^{a}(2.09)	5.02^{a}(1.89)	5.87^{c}(1.58)	4.00^{bc}(2.35)	3.37^{a}(1.92)
p value	**0.61**	**0.52**	**0.63**	**0.96**	**0.92**	**0.92**	**0.93**	**0.87**

Table 4.3.9: continued

	Flavour attributes						
Main Effects	**Earthy**	**Bitter**	**Sweet**	**Sour**	**Salty**	**Cocoa**	**Woody**
Sorghum cowpea ratio							
100% Sorghum	2.91^{a}(1.60)	1.87^{a}(1.06)	2.43^{a}(1.46)	1.84^{a}(0.85)	2.30^{a}(1.29)	2.13^{a}(1.13)	2.68^{a}(1.50)
75:25 Sorghum cowpea	3.58^{b}(1.79)	1.91^{a}(1.25)	2.62^{a}(1.46)	1.83^{a}(0.89)	2.51^{ab}(1.15)	2.47^{a}(1.25)	3.08^{a}(1.48)
50:50 Sorghum cowpea	4.07^{b}(2.07)	1.93^{a}(1.26)	2.58^{a}(1.48)	2.09^{a}(1.21)	2.74^{b}(1.26)	2.95^{b}(1.34)	3.18^{a}(1.73)
p value	**<0.01**	**0.96**	**0.77**	**0.28**	**0.12**	**<0.01**	**0.196**
Salts effects							
No salt	3.54^{a}(1.96)	1.95^{a}(1.26)	2.46^{a}(1.38)	1.88^{a}(1.03)	2.16^{a}(1.02)	2.49^{a}(1.28)	2.96^{a}(1.60)
Salted	3.50^{a}(1.81)	1.85^{a}(1.12)	2.62^{a}(1.54)	1.96^{a}(0.97)	2.88^{b}(1.34)	2.54^{a}(1.29)	3.00^{a}(1.56)
p value	**0.89**	**0.60**	**0.45**	**0.59**	**<0.01**	**0.79**	**0.87**
Main effects interaction							
100% Sorghum No salt	2.82^{a}(1.76)	1.99^{a}(1.29)	2.33^{a}(1.56)	1.70^{a}(0.85)	1.69^{a}(0.79)	2.10^{a}(1.15)	2.60^{a} (1.51)
100% Sorghum Salted	2.99^{ab}(1.46)	1.74^{a}(0.77)	2.53^{a}(1.37)	1.97^{a}(0.85)	2.92^{bc}(1.40)	2.16^{a}(1.13)	2.76^{a} (1.50)
75:25 Sorghum cowpea No salt	3.86^{bc}(1.81)	1.80^{a}(1.08)	2.55^{a}(1.26)	1.80^{a}(0.83)	2.45^{b}(1.16)	2.43^{ab}(1.25)	3.12^{a} (1.53)
75:25 Sorghum cowpea Salted	3.30^{abc}(1.75)	2.02^{a}(1.41)	2.68^{a}(1.66)	1.87^{a}(0.95)	2.57^{bc}(1.15)	2.50^{ab}(1.27)	3.04^{a} (1.46)
50:50 Sorghum cowpea No salt	3.93^{bc}(2.14)	2.05^{a}(1.41)	2.49^{a}(1.35)	2.14^{a}(1.32)	2.35^{b}(0.91)	2.93^{b} (1.34)	3.15^{a} (1.75)
50:50 Sorghum cowpea Salted	4.20^{c}(2.02)	1.80^{a}(1.10)	2.66^{a}(1.62)	2.04^{a}(1.11)	3.14^{c}(1.44)	2.97^{b} (1.36)	3.20^{a} (1.73)
p value	**0.40**	**0.47**	**0.99**	**0.60**	**0.04**	**0.99**	**0.92**

Mean values with different letters in a column differ significantly at p<0.05; Standard deviation given in parentheses
n=30
Attribute Scale: 1= least perceived (not intense); 9= most perceived (very intense)

4.3.4.5 Mouthfeel

Inclusion of cowpea flour and/or salt had no influence on the mouthfeel attributes of the extruded snacks (Table 4.3.10). Similarly, their interaction had no effect. All snacks had the same rate of break down, moisture absorption, doughiness and grittiness. This can be as a result of using the same extrusion cooking and drying conditions. The rate of breakdown of the snacks was slow, meaning they did not melt in the mouth. The snacks were also perceived as dry, since they needed a lot of moisture/saliva during mastication. Furthermore, snacks were perceived to be not fully cooked as there was a certain degree of doughiness. Also, snacks were perceived to be gritty. This can be attributed to poor hydration of starch granules during extrusion. Poor hydration of the starch granules results in incomplete cellular expansion and separation of the cells which limits starch granule expansion resulting in the grainy mouthfeel (Mwangela et al., 2006).

Table 4.3.10: Effects of compositing sorghum with cowpea, addition of salt and their interaction on the mouthfeel of the extruded snacks

	Mouthfeel Attributes			
Main Effects	**Rate of breakdown**	**Moisture Absorption**	**Doughiness**	**Grittiness**
Sorghum cowpea ratio				
100% Sorghum	5.39[a](1.64)	5.54[a](1.71)	3.50[a](2.01)	5.28[a](1.98)
75:25 Sorghum cowpea	5.26[a](1.54)	5.51[a](1.68)	3.59[a](1.82)	5.38[a](1.71)
50:50 Sorghum cowpea	5.77[a](1.46)	5.26[a](1.78)	3.93[a](2.01)	5.17[a](1.93)
p value	**0.18**	**0.63**	**0.44**	**0.83**
Salts effects				
No salt	5.49[a](1.56)	5.43[a](1.68)	3.67[a](1.92)	5.29[a](1.91)
Salted	5.46[a](1.55)	5.44[a](1.77)	3.67[a](1.98)	5.26[a](1.84)
p value	**0.92**	**0.99**	**0.99**	**0.93**
Main effects interaction				
100% Sorghum No salt	5.26 [a](1.72)	5.65[a] (1.75)	3.33[a] (1.89)	5.17[a] (2.17)
100% Sorghum Salted	5.52[a] (1.58)	5.42[a] (1.69)	3.66[a] (2.14)	5.39[a] (1.80)
75:25 Sorghum cowpea No salt	5.49[a] (1.51)	5.38[a] (1.58)	4.17[a] (1.96)	5.36[a] (1.72)
75:25 Sorghum cowpea Salted	5.04[a] (1.55)	5.65[a] (1.78)	3.69[a] (2.06)	5.40[a] (1.74)
50:50 Sorghum cowpea No salt	5.71[a] (1.46)	5.28[a] (1.73)	3.52[a] (1.87)	5.35[a] (1.89)
50:50 Sorghum cowpea Salted	5.82[a] (1.48)	5.25[a] (1.86)	3.66[a] (1.80)	5.00[a] (1.99)
p value	**0.42**	**0.74**	**0.49**	**0.69**

Mean values with different letters in a column differ significantly at $p<0.05$; Standard deviation given in parentheses
n=30
Attribute Scale: 1= least perceived (not intense); 9= most perceived (very intense)

4.3.3.6 Aftertaste

Compositing of the sorghum with cowpea had a significant effect on the nutty and metallic aftertaste of the extruded snacks (Table 4.3.11). The addition of salt had no significant effect on the aftertaste of the extruded snacks. Inclusion of cowpea flour had more influence on the nutty and metallic aftertastes than astringent, bitter, sour and umami aftertaste attributes. Nutty aftertaste was increased by cowpea inclusion. The resulting composite snacks were rated higher than the sorghum snacks. This nutty flavour development can be attributed to dry heating that takes place during extrusion and Maillard reaction and caramelisation interaction which occur during extrusion (Sachetti et al., 2004).

Metallic aftertaste progressively increased with the increase in cowpea ratio (Table 4.3.11). Metallic taste is associated with minerals, especially iron (Martınez-Navarrete et al., 2002). In fact, iron content of the snacks increased progressively with the inclusion of cowpeas.

Table 4.3.11: Effects of compositing sorghum with cowpea, addition of salt and their interaction on the aftertaste of the extruded snacks

	Aftertaste Attributes					
Main Effects	**Astringent**	**Bitter**	**Sour**	**Nutty**	**Umami**	**Metallic**
Sorghum cowpea ratio						
100% Sorghum	3.47[a](2.05)	1.93[a](1.20)	1.98[a](1.03)	2.80[a](1.74)	2.84[a](1.57)	2.83[a](1.68)
75:25 Sorghum cowpea	3.38[a](1.77)	1.82[a](1.05)	1.94[a](1.02)	3.74[b](1.81)	3.43[ab](1.78)	3.24[ab](1.61)
50:50 Sorghum cowpea	3.26[a](1.74)	1.86[a](1.21)	2.11[a](1.22)	4.13[b](1.99)	3.48[b](1.81)	3.66[b](1.97)
p value	**0.84**	**0.89**	**0.68**	**<0.01**	**0.09**	**0.04**
Salts effects						
No salt	3.38[a](1.89)	1.87[a](1.17)	1.98[a](1.09)	3.44[a](1.85)	3.26[a](1.79)	3.14[a](1.82)
Salted	3.36[a](1.85)	1.87[a](1.13)	2.03[a](1.09)	3.67[a](2.00)	3.24[a](1.69)	3.34[a](1.76)
p value	**0.93**	**0.98**	**0.76**	**0.40**	**0.95**	**0.45**
Main effects interaction						
100% Sorghum No salt	3.34[a](2.08)	1.96[a](1.30)	1.89[a](0.92)	2.66[a](1.78)	2.77[a](1.56)	2.80[a](1.76)
100% Sorghum Salted	3.60[a](2.06)	1.90[a](1.12)	2.07[a](1.14)	2.94[ab](1.73)	2.91[a](1.61)	2.85[a](1.63)
75:25 Sorghum cowpea No salt	3.47[a](1.79)	1.69[a](0.87)	1.86[a](0.91)	3.67[bc](1.78)	3.52[a](1.92)	3.16[ab](1.66)
75:25 Sorghum cowpea Salted	3.28[a](1.79)	1.95[a](1.21)	2.02[a](1.14)	3.81[bc](1.86)	3.34[a](1.65)	3.32[ab](1.58)
50:50 Sorghum cowpea No salt	3.33[a](1.78)	1.96[a](1.32)	2.20[a](1.38)	4.00[c](1.78)	3.48[a](1.83)	3.47[ab](2.02)
50:50 Sorghum cowpea Salted	3.19[a](1.73)	1.77[a](1.09)	2.01[a](1.04)	4.27[c](2.20)	3.47[a](1.82)	3.86[b](1.94)
p value	**0.78**	**0.56**	**0.58**	**0.98**	**0.89**	**0.86**

Mean values with different letters in a column differ significantly at $p<0.05$; Standard deviation given in parentheses
n=30
Attribute Scale: 1= least perceived (not intense); 9= most perceived (very intense

4.3.5 Instrumental Analyses

4.3.5.1 Colour

Table 4.3.12: Effects of compositing sorghum with cowpeas, addition of salt and their interaction on the colour of extruded snacks

		Colour	
Main Effects	**L* value**	**a* value**	**b* values**
Sorghum cowpea ratio			
100% sorghum	64.7^{b}(1.19)	7.59 ^{a} (0.54)	12.2 ^{b} (0.48)
75:25 Sorghum cowpea	63.3 ^{a}(0.84)	7.27 ^{a} (0.27)	11.7 ^{a} (0.65)
50:50 Sorghum cowpea	62.6 ^{a}(1.43)	7.43 ^{a} (0.54)	11.4 ^{a} (0.52)
p value	**<0.01**	**0.21**	**<0.01**
Effects of salt			
No salt	63.4 ^{a}(1.43)	7.22 ^{a} (0.48)	11.5 ^{a} (0.52)
Salted	63.7 ^{a}(1.48)	7.64 ^{b} (0.38)	12.0 ^{b} (0.64)
p value	**0.44**	**<0.01**	**<0.01**
Interaction of cowpea ratio and salt			
100% Sorghum No salt	64.4 ^{b}(1.01)	7.28 ^{a} (0.57)	11.9^{bc} (0.46)
100% Sorghum Salted	64.9 ^{b}(1.41)	7.90 ^{b} (0.31)	12.5 ^{c} (0.30)
75:25 Sorghum cowpea No salt	63.0 ^{a}(0.79)	7.18 ^{a} (0.12)	11.5 ^{ab} (0.35)
75:25 Sorghum cowpea Salted	63.7^{ab}(0.76)	7.37 ^{a} (0.36)	11.9 ^{b} (0.83)
50:50 Sorghum cowpea No salt	62.7^{a}(1.81)	7.21 ^{a} (0.65)	11.2 ^{a} (0.49)
50:50 Sorghum cowpea Salted	62.4^{a}(1.07)	7.65 ^{ab} (0.32)	11.7 ^{ab}(0.37)
p value	**0.55**	**0.47**	**0.93**

Mean values with different letter in column differ significantly at p<0.05; Standard deviation given in parentheses
n=5

Inclusion of cowpea flour to the sorghum had a significant effect on the colour of the extruded snacks (Table 4.3.12). L* and b* values were affected, whereas the a* values were not. The L* and b* values progressively decreased with an increase in cowpea ratio, meaning that the snacks became progressively darker and yellow. Similar results were found by the sensory panellists (Table 4.3.6). The darker colour can be attributed to the Maillard browning (Hallén et al., 2004).

The addition of salt also had a significant effect on the colour of the extruded snacks, affected the a* and b* values. This slightly strengthened or intensified the red and yellow colours of the snacks, positively contributing to the darker colour of the snacks through Maillard browning. This is because salt facilitates osmosis which draws moisture out of the cells resulting in an increased Maillard reaction during extrusion cooking (Conti-Silva et al., 2012).

4.3.5.2 Texture

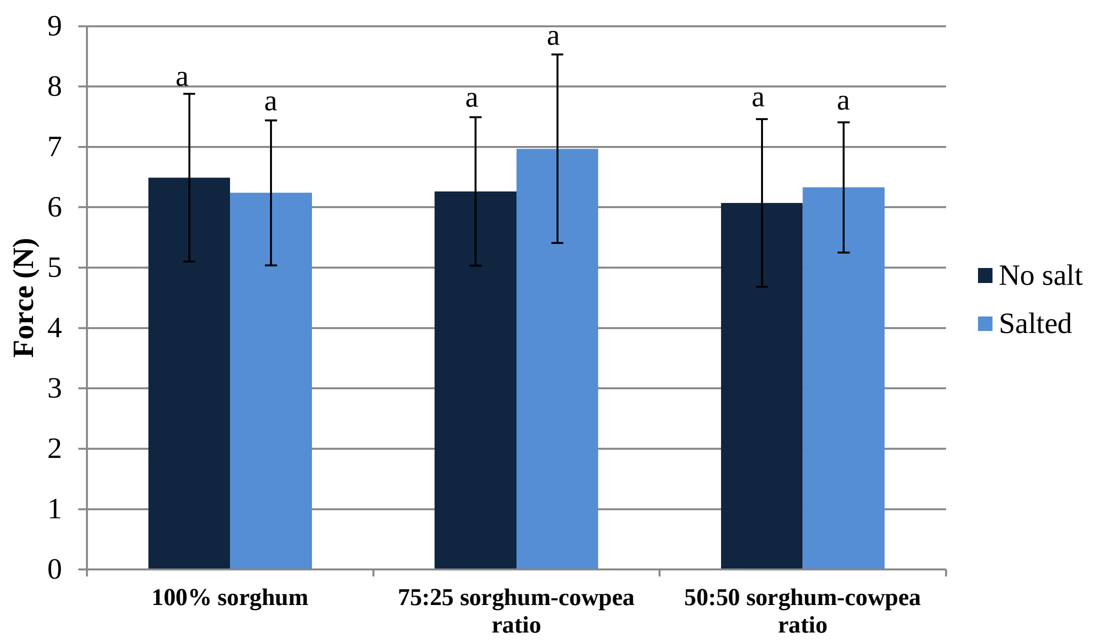


Figure 4.2: Effects of compositing sorghum with cowpea on the texture (hardness) of extruded snacks. Error bars indicate the standard deviation.

Inclusion of cowpea flour and salt had no significant influence on the cutting force of the extruded snacks (Figure 4.2). The snacks were not hard as the cutting force was below 10N. The snacks hardness was also rated low by trained sensory panel which shows that they were not hard (Table 4.2.3). This is related to the high expansion ratio of the snacks. According to a review by Moraru and Kokini (2003), fibre increases hardness in extrudates by disrupting the continuous structure of the melt, impeding the elastic structure during expansion. In the snacks the fibre content was very low (<4%) which could be the reason for the reduced hardness of the snacks.

4.3.5.3 The expansion ratio

Inclusion of cowpea flour progressively increased the expansion of the snacks. The high protein content in cowpeas was expected to reduce the expansion ratio of the extruded snacks as the starch content would be reduced.

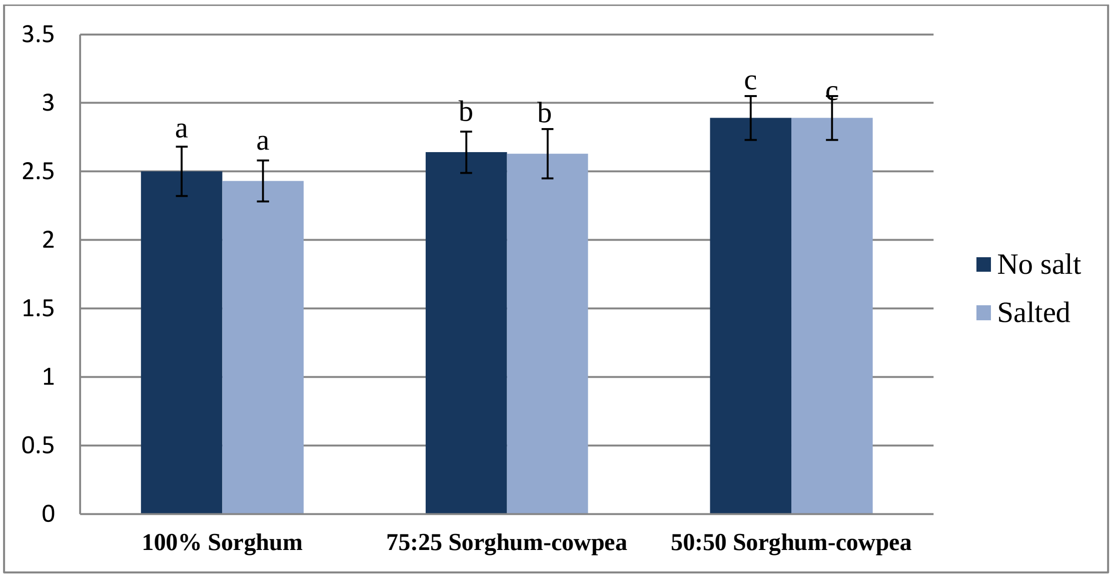


Figure 4.3: Effects of compositing sorghum with cowpea on the expansion ratio of extruded snacks. Error bars indicate the standard deviation.

This increase in expansion can be attributed to the fine particle size of the cowpea flour. During milling of cowpeas, a huge amount of fine dust was produced and the particle size was less than 500µm. According to a review by Moraru and Kokini (2003) fine particle size increases expansion because they are sufficiently plasticized by water resulting in a melt during extrusion cooking.

4.4 Conclusions

Compositing sorghum with cowpeas in making extruded snacks improves the nutrition value of the snacks in terms of protein content, protein digestibility, protein quality and mineral availability. These improvements are imperative in addressing PEM in school-going children. The sensory properties of the snacks are not greatly affected by the addition of cowpeas. The composite snacks have a higher expansion ratio compared to the sorghum snacks. Also, the hardness of the snacks is similarly rated which makes the composite snacks suitable for use to address PEM. The beany flavour is rated high in the composite snacks but, the addition of commercial flavours could mask the beany flavour. The positive nutritional improvement and good sensory aspects of the composite snacks makes them a potential protein rich supplementary food for use in the alleviation of PEM in school going-children.

5. GENERAL DISCUSSION

This chapter is divided into two sections. The first section critically reviews the experimental work that was used. The second section evaluates the major findings concerning the effects of compositing sorghum with cowpeas on the nutritional and sensory quality of extruded snacks. This section also discusses the potential of the snacks for local businesses and as a potential protein rich supplementary food that can be used in alleviation of PEM in school-going children.

5.1 Critical review of the experimental work

Finely milled refined sorghum was used in the study. Such sorghum meal is widely purchased in the rural and semi-urban communities of Southern Africa. Most people do not grow their own sorghum. Hence, the use of the meal was of practical relevance to the study. The sorghum meal is milled from red non-tannin sorghum which has better protein digestibility than tannin sorghum (Serna-Saldivar and Rooney, 1995). The use of red sorghum is of agronomic advantage to farmers as it is generally not eaten by birds. Cowpeas are also popular legumes in the rural and semi-urban areas in sub-Saharan Africa where they are used to complement cereal staples as a source of proteins (Onyenekwe et al., 2000).

During extrusion cooking the fat forms complexes with other food constituents on shearing, which make it difficult to extract from the matrix (Björck and Asp, 1983). The method of fat extraction plays a major role in the quantity of extractable fat that can be obtained (Camire, 2000). In this study, non-polar solvents were used for the extraction of the fat. This method was found to give apparently less fat on extrudates (Table 4.3.1). Acid hydrolysis can probably give better fat yield in extrudates compared to the non-polar solvent method (Camire, 2000). It would have been useful to apply both assays for fat extraction on the snack blends and compare the quantities of fat extracted.

Analysis of the 100% cowpeas would have assisted in the comparison and discussion of the chemical analysis of the blends and the sorghum versus cowpeas. This would have been specifically valuable with regard to mineral and phytate contents after extrusion cooking. It would have aided in determining the effects of extrusion cooking and different ratios on these minerals (Table 4.3.4 and Table 4.3.5). Also, phytate has a great influence on mineral bioaccessibility of foods. Since cowpeas contain high amounts of phytate, this would negatively affect the mineral quality of the snacks (Hallén et al., 2004). Quantifying the phytate contents of the blends before and after extrusion cooking would be useful.

Mineral bioaccessibility of the extruded snack blends was performed in the study. A single *in vitro* dialysability assay was used to estimate the amount of minerals that were released from the snack blends upon digestion. This assay measures the solubility of the minerals in preparation for absorption (Etcheverry et al., 2011). It is useful at the initial phase of product development, as applied in this study, to test if the minerals will be released from the food matrix and made available for absorption. However, there are concerns about the reliability of the assay and therefore it is regarded as an indicator for relative and not actual numeric effects (Fairweather-Tait et al., 2005). Bioaccessibility assessment is the first step of determining bioavailability which is the amount of released nutrient that is absorbed in the system. Use of an *ex vivo* bioavailability assay, for example Caco-2-cell culture method (Wenzel and Somoza, 2005) in the study could have been useful in the estimation of minerals bioavailable in the snack blends.

Protein digestibility is an indicator of protein quality which measures protein susceptibility to proteolysis during digestion (WHO/ FAO/ UNU, 2007). A protein source with high digestibility is potentially of better nutritional value than one of low digestibility as it will provide more amino acids for absorption after proteolysis. *In vitro* protein digestibility (IVPD) was assayed using both the pepsin and multienzyme methods. The pepsin method uses pepsin enzyme only and estimates hydrolysis in the stomach but does not precisely simulate what happens in humans during the digestion of proteins as there is more than one enzyme involved (Boisen and Eggum, 1991). The multienzyme IVPD involves trypsin, chymotrypsin and peptidase enzymes which estimate hydrolysis in the stomach, small intestines and hind gut of simple stomach animals (Hsu et al., 1977).

Protein quality can also be determined using *in vivo* assays in both humans and animals e.g. rats. These assays can be used to determine protein bioavailability (WHO/FAO/ UNU, 2007). There are a number of parameters that are generally measured, for example protein efficiency ratio (PER) which measures rat growth as weight gain per gram of fed protein (Smith, 2003). PER is, however, generally limited to infant foods only as it involves weanling rats whose application is similar only to infants but not to other age groups (Serrem, 2010). There is also the Net Protein Ratio (NPR) parameter which is an improvement on PER and accounts for the maintenance requirement of the weanling rats (Serrem, 2010). True Protein Digestibility

(TPD) is obtained from the difference between the nitrogen ingested and nitrogen excreted in faeces (WHO/ FAO/ UNU, 2007). The limitation of TPD is the little or no information provided on how much of the absorbed nitrogen is retained or used by the body.

TPD forms part of the required measurements to compute *in vivo* protein digestibility corrected amino acid scores (PDCAAS). PDCAAS has formally replaced PER as the latter was only limited to infants (FAO/ WHO, 1991). PDCAAS is more appropriate for the estimation of protein quality. The present study utilized the pepsin and multienzyme IVPD to compute PDCAAS which determines the trend in protein digestion. However, it would be necessary to compute the *in vivo* PDCAAS using the TPD as it seems to be more realistic to human studies. In this calculation, the amount of limiting amino acid in a protein is compared to the amount of that amino acid in a reference protein and the *in vivo* measure of protein digestibility by rats.

The aim of the present study was to develop snacks of good nutrition quality that can be included as a snack for school-going children during their nutrition breaks with the goal of providing macronutrients that can in turn address PEM and micronutrient availability. The study focused on *in vitro* nutrient assays to determine the nutrition quality of the snacks. Therefore there is a need to conduct *in vivo* assays to improve the value of the study. The use of animal models e.g. rats is suggested in the study to effectively estimate and simulate what would happen to the human body. Additionally, a human intervention study should be performed to test if the snacks perform to expectations.

Descriptive sensory evaluation was used to determine the sensory characteristics of the snack blends. This is a specialized form of sensory analysis that may include all the sensory parameters of the food or can be limited to certain aspects of interest like in flavour or texture profiling (Einstein, 1991). The descriptive sensory evaluation involved the use of a trained panel that was able to reliably describe and quantify differences in the sensory properties of snack blends presented to them.

Consumer sensory testing of the snack blends is also desirable to determine the level of liking and disliking of the sensory properties of the snack blends. This information is vital to the improving and optimizing the snack blend that is most liked. Preference and acceptance tests are needed to give direction to what snack blend would be liked the most, how much the blend was liked and if the sensory attributes in the blend are acceptable to the consumers (Guinard, 2001). To effectively evaluate the level of liking, the snack blends need to be flavoured, so that they are more like the commercial snacks currently available. Furthermore, it would be best to conduct the evaluation with children (3-10 years) at schools, as they are the target market for the snack blends and the location would be their comfort zone. However, parental consent is required for such studies with children under 18 years. This may leave researchers with no option but to conduct such studies with parents or caregivers as they decide on what the children eat or what goes to the lunchbox.

5.2 Effects of compositing sorghum with cowpea on the nutritional and sensory quality of extruded snacks

As reported in Chapter 4.3, compositing sorghum with cowpeas substantially improved the nutrition quality of the extruded snacks. The improvements were both in protein quality and mineral content. Improved protein quality was shown by the increases in protein content, in vitro protein digestibility, lysine content and calculated Protein Digestibility Corrected Amino Acid Score (PDCAAS). The improvements were directly related to the cowpea ratio used. The improvements in the protein quality were because cowpeas are high in protein mainly globulins, which are rich in lysine and have better digestibility as compared to sorghum prolamins (Taylor and Schüssler, 1986; Duodu et al., 2003). The consumption of a 30 g bag of the composite snack would provide 4-5g protein, which is 15-31% of the protein daily requirement for school-age children (WHO/ FAO/ UNU, 2007). Compositing sorghum with cowpea almost doubled the lysine score. Despite the favourable conditions for Maillard reaction in extrusion cooking (Singh et al., 2007), the protein lysine content was not greatly affected considering that it is approximately 6.8% in cowpeas and 2% in sorghum (USDA, 2014).The absence of significant lysine reduction was probably because of the short residence time in the extruder barrel. Also, the calculated PDCAAS was 0.85 which is higher than the recommended 0.79 for children 3-10 years of age (WHO/UNU/FAO, 2007). These improvements are imperative to the goal of addressing PEM in school-going children.

Compositing with cowpea also slightly increased the zinc and greatly increased calcium contents of the snack blends. The increase in zinc is such that a 30 g serving would provide up to 21% of the daily requirements for 3 year old children. However, the high phytate content in plant foods such as cowpeas adversely affects the bioaccessibility of these minerals (Weaver and Kannan, 2002). In the present study, the effects of extrusion cooking on phytate content were not investigated but a study by Vilakati (2016) on extrusion cooking of sorghum-cowpea RTE meal showed that extrusion cooking did not have a significant effect on the phytate content of a composite meal. Phytate can chelate and precipitate minerals like iron, calcium and zinc, thereby decreasing their bioavailability (Weaver and Kannan, 2002). This, however, does not negate the fact that these composite snacks are of better protein content (Chapter 4; Table 4.3.1) than their 30 g commercial counterparts available in South Africa; for example, Simba Niknaks (maize snacks) (6.2% protein) and Carnival Jiggies (maize snacks) (6.4% protein).

To further improve the protein quality of extruded snacks the use of defatted soybeans and peanuts could be investigated. Peanuts are richer in protein (approximately 26%) and oil (approximately 50%) than cowpeas (USDA, 2014), which is better for addressing PEM. A 50% defatted soybean flour composite has been successfully used in making biscuits that were accepted to school children (Serrem et al., 2011). However, there is also a possibility of less expanded snacks and poorer textural properties with peanut composite because of the high fat content which can impair the performance of the extruder by decreasing torque through the reduction of slip in the barrel (Camire, 2000). High lipid content also reduces pressure produced in the extruder (Singh et al., 2007). The fat content of peanuts could have to be adjusted to less than 5% to facilitate steady extrusion and good texture (Singh et al., 2007). To improve the micronutrient content of the snacks, their vitamin contents should be determined and fortification with vitamin A, D and E may be useful. Also, fortification with iron, as is done with maize meal in South Africa (van Jaarsveld et al., 2015), could be considered. Probably, this would better balance the iron: phytate ratio and enhance bioavailability.

The beany flavour of the composite snacks is of concern as it was picked by the panel (Chapter 4.3.3.4; Table 4.3.9). Although given an average rating of only 66%, the descriptive sensory panel, however, mentioned that the flavour blended well with the salt, which somewhat masked the beany flavour. As mentioned (Chapter 5.1), to improve on the flavour of the snacks adding a commercial flavouring could be valuable. Addition of a colourant would perhaps also improve the appearance so as to match the flavour and colour of commercial snacks such as Niknaks and Jiggies. Considering the brownish colour of the sorghum-cowpea composite snacks, barbeque, tomato and smoked beef flavouring could complement the appearance and mask the beany flavour. These flavours are commonly used with snacks such as Niknaks and Jiggies and are familiar to children in Southern Africa. If the beany flavour can be completely masked then it may be possible to use the 50:50

sorghum-cowpea blend which was substantially more nutrient dense than the lower ratios of cowpeas to sorghum. This would also reduce the quantity of snacks that need to be consumed to meet the protein RDA.

However, generally snack blends with high protein content tend to be hard because the protein hinders starch expansion (Olapade and Aworh, 2012). This was not the case with the sorghum-cowpea blends. They were rated the same as the sorghum snack by the panel in terms of hardness (Chapter 4.3.3.3; Table 4.3.8) and the also texture analyzer data (Figure 4.3) were not significantly different. The fact that the sorghum-cowpea snacks were not excessively hard was due probably to their high expansion ratio. This can be as a result of using flour of small particle size (≤500 μm) which can be easily plasticized in a melt during extrusion cooking (Moraru and Kokini, 2003).

It is generally easier for children to consume snack foods rather than other types of complementary foods such as porridge (Nicklaus et al., 2004), meaning they do not need much encouragement or reminding to consume snacks but rather ask for more. The use of the sorghum-legume snack blends, more especially the 50:50 sorghum-cowpea blend, makes it easier to reach out to many children with little effort in comparison to other protein-rich complementary foods. Further, sorghum-cowpea snacks are not highly perishable as they are low in moisture and could be stored at ambient temperature for several weeks if kept dry in air-tight packaging. They can be used in school nutrition programmes to address the protein and other nutrient needs of vulnerable children. They are also suitable as product for small food processing businesses as extrusion cooking is relatively a straight-simple technology. A drawback, however, is the cost of a good quality extrusion cooker which is very expensive (at least US$ 50,000). However, as a long term investment it can be profitable as extrusion cookers have continuous operation and hence a very high product output (which can be above 10 000 kg/hour depending on the size) (Riaz, 2012). In addition, making this intervention a community based approach could help in sustaining the project as communities prefer to support their own programmes (Adhikari et al., 2007). For example, in a study by Kobbail (2011), a rural community in South Sudan accepted a project based on an idea that it would be owned and managed by its community members. So community ownership of a programme is imperative.

6. CONCLUSIONS AND RECOMMENDATIONS

The nutrition quality of sorghum-based extruded snacks in terms of protein quality and mineral content is improved through the inclusion of cowpeas. This is because cowpea has a high protein content, mainly globulins which are richer in lysine first limiting indispensable amino acid than the kafirins in sorghum. Protein digestibility and calculated PDCAAS of the snacks are substantially improved through the addition of cowpeas due to globulin proteins which are more digestible than the sorghum prolamins. Calcium, iron and zinc contents are also improved through the inclusion of cowpea because it has a higher mineral content than sorghum. However, due to the high phytate content in cowpeas, the improvement in the mineral content of the extruded snacks could be negated.

Compositing with cowpea has no significant effects on the texture of extruded snacks. The snacks were expected to be harder when compared to the 100% sorghum snacks because the composites had a higher protein content which would hinder starch expansion. The hardening effect was probably offset by the fine particle size of milled cowpeas. Such fine particles are easily plasticized in a melt during extrusion cooking, leading to a well expanded snack.

The addition of cowpea to sorghum imparts a distinctive beany flavour to the extruded composite snacks. The beany flavour is the major difference between the composite and 100% sorghum snacks. To mask the beany flavour, commercial flavourants and colourants are suggested as they could also improve the appearance of the snacks to match their commercial counterparts. Flavours like barbecue (BBQ), tomato and smoked beef are common maize commercial snacks in Southern Africa and children are familiar with them. Such flavours when used in the composite snacks could also mask the beany flavour without having to introduce new flavour to the market. Once that is achieved, a consumer sensory evaluation is proposed to ascertain consumer acceptance of the snacks in comparison with the commercial counterparts made from maize.

This study established that with the parameters set optimally, extrusion cooking is a simple technology that can be used to manufacture sorghum-cowpea snacks of high protein quality and digestibility with improved mineral content. Children are familiar with extruded snacks, hence, such composite snacks have great potential to be used as a protein-rich supplementary food to prevent protein-energy malnutrition among school-going children in southern Africa.

7. REFERENCES

AACC International, 2000. Approved Methods of the American Association of Cereal Chemists, 10th edition. 44-15A Moisture-air oven methods, 08-01 Ash- basic method, 46-30 Crude protein combustion method and 30-25 Crude fat in wheat, corn, and soy flour, feeds and mixed feeds: American Association of Cereal Chemists, St Paul, Minnesota

Adebooye, O. C. and Sing, V., 2007. Effect of cooking on the profile phenolics, tannins, phytate, amino acid, fatty acid and mineral nutrients of whole grain and decorticated vegetable cowpea (*Vignaunguiculata L. Walp*). *Journal of Food Quality,* **30:** 1101-1120

Adhikari, B., Williams, F. and Lovett, J. C., 2007. Local benefits from community forests in the middle hills of Nepal. *Forest Policy and Economics,***9:** 464-478

Akdogan, H., 1999. High moisture food extrusion: A review. *International Journal of Food Science and Technology*, **34**: 195-207

Alonso, R., Aguirre, A., and Marzo, F., 2000. Effects of extrusion and traditional processing methods on antinutrients and *in vitro* digestibility of protein and starch of faba and kidney beans. *Food Chemistry,* **68:** 159-165

Alonso, R., Rubio, L. A., Muzquiz, M. and Marzo, F., 2001.The effect of extrusion cooking on mineral bioavailability in pea and kidney bean seed meals. *Animal Feed Science and Technology*, **94:** 1-13

Anton, A. and Luciano, F., 2007. Instrumental texture evaluation of extruded snack foods: a review. *Journal of Food,* **5:** 245-251

Anton, A. A., Fulcher, R. G. and Arntfield, S. D., 2009. Physical and nutritional impact of fortification of corn starch-based extruded snacks with common bean (*Phaseolus vulgaris L.)* flour: Effects of bean addition and extrusion cooking. *Food Chemistry,* **113**: 989-996

Anyango, J. O., 2009. Improvement in the protein quality of African sorghum foods through compositing with cowpea. MSc. Dissertation. University of Pretoria, Pretoria

Anyango, J. O., de Kock, H. L. and Taylor, J. R. N., 2011. Impact of cowpea addition on the Protein Digestibility Corrected Amino Acid Score and other protein quality parameters of traditional African foods made from non-tannin and tannin sorghum. *Food Chemistry,* **124:** 775-780.

AOAC, 2000. Official Method of Analysis 920.39 (17th edition). Volume I. Association of Official Analytical Chemists, Washington, DC.

Arntfield, S.D., Scanlon, M.G., Malcomson, L.J., Watts, B., Ryland, D. and Savoie, V., 1997. Effects of tempering and end moisture content on quality of micronized lentils. *Food Research International*, **30**: 371-380.

Batham, J., Sharma, G. K., Khan, M. A. and Govindaraj, T., 2013. Effects of micronisation on properties of Buckwheat seed (*Fagopyrum esculentum*). *International Journal of Agriculture and Food Science,* **3:** 22-27.

Bellido, G.G., Arntfield, S., Scanlon, M.G., and Cenkowski, S., 2003. The effect of micronization operational conditions on the physicochemical properties of navy beans (*Phaseolus vulgaris L*.) *Journal of Food Science*, **68**: 1731-1735.

Bhutta, Z. A., Ahmed, T., Black, R. E., Cousens, S., Dewey, K., Giugliani, E., Haider, B. A., Kirkwood, B., Morris, S. S., Sachdev, H. P. S. and Shekar, M., 2008. What works? Interventions for maternal and child undernutrition and survival. Maternal and child undernutrition. *The Lancet Series* 3. Available online at: www.who.int/nutrition/topics/Lancetseries_Undernutrition3.pdf. Accessed on the 15 January 2015

Bidlingmeyer, B.A., Cohen, S.A., and Tarvin, T.L. 1984.Rapid analysis of amino acids using pre-column derivatisation. *Journal of Chromatography,* **336**: 93-104

Björck, I. and Asp, N. G., 1983. The effects of extrusion cooking on nutritional value –A literature review. *Journal of Food Engineering,* **2**: 281-308

Boge, E. L., Boylston, T. D. and Wilson, L. A., 2009. Effect of cultivar and roasting method on composition of roasted soybeans. *Journal of the Science of Food and Agriculture,* **89:** 821-826

Boisen, S. And Eggum, B., 1991. Critical evaluation of in vitro methods for estimating digestibility in simple-stomach animals. *Nutrition Research Reviews,* **4:** 141-162

Brabin, B. J. and Coulter, J. B. S., 2003. Nutrition-associated disease. In: Manson's Tropical Diseases. Cook, G. C. and Zumla, A. I. (Eds). Saunders, London. Pages 561-580

Brannan, G. L., Setser, C. S., Kemp, K. E., Seib, B. A. and Roozeboom, K., 2001. Sensory characteristics of grain sorghum hybrids with a potential for use in human foods. *Cereal Chemistry,* **78**: 693-700.

Brown, K. H., 1991. Appropriate diets for the rehabilitation of malnourished children in the community setting. *Acta Paediatrica Scandanavica Supplement,* **374:**151-159

Camire, M. E.,1991. Protein modification by extrusion cooking. *Journal of the American Oil Chemist's Society,* **68:** 200-205.

Camire, M. E., 2000. Chemical and nutritional changes in food during extrusion. In: Extruders in Food Applications. Riaz, M. N. (Ed). CRC Press. Boca Raton, Florida. Pages 127-147

Carvalho, S. M. P. and Vasconcelos, M. W., 2013. Producing more with less: Strategies and novel technologies for plant-based food biofortification. *Food Research International,* **54:** 961-971

Cenkowski, S. and Sosulski, F.W.R., 1997. Physical and cooking properties of micronisation lentils. *Journal of Food Processing and Engineering,* **20**: 249-264

Chaiyakul, S., Jangchud, K., Jangchud, A., Wuttijumnong, P. and Winger, R., 2009. Effect of extrusion conditions on physical and chemical properties of high protein glutinous rice-based snack. *Food Science and Technology,* **42**: 781-787.

Chan, C. W. and Phillips, R.D., 1994. Amino acid composition and subunit constitution of protein fractions from cowpea (*Vignaunguiculata L. Walp*) seeds. *Journal of Agricultural and Food Chemistry,* **42:** 1857-1860

Cheftel, J. C., 1986. Nutritional effects of extrusion cooking. *Food Chemistry,* **20**: 263-283

Conti-Silva, A. C., Bastos, D. H. and Areas, J. A., 2012. The effects of extrusion conditions and the addition of volatile compounds and flavour enhancers to corn grits on the retention of the volatile compounds and texture of the extrudates. *International Journal of Food Science and Technology,* **47:** 1896-1902.

Coulibaly, O., Alene, A. D., Manyong, V., Sanogo, D., Abdoulaye, T., Chianu, J., Fatokun, C., Kamara, A., Tefera, H. and Boukar, O., 2009.Situation and outlook for cowpea and soybean in sub-Saharan Africa. *Situation and outlook for the tropical legume improvement-II project in West and East Africa*

Day, L. and Swanson, B. G., 2013. Functionality of protein-fortified extrudates. *Comprehensive reviews in Food Science and Food Safety*, **12:** 546-564

De Roos, K.B., 2006. A review: Understanding and controlling the behaviour of aroma compounds in thermally processed foods. *Trends in Food Science and Technology*, **17**: 236-243

Devi, N. L., Shobha, S., Tang, X., Shaur, S. A., Dogan, H. and Alavi, S., 2013. Development of protein-rich sorghum-based expanded snacks using extrusion technology. *International Journal of Food Properties*, **16:** 263-276

Diaz, M., Rosado, J., Allen, H., Abrams, H. and Garcia, O. P., 2003. The efficacy of a local ascorbic acid-rich food in improving iron absorption from Mexican diets: A field study using stable isotopes. *American Journal of Clinical Nutrition*, **78**: 436-440

Dillon, S. L., Shapter, F. M., Henry, R. J., Cordeiro, G., Izquierdo, L. and Slade Lee, L., 2007. Domestication to crop improvement: Genetic resources for sorghum and saccharum (*Andropogoneae).* A review.*Annals of Botany*, **100**: 975-989

Drewnoski, A. and Gomez-Cameros, C., 2000. Bitter taste, phytonutrients and the consumer: A review. *American Journal of Clinical Nutrition*, **72**: 1424-1435

Duncan, T., 2001. Commission on microeconomics and health. Health, nutrition and economic prosperity, a micro economic perspective.CMH Working Paper No WGI:7. World Health Organization, Geneva

Duodu, K. G., Minnaar, A., 2011. Legume composite flours and baked goods: Nutritional, functional, sensory and phytochemical qualities. In: Flour and Breads and their Fortification in Health and Disease Prevention. Preedy, V.R., Watson, R.R. and Patel, V. (Eds), Academic Press, London, 193-194

Duodu, K. G., Taylor, J. R. N., Belton, P. S. and Hamaker, B. R., 2003. Factors affecting sorghum protein digestibility. *Journal of Cereal Science*, **38**: 117-131

Duodu, K. G., Nunes, A., Delgadillo, I., Parker, M. L., Mills, E. N. C. and Belton, P. S., 2002. Effect of grain structure and cooking on sorghum and maize in vitro protein digestibility. *Journal of Cereal Science*, **35**:161-174

Duranti, M., 2006. Grain legume proteins and nutraceutical properties. *Fitoterapia*, **77**: 67-82

Egounlety, M. and Aworh, O., 2003. Effect of soaking, dehulling, cooking and fermentation with *Rhizopus oligosporus* on the oligosaccharides, trypsin inhibitor, phytic acid and tannins of soybean (*Glycine max Merr*.), cowpea (*Vigna unguiculata L. Walp*) and groundbean (*Macrotyloma geocarpa Harms*). *Journal of Food Engineering*,**56:** 249-254

Ehlers, J. D., and Hall, A. E., 1997. Cowpea (*Vigna unguiculata L. Walp*). *Field Crops Research*, **53**:187-204

Einstein, M. A., 1991. Descriptive techniques and their hybridization. In: Sensory Science Theory and Applications in Foods. Lawless, H. T. and Klein, B. P. (Eds). Marcel Dekker, New York. Pages 317-338

Etcheverry, M. F., Lum, P. J., Evans, J. L., Sanchez, E., De Lazzari, E., Mendez-Arancibia, E., Sierra, E., Gatell, J. M., Page, K. and Joseph, J. 2011. HIV vaccine trial willingness among injection and non-injection drug users in two urban centres, Barcelona and San Francisco. *Vaccine*,**29:** 1991-1996.

Fairweather-Tait, S., Lynch, S., Hotz, C., Hurrell, R., Abrahamse, L., Beebe, S., Bering, S., Bukhave, K., Glahn, R. & Hambidge, M. 2005. The usefulness of in vitro models to predict the bioavailability of iron and zinc: a consensus statement from the HarvestPlus expert consultation. *International Journal for Vitamin and Nutrition Research*,**75:** 371-374.

FAO and ICRISAT, 1996. The World Sorghum and Millet Economies: Facts, Trends and Outlook. Food and Agriculture Organization (FAO) and International Crop Research Institutefor the Semi-Arid Tropics (ICRISAT), Rome/ Patancheru, India

FAO/WHO, 1991. Protein Quality Evaluation. The Report of the Joint FAO/ WHO Expert Consultation. Food and Nutrition Paper No.51. Food and Agriculture Organization,Rome

FAO/ WHO, 1992. Preventing specific micronutrient deficiencies. International Conference on Nutrition. Food and Agriculture Organization, Rome. Pages 11-12

FAO, 1995. Sorghum and Millets in Human Nutrition. FAO Food and Nutrition Series No 27. Food and Agriculture Organization of the United Nations, Rome.

FAO, 1996. The State of Food and Agriculture.FAO Economic and Social Development papers. FAO Agriculture series No. 29. FAO, Rome

FAO, 2003. Food Energy: Methods of Analysis and Conversion Factors. FAO Food and Nutrition Paper 77. Food and Agriculture Organization, Rome. Pages 18-37.

FAO, 2011. The State of Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome

FAO, 2014. The State of Food Insecurity in the World 2014. Food and Agriculture Organization of the United Nations, Rome

FAO, IFAD and WFP, 2015. The State of Food Insecurity in the World 2015.FAO, Rome

FAOSTAT3, 2015. Faostat3.org/browse/Q/QC/E. Last accessed 12 December, 2015.

Fasina, O. O., Tyler, K. T., Pickard, M. D. and Zhang, G. H., 1999. Infrared heating of hulless and pearled barley. *Journal of Food Processing and Preservation*, **23**: 135-151.

Filli, K.B. and Nkama, I., 2007. Hydration properties of extruded fura from millet and legumes. *British Food Journal*, **109:** 68-80.

Filli, K. B., Nkama, I., Jideani, V. A., and Abubakar, V. A., 2013. Application of response surface methodology for the evaluation of proximate composition and functionality of millet-soybean fura extrudates. *Wudpecker Journal of Food Technology*, **1**:74-94

Food and Nutrition Board of the National Academy of Sciences, 2001.Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. A report of the Panel on Micronutrients. National Academies Press, Washington, DC

Freitas, R. L., Teixeira, A. R., and Ferreira, R. B., 2004. Characterization of the protein from *Vigna unguiculata* seeds. *Journal of Agricultural and Food Chemistry*, **52**: 1682-1687

Gibson, R. S., Bailey, K. B., Gibbs, M. and Ferguson, E. L., 2010. A review of phytate, iron, zinc, and calcium concentrations in plant based complementary foods used in low-income countries and implications for bioavailability. *Food and Nutrition Bulletin*, **31:**134-146

Griffith, L. D., Castell-Perez, M. E. and Griffith, M. E., 1998. Effects of blend and processing method on the nutritional quality of weaning foods made from select cereals and legumes. *Cereal Chemistry*, **75**: 105-112

Guinard, J. –X., 2001. Sensory and consumer testing with children. *Trends in Food Science and Technology*, **11**: 273-283

Hagenimana, A., Ding, X. and Fang, T., 2006. Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science*, **43**: 38-46

Hallén, E., İbanoğlu, Ş. and Ainsworth, P. 2004. Effect of fermented/ germinated cowpea flour addition on the rheological and baking properties of wheat flour. *Journal of Food Engineering*, **63:** 177-184

Hamaker, B. R., Kirleis, A. W., Mertz, E.T. and Axtell, J. D., 1986. Effect of cooking on protein profiles and *in vitro* digestibility of sorghum and maize. *Journal of Agricultural and Food Chemistry,* **34**: 647-659

Hamaker, B. R., Kirleis, A. W., Butler, L. G., Axtell, J. D. and Mertz, E. T., 1987. Improving the in vitro protein digestibility of sorghum with reducing agents. *Proceedings of the National Academy of Sciences USA,* **84**: 626-628

Hassan, I.A.G. and El Tinay, A. H.,1995. Effects of fermentation on tannin content and in vitro protein and starch digestibilities of two sorghum cultivars. *Journal of Food Chemistry,* **53:** 149-151

Henley, E. C., Rooney, L. W., Dahlberg, J., Bean, S., Weller, C., Turner, N., Awika, J., Haub, M. and Smail, V., 2010. Sorghum: an ancient, healthy and nutritious old world cereal. In:United Checkoff Program. Henley E. C. (Ed). St. Louis, Missouri

Henry-Unaeze, H. and Ibe, L., 2013. Effect of family structure on nutritional status of pre-school children (2-5 years) in a rural Nigerian population. *Journal of Biology, Agriculture and Healthcare,* **3:** 37-49

Hoke, K., Housova, J. and Houska, M. 2005. Optimum conditions of rice puffing. *Czech Journal Food of Science,* **23:** 1-11.

Hotz, C. and Gibson, R. S., 2007. Traditional food processing- preaparation practices to enhance the bioavailability of micronutrients in plant-based diets. *Journal of Nutrition,* **137**:1097-1100

Hsu, H. W., Vavak, D. L., Satterlee, L. D. and Miller, G. A.,1977. A multi-enzyme technique for estimating protein digestibility. *Journal of Food Science,* **42**: 1269-1273

Ilo, S. and Berghofer, E., 2003. Kinetics of Lysine and other amino acids loss during extrusion cooking of maize grits. *Journal of Food Science,* **68:** 496-502

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 2009. Crops: Sorghum. www.icrisat.org/sorghum/sorghum.htm. Accessed November 2015

Institute of Medicine, Food and Nutrition Board (IOM). 2004. Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids (Macronutrients).National Academies Press, Washington DC. Pages 589-768

Iqbal, A.,Khalil, I. A., Ateeq, N. and Kahn, M. S., 2006. Nutritional quality of important food legumes.*Food Chemistry*, **97**: 331-335

Iwe, M. O., van Zuilichem, D. J., Ngoddy, P. O., and Lammers, W., 2001. Amino acid and protein digestibility index of mixtures of extruded soy and sweet potato flours. *Lebensmittel Wissenchaft and Technology*, **34:** 71-75

Kebakile, M. M., Rooney, L.W., and Taylor, J. R. N., 2007. Effects of hand pounding, abrasive decortication, roller milling and sorghum type on meal extraction quality. *Cereal Food World,* **52**: 129-137

Kerr, W. L., Ward, C. D. W., Mc Watters, K. H., Resurrecion, A. V. A., 2001. Milling and particle size of cowpea flour and snack chip quality. *Food Research International*, **34:** 39-45

Khanum, S., Ashworth, A., Huttly, S. R. A., 1994.Controlled trial of three approaches to the treatment of severe malnutrition. *The Lancet*, **344:**1728-1732

Khatoon, N. and Prakash, J., 2004. Nutritional quality of microwave-cooked and pressure-cooked legumes. *International Journal of Food Science and Nutrition,* **55**: 441-448

Kobbail, A. A. R., 2011. Local people attitudes towards community forestry practices: A case study of Kosti Province-Central Sudan. *International Journal of Forestry Research*, **2012:**1-8

Kokini, J. L., Chang, C. N. and Lai, L.S., 1992. The role of rheological properties on extrudates expansion: In: Food Extrusion Science and Technology. Marcel Dekker, New York. Pages 631-653

Kulp, K., 2000. Handbook of Cereal Science and Technology. CRC Press, Boca Raton, Florida. Pages 147-177

Kumar, N., Sarkar, B. C. and Sharma, H. K., 2010. Development and characterization of extruded product of carrot pomace, rice flour and pulse powder. *African Journal of Food Science*, **4**: 703-717

Lai, H. M. and Cheng H. H., 2004. Properties of pregelatinized rice flour made by hot air or gun puffing. *International Journal of Food Science and Technology*, **39**: 201-212.

Lestienne, I., Icard-Vernière, C., Mouquet, C., Picq, C. and Trèche, S. 2005. Effects of soaking whole cereal and legume seeds on iron, zinc and phytate contents. *Food Chemistry,***89:** 421-425.

Lewicki, P. P., 2004. Water as the determinant of food engineering properties. A review. *Journal of Food Engineering*, **61**: 483-495

Li, S. –Q., Zhang, H. Q., Tony Jin, Z., Hsieh, F. –H., 2005. Textural modification of soya bean/ corn extrudates as affected by moisture content, screw speed and soya bean concentration. *International Journal of Food Science and Technology*, **40**: 731-738

Lue, S. & Huff, H., 1991. Extrusion cooking of corn meal and sugar beet fiber: effects on expansion properties, starch gelatinization, and dietary fiber content. *Cereal chemistry*, **68:** 227-234

Mangala, S. L., Mahadevamma, N. G. M. and Tharanathan, R. N., 1999. Resistant starch from differently processed rice and ragi (finger millet).*European Food Research and Technology*, **209:** 32-37.

Mannar,V. and Gallego, E.B., 2002. Iron Fortification: Country level experiences and lessons learned. *Journal of Nutrition*, **132:** 856s- 858s.

Martınez-Navarrete, N., Camacho, M., Martınez-Lahuerta, J., Martınez-Monzó, J. and Fito, P., 2002. Iron deficiency and iron fortified foods—a review. *Food Research International*, **35:** 225-231.

Mayer, J. E., Pfeiffer, W. H. and Beyer, P., 2008. Biofortified crops to alleviate micronutrient malnutrition. *Current Opinions in Plant Biology*, **11**:166-170

Meng, X., Threinen, D., Hansen, M. and Driedger, D., 2010. Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack. *Food Research International*, **43**: 650-658

Mercier, P. and Feillet, P., 1975. Modification of carbohydrate components by extrusion cooking of cereal products. *Cereal Chemistry*, **52:**283-297

Miller, D. D. and Welch, R. M., 2013. Food system strategies for preventing micronutrient malnutrition. ESA Working Paper No.13-06. Agricultural Development Economics Division, FAO.www.fao.org/economic/esa Last accessed December 2015

Mishra G., Joshi, D. C., and Panda, B. K., 2014. Popping and puffing cereal grains: A review. *Journal of Grain Processing and Storage*, **1**: 34-46

Moraru, C.I. and Kokini, J. L., 2003. Nucleation and expansion during extrusion and microwave heating of cereal foods. *Comprehensive Reviews in Food Science and Food Safety*, **2:**147-165

Moscicki, L. and van Zuilichem, D. J., 2011. Extrusion-cooking and related technique.Extrusion-cooking techniques: applications, theory and sustainability. *Wiley, Weinheim*, 1-24

Muller, O. and Krawinkel, M., 2005. Malnutrition and health in developing countries: a review. *Canadian Medical Association Journal*, **173**: 279-286

Muscaritoli, M., Molfino, A., Bollea, M. R. and Fanelli, F. R., 2009. Malnutrition and wasting in renal disease. *Current Opinion in Clinical Nutrition and Metabolic Care*, **12**: 378-383

Mwangela, A. M.,Waniska, R. D. and Minnaar A., 2006. Hydrothermal treatments of two cowpea (Vignaunguiculata L. Walp) varieties: effect of micronisation on physicochemical and structural characteristics. *Journal of the Science of Food and Agriculture*, **86**: 35-45

Nath, A. and Chattopadhay, P. K., 2007. Optimization of oven toasting for improving crispness and other quality attributes of ready-to-eat potato-soy snack using response surface methodology. *Journal of Food Engineering*, **80**: 1282-1292

Nestel, P., Bouis, H. E., Meenakshi, J. V., Pfeiffer,W., 2006. Biofortification of staple food crops. *Journal of Nutrition*, **136**: 1064-1067

Nicklaus, S., Boggio, V., Chabanet, C. and Issanchou, S., 2004. A prospective study of food preferences in childhood. *Food Quality and Preference*,**15:** 805-818

Nwabueze, T. U. 2007. Effect of process variables on trypsin inhibitor activity (TIA), phytic acid and tannin content of extruded African breadfruit–corn–soy mixtures: A response surface analysis. *LWT - Food Science and Technology*, **40:** 21-29

Ofuya, Z. and Akhidue, V., 2006. The role of pulses in human nutrition: A review. *Journal of Applied Sciences and Environmental Management,* **9:** 99-104

Okaka, J. C. and Potter, N. N., 1979.Physico-chemical and functional properties of cowpea powders processed to reduce beany flavour. *Journal of Food Science,* **44**: 1235-1240

Olapade, A. A., and Aworh, O. C., 2012. Evaluation of extruded snacks from blends of acha (*Digitaria exilis*) and cowpea (*Vigna unguiculata*) flours. *Agricultural Engineering International: Commission Internationale du Genie Rural (CIGR) Journal,* **14:** 210-217

Onwulata, C.I., Smith, P. W., Konstance, R.P. and Holsinger, V.H., 2001. Incorporation of whey products in extruded corn, potato or rice snacks. *Food Research International*, **34**: 679-687

Onyenekwe, P. C., Njoku, G. C. and Ameh, D. A., 2000. Effect of cowpea (*Vigna unguiculata L. Walp*) processing methods on flatus causing oligosaccharides. *Nutrition Research*, **3**: 349-358

Osman, M., 2004. Chemical and nutrient analyses of baobab (*Adanvonia digitata*) fruit and protein solubility. *Plant Foods for Human Nutrition,* **59**: 29-33

Oste, R. E., and Sjodin, P., 1984. Effect of maillard reaction products on protein digestion. *In vivo* studies on rats. *Journal of Nutrition,* **114**: 2228-2234.

Otten, J. J., Hellwig, J. P. and Meyers, L. D., 2006. DRI, Dietary Reference Intakes: The Essential Guide to Nutrient Requirements, National Academies Press, Washington DC. Pages 5-144

Parker, M. L., Grant, A., Rigby, N. M., Belton, P.S. and Taylor, J. R. N., 1999. Effects of popping on the endosperm cell walls of sorghum and maize. *Journal of Cereal Science,* **30**: 209-216

Pelembe, L., Erasmus, C. and Taylor, J. 2002. Development of a protein-rich composite sorghum–cowpea instant porridge by extrusion cooking process. *LWT-Food Science and Technology,* **35:** 120-127

Peréz-Navarrete, C., González, R., Chel- Guerrero, L. and Betancur- Ancona D., 2008. Effect of extrusion on nutritional quality of maize and Lima bean flour blends. *Journal of the Science of Food and Agriculture*, **86**: 2477-2484

Phillips, R. D., McWatters, K. H., Chinnan, M. S., Hung, Y.C., Beuchat, L. R., Sefa-Dedeh, S., Sakyi-Dawson, E., Ngoddy, P., Nnanyelugo, D., Enwere, J., Komey, N. S., Liu, K., Mensa-Wilmot, Y., Nnanna, L. A., Okeke, C., Prinyawiwatkul, W. and Saalia, F. K., 2003. Utilization of cowpeas as human food. *Field Crops Research*, **82:** 193-213

Pinero, D. J., Li, N. Q., Connor, J. R. and Beard, J. L., 2003. Variations in dietary iron alter brain iron metabolism in developing rats. *Journal of Nutrition*, **130**: 254-263

Priyanka, K., Aparna, K. and Lakshimi, D. N., 2012. Development and evaluation of RTE (Ready to Eat) extruded snacks using egg albumin powder and cheese powder. *Agriculture and Engineering International: Commission Internationale du Genie Rural (CIGR) Journal,* **14**: 179-187

Prinyawiwatkul, W., McWatters, K. H., Beuchat, L. R., and Phillips, R. D., 1997. Functional characteristics of cowpea (*Vigna unguiculata*) flour and starch as affected by soaking, boiling and fungal fermentation before milling. *Food Chemistry*, **58**: 361-372

Reddy, N. R., Pierson, M. D., Sathe, S. K., and Salunkhe, D.K., 1985. Dry bean tannins: a review of nutritional implications. *Journal of the American Oil Chemistry Society*, **62**: 541-549

Reddy, N., 2002.Occurrence, distribution, content and dietary intake of phytate. In: Food phytates. Reddy, N. R. and Sathe, S. K. (Eds).CRC Press. Boca Raton, Florida. Pages 25-52

Riaz, M.N., 2006. Extruded snacks. In: Handbook of Food Science, Technology and Engineering. CRC Press. Boca Raton, Florida. Pages 168-175

Riaz, M., 2012. Cereal extrusion technology for small food processing enterprises. *Quality Assurance and Safety of Crops and Foods,* **4:** 156-156

Riaz, M. N., 2013. Maintaining ingredient quality in extruded feeds. *International Aquafeed,* **16:** 12-16

Rooney, L. W. and Serna-Saldivar, S. O., 2003 (2nd edition). Food uses of whole corn and dry milled fraction. In: Corn Chemistry and Technology. White, P. and Johnson, L. (Eds). American Association of Cereal Chemists, St Paul, Minnesotta. Chapter 13, Pages 495-535

Roulet, M., 1994. Protein-energy malnutrition in cystic fibrosis patients. *Acta Paediatrica*, **83**: 43-48

Ruel, M.J. and Levine C.E., 2000. Assessing the Potential of Food Based Strategies to Reduce Vitamin A and Iron Deficiencies: A review of current evidence. International Food Policy Research Institute, Washington DC

Sachs, J. D. and McArthur, J. W., 2005. The Millennium Development Project: A plan for meeting the Millennium Development Goals. *The Lancet*, **365**: 347-535

Sacchetti, G., Pinnavala, G. G., Guidoline, E. and Rosa, D. M., 2004. Effect of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour based snack-like products. *Food Research International*, **37:** 527-534

Sathe, S. K. ,Wolf, W. J., Roux, K. H., Teuber, S. S., Venkatachalam, M., Sze-Tao, K. W. C., 2002. Biochemical characterisation of amandin, the major storage protein of almond (*Prunusdulcis L.). Journal of Agricultural and Food Chemistry,* **50:** 4333-4341

Schofield, C. and Ashworth, A., 1996. Why have mortality rates for severe malnutrition remained so high? *Bulletin of the World Health Organization,* **74**: 223-229

Serna-Saldivar, S.O., and Rooney, L.W., 1995. Structure and chemistry of sorghum and millets. In: Sorghum and Millets: Chemistry and Technology. Dendy, D. A. V. (Ed.) American Association of Cereal Chemistry, St Paul, Minnesotta. Pages 69-124

Serna-Saldivar, S.O., Clegg, C., and Rooney, L.W. 1994. Effects of parboiling and decortication on the nutritional value of sorghum (*Sorghum bicolor L. Moench*) and pearl millet (*Pennisetum glaucum L.*).*Journal of Cereal Science,* **19**:83-89

Serrem, C. A., 2010. Development of soy fortified sorghum and bread wheat biscuits as a supplementary food to combat Protein Energy Malnutrition in young children. PhD Thesis. University of Pretoria, Pretoria

Serrem, C. A, de Kock, H. L. and Taylor, J. R. N., 2011. Nutritional quality, sensory quality and consumer acceptability of sorghum and bread wheat biscuits fortified with defatted soy flour. *International Journal of Food Science and Technology,* **46:** 74-83

Shewry, P. R., Napier, J. A., and Tatham, A. S., 1995. Seed storage proteins: structures and biosynthesis. *Plant Cell*, **7**:945-956

Shukla, T., 1994. Future snacks and snack food technology. *Cereal Foods World*, **39**: 704-715

Singh, A., Baoule, A. L., Ahmed, H. G., Dikko, A. U., Aliyu, U., Sokoto, M. B., Alhassan, J., Musa, M., Haliru, B., 2011. Influence of Phosphorus on the performance of cowpea (*Vigna unguiculata L. Walp)* varieties in the Sudan savanna of Nigeria. *Agricultural Science,* **2**: 313-317

Singh, B. B., Ajeigbe, H. H., Tarawali, S. A., Fernandez-Rivera, S. and Abubakar, M., 2003. Improving the production and utilization of cowpeas as food and fodder. *Field Crops Research*, **84:**169-177

Singh, S., Gamlath, S. and Wakeling, L., 2007. Nutritional aspects of food extrusion: a review. *International Journal of Food Science & Technology,* **42:** 916-929.

Smith, D. M., 2003(3rd edition).Protein separation and characterization procedures. In: Food Analysis. Nielsen, S. S. (ed). Academic/ Plenum Publishing, New York. Pages 247-268

Sokhey, A. S., Kollengode, A. N., and Hanna, M. A., 1994. Screw configuration effects on corn starch expansion during extrusion. *Journal of Food Science*, **59**: 895-898

Soukolis, C. and Aprea, E., 2012. Cereal bran fractionation: Processing techniques for the recovery of functional components and their applications to the food industry. *Recent Patent Food and Nutrition Agriculture,* **4:** 61-77

Stone, H. and Sidel, J., 2004. Introduction to sensory evaluation. Sensory Evaluation practices. Elsevier Academic Press. Boston, Massachusetts. Pages 1-19

Sultan, S., Anjum, F.M., Butt, M.S., Huma, N. and Suleria, H. A. R., 2014. Concept of double salt fortification; a tool to curtail micronutrient deficiencies and improve human health status. A review. *Journal of the Science of Food and Agriculture,* **94**: 2830-2830

Taiwo, K. A. 1998. The potential of cowpea as human food in Nigeria. *Technovation*, **18**: 469-481

Taylor, J. and Taylor, J. R. N., 2002.Alleviation of adverse effects of cooking on sorghum protein digestibility through fermentation in traditional African porridges. *International Journal of Food Science and Technology*, **37**: 129-137

Taylor, J. R. N., and Emmambux, M. N., 2008. Products containing other speciality grains: sorghums, the millets and pseudo cereals. In: Technology of functional cereal products. Hamaker, B. R. (Ed). Woodhead Publishing. Cambridge, England. Pages 281-335

Taylor, J.R.N., and Schüssler, L., 1986. The protein compositions of the different anatomical parts of sorghum grain. *Journal of Cereal Science*, **4**: 361-369

Taylor, J. R. N., 2003. Overview: Importance of sorghum in Africa. In: Belton, P. S. and Taylor, J. R. N. (Eds), Afripro, workshop on proteins of sorghum and millets: Enhancing nutritional and functional properties for Africa. Pretoria, South Africa.www.afripro.org.uk/papers/paper01Taylor.pdf. Accessed in November 2015

Taylor, J. R. N., Schober, T. J., and Bean, S. R., 2006. Novel food and non food uses for sorghum and millets: A review. *Journal of Cereal Science*, **44**: 252-271

Tumwet, T., Kirogo, V. and Warjohi, P., 2005. The role of home economics extension programme in improving household food and nutrition. In: Food and Nutrition Security for Health and Development. Makhokha, A.O. and Wangalachi, A. (Eds). Proceedings of the Inaugural National Nutrition Congress. Kenya Coalition for Action in Nutrition, Nairobi, Kenya

UNICEF, 2004.The State of the World Children. Annual report 2004. www.unicef.org/publications/index_27262.html. Accessed 12 December, 2015

USDA, 2014. USDA National Nutrient Database for Standard Reference, Release 28. http://www.ars.usda.gov/nutrientdata. Accessed on 15 December 2015

Ushakumari, S. R., Latha, S. and Malleshi, N. G., 2004. The functional properties of popped, flaked, extruded and roller-dried foxtail millet (*Setaria italica*). *International Journal of Food Science and Technology*, **39:** 907-915

Uzogara, S. and Ofuya, Z., 1992. Processing and utilization of cowpeas in developing countries: a review. *Journal of Food Processing and Preservation*,**16:** 105-147 van Jaarsveld, P. J., Faber, M. and van Stuijvenberg, M. E., 2015. Vitamin A, iron, and zinc content of fortified maize meal and bread at the household level in 4 areas of South Africa. *Food and Nutrition Bulletin*,**36:** 315-326

Van Lieshout, M. and West, C.E., 2004. Micronutrient Malnutrition Course for Southern Africa. ARC, Pretoria. University of Pretoria, Pretoria. Micronutrient Initiative Education, Hellen Keller International, Dhaka, Bangladesh

Veronica, A. O., Olusola, O. O., and Adebowale, E. A., 2006.Qualities of extruded puffed snacks from maize/ soybean mixture. *Journal of Food Processing Engineering*, **29**: 149-161

Vilakati, N., 2016. Protein, iron and zinc content and bioaccessibility of a ready-to-eat sorghum and cowpea meal developed for 2-5 year old African children. PhD Thesis, University of Pretoria, Pretoria

Vilakati, N., MacIntyre, U., Oelofse, A. and Taylor, J. R. N., 2015. Influence of micronization (infrared treatment) on the protein and functional quality of a ready-to-eat sorghum-cowpea African porridge for young child-feeding. *LWT-Food Science and Technology*, **63:** 1191-1198

Waniska, R.D., Rooney, L. W., and McDonough, C. M., 2004. Sorghum: utilization. *Encyclopedia of Grain Science*, 126-136

Weaver, C. M. and Kannan, S., 2002. Phytate and mineral bioavailability. In: Food Phytates. Reddy, N. R and Sathe, S. K. (Eds).CRC Press. Boca Raton, Florida. Pages 211-223

Wenzel, E. and Somoza, V., 2005. Metabolism and bioavailability of trans-resveratrol. *Molecular Nutrition and Food Research*, **49:** 472-481

White, P. J., and Broadley, M. R., 2005. Biofortifying crops with essential mineral elements. *Trends in Plant Science*, **10**: 587-595

Whitney, E. and Rolfes, S. R., 2013 (13th edition). Weight management. Overweight, Obesity and Underweight. In: Understanding Nutrition.Wadsworth. Belmont, Carlifornia: Pages 259-291

WHO/FAO/UNU, 2007.Protein and Amino Acid Requirements in Human Nutrition. WHO Technical Report Series No. 935. World Health Organization, Geneva.

Zasoki, R. and Barau, R., 1977. A rapid nitric perchloric acid digestion method for multi-element tissue analysis. *Communications in Soil Science and Plant analysis*, **8:** 425-436

Zheng, G.H., Fasino, O., Sosulski, F.W. and Tyler, R.T., 1998. Nitrogen solubility of cereals and legumes subjected to micronisation. *Journal of Agricultural and Food Chemistry*, **44**: 4157-4160

Žilić, S., Hadži-TaškovićŠukalović, V., Milašinović, M., Ignjatović-Micić, D., Maksimović, M. and Semenčenko, V., 2010. Effect of micronisation on the composition and properties of the flour from white, yellow and red maize. *Food Technology and Biotechnology,* **48:** 198-206