THE DEVELOPMENT OF AMADUMBE (*COLOCASIA ESCULENTA* (L.) SCHOTT) - SOYA COMPOSITE BISCUITS WITH IMPROVED NUTRITIONAL AND SENSORY PROPERTIES

By

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Submitted in part fulfilment of the requirements

for the degree of

MASTER OF SCIENCE IN AGRICULTURE

at the

UNIVERSITY OF SOUTH AFRICA

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JUNE 2018

DECLARATION

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I declare that the above thesis is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. I further declare that I have not previously submitted this work, or part of it, for any degree or examination in any other higher education institution.

SIGNATURE: ______________________ **DATE**: November 2017

DEDICATION

This dissertation is dedicated to my God for the gift of life, good health, courage and wisdom.

ACKNOWLEDGEMENTS

I would like to acknowledge the following people for helping me to successfully complete this study:

- Dr Frederick Tabit for his excellent guidance, constructive criticism and encouragement throughout the study;
- Dr Eric Amonsou, my co-supervisor, for the tremendous supervision and guidance during the execution of the study;
- The entire staff of the Department of Life and Consumer Science at the University of South Africa, as well as the Department of Biotechnology and Food Science at the Durban University of Technology for their assistance and approval granted during this study;
- The Department of Research at the University of South Africa and NRF, South Africa, for providing the funds needed for this study;
- My father, Mr Philemon Mogami Mokhele, my mother, Mrs Rosemary Matshidiso Mokhele, my brother, Mr Hosea Boikanyo Mokhele, my sister, Mrs Mmaletsatsi Catherine Matlhobogoane, my aunt, Miss Consolate Maphage, my uncles, Mr Sello Benjamin Maphage and Mr Jacob Tsimane Maphage, for their unlimited prayers; and
- My four children, Tshegofatso, Otlotleng, Khensani and Rhulani Mokhele, for their patience and love while I was doing my study.

ABSTRACT

The Amadumbe crop [*Colocasia esculenta* (L.) Schott] is a traditional Southern African tuber crop which is rich in starch, mucilage and micronutrients. Amadumbe tubers have limited amount of proteins and as a result, amadumbe-processed foods lack adequate protein. The purpose of this study was therefore to develop protein-rich amadumbe-soya composite biscuits, which would be acceptable to consumers. Biscuits were prepared by combining amadumbe and soya flours at ratios: 90:10, 70:30 and 50:50. Functional properties of composite flours and the physical properties of composite biscuits were determined. The proximate composition, amino acid composition and protein digestibility of composite biscuits were determined. Consumer acceptability test of biscuits was performed using nine-point hedonic scale. The results indicated that the 90% amadumbe and 10% soya composite biscuits had high significant values of moisture, ash, carbohydrates contents and energy values. The 50% amadumbe and 50% soya composite biscuits had significantly high values of fat, crude protein contents and acid detergent fibre (ADF). The protein digestibility, amino acid contents, especially the lysine contents of composite biscuits increased significantly ($p \leq 0.05$) with an increase in the percentage of soya. The mineral contents of composite biscuits; Ca, Mg, P, Zn, Cu, Mn and Fe increased significantly ($p \leq 0.05$) with the increase of soya in the composite biscuits. There was a significant difference in the mean taste acceptability and mean overall acceptability when the soya concentration was increased to 50%. Soya was successfully used to produce amadumbe composite biscuits with better nutritional quality with respect to protein content, amino acid profile and selected mineral contents and which were acceptable to consumers.

Keywords: Amadumbe-soya biscuit, consumer acceptance, lysine, protein digestibility

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CHAPTER 1: INTRODUCTION

1.1 Background information

Amadumbe (*Colocasia esculenta* (L.) Schott) is a tropical tuber crop produced for its underground corms and which is found in many regions of Africa (Kaur *et al*., 2013). Amadumbe is also referred to as taro in the Pacific Islands and cocoyam in West Africa (Mc Ewan *et al*., 2010). In South Africa, amadumbe tubers are grown in KwaZulu-Natal, Eastern Cape, Mpumalanga and Limpopo Provinces. Amadumbe were introduced in the country and are now recognised as a traditional crop (Mabhaudhi & Modi, 2013; DAFF, 2011b). Amadumbe is rich in starch (70-80%) and mucilage (10%), as well as micronutrients such as iron, vitamin A and vitamin B_2 (Naidoo *et al*., 2015; Soudy *et al*., 2014; Arenillo *et al*., 2012; DAFF, 2011b; Salwa, *et al*., 2010; Ammar *et al*., 2009). However, unlike other staple crops such as maize and sorghum, amadumbe is still much underutilised (Mabhaudhi & Modi, 2013). Traditionally, amadumbe corms are boiled, roasted, baked or fried before consumption (DAFF, 2011a; DAFF, 2011b; Lebot *et al*., 2011). Amadumbe contains very small size starch granules (1.4 to 5 µm) which make it highly digestible and suitable for the preparation of infant foods (Owusu-Darko *et al*., 2014; Jane *et al*., 1992). Amadumbe has limited amount of proteins and, as a result, amadumbe processed foods lack protein. Children consuming amadumbe products are mostly likely to suffer from protein-energy malnutrition. This problem may be overcome by complementing amadumbe with protein rich crops.

Leguminous protein-rich grains, such as soya, have been used to compose low protein foods to improve protein quality and digestibility. Wheat flour (80%) has been fortified with soya flour (20%) to produce a fortified biscuit with improved protein content of up to 9.3% from 7.31% (Awasthi *et al*., 2012). Amadumbe flour is also considered as an alternative ingredient for cakes, baked products and beverages (Arenillo *et al*., 2012; Sanful, 2011). Amadumbe supplemented wheat bread produced desirable organoleptic quality, increased moisture and ash, but showed a decrease in protein, fat, carbohydrates and energy (Sanful, 2011). Furthermore, the making of wheat bread with 10% amadumbe flour did not adversely affect the rheological and organoleptic properties of the composite bread produced (Ammar *et al*., 2009). The development of more popular and nutritious food from amadumbe may be necessary to improve its utilisation and commercialisation. Amadumbe corms may be processed into canned corm portions, flour, beverage, chips, and flakes (Lebot *et al*., 2011).

The purpose of this study was to develop protein rich amadumbe-soya composite biscuits which would be acceptable to consumers.

1.2 Problem statement

Amadumbe is commercialised in parts of the world such as Asia, the Pacific and some African countries. However, in South Africa, it is not commercially popular and is considered the food of the poor. As a result, commercial farmers have shown no interest in the crop (Lewu *et al*., 2010a). Due to its unpopularity, the nutritional benefits of amadumbe have not been exploited in many developing countries; this is notwithstanding the prevalence of food shortages and malnutrition among some rural people (Buragohain *et al*., 2013). Furthermore, amadumbe contains zinc which can aid in the alleviation of zinc deficiency often associated with stunting (Alcantara *et al*., 2013). The economic and commercial potential of amadumbe has not been exploited even though, because of its high carbohydrate content of up to 95% and mineral content of up to 5.5%, it forms part of the staple food in several rural communities in developing countries (Kaur *et al*., 2013; Himeda *et al*., 2012). In South Africa, amadumbe is mainly cultivated for subsistence by rural farmers. Amadumbe and other indigenous crops can be important in the fight against food insecurity in rural communities, especially considering that they can survive drought, poor harvests, as well as generate income (Mavengahana *et al*., 2013; Dweba & Mearns, 2011; Baiphethi & Jacobs, 2009). The development of value added amadumbe products will encourage farmers to grow more amadumbe. This will result in income generation and food security in rural communities.

1.3 Motivation for the research

Amadumbe is a traditional staple root crop in South Africa, which is currently underutilised. Therefore, developing amadumbe-soya protein enriched composite biscuits will add value to amadumbe, improve its image and encourage farmers to grow more amadumbe. This will result in income generation and food security in rural communities. Furthermore, a nutrient rich amadumbe-soya composite biscuit will improve the utilisation, as well as the commercial value of the amadumbe plants. It is expected that government will make use of amadumbe protein-rich biscuits that will be produced from this research in school feeding schemes, especially in poor rural communities. It is hoped that this will contribute to the alleviation of protein-energy malnutrition among school children.

CHAPTER 2: LITERATURE REVIEW

2.1 Amadumbe (*Colocasia esculenta* (L.) Schott): An indigenous traditional food crop with potential dietary and economic benefits

Amadumbe (*Colocasia esculenta* (L.) Schott) is a tropical tuber crop produced for its underground corms and which is found in many regions of Africa (Kaur *et al*., 2013). It is also referred to as taro in the Pacific Islands and as cocoyam in West Africa (McEwan *et al*., 2010). Amadumbe is traditionally cultivated in the coastal and subtropical areas of South Africa, namely in the KwaZulu-Natal, Mpumalanga and Eastern Cape provinces. It is often sold in informal markets and rarely in some supermarkets (DAFF, 2011b). In many other African countries, amadumbe plays an important role in the livelihoods of millions of smallholder farmers who cultivate, produce and commercialise it on a small scale (Macharia *et al.*, 2014). However, in South Africa, it is not commercially popular and is considered food for the poor. Commercial farmers have shown no interest in the crop (Lewu *et al*., 2010a). Unlike other staple crops, such as maize and sorghum, amadumbe is still underutilised (Mabhaudhi & Modi, 2013).

2.2 The amadumbe plant

The amadumbe plant, which is an indigenous food crop in South Africa, is a perennial crop that can tolerate a wide range of wet and dry farming land sites. In South Africa, it is mostly produced by rural farming communities for subsistence and not for trading (DAFF, 2011b). The amadumbe plant consists of two botanical varieties, namely *C. esculenta* var. Esculenta, which is characterised by a large main or central corm and several smaller side cormels, and *C. esculenta* var. Antiquorum, which is characterised by a relatively small central corm and well-developed side cormels (Mergedus *et al*., 2015). The amadumbe plant is characterised morphologically by aerial leaves (Figure 2.1). These are supported by a subterranean stem (corm) which often gives rise to several cormels (Figure 2.2). Both corms and cormels of the amadumbe plant are used as food and for vegetative propagation (Owusu-Darko *et al*., 2014).

Figure 2.1 Growing amadumbe (*Colocasia esculenta* (L.) Schott) plants (Courtesy of Dr TF Tabit)

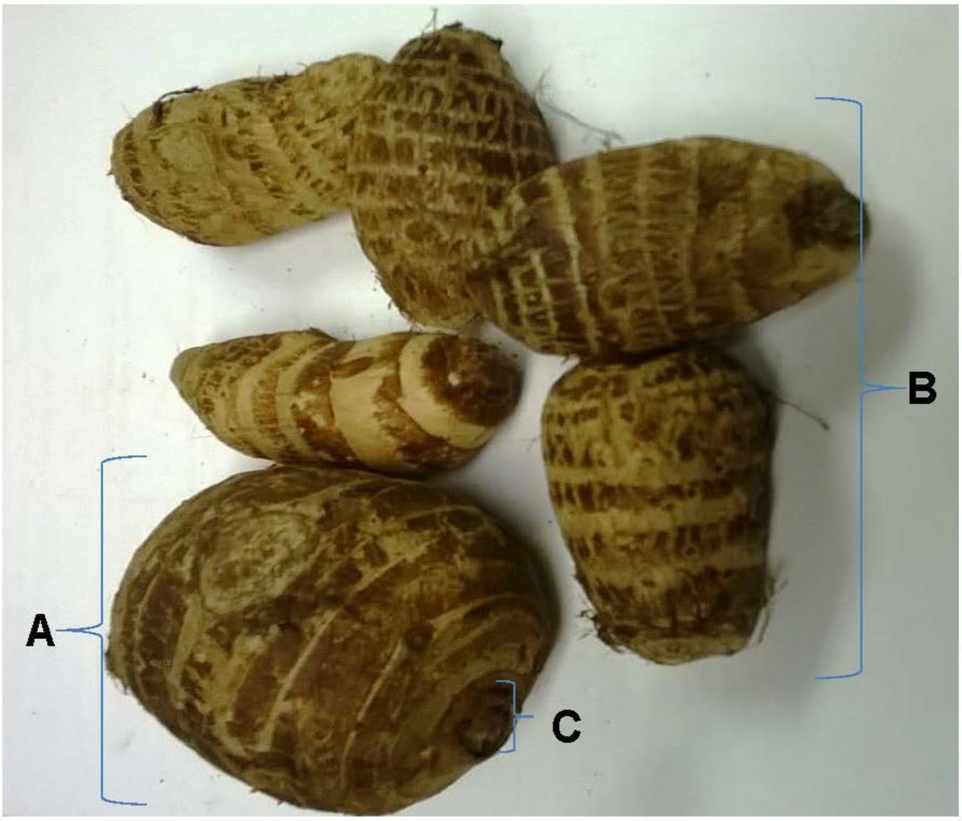

Figure 2.2 Amadumbe (*Colocasia esculenta* (L.) Schott): A = subterranean corm, B = cormels, C = Huli (Apical region of the corm). (Courtesy of Dr TF Tabit)

2.3 Production of amadumbe

Amadumbe is produced mostly in developing countries located in tropical and subtropical regions in sub-Saharan Africa, the Pacific Islands, Asia and the Caribbean (Fujimoto, 2008). In South Africa, amadumbe is grown mainly by rural farming communities in tropical and subtropical areas in KwaZulu-Natal, the Eastern Cape and Mpumalanga (DAFF, 2011b; McEwan *et al*., 2010). The amadumbe crop can be grown on various land types ranging from wetland to dryland. Given its adaptation to various climatic conditions, amadumbe can play a vital role in solving the food shortage problem due to climatic factors (DAFF, 2011b). In Africa, amadumbe is produced mostly by subsistence farmers in the following West and Central African countries: Nigeria, the Ivory Coast, Cameroon, Ghana, Egypt, Rwanda, Gabon, Liberia and Nigeria. Cameroon, Ghana and the Ivory Coast were identified by the FAO as countries in Africa producing the most amadumbe (Adejumo *et al*., 2013). Other major non-African producing countries are China, Japan, the Philippines and Thailand in Asia; in the

Pacific Islands production is dominated by Papua New Guinea, Samoa, the Solomon Islands, Tonga and Fiji (Akwee *et al*., 2015).

2.3.1 Cultivation of amadumbe

In the tropical regions of most West and East African countries, amadumbe is often planted in the early rainy season, around March to May, and is harvested at the onset of the dry season from September to January (Fujimoto, 2008). The amadumbe crop can be grown simultaneously with other crops such as maize, cassava and plantain (Mbong *et al*., 2013). In South Africa, amadumbe is usually planted in November, and this is followed by pest, disease and weed control in March and harvesting when the plants are matured, that is when the leaves turn yellow and start to dry (DAFF, 2011b). The four types of planting materials used to plant amadumbe are side suckers (lateral growth from the corm of the main plant), cormel (small corms that bud off from the main corm), huli (the apical region of the corm) (Figure 2.1), as well as smaller corm pieces resulting from splitting a large amadumbe corm (Onwueme, 1999). There are two major ways in which amadumbe can be cultivated, namely wetland cultivation where amadumbe is grown on stream banks or in low-lying marshy areas with hydromorphic soils, and dryland cultivation which essentially depends on rainfall or irrigation (Fujimoto, 2008; Onwueme, 1999).

2.3.2 Amadumbe plant diseases

In most cases, amadumbe plant diseases can be self-limiting. However, they can become quite severe in certain regions or at certain times during the cropping season and result in low yields (Onwueme, 1999). Certain pests and diseases can lead to poor production of amadumbe. For example, the amadumbe leafhopper (*Tarophangus proserpina*) can transmit blight caused by the fungal species *Phytophthoptora colocasiae,* which causes the death of amadumbe plants (Mbong *et al*., 2013). Other diseases include amadumbe soft rot, caused by *Pythium,* a fungal genus that attacks the roots and corms and causes rot. Sclerotium rot, caused by the fungal species *Sclerotium rolfsii,* causes stunting of the plant and rotting of corms. *Cladosporium* leaf spot, caused by the fungal species *Cladosporium colocasiae*, causes brown spots to appear on the older leaves (Deo *et al*., 2009). In the inland and wetlands of the north-eastern and southern regions of Mount Cameroon, an outbreak of *Pythium myriotylum* resulted in low yields of amadumbe (Orock & Lambi, 2014). Avoidance of fungal contamination of planting materials and the growing of amadumbe plant using hygienic methods, together with the use of fungicides to control fungi diseases, are measures that can be used to mitigate against low yields caused by fungal diseases (Jackson & Gollifer, 1975).

2.4 Chemical and mineral composition of amadumbe corm

In this section, the nutrient, mineral, vitamin, amino acid and anti-nutrient factors of the amadumbe corm and leaves will be reviewed. Tables 2.1 and 2.2 show the chemical and mineral composition of amadumbe corm and leaves.

2.4.1 Nutrient composition of amadumbe corm

Even though the nutritional composition of roots and tubers may vary slightly from place to place, depending on the climate, soil and crop variety, amadumbe, in general, possesses sufficient amounts of most micronutrients required for healthy living (Ndabikunze *et al*., 2011). As shown in Table 2.1, amadumbe is as an important staple food crop, which contains substantial amounts of moisture ranging from 63.6% to 72.4% of the fresh amadumbe corm, as well as carbohydrates ranging from 23.03 to 86.11 g/100 g dry weight, making it an excellent energy supply. On a dry weight-basis, amadumbe has a protein content ranging from 1.10 to 3.80 g/100 g, a fibre content ranging from 1.34 to 4.30 g/100 g, an ash content ranging from 1.20 to 2.69 g/100 g and a fat content ranging from 0.20 to 0.40 g/100 g. Amadumbe is a good source of both insoluble and soluble dietary fibre, which may have a positive effect on glycaemic control (Alinnor & Akalezi, 2010). The most prominent vitamins and their content in amadumbe per 100 g dry weight are β-carotene, which is up to 93.6 mg and ascorbic acid, which ranges from 12 to 21 mg. This is followed by niacin, which ranges from 0.64 to 2.7 mg, riboflavin, from 0.05 to 0.1 mg and thiamine, from 0.05 to 0.07 mg.

2.4.2 The mineral content of amadumbe corm

The amadumbe corm possesses substantial amounts of different minerals with the most abundant (per 100g dry weight) being potassium which ranges from 209.13 to 345.30 mg. This is followed by sodium, which ranges from 82.13 to 270.83 mg, magnesium, from 31 to 216 mg, calcium, from 31 to 216 mg, phosphorus from 36 to 54 mg, iron from 1.16 to 10.80 mg, zinc from 1.10 to 1.67 mg, and copper from 0.008 to 10.06 mg. Compared to other tubers, such as cassava, amadumbe corm possesses a substantial amount of iron and copper that can supply the WHO RDA for both adults and children when consumed in appropriate quantities (Alinnor & Akalezi, 2010).

2.4.3 The content of anti-nutritional factors in amadumbe corm

The amadumbe corm possesses some anti-nutritional factors which are mostly in the form of oxalates and phytates. Anti-nutritional factors are compounds that reduce the bioavailability of nutrients such as proteins, vitamins and minerals. This makes it difficult for the body to absorb adequate amounts of these nutrients during digestion, even when they are present in food in considerable amounts (Gilani *et al*., 2012; Akande *et al*., 2010). The total oxalate composition in amadumbe corm ranges from 234 to 411 mg/100 g dry weight, of which 60 to 70% are water soluble oxalate. The different types of oxalate (per 100 g dry weight) are water-soluble oxalate, which ranges from 163 to 201 mg, and calcium oxalate, which ranges from 71 to 144 mg. These oxalate levels do not pose a problem in the use of amadumbe as food because a significant amount of oxalate is leached out during cooking, leaving behind non-toxic levels that do not significantly influence the absorption of minerals during digestion (McEwan *et al*., 2014; Huang *et al*., 2007). Peeling the amadumbe corm prior to boiling also contributes to the removal of oxalate because the outer skins of amadumbe corms contain a higher concentration of calcium oxalates than the flesh (Ravindran *et al*., 1996). Processing techniques, such as drum-drying, have been found to reduce the oxalate content of amadumbe products to non-harmful levels (Sefa-Dedeh & Agyir-Sackey, 2004). Unlike their baked counterparts, boiled amadumbe corms lose substantial amounts of soluble oxalate leaving just 17.7 mg/100 mg (Savage & Catherwood, 2007).

The phytic acid composition of amadumbe corm ranges from 139 to 169 mg and these levels are like those of other tropical root crops such as yam and cassava tubers, as well as some cereals, grains and sweet potatoes. These phytic acid levels do not significantly influence the bioavailability of minerals during digestion of food in the small intestine (Huang *et al*., 2007). It should be noted that phytic acid binds mineral metal ions, especially zinc, iron and calcium to form phytates which are insoluble complexes that cannot be digested or absorbed in the intestine due to the absence of digestive enzymes for phytate (Coulibaly *et al*., 2011). Like oxalate, the phytic acid/phytate level in amadumbe comb can significantly be reduced by boiling and discarding the water used for boiling (Alcantara *et al*., 2013).

2.4.4 Chemical and mineral composition of amadumbe leaves

Table 2.2 shows that amadumbe leaves have a protein content of about 0.5 µg/100 g fresh weight (FW) and a fibre content of about 30.3 g per 100 g FW. The calorific value of amadumbe leaves ranges from 600 to 1675 KJ/100 g, with a carbohydrate content of about 29.95 g/100g FW. Fresh weight is the weight of amadumbe leaves that did not wilt after harvesting. The most abundant vitamins in amadumbe leaves are ascorbic acid (36 mg), niacin (1.3 mg), and vitamin E (1.1 mg) per 100 g FW (see Table 2.2). The other vitamins comprise riboflavin (0.38 mg), thiamine (0.14 mg) and etinol (424 µg) per 100 g FW. Similarly, the most abundant minerals in amadumbe leaves are phosphorus (76 mg), sodium (79.52 to 82 mg), magnesium (7.30 to 30 mg), iron (0.7 to 25 mg), zinc (0.25 to 26 mg) and calcium (0.19 to 18 mg). The essential amino acids of amadumbe leaves are, in g/16 g nitrogen, histidine (10.2), leucine (12.7), threonine (6.2), valine (9.4), methionine (1.7), isoleucine (12.7), phenylalanine (8.0) and lysine (11.7). The content of other amino acids is glutamic acid (17.2), aspartic acid (13.3), alanine (10), arginine (9), glycine (8.8), proline (7.5), serine (5.3) and tyrosine (2.8) (Amagloh & Nyarko, 2012; Maunder & Meaker, 2007; Oscarsson & Savage, 2007; Ejoh *et al*., 1996).

The total oxalate content of amadumbe leaves ranges from 484 to 589 mg per 100 g FW, of which 74% is soluble oxalate. The young amadumbe leaves contain more oxalate than the more matured leaves, with up to about 589 mg total oxalates/100 g leaves against 443 mg total oxalates/100 g FW in the more matured leaves (Oscarsson & Savage, 2007). Boiling amadumbe plant tissues in water leaches about 64 to 77% of the total soluble oxalates into the cooking water (Catherwood *et al*., 2007). Similarly, baking young and old amadumbe leaves with milk can decrease the soluble oxalate content by 21.4 to 43.2% (Savage *et al*., 2009; Oscarsson & Savage, 2007). By contrast, baking amadumbe leaves has been found to concentrate the oxalate content of the cooked dish (Oscarsson & Savage, 2007).

Table 2.1 Chemical composition of amadumbe (*Colocasia esculenta* (L.) Schott) on dry weight basis

Proximate (g/ 100 g)	**Moisture** 63.6%–72.4%	**Protein** 1.10-3.80	**Fat** 0.20-0.40	**Carbohydrate** 23.03-86.11	**Fibre** 1.34-4.30	**Ash** 1.20-2.69		
Energy (kJ/ 100 g)	406-1022.27							
Vitamins (per 100 g FW)	**Retinol (µg)** <LOD	**β-carotene (mg)** 93.6	**Thiamine (mg)** 0.05-0.07	**Riboflavin (mg)** 0.05-0.1	**Niacin (mg)** 0.64 -2.7	**Ascorbic acid (mg)** 12-21		
Minerals	**Ca** 32.03-55	**P** 36-54	**Mg** 31-216	**Na** 82-270.83	**K** 209.13-345.30	**Fe** 1.16- 10.80	**Zn** 1.10-1.67	**Cu** 0.008-10.06
Anti-nutrients (mg/ 100g FW)	**Total oxalate** 234-411	**Phytic acid** 139-169	**Calcium oxalate** 71-144	**Water-soluble oxalate** 163-201				

Adapted from Alcantara *et al*., 2013; Ndabikunze *et al.*, 2011; Alinnor & Akalezi, 2010; Huang *et al*., 2007; Huang *et al*., 2000; Wills *et al*., 1983.

LOD: Limit of detection.

Table 2.2 Chemical composition of amadumbe (*Colocasia esculenta (L.*) Schott) leaves on fresh weight (FW) basis

Proximate (g/ 100 g)	**Moisture**	**Protein**	**Fat**	**Carbohydrate**	**Fibre**	**Ash**			
	NA	0.5	0.1	29.5	30.3	NA			
Energy (kJ/ 100 g)	600 - 1675								
Vitamins (per 100 g FW)	**Retinol (µg)**	**β-carotene (mg)**	**Thiamine (mg)**	**Vitamin E (mg)**	**Riboflavin (mg)**	**Niacin (mg)**	**Ascorbic acid (mg)**		
	424µg	dna	0.14	1.1	0.38	1.3	36		
Minerals	**Ca**	**P**	**Mg**	**Na**	**K**	**Fe**	**Zn**	**Mn**	**Cu**
	0.19-18	76	7.03-30	79.52-82.00	0.15-0.19	0.7-2.25	0.27-26.02	0.68	dna
Anti-nutrients (mg/ 100 g FW)	**Total oxalate**	**Phytic acid**	**Calcium oxalate**	**Water-soluble oxalate**					
	424-589	48.42-96.58	NA	NA					
Amino acid (g/ 16 g N)	**Glutamic acid**	**Aspartic acid**	**Leucine**	**Lysine**	**Histidine**	**Alanine**	**Valine**	**Arginine**	
	17.2	13.3	12.7	11.7	10.2	10	9.4	**9.0**	
	Glycine	**Phenylalanine**	**Proline**	**Isoleucine**	**Threonine**	**Serine**	**Tyrosine**	**Methionine**	
	8.8	8.0	7.5	7.1	6.2	5.3	2.8	1.7	

Adapted from Amagloh & Nyarko, 2012, Maunder & Meaker, 2007, Oscarsson & Savage, 2007, Ejoh *et al*., 1996. NA: Not available

2.4.5 Nutritional benefits

Amadumbe corm is a good source of carbohydrate, fibre, minerals and vitamins. Large servings of amadumbe corms can be an alternative source of dietary protein, thiamine, riboflavin, iron, phosphorus, zinc, vitamin B_6, vitamin C, niacin, potassium, copper and manganese (DAFF, 2011a; Soudy *et al*., 2010). Amadumbe is one of the major sources of energy in many tropical and sub-tropical areas rural communities. They constitute up to a third of their total food intake. Furthermore, amadumbe corm can be an alternative non-animal source of zinc, which can be used to combat zinc deficiency related to stunting (Alcantara *et al*., 2013). Young amadumbe leaves are rich in phenolic flavonoid pigment antioxidants such as ß-carotenes and cryptoxanthin, as well as vitamin A. They are also rich in carbohydrates, fibre, protein and minerals (Ejoh *et al*., 1996).

2.5 Potential contribution of amadumbe to food security

The amadumbe crop, which has an adequate nutrient composition and the potential to contribute to food sustainability and income generation of rural communities, has been neglected by farmers and researchers. Because of this, very little is known about its agronomic potential and, therefore, it is an underutilised crop (Akwee *et al*., 2015). In some rural communities in South Africa, amadumbe producers often consume their own produced amadumbe and sell it to local communities (from the garden gate) or to hawkers in nearby towns (Tembe, 2008). Due to its ability to survive dry conditions, amadumbe can be valuable in ensuring food availability in arid areas of South Africa and during seasons of low rainfall (Mabhaudhi *et al*., 2014).

In most West African countries, such as Ghana, amadumbe is cheaper than other roots and tubers, and its promotion enhances food security in poor rural communities (Darkwa & Darkwa, 2013). The promotion and modernisation of indigenous amadumbe-based food products and dishes can lead to an increase in consumption, and an increase in food sustainability in many rural communities (Owusu-Darko *et al*., 2014).

2.6 Amadumbe products with a potential for commercialisation

2.6.1 Products for human consumption

The promotion of amadumbe food products can play a role in enhancing food availability and nutrition of many rural communities in sub-Saharan Africa because of its nutritive value and its cheaper price compared to other root and tuber crops (Darkwa & Darkwa, 2013). Amadumbe can, therefore, be exploited to produce various commercially viable processed products or both humans and animals (Adejumo *et al*., 2013; Del Rosarlo *et al*., 1999). Starch extracted from taro corms can be transformed into RS3-rich resistant starch by applying heating, autoclaving, enzymatic debranching (with pullulans), retrogradation and drying processes. The lower *in vitro* starch digestibility and expected glycaemic index (eGI) of amadumbe resistant starch make it suitable for the formulation of foods, especially for diabetic persons and those who are interested in weight management. Furthermore, the *in vitro* bile acid binding capacity of taro resistant starch has also been noted as potentially health-promoting due to its putative cholesterol-lowering effect (Simsek & El, 2012). The combination of yam and cocoyam flours results in a composite flour that can produce fufu with better tasting and sensory qualities compared to that of yam flour alone. Fufu is a thick paste made by boiling starchy root/tuber flours and, in West Africa, yam is far more expensive and highly commercialised than amadumbe (Ezeocha *et al*., 2011). In Cameroon amadumbe corm is peeled, boiled, pounded and mashed into a paste in a mortar to form a local starch based dish referred to as achu (Njintang *et al*., 2006).

A wheat flour composite consisting of 10% amadumbe has been used to produce composite bread with acceptable organoleptic properties, and the rheological properties of the dough were not adversely affected (Ammar *et al*., 2009). A mixture of amadumbe starch and xanthan gum is used as an additive to improve the specific volume, slice shape, crumb softness and sensory characteristics such as visual appearance, taste and aroma of the bread (Alam *et al*., 2015). Following extrusion, it was found that amadumbe corm possessed an expansion ratio very close to 16 at a temperature of about 120ºC. This shows that amadumbe can effectively be used to produce extruded snack foods (Maga *et al*., 1993). Composite flour mixtures made from amadumbe and maize flour have been used to produce puffed extruded snacks with good consumer acceptance (Rodríguez-Miranda *et al*., 2011).

Good quality amadumbe leaves can be preserved and used in food preparation. It is prepared by inactivating the enzyme responsible for the browning of chopped leaves. This is done by blanching the leaves in water containing 13.74% ascorbic acid, followed by a further blanching in water containing 1% bicarbonate (Kaushal *et al*., 2012). In Cameroon, fresh chopped amadumbe leaves are mixed with pounded water-soaked cowpea to prepare a local protein rich staple dish referred to as koki. Furthermore, finely chopped leaves and petioles of amadumbe are dried and subsequently used for the preparation of soup (Mbong *et al*., 2013).

2.6.2 Products for animal consumption

Amadumbe can be exploited to produce animal feed, thus reducing the competition between humans and animals for maize (Adejumo *et al*., 2013). Unlike raw amadumbe corm meal which suppressed feed intake and growth, peeled and boiled amadumbe corm supplemented with calcium can be combined to constitute up to 200 g per kg of chick diet (Ravindran *et al*., 1996). Maize has been replaced with up to 50% of boiled and sun-dried pieces of amadumbe cormels to produce feed for weanling pigs without affecting their growth (Agwunobi *et al*., 2002). Replacing maize totally with boiled and dried amadumbe corm chips (5 mm thick) has been done in Nigeria to produce feed for broiler finishers (Ologhobo & Adejumo, 2011).

Amadumbe leaves and petioles harvested continuously from an amadumbe plant, to a total harvest of up to 64%, have been used for feeding pigs without affecting the corm yield of the plant (Kaensombath & Frankow-Lindberg, 2012a). Furthermore, replacing up to 50% of soybean crude protein with ensiled amadumbe leaves did not negatively affect growth performance, carcass traits and organ weight in pigs (Kaensombath & Lindberg 2012b). Shrimp feed containing boiled amadumbe leaves and 23% shrimp meal protein is used to replace shrimp meal in fertilized ponds in Kenya for up to 84 days without compromising the growth performance and survival of shrimps (Mathia & Fotedar, 2012).

2.6.3 Products from the application of food technology

The high viscosity of amadumbe starch makes it suitable for use in food technological applications where a high thickening power as well as a small particle size is desired, such as in bread or noodle production (Kaur *et al*., 2013). The amadumbe corm possesses mucilage which exhibits unique rheological properties, making the plant suitable for use as a commercial food thickener and stabiliser (Njintang *et al*., 2006). The small granular starch size of amadumbe can be used as a good filler for biodegradable plastic film for food products (Jane *et al*., 1992).

2.7 Soya composite biscuits

Biscuits are consumed by many people because they are popular, less costly, have longer shelf life and varied taste (Man *et al.*, 2014; Masoodi & Aeri-Khalid Bashid, 2012). Biscuits are made with refined wheat flour which has refined carbohydrates, less fibre and wheat protein and which is deficient in some indispensable essential amino acids (Aleem Zaker *et al*., 2012; Kar *et al*., 2012). Therefore, composite flour technology for wheat supplementation with soya, which is protein-rich material, could be a good method of overcoming malnutrition (Aleem Zaker *et al*., 2012). Soya flour contains essential amino acids such as lysine, and antioxidants such as isoflavones, which provide functional benefits to food processors (Siddiqui *et al*., 2003). Soya ingredients improve moisture and flavour retention, enhance texture of food and improve digestibility (Kar *et al*., 2012). Proximate composition, microbial study and sensory evaluation have shown that protein rich biscuits that were made using major seed protein concentrates, such as soya, sesame and sunflower, had better acceptability (Kar *et al*., 2012). Furthermore, composite biscuits made of sorghum and defatted soya improved nutritional characteristics, increased protein and mineral compositions and met the daily dietary requirements, especially for children (Omoba & Omogbemile, 2013).

2.7.1 Physical properties of composite biscuits

Protein enrichment of biscuits has been found to cause a reduction in the spread factor of composite biscuits due to the protein that is binding water and restricting the spread of biscuits (Siddiqui *et al*., 2003). Composite cookies made from wheat, yam and soya showed an increase in diameter and thickness between composite cookies made from wheat, yam and soya bean and 100 % wheat cookies (Apotiola & Fashakin; Ly 2013). Furthermore, biscuits enriched with 10% soya flour and 40% cassava flour showed an increase in diameter, spread ratio and a decrease in weight (Oluwamukomi *et al*., 2011). An increase in the level of substitution of composite flour of rice, bran and soya in wheat biscuits resulted in decreased width, spread ratio and increased thickness (Mishra & Chandra, 2012).

2.7.2 Nutritional properties of composite biscuits

The first limiting amino acid in cereal products is lysine content. Baking destroys lysine content by 10% and research has given considerable attention to enriching cereal-based food with other protein sources, such as oilseeds and legume proteins, because they contain lysine which is an essential amino acid in cereal-based products (Olagunju & Ifesan, 2013). Olagunju and Ifesan (2013) found that wheat biscuits that were supplemented with 5% sesame flour had an increase of protein 17.2%, fat 21.73% and ash content of 2.35%, while the 15% sesame supplementation had an increase of 18.8% of protein content, 25.02% of fat content and 4.21% of ash content. Apotiola and Fashakin; Ly (2013) showed that the substitution of wheat flour with yam flour and soya flour led to an increase in the protein content. It was also found that across all parameters, such as sensory attributes (colour, taste, texture and overall acceptability) and nutrients (carbohydrates, crude fibre, ash, protein and fat), 10% yam flour, 10% soya flour and 80% wheat flour blends produced good results overall.

2.7.3 Sensory properties and consumer acceptability of composite biscuits

Siddiqui *et al*. (2003) indicated that when wheat is supplemented with a high lysine product, like soya bean flour, the supplementation improved the nutritional quality and the functional properties and that both quality and quantity of wheat flour is improved. A 33.33% blend of amadumbe flour with wheat flour has been recommended for an acceptable textural quality (breaking strength), sensory qualities (colour, flavour and crispiness) and overall acceptability in snap cookie production (Tekle, 2009). Furthermore, a 10% amadumbe flour blend with wheat flour produced acceptability (Amon *et al*., 2011). According to Awasthi *et al*. (2012), in their study, the treatment of 10% and 20% soya flour substitution replacing wheat flour, was found to be the best organoleptically with the following sensory attributes/properties: colour and appearance; body and texture; flavour and taste; and, finally, overall acceptability.

2.7.4 Sensory evaluation of composite biscuit products

Sensory evaluation of composite biscuits that were conducted by Ayo *et al*. (2007), Himeda *et al*. (2012) and Oluwamukomi *et al*. (2011) all used hedonic scales varying from 1 (dislike extremely) and 9 (liked extremely) to evaluate composite biscuits. Sensory attributes that were evaluated were colour, flavour, taste, texture and overall acceptability. Total number of panellist (staff members and students) that were used ranged from 20 to 50. The wheat biscuit supplemented with soya bean flour is acceptable at a substitution of up to 15% (Ayo *et al*., 2007). In a study done by Oluwamukomi *et al*. (2011), it was found that biscuits with 100% wheat flour had no significant difference in sensory qualities compared to biscuits with 40%

substitution of cassava. Himeda *et al*. (2012) showed that composite biscuits with up to 30% amadumbe flour, are either acceptable or better than those made of 100% wheat flour and might have attractive taste with substitution of between 5 to 10% amadumbe flour.

2.8 Aim and objectives

The aim of this research is to develop nutrient rich amadumbe-soya composite biscuits, which can contribute to the alleviation of protein-energy malnutrition in poor rural communities, as well as add value to the amadumbe crop in South Africa.

The objectives of this research are:

- To analyse the proximate composition and functional properties of amadumbe-soya composite biscuits;
- To evaluate the physical properties (e.g. weight, diameter, spread ratio and energy) of amadumbe-soya composite biscuits; and
- To analyse the nutritional qualities, mineral composition and consumer acceptance of amadumbe-soya composite biscuits.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Materials and Methods

Amadumbe corms used in the study were bought from Jozini Makhatini Research Station (Kwa-Zulu Natal). Soya beans were bought from Soya Foods Company (Pty Ltd) in Bryanston, South Africa. White bread wheat flour bought from Tiger Consumer Brands Ltd, Bryanston, South Africa, was used as a reference flour for baking.

3.2 Preparation of amadumbe flour

Amadumbe flour was prepared using the method described by Alcantara *et al*. (2013). Raw amadumbe corms were peeled and washed in running water. Amadumbe corms were cut into chips, washed again and dried for 16 h in an oven at 55°C. The dried corms were milled into flour using a hammer mill (Restsch GmbH 5657 HAAN, West German, type SK-1). The flour was sieved through 250 µm sieve and then stored in large airtight zip lock bags at 4°C until it was used.

3.3 Preparation of soya bean flour

Soya bean flour was prepared using the method described by Oluwamukomi *et al*. (2005). Soya beans (1 kg) were cleaned, washed and boiled in water at 100°C for 30 min. After boiling, the soya beans were dehulled manually, oven dried for 16 h at 55°C and milled in a hammer mill (Restsch GmbH 5657 HAAN, West German, type SK-1) to obtain flour. The soya bean flour was sieved through 250 µm sieve and then stored in large airtight zip lock bags at 4°C until used.

3.4 Preparation of amadumbe-soya composite flours

Amadumbe and soya flours were mixed in the following ratios: 90:10, 70:30 and 50:50 using a Kitchen Aid heavy duty electric mixer (Model 5 KS, USA) and sieved through a 250 µm sieve. Composite flours were stored in airtight zip lock plastic bags, cold stored at 4°C until they were used (Okpala & Chinyelu, 2011).

3.5 Preparation of amadumbe-soya composite biscuits

The ingredients used for making biscuits were purchased from various supermarkets in Kwa-Zulu Natal, South Africa. The ingredients include different flours (white wheat bread, amadumbe, soya, amadumbe-soya composite), white sugar "Selati" (TSB Sugar, Malelane, South Africa), sunflower oil "Sunfoil" (Bought from Willowton Oil, Pietermaritzburg, South Africa), vanilla essence and "Bokomo-Moirs" baking powder (Bought from Pioneer Foods Ltd, Cape Town, South Africa). For biscuit preparation, the basic ingredients comprised of 225 g flour, 56 g sugar, 1.5 g baking powder, 66 g sunflower oil, 100 ml water and 13.5 g vanilla essence (Table 3.1). Biscuits were prepared as described by Serrem *et al*. (2011); Serrem 's Thesis, 2010). Dough was prepared by mixing all the dry ingredients together, followed by the addition of oil and water. The dough was kneaded for 3 min at medium speed using a heavy duty electric mixer (Model 5 KS, USA) to obtain a firm dough. The dough was later manually rolled out on a steel tray, to a height of 10 mm and cut into circular shapes using a 4.5 cm diameter biscuit cutter. The cut dough pieces were transferred onto a baking tray lined with aluminium foil and placed in a preheated electric oven set at 180 ± 2°C for 25 ±5 min to obtain biscuits. After baking, biscuits were cooled down for 30 min at ambient temperature. Three batches of prepared biscuits were packed in medium sized airtight zip lock bags and stored at 4°C until they were analysed.

Table 3.1 Formulation of the preparation of wheat, amadumbe, soya and amadumbe-soya composite biscuits

Samples	Amadumbe flour (g)	Soya flour (g)	Sugar (g)	Sunflower oil (g)	Baking powder (g)	Vanilla essence (g)	Water (g)
Standard (White wheat bread flour (100%)	225 (48.7)	0	56 (12.1)	66 (14.3)	1.5 (0.3)	13.5 (2.9)	100(21.7)
Amadumbe flour (100%)	225 (48.7)	0	56 (12.1)	66 (14.3)	1.5 (0.3)	13.5 (2.9)	100 (21.7)
Soya (100%)	0	225 (48.7)	56 (12.1)	66 (14.3)	1.5 (0.3)	13.5 (2.9)	100 (21.7)
Amadumbe (90): soya flour (10)	202.5 (43.8)	22.5 (4.9)	56 (12.1)	66 (14.3)	1.5 (0.3)	13.5 (2.9)	100 (21.7)
Amadumbe (70): soya flour (30)	157.5 (34.1)	67.5 (14.6)	56 (12.1)	66 (14.3)	1.5 (0.3)	13.5 (2.9)	100 (21.7)
Amadumbe (50): soya flour (50)	112.5 (24.4)	112.5 (24.4)	56 (12.1)	66 (14.3)	1.5 (0.3)	13..5 (2.9)	100 (21.7)

Figures in parentheses are percentages. (Serrem's Thesis, 2010)

3.6 Proximate composition

The proximate composition of amadumbe, soya and amadumbe-soya composite biscuits was analysed as follows:

3.6.1 Moisture content

The moisture was determined using AOAC (1980). Moisture tins were dried in an oven at 103°C for 1 h. The tins were then cooled in a desiccator for about 10 min. The tins were weighted and 2 g of milled sample weighed into the tins and dried in an oven for 4 h at 103°C. The sample was cooled for 10 min and weighted.

The moisture content (%) was calculated as follows:

$$\% \text{ Moisture} = \frac{[(\text{mass food+tin})\text{- (mass tin)}]\text{- }[(\text{mass dry food+tin})\text{- (mass tin)}] \text{ x } 100}{[(\text{mass food+tin})\text{- (mass tin)}]}$$

3.6.2 Crude protein content

Crude protein was determined with 100 mg of each sample using the thermal combustion (Dumas) method. The procedure involves three phases of analysis where the nitrogen in the protein is released through chemical decomposition by heat (combustion). The three phases were:

1. Sample drop purge phase: The encapsulated samples were placed in the loading head, sealed and purged of any atmospheric gases that entered during sample loading. The ballast volume and gas lines were also purged.
2. Burn phase: The sample was combusted at 850°C in a stream of oxygen.
3. Analyse phase: Nitrogen containing compounds were converted to nitrogen which is oxidized to oxides of nitrogen; water produced was condensed and removed. Oxides of nitrogen were carried by helium gas to a thermal conductivity detector and reduced to nitrogen for estimation. The carbon dioxide and sulphur dioxide formed were removed by selective absorption. The nitrogen content was converted to percentage (%) protein by using a protein conversion factor of 6.25 (Kayitesi *et al*., 2010; Kayitesi Dissertation, 2009).

3.6.3 Fat content

Fat content of biscuit was determined by the Soxhlet extraction method. Each sample (3 g) was weighed into an extraction thimble in which fat was extracted for one hour using the petroleum ether solvent (40-60°C). Thereafter, the petroleum ether extract was dried in an oven at 103°C for 30 min. Total fat content was obtained by calculating weight of extract as a percentage of the original sample. The difference in weight was received as mass of fat and expressed in percentage of the sample. The percentage (%) oil content is percentage fat and is calculated as follows:

$$\% \text{ Fat} = W2 - W1/W3 \times 100$$

Where: W1 = weight of the empty extraction flask, W2 = weight of the flask and oil extracted, W3 = weight of the sample (AOAC, 1990).

3.6.4 Fibre content (Acid detergent fibre (ADF) and Neutral detergent fibre (NDF) content

Dry sample (0.1 g) was weighed and filled inside a polyethylene bag. The bag was heat sealed using a low flame. Ten (10) ml of the detergent (prepared according to Goering and Van Soest, 1970) and 2 ml of decalin (decahydronaphthalene) per 100 ml of detergent solutions were added inside the 1L flask to control foaming. The flask was heated with the keeping the temperature between 95-100°C for 60 min for NDF and 70 min for ADF. The bags were taken out and washed with boiling water until they were free of any detergent solution. They were then rinsed with acetone 3 or 4 times and oven dried over-night and weighed. The percentages (%) of NDF and ADF were calculated considering the weight of polyester bag, the sample and the residue after digestion (Contreras *et al*., 1999).

3.6.5 Ash content

Each sample (3 g) of flour was weighted and burned in a furnace which had been set at 550°C for 6 h. The residue was cooled to room temperature inside a desiccator and weighed. The ash content was obtained by calculating the weight of the residue as a percentage of the original sample weight. The weight of the residual ash was then calculated as ash content (AOAC, 1990).

$$\% \text{ Ash} = \text{Weight of ash} \,/\, \text{Weight of sample} \times 100$$

3.6.6 Carbohydrate content

The carbohydrate was calculated using estimation by difference AOAC (2000). The fibre, crude protein and fat content were subtracted from organic matter, and the remainder was accounted for as carbohydrates:

$$\% \text{ Carbohydrates} = 100 - (\text{protein} + \text{fat} + \text{ash} + \text{fibre})$$

3.6.7 Energy value

Energy value of the biscuit was calculated using Atwater calorie conversion factors, based on assumptions that each gram of carbohydrate, fat and protein will yield 17 kJ (4.0 kcal), 37 kJ, (9.0 kcal) and 17 kJ (4.0 kcal), respectively. The values were expressed in kJ (Osborne & Voogt, 1978).

3.7 Functional properties of amadumbe-soya composite flours

3.7.1 Water absorption capacity

The water absorption capacity (WAC) of each flour was measured using the centrifugation method as described by Arise *et al*. (2015). One (1) gram of each flour was dispensed in a 50 mL pre-weighed centrifuge tube containing 10 mL of distilled water. The dispersions were vortexed for one (1) minute and later held still for 30 min, followed by centrifugation (using Eppendorf 5810R Centrifuge, Germany) for 30 min at 3000 rpm. The supernatant was decanted and the excess water in the upper phase was left to drain for 15 min and the residue inside the tube was weighed again to determine the amount of water that was retained per gram of the sample. The WAC was expressed as grams of water or oil bound per gram of the sample on a dry basis.

3.7.2 Oil absorption capacity

The oil absorption capacity (OAC) of each flour was measured using the method described by Arise *et al*. (2015). One (1) gram of each flour was dispensed in a 50 mL pre-weighed centrifuge tube containing 10 mL of distilled water. The dispersions were vortexed for one (1) minute and later held still for 30 min, followed by centrifugation for 25 min at 3000 rpm. The separated oil was removed and the sample was reweighed. The OAC was expressed as grams of water or oil bound per gram of the sample on a dry basis.

3.7.3 Swelling index

The swelling index (SI) of flour was determined using the method described by Abbey & Ibeh (1988). One (1) g of each flour was dispensed in a 50 mL pre-weighed centrifuge tubes containing (ten) 10 mL of distilled water. The volume occupied by the sample was recorded before (five) 5 ml of distilled water was added to the sample. The sample was left to stand undisturbed for an hour, and after that the volume was observed and recorded again. The swelling ability index of the sample was given by the following formula:

Swelling index = volume occupied by sample after swelling / volume occupied by sample before swelling.

3.8 Physical properties of amadumbe-soya composite biscuits

3.8.1 Physical dimensions

The physical dimensions of each biscuit were determined as described by Akaerue & Onwuka (2013). Each biscuit was weighed using a balance, and the diameter and height were measured with a calibrated ruler. The spread ratio was calculated using the formula:

$$\text{Spread ratio} = \text{Diameter}/\text{Height}$$

3.8.2 Instrumental texture analysis

The breaking strength of the biscuit was measured using Gaines' (1991) three-point bend test with the aid of the Instron Universal Testing Instrument (EZ-SX, Shimadzu). The compression strength of the biscuit was measured at a 20% level of compression with a crosshead speed of 3 mm/sec. Peak force (kg) was recorded.

3.8.3 Instrumental colour analysis

Colour measurements of flour sample were determined by using a Colour Flex EZ (A60-1014-593; Hunter Associates Laboratory, Reston, VA, USA) and were expressed in terms of lightness (L*), red-green characteristics (a*-value) and blue-yellow characteristics (b*-value).

White wheat bread flour was used as a reference. Before measuring the colour, the colour instrument was calibrated against white and black colour tiles (Arise *et al*., 2015).

3.9 Protein quality of amadumbe-soya composite biscuits

3.9.1 Protein digestibility

Sample (0.2 g) was weighed and 35 ml of 0.1M phosphate buffer: pH 2 containing 1.5 mg pepsin/ml was added. The pepsin-sample mixture was incubated at 37^{o}C for 2 h with continuous shaking. Digestion was stopped by adding 2 ml of 2M NaOH, and the suspension was centrifuged at 4800 rpm at 4^{o}C for 20 min and the supernatant discarded. The residue was washed with 15 ml of 0.1M phosphate buffer: pH 7 and centrifuged again. Supernatant was discarded and the residue was washed on Whatman's No 3-filter paper which contained the undigested protein residue and was folded and placed in a digestion tube and dried for 2 h at 80^{o}C. The dried sample was analysed using the micro Kjeldahl method (Hamaker, 1987).

$$\text{\% Protein digestibility} = \frac{\text{Total protein - Residual protein after pepsin digestion}}{\text{Total protein}} \text{ X } 100$$

3.9.2 Amino acids composition

The amino acid composition of the protein extracts was determined with the Pico-Tag method advocated for by Bidlingmeyer, *et al*. (1984). This method was based on reversed-phase chromatography. Prior to chromatographic analysis, amadumbe-soya composite protein was hydrolysed in 6 M HCL containing 0.05% phenol at 116°C under vacuum for 24 h (Siwela & Amonsou, 2016).

3.9.3 Amino acid (chemical) score and protein digestibility corrected amino acid score (PDCAAS)

The PDCAAS was calculated by obtaining the product of the amino acid score (AAS) and the true faecal N (faecal amino acid digestibility) as described by Schaafsma (2012).

$$\text{\%PDCAAS} = \frac{\text{Mg of limiting amino acid in 1g of test protein}}{\text{Mg of same amino acid in 1g of reference protein}} \text{ X faecal true digestibility X } 100$$

Amino acid scores (AAS) of samples were obtained by dividing the content of first limiting essential amino acid (histidine, threonine, lysine, tryptophan, valine, isoleucine, phenylalanine, etc) in a test protein (mg/g) by the content of corresponding amino acid in a reference protein (mg/g) multiplied by 100 (Caire-Juvera *et al*., 2013; FAO /WHO, 1991).

3.10 Mineral content

The mineral content of the dried samples was determined using the AOAC, 1990 method. Each sample (3 g) of flour was weighted and burned in a furnace which had been set at 550°C for 6 h. The residue was cooled to room temperature inside a desiccator and weighed. The ash content was obtained by calculating the weight of the residue as a percentage of the original sample weight. The weight of the residual ash was then calculated as ash content. Ash was dissolved in 20 ml of 1N HCl and was heated for 5 min at 80-90°C. The solute was then transferred quantitatively to a 100-ml volumetric flask and distilled water was added to level it. Calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), sodium (Na) and potassium (K) were determined using Atomic Absorption Flame Emission Spectrophotometer (AA-6200 Shimadzu Corp. Kyoto Japan) with air acetylene flame at 722 nm. Each sample was analysed in triplicate. Quantification was accomplished by comparison with a standard curve drawn using a standard solution of known concentration at 0.5, 1.00, 1.5 and 2.5 ppm. Phosphorus (P) was determined by the Flame Photometric method (AOAC, 2000). Each sample was analysed in duplicate.

3.11 Consumer acceptance of amadumbe-soya bean composite biscuits

A total of 50 individuals was recruited around the Durban University of Technology campus and screened using a screening questionnaire to constitute an untrained panel. The screening criteria included the consumption of biscuits at least once a week and the absence of food allergies. Members of the panel were told that they could withdraw from the study at any time they deemed fit and they were asked to sign a consent form prior to the tasting of samples. A total of five types of biscuits, amadumbe (100%), soya (100%) and amadumbe-soya composites with ratios 90:10, 70:30 and 50:50 each with a three-digit number code, were presented to each member of the panel. Each sample was tested for colour, aroma, taste, texture and overall acceptability using a nine-point hedonic scale. The nine structural acceptability levels ranged from 9 for “like extremely”, 8 for “like very much, 7 for “liked moderately”, 6 for “liked slightly”, 5 for “neither like nor dislike, 4 for “disliked slightly”, 3 for “disliked moderately”, 2 for “dislike very much” and 1 for “dislike extremely. The overall acceptability of the biscuits was determined from the scores by determining the mean values. Questions and scales were displayed on sensory evaluation forms (Kayitesi *et al.*, 2010).

CHAPTER 4: RESULTS

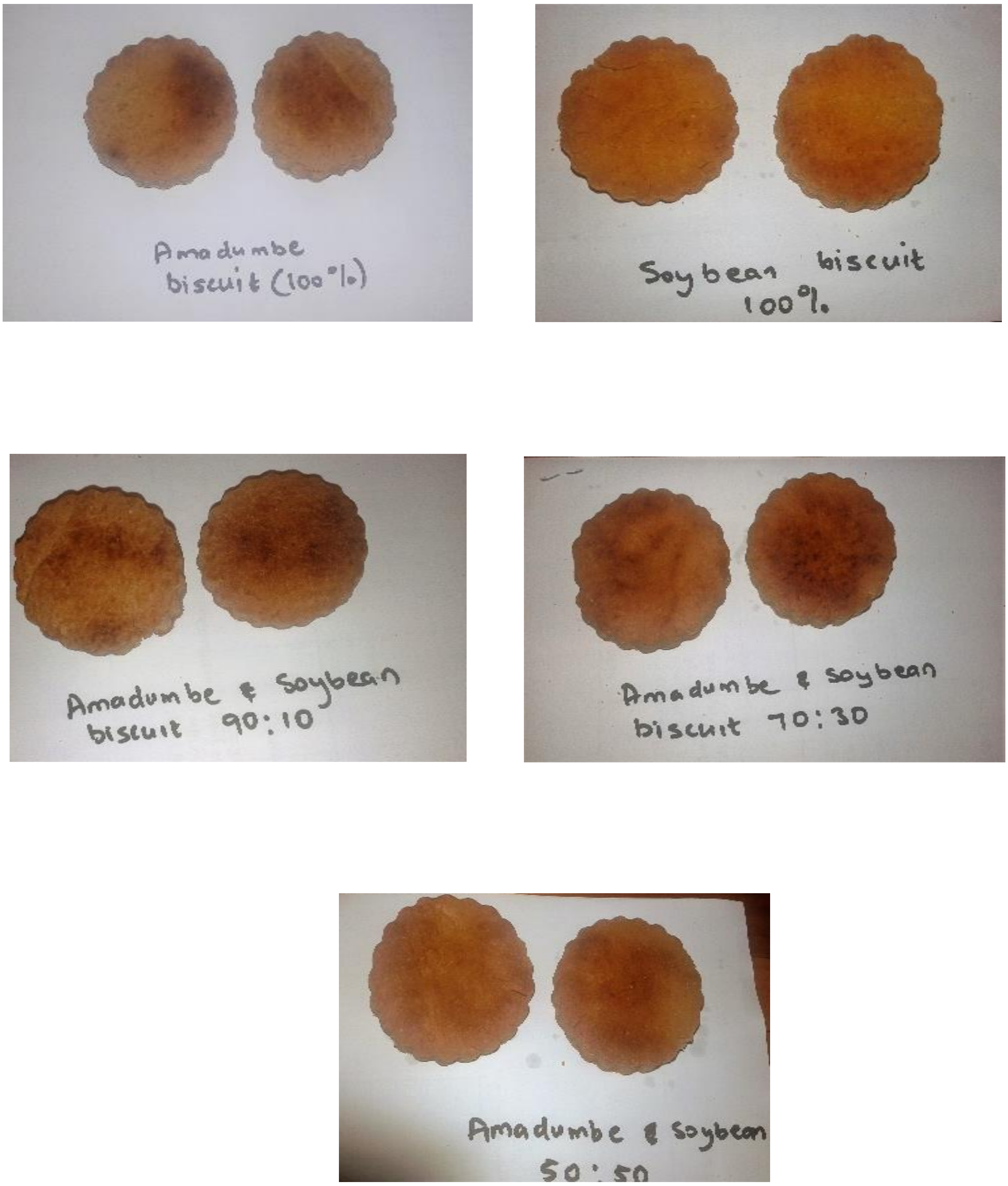

Figure 4.1 Amadumbe-soya composite biscuits

4.1 Proximate composition of amadumbe-soya composite biscuits

4.1.1 Moisture content

The moisture content of the amadumbe (100%) biscuits was higher and significantly ($p \leq 0.05$) different to that of the soya (100%) biscuits. There was a non-significant ($p \geq 0.05$) decrease in the moisture content of the different amadumbe-soya composite biscuits with the increase in the percentage of soya of up to 30%. However, there was a significant ($p \leq 0.05$) decrease in the moisture content when the percentage of soya in the composite biscuits was increased to 50% (Table 4.1).

4.1.2 Ash content

The ash content of the amadumbe biscuits was higher and significantly different ($p \leq 0.05$) to those of the soya biscuits. Furthermore, there was a significant ($p \leq 0.05$) reduction in the ash content of amadumbe-soya composite biscuits when the percentage of soya was increased to 50% in the composite biscuits.

4.1.3 Fat content

The fat content of the soya biscuits was higher and significantly ($p \leq 0.05$) different to those of the amadumbe biscuits. The fat content of amadumbe-soya composite biscuits significantly ($p \leq 0.05$) increased with the increase in the percentage of soya in the composite to 10, 30 and 50%.

4.1.4 Fibre content (Acid detergent fibre (ADF) and Neutral detergent fibre (NDF))

The ADF and NDF content of the soya biscuits was higher and significantly ($p \leq 0.05$) different to those of the amadumbe biscuits. However, there was no significant ($p \geq 0.05$) increase in the ADF of composite biscuits with the increase in percentage of soya flours. Alternatively, a significant ($p \leq 0.05$) reduction in the NDF content in the composite biscuits was only observed when the portion of soya was increased to 50%.

4.1.5 Crude protein content

The crude protein content of soya biscuits was higher and significantly different ($p \leq 0.05$) to those of the amadumbe biscuits. Furthermore, there was a significant ($p \leq 0.05$) increase in the crude protein content of composite biscuits when the percentage of soya was increase to 10, 30 and 50%.

4.1.6 Carbohydrate content

The carbohydrate content of amadumbe biscuits was higher and significantly ($p \leq 0.05$) different to those of the soya biscuits. There was also a significant ($p \leq 0.05$) reduction in the carbohydrate content of amadumbe-soya composite biscuits when the percentage of soya was increased to 10, 30 and 50%.

4.1.7 Energy value

The energy value of amadumbe biscuits was higher than those of the soya biscuits. There was a decrease in the energy value of amadumbe-soya composite biscuits when the percentage of soya was increased from to 10, 30 and 50%.

Table 4.1 Proximate composition of amadumbe-soya composite biscuits (g/100 g)

	Flour blends (Wheat: Amadumbe: Soya) biscuits				
Variables	**Amadumbe (100%)**	**Soya (100%)**	**Amadumbe-soya (90:10)**	**Amadumbe-soya (70:30)**	**Amadumbe-soya (50:50)**
Moisture	$7.44^{bc} \pm 0.08$	$6.07^{d} \pm 0.24$	$8.42^{a} \pm 0.03$	$8.22^{a} \pm 0.08$	$6.76^{cd} \pm 0.16$
Ash	$3.45^{a} \pm 0.01$	$2.62^{c} \pm 0.23$	$3.35^{a} \pm 0.08$	$3.13^{b} \pm 0.05$	$3.03^{b} \pm 0.01$
Fat	$19.59^{e} \pm 0.41$	$37.3^{a} \pm 0.17$	$21.2^{d} \pm 0.18$	$24.78^{c} \pm 0.05$	$28.8^{b} \pm 0.35$
ADF	$3.23^{c} \pm 0.44$	$6.37^{a} \pm 0.05$	$4.59^{b} \pm 0.19$	$4.83^{b} \pm 0.13$	$5.11^{b} \pm 0.39$
NDF	$5.01^{c} \pm 1.22$	$15.3^{a} \pm 1.63$	$5.19^{c} \pm 0.14$	$6.42^{c} \pm 0.19$	$8.72^{b} \pm 0.91$
Crude Protein	$4.59^{f} \pm 0.00$	$32.3^{a} \pm 0.08$	$7.0^{e} \pm 0.04$	$13.2^{c} \pm 0.14$	$19.2^{b} \pm 0.18$
Carbohydrates	$64.9^{a} \pm 0.49$	$21.7^{f} \pm 0.27$	$59.9^{c} \pm 0.19$	$50.7^{d} \pm 0.16$	$42.2^{e} \pm 0.04$
Energy value (Kcal)	600.7	465.07	449.9	437.34	414.73

Values expressed as Mean ± SD and Mean within rows with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference ($p \leq 0.05$). Acid detergent fibre: Neutral detergent fibre: *CHO: Total carbohydrate including fibre calculated by difference.

4.2 Functional properties of amadumbe-soya composite flours

4.2.1 Water absorption capacity

The water absorption capacity (WAC) of the amadumbe flour was higher and significantly ($p \leq 0.05$) different to that of the soya flour. There was a non-significant ($p \geq 0.05$) decrease in the WAC of the different amadumbe-soya composite flours with the increase in the percentage of soya flour from 10 to 50%. (Table 4.2).

4.2.2 Oil absorption capacity

The oil absorption capacity (OAC) of amadumbe flour was higher and significantly ($p \leq 0.05$) different from those of soya flour. There was a non-significant ($p \geq 0.05$) decrease in the OAC of the different amadumbe-soya composite flours with the increase in the percentage of soya flour from 10 to 50%.

4.2.3 Swelling index

There was no significant ($p \geq 0.05$) difference in the swelling index (SI) of amadumbe flour and soya flour. Similarly, there was no significant ($p \geq 0.05$) difference in the SI of the amadumbe-soya composite flours.

Table 4.2 Functional properties amadumbe-soya composite flours (g/g)

Composite flours	Water Absorption Capacity (g/g)	Oil Absorption Capacity (g/g)	Swelling Index (g/g)
Soya (100%)	$1.24^{c} \pm 0.06$	$0.75^{ab} \pm 0.00$	$1.32^{ab} \pm 0.07$
Amadumbe (100%)	$1.97^{a} \pm 0.34$	$0.93^{a} \pm 0.20$	$1.24^{ab} \pm 0.09$
Amadumbe-soya (90:10)	$1.94^{a} \pm 0.08$	$0.77^{ab} \pm 0.03$	$1.34^{ab} \pm 0.08$
Amadumbe-soya (70:30)	$1.75^{ab} \pm 0.08$	$0.74^{ab} \pm 0.01$	$1.35^{a} \pm 0.04$
Amadumbe-soya (50:50)	$1.50^{bc} \pm 0.10$	$0.69^{b} \pm 0.18$	$1.36^{a} \pm 0.00$

Values expressed as Mean ± SD and Mean within column with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference ($p \leq 0.05$).

4.3 Physical properties of amadumbe-soya composite biscuits

The height of amadumbe biscuits was slightly higher but not significantly ($p \geq 0.05$) different to that of the soya biscuits. There was a non-significant decrease ($p \geq 0.05$) in the height of amadumbe-soya composite biscuits when the percentage of soya was increased to 10, 30 and 50%.

The weight of amadumbe biscuits was higher and significantly ($p \leq 0.05$) different to those of the soya biscuits. There was an insignificant ($p \geq 0.05$) decrease in the weight of the different amadumbe-soya composite biscuits with the increase in the percentage of soya up to 30%. However, there was a significant ($p \leq 0.05$) decrease in the weight when the percentage of soya in the composite biscuits was increased to 50%.

The diameter of amadumbe biscuits was not significantly ($p \geq 0.05$) different to those of the soya biscuits. Similarly, there was non-significant ($p \geq 0.05$) difference in the diameter of amadumbe-soya composite biscuits when the percentage of soya was increased from to 10, 30 and 50%.

The spread ratio of soya biscuits was higher and significantly ($p \leq 0.05$) different to those of the amadumbe biscuits. There was a non-significant ($p \geq 0.05$) difference in the spread ratio of amadumbe-soya composite biscuits when the percentage of soya beans was increased to 10% and 30%. However, there was a significant ($p \leq 0.05$) increase in the spread ratio when the percentage of soya in the composite biscuits was increased to 50%.

The hardness of amadumbe biscuits was higher and significantly ($p \leq 0.05$) different to those of the soya biscuits. There was insignificant reduction ($p \geq 0.05$) in the hardness of amadumbe-soya composite biscuits when the percentage of soya was increased from 10 to 30% and from 30 to 50% (Table 4.3).

Table 4.3 Physical properties of composite biscuits produced from amadumbe and soya flours blends (n = 3)

% Blends	Height (cm)	Weight (g)	Diameter (cm)	Spread ratio (cm)	Hardness
Soya (100%)	7.83 ^{ab} ±1.59	10.96 ^{a} ±0.71	45.08 ^{a} ±0.99	5.95 ^{c}±1.16	10.09 ^{a} ±1.93
Amadumbe (100%)	8.83 ^{b} ±1.85	13.19 ^{b} ±1.49	44.17 ^{a} ±0.72	5.19 ^{b}±1.00	104.69 ^{e}±18.26
Amadumbe-soya (90:10)	8.42 ^{ab} ±1.17	12.81 ^{b} ±0.76	44.33 ^{a} ±0.89	5.35 ^{bc}±0.68	48.07 ^{c} ±15.51
Amadumbe-soya (70:30)	8.25 ^{ab} ±1.42	12.78 ^{b} ±1.05	44.58^{a}±0.67	5.35 ^{bc}±0.95	35.41 ^{bc} ±15.09
Amadumbe-soya (50:50)	7.50 ^{a} ±0.79	11.28 ^{a} ±1.14	44.42 ^{a} ±0.90	5.98 ^{c}±0.57	29.32 ^{b} ±7.47

Values expressed as Mean ± SD and Mean within column with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference $p \leq 0.05$.

4.4 Colour parameters of amadumbe-soya composite biscuits

The L* value (measure of lightness characteristics) of amadumbe biscuits was not significantly ($p \geq 0.05$) different to those of the soya bean biscuits. There was no significant ($P \geq 0.05$) difference in the L* value of amadumbe-soya bean composite biscuits when the percentage of soya beans was increased to 10 and 30% and there was a significant decrease ($p \leq 0.05$) when the percentage of soya was added to up to 50% (Table 4.4). The a* value (which is a measure of red-green characteristics) of amadumbe biscuits was higher but not significantly ($p \geq 0.05$) different to those of the soya bean biscuits. There was no significant difference ($p \geq 0.05$) in the L* value of amadumbe-soya bean composite biscuits when the percentage of soya was increased to 10, 30 and 50%. The b* value (which is the measure of blue-yellow characteristics) of amadumbe biscuits was higher and significantly different ($p \leq 0.05$) to those of the soya biscuits. There was no significant difference ($p \geq 0.05$) in the b* value of amadumbe-soya bean composite biscuits when the percentage of soya bean was increased to 10, 30 and 50%.

Table 4.4 Colour parameter of composite biscuits produced from amadumbe and soya flours blends (n = 3)

	Colour parameters for amadumbe-soya composite biscuits		
% Blends	L*	a*	b*
Soya (100 %)	56.51 ^{a} ±2.29	9.53 ^{a} ±2.52	27.79 ^{a} ±2.51
Amadumbe (100 %)	56.68 ^{a} ±2.59	12.96 ^{ab} ±2.83	34.88 ^{c} ±1.02
Amadumbe-soya (90:10)	55.31 ^{b} ±2.85	11.50 ^{ab} ±2.81	30.86 ^{b} ±1.86
Amadumbe-soya (70:30)	54.86 ^{b} ±2.64	13.64 ^{b} ±2.18	31.57 ^{b} ±0.92
Amadumbe-soya (50:50)	51.25 ^{c} ±2.54	14.27 ^{b} ±2.14	31.61 ^{b} ±1.22

L*(lightness characteristics) a* (red-green characteristics) b* (blue-yellow characteristics). Values expressed as Mean ± SD and Mean within column with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference $p \leq 0.05$.

4.5 Nutritional quality of amadumbe-soya composite biscuits

4.5.1 The amino acids composition

The amino acid data of amadumbe-soya composite biscuit is shown in Tab1e 4.5, the major amino acids of composite biscuits were aspartic acid and glutamic acid. The content of lysine and histidine was significantly ($p \leq 0.05$) higher in soya biscuits than in amadumbe biscuits and amadumbe-soya composite biscuits. The increase in the percentage of soya in the composite biscuits gave rise to a significant ($p \leq 0.05$) increase in the levels of lysine in composite biscuits, while the content of histidine did not show any significant changes. Conversely, the content of essential amino acids, such as threonine, valine, leucine and phenylalanine, were significantly ($p \leq 0.05$) higher in amadumbe biscuits than in soya biscuits and amadumbe-soya composite biscuits. However, the reduction in the percentage of amadumbe in the composite biscuits did not lead to a significant ($p \leq 0.05$) reduction in the percentage of these amino acids in the composite biscuits. The two most abundant amino acids in the composite biscuits were aspartic and glutamic acids which may include glutamine and asparagine. This reflects the high content of aspartic acid and glutamic acid in amadumbe and soya biscuits respectively. Overall, the addition of soya flour to amadumbe flour resulted in composite biscuits with increased amino acids in those contents whose amino acid were either low in amadumbe flour or soya flour and at the same time maintaining those whose contents were high in either amadumbe flour or soya flour.

Table 4.5 Amino acid composition of amadumbe-soya composite biscuits (mg/g protein)

Amino Acids	Amadumbe (100%)	Soya (100%)	Amadumbe-soya (90:10)	Amadumbe-soya (70:30)	Amadumbe-soya (50:50)	[¥]Reference pattern
Essential						
Histidine	$19.6^{d} \pm 0.00$	$23.69^{a} \pm 0.66$	$21.30^{b} \pm 1.01$	$21.97^{bc} \pm 0.00$	$21.36^{c} \pm 0.14$	16
Threonine	$39.22^{a} \pm 0.00$	$36.53^{c} \pm 0.44$	$38.01^{b} \pm 1.01$	$36.99^{bc} \pm 0.53$	$37.08^{c} \pm 0.74$	25
Valine	$47.93^{a} \pm 0.00$	$41.18^{c} \pm 0.44$	$47.53^{a} \pm 2.22$	$46.29^{ab} \pm 0.54$	$44.59^{b} \pm 2.21$	40
Isoleucine	$31.59^{c} \pm 1.54$	$40.25^{a} \pm 0.44$	$35.59^{b} \pm 1.01$	$35.75^{b} \pm 0.00$	$35.98^{b} \pm 1.47$	31
Leucine	$78.43^{a} \pm 0.00$	$71.06^{c} \pm 0.66$	$77.69^{a} \pm 1.01$	$75.21^{ab} \pm 0.00$	$74.97^{b} \pm 1.84$	61
Phenylalanine	$53.38^{a} \pm 1.54$	$47.06^{c} \pm 1.32$	$52.75^{a} \pm 1.00$	$51.59^{ab} \pm 0.54$	$49.01^{b} \pm 1.10$	41
Lysine	$30.50^{c} \pm 0.00$	$52.01^{a} \pm 2.63$	$32.65^{c} \pm 0.00$	$45.08^{b} \pm 0.53$	$49.88^{a} \pm 1.48$	48
Non-Essential						
Aspartic acid	$127.45^{a} \pm 1.54$	$96.59^{d} \pm 10.94$	$126.35^{a} \pm 1.0$	$117.58^{b} \pm 0.00$	$112.79^{c} \pm 3.32$	
Glutamic acid	$106.75^{c} \pm 0.00$	$157.44^{a} \pm 11.17$	$100.64^{d} \pm 2.02$	$107.07^{c} \pm 0.00$	$127.66^{b} \pm 5.52$	
Serine	$54.47^{a} \pm 0.00$	$48.61^{c} \pm 0.88$	$53.89^{a} \pm 0.00$	$52.86^{ab} \pm 0.54$	$51.96^{b} \pm 0.74$	
Glycine	$49.02^{a} \pm 1.54$	$38.55^{d} \pm 1.10$	$48.57^{a} \pm 2.02$	$45.04^{b} \pm 1.07$	$43.72^{c} \pm 1.10$	
Arginine	$59.91^{c} \pm 1.54$	$66.10^{a} \pm 0.66$	$60.09^{c} \pm 3.03$	$61.50^{b} \pm 0.54$	$63.50^{ab} \pm 5.90$	
Alanine	$42.48^{a} \pm 1.54$	$38.24^{c} \pm 1.10$	$42.38^{a} \pm 0.00$	$41.39^{ab} \pm 0.00$	$40.24^{b} \pm 1.10$	
Proline	$41.39^{b} \pm 0.00$	$46.60^{b} \pm 1.10$	$45.50^{a} \pm 1.01$	$43.18^{b} \pm 0.00$	$42.45^{b} \pm 1.10$	
Tyrosine	$38.13^{a} \pm 1.51$	$30.50^{d} \pm 1.10$	$39.86^{a} \pm 3.03$	$37.07^{b} \pm 2.14$	$34.39^{c} \pm 2.58$	

Values expressed as Mean ± SD and Mean within rows with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference ($P \leq 0.05$). ¥= Reference pattern is the WHO, 2007 amino acid requirement pattern based on amino acid requirements of preschool-age child between 3-10 years

4.5.2 Amino acid (chemical) scores

The chemical scores of histidine and lysine were significantly ($p \leq 0.05$) higher in soya biscuits than in amadumbe biscuits and these chemical scores significantly ($p \leq 0.05$) increased with the increase in the percentage of soya in composite biscuits. The chemical scores of threonine, valine, leucine, and phenylalanine were significantly ($p \leq 0.05$) higher in amadumbe biscuits than in soya biscuits. However, only the chemical scores of valine and phenylalanine decreased significantly ($p \leq 0.05$) with the decrease in the percentage of amadumbe in the composite biscuits. Overall, the addition of soya flour to amadumbe flour resulted in products with an improved chemical score for those amino acids whose chemical scores were either low in amadumbe biscuits or in soya biscuits and at the same time maintaining the scores for those amino acids whose contents were higher in either amadumbe or soya biscuits.

Table 4.6 Amino acids (chemical) scores of amadumbe-soya composite biscuit

Essential Amino Acids	Amadumbe (100%)	Soya (100%)	Amadumbe-soya (90:10)	Amadumbe-soya (70:30)	Amadumbe-soya (50:50)
Histidine	$1.23^{e} \pm 0.01$	$1.47^{e} \pm 0.01$	$1.34^{d} \pm 0.01$	$1.37^{c} \pm 0.01$	$1.40^{b} \pm 0.01$
Threonine	$1.57^{a} \pm 0.01$	$1.46^{d} \pm 0.01$	$1.52^{b} \pm 0.01$	$1.48^{c} \pm 0.01$	$1.48^{c} \pm 0.01$
Valine	$1.20^{a} \pm 0.01$	$1.03^{d} \pm 0.01$	$1.19^{a} \pm 0.01$	$1.16^{b} \pm 0.01$	$1.11^{c} \pm 0.01$
Isoleucine	$1.02^{d} \pm 0.01$	$1.30^{a} \pm 0.01$	$1.05^{c} \pm 0.01$	$1.15^{b} \pm 0.01$	$1.16^{b} \pm 0.01$
Leucine	$1.29^{a} \pm 0.01$	$1.16^{d} \pm 0.01$	$1.27^{b} \pm 0.01$	$1.23^{c} \pm 0.01$	$1.23^{c} \pm 0.01$
Phenylalanine	$1.30^{a} \pm 0.01$	$1.15^{d} \pm 0.01$	$1.29^{a} \pm 0.01$	$1.26^{b} \pm 0.01$	$1.20^{c} \pm 0.01$
Lysine	$0.64^{e} \pm 0.01$	$1.08^{a} \pm 0.01$	$0.68^{d} \pm 0.01$	$0.94^{c} \pm 0.01$	$1.04^{b} \pm 0.01$

Values expressed as Mean ± SD and Mean within rows with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference ($p \leq 0.05$).

4.5.3 Protein digestibility and protein digestibility corrected amino acid score (PDCAAS)

Lysine was found to be the limiting amino acid for amadumbe biscuits and amadumbe-soya composite biscuits, while valine was the limiting amino acid for the soya biscuits. The increase in the percentage of soya resulted in a small increase in the *in vitro* protein digestibility of composite biscuits up to a value of 0.99 at 50% soya bean addition. The addition of soya to amadumbe improved the protein digestibility corrected amino acid score (PDCAAS) of composite biscuits to a value of 1 at 50% soya addition.

Table 4.7 Protein digestibility and protein digestibility corrected amino acid score (PDCAAS) amadumbe-soya biscuits

Flours	Protein digestibility (%)	Limiting amino acid chemical score	PDCAAS
Amadumbe (100%)	96	Lysine (0.64)	0.61
Soya (100%)	99	Valine (1.03)	1.02
Amadumbe-soya (90:10)	97	Lysine (0.68)	0.66
Amadumbe-soya (70:30)	98	Lysine (0.94)	0.92
Amadumbe-soya (50:50)	99	Lysine (1.04)	1.03

4.6 Mineral analysis of amadumbe-soya composite biscuits

There was an increase in the content of Ca, Mg, P. Zn, Cu, Mn and Fe in composite biscuits when the percentage of soya in the composite biscuits was increased. The increase in the mineral content was only significant ($p \leq 0.05$) for Mg P, Zn, Mn and K. However, there was a decrease in the content of K & Na in composite biscuits when the percentage of soya was increased in the composite biscuits (Table 4.8).

Table 4.8 Mineral composition of amadumbe-soya composite biscuits

Mineral	Amadumbe (100%)	Soya (100%)	Amadumbe-soya (90:10)	Amadumbe-soya (70:30)	Amadumbe-soya (50:50)
Ca (g/ 100g)	0.08 ^{d} ±0.00	0.15 ^{a} ±0.00	0.09 ^{c} ±0.00	0.10 ^{a} ±0.00	0.11 ^{a} ±0.01
Mg (g/ 100g)	0.05 ^{e} ±0.00	0.13 ^{a} ±0.01	0.06 ^{d} ±0.00	0.08 ^{c} ±0.00	0.09 ^{b} ±0.01
K (g/ 100g)	1.20 ^{a} ±0.03	0.54 ^{d} ±0.01	1.13 ^{a} ±0.01	0.99 ^{b} ±0.13	0.79 ^{c} ±0.13
Na (g/ 100g)	0.14 ^{a} ±0.01	0.09 ^{d} ±0.01	0.12 ^{b} ±0.00	0.11^{bc} ±0.01	0.11 ^{bc} ±0.00
K/Ca^{+}Mg (g/ 100g)	3.74 ^{a} ±0.11	0.78 ^{f} ±0.01	3.07 ^{b} ±0.03	2.19 ^{c} ±0.04	1.60 ^{d} ±0.16
P (g/ 100g)	0.17 ^{e} ±0.00	0.44 ^{a} ±0.00	0.19 ^{d} ±0.00	0.25 ^{c} ±0.01	0.30 ^{b} ±0.01
Zn (mg/kg)	4.00 ^{f} ±0.00	30.0 ^{a} ±0.00	9.00 ^{e} ±0.00	13.0 ^{d} ±0.00	17.0 ^{c} ±0.00
Cu (mg/kg)	1.00 ^{c} ±1.41	6.50 ^{a} ±0.71	0.75 ^{c} ±0.36	2.00 ^{bc} ±0.00	4.00 ^{b} ±1.41
Mn (mg/kg)	2.00 ^{e} ±0.00	23.0 ^{a} ±0.00	4.75 ^{d} ±1.06	11.0 ^{c} ±0.00	14.0 ^{b} ±1.41
Fe (mg/kg)	24.0 ^{c}±2.83	38.0 ^{b} ±0.00	26.0 ^{c} ±0.00	32.0 ^{b} ±1.41	38.0 ^{bc} ±2.83

Values expressed as Mean ± SD and Mean within rows with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference ($p \leq 0.05$).

4.7 Consumer acceptance of amadumbe-soya composite biscuits

Except for texture, there were no significant differences ($p \geq 0.05$) between the mean acceptability of the colour, aroma and taste of 100% amadumbe and 100% soya biscuits. Similarly, an increase in the percentage of soya in the amadumbe composite biscuits did not produce any significant difference ($p \geq 0.05$) in the mean acceptability of the colour, aroma, taste and texture of composite biscuits. However, an increase in the percentage of soya in composite biscuits resulted in small but insignificant increases ($p \geq 0.05$) in the mean acceptability of aroma, taste, texture and overall acceptability of composite biscuits.

Table 4.9 Consumer acceptability of amadumbe-soya composite biscuits (N = 50)

Biscuits	Colour	Aroma	Taste	Texture	Overall Acceptability
Amadumbe (100%)	6.96 ^{ab}± 1.80	6.86 ^{a}± 1.77	6.52 ^{ab}± 1.98	6.02 ^{a}± 2.08	6.24 ^{a}± 1.95
Soya (100%)	7.60 ^{a}± 1.83	6.48 ^{a}± 1.99	6.36 ^{a}± 1.87	6.74 ^{b}± 1.97	6.28 ^{a}± 2.19
Amadumbe-soya (90:10)	6.90 ^{ab}± 1.72	6.70 ^{a}± 1.79	6.44 ^{b}± 2.03	6.00 ^{a}± 2.07	6.52 ^{a}± 1.92
Amadumbe soya (70:30)	6.70 ^{b}± 2.14	6.72 ^{a}± 1.77	6.62 ^{ab}± 1.82	6.32 ^{a}± 1.85	6.50 ^{ab}± 2.00
Amadumbe-soya (50:50)	7.26 ^{ab}± 1.68	6.96 ^{a}± 1.71	7.20 ^{b}± 1.43	6.70 ^{ab}± 1.88	6.88 ^{b}± 1.86

Values expressed as Mean ± SD and Mean within rows with the same superscript letters are not significantly different ($p \geq 0.05$), otherwise significantly different at difference ($p \leq 0.05$). Hedonic scale: 9 for “like extremely”, 8 for “very much”, 7 for “like moderately”, 6 for “like slightly5 for “neither like nor dislike, 4 for “dislike slightly, 3 for “dislike moderately”, 2 for “dislike very much” and 1 for “dislike extremely.

CHAPTER 5: DISCUSSION

5.1 Proximate composition of amadumbe-soya composite biscuits

5.1.1 Moisture content

The moisture content of biscuits is described as an indicator of dry matter in the food (Adebowale *et al*., 2012) and the higher the moisture content of flour the higher the shelf instability (Omoba & Omogbemile, 2013). Low moisture content of flours assures longer shelf-life by reducing the susceptibility of flours to microbial growth which in turn can lead to food spoilage (Mishra & Chandra, 2012). There was a decrease in moisture content when soya was added, but this was only significant after 50% was added. Bunde *et al*. (2010) reported that usage of soya flour in baked products resulted in moisture absorption which led to an increase in freshness and a reduction of recrystallization of amylopectin during storage. The moisture content of all biscuits falls within the recommended value which is below 12% (Kaur *et al*., 2013). The 50% amadumbe composite flour is recommended to produce biscuits with low water content.

5.1.2 Ash content

The ash content of flours is defined as inorganic residue that remains after the water and the organic matter are removed in the presence of an oxidising agent by heating process (Omoba & Omogbemile, 2013). The ash content of flour is an indicator of the amount of minerals present in the food and it aids in metabolising other organic compounds nutritionally, for example, carbohydrates and fats (Ojinnaka & Nnorom, 2015). Different varieties of amadumbe possess different ash content due to differences in their calcium oxalates crystals (Rodrigues-Miranda *et al*., 2011). The 50% amadumbe composite flours recommended to produce biscuits with optimum mineral residue.

5.1.3 Fat content

The fat content of flour which is the sum of all fatty acids obtained from total lipid extract expressed as triglycerides (Eller & King, 1996) can influence the shelf-life of amadumbe composite biscuits. High fat content in biscuits can promote rancidity and the development of off odour (Okpala & Ekwe, 2013). The addition of soya flour to amadumbe flour increased the fat content of the resulting composite flours. This is because soya beans are rich in oil ranging from 20-22% (Mishra & Chandra, 2012). Other researchers also found an increase in fat content in malted sorghum flour composite biscuits with an increase in the proportion of soya bean flour (Bolarinwa *et al*., 2016). Despite its ability to promote rancidity, fat contributes to the texture, structural integrity, lubrication and increased air incorporation in dough during the making of biscuits (Sozer *et al*., 2014). Composite flour with 90% amadumbe and 10% soya will produce composite biscuits with the lowest fat content and hence will be more stable in terms of shelf-life and stability after packaging (Omoba & Omogbemile, 2013).

5.1.4 Fibre content (Acid detergent fibre (ADF) and Neutral detergent fibre (NDF))

The ADF content of flours can be described as a measure of a portion of the cell wall called lignin and cellulose, while the NDF (crude fibre) content of flours can be described as a measure of total plant cell wall material; it consists of hemicellulose, cellulose and lignin (Contreras *et al*., 1999). The ADF content of flour can be used to predict the energy content of the forage, while NDF can be used in diet formulation to ensure adequate fibre (Contreras *et al*., 1999). The addition of soya flour significantly increases the ADF content in the composite flours because of the high content of ADF and NDF of soya as indicated in Table 4.1. The fibre content of ADF and NDF of the present study is comparable to 12.2% and 8.2% respectively as reported by Macdonald *et al.* (2011) for full fat soya bean meal. The composite biscuit with 50% amadumbe and 50% soya is recommended because it has the highest fibre content and contributes easily to the recommended fibre intake of not more than 25g/day (Perezgonzalez, 2011).

5.1.5 Crude protein content

Crude protein is an important macronutrient for growth and maintenance of the body (Kayitesi *et al*., 2012). It influences food processing by trapping the starch in flour mixtures and contributes to the formation of the internal structure of biscuits (Maache-Rezzoug *et al*., 1998). The increase of protein content was expected considering that soya bean flour which has a high protein content has been used to enrich the sorghum composite (Omoba & Omogbemile, 2013). Leguminous protein-rich grain like soya has been used in compositing low protein foods to improve their protein quality (Awasthi *et al*., 2012). Composite biscuits with 50% amadumbe and 50% soya contained the highest crude protein content, hence are likely to contribute to the recommended daily protein requirements for children (Dovi Dissertation, 2013).

5.1.6 Carbohydrate content

Amadumbe corms are a good source of carbohydrate and they supply a quick source of metabolisable energy, as well as aid in fat metabolism (Ogulankin *et al*., 2012). Amadumbe is noted to be good for diabetics and for people with gastrointestinal disorders because it contains high levels of gums which help in reducing high blood pressure (Himeda *et al*., 2012). The significant reduction of carbohydrates is expected because of the dilution of soya bean flour in the biscuit formulation. A study conducted by Serrem *et al*. (2011) revealed a reduction of carbohydrate content on soya composited biscuits. The carbohydrate content of flour influences food processing by acting as a good source of metabolisable energy and by assisting in the metabolism of fats (Kaushal *et al*., 2012). The 90% amadumbe and 10% soya composite biscuits produced acceptable carbohydrate contents, hence can easily contributes to the recommended dietary intake of between 55-75% of energy intake (Perezgonzalez, 2011).

5.1.7 Energy value

Amadumbe flour has a very high energy content because of its starch content and it possesses small starch grains which are about a tenth of that of a potato of about 1-6.5 micrometres (Dakwa & Dakwa, 2013). The 90% amadumbe and 10% soya composite biscuit produced the highest energy values and can contribute the most in achieving the recommended minimum energy intake for children between 3 to 5 years and 7 to 10 years old. It is about 1600 kcal and 1900 kcal and about 2663 kcal for men and 1753 kcal for women (Khattak & Khattak, 2002; WHO, 1985).

5.2 Functional properties of amadumbe-soya composite biscuit

5.2.1 Water Absorption Capacity (WAC)

The high WAC of amadumbe flour compared to soya flour may be attributed to high content of carbohydrate (up 95.5% dry weight basis) and mucilage (up to 10% dry weight basis) (Kaur *et al*., 2013; Tattiyakul *et al*., 2005). Mucilage contributes significantly to water absorption due to the presence of hydroxyl groups in the mucilage chemical structure (Naidoo *et al*., 2015; Aboubakar *et al*., 2008). Wild amadumbe flour has been found to possess a higher level of WAC than cultivated amadumbe flour and this has been attributed to its slightly higher protein, low fat content and small starch granules (Naidoo *et al*., 2015). The high-water absorption of amadumbe flour seems to influence the WAC in the mixture and the high value indicates a loose structure of starch polymers (Ojinnaka & Nnorom, 2015) and it assures product cohesiveness (Awolu *et al*., 2015). There was a small decrease in the WAC when the soya percentage was increased and this can be attributed to high protein content in soya flour which explains its ability to absorb more water (Akubor & Onimawo, 2003). The WAC of amadumbe flour enhances viscosity in products like gravies and soups (Kaur *et al*., 2013). The WAC is important mostly in bulking, and consistency of products in baking applications (Okpala *et al*., 2012). Both WAC and OAC are constrictions that affect the mouthfeel, texture and consistency of food products (Cheng & Bhat, 2016). The high-water absorption capacity of 90% amadumbe and 10% soya composite biscuits flour is recommendable and Okpala *et al*. (2012) reported that flour with high water absorption is useful in baked products because it prevents staling by reducing moisture loss (Okpala *et al*., 2012).

5.2.2 Oil absorption capacity (OAC)

Oil absorption capacity (OAC) is defined as the capability of flour to absorb oil (Obadina *et al*., 2016). Products with high OAC can act as better retainers of food flavours (Awulo *et al*., 2015). They can be used to produce food products with better mouth-feel and flavour (Kaur *et al*., 2013). Amadumbe flour has a higher OAC compared to soya flour hence the OAC of composite flour decreased significantly when composite biscuits contained 50% soya. This can be attributed to differences in low oil binding capacities in soya due to the presence of lesser non-polar side chains which can bind the hydrocarbon side chain of oil (Awulo *et al*., 2015; Kaushal *et al*., 2012). Low oil absorption capacity is desirable for amadumbe-soya composite biscuits since flours with high oil content have least affinity to absorb oil. It has been reported by other researchers that hydration is vital to improve the handling characteristics of baked products (Obasi *et al*., 2009; Akubor & Ukwuru, 2003). The 50% amadumbe and 50% soya composite biscuits are said to be good at retaining oil.

5.2.3 Swelling index (SI)

Swelling Index (SI) can be described as a measure of capability of starch to immobilise water and swells (Apiotola & Fashakin; Ly., 2013). The swelling index of flour influences food processing by indicating the extent of the associative forces within the flour granules (Ojinnaka & Nnorom, 2015). The SI of amadumbe and soya flour were not significantly different hence the addition of soya to amadumbe flour did not significantly affect the SI of the resulting composite flours. High swelling capacity has been reported as part of the criteria for a good quality product (Ubbor & Akobundu, 2009).

5.3 Physical properties of amadumbe-soya composite biscuits: height, weight, diameter, spread ratio and hardness

There was no significant difference in the height of 100% amadumbe and 100% soya biscuits. There was an insignificant decrease in height of composite biscuits due to the addition of soya. The weight of 100% amadumbe biscuits was significantly higher than that of 100% soya biscuits, thus, there was a significant decrease after the percentage of soya was increased to 50%. Variations in the weight of cookies that were incorporated with legume flours was reported to be due to different water capacities (Thongram *et al*., 2016). Agrarhar-Murugkar *et al.* (2015) indicated that lower weight loss in biscuits was desirable to retain shape and that weight loss of biscuits is due to water that is evaporated during baking. Weight variations could be due to high water holding capacity (Thongram *et al*., 2016). There was no significant difference in the diameter of 100% amadumbe biscuits and 100% soya biscuits, hence there were no significant differences in the diameter of the composite biscuits.

Diameter is defined as the size of a circle passing through the centre and touching two edges (Thongram *et al*., 2016). The protein content could be the factor that affects the diameter. Heated protein gluten in the flour undergoes glass transition, thus gaining mobility and allowing it to interconnect and form a network; this increases the viscosity and stops the cookie dough from flowing (Thongram *et al*., 2016). The spread ratio of 100% amadumbe biscuit was significantly lower than that of 100% soya biscuits, hence there was a significant decrease in the spread ratio of composite biscuits after the percentage of soya was increased to 50%. Lower spread ratio implies better rising ability of cookies (Cheng & Bhat, 2016). Spread ratio is regarded as a parameter for quality in biscuits and it correlates with texture, grain fineness, bite and overall mouthfeel of the biscuits. Factors that affect the spread ratio are the expansion of dough by leavening and flow of gravity (Agrarhar-Murugkar *et al*., 2015). Chinma and Gernath (2007) reported a decrease in spread ratio in cassava/soyabean/mango composite biscuits due to flour hydrophilic nature. The low spread ratio indicates that the starches in the cookies are hydrophilic (Thongram *et al*., 2016). The spread ratio is reported to be influenced by dough expansion, set time and its flow during baking (Sozer *et al*., 2014) and protein content (Cheng & Bhat, 2016). During the baking process, the moisture is absorbed by hydrophilic starch granules and they become swollen and gelatinized. The gelatinisation process increases the dough viscosity and results in a reduced cookie spread (Okpala & Chinyelu, 2011).

The hardness of the 100% amadumbe biscuit was significantly higher than that of 100% soya biscuits, hence there was a significant decrease in hardness of composite biscuits after the percentage of soya was increased to 50%. Hardness of biscuits depends on the composition and structure of flour used for baking. Hardness is a vital aspect to consumers because it affects the quality of biscuits and the perception of consumers (Adebiyi *et al*., 2016).

5.4 Colour parameter of amadumbe-soya composite biscuits

Colour is regarded as an important criterion by consumers to accept baked products and it affects the quality of the food products (Thongram *et al*., 2016; Noorfarahzilar *et al*., 2014). Desirable colour of baked biscuit is brown and it is regarded as index used for quality (Bunde *et al*., 2010). During the baking process, there is a generation of colour on the surface of the cookies due to Maillard reaction (non-enzymatic browning) between amino acids and reducing sugars and sugar caramelization (Thongram *et al*., 2016). There was no significant difference in the lightness and red green colour of 100% amadumbe biscuits and 100% soya biscuits. There was a significant decrease in the lightness and red green colour of composite biscuits made up of 90% amadumbe and 10% soya; and 70% amadumbe and 30% soya compared to that of 50% amadumbe and 50% soya. Factors that are contributing to colour difference in baked products are the amino acids and reducing sugars in the biscuit blend (Thongram *et al*., 2016). The blue-yellow colour of 100% amadumbe biscuits is higher than that of 100% soya biscuits. This could due to the pigments in flour and the effect of baking, as well as the applied heat (Kaushal *et al*., 2012).

5.5 Nutritional quality of amadumbe-soya composite biscuits

5.5.1 The amino acids composition

Aspartic acid and glutamic acid were the most abundant amino acids in the amadumbe-soya composite biscuits. The high content of aspartic acid/asparagine and glutamic acid/glutamine of 14.4-17.2% and 10.3-13.6% was found in both amadumbe flour and mucilage (Njintang *et al*., 2014; Mbofung *et al*., 2006). Aspartic acid and glutamic acid which are important components of human tissues, such as blood proteins, hormones and enzymes, contribute to the proper functioning of many biological activities in the human body (Potter & Hotchkiss., 1995). Compared to soya, amadumbe possesses a relatively lower amount of lysine, thus the addition of soya to amadumbe increases the levels of lysine in composite biscuits (Juliati *et al*., 2015). Soya beans which are known to be a rich source of protein have been used to complement the lysine content of lysine-limited cereal diets (Khetarpaul *&* Goyal, 2007).

The contents of essential amino acids, such as threonine, valine, leucine and phenylalanine, were significantly higher in amadumbe. This was expected considering that amadumbe corms have been found to contain substantial amounts of leucine, threonine, arginine, valine and phenylalanine but have low amounts of histidine, lysine and isoleucine (Melese & Negussie, 2015; Adane, *et al*., 2013). Like amadumbe, many root crops have been found to be rich in threonine, leucine and phenylalanine (Kaushal *et al*., 2012; Ugwu, 2009). Soya was successfully used to increase the content of those essential amino acids which were low in amadumbe, while at the same time maintaining those whose content was high in amadumbe. The presence of adequate quantities of all amino acids in the diet enables optimal growth and proper functioning of the body (Caire-Juvera *et al*., 2013; Kayitesi *et al*., 2012). The fortification of amadumbe flour with soya has been found to maintain adequate levels of heat sensitive amino acids such as lysine, arginine and histidine (Obadina *et al*., 2016).

5.5. Amino acids chemical scores

The improvement in the chemical score of the composite biscuits due to the addition of soya resulted in composite biscuits with improved protein quality which, in turn, enhanced their ability to support optimal growth in humans (Mosha *et al*., 2010).

5.5.3 Protein digestibility

Protein digestibility, which is an estimate of the amount of protein that can be absorbed into the body from a protein diet (Okpala & Chinyelu, 2011), was higher in 100% soya biscuits than in 100% amadumbe biscuits. The lower protein digestibility of 100% amadumbe biscuits could be due to the presence of anti-nutritional factors such as phytic acids, which could have connected with protein to form a protein-mineral complex that can inhibit the activities of the protein degrading enzyme (Rathi *et al*., 2004; Soudy *et al*., 2014). The 50% amadumbe and 50% soya composite flour possess the highest digestibility values and are, thus, recommended to produce amadumbe composite biscuits with the most protein digestibility.

5.5.4 Protein digestibility corrected amino acid score

The protein digestibility corrected amino acid score (PDCAAS) measures the quality of protein in terms of its available indispensable amino acid contents and its digestibility (Vilakati *et al*., 2015, Dabbour & Takruri, 2002). The PDCAAS increased slightly with an increase in the percentage of soya in composite biscuits thereby ensuring that adequate amounts of the essential amino acid, such as lysine, are present in amadumbe composite biscuits (Shaheen *et al*., 2016). Soya has been used elsewhere to improve protein digestibility and PDCAAS sorghum biscuits (Serrem *et al*., 2011). The composite flour of 50% amadumbe and 50% soya is recommended to produce amadumbe composite biscuits since it contains PDCAAS close to one.

5.6 Mineral composition of amadumbe-soya composite biscuits

There was an increase in the amounts of Fe, Zn, and Mn. Fe in 100% soya biscuits was expected since soya beans have been found to contain a substantial amount of these minerals (Julianti et al., 2015). Alternatively, amadumbe corms have been found to contain substantial amounts of K and Fe (Mergedus *et al*., 2015; Mwenye *et al*., 2011). Root crops are a good source of carbohydrates and, because of that, they require high amounts of K and Na (Marschner, 1995). Most minerals, especially Na and K, are important in maintaining the osmotic balance of the fluids in the body (Mergedus *et al*., 2015), as well as controlling the absorption of glucose and many other compounds and minerals in the body (Omoba & Omogbemile, 2013). As reflected in the total ash values, the addition of soya flour to amadumbe flour resulted in composite

biscuits with improved amounts of individual minerals, especially those that were lacking in either amadumbe flour or soya flour.
Therefore, the consumption of micro nutrient-rich composite biscuits will contribute to the building of a strong immune system by helping the body digest, absorb and utilize the nutrients required by the body (Lewu *et al*., 2010b). The consumption of these composite biscuits with fairly substantial amounts of Fe and Zn, which were substantially high in composite biscuits, can help in curbing iron and zinc deficiency in children (Melese & Negussie, 2015; Dakwa & Dakwa, 2013). The recommended daily Fe intake for primary school children is between 8-10 mg and the tolerable upper iron intake is 40 mg per day (Mosha *et al*., 2010). Biscuits containing 50% amadumbe and 50% soya will contribute the most in attaining the daily Fe intake in children and adults. Fe is good for increasing rapid growth and expansion of blood volume and muscle mass (Mosha *et al*., 2010).

5.7 Consumer acceptability of amadumbe-soy composite biscuits

Sensory evaluation was conducted to measure, analyse and interpret consumers' potential response to the different amadumbe-soya composite biscuits through the senses of sight, smell, touch and taste (Stone & Sidel, 1993). The colour, aroma, taste and texture of composite biscuits did not change significantly with the increase in the percentage of soya. Browning of biscuits is often observed during baking due to Maillard reaction resulting from a reaction of reducing sugars and amino acid during the heating (baking) process (Ndife *et al*., 2014; Chinma & Gernah, 2007). The resulting colour was generally acceptable to consumers even when the composition of soya was 50% in the composite biscuit. Colour plays an important role in product acceptability and is the parameter used in judging baked biscuits. Colour provides information not only to reflect on raw materials, but to also consider the quality and formulation of the product (Ojinnaka & Nnorom 2015; Ikpeme-Emmanuel *et al.*, 2009;).

The aroma of all the different biscuits was generally acceptable for all the composites. Aroma is an attribute that is reported to have an influence on the acceptability of baked products even before they are tasted (Ubbor & Akobundu 2009). The same concentration of vanilla essence was used in all composite biscuits. This might have contributed to how the consumer perceived the biscuits and resulted in the aroma acceptance mean not being significantly different. Dovi's Dissertation, (2013) study showed that consumers did not perceive the difference in the aromas of the sorghum and sorghum-cowpea biscuits. Lawless and Heyman (2010) reported that the aroma is better perceived through a double role of olfaction system by smelling through the external sensory system and in the mouth through the internal sensory system, where the aroma rises and passes up into the nasal cavity from the rear direction. The flavour of food arises from a subtle interaction of taste and aroma. It imparts a pleasing and displeasing sensory experience to consumers and, ultimately, determines biscuit acceptance or rejection (Ojinnaka & Nnorom, 2015).

The taste of biscuits is an important attribute that determines the acceptability of the composite biscuits and this could have a high impact on the success of developed products in the market (Farzana & Mohajan, 2015). The similarity in the taste acceptance of the composite biscuits can be attributed to the inclusion of soya which has a high fat content. Fat can modify the structure of a biscuit and play a role in the rate of hydration, as well as the pattern and rate of aroma release during eating (Burseg *et al*., 2009). Similarities in taste acceptance of the composite biscuits can be attributed to the fat content in soya. Fat acts as a flavour enhancer and, in baked products, it improves the sensory quality content. Soya is known to be a flavour retainer and it enhances the flavour in biscuits (Apotiola & Fashakin; Ly 2013).

The texture of the crust is related to the external appearance of the biscuit, the top implies the roughness or the smoothness of the crust (Farzana & Mohajan, 2015) and is important in justifying the acceptability of biscuits (Ndife *et al*., 2014). The texture of composite biscuits did not show any major variation when the percentage of soya was increased. Texture is regarded as a complex perception; the visual is the first input, the second is the touch and the third is the feeling in the mouth, which is detected by the teeth and tactile nerve cells on the tongue and palate (Shiny & John, 2014). The structure of solid food is related to attributes like hardness, crumbliness and crispiness which might affect perceived flavour through cross modal interactions. The 50% amadumbe and 50% soya biscuits were mostly accepted by consumers. Results showed that the biscuits that were more acceptable were softer than 100% amadumbe biscuits. Burseg *et al*. (2009) indicates that fat is a key factor as it can affect a range of factors such as aroma partition, food structure and sensory attributes like mouth-feel. The hardness of biscuits decreased when soya was added in the composite biscuit whereas the texture of the composite biscuit showed an increase in how the biscuit is perceived. The textural attribute showed that the composite biscuit of 50 % amadumbe and 50% soya is liked moderately. The hardness of amadumbe could be due to an increase in carbohydrate starch granules which are responsible for gel and structure formation in baked goods (Okpala & Egwu 2015).

The overall acceptance results indicate that all biscuit formulations are generally accepted by consumers (Sanful, 2011). Sensory quality attributes must be acceptable to consumers as they determine the eventual preference, selection and consumption of amadumbe composite biscuits by consumers (Mosha *et al*., 2010).

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusions

For the proximate composition of composite biscuits, the 90% amadumbe and 10% soya biscuits had high significant values of moisture content, ash, carbohydrates and energy values. The values of composite biscuits for moisture were significantly higher than of 100% amadumbe and 100% soya, while for carbohydrates, they were significantly higher than those of 100% soya biscuits. The energy values were significantly lower than those of 100% amadumbe and 100% soya. The 50% amadumbe and 50% soya had significantly high values of fat, acid detergent fibre (ADF), Neutral detergent fibre (NDF) and crude protein and the values were significantly higher than those of the 100% amadumbe biscuits. The 90% amadumbe and 10% soya had high significant values of water absorption capacity and oil absorption capacity and the values were significantly higher than those of 100% soya. There was no significant difference in the swelling index of amadumbe-soya composite biscuits.

Physical properties, such as height, weight and hardness of 90% amadumbe and 10% soya, were significantly higher than the other composite biscuits and 100% soya biscuits. The diameter of composite biscuits of 100% amadumbe and 100% soya were not significantly different. The spread ratio of 50% amadumbe and 50% soya was significantly higher than the other composite biscuits and 100% amadumbe biscuits. The colour parameter L*, which is lightness and red green colour of 90% amadumbe and 10% soya, was significantly higher than in other composite biscuits and significantly lower than those of 100% amadumbe and 100% soya. The a* value, which is a measure of red-green characteristics of 50% amadumbe and 50% soya, was significantly higher than that of other composite biscuits and 100% soya biscuits.

Amadumbe-soya composite biscuits have improved nutritional quality in terms of protein content, lysine and quality and mineral content compared to 100% amadumbe biscuits. Major amino acids of composite biscuits were aspartic acid and glutamic acid. The 50% amadumbe and 50% soya biscuits were significantly higher than the other composite biscuits and of the 100% amadumbe biscuits. There was improved protein digestibility in composite biscuits when the percentage of soya was increased to 50%. The 50% amadumbe and 50% soya biscuits had the highest protein digestibility compared to 100% amadumbe. Lysine was found to be the limiting amino acid for amadumbe biscuits and amadumbe-soya composite biscuits, while valine was the limiting amino acid for the soya biscuits. The addition of soya to amadumbe improved protein digestibility corrected the amino acid score (PDCAAS) of composite biscuits to a value of 1 at 50% soya addition. There was a significant difference in the mean taste acceptability and the mean overall acceptability when the percentage of soya was increased to 50%. There were no significant differences in the mean acceptance value of colour, aroma and texture. Consumers liked the composite biscuits of 50% amadumbe and 50% soya moderately.

6.2 Recommendation

For product development, the composite flours of amadumbe and soya would be useful in product formulations as bakery products where hydration is important to improve handling characteristics are required. It is important for future studies to determine the shelf-life of biscuits and to investigate the composition of amadumbe and defatted soya biscuits. This might provide direct comparison of the nutritional and sensory characteristics of the biscuits.

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APPENDIX A: ETHICS APPROVAL LETTER

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 25/02/2015

Ref #: **2015/CAES/023**
Name of applicant: **Ms TM Mokhele**
Student #: **30977525**

Dear Ms Mokhele,

Decision: Ethics Approval

Proposal: Development of amadumbe (*Colocasia esculenta (L) scott*)-soya composite biscuits with improved nutritional and sensory properties

Supervisor: Dr FT Tabit

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the development and testing of the nutritional properties of the biscuits, **but not for the sensory trials phase of the research**.

Please consider point 4 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 25 February 2015.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*

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Open Rubric

3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*
4) *The application contained very little information on the sensory trials that are planned. The researcher must submit a comprehensive explanation of this phase of the research to the Committee including the following: How will participants be recruited? How will the trials be executed? Provide a step-by-step explanation of the methodology to be followed. What information will be given to the participants beforehand?*

Note:
The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

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APPENDIX B SCREENING QUESTIONNAIRE FOR PARTICIPANTS

1. How often do you consume biscuits?

At least once every two weeks	
At least once every three weeks	
At least once a month	
More than once a month	
Never	Closed

2. **What is your work status**?

	Unemployed
	Do not work – student
	Do not work – housewife
	Work part time (8-29 hours per week)
	Work full time (30+ hours per week)

3. **Which industry do you work in?**

CLOSE	Market research industry
CLOSE	Advertising company
CLOSE	Food industry
	Other: Name________________________

4. **Which industry does your family or siblings work in?**

CLOSE	Market research industry
CLOSE	Advertising company
CLOSE	Food industry
	Other____________________________

5. **Are you good in English?**

	Yes
CLOSE	No

6. Biographical data of suitable participants

Name: ____

Race: ____

Gender: ____

Age____

Tel: ____

E-mail address: ____

7. Sensory evaluation Schedule for suitable participants

Time	
Date	
Venue	

APPENDIX C SCORE CARD FOR CONSUMER ANALYSIS AMADUMBE-SOYA COMPOSITE BISCUITS

Name: ____

Date:____

Set No: ____

Code: ____

Age: ____________________

Product code: _____________________________________

INSTRUCTION

Please take a sip of water before and after you have tasted a sample.

Please evaluate the amadumbe /soya composite biscuits for the selected characteristics in the order given from **LEFT** to **RIGHT**

Please make a cross on the line in the box which indicates how well you like it.

Hedonic Scale		Mark X	Colour	Aroma	Taste	Texture	Overall acceptability
9	Like extremely		_____	____	____	____	______
8	Like very much		_____	____	____	____	______
7	Like moderately		_____	____	____	____	______
6	Like slightly		_____	____	____	____	______
5	Neither like nor Dislike		_____	____	____	____	______
4	Dislike slightly						
3	Dislike moderately		_____	____	____	____	______
2	Dislike very much		_____	____	____	____	______
1	Dislike extremely		_____	____	____	____	______

Thank you for your response.

APPENDIX D CONSENT FORM

TITLE OF RESEARCH PROJECT

DEVELOPMENT OF AMADUMBE (COLOCASIA ESCULENTA (L) SCOTT)-SOYA COMPOSITE BISCUITS WITH IMPROVED NUTRITIONAL AND SENSORY PROPERTIES

Dear Mr/Mrs/Miss/Ms ______________________________ Date....…/……... /20......

NATURE AND PURPOSE OF THE STUDY

The aim of this study is to determine the sensory properties and consumer acceptability of amadumbe- soya composite biscuits.

RESEARCH PROCESS

People who patronise and eat biscuits at least once a month will be required to taste and visualise amadumbe-soya composite biscuits. Your socio-demographic information, such as your gender and age, will also be recorded. You will be required to taste, visualize biscuits and fill your assessments of the biscuits in your score cards.

CONFIDENTIALITY

Your assessments of the biscuits and your biographic details will be regarded as strictly confidential, and only members of the research team will have access to such information.
No data published in dissertations or journals will contain any information by means of which you may be identified. Your anonymity is therefore ensured. All data will be kept safe in the Department of Life and Consumer Science by Dr FT Tabit.

WITHDRAWAL CLAUSE

You should understand that you may withdraw from the study at any time. You are therefore participating voluntarily until such time that you state otherwise.

POTENTIAL BENEFITS OF THE STUDY

Amadumbe is a traditional staple root crop in South Africa and is currently underutilised. Therefore, developing amadumbe-soya composite biscuits will add value to amadumbe, improve its image and encourage farmers to grow more amadumbe which will result in income generation and ensure food security in rural communities. Furthermore, a nutrient rich amadumbe-soya composite biscuit will improve the utilisation and commercial value of the amadumbe plants.

INFORMATION (contact information of your supervisors)

If there is any question concerning this study, contact the following: DR Frederick Tabit, 011 471 2080, Department of Life and Consumer Sciences, University of South Africa. DR EO Amonsou, 031 373 5328, Durban University of Technology

CONSENT

I, the undersigned, ………………………………………………………………….… (full name) have read the above information relating to the project and have also heard the verbal version, and declare that I understand it. I have been afforded the opportunity to discuss relevant aspects of the project with the project leader, and hereby declare that I agree voluntarily to participate in the project.

I indemnify the university and any employee or student of the university against any liability that I may incur during this project.

I further undertake to make no claim against the university in respect of damages to my person or reputation that may be incurred because of the project/trial or through the fault of other participants, unless resulting from negligence on the part of the university, its employees or students.

I have received a signed copy of this consent form.

Signature of participant: ....

Signed at ………………………………… on …………………………………

WITNESSES

1 ....

2 ....

APPENDIX E: SIMILARITY INDEX (TURN-IT-IN REPORT)

(to be inserted)