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Development of Orange Fleshed Sweet Potato and Bambara groundnut-based snacks for School children in Tanzania

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DECLARATION

I, Buzo Honi declare that this thesis is my original piece of work and has not been submitted to any university or institution for the award of any degree.

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DEDICATION

This work is dedicated to my parents, my father, Mr. Honi Maige, and the late beloved mother, Sinna Maduhu, who made the foundation of my education.

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TABLE OF CONTENTS

DECLARATION... ………………..ii

DEDICATION.. iii

ACKNOWLEDGEMENT iv

TABLE OF CONTENTS v

LIST OF TABLES vii

LIST OF FIGURES viii

ACRONYMS ix

ABSTRACT x

1. INTRODUCTION.. 1

1.1 Background 1

1.2 Problem statement... 4

1.3 Objectives 4

1.3.1 General objective 4

1.3.2 Specific objectives 4

1.4 Significance of the stud... 5

1.5 Hypothesis... 5

2. LITERATURE REVIEW 6

2.1 Sweet potato in Tanzania 6

2.2 Bambara groundnut... 9

2.3 Extrusion cooking technology 12

2.4 Nutritional requirements for school children 15

2.5 Shelf life testing 16

2.6 Consumer acceptability testing 19

3. RESEARCH MANUSCRIPTS 20

3.1 Development and assessment of nutritional quality, sensory properties and consumer acceptability of Orange Fleshed Sweet Potato and Bambara groundnut-based snacks for school children 20

Abstract……………………………………………………………………………..20

3.1.1 Introduction.. 22

3.1.2 Material and Methods 23

3.1.3 Results and Discussion 28
3.1.3.1 Nutritional quality of formulated OFSP and Bambara groundnut-based snacks28
3.1.3.2 Descriptive sensory profiling and consumer acceptability of the developed snacks 32
3.1.4 Conclusion 39
3.1.5 References.. 40
3.2 Pro-vitamin A retention and shelf life prediction of extruded Orange Fleshed Sweet Potato and Bambara groundnut-based snacks.. 44
3.2.1 Introduction.. 45
3.2.2 Materials and methods 46
3.2.3 Results and Discussion 46
3.2.3.1 Pro-vitamin A retention during extrusion cooking 46
3.2.3.2 Shelf life prediction of the formulated snack.. 49
3.2.4 Conclusion 52
3.2.5 References.. 53
4. GENERAL DISCUSSION 58
4.1 Nutritional quality of the developed snacks.. 58
4.2 Descriptive sensory profiling and consumer acceptability of the developed snacks............. 59
4.3 Effect of extrusion on pro-vitamin A retention... 60
4.4 Shelf life prediction of extruded snacks.. 61
5. CONCLUSIONS AND RECOMMENDATION.. 62
6. REFERENCES.. 63
7. APPENDICES 80

LIST OF TABLES

Table 2.1: Sweet potato production trend in Tanzania ... 6
Table 2.2: Nutrients in white fleshed and orange fleshed sweet potato of 100g boiled and mashed ... 8
Table 2.3:Nutritional composition of Bambara groundnut comparison of and some legume crops ... 10
Table 2.4: Anti-nutritional factors of raw, toasted and boiled Bambara groundnut ... 11
Table 2.5: Recommended dietary intakes (RDI) of selected nutrients for children aged 4 -13 years ... 16
Table 3.1:Formulation of orange fleshed sweet potato (OFSP) and Bambara groundnut (BN) composite flours for extruded snack production ... 24
Table 3.2: Attributes, definitions and anchors used in descriptive sensory panel training ... 28
Table 3.3: Effect of ingredient concentrations on the proximate composition of orange fleshed sweet potato (OFSP) and Bambara groundnut extruded snacks ... 29
Table 3.4: Percentage contribution of the formulated snacks to the recommended dietary intake (RDI) of children aged 9-13 ... 30
Table 3.5: Effect of ingredient concentrations on the mineral content of orange fleshed sweet potato (OFSP) and Bambara groundnut extruded snacks ... 31
Table 3.6: Percentage contribution of the formulated snacks to the recommended dietary intake (RDI) for minerals of children aged 9-13 ... 32
Table 3.7: Characteristics of the consumer acceptability panel (N=73) ... 33
Table 3.8: Acceptability scores for formulated snacks ... 33
Table 3.9: Retention (%) of pro-vitamin A in extruded Orange fleshed sweet potato and Bambara groundnut-based snacks ... 48
Table 3.10: Peroxide value produced during two months storage at room temperature ... 48
Table 3.11: Shelf life prediction using room temperature data ... 51
Table 3.12: Vitamin A content of Maize-OFSP flat-breads ... 57
Table 7.1: Mean intensity score of the developed snacks ... 80
Table 7.2: Pro-vitamin A retention in developed snacks ... 80
Table 7.3: ANOVA table of effect of extrusion on pro-vitamin A retention ... 80

LIST OF FIGURES

Figure 2.1: Orange Fleshed Sweet Potato tubers……………………………………………………7

Figure 2.2: Cream with white eye Bambara groundnut seeds……………………………………9

Figure 3.1: Beta-carotene standard plot……………………………………………………………26

Figure 3.2: Spider plot showing mean intensity ratings of descriptive attributes of formulated snack samples.. 34

Figure 3.3: Bi-plot from PCA of descriptive sensory data for formulated snack samples 35

Figure 3.4: Correlation loading from partial least squares regression of formulated snack samples with descriptive data as X-variables and hedonic rating as Y variables 36

Figure 3.5: Photographs of the extruded RTE snacks from OFSP and Bambara groundnut (BN).. 38

Figure 3.6: The effect of extrusion on pro-vitamin A retention in orange fleshed sweet potato (OFSP) and Bambara extruded snacks.. 47

Figure 3.7: Peroxide value produced during two months storage at room temperature 50

ACRONYMS

AOAC……………………………….	Association of Official Analytical Chemists
CIP…………………………………...	International Potato Center
CRD………………………………….	Completely Randomized Design
FAO………………………………….	Food and Agriculture Organization
HTST………………………………...	High Temperature Short Time
ISO…………………………………..	International Organization for Standardization
LSD……………………………….....	Least Significant Difference
OFSP………………………….......	Orange Fleshed Sweet Potato
QDA………………………………..	Quantitative Descriptive Analysis
SUA………………………………….	Sokoine University of Agriculture
TFNC………………………………...	Tanzania Food and Nutrition Centre
UNICEF……………………………..	United Nation International Children Emergence Fund
UNU…………………………........	United Nations University
URT………………………………….	United Republic of Tanzania
VITAA……………………………....	Vitamin A for Africa
WHO………………………………...	World Health Organization
WFP………………………………....	World Food Programme

ABSTRACT

Development of snacks using locally under-utilized crops such as orange fleshed sweet potatoes (OFSP) and Bambara groundnut is crucial for alleviating under-nutrition among primary school children through food-based approach. This study was aimed at developing an acceptable, shelf stable, nutrient dense snack from OFSP and Bambara groundnut. The 100% OFSP, 100% Bambara groundnuts and composite snacks at different levels of OFSP flour substitution were prepared and assessed for proximate composition, mineral and pro-vitamin A content, sensory properties, consumer acceptability and shelf life stability. The effect of extrusion on nutritional quality of the snacks was also assessed. The results showed that there were significant differences ($p<0.05$) in proximate composition between the developed snacks. Protein contents ranged from 4.08 ± 0.26 g/100g DM in 100% OFSP snacks to 15.03 ± 0.34 g/100g DM in 100% Bambara groundnut while pro-vitamin A ranged from 0.54 ± 0.05 mg/100g DM in 100% Bambara groundnut to 17.33 ± 0.48 mg/100g DM in 100% OFSP. Vitamin A retention after extrusion ranged between 59.08% (Bambara groundnut 100%) to 86.50% (OFSP_ 20%). The substitution of OFSP by Bambara groundnut in the formulation increased magnesium, phosphorous, potassium and iron and decreased calcium and sodium contents in the composite snacks. OFSP based snacks had higher mean acceptability scores (6.62 – 7.0) than the 100% Bambara groundnuts based snack (5.88) with orange colour and sweetness being the drivers for consumer liking of the snacks. Predicted shelf life at room temperature ranging between 118 – 150 days. The study showed that development of OFSP substituted with Bambara groundnut up to 40% enhances nutritional quality of the products, retains sensory properties and is acceptable by consumers with colour and sweetness being the main drivers for their liking.

Key words: Orange fleshed sweet potatoes; Bambara groundnut; Extrusion; Pro-vitamin A; Under-nutrition; Quantitative Descriptive Analysis.

1. INTRODUCTION

1.1 Background

Under-nutrition associated with inadequate energy intakes and micronutrient deficiencies, such as iron and vitamin A is becoming a serious problem for school children in many developing countries (Manna *et al*., 2011; Mosha *et al*., 2010). According to FAO (2007), school children in Tanzania perform poorly in schools and this is associated with high dropout rates and is partly due to malnutrition and health related problems. It is estimated that, 22% of school age children in Tanzania are stunted owing to chronic inadequate intake of energy and other nutrients (FAO, 2007). Also about 40% of school aged children in Tanzania have iron deficiency and 24% have vitamin A deficiency (TDHS, 2004/2005). Tanzania Demographic Health Survey TDHS (2010) shows the rate of malnutrition of children below five years old is; stunting (low height-for-age) 42%, wasting (low weight-for height); 5%, anemia 69%, vitamin A deficiency35% and Iron deficiency 33%. This indicates that children start primary schools with poor nutritional status. These nutritional problems adversely affect children's school attendance, scholastic performance and concentration in class (UNICEF, 2003). Consequently, their cognitive development either through physiological changes or by reducing their ability to participate in learning experiences are also affected (Partnership in Child Development, 2002). Malnourished children cannot afford to learn properly because of cognition problems, micronutrient deficiencies, stunting and other long-term consequences of earlier malnutrition (Bundy *et al*., 2009).

Under-nutrition among school children (7-13years) in Tanzania is contributed by poverty, food insecurity and lack of school feeding programmes thus exposing children to short-term hunger (WFP, 2009). Factors contributing to short-term hunger in school children include: the long distances children have to travel to school and cultural meal practices that include no or small breakfasts (Partnership for Child Development, 1999). Other factors such as lack of access to clean water, sanitation and health care also play a role in under-nutrition (UNICEF, 2003).
Minerals and vitamins are required to build resistance against common infections and support physical growth and development (TFNC, 2006). Micronutrient supplements are commonly used to alleviate malnutrition but the approach is not sustainable because of inaccessibility in the rural areas. Food-based approaches are one part of a strategy for reducing under-nutrition in Tanzania

(Temu *et al*., 2014; Helen Keller International, 2012). Increasing consumption of key micronutrients food sources (especially vitamin A and iron) is a sustainable approach to alleviate under-nutrition (Bengtsson *et al.,* 2009).

Intensive utilization of locally available crops as sources of energy, protein, vitamin and minerals will help in fighting under-nutrition among school children. Crops source of carbohydrate locally available in Tanzania include cereals (maize, sorghum, millet, rice and wheat), roots and tubers (cassava, sweet potato, Irish potato and yams) and banana whereas crop sources of protein include beans, soy beans, cowpeas, pigeon peas, bambara groundnut *(Vigna subterranea* (L.)) and ground nut. The promotion and utilization of the orange fleshed sweet potato (OFSP) is on the rise in Tanzania with organizations like Helen Keller International, Vitamin A for Africa (VITAA) and International Potato Center (CIP), working together to promote its utilization. However, despite the promotion and its merit, the rate of its adoption is low compared to the traditional varieties. Therefore, the use of OFSP as a source of energy and means of fighting vitamin A deficiency in Tanzania is of significance (Waized *et al*., 2015). However, in some cases the high preference for local varieties of sweet potato has resulted in underutilization of OFSP (Temu *et al*., 2014).

Bambara groundnut which is a source of Protein, CHO, fats and minerals including Iron can be used to alleviate under-nutrition among school children. It is readily available but under-utilized and not well promoted in the local or international markets (Hillocks *et al*., 2011).Therefore, incorporation Bambara groundnut which is the good source of carbohydrate, protein, minerals and fats (Bamshaiye *et al.,* 2011; Mune *et al.,* 2011) can be used to alleviate under-nutrition among primary school children because it is readily available and affordable. OFSP can be incorporated with Bambara groundnut in balanced ratios to produce a nutritious snack that can contribute towards reducing protein-energy and micronutrient deficiency among primary school children.

Snack foods have become an integral part of the eating habits of the majority of the world's population including children (Dehghan-Shoar *et al*., 2010). The basic criteria that a snack should meet are convenience, manageable portions and the actual fulfillment of short-term satisfaction of hunger (Hazarika *et al.,* 2013). Most snack foods are cereal or grain-based products which are generally low in protein and often, high in fat content and normally considered as a low value products (Noorakmar *et al*., 2012). The disadvantage of foods eaten as snack is that they may provide a large portion of a child's daily calorie needs especially from carbohydrates and fats. It is therefore important to choose food ingredients which contribute vitamins, minerals and other nutrients necessary for health, growth and development. Preparation of snacks from natural ingredients or components to yield products of specific functional properties and some are nutritionally balanced (Saxena and Thakur, 2000), and also they can be sources of energy, protein and micronutrients. Furthermore, due to its advantages that, the children worldwide are attracted to several snack products which are particularly tasty and easy to be carried and consumed (Filli *et al*., 2013), moreover serve as a vehicle for meeting school children nutritional requirements and micro-nutrient supplementation. Also provides calories satisfying short-term hunger and often eaten in a hurry (James and Nwabueze, 2013; Ocheme *et al*., 2011; Rhee *et al.,* 2004). Therefore, a lot of works have been done to improve the nutritive values of the snack foods by incorporation of protein sources derived from plant or animals (Anton *et al.,* 2009; Rhee *et al.,* 2004; Senthil *et al.,* 2002).

In most developing countries the process of snack production is largely a home art. This makes them to differ considerably from one community to another in terms of nutritional composition, microbiological safety and sensory attributes (James and Nwabueze, 2013). Also deterioration of nutritional quality, owing to high temperature, is a challenging problem in most traditional cooking methods (Singh *et al*., 2007). Extrusion has been employed in developing a wide range of raw materials from cereal flour, starch granules, tubers and legumes into semi-cooked or completely cooked food products such as breakfast cereals, snacks, flakes and quick cooking pasta products (Leszek, 2011; Nwabueze, *et al*., 2008; Iwe, 2001). Extrusion cooking is preferable to other food-processing techniques in terms of significant nutrient retention, due to the high temperature and short time required (Singh *et al*., 2007; Guy, 2001). In addition, extrusion not only improves digestibility but also improves the nutrients bioavailability compared to conventional cooking (James and Nwabueze, 2013; Singh *et al.,* 2010). The use of extrusion in snacks production can produce snacks which are consistent and nutritious from locally available crops.

1.2 Problem statement

Locally available food crops can be used to formulate nutritious snacks that can contribute towards alleviating under-nutrition. OFSP is extremely rich in beta-carotene; a naturally occurring pigment that is easily converted into vitamin A in the body (Mitra, 2012). OFSP is also rich in carbohydrates, fiber and is a good source of vitamins C, E, K, and several B vitamins (Burri, 2011). Incorporating OFSP with Bambara groundnut which is a good source of protein, vitamin (thiamine, riboflavin, niacin and carotene), minerals and fats (Bamshaiye *et al.*, 2011; Mahala and Mohamed, 2010) could efficiently be used to reduce the problem of under-nutrition in primary school children.

Although it is possible to combine OFSP and Bambara groundnut to produce a nutritious product, the actual formulations to achieve this have not yet been developed. Additionally, the effects of extrusion cooking on the sensory characteristics, consumer acceptability, nutrient retention and shelf life stability in the product have also not been evaluated. The purpose of this study was to develop an acceptable, shelf stable, nutrient dense snack from Orange Fleshed Sweet Potato and Bambara groundnut by extrusion cooking technology.

1.3 Objectives

1.3.1 General objective

The general objective of this study was to develop an acceptable, shelf stable, nutrient dense snack from Orange Fleshed Sweet Potato and Bambara groundnut.

1.3.2 Specific objectives

The specific objectives of the study were:

1. To determine the nutritional quality of formulated OFSP and Bambara groundnut-based snacks
2. To determine the sensory characteristics and consumer acceptability of formulated OFSP and Bambara groundnut-based snacks.

3. To determine the effect of extrusion on pro-vitamin A retention in OFSP and Bambara groundnut-based snacks
4. To determine the shelf stability of the formulated OFSP and Bambara groundnut-based snacks

1.4 Significance of the study

To address the problems of under-nutrition and under-utilization of the potential OFSP and Bambara groundnut, the information obtained from this study will serve as basis for increasing utilization of OFSP and Bambara groundnut as well as reducing under-nutrition among the primary school children in the country. The increased utilization in turn will lead to increased production of OFSP and Bambara groundnut and income to farmers, traders, and processors. This will lead to overall reduction in under-nutrition, poverty and food insecurity within the country.

1.5 Hypothesis

1. There is no difference in nutrient composition, sensory quality and consumer acceptability between the developed OFSP and Bambara groundnut-based snacks.
2. Extrusion cooking has no effect on pro-vitamin A retention on developed OFSP and Bambara groundnut-based snacks
3. There is no difference in shelf life stability of the developed OFSP and Bambara groundnut-based snacks

2. LITERATURE REVIEW

2.1 Sweet potato in Tanzania

Sweet potato (*Ipomoea batatas* (L) Lam) is an important tuber crop grown in the tropics, sub-tropics and warm temperate regions of the world for its edible storage roots. Over 7 million tons (about 5% of global production) of sweet potatoes are produced in Africa most of which is produced from the East and Southern Africa region (Olapade and Ogunade, 2014). The principal sweet potato producers in East Africa include Uganda, Tanzania, Kenya, Rwanda and Burundi. Tanzania is the second producer of sweet potato in East Africa after Uganda (Bengtsson *et al*., 2009). Tanzania produced a total of 1,322,000 MT of sweet potatoes in 2007 (FAO, 2007).

In Tanzania sweet potato is the third most important root and tuber crop after cassava and the round potato. Lake Zone in Tanzania produces more than 330,600 tons per year, which is grown by small scale farmers for food and income (United Republic Tanzania, 2011). Sweet potato is regionally very important in the Lake Zone, where it is a primary staple food and produced by 99 per cent of farming households (Sindi and Wambugu, 2012). Sweet potato area harvested, total production and yield trend in Tanzania (2005 -2010) are shown (Table 2.1).

Table 2.1: Sweet potato production trend in Tanzania

Year	Area harvested (ha)	Total Production (MT)	Yields (Production per hectare (MT/ha)
2005	469,110	1,414,820	3.0
2006	480,000	1,396,400	2.9
2007	450,000	1,322,000	2.9
2008	460,000	1,379,000	2.9
2009	465,000	1,381,120	2.9
2010	480,000	1,392,000	2.9

Source: FAOSTAT (2010).

The flesh colour of the root varies from various shades of white, cream, yellow to dark-orange depending upon the carotenoid content. Carotenoid pigments are responsible for the cream, yellow, orange or deep orange flesh colours of sweet potato roots as an example of orange fleshed sweet potato shown (Figure 2.1).

Figure 2.1: Orange Fleshed Sweet Potato tubers

The percentage total carotenoid present as beta-carotene is high in deep OFSP cultivars being 89.9% (Woolfe, 1992). The naturally high β-carotene containing variety of sweet potato (OFSP), which has a dark orange root was originally developed in the United States through conventional breeding and was successfully introduced into a home-gardening project in South Africa (Van Jaarsveld *et al.,* 2005). Carotenoids have been linked with the enhancement of immune body system (Mitra, 2012). This attribute may be exploited to introduce an attractive colour into foods to which sweet potato is added. The depth of the flesh colour is largely a function of the concentration of beta-carotene. OFSP varieties are believed to represent the least expensive, year-round source of dietary vitamin A available to poor families in Sub Sahara Africa. OFSP has main importance as a source of Vitamin A especially for children, lactating mothers and other people with low immunity (Vimala, 2011). The roots are used as a source of different nutrients depends on the varieties as shown (Table 2.2).

Table 2.2: Nutrients in white fleshed and orange fleshed sweet potato of 100g boiled and mashed

Variety	Nutrient						
	Energy (kCal)	Protein (g)	Fiber (g)	Iron (mg)	Zinc (mg)	Vitamin A (mcg RAE)	Vitamin C (mg)
OFSP	76	1.37	2.5	0.72	0.2	588	12.8
WFSP	76	1.37	2.5	0.72	0.2	0.05	12.8

Source: Helen Keller International (2012).
RAE; Retinol Activity Equivalent: 1 RAE =1mcg retinol = 12 mcg beta-carotene. OFSP (orange fleshed sweet potato), WFSP (white fleshed sweet potato).

Despite their nutritional and health values, the use and consumption of flesh OFSP tubers are limited by the fact that they are subjected to extensive post-harvest losses. Consequence of their high moisture content, sustained metabolism and microbial attack, leading to damage during harvest and storage shorten their shelf life (Temu *et al*., 2014). These problems could be solved by converting the tubers from perishable to non-perishable products through food processing in order to manufacture new food products such as snack foods.

Efforts of delivering OFSP in utilization suggests that farmers will grow and consumers will buy and eat them, but food-based approaches in general have faced challenges in providing sufficient quality evidence that they can deliver nutrition improvements in a cost effective manner (Mitra *et al.*, 2012**).** According to Ocloo *et al.* (2011), it was suggested that there is a need for continued effort to develop OFSP production towards improved processing technology and value added products. Commercial utilization of OFSP for industrial raw materials like flour and starch is nonexistent although it has the potential of adding value to the produce and helping create new domestic and export market niches for new products. There are developed sweet potato recipes for various products including bakery, fried and roasted snack products, preserves such as jam, ketchup and juice, weaning food including porridge and mashes which increased utilization (Oweri *et al.*, 2007). However, increase in utility would also depend on thorough understanding of the effect of processing on their properties and functionality (Ocloo *et al.,* 2011). Therefore, there is a need of developing products to increase OFSP utilization aimed at producing products that meet customer needs in terms of improved nutrition, tastes and preferences.

2.2 Bambara groundnut

Bambara groundnut (*Vigna subterranea* (L.) Verdc.), originated in West Africa but has become widely distributed throughout the semi-arid zone of sub-Saharan Africa (SSA) (Azam-Ali *et al*., 2001). It is an indigenous African grain legume and is one of the more important crops grown on the African continent (Abu-Salem and Abou-Arab, 2011). Bambara groundnut yields well under conditions which are too arid for groundnut, maize and sorghum (Hillocks *et al.*, 2012).Its drought tolerance behavior makes Bambara groundnut a useful legume to include in climate change adaptation strategies. In Tanzania Bambara groundnut production is about 800,000 tons per year (2013/2014). Its utilization can be cooked together with other foods like maize and dried sweet potato and can be used as a sauce to main dish. Bambara groundnut seeds vary in shape, size and colour of the seed coat. They may be round or elliptical in shape with cream, broom, black, red colour, with white or black –eyed. In Tanzania the majority of peasants grow cream variety with white eye as shown (Figure 2.2)

Figure 2.2: Cream with white eye Bambara groundnut seeds

The major component of the bean is carbohydrate, mainly starch, which is up to 50%. It also contains about 24% protein with a good balance of the essential amino acids and relatively high proportions of lysine (6-8%) and methionine (1-3%) (Belewu *et al*., 2008). The minor components in these beans include minerals, vitamins and anti-nutritional factors such as trypsin inhibitors and polyphenols (Eltayeb *et al*., 2011).

Sharing a high nutritive value with other widely consumed legumes, Bambara groundnut has an appealing flavour which is reflected in demand from small local and niche markets (Mazahib, 2013). Despite its high and balanced protein content, Bambara groundnut remains under-utilized because it takes a long time to cook and it has poor milling characteristics, as does not dehull easily (Hillocks *et al.,* 2012). Nutritionally bambara groundnut is regarded as the third most important legume crop after groundnuts and cowpeas in Africa as shown (Table 2.5), but due to its low status, it is seen as a snack or food supplement but not a lucrative cash crop (Bamshaiye *et al*., 2011).

Table 2.3: Nutritional composition of Bambara groundnut comparison of and some legume crops

Nutrient	**Bambara**	**Soya**	**chickpea**	**Cow pea**	**Kidney**
Carbohydrate (g)	61.6	30.2	60.6	59.6	60
Energy (kCal)	390	416	364	343	333
Protein (g)	24.8	36.5	19.3	23.8	23.6
Fat (g)	6.55	19.7	6.0	2.1	0.8

Source: Bamshaiye *et al.* (2011)

Bambara groundnut seeds can be eaten fresh or cooked while still immature. At maturity, they become very hard and require boiling before further preparation. In many West African countries, the fresh pods are boiled with salt and eaten as a snack (Azam-Ali *et al*., 2001). In Côte d'Ivoire, the seed is used to make flour, which makes it more digestible. The flour can be used to make a stiff porridge and roasted seeds can be boiled, crushed and eaten as a relish (Hillocks *et al.*, 2012).Existing Bambara groundnut products (flour, roasted and boiled seeds) are not well promoted in the local or international markets (Murevanhema and Jideani, 2013). New products are needed that draw attention to its natural nutritional and culinary advantages (Hillocks *et al.,* 2012). The seed contains anti-nutritional factors, it must be properly processed to eliminate or reduce their concentration to a level where it will not be harmful to consumer (Isikwenu *et al*., 2013; Akanji *et al.,* 2003). Effects of toast and boil on anti-nutritional factor of Bambara groundnut are shown (Table 2.4).

Table 2.4: Anti-nutritional factors of raw, toasted and boiled Bambara groundnut

Parameters	Raw	Toasted	Boiled
Trypsin Inhibitor ($TUmg^{-1}$)	28.60	22.10	21.60
Tannin ($mg100g^{-1}$)	0.38	0.14	0.10
Saponin ($mg100g^{-1}$)	0.10	0.05	0.06
Phytate ($mg100g^{-1}$)	0.05	Trace	Trace
Oxalate ($mg100g^{-1}$)	0.60	0.38	0.37

Source: Isikwenu *et al*. (2013).

The Bambara seed stores very well and is not prone to attack by pests or disease. However, the dried seed becomes very hard to cook, requiring large amounts of time, effort and fuel. According to farmers, the decline in Bambara groundnut production is due to lack of adequate processing techniques to promote its utilization (Christina, 2009). This limitation is believed to be the main constraint to its increased utilisation. From the point of view of utilization, cooking quality of Bambara groundnut is very important. Therefore, lack of adequate processing techniques to overcome the hard-to-cook effect has limited its utilization and hence reduced its production (Filli *et al*., 2013; Abdulsalami and Sheriff, 2010).It may be expected that Bambara groundnut will be utilized more extensively if suitable fast processing technology like extrusion is adopted on a commercial basis which can make its products more acceptable, nutritious and digestible (Filli *et al*., 2013). Researches have been done to assess the suitability of Bambara groundnut in weaning foods. It shows potential for the fortification of traditional weaning foods in Africa (Mazahib *et al*., 2013, Mbata, 2009). Also according to Ouedraogo *et al*. (2008) described Bambara groundnut seeds as a complete balanced diet, making it a good supplement to “Burkinabé” diet mainly based on cereal (sorghum, maize and millet).

According to Mbata *et al*. (2009), it was revealed that, protein content was increased from 10 to 16.4% when boiled Bambara groundnut was added to fermented maize dough. The incorporation of Bambara groundnut in maize dough also resulted in an increase in fat, ash, lysine and tryptophan content, compared to unfortified maize dough. It was concluded that the most appropriate technique for the production of bambara-fortified high protein fermented maize dough, would be to incorporate boiled whole seeds in soaked maize, before milling and fermentation (Mbata *et al*., 2009).

It was reported that, the nutritional composition of cooking banana as a weaning food can be enhanced through supplementation with fermented Bambara groundnut flour. This is according to Ijarotimi and Olopade, (2009), the composition of the formulated weaning food containing 70% cooking banana and 30% Bambara groundnut flour, was nutritionally adequate to support child growth and development. In conclusion, the nutritional quality of Cooking Banana and fermented Bambara Groundnut mix of 60:40 ratio was better than 'ogi; and comparable to the nutrend (commercial weaning formula). This implies that it can be used to replace low quality traditional weaning food and the expensive commercial weaning formula.

Another study was conducted on fortification of sorghum and bambara groundnut by Olonila *et al*. (2012) and revealed that fortification of Sorghum meal with Bambara groundnut by 30% can be able to alleviate problems of protein-energy malnutrition as a weaning supplement.

2.3 Extrusion cooking technology

Extrusion is a process which combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming. Food extruders (extrusion-cookers) belong to the family of high temperature short time (HTST) equipment, capable of performing cooking tasks under high pressure (Fellows, 2000). According to Riaz *et al*. (2007), extrusion cooking is defined as a unique tool to introduce the thermal and mechanical energy to food ingredients, forcing the basic components of the ingredients, such as starch and protein, to undergo chemical and physical changes. In addition, extrusion process denatures undesirable enzymes; inactivates some anti-nutritional factors (trypsin inhibitors, haemagglutinins, tannins and phytates); sterilizes the finished product; gelatinization of starch; denaturation of proteins; partial dextrinization of starch; and retains natural colours and flavours of foods (Pathania *et al*., 2013;Anounye *et al*., 2012; Singh *et al*., 2007; Bhandari *et al.*, 2001; Fellows, 2000).

Extrusion is advantageous for vulnerable food and feed as exposure to high temperatures for only a short time will restrict unwanted denaturation effects on, for example, proteins, amino acids, vitamins, starches and enzymes. Physical technological aspects like heat transfer, mass transfer, momentum transfer, residence time and residence time distribution have a strong impact on the food and feed properties during extrusion-cooking and can drastically influence the final product quality (Singh and Helman, 2009).

Extrusion is a popular means of preparing snacks, pasta and ready-to-eat foods (Fellows, 2000; Harper, 1979). It has been investigated as a means of improving the nutrient profile for example increasing levels of dietary fibre (Stojceska *et al*., 2010) and enriching foods with nutrients such as lycopene (Dehghan-Shoar *et al*., 2010). It offers hope for improving nutrition in less-developed nations and can produce shelf-stable foods free from microbial contamination that can be stored in preparation for famines and natural disasters (Guy, 2001). Advantages of extrusion include: efficient energy utilization, high nutrient retention and versatility with respect to ingredient selection and textures of products that can be produced (Guy, 2001).

It has been used to develop various types of snack foods, mainly from corn meal, rice, wheat flour, or sweet potato flour, in many shapes and variety of textures (Singh *et al*., 2007).Extruded product quality can vary considerably depending on the extrusion processing conditions such as extruder type, screw configuration, feed moisture, and temperature profile in the barrel sections, screw speed and feed rate (Camire, 2001). Nutritional effects of processing however depend on factors including type of extruder, process parameters and screw configuration (Oluwole *et al*., 2013; Zarzycki *et al*., 2010; Iwe and Ngoddy, 2000).

Effect during extrusion cooking on starch is mechanical disruption of the cell walls which facilitate digestion and absorption. This mechanical breakdown of starches reduces the viscosity of gruels made from extruded cereals to enhance their caloric and nutrient density(Mercier, 2006; Ding *et al.*, 2005: Brümmer *et al*., 2002). However, the effect of starch during extrusion is of great important on the quality of the final product. Starch serves as a functional ingredient in extruded products which contribute to the expansion. The expansion which in turn relate to the crispiness is important to determine the acceptability of particular type of snack (Noorakmar *et al*., 2012).

The modification of proteins during extrusion cooking is mainly attributed to thermal and shear effects (Singh *et al.*, 2007). Protein denaturation is the primary thermal effect. Under the influence of high temperature and moisture, native proteins lose their structure (globular, miscellar etc.), unfold, adsorb water and melt. Just as starch gelatinization, in extrusion cooking, protein denaturation occurs at lower moisture content, resulting in a high viscosity melt (Nor *et al*., 2013).

Effect of extrusion on vitamins have been reported, although extrusion is often carried out at relatively high temperatures, the retention time is very short and thus there is less destruction than expected (Athar *et al*., 2006; Camire, 2001). As vitamins differ greatly in chemical structure and composition, their stability during extrusion is variable. The extent of degradation depends on various parameters during food processing and storage (Singh *et al.*, 2007). Lipid-soluble vitamins; vitamins D and K are fairly stable and vitamins A, E and their related compounds – carotenoids and tocopherols, respectively are not stable in the presence of oxygen and heat (Fonseca *et al*., 2008; Killeit, 1994).

There are many factors that have an impact on vitamin retention during extrusion including extrusion moisture and vitamin concentrations in the raw materials (Pathania *et al*., 2013). Generally, the retention of vitamins in extrusion cooking decreases with increasing temperature, screw speed and specific energy input (Camire, 2001). It also decreases with decreasing moisture, feed rate and die diameter (Riaz *et al*., 2009). So depending on the vitamin concerned, considerable degradation can occur. Extrusion technology is increasingly used for the production of snack foods and has been investigated in connection with improving dietary profile of snacks **(**Potter *et a*l., 2013; Jisha *et al*., 2010)

Extrusion usually has little impact on minerals as they are fairly inert (Singh *et al*., 2007). Extrusion processing may reduce mineral particle size and embed the minerals throughout the product matrix owing to the dispersive and distributive mixing forces present. Minerals, on the other hand, can accelerate wear on extruder components owing to their abrasiveness (Fellows, 2000). Also during extrusion cooking sugar is a plasticizer and will reduce the glass and melt transition temperatures of a recipe. Sugar liquefy during the heat and shear of the extrusion process reducing extrudate viscosity and upon cooling, the product will become crispy (Ozer *et al*., 2006).

Extrusion cooking has been used to partially or totally inactivate several known anti-nutritional compounds that limit the widespread use of Bambara groundnut as a primary staple food (Shimelis and Rakshit, 2007).According to Oluwelo *et al*. (2013), it was reported that heat generally played a significant role in reducing trypsin inhibitor when a blend of yams and Bambara nut (4:1) was extruded. The trypsin inhibitor observed to be 8.08 ± 0.25 mg/100g at extrusion conditions (130°C barrel temperature, 70 r.p.m. and 15% feed moisture content) and 1.62±0.23 mg/100 g at extrusion conditions (150 °C barrel temperature, 60 rpm screw speed and 12.5% feed moisture content).

2.4 Nutritional requirements for school children

Primary school children are active and growing fast, therefore they need: adequate energy giving foods especially those of plant origin (cereal or root crop-based foods) as well as body building foods especially those of animal origin (meat or fish) or pulses. These children also need protective foods especially those of plant origin that are rich in the vitamins A, B-group and C as well as the minerals (Tanzania Food and Nutrition Centre, 2006). School-aged children grow significantly, but at slower rate, whilst being very physically active in general (Luzi, 2010). As a result, their nutritional needs are high and critical. Additionally, genetic background, gender, body size and shape are all important determinants of nutrient requirement.

Caloric needs vary depending on the child's current rate of growth, the amount of physical activity, and the child's metabolism (Manna *et al*., 2011). It is important that children consume enough calories to ensure proper growth and to spare protein from being used for energy. It is important for school-age children to meet the recommended intake levels of all essential vitamins and minerals. The Reference Dietary Intakes for school age group are shown (Table 2.5).

Table 2.5: Recommended dietary intakes (RDI) of selected nutrients for children aged 4 -13 years

Nutrient	RDI for age and sex		
	4-8 years	**Male 9-13years**	**Female 9-13years**
Carbohydrate (g/day)	130	130	130
Protein (g/day)	17	34	34
Fiber (g/day)	25	31	26
Energy (kCal/day)	1200	1600	1800
Calcium (mg/day))	800	1300	1300
Phosphorus (mg/day)	500	1250	1250
Magnesium (mg/day)	130	240	240
Iron (mg/day)	10	8	8
Zinc (mg/day)	5	8	8
Vitamin A (mcg RE)	400	600	600
Sodium (mg/day)	1200	1500	1500
Potassium (g/day)	3.8	4.5	4.5

Source: Dietary Reference Intakes series, Institute of Medicine (2002).

2.5 Accelerated shelf life testing

Shelf life is a finite length of time for a food product to retain a required level of organoleptic and safety qualities under stated conditions of storage after production (Cardelli and Labuza, 2001). The shelf life of a product commences from the time the food is manufactured and its length depends on ingredients, manufacturing process, type of packaging and storage conditions (Jaya and Das, 2005). Direct methods used in determining shelf life of a product involve storing the product under pre-selected conditions for a period of time longer than the expected shelf life and checking the product at regular intervals to see when it begins to spoil. The experimental determination of shelf-life using direct method can require a considerable amount of experimentation, with consequent costs and demands on time. When the actual storage time is long, shelf-life studies are based on accelerated shelf life testing (ASLT). This technique shortens the process of obtaining the experimental data (Kebede *et al*., 2015; Mizrahi, 2000).With accelerated shelf life testing the trial period is shortened by deliberately increasing the rate of deterioration (Martins and Silva, 2004). This is usually done by increasing the storage temperature. The results are then used to estimate the shelf life under normal storage conditions (Yang *et al.*, 2013).

Accelerated shelf-life testing (ASLT) methods have been used to predict shelf-life at normal conditions (Rao *et al.*, 2012) based on data collected at high temperature or high humidity conditions (Achour *et al.*, 2001). The data from higher testing temperatures in food quality loss are used to determine shelf-life at regular storage conditions through the use of Arrhenius or Linear equations (Gulla and Waghray, 2012). Food products are conditioned and stored at elevated temperature and/or humidity and the quality changes of the product are evaluated at a specific sampling rate (Achour *et al.*, 2001). ASL study could significantly shorten the duration of shelf life study to half or quarter of the direct method (Cardelli and Labuza, 2001).One of the principal methods of predicting the shelf life of processed food products is to monitor the level of lipid degradation in fat containing foods stored at elevated temperatures. Much of the science of accelerated shelf life estimation has involved lipid degradation reaction rates (Corradini and Peleg, 2007).

The quantitative approach to shelf life prediction requires that the deteriorative mechanisms limiting shelf life of the specific food be identified and that the index of deteriorative reaction be measured as a function of time. Since the chemical reactions in food can be very complex it is usually easier to examine a reaction from purely mathematical or semi empirical approach based on chemical laws rather than on a mechanistic approach in which each step must be known (Labuza and Kamman, 1983).

The loss of quality for most foods can be presented by a mathematical equation of the following form: $\pm \frac{dA}{d\theta} = KA^n$(Labuza, 1982)

Where: A = the quality factor measured

θ = time

k = a constant which depends on temperature and water activity

n = a power factor called order of the reaction which defines whether the rate is dependent on the rate is dependent.

$\pm \frac{dA}{d\theta}$ = the rate of change of time. A negative sign is used if the deterioration is loss of A and positive if it is for production of undesirable products

For quality a change in foods, the reaction order has generally been shown to be either 0 or 1 depending on the reaction involved (Labuza, 1982; Pope, 1980). If n = 0 the reaction is said to be zero order with respect to A. This means that the rate of loss of A is constant and independent of the concentration of A. zero order reaction is mainly applicable to non enzymatic browning in dried foods and lipid oxidation in dried foods and snacks (Labuza, 1982). When n = 1 the reaction is first order whereas the loss of quality is dependent on the amount of A left. The deterioration which falls in first order reaction includes vitamin and protein loss in dried foods and vegetable rancidity in dried foods (Labuza, 1982). In some studies reactions were described by nonlinear equations such as polynomial equations (Smoot and Nagy, 1980).

The principle factor affecting the kinetics of reactions in processed and dried foods is temperature. Increases in temperature are known to accelerate deteriorative reactions in food and thus reduce shelf life of food. Temperature is assumed to follow the Arrhenius equation (Labuza, 1982)

$$K = k_o \exp^{(Ea/RT)}$$

Where

K= rate constant

K_o= pre exponential constant

E_a = Activation Energy

R = Gas constant

T = Absolute temperature

Arrhenius equation is the best approach in modeling temperature dependence (Saguy and Karel, 1980). The Arrhenius model unlike other models of temperature dependence has a thermodynamic basis (Labuza and Kamman, 1983). The activation energy is generally derived from the slope of a plot of natural logarithm of rate of constant (k) versus the inverse of absolute temperature and depends on compositional factors such as water activity, moisture content and solid concentration. When the reaction mechanism changes with temperature the activation energy may vary substantially.

Large statistical errors are commonly associated with the calculations of the temperature dependence of the reactions. Some studies have suggested methods of analyzing kinetic data which provide statistically more reliable results (Cohen and Saguy, 1985). Arrhenius plot can also be used to establish shelf life plots of specific products based on a known end point quality deterioration value (Labuza and Kamman, 1983). There could be many limitations besides statistical errors in using the Arrhenius and shelf life plots to predict shelf life at lower temperature. Generally the problem occurs because some reactions which predominate at higher temperature do not pre dominate at lower temperature (Labuza and Riboh, 1982).

2.6 Consumer acceptability testing

Sensory evaluation is a scientific discipline that analyses and measures human responses to the composition of food and drink, e.g. appearance, touch, odour, texture, temperature and taste (Lawless and Heymann, 2010). Human senses have been used for centuries to evaluate foods. When we eat, we always form judgments to the food we eat or drink (Kelly *et al*., 2009). There are two main types of consumer acceptability testing of foods. The first is the difference testing whereby attempting to answer whether any perceptible difference exists between two types of foods (Adinsi *et al*., 2014). The second type is those quantify the perceive intensities of the sensory characteristics of a food product. This is known as descriptive sensory which is performed by using trained judges (Murray *et al.,* 2001).

Training improves an individual's sensitivity and memory to provide precise, consistent, and standardized sensory measurements that can be reproduced (Meenakshi *et al.,* 2010). For panelists to make objective decisions, they must be trained to disregard their personal preferences. Training involves the development of a vocabulary of descriptive terms. Each panelist must detect, recognize, and agree upon the exact suggestion of each descriptive term. The use of specially prepared reference standards or competitor's products is allowed. This can demonstrate variation in specific descriptive terms and help panelists during training to be more consistent in their judgments (Gámbaro, 2012). Argue the evaluation techniques for odor, appearance, flavor, and texture and agree upon a common procedure. Panelists must also become familiar with the test method. Training time (from weeks to months) is a function of the product, the test procedure, and the capability of the panelists.

Research had been done to evaluate sensory properties and consumer acceptance of different coloured sweet potatoes in Tanzania, the survey results showed that high starch, good taste, cooking quality and flesh colour were major drivers in consumer acceptance of sweet potatoes cultivars (Tomlins *et al*. 2004).

3. RESEARCH MANUSCRIPTS

3.1 Development and assessment of nutritional quality, sensory properties and consumer acceptability of Orange Fleshed Sweet Potato and Bambara groundnut-based snacks for school children

Abstract

Development of Orange Fleshed Sweet Potato (OFSP) and Bambara groundnut snacks is important to alleviate under-nutrition among primary school children through food-based approach which is believed to be sustainable. The objective of this research was to develop nutritious snacks from OFSP and Bambara groundnut, and evaluate the effect of extrusion cooking on proximate composition, sensory characteristics and consumer acceptability of the snacks. Six formulations of OFSP + Bambara groundnut (with OFSP and Bambara groundnut ranging from 0 – 100%) were prepared and extruded (feeding rate of 10.15 kg/hr, screw speed of 30 rpm and barrel temperature: 100 $^{\circ}$C and 130 $^{\circ}$C in first and second zones respectively). Proximate analysis was done according to AOAC methods, minerals were analyzed using Atomic Absorption Spectrophotometry and pro-vitamin A was analysed using U.V visible spectrophotometer. There were significant differences ($p<0.05$) in proximate composition, mineral content and Pro-vitamin A content between the different developed snacks. Increase in concentration of Bambara groundnut in the formulation resulted in reduction of carbohydrate and pro-vitamin A and increased in protein, fat, fibre and ash content. Protein content ranged between 4.08 ± 0.26 g/100g DM (OFSP 100%) to 15.03 ± 0.34g/100g DM (Bambara groundnut100%). Pro-vitamin A ranged from 0.54 ± 0.05 mg/100g DM (Bambara groundnut 100%) to 17.33 ± 0.48mg/100g DM (OFSP 100%). Substituting of OFSP by Bambara groundnut in the formulation brought an increase in magnesium, phosphorous, potassium and iron and decreased in calcium and sodium. OFSP based snacks had higher mean acceptability scores (6.62 – 7.0) than 100% Bambara groundnut based snack (5.88). The colour hue (orange) and sweetness were drivers for consumer liking of snacks contains OFSP. Generally the study showed that development of OFSP substituted with Bambara groundnut up to 40% enhances nutritional quality of the snacks, retains sensory properties and yields acceptable snacks.

Key words: Orange Fleshed Sweet Potato; Bambara groundnut; Extrusion; school children; Under-nutrition; Quantitative Descriptive Analysis.

3.1.1 Introduction

Under-nutrition associated with inadequate energy intakes and micronutrient deficiencies of iron and vitamin A are becoming a serious problem for school children in many developing countries (Manna *et al*., 2011; Mosha *et al*., 2010). According to FAO (2007), school children in Tanzania perform poorly in schools. The poor performance is associated with high dropout rates and is partly due to malnutrition and health related problems. It estimated that, 22% of school age children in Tanzania are stunted owing to chronic inadequate intake of energy and other nutrients (UNICEF, 2003). These nutritional problems adversely affect school children's attendance, scholastic performance and concentration in class (UNICEF, 2003). About one-third of children in Tanzania are deficient in iron and vitamin A, which are required in small amounts but are crucial to children's health and development (TFNC, 2012). Under-nutrition among school children in Tanzania is contributed by poverty, food insecurity and lack of school feeding programme which expose them to short-term hunger (WFP, 2009).

Micronutrient supplements are commonly used to alleviate malnutrition but the approach is not sustainable because of inaccessibility in the rural areas. Food-based approaches are one part of a strategy for reducing under-nutrition in Tanzania (Temu *et al*., 2014; Helen Keller International, 2012). Increasing consumption of key micronutrients (vitamin A and Iron) food sources is a sustainable approach to alleviate under-nutrition (Bengtsson *et al.,* 2009). Therefore intensive utilization of locally available crops as sources of energy, protein, vitamin and minerals will help in fighting under-nutrition among school children.

The use of Orange Fleshed Sweet Potato (OFSP) as a source of energy and means of fighting vitamin A deficiency in Tanzania and other African countries has been of significance (Waized *et al*., 2015). However, in some cases the high preference for local varieties of sweet potato has resulted in underutilization of OFSP (Temu *et al*., 2014). Incorporation Bambara groundnut which is the good source of carbohydrate, protein, minerals and fats (Bamshaiye *et al.,* 2011) can be used to alleviate under-nutrition among school children because it is readily available and affordable. Therefore, the development of Ready-to-Eat (RTE) extruded snack products using a combination of OFSP and Bambara groundnut could serve as a means of alleviating short-term hunger and micronutrient deficiencies among the school children.

Snack foods have become an integral part of the eating habits of the majority of the world's population including children (Dehghan-Shoar *et al*., 2010). In most developing countries, snacks production is a home art which results in the products differing significantly in terms of nutritional composition, microbiological safety and sensory attributes from one community to another (James and Nwabueze, 2013). Extrusion cooking can be adopted at industrial level to develop and produce snacks of consistent quality. Extrusion has been used to develop products from a wide range of raw materials including cereal flour, starch granules, tubers and legumes. Some of the products developed include semi-cooked or completely cooked breakfast cereals, snacks, flakes and quick cooking pasta (Leszek, 2011; Nwabueze, *et al*., 2008; Iwe, 2001). The objective of this research was to develop an acceptable and nutritious snack from OFSP and Bambara groundnut. The study evaluated the effect of varying the ingredient formulation on the nutritional quality, sensory characteristics and consumer acceptability of the formulated snacks.

3.1.2 Material and Methods

Study area

This study was conducted at the Department of Food Science and Technology, Sokoine University of Agriculture (SUA), Tanzania. Solar drying of OFSP was done at Danida pilot project premises, SUA. Product development (formulation and extrusion) and Laboratory analyses were done at the Department of Food Science and Technology, Sokoine University of Agriculture (SUA).

Materials

Jewel variety of Orange-fleshed sweet potato was purchased from the Ukiliguru Agricultural Research Institute, Mwanza. Bambara groundnuts, ingredients and materials for sensory evaluation were purchased from markets and supermarkets in Morogoro, Tanzania. Analytical grade chemicals and reagents for chemical analysis were purchased from suppliers in Morogoro and Nairobi.

Methods

Research design

A Completely Randomized Design (CRD) was used in this study and the treatment was the different formulations. The effect of this factor on proximate composition, mineral contents, Pro-vitamin A, sensory quality and consumer acceptability were determined.

Product development

Preparation of OFSP and Bambara groundnut flours

Orange Fleshed Sweet Potato tubers were washed with clean water to remove soil and dirt and then peeled using a kitchen knife. The tubers were then chipped to approximately 0.2-0.4 cm width, 2-5cm length and 0.1-0.3 cm thick using a chipping machine (Model CH, Intermech Engineering, Morogoro) and dried in a walk-in solar drier for 24 hours. The dried chips were milled into flour using commercial hammer mill(Model CH, Intermech Engineering, Morogoro) having mesh screen of 0.8 mm. Bambara groundnuts were sorted, washed, sun dried and milled.

Preparation of composite flours

The experimental composite flour was formulated using a substitution method (Table 3.1).

Table 3.1: Formulation of orange fleshed sweet potato (OFSP) and Bambara groundnut (BN) composite flours for extruded snack production

Formulation	% of ingredient in the formulation	
	OFSP	Bambara groundnut
OFSP_ (0%)	100	0
OFSP_1 (20%)	80	20
OFSP_2 (40%)	60	40
OFSP_3 (60%)	40	60
OFSP_4 (80%)	20	80
BN_(100)	0	100

Extrusion of the formulations

The formulated composite flour was pre-prepared by adding 3g sugar, 2 g salt and 3 g cooking oil for every 100 g of composite. Moisture content was adjusted to 14% by adding distilled water and left for four hours at room temperature to attain moisture content equilibrium state (Oluwole *et al*., 2013; Hazarika *et al*., 2013). The formulated composite flour was extruded using co-rotating twin screw extruder with L/D ratio of 16:1 and screw diameter of 60 mm, model Js-60D, China. The extruder conditions were: feeding rate of 10.15 kg/hr, screw speed of 30 rpm and barrel temperature was set at 100°C and 130°C in first and second zones respectively. After extrusion the samples were collected, cooled to room temperature under natural convection conditions, sealed in polyethylene bags and stored at -18 °C prior to analysis.

Chemical Analyses

Proximate Analysis

Moisture content was determined according to standard oven drying method (AOAC, 1995:930.15).Crude protein was determined according to the AOAC (1985;920.87method), using block digestion and steam distillation (Kjeltec ™ 8200 Auto distillation unit 2012). The fat content was determined by solvent extraction method as described in standard method (AOAC, 1995; 920.85) using Soxtec™ 2055. The ash content was determined by heating a sample in a muffle furnace as described in standard method (AOAC, 1995; 923.03). Crude fibre was determined using dilute acid and alkali hydrolysis as described by AOAC (1995; 920.86) using Fibertec 2010.The carbohydrate content was determined by a difference standard method according to AOAC, 1995.

Determination of Mineral Content

The analysis of minerals was done according to the AOAC (1995) procedures. The mineral content was determined by the use of Unicam 919 Atomic Absorption Spectrophotometer (AAS). Test portions were dried and then ashed at 450°C under a gradual increase (about 50 °C/hr) in temperature.

Determination of beta carotene

Pro-vitamin A was determined using the method described by Rodriguez-Amaya and Kimura (2004). About 2-3 g of sweet potato flour was weighed, transferred into a motor and about 1.5g of celite was added. The mixture was grounded with 50 ml of acetone (acetone refrigerated at 4^0 C for 2 hours prior to use) being added slowly then filtered using cotton wool plugged into the fume. The extraction was repeated until the sample from the mortar was devoid of colour. About 40 ml of petroleum ether was put in a separating funnel (250 – 500 ml capacity) and acetone was added. Distilled water was added slowly along the neck without shaking to avoid emulsion formation. The two phases were then left to separate and the lower aqueous layer discarded, the sample was washed 3-4 times with distilled water (approx 200 ml) each time to remove residual acetone, in the last phase washing was done ensuring no any amount of the upper phase was discarded. Then the upper layer was collected into 50 ml flask using anhydrous sodium sulphate filter arrangement to remove residual water and the absorbance was determined by using a spectrophotometer (Rodriguez-Amaya, 2001).The absorbance was determined at a wavelength of 450 nm and beta carotene was calculated using the equation of the standard curve (Figure 3.1).

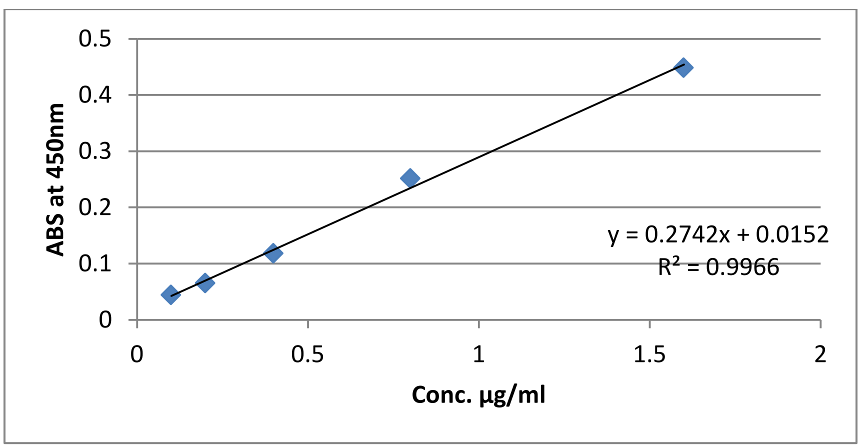

Figure 3.1: Beta-carotene standard plot

Sensory evaluation

Consumer acceptability test

The test was conducted by using 73 untrained consumers aged 20-39 years using a 9 point hedonic scale (where 1 = dislike extremely and 9 = like extremely) as described by Lawless and Heyman (2010). This was done because it has been reported that, difference testing and descriptive analysis are best left to adults who have similar perceptions to those of children, and yet greater cognitive abilities, as required to carry out difference testing, scaling and descriptive analysis (Guinard, 2001). The samples were coded with 3-digit random numbers using statistical random tables and served to the panelists in a randomized order. Distilled water was provided for rinsing the palate. The panelists were instructed to indicate their degree of liking or disliking of different snack samples. The use of adults to taste the product intended for children is due to the fact that

difference testing and descriptive analysis are best left to adults who have similar perceptions to those of children, and yet greater cognitive abilities, as required to carry out difference testing, scaling and descriptive analysis (Guinard, 2001)

Quantitative Descriptive Analysis (QDA)

QDA is a useful and highly informative class of sensory tests. It answers the question of what is the nature and magnitude of different between tested samples. It was used because the study tried to identify the needed attributes for the product acceptance. Descriptive sensory profiling was conducted at the Department of Food science and Technology using a trained sensory panel of 10 assessors, comprising of 7 male and 3 female aged 22 - 27 years according to method described in Lawless and Heyman (2010). The assessors were selected and trained according to ISO Standard (1993). In a pre-testing session the assessors were trained in developing sensory descriptors and the definition of the sensory attributes. The assessors developed a test vocabulary describing differences between samples and they agreed upon to a total number of attributes on whiteness, colour hue, sweetness, hardness, saltiness, crispiness and oiliness. An unstructured line scale was used for rating the intensity of each attribute. The left side of the scale corresponded to the lowest intensity of each attribute (value1) and the right side corresponded to the highest intensity (value 9). The samples were coded with 3-digit random numbers and served to each panelist in a randomized order. Panelists were requested to rate the identified attributes using the scales developed during training. Water was provided for rinsing the palate. The average responses were used in the univariate and multivariate analyses.

Table 3.2: Attributes, definitions and anchors used in descriptive sensory panel training

Attribute		Definition	Anchors
Colour	Colour hue	Orange: anything associated with orange colour.	Low to high
	Whiteness	Degree of whiteness	Low to high
	Color intensity	Clear, strong colour	Low to high
Oiliness	Oiliness	The presence of visible oil	Low to high
Taste	Sweetness	The taste associated with sucrose solution	Low to high
	Saltiness	The test associated with table salt	Low to high
Texture	Hardness	The force required to bite through the sample	Low to high
	Crispiness	Cracks, you can force your teeth through the sample slowly, more light than crackling	Low to high

Source: Research Panel

Statistical data analysis

Data obtained were analysed by using the R statistical package (R Development Core Team, Version 3.0.0 Vienna, Austria). Analysis of variance (Anova) was used to determine the significant differences between the main factors. Means were separated using Tukeys Honest Significant difference ($\alpha = 0.05$). Principal component analysis (PCA) was used to determine the systematic variations in sensory data. Data were presented in tabular and graphical forms.

3.1.3 Results and Discussion

3.1.3.1 Nutritional quality of formulated OFSP and Bambara groundnut-based snacks

Proximate composition

Ingredient concentration had a significant ($p<0.05$) effect on the proximate composition of the formulated snacks. Increasing the concentration of Bambara groundnut in the formulations resulted in reduction of moisture, carbohydrate and pro-vitamin A and increase in protein, fat, fibre and ash content (Table 3.3).

Table 3.3: Effect of ingredient concentrations on the proximate composition of orange fleshed sweet potato (OFSP) and Bambara groundnut extruded snacks

Product	Proximate composition (g/100g DM)							
	Moisture	Protein	Fat	Fibre	Ash	CHO	Energy (kcal)	Vitamin A µg RE/100gDM
OFSP_ (0%)	8.34±0.50^{d}	4.08±0.26^{a}	4.20±0.092^{a}	5.29±0.03^{ab}	0.09±0.02^{a}	78.00±0.67^{f}	366.13±2.43^{a}	1365±0.48^{e}
OFSP_1 (20%)	5.16±0.20^{a}	6.94±0.09^{b}	5.91±0.04^{b}	5.42±0.09^{a}	2.31±0.31^{b}	72.35±0.56^{e}	368.63±0.23^{a}	929±0.20^{d}
OFSP_2 (40%)	6.60±0.29^{bc}	8.06±0.09^{c}	7.48±0.09^{c}	5.81±0.17^{b}	4.51±0.13^{b}	67.53±0.77^{d}	369.71±1.90^{a}	724±0.09^{c}
OFSP_3 (60%)	6.72±0.12^{c}	9.58±0.39^{d}	8.42±0.13^{d}	6.75±0.06^{c}	4.66±0.04^{b}	63.87±0.61^{c}	370.37±2.23^{a}	321±0.19^{b}
OFSP_4 (80%)	4.74±0.38^{a}	12.93±0.31^{e}	9.91±0.12^{e}	6.45±0.00^{c}	4.48±0.06^{b}	61.50±0.10^{b}	386.90±1.90^{b}	300.5±0.23^{b}
BN_(100)	5.43±0.24^{ab}	15.03±0.34^{f}	12.74±0.02^{f}	6.46±0.31^{c}	4.80±0.26^{b}	55.53±0.15^{a}	396.94±0.90^{c}	42.5±0.05^{a}

Values are means ± standard deviations (n = 2). Mean values with different superscript letter along the column are significantly different (p<0.05).

The moisture content of the samples ranged between 4.74-8.34 g/100 g DM which is the level recommend for preventing the growth of moulds in extruded products (Guy, 2001). This goes together with the range reported by Hazarika *et al*. (2013) (5.0-9.84%) when rice flour 85%+sweet potato15% was extruded into Ready-To-Eat (RTE) snacks. The ash content increased as the amount of Bambara groundnut increased in the formulation since Bambara groundnut is a good source of minerals (Amarteifio *et al*., 2006).

There was a significant increase in the crude protein of the samples (P < 0.05) due to replacement of OFSP flour with Bambara groundnut flour in the formulations as Bambara groundnut is a good source of protein (Okonkwo and Opara, 2010; Okpuzor *et al*., 2010). Bambara groundnut is rich in protein, having four times as protein as OFSP. Protein content of the snacks ranged between 4.08 - 15.03 g/100 g DM. The snacks can supply 12 - 44.2% of the recommended dietary intake of protein for 9 – 13years upon consuming 100 g of snacks (Table 3.4)

Table 3.4: Percentage contribution of the formulated snacks to the recommended dietary intake (RDI) of children aged 9-13

Product	Percentage of RDI met by 100 g of the formulated snack				
	Protein	**Fiber**	**Energy**	**Carbohydrate**	**Vitamin A**
OFSP_ (0%)	12	20.3	22.9	60	227
OFSP_1 (20%)	20.4	20.8	23.1	55.7	155
OFSP_2 (40%)	23.7	22.3	23.1	51.9	121
OFSP_3 (60%)	28.2	23.8	23.1	47.3	54
OFSP_4 (80%)	38	24.8	24.2	42.7	50
BN_(100)	44.2	26.0	24.8	41.1	7

Note: For computation of percentage contribution, RDI of children aged 9-13 years was based on Dietary Reference Intakes series, Institute of Medicine (2002).

Fibre is important in the diet for enhancing bowel movement, preventing overweight and constipation and reducing the risk of colon cancer (Ayinde *et al*., 2012; Anderson *et al.*, 2009). The crude fibre content increased as amount of Bambara groundnut increased in the formulation. This is because Bambara groundnut is a good source of fiber (Bamshaiye *et al*., 2011). Fiber content ranged from 5.29 g/100 g DM in OFSP_ (0%) to 6.75 g/100 g DM in OFSP_ (60%). The ideal RDI of fibre is 25–31 g for school age children aged 4–13 years. Consumption of 100 g of snacks per day would provide about 20 - 24% of the recommended daily intake for fibre.

Carbohydrate content of snacks decreased as amount of Bambara groundnut increased in the formulation. It ranged between 55.5 – 78 g/100 g and can meet RDI range of 43-60% of 9-13 years consuming 100 g of snacks. The amount of energy for all formulations ranged between (316.96-366.19) kCal/100 g which indicates that consumption of the snacks can contribute significant amount of energy. For a child aged 9-13 years consuming 100 g of snacks can be able to achieve 22.9-24.8% of RDI for energy.

Vitamin A contents of the formulated snacks showed a significantly different at ($p<0.05$). The highest amount of vitamin A was observed in product OFSP _ (0%) which was (1365±0.48µg RE/100gDM) while the lowest amount was 42.5±0.05 µg RE/100gDM in BN_ (100%). Consumption of 100 g of snacks can contribute to 7-227% of RDI for the age group. This indicated that most of the snacks were good source of vitamin A.

Therefore, according to Reference Dietary Intakes for energy, carbohydrate, fiber, fat and protein (2002/2005) report for 7-13years, the products can contribute a significantly amount of macro elements as shown (Table 3.3).

Mineral content

Minerals content of the formulated snacks were significantly different ($p<0.05$). The results showed that increased amount of Bambara groundnut in the formulation resulted in increase in magnesium, phosphorus, potassium and iron and decrease in calcium and sodium (Table 3.5).

Table 3.5: Effect of ingredient concentrations on the mineral content of orange fleshed sweet potato (OFSP) and Bambara groundnut extruded snacks

Product	Mineral contents (mg/100g DM)					
	Ca	Mg	P	K	Fe	Na
OFSP_ (0%)	$73.01±0.35^{b}$	$71.12±0.21^{a}$	$215.96±0.09^{a}$	$649.89±0.32^{a}$	$5.26±0.09^{a}$	$453.08±0.17^{f}$
OFSP_1 (20%)	$71.70±0.44^{b}$	$82.22±0.13^{b}$	$220.61±0.62^{b}$	$838.03±0.42^{b}$	$5.99±0.10^{d}$	$429.98±0.32^{e}$
OFSP_2 (40%)	$71.63±0.30^{b}$	$102.16±0.26^{c}$	$262.05±0.37^{c}$	$846.32±0.49^{c}$	$6.07±0.67^{ab}$	$364.24±0.44^{d}$
OFSP_3 (60%)	$67.03±0.44^{a}$	$106.15±3.38^{d}$	$285.98±0.68^{d}$	$867.18±0.42^{d}$	$6.62±0.19^{b}$	$323.84±0.41^{c}$
OFSP_4 (80%)	$66.09±0.65^{a}$	$119.79±0.61^{e}$	$302.84±0.41^{e}$	$1007.31±0.45^{e}$	$7.06±0.20^{b}$	$310.93±0.38^{b}$
BN_(100%)	$65.70±0.54^{a}$	$121.09±0.31^{f}$	$311.00±0.38^{f}$	$1015.95±0.99^{f}$	$8.66±0.13^{c}$	$201.16±0.61^{a}$

Values are means ± standard deviations (n = 2). Mean values with different superscript letter along the column are significantly different ($p<0.05$).

For sodium, the concentration ranged from 65.7mg/100g in the OFSP_1 (20%) to 73mg/100g in OFSP_2 (40%). Sodium concentration of 1200 - 1500 mg has been recommended per day as adequate for primary school age children (6–13years) by (FNB-IOM, 2003). The concentration of sodium in the snacks can provide 5.1-5.6% of RDI.

Table 3.6: Percentage contribution of the formulated snacks to the recommended dietary intake (RDI) for minerals of children aged 9-13 years

Product	Percentage of RDI met by 100 g of the formulated snack					
	Ca	**Mg**	**P**	**K**	**Fe**	**Na**
OFSP_ (0%)	5.6	29.6	17.3	14.4	65.6	30.2
OFSP_1 (20%)	5.5	34.3	17.6	18.6	74.9	28.7
OFSP_2 (40%)	5.4	44.2	21.0	18.8	75.9	24.3
OFSP_3 (60%)	5.3	44.4	22.9	19.3	82.8	21.6
OFSP_4 (80%)	5.2	49.9	24.2	22.4	88.3	20.7
BN_ (100%)	5.1	50.5	24.9	22.6	108.3	13.4

Iron concentrations differed significantly ($p<0.05$) among the snacks. The concentration of iron in the snacks ranged from 5.26 mg/100 g to 8.66 mg/100 g. According to the FNB-IOM (2003), the recommended daily intake of iron for primary school children is 8 – 10 mg. The snacks can provide 65.6-108 % of RDI for iron for primary school children upon consuming 100 g. Recommended small serving of snacks for iron is 70g which can contribute around 50% of RDI of primary school children age group.

For magnesium which ranged between (71.12-121.09) mg/100 g DM and the RDI for school children is (130-240) mg. This implies that upon consuming 100 g can supply a range of 26.9-50.2 %RDI for 9-13 years. Generally the formulated snacks can meet the RDI for selected minerals (calcium, magnesium, phosphorous, potassium, iron and sodium) in different amount which are key elements during children development.

3.1.3.2 Descriptive sensory profiling and consumer acceptability of the developed snacks

Consumer characteristics

The general characteristics of the panel are summarized in table 3.7.

Table 3.7: Characteristics of the consumer acceptability panel (N=73)

Characteristic	Category	Frequency	Percent
Gender	Male	45	61.64
	Female	28	38.36
	Total	**73**	**100**
Age group	20-29	71	97.26
	30-39	2	2.74
	Total	**73**	**100**
Education level	Bachelor degree	66	90.41
	Diploma	07	9.59
	Total	**73**	**100**

Mean acceptability scores of the snacks

Mean hedonic scores for the formulated snacks were significantly different ($p<0.05$). Overall acceptability of the snacks ranged between 5.88–7.0 as shown (Table 3.8).

Table 3.8: Acceptability scores for formulated snacks

Product	**Acceptability scores**				
Formulation	Aroma	Color	Taste	Texture	Overall accept.
OFSP_ (0%)	6.67 ± 1.44^{b}	7.29 ± 1.35^{c}	7.08 ± 1.44^{c}	6.68 ± 1.73^{c}	7.0 ± 1.39^{c}
OFSP_1 (20%)	$6.1\pm 9\ 1.24^{ab}$	6.71 ± 31^{bc}	6.45 ± 1.47^{ab}	$6.55\ 1\pm.50^{c}$	6.62 ± 1.39^{bc}
OFSP_2 (40%)	6.61 ± 1.23^{b}	7.16 ± 1.39^{c}	6.69 ± 1.40^{bc}	6.33 ± 1.75^{bc}	6.66 ± 1.44^{bc}
OFSP_3 (60%)	6.45 ± 1.23^{b}	6.51 ± 1.44^{b}	6.36 ± 1.51^{ab}	5.82 ± 1.62^{ab}	6.38 ± 1.24^{ab}
OFSP_4 (80%)	6.34 ± 1.33^{b}	$7.01\pm1.45b^{c}$	6.51 ± 1.69^{ac}	6.58 ± 1.42^{c}	6.66 ± 1.39^{bc}
BN_ (100%)	5.81 ± 1.55^{a}	5.39 ± 1.79^{a}	5.69 ± 1.78^{a}	5.66 ± 2.00^{a}	5.88 ± 1.76^{a}

Values are means ± standard deviations (n = 2). Mean values with different superscript letter along the column are significantly different ($p<0.05$).

Aroma, colour and overall acceptability scores were significant ($p<0.05$) different between the snacks. Aroma ranged between 5.81 for BN_ (100%) to 6.67 (OFSP_ (0%)). The colour ranged between 5.39 BN_ (100%) to 7.29 OFSP_ (0%) while overall acceptability ranged between 5.88 (like) to 7.0 (like moderately). Pure OFSP snacks had significantly higher acceptability score than the pure Bambara groundnut snacks. The findings showed that overall acceptability of the snacks decreases gradually as the amount of Bambara groundnut increases in the formulation. This is because as Bambara groundnut increases there is a decrease of sweetness and color hue (orange). The same applies to attributes aroma, taste and texture (Table 3.8).

Quantitative Descriptive Analysis (QDA)

Spider plot mean intensity ratings of descriptive attributes of formulated snack samples were significantly different ($p<0.05$). The snacks with lower concentrations of Bambara groundnut had higher mean intensity in colour hue and sweetness attributes compared to other snacks (Figure 3.1).

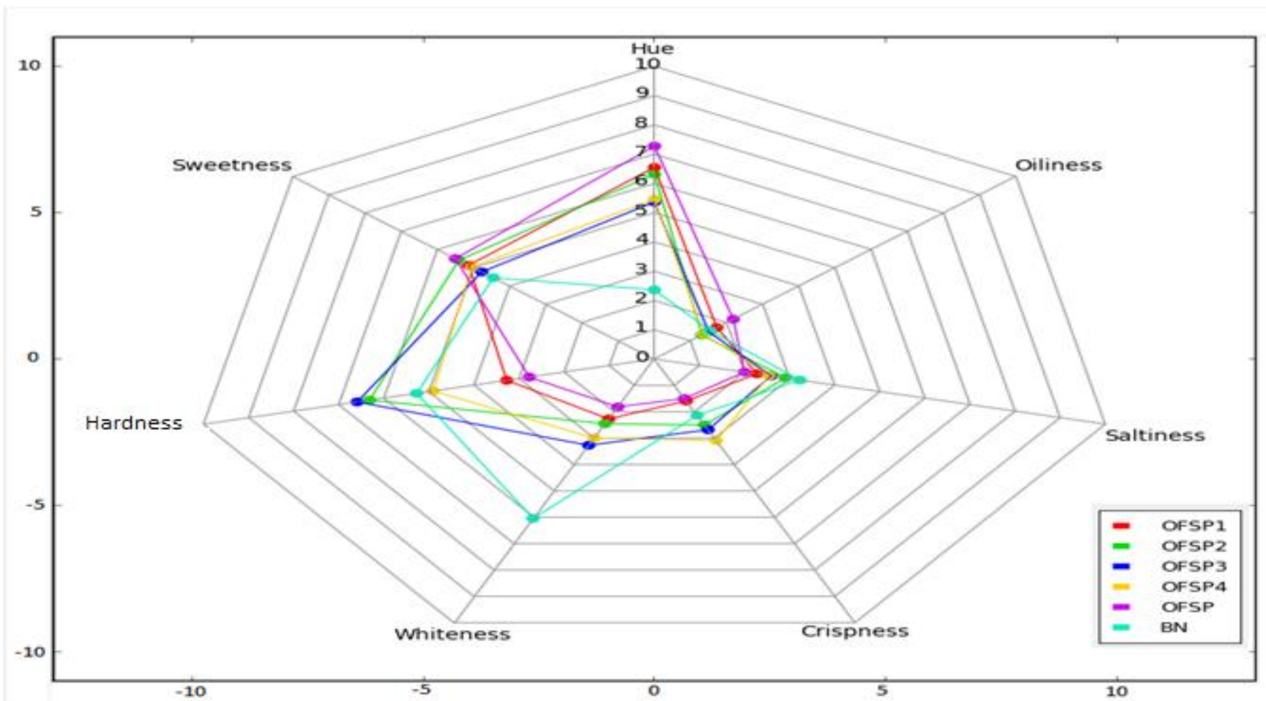

Figure 3.2: Spider plot showing mean intensity ratings of descriptive attributes of formulated snack samples. OFSP=100%OFSP; OFSP1= 80%OFSP + 20%Bambara; OFSP2=60%OFSP + 40%Bambara; OFSP3= 40%OFSP + 60%Bambara; OFSP4=20%OFSP + 80%Bambara; BN= 100%Bambara.

The high hardness score in most products could be associated with high amounts of starch. Amount and type of starch present in food material has a greater influence on the extruded final product's texture or hardness (Delcour *et al*., 2010). This is because during extrusion water penetrates the starch granules and separates the amylose and amylopectin chains from each other causing the granule to swell and soften; this is known as gelatinization (Thao and Noomhorm, 2011). On cooling the amylose and amylopectin chains slowly rebond and the granule becomes firmer and harder, this process is known as retrogradation (Wrangham and Conklin-Brittain, 2003; Weissenborn *et al*., 1994).

Principle Component of descriptive analysis of sensory data

Bi-plot with two first significant principal components from the principal component analysis (PCA) on the average sensory attributes

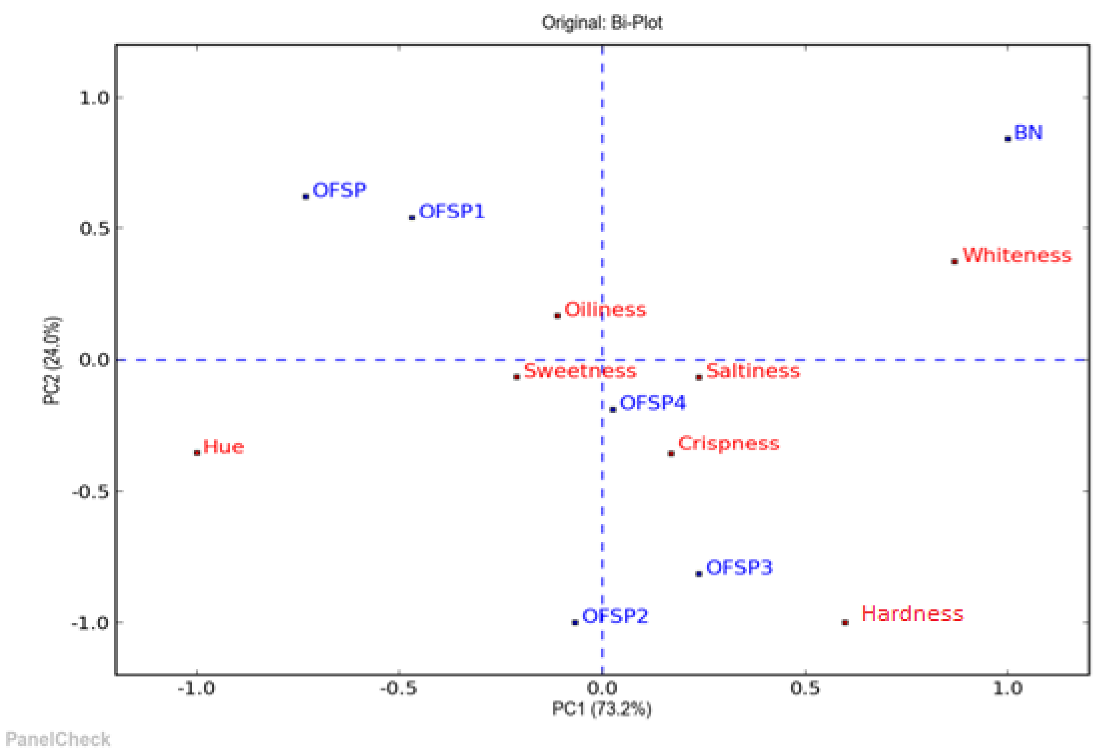

Figure 3.3: Bi-plot from PCA of descriptive sensory data for formulated snack samples

The results show that PC 1 which accounted for 73.2% of the systematic variation in the data while PC 2 accounted for 26.8% of the variation. Snacks were well separated with their corresponding attributes. Product OFSP, OFSP1 and OFSP2 correlated positively with descriptive attributes hue colour, sweetness and oiliness. Product OFSP3, OFSP4 and BN correlated positively with attributes whiteness, saltiness and hardness. Therefore, these results indicate the variation between products was explained by attribute sweetness, oiliness and colour hue on one side and attribute whiteness, saltiness, hardness and crispness on the other side along PC1. While PC2 was mainly described by variation in whiteness and oiliness with the rest attributes.

Relationship between descriptive data and hedonic liking by partial least square regression The result from a partial least square regression (PLSR) using descriptive data as X-variables and liking rated by consumers as Y-variables.The results showed that the majority of the consumers fall to the right of the vertical Y-axis which means the acceptance values of these consumer go in the direction of liking associated with sweetness and colour hue (Figure 3.3).

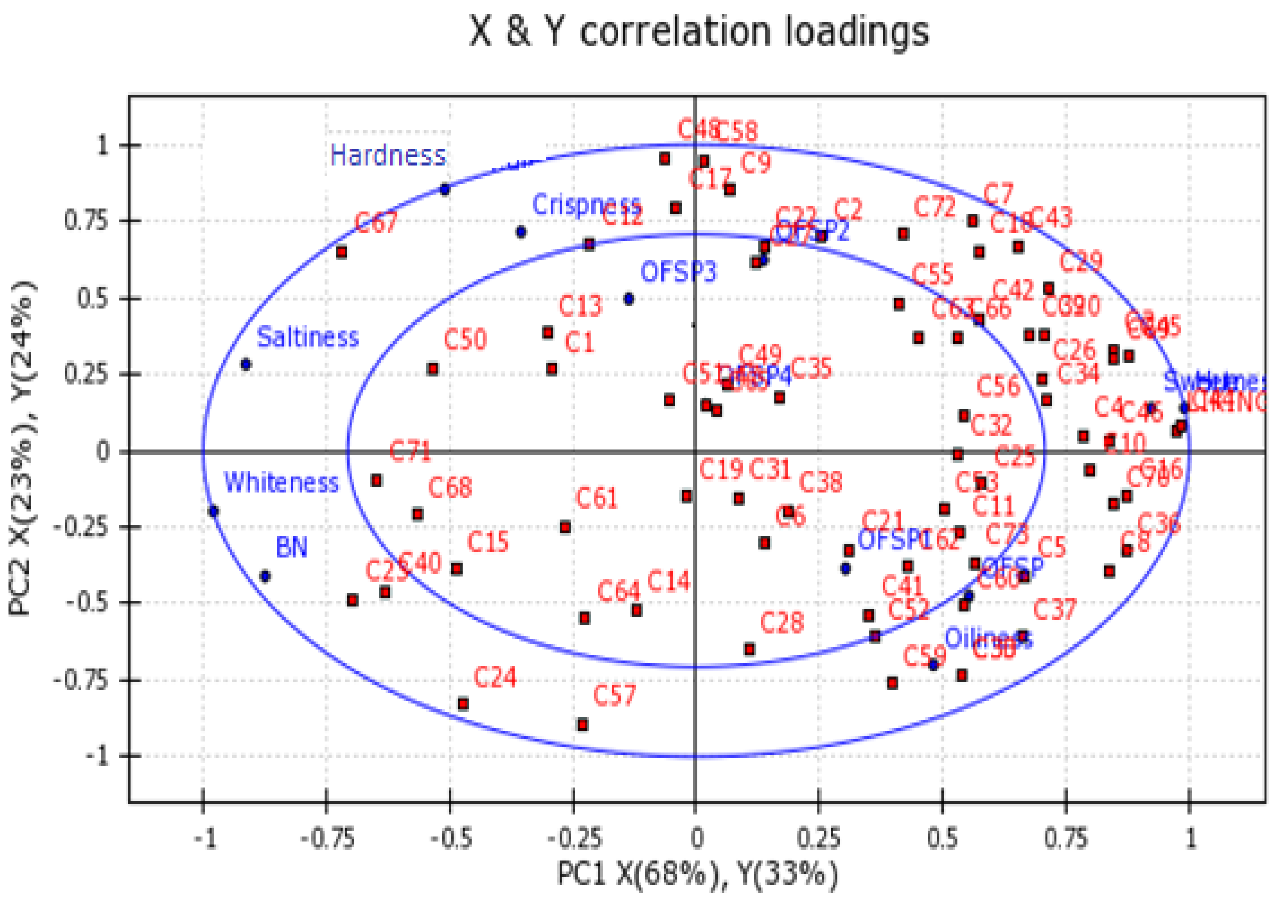

Figure 3.4: Correlation loading from partial least squares regression of formulated snack samples with descriptive data as X-variables and hedonic rating as Y variables

Also it indicated that most consumers prefered all products containing orange fleshed sweet potato than product containing 100% bambara groundnut. Therefore the color hue and sweetness attributes were the key attributes which drove the consumer to like the products. This goes in line with the statement that colour and appearance are the initial quality attributes that attract person to a food product. Thus considered them as an index of the inherent good quality of foods associated with the acceptability (Singh-Ackbarali and Maharaj, 2014). As Dehghan-Shoar *et al*. (2010) reported that acceptability depends mainly on the organoleptic properties of the snacks, which are usually measured in terms of texture, taste and colour.

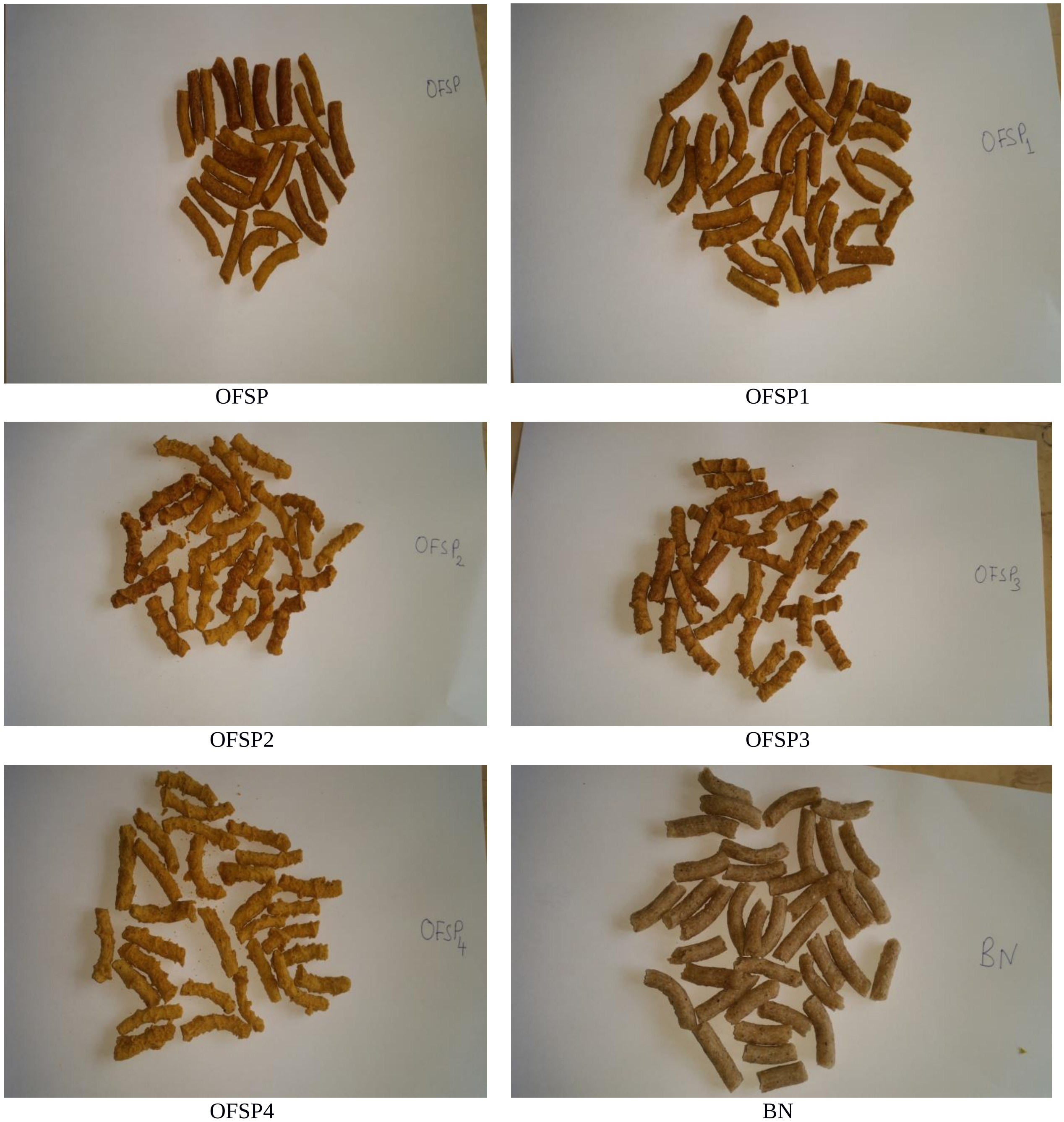

Figure 3.5: Photographs of the extruded RTE snacks from OFSP and Bambara groundnut (BN). OFSP =100%OFSP, OFSP1 = 80%OFSP + 20%Bambara, OFSP2 = 60%OFSP + 40%Bambara, OFSP3 = 40%OFSP + 60%Bambara, OFSP4 = 20%OFSP + 80%Bambara and BN = 100%Bambara.

3.1.4 Conclusion

The formulated snacks have significant amounts of nutrients required to accommodate the RDI requirements for school children. Products containing 100% OFSP had high levels of vitamin A, in addition to the good sensory attributes. These products with their high level of vitamin A and good performance in sensory assessment could therefore play a very crucial complementary role to fight against micronutrient deficiency (vitamin A) in several communities of Tanzania and other developing countries where sweet potatoes is a staple food. The varied consumer preferences provided insight in the sensory attributes that are important in individual consumer acceptability of samples. Preference mapping results showed colour and sweetness as the most important drivers of consumer liking of the formulated snacks.

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3.2 Pro-vitamin A retention and shelf life prediction of extruded Orange Fleshed Sweet Potato and Bambara groundnut-based snacks

Abstract

Evaluating the effect processing on nutrient retention and predicting the shelf life is important when developing new products. Six formulations of OFSP + Bambara groundnut (with OFSP and Bambara groundnut ranging from 0 – 100%) were prepared and extruded (feeding rate of 10.15 kg/hr, screw speed of 30 rpm and barrel temperature: 100 °C and 130 °C in first and second zones respectively). The effect of extrusion on pro-vitamin A retention and the shelf life of the extruded snacks was evaluated. Atomic Absorption Spectrophotometry was used to determine pro-vitamin A while storage of products at room temperature was used to predict the shelf life of the snacks. Peroxide values were used as an index of quality loss. Extrusion resulted in a significant loss ($p<0.05$) of pro-vitamin A (un-extruded samples: 0.90 – 20.73 mg/100g DM and extruded samples: 0.54 – 17.33 mg/100g DM). Pro-vitamin A retention in the extruded snacks ranged between 55.53 ± 0.15% (Bambara groundnut 100%) to 86.50 ± 0.67% (OFSP 80% + 20% Bambara groundnut). Shelf life predictions using room temperature data gave a shelf life ranging between 118 – 150 days. Despite the loss of pro-vitamin A during extrusion, substantial amount of up to 86.5% was retained in the extruded samples. Therefore extrusion can be used in production of relatively shelf stable and high source of pro-vitamin A snacks from OFSP and Bambara groundnuts.

Key words: Orange fleshed sweet potatoes; Bambara groundnut; Extrusion; Pro-vitamin A; Shelf life testing.

3.2.1 Introduction

The global lifestyle, which is characterized by limited free time and increased working hours, has led to an increased demand of ready-to-eat products (Filli *et al.,* 2013). Consumers want snacks that taste, smell and look good, in addition are nutritionally superior and healthy (Hazarika *et al*., 2013). Extrusion cooking technology has been employed in developing a wide range of raw materials from cereal flour, tubers and legumes into semi-cooked and ready-to-eat food products. Examples of extruded products include breakfast cereals, snacks, flakes and quick cooking pasta (James and Nwabueze, 2013; Leszek, 2011; Nwabueze, *et al.*, 2008; Iwe, 2001). Like other thermal processing methods, extrusion has effects on pro-vitamin A retention in any processed food source of pro-vitamin A (Nayak *et al*., 2011). The destruction of pro-vitamin A was reported to be low compared to conventional traditional methods since extrusion uses high temperatures and short time (Singh *et al*., 2007). The destruction of pro-vitamin A depends on the processing condition used such as moisture content, screw speed, feed rate and temperature (Singh *et al.,* 2010). High temperatures, low moisture content and low screw speeds contribute to high destruction of pro-vitamin A during extrusion cooking (Singh *et al.,* 2010). Retention also depends on other food ingredient present in the formulation, for example the amount and type of starch and protein can affect the retention of pro-vitamin A (Fonseca *et al*., 2008).

Processed foods deteriorate during storage from their first date of production. Shelf life testing of processed snacks is important in new product development procedures. Before setting the experiment for shelf life testing, one must identify the indices of quality loss of a particular product. It is important to study the deteriorative modes of the food product in order to predict their shelf lives (Villota and Hawkes, 1992). Shelf life determination of a product involves storing the product under pre-selected conditions for a period of time longer than the expected shelf life and checking the product at regular intervals to see when it begins to spoil (Cardelli and Labuza, 2001). This method requires a considerable amount of experimentation making the procedure costly and time consuming. The estimation of shelf life requires identification of the major spoilage agent or reactions and selecting of appropriate indices of spoilage.

Lipid oxidation is reported to be the major cause of spoilage in processed food products (Hornero-Méndez *et al*., 2001; Artz *et al*., 1992). The process results in production of peroxides and eventually aldehydes which affect the aroma of food (Fakhri and Qadir, 2011).The oxidation of lipids and fats in foods cause loss of fat soluble vitamins and production of flavor, palatability problems and production of toxic substances which can cause food poisoning (Shantha and Decker, 1994). One of the principal methods of predicting the shelf life of processed food products is to monitor the level of lipid degradation during products storage (Corradini and Peleg, 2007). Therefore the objective of this study was to determine the pro-vitamin A retention and the shelf life of extruded OFSP and Bambara groundnut-based snacks.

3.2.2 Materials and methods

Pro-vitamin A retention in the snacks was determined using Atomic Absorption Spectrophotometry (Rodriguez-Amaya and Kimura, 2004). The percentage retention of pro-vitamin A was calculated by considering the amount of pro-vitamin A before and after extrusion. Storage of products at room temperature was used to determine the shelf life of the different formulated snacks. Portions (5g) of each sample were packed and sealed in transparent polyethylene bags and stored at room temperature. This was done to facilitate observation of products changes. Sampling for analysis was done at 0, 14, 28, 42 and 56 days for samples stored at room temperature (Yang *et al.*, 2013). Peroxide values were measured and used as indices of quality loss during storage (AOAC, 1995: method 965.33). The peroxide values of samples stored at room temperature were plotted against time to determine at which point the critical peroxide value (10meq/ kg sample) would be obtained under conditions of fluctuating room temperature storage.

3.2.3 Results and Discussion

3.2.3.1 Pro-vitamin A retention during extrusion cooking

Extrusion significantly ($p<0.05$) reduced the pro-vitamin A content of all snack formulations (Figure 3.5) un-extruded samples having higher values of (0.90 ± 0.02 - 20.73 ± 0.67 mg/100 g) than extruded samples with values ranged from (0.54 ± 0.05 - 17.33 ± 0.48 mg/100 g). Pro-vitamin A was highest in 100% OFSP-based snacks (17.33 ± 0.48 mg/100 g) and lowest in 100% Bambara groundnut-based snacks (0.54 ± 0.05 mg/100 g). The pro-vitamin A content decreased as the proportion of OFSP in the formulation reduced.

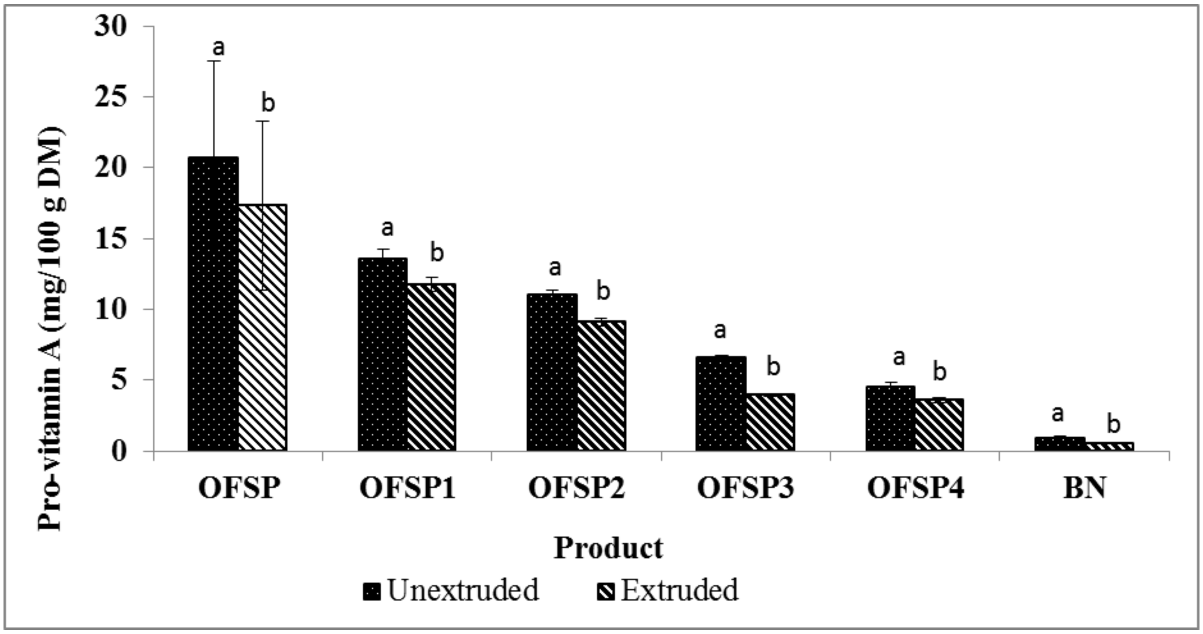

Figure 3.1: The effect of extrusion on pro-vitamin A retention in orange fleshed sweet potato (OFSP) and Bambara extruded snacks. Values are expressed as mean ± SD (n=3). Bars with different letters are significantly different at p<0.05. OFSP = 100% OFSP; OFSP1= 80% OFSP + 20% Bambara; OFSP2 = 60% OFSP + 40% Bambara; OFSP3 = 80% OFSP + 60% Bambara; OFSP4 = 20% OFSP + 80% Bambara; BN = 100% Bambara.

The percentage recoveries showed that, despite the loss, substantial amounts of pro-vitamin A (about 60 – 87%) were retained in the extruded samples (Table 3.9).The formulation of the snacks significantly affected ($p < 0.05$) the retention of pro-vitamin A (Table 3.9). Highest retention was observed in 100% OFSP-based snack and snacks containing 20 % and 40 % Bambara groundnut. Lowest retention was observed in 100% Bambara groundnut-based snack.

Table 3.9: Retention (%) of pro-vitamin A in extruded Orange fleshed sweet potato and Bambara groundnut-based snacks

Product code (% of Bambara nut in the formulation)	Pro-vitamin A retention (%)
OFSP_ (0%)	86.50±3.62^{b}
OFSP_1 (20%)	83.58±0.43^{b}
OFSP_2 (40%)	82.21±0.11^{b}
OFSP_3 (60%)	80.35±2.76^{b}
OFSP_4 (80%)	70.30±6.23^{a}
BN_ (100%)	59.56±4.60^{a}

Mean values with different superscript letter along the column are significantly different ($p < 0.05$). Temperature profile (100 °C and 130 °C for zone1 and zone 2 respectively), screw speed of 30 rpm, feed rate of 14.15 kg/h and feed moisture content of 14%). OFSP refers to Orange Fleshed Sweet Potato and BN refers to Bambara groundnut.

Extrusion resulted in loss of pro-vitamin A ranging from 13 to 40% depended on the formulation. The percentage retention was highest in pure OFSP-based snacks and lowest in Bambara groundnut-based snacks. Substituting OFSP with Bambara groundnut up to 80% did not significantly affect retention. The results for Pro-vitamin A retention of the extruded products showed that the retention was up to 86.5% on extrusion cooking (Table 3.9). Findings showed high retention was on product having 80%OFSP + 20% BN of about 86.5%. Therefore this study concluded that the effect of extrusion cooking on Pro-vitamin A was low because the method retained up to 86%. According to Riaz *et al*. (2009). Other studies reported that, there are always significant effects on pro-vitamin A during extrusion cooking and generally reducing them. This is expected because pro-vitamin A (carotenoids) are heat-sensitive and most likely are sensitive to shear and pressure as well (Beswa *et al*., 2015; Waramboi *et al*., 2013; Grela *et al* 1999).

Waramboi *et al*. (2013), revealed that extrusion cooking technology have a significant effect on pro-vitamin A retention depends on processing conditions used, extrusion at 120 °C, 40% moisture and 300 rpm screw speed retained carotenoid maximally at more than 80% of OFSP flour. Also Fonseca *et al.,* (2008), reported that retention of total carotenoids content of OFSP flour processed at 120°C, moisture content 10% and screw speed 170 rpm retained 72.15% carotenoids content.

3.2.3.2 Shelf life prediction of the formulated snack

Shelf life prediction was done using amount of peroxide value produced during storage of the snacks at fluctuating room temperature conditions. The snacks were stored at room temperature and the trend of peroxide production was as shown (Table 3.10).

Table 3.10: Peroxide value produced during two months storage at room temperature

		Peroxide value (meq/kg sample)			
		Storage days at room temperature			
Product	**0**	**14**	**28**	**42**	**56**
OFSP_ (0%)	2.54±0.01	2.69±0.39	3.81±0.17	4.53±0.34	5.90±0.22
OFSP_1 (20%)	2.45±0.35	2.58±0.28	3.70±0.01	4.29±0.16	5.45±0.22
OFSP_2 (40%)	2.63±1.48	2.65±0.23	3.75±0.03	4.15±0.17	5.48±0.08
OFSP_3 (60%)	2.85±0.12	2.97±0.5	3.84±0.33	4.57±0.23	5.90±0.09
OFSP_4 (80%)	3.09±0.36	3.55±0.19	4.09±0.06	4.62±0.16	6.31±0.21
BN_ (100%)	2.98±0.01	3.58±0.11	4.72±0.34	5.20±0.38	6.40±0.01

Values are expressed as mean±SD (n=2)

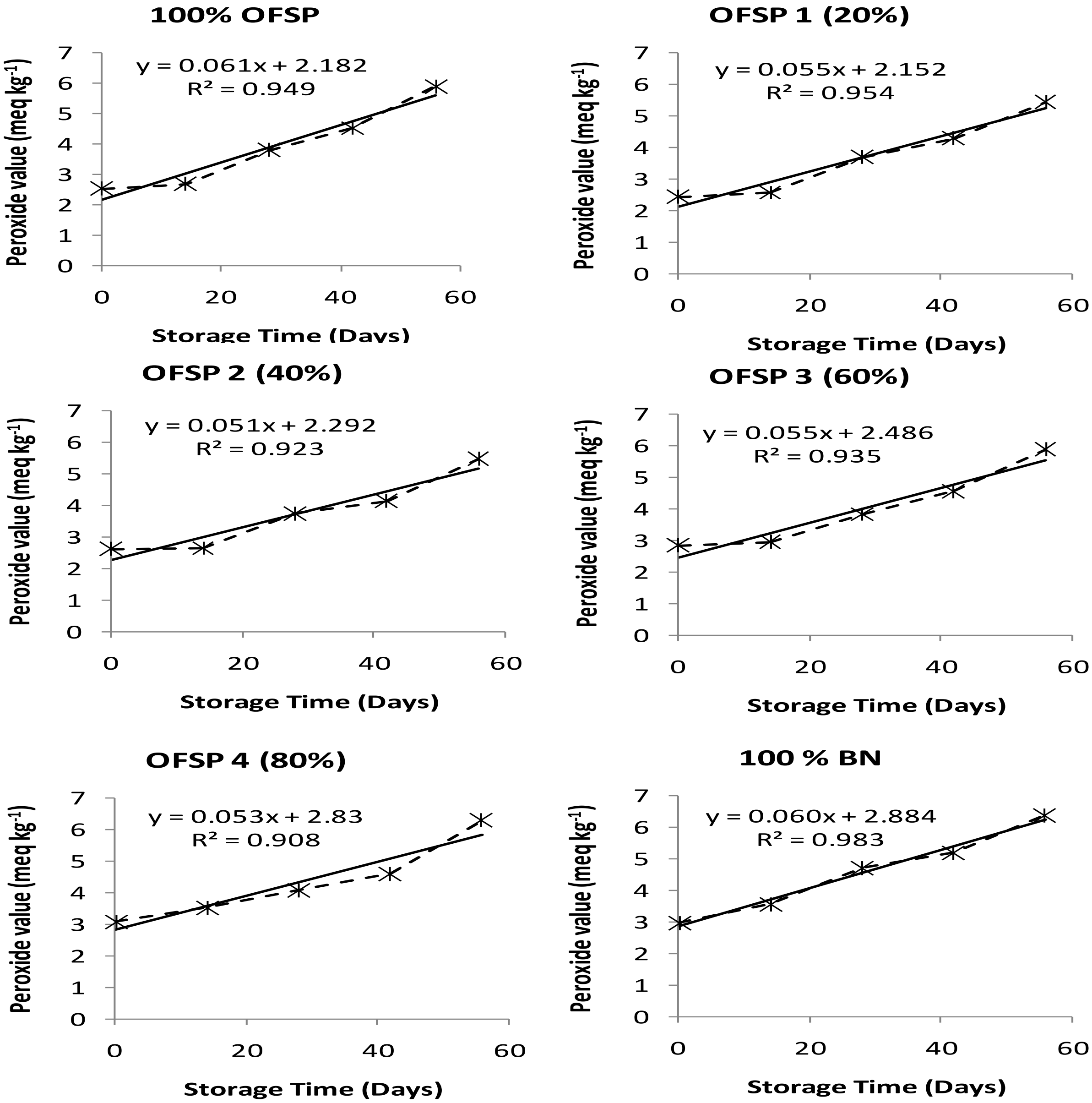

Figure 3.2: Peroxide value produced during two months storage at room temperature

Changes in peroxide values of orange fleshed sweet potatoes (OFSP) and Bambara groundnut-based extruded snacks stored at room temperature produced during two months of storage.

The values of peroxide value were OFSP: 100%(OFSP) = 5.90 ± 0.22 meq/kg sample; OFSP1 (80%OFSP + 20%BN) = 5.45 ± 0.22 meq/kg sample; OFSP 2 (60% OFSP + 40% BN) = 5.48 ± 0.08 meq/kg sample; OFSP 3 (40%OFSP + 6O%BN) = 5.90 ± 0.09 meq/kg sample; OFSP 4 (20%OFSP + 80%BN) = 6.31 ± 0.21 meq/kg sample; and BN (100% BN) = 6.40 ± 0.01 meq/kg sample.

Peroxide value did not reach 10 meq in all the formulations stored at room temperature for two months. This is because room temperature was not fixed, always was fluctuating and cannot continuously accelerate the lipid oxidation reaction within the snacks. The temperature in the laboratory varied between 26°C – 24°C at noon and 20°C – 19°C in early morning. Using equations on each product graph and the 10meq/kg sample critical amount of Peroxide value in extruded snacks, the shelf life could be estimated to be 118 - 150 days as shown (Table 3.11).

Table 3.11: Shelf life prediction using room temperature data

Products	Equation	R^2	Estimated shelf life (days)
OFSP_ (0%)	y= 0.0514x + 2.292	0.9231	150
OFSP_1 (20%)	y= 0.0551x + 2.152	0.9546	142
OFSP_2 (40%)	y= 0.055x + 2.486	0.9351	137
OFSP_3 (60%)	y= 0.0536x + 2.83	0.9085	134
OFSP_4 (80%)	y= 0.0611x + 2.182	0.9493	128
BN_ (100%)	y= 0.0604x + 2.884	0.9836	118

Extruded products are susceptible to lipid oxidation due to their low moisture content, increased surface area due to expansion and presence of iron, a catalyst for oxidation from wearing of screws (Barden, 2014; Ekwenye, 2006; Camire, 2005). Production of peroxide value was used as a quality loss at room temperatures in order to predict the shelf life of snacks. According to this study the predicted shelf life using room temperature data ranged between 118 - 150 days.

The oxidation process of lipid and fats is complex because it always takes place by chain reactions either in dark involving free radicals, called autoxidation, or light-dependent reactions known as photo-oxidation (Gutierrez and Fernandez, 2002). Catalytic systems like light, oxygen, temperature, enzymes (lipase) and metals can accelerate lipids oxidation (Kumar *et al.,* 2015; Viscidi *et al.,* 2004). For dried and processed food which are susceptible to oxidative deterioration the influence of oxygen is of major importance particularly when dealing with packaging materials which are permeable to oxygen (Rosario and Francisco, 2005). However the effect of oxygen is simply a question of total amount available for reaction with food components (Saguy and Karel, 1980). If the amount is limited to a level that causes no significant effect in the food and no additional oxygen coming into contact with the food then the reaction rate is irrelevant (Winkler-Moser and Breyer, 2011). In order to improve the shelf life of dried and processed foods like snacks oxygen and light must be controlled and storage temperature should be minimized (Jehad *et al.*, 2014).

3.2.4 Conclusion

Effect of extrusion cooking on pro-vitamin A retention was evaluated and revealed that despite the losses that occurred, substantial amounts were retained in the snacks. Therefore extrusion cooking can be used in processing foods source of pro-vitamin A. Shelf life predicted ranged between 118-150 days depending on the formulations.

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4. GENERAL DISCUSSION

4.1 Nutritional quality of the developed snacks

The observed significant variations in proximate composition of the developed snacks could be associated with substitution of OFSP with Bambara groundnuts flour in the formulation. Various literatures have indicated that Bambara groundnuts are rich in protein (Mazahib *et al*., 2013; Hillocks *et al.,* 2012; Bamshaiye *et al*., 2011; Okonkwo and Opara, 2010 and Okpuzor *et al*., 2010). Consumption of 100 g of OFSP_ (0%) snacks could supply RDI of about 12% protein while the same amount of OFSP_4 (80%) could supply 38 % protein for school children aged 7-13 years. The decrease in carbohydrate content with increase in Bambara groundnut flour could be explained by the fact that, OFSP are a good source in carbohydrate than Bambara groundnut (Olapade and Ogunade, 2014). The findings indicate that, consumption of 100 g of OFSP_4 (80%) could supply RDI of about 47% of carbohydrate while consumption of the same amount of OFSP_ (0%) snack could provide 60 % of carbohydrate. Moreover consumption of 100 g of snacks per day would provide about 20 - 24% of the recommended daily intake for fibre according to FNB-IOM, (2003). Fibre is an important dietary component in the diet for enhancing bowel movement, preventing overweight and constipation and reducing the risk of colon cancer (Ayinde *et al*., 2012; Anderson *et al.*, 2009).

The amount of vitamin A in the snacks ranged between 42.5±0.05 - 1365±0.48 **(µg** RE/100g DM) which is high compared to amount in flat-bread developed from maize-OFSP blends as follows (Table 3.12)

.

Table 3.12: Vitamin A content of Maize-OFSP flat-breads

Maize:OFSP ratios	**VA content (**µg **RE/100g)**
75:25	277.58
70:30	314.22
65:36	344.33

Source: Tadesse *et al*. (2015)

The significant and progressive decrease in pro-vitamin A with increased substitution of Bambara groundnut in the formulations could be explained by the fact that, OFSP is a richer source of pro-vitamin A (Waized *et al.*, 2015; Mitra, 2012; Burri, 2011) than Bambara groundnut. The findings indicate that, consumption of the snacks could supply RDI of 7 - 227% vitamin A for 7-13 years school children which implying that most of the snacks were good sources of vitamin A and can be used to alleviate vitamin A deficiency among primary school children. Alleviating vitamin A deficiency among them is required to build resistance against common infections and support physical growth and development (TFNC, 2006).

Moreover, substitution of OFSP with Bambara groundnut in the formulation led to increased magnesium, phosphorous, potassium and iron and decrease in calcium and sodium contents. This is because Bambara groundnut is a good source of magnesium, phosphorous, potassium and iron (Isikwenu *et al.,* 2013; Amarteifio *et al.,* 2006). Generally the snacks can supply RDI of about 65.6 -108 % of iron, 5.1-5.6% of calcium, 30-50.5% of magnesium, 17-255% of phosphorus, 14-23 % potassium and 13-30% sodium in 100 g of snacks. Generally the study showed that development of OFSP substituted with Bambara groundnut up to 40% enhances nutritional quality of the products (contributes 76% and 151% RDI for iron and vitamin A respectively), retains sensory properties and acceptable by consumers with attributes colour and sweetness which make consumers to like the snack.

4.2 Descriptive sensory profiling and consumer acceptability of the developed snacks

The findings showed that the scores of aroma, taste, texture and overall acceptability of the snacks decreased gradually as the amount of Bambara groundnut in the formulation increased. On the other hand, most products had high mean scores in hardness attribute which could be associated to high amount of starch. Type and amount of starch present in a food material has a greater influence on the extruded final product's texture or hardness (Delcour *et al.*, 2010). During extrusion water penetrates the starch granules and separates the amylose and amylopectin chains from each other causing the granule to swell and soften, this is known as gelatinization (Thao and Noomhorm, 2011). On cooling the amylose and amylopectin chains slowly rebond and the granule becomes firmer and harder, this process is known as retrogradation (Wrangham and Conklin-Brittain, 2003; Weissenborn *et al.*, 1994).

Generally, the preference mapping findings indicated that most consumers prefered all products containing orange fleshed sweet potato asscoiated with colour hue and sweetness than those containing 100% bambara groundnut. This suggests that, the two attribues (colour and sweetness) were the drivers for cosumer liking of the snacks. The findings are in line with the statement that colour and appearance are the initial quality attributes that attract a person to a food product. Thus considered as indices of the inherent good quality of foods associated with the acceptability (Singh-Ackbarali1 and Maharaj, 2014; Oferi *et al*., 2009). As Dehghan-Shoar *et al*. (2010) reported that acceptability depends mainly on the organoleptic properties of the snacks, which are usually measured in terms of texture, taste and colour.

4.3 Effect of extrusion on pro-vitamin A retention

The results showed that extrusion significantly ($p<0.05$) reduced the pro-vitamin A content of all snack formulations. The reduction could be explained by the fact that, pro-vitamin A (carotenoids) are heat-sensitive and most likely are sensitive to shear and pressure as well (Beswa *et al*., 2015; Waramboi *et al*., 2013; Grela *et al.*, 1999). Similarly, Riaz *et al*. (2009) reported that there are always significant losses of pro-vitamin A during extrusion. Nevertheless, the percentage recoveries showed that, despite the loss, substantial amounts of pro-vitamin A (60 – 86%) were retained in the extruded samples.

Waramboi *et al*. (2013), revealed that extrusion cooking technology have a significant effect on pro-vitamin A retention depending on processing conditions used. Mechanisms of destruction of pro vitamin A were processing temperature and time taken for the process and components that could prevent its destruction including low processing temperature, short processing time and high screw speed. Extrusion at 120 °C, 40% moisture and 300 rpm screw speed retained carotenoid maximally at more than 80% of OFSP flour. Fonseca *et al.* (2008), reported that retention of total carotenoids content of OFSP flour processed at 120°C, moisture content 10% and screw speed 170 rpm retained 72.15% carotenoids content. According to this study, effect of extrusion cooking on Pro-vitamin A was low because the method retained up to 86%. Therefore extrusion can be used in production of high pro-vitamin A snacks from OFSP and Bambara groundnuts.

4.4 Shelf life prediction of extruded snacks

The results showed that predicted shelf life using room temperature data ranged between 118-150 days. Temperatures at room were not constant (fluctuated during the day and night). In essence, the fluctuating temperatures cannot continuously accelerate the lipid oxidation reaction.

Fat and lipid oxidation is one of the factors that affect shelf life stability of processed food products. It is a complex process that takes place by chain reactions either in dark involving free radicals (autoxidation) or light-dependent reactions known as photo-oxidation (Gutierrez and Fernandez, 2002). Catalytic systems like light, oxygen, temperature, enzymes (lipase) and metals can accelerate lipid oxidation (Kumar *et al.,* 2015; Viscidi *et al.,* 2004). For dried and processed food which are susceptible to oxidative deterioration the influence of oxygen is of major importance particularly when dealing with packaging materials which are permeable to oxygen (Rosario and Francisco, 2005). However, the effect of oxygen is simply a question of total amount available for reaction with food components (Saguy and Karel, 1980). If the amount is limited to a level that causes no significant effect in the food and no additional oxygen is coming into contact with the food then the reaction rate is irrelevant (Winkler-Moser and Breyer, 2011). In order to improve the shelf life of processed foods like snacks oxygen and light must be controlled, and storage temperature should be minimized (Jehad *et al.,* 2014).

5. CONCLUSIONS AND RECOMMENDATIONS

In view of the findings, formulation of OFSP and Bambara groundnuts composite snacks increased protein, fat, ash, fibre and energy values of the products with increased OFSP flour substitution. However, carbohydrate and pro-vitamin A of the products decreased significantly with the same increment of OFSP substitution. Moreover, with exception of sensory attribute of hardness the, aroma, taste and texture of the snacks decreases gradually as the amount of Bambara groundnut increases in the formulation. The orange fleshed sweet potato based snacks had higher overall acceptability with colour and sweetness being the main drivers for consumer liking of the products.

The effect of extrusion on the pro-vitamin A of the developed snacks was significant with extruded products having lower values than un-extruded products. However, despite the loss, substantial amounts of pro-vitamin A (60 – 86%) were retained in the extruded samples. Extrusion can be used to produce shelf stable OFSP and bambara groundnut based snacks. A shelf life of 118- 150 days was estimated under fluctuating room temperatures. Extrusion can therefore be used to produce acceptable and shelf stable OFSP and Bambara groundnut based snacks rich in pro-vitamin A content.

However, according to these findings, further research is needed to assessing the bioavailability of vitamin A and iron from extruded OFSP and Bambara groundnut based snacks. Also the use of anti-oxidant during extrusion of OFSP and Bambara groundnut based snacks in order to retard the oxidative rancidity during storage, hence extend the shelf lives of the snacks.

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7. APPENDICES

Table 7.1: Mean intensity score of the developed snacks

	Attributes						
Product	Crispiness	Hue	Whiteness	Oiliness	Hardness	Saltiness	sweetness
OFSP_ (0%)	1.50± 0.60^{a}	7.27±1.49^{c}	1.82±1.33^{a}	2.18±1.18^{b}	2.77±1.60^{a}	2.00±0.76^{a}	5.50±1.97^{a}
OFSP_1 (20%)	1.59± 0.59^{ab}	6.55±1.30^{bc}	2.27±1.35^{ab}	1.72±0.63^{ab}	3.27±1.83^{a}	2.27±1.03^{ab}	5.13±1.73^{a}
OFSP_2 (40%)	2.50± 1.19^{bc}	6.31±1.67^{bc}	2.45±1.44^{ab}	1.31±0.43^{a}	6.32±1.64^{bc}	2.90±1.47^{ab}	5.41±1.50^{a}
OFSP_3 (60%)	2.68 ±1.17^{c}	5.36±1.39^{b}	3.27±1.61^{b}	1.50±0.74^{a}	6.59±1.74^{c}	2.59±1.18^{ab}	4.77±1.80^{a}
OFSP_4 (80%)	3.09± 1.74^{c}	5.45±1.34^{b}	3.00±1.38^{ab}	1.36±0.49^{a}	4.91±1.95^{b}	2.55±1.30^{ab}	5.05±1.70^{a}
BN_(100%)	2.14 ±0.99^{abc}	2.36±1.26^{a}	6.05±1.50^{c}	1.55±0.60^{a}	5.27±1.70^{bc}	3.23±1.48^{b}	4.45±1.84^{a}

Mean values with different superscript letter along the column are significantly different at $p<0.05$.

Table 7.2: Pro-vitamin A retention in developed snacks

Product	**Un-extruded**	**Extruded**	**Pro-vitamin A retention (%)**
OFSP_(0%)	20.73±0.67	17.33±0.48^{e}	83.58±0.43^{b}
OFSP_1 (20%)	13.60±0.27	11.80±0.20^{d}	86.50±3.62^{b}
OFSP_2 (40%)	11.05±0.12	9.09±0.09^{c}	82.21±0.11^{b}
OFSP_3 (60%)	6.61±0.37	4.57±0.19^{b}	70.30±6.23^{a}
OFSP_4 (80%)	4.50±1.19	3.80±0.23^{b}	80.35±2.76^{b}
BN_(100%)	0.90±0.02	0.54±0.05^{a}	59.56±4.60^{a}

Table 7.3: ANOVA table of effect of extrusion on pro-vitamin A retention

Treatment	**OFSP**	**OFSP1**	**OFSP2**	**OFSP3**	**OFSP4**	**BN**
Un-extruded	20.73	13.6	11.05	6.61	4.5	0.9
Extruded	17.33	11.76	9.09	3.97	3.61	0.54
t-value	-5.7986	-6.9494	-18.6	-8.906	-6.5192	-9.3279
p-value	0.02848	0.02008	0.002878	0.01237	0.02273	0.0113

Quantitative Descriptive Analysis form

Name…………………………………………… Sex……………………...Time………………

Please evaluate each of the coded samples in the order they listed. Choose appropriate number in the scale from 1 to 9, where 1 is low intensity and 9 is high intensity. How do you find the following characteristics for the extruded snacks? Put the appropriate number against each characteristic.

Sample #.................................

Hue ____

Faint 1 2 3 4 5 6 7 8 9 very concentrated

Sweetness____

Not sweet 1 2 3 4 5 6 7 8 9 very sweet

Hardness____

Not hardy1 2 3 4 5 6 7 8 9 very hard

Whiteness____

Grey 1 2 3 4 5 6 7 8 9 very white

Oiliness____

Not oily1 2 3 4 5 6 7 8 9 very oily

Saltiness ____

Not salty 1 2 3 4 5 6 7 8 9 very salty

Crispiness____

Not crispy 1 2 3 4 5 6 7 8 9 very crispy

Sensory Evaluation Form

Panelist No…………………………………… Sex…………………………………

Age group (a) 10-20 years (b) 20-30 years (c) 30 - 40 years (d) above 40 years

Time………………………………….. Date……………………………….............................

Education level (a) Bachelor degree (b) Master's degree (c) others: specify………………………

Please look and taste each of the (6) coded snack samples. Indicate how much you like or dislike each sample by checking the appropriate sample attribute and indicate your reference (1-9) in the column against each attribute. Put the appropriate number against each attribute.

9 – Like extremely

8 – Like very much

7- Like moderately

6- Like

5- Neither like nor dislike

4- Dislike

3- Dislike moderately

2- Dislike very much

1- Dislike extremely

Attributes	Sample codes					
colour						
Taste						
Aroma						
Texture(hardness)						
Overall acceptability						
Would you prefer to buy a product?	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No

Comments

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