UNIVERSITY OF CAPE COAST

ORANGE-FLESHED SWEET POTATO (OFSP) – CASSAVA COMPOSITE GARI: EFFECTS OF PROCESSING VARIABLES AND STORAGE ON BETA-CAROTENE AND SENSORY QUALITIES

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2020

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Thesis submitted to the Department of Agricultural Engineering, School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy degree in Food and Post-Harvest Technology.

MARCH 2020

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature ……. Date ……

Name: Emmanuel Ebo Atobrah

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature …….. Date ……

Name: Prof. Ernest Ekow Abano

Co-Supervisor's Signature …… Date ……

Name: Dr Ernest Teye

ABSTRACT

Incorporating orange-fleshed sweet potato (OFSP) into gari could increase the nutritional value of gari. This work sought to improve the nutritional quality of gari by incorporating OFSP into the gari. Multivariate response surface was used for the optimization of the optimum amount of OFSP and the fermentation duration required in producing a good quality gari. The results showed that beta-carotene content increased with increasing fermentation duration and increasing OFSP percentage. However, OFSP amount did not affect the swelling capacity while a longer fermentation period reduced the swelling capacity of the OFSP–cassava composite gari. Incorporation of OFSP into gari lowered its sensory attributes, while attributes such as texture and overall acceptability increased with fermentation duration. Furthermore, the OFSP amount and fermentation duration affected the lightness (L*) and redness (a*) of the gari, but did not influence the yellowness (b*) of the gari. Producing gari by using 90% cassava and 10% OFSP (9:1 ratio of cassava to OFSP) and fermenting for 2.21days gave the best quality gari based on the beta-carotene content of 19.8 µg/ml, swelling capacity of 3.2 and sensory attributes. Moreover, both storage conditions and storage durations influenced the beta-carotene content of the gari but did not affect the swelling capacity, bulk density and colour of OFSP–cassava composite gari significantly. The profit on the OFSP–cassava composite gari was determined to be higher than that of 100% cassava gari. Orange-fleshed sweet potato could therefore be incorporated into gari to improve the vitamin A content of gari and thereby improve the economic status of gari processors.

ACKNOWLEDGEMENT

My utmost gratitude goes to my main supervisor, Prof. Ernest Ekow Abano for his patience, guidance, constructive criticisms and encouragement and for the various support he offered to enable me to complete my work. I am grateful to my Co-supervisor, Dr Ernest Teye for his encouragement and guidance as well as the various supports he offered me throughout the project work. I express my heartfelt gratitude to Dr Enoch Quayson (Department of Biochemistry, UCC), Dr Martin Bosompim (Department of Agric Economics and Extension, UCC) and Mrs Margaret Forson (Ministry of Food and Agriculture, Cape Coast) for impacting the project with their rich knowledge and expertise as team members.

To Dr Benjamin Anderson, Mr Andrew Huzortey and Mr Charles Amuah of the Department of Physics Research laboratory (LAFOC), UCC and Mr Jonathan Ntow of Department of Laboratory Technology laboratory, UCC, I say God richly bless you for helping in the laboratory analysis of this work.

I am also grateful to the Agro-processing students; Joyce, Selina, Michael and Noah and Araba (teaching assistant, department of Agric engineering, UCC) and Duakor gari processors for the diverse assistance offered towards this work. A special thanks to my friend Delali for the encouragement, secretarial work and support offered throughout the project work and Mr Lawrence Arthur for assisting in the data analysis.

Finally, I express my heartfelt gratitude to DRIC, UCC for providing financial support for the completion of this project.

DEDICATION

To my friend Delali, parents, Mr. and Mrs. Atobrah and brothers, Samuel and Daniel

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Beta-carotene is one of over 600 compounds jointly known as carotenoids. These compounds are lipophilic tetraterpenoids showing red, orange or yellow pigmentation due to intense absorbance in the visible spectral area and are mainly found in dark or coloured fruits and green leafy vegetables (Besarab, Gerasimovich, Kanterova, & Novik, 2018; Bogacz-radomska & Harasym, 2018). Carotenoids are soluble in fat and therefore affect several biological activities, such as photosynthesis, vision process, or sweeping of free radicals and singlet oxygen (Geens, Dauwe, & Eenas, 2009; Odriozola-Serrano, Soliva-Fortuny, Hernández-Jover, & Martin-Belloso, 2009; Widomska, Kostecka-Gugała, Latowski, Gruszecki, & Strzałka, 2009). As of now distinctive concern of carotenoids is dependent on their wide application as provitamin A and characteristic colorants in pastry shop, butter, refreshment drinks, make-up; nourish premixes in fishery; cancer and infection preventing agents; natural reagents and medicine (Frengova, Simova, & Beshkova, 2004; Mata-Gómez, Montañez, Méndez-Zavala, & Aguilar, 2014; Saddozai, Hameed, & Kousar, 2005).

Beta-carotene has high bioactivity and possesses colouring properties, which make it a great food additive and industrial as well as medicinal raw material. Among the various carotenoids, beta-carotene is reported to have the highest vitamin A activity. Beta-carotene is used as an orange-red pigment in the production of food products such as pastry, edible fats, ice cream and non-alcoholic beverages in the food industry. It is also used as a colouring agent

for tablets in the pharmaceutical industry. Also, beta-carotene is used as a bioactive ingredient in skin protective creams and as oral sun protectants in the cosmetic industry (Bogacz-radomska & Harasym, 2018; Sies & Stahl, 2004). Beta-carotene is found in all human tissues including the blood and performs several functions in the human body. Among the several functions, the important one in the body of humans is related to provitamin A supply (Bogacz-radomska & Harasym, 2018). Beta-carotene is converted into vitamin A and is the main precursor for vitamin A in the diet of humans. Nonetheless, vitamin A deficiency is a serious public health concern in Africa including Ghana. This has been the major cause of child mortality and sicknesses in African children (Black et al., 2008).

Vitamin A deficiency (VAD) prevalence in Ghana is estimated at 76% (Odunitan-Wayas, Kolanisi, Chimonyo, & Siwela, 2015). Meanwhile, the VAD prevalence for Africa is estimated at 41.6% (Jarosz & Rychlik, 2012), this shows that Ghana's estimate of 76% is very high, being almost double that of the estimate for all African countries. According to Food and Agriculture organization (FAO) statistics on food systems, Ghana ranks third to Sao Tome and Principe and Kenya, which have VAD estimates of 95.6% and 84.4% respectively (Jarosz & Rychlik, 2012; Odunitan-Wayas et al., 2015). VAD is the leading cause of preventable blindness and contributes to the severity of infections, child mortality, maternal mortality and poor pregnancy outcomes. It is reported that more than half of children below the age of 5 years are affected by sub-clinical vitamin A deficiency and that VAD caused 1 out of every 3 deaths of children below 5 years in Ghana between 2001 and 2005 (UNICEF & Initiative, 2004). VAD prevalence is highest among children

under 5 years of age and women of childbearing age. VAD prevalence among women of childbearing age is estimated at 20% in Ghana (Pre-sac, 2000). The current report shows it is now at 35.6% (Glover-amengor, Agbemafle, Hagan, Mboom, & Gamor, 2016).

The main cause of VAD is a low dietary intake of foods rich in vitamin A or it's precursors. This is a main problem among the poor since their diets tend to be of limited diversity and low in foods of animal origin. Infections also contribute to VAD. Promotion of food-based diets rich in vitamin A is considered the most sustainable approach to addressing VAD (Low et al., 2007), with supplementation considered a short-term strategy and fortification as medium term. Golden rice, carrot, and Orange-fleshed sweet potatoes (OFSP) are among the best sources of beta-carotene. However, golden rice is not grown in Ghana while carrot, on the other hand, is expensive, leaving OSFP as the viable option to meet the vitamin A needs of Ghanaian citizens (Low et al., 2007). Increased consumption of OFSP products, therefore, has the potential to contribute to improved vitamin A status among Ghanaians. Incorporation of OFSP into food systems as a strategy to improved nutrition has been suggested (Laurie et al., 2018). The potential of OFSP to improve the vitamin A status in young children has been confirmed in both efficacy and effectiveness studies (Hotz et al., 2012; Hotz et al., 2012; Tumwegamire, Kapinga, Zhang, Crissman, & Agili, 2004; van Jaarsveld et al., 2005). Yellow flesh cassava is reported to contain some amount of beta-carotene and retains most of the beta-carotene when prepared into gari as compared to other food products (Duah, 2016). OFSP, which is reported to have much more beta-carotene, can be incorporated into gari for greater retention. During gari

processing, the paste is typically fermented for up to 3 days before roasting. The fermentation process and roasting affect the taste, flavour and colour of the gari. It is against this background that this study was carried out to develop OFSP-cassava composite gari to investigate how the proportionate amount of OFSP and fermentation duration of the dough affect the beta-carotene and sensory quality of OFSP-Cassava gari.

1.2 Statement of the Problem

Ghana needs a robust approach to dealing with malnutrition among the poor and children. The rate of death, malnutrition, hunger and infections as well as hidden hunger affecting children, pregnant women and the poor is simply unacceptable. According to Simler et al. (2005), 1 out of every 3 deaths of children below 6 years in Ghana is due to a deficiency in vitamin A. Moreover, it is estimated that 110,000 of Ghanaian children will die between 2011 and 2020 due to vitamin A deficiency (Aguayo & Baker, 2005).

The government of Ghana in dealing with vitamin A deficiency problems in the country has employed some policies. So far, the main policies dealing with vitamin A issues in the country are the fortification of vegetable oil with vitamin A and vitamin A supplementation to children below the age of 6 years. In spite of these policies, vitamin A deficiency remains a challenge in the country. This could be due to issues related to access to vitamin A vehicles such as vegetable oil. A micronutrient survey conducted in the country in 2017 shows that almost half of high-risk areas in the country do not use vegetable oil (Ghana Micronutrient Survey (GMS), 2017). Moreover, the qualitative analysis of samples of vegetable oil in the market indicated that close to fifty

per cent of them were not sufficiently fortified and about thirty-three per cent not fortified at all (Ghana Micronutrient Survey (GMS), 2017).

This study, therefore, sought to in-cooperate vitamin A into the diet that is commonly eaten by people at high risk of vitamin A deficiency. The study also sought to establish the optimum amount of OFSP and fermentation duration for OFSP–cassava composite gari.

1.3 Research Objective

The main objective of the study was to improve the quality of gari by incorporating orange-fleshed sweet potato into the gari. To achieve the main objective, the following specific objectives were pursued:

1. to investigate the influence of OFSP amount and fermentation duration on the nutritional (beta-carotene) and sensory quality (Colour (L*, a*, b*), texture, swelling ability, taste, flavour, overall acceptability) of processed OFSP–cassava composite gari.

2. to establish the optimum cassava-OFSP ratio and fermentation duration for OFSP–cassava composite gari based on the concept of multivariate desirability index.

3. to determine the effect of storage conditions and duration on the nutritional quality of OFSP–cassava composite gari.

4. to determine the profitability of OFSP–cassava composite gari

1.4 Research Questions

The following specific research questions guided the study.

1. What is the influence of OFSP amount and fermentation duration on the nutritional and sensory quality (beta-carotene, colour (L*, a*, b*), texture,

swelling ability, taste, flavour, overall acceptability) of processed OFSP–cassava composite gari?

2. What are the cassava-OFSP ratio and fermentation duration required to produce OFSP?

3. What are the effects of storage conditions and duration on the nutritional quality of OFSP–cassava composite gari?

4. Will OFSP–cassava composite gari give a higher profit than 100% gari?

1.5 Significance of the Study

Since vitamin A deficiency remains a public health issue in Ghana, the development of beta-carotene fortified gari would help deal with vitamin A deficiency in Ghana. Under normal nutrition with accessible and availability of diverse food consumption, energy and micronutrient requirements are met. However, this is not the case in poor communities. Their diet is usually not diversified and gari forms part of their major food component and diet. Incorporating OFSP into gari, one of the main diets in the country would, therefore, make vitamin A readily accessible by the high-risk populace in the country.

It would increase the production of OFSP thereby creating more jobs and improving the income of farmers. Gari processors would also benefit from the incorporation of OFSP into gari since profit may be maximized. It would also deal with the issue of storage of OFSP. Since the product would be stored in the form of gari, which has low moisture content, the storability of the product would be increased.

It will also give an indication of the best conditions to store OFSP products. Beta-carotene is known to be sensitive to temperature, heat, and light. The

results from the storage of the product would give an understanding of the storage dynamics of beta-carotene, and hence, the best conditions to store the product.

1.6 Delimitation

There are several varieties of cassava and orange-fleshed sweet potato; however, this study focused on the use of "Afisiafi" cassava. This is because "Afisiafi" cassava is the main variety of cassava used for the production of gari in the Central region, especially in the Komenda-Edina-Eguafo-Abirem municipality.

1.7 Limitation

The ethanol used for the extraction of beta-carotene could not extract easily. The gari samples were ground with the ethanol to enhance the extraction. However, this could lead to some of the beta-carotene not extracted from the gari samples.

1.8 Organisation of the Study

Chapter 1 of this study introduced the background to the study, the problem under investigation, the purpose of the study, research questions, significance of the study, delimitation and limitation of the study and ended with the organisation of the study. Chapter 2 presents a review of relevant literature and research on beta-carotene, vitamin A deficiency, orange-fleshed sweet potato and gari. The methodology used for the project, concepts that underlie these methods, the rationale for applications of such methods, and approaches to data analysis are outlined in chapter 3. Chapter 4 contains the results of the data collected and their discussion.

Chapter 5 offers a conclusion of the findings, implications for practice, and recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Beta-Carotene availability

2.1.1 Sources and Types of Beta-carotene

Beta-carotene is a hydrocarbon carotenoid synthesized by plants (Bogacz-radomska & Harasym, 2018). It is mainly found in the thylakoid membranes within the chloroplasts of plants. It is found in vegetables such as carrots, sweet potatoes, spinach and other leafy and green vegetables and fruits. Due to its biological functions, it is extracted from these plants for use as a food colourant and the fortification of foods, generally deficient in beta-carotene but form major staple food for VAD prone population. It is extracted via physicochemical and biotechnological processes. It can also be manufactured through chemical means (Bogacz-radomska & Harasym, 2018). Beta-carotene like many other carotenoids has antioxidant effects when consumed by humans (Riccioni, 2009). Due to this, beta-carotene is known to reduce the development of several diseases. For instance, studies conducted by Böhm, Puspitasari-Nienaber, Ferruzzi, & Schwartz (2002), Cranganu and Camporeale (2009) and Di Mascio, Kaiser and Sies (1989) show that beta carotene reduced the development of cancer. However, Druesne-pecollo et al. (2010) concluded that supplementation of beta-carotene has no preventive effect on the development of cancer. They observed an increase in the risk of lung and stomach cancers in smokers and other subjects that worked with asbestos and were given 20 – 30 mg of beta carotene per day (Druesne-pecollo et al., 2010).

2.1.2 Bioavailability of Beta-carotene and other Carotenoids

Even though many food products are reported to contain high levels of beta-carotene or carotenoids in them, the availability of these carotenoids in the body after taking them is of great importance. Though not investigated in this study, Castenmiller and West (1997) and Yeum and Russell (2002) reported that the type of carotenoid, its percentage component in the food matrix as well as the environmental conditions within which the carotene containing–food product was prepared, affect its bioavailability in the body. This clearly shows that the bioavailability of carotenoids is influenced by the state of the carotene itself and the presence of other compounds (Prince & Frisoli, 1993) as well as the physiological activities within the individual. Some types of carotenoids, such as lycopene and beta-carotene exist in microcrystalline form making them a little difficult to be released as compared to the carotenes engulfed in fats. Treatments of food, which tend to break cell walls and cause cleavages of bonds, increase the accessibility of carotenoids and make them readily available. Many studies have shown that heat treatment of food improves the bioaccessibility of carotenoids (Bernhardt & Schlich, 2006; Fernandez-Garcia et al., 2012). On the other hand, the characteristics of the consumer such as health status (infections), age, sex and nutrition of the person can also influence the amount and ease of release of carotenoids in the body from the food (Castenmiller & West, 1997; Yeum & Russell, 2002). Since carotenoids and especially beta-carotene are lipophilic, any infections that disrupt the absorption of fats in the gastro-intestinal tract also affect the absorption of beta-carotene. Also, certain drugs such as sulfonamides can reduce the bioavailability of beta-carotene when taken alongside beta-carotene

carriers (Castenmiller & West, 1997). Other food products apart from drugs can also have either positive or negative correlation on the bioavailability of carotenoids, this is because these substances interact with each other as found in beta-carotene and lutein (Kostic, White, & Olson, 1995). Vitamin E is found to have a positive impact on the absorption of beta-carotene (Fiedor & Burda, 2014). Olson (1994) proposed that just about 5% of the carotenoids eaten is absorbed through the gastrointestinal tract, though more than 50% is from micellar suspensions.

2.1.3 Beta-carotene Sensitivity and Degradation

It is reported that beta-carotene isomerizes at high temperatures resulting in the development of their characteristic bright colours but resulting in the decrease in all-trans beta-carotene in the finished product (Fratianni, Cinquanta, & Panfili, 2010; Meléndez-Martínez, Escudero-Gilete, Vicario, & Heredia, 2010). Chilungo, Muzhingi, Truong, and Allen (2019) reported that beyond 37°C beta-carotene tends to be degraded. In their study, they compared beta-carotene content of OFSP composite flours and puree with the beta-carotene content of finished products made from the flour and puree. They reported that after processing, chapatis lost between 17.77% and 24% of all-trans beta-carotene. In addition, porridges lost between 29% and 35% of all-trans beta-carotene. They suggested that the lower beta-carotene retention in porridges could be because of the prolonged time of heating as compared to the time for cooking chapatis.

Similar findings were reported by Bechoff, Poulaert and Tomlins (2011) who reported lower beta-carotene retention in orange-fleshed sweet potato porridge as compared to chapatis made from orange-fleshed sweet

potato composite flour. Beta-carotene retention was also reported to decrease by 48% in porridge and 25% in bread made from yellow corn meal (Kean, Hamaker, & Ferruzzi, 2008). The percentage loss of beta-carotene, according to these researchers, was due to isomerization of this hydrocarbon due to heat treatment. After the final heat treatment of food was reached, all-trans beta-carotene was found to isomerize into 13-cis beta-carotene and 9-cis beta-carotene (Bechoff et al., 2011; Chandler & Schwartz, 1988). Conversely, isomerization of beta-carotene by heat treatment was not identified as causing degradation in the carotenoid. Instead, Chilungo et al. (2019) reported that factors such as the genotype of the orange-fleshed sweet potato, interactions between food components and variations in food preparation methods are responsible for the decrease in the beta-carotene content. Furthermore, Bechoff and his colleagues in their study in 2018 updated their earlier suggestion that other factors such as the beta-carotene dissolving in water prior to dewatering also caused a reduction in the beta-carotene content in the finished product.

Moreover, Wingqvist (2011) also found a contradicting effect of high temperature on beta-carotene degradation. After 2 hours of boiling at a temperature of 70°C, Wingqvist (2011) found no significant change in the beta-carotene content in the extract. This finding is comparable with that of Chilungo et al. (2019) and Hedren, Diaz and Svanberg (2002). They concluded that processing methods that break up the cell and cell walls including high-temperature treatment make beta-carotene easily accessible (Chilungo et al., 2019; Hedren, Diaz, & Svanberg, 2002). Chilungo et al. (2019) further explained that decrease in beta-carotene content of deep-fried

food was because carotene leached from the product to the oil rather than just being degraded because of high-temperature treatment.

2.2 Nutritional Importance of Vitamin A

2.2.1 Importance of Vitamin A in diet

Vitamin A is a cluster of lipophilic biomolecules needed by humans to perform various vital metabolic functions. The vitamin has three main forms retinal, retinol and retinoic acid. Retinal functions as light-absorbing metabolite required for colour and scotopic vision. Retinoic Acid (RA) functions as a hormone-like factor for growth. All forms of vitamins are tested to have β-ionone, which is essential for the biological activity of the vitamin. Beta-carotene (BC), which is an orange-yellowish pigment of carrot and orange-fleshed sweet potato, is the major plant source of pro-vitamin A (Muzhingi, Yeum, Qin, & Tang, 2008). Bechoff and others (2011) also referred to vitamin A as a genomic term that describes a compound with a beta-ionone structure having a descriptive genetic activity of retinol. Vitamin A is found in animal products; eggs, liver, milk and fortified foods (Sommer, 2001). Vitamin A precursors are those carotenes that have the biotic activity of vitamin A following intestinal transition to retinol; cryptoxanthin, beta-carotene and alpha-carotene. They largely occupy yellow and green vegetables and fruits. Vitamin A activity is stated in units of weight as Retinol Equivalences (RE) where 1µg RE is equivalent to 1µg retinol.

The whole cluster of multipart, which may structurally relate to retinol is referred as retinoid, including both the natural form of vitamin A and synthetic compounds with or without biological activities (Kidmose, Yang, Thilsted, Christensen, & Brandt, 2006). Provitamin A carotenoids in plant

foods are directly taken by enterocytes. In the case of beta-carotene, the molecules may be cleaved centrally to two molecules of retinal before incorporation into chylomicrons and conveyed to the liver and other tissues (Veda, Platel, & Srinivasan, 2010). The liver stores 50 – 80% of total vitamin A in the body and it is released from the liver bound to retinol-binding protein (RBP). The RBP complex combines with transthyretin and then carried to specific cells through an aqueous environment of the general circulation and oxidized to its major metabolite retinaldehyde, the chromophore for the protein rhodopsin in the retina (Pugliese et al., 2013).

Vitamin A has specific functions in the human body. Preventing night blindness is a function of vitamin A. Wide range of animal studies evidenced the significance of vitamin A for normal growth and development where its deficiency leads to stunted growth in humans and animals. Vitamin A plays a vital role in cell differentiation. The absence or limited presence of vitamin A in a diet causes keratinization of mucus-secreting ciliated epithelium on sensitive tissues of the skin, trachea, cornea, salivary gland and testis and the case of the eye blindness may result (Teow et al., 2007). Deficiency of vitamin A is related to anaemia, with low serum iron and excessive iron storage in the liver. Vitamin A protects against infections where low supply exposes the body to decreased resistance to infections, and destruction of skin and epithelial structures.

A research on the biological effects of vitamin A in humans, classified functions in: immunity, vision, development of red blood cells, dermatology, gene expression, human growth and development, taste and hearing and spermatogenesis. Each of these classifications has vital roles played by one or

more of the forms of vitamin A. Vitamin A is vital for regular function of the immune system, required for both adaptive and innate immunity (Ray & Tomlins, 2010). Vitamin A is an immune booster that facilitates the antibody response, restores the integration of all mucosal cells ability to advance the antibody reaction to vaccines for diphtheria, tetanus and measles. Effect of vitamin A supplementation on adults and geriatric age group has however not been largely researched (Muzhingi et al., 2008).

Vitamin A plays a vital role in the development of red blood cells. It simplifies the organization of iron stores to the emerging erythrocytes where it is merged into haemoglobin, the oxygen career complex protein. In a study by Hiranvarachat, Suvarnakuta, and Devahastin (2008) among school children in Argentina, haemoglobin (Hb) concentration improved in children who ate biscuit fortified with vitamin A and iron relative to children who received fortification in iron only. The impact of vitamin A on iron metabolism and the relevance of providing low-income communities with fortified micronutrients were established in the study.

The tone of the skin and its general appearance and nourishment largely depends on vitamin A. Isoform (RA) switches genes that separate immature skin cells into mature epidermal cells (Teow et al., 2007). Alitretinoin, which is a physiological vitamin A derivative with strong anti-inflammatory and associate metabolisms, has shown to enhance photo-age and chronically-age skin pathologies. Vitamin A rich diets promote the deposition of collagen fibre and prevent destruction occurring on photo-age and chronically-age skin types. Synthesis of modified proteins in diets requires a balanced amount of vitamin A to promote good health and vitality, as a

significant deficiency in vitamin A in diets causes a number of skin diseases, as well as down-regulation of a distinctive gene, referred as CCNI (cysteine-rich protein). This is shown in the dermis and chronically- aged photo-aged skins in humans (Ndolo, Nungo, Kapinga, & Agili, 2007).

OFSP bread with beta-carotene fed to male adults with low sperm cells caused improvements in the process of spermatosis in a six months longitudinal study in Higher Institute of Medicine Studies, Santiago de Cuba (Maiani et al., 2009). Spermatosis a natural process where male primary germ cells experience revision to generate several cells referred to as spermtagonia, and through further processes develop into sperm cells, has been known to improve with Vitamin A supplementation. The development of adult mammalian spermatogenesis requires an adequate supply of Vitamin A to complete results. Vitamin A deficiency decreased testicular expression of the all-trans retinoic acid-responsive gene (De Moura, Miloff, & Boy, 2015).

2.2.2 Oil Consumption and Vitamin A Content

The Ghana micronutrient survey conducted in 2017 revealed that almost 26% of Ghanaian households do not use vegetable oil, a situation very prominent in the three Northern Regions. About 83% of Upper West Region, 57% of the Upper East Region and 26% of Northern Region households do not use vegetable oil. In total, about 48% of the people of the northern zone do not live on vegetable oil. The study also revealed after its quantitative analysis of the oil in the Ghanaian market that, only about 55.6% of oil in the Ghanaian market is fortified enough with vitamin A, such oil brands had vitamin A concentration of 10 ppm or above. Also, only about 35.7% of oil in the northern zone had sufficient vitamin A content. In the Western region, as low

as 29.5% of oil had sufficient concentration of vitamin A. However, in contrast, over 60% of oil found in Volta, Central, Brong Ahafo and Ashanti regions had adequate vitamin A concentration (Ghana Micronutrient Survey [GMS], 2017).

Surprisingly, close to 50% of oil samples in the market are not sufficiently fortified. They have vitamin A content to be below 10 ppm. What is even alarming is that one-third of the oil samples were found not fortified at all. This could be as a result of issues relating to the unstable nature of retinyl palmitate, the retinol form in the oil. Technological practices at the manufacturing industries could as well be a factor (Ghana micronutrient survey [GMS], 2017).

2.2.3 Fortification Programs to Combat Micronutrient Deficiencies in Ghana

Salt fortification with iodine was first enforced by law in Ghana in 1996. This was the beginning of food fortification in the country, after which wheat and vegetable oil were by law to be fortified. Currently, standards for food fortification are available for salt, wheat and vegetable oil. Salt is to be fortified with iodine; wheat with iron, zinc and vitamin B complex and vegetable oil with vitamin A.

Research carried out in 2011 showed that 95% of oil specimens were sufficiently fortified with vitamin A. In spite of this, vitamin A deficiency was still prevalent in the country and 1 out of every 3 children under 6 years was estimated to die due to vitamin A deficiency (Simler et al., 2005). Over the years, research has shown that the vitamin A content of oil samples in the

country that have adequate vitamin A content has reduced to about 50% (Ghana Micronutrient Survey [GMS], 2017).

To address this severe public health problem, multiple approaches should be used. GMS suggested three ways to combat the vitamin-A deficiency menace:

1. Not only should vitamin A supplementation be improved, but also women should be encouraged to send their children to the clinics and hospitals for vitamin A supplementation twice a year until their children are 6 years old. This will reduce the rate of infections and mortality.

2. Regular supervision should be carried out both at the factory and at the market to ensure that vegetable oil is sufficiently fortified with vitamin A. This will help increase the vitamin A reserves in the body.

3. Other alternatives to dealing with vitamin A deficiency should be highly promoted other than the use of vegetable oil. This is necessary because high-risk vitamin A communities in the country also consume less vegetable oil. These alternatives could include encouraging people to eat vitamin A rich foods or introduction of bio-fortified foods easily adapted to vitamin A risk communities.

2.3 Sweet Potato

2.3.1 Origin and Cultivation of Sweet Potato

Sweet potato (*Ipomoea batatas*) is one of the world's staple crops especially in Africa and Asia where it plays an important role in their diet (Laurie, Faber, Adebola, & Belete, 2015). The crop is thought to have originated from Latin America (Davidson, 1999) from where it spread to Europe then Africa and Asia (Katayama, Kobayashi, Sakai, Kuranouchi, & Kai, 2017). It is cultivated all over the world between sea level and an altitude

of 2700 m (Sullivan, Asher, & Blamey, 1997). Sweet potato is a hardy crop, which needs just sufficient water for growth and matures within 90 – 120 days (Southern Exposure Seed Exchange, 2016). The roots of sweet potato are oblong shaped and taper towards the end with a variety of colours depending on the cultivar. The cover of the smooth tubers or roots is white, red, orange, yellow, purple or brown (Umesh, 2009). The nature and shape of the stem of sweep potato depend on the growth habit of the cultivar and soil moisture, but usually cylindrical. The simple and spiral leaves are organized alternatively on the stem. Its colour ranges from yellowish-green and purple pigment at the leaf's blades. Sweet potatoes are edible tuberous roots with long tinkered smooth skin. They have high nutrient components and sweetness, short growing durations (Farley & Drost, 2010)

Apart from the Western Region, all other regions of Ghana cultivate sweet potato, with the Upper West, Upper East and Eastern Regions being the major growing areas. Greater Accra and Ashanti regions, however, are the least sweet potato growing areas (MoFA and SRID, 2009). Some sweet potato farmers have formed associations that benefit from support and assistance from Ministry of Food and Agriculture and this tend to increase sweet potato production in some communities of the country (Aidoo et al., 2014). Sweet potato has an annual world production of 115 million tonnes and ranks 7th among global food crops. About 92% of sweet potato supply is produced in the Pacific Island and Asia with 89% in China (Chan, Bhat, & Karim, 2009). Sweet potato gives 90 calories of energy as compared to potato, which provides 70 calories for every 100 g consumed and it is a good source of vitamin A, B and K; minerals and dietary fibre (Sanni et al., 2005). The

orange-fleshed sweet potato contains a great amount of beta-carotene (Laurie et al., 2015). The sweet potato does not contain cyanide a limiting property of cassava (Karim, Adebanke, Akintayo, & Awoyale, 2016). In spite of the significant health benefit of orange-fleshed sweet potato over other roots and tubers, some communities in Sub-Saharan Africa are more committed to the cultivation of other tuber crops over OFSP (Bienabe & Vermeulen, 2008; Laurie et al., 2015; Setumo, 2014). This may be because OFSP is seen by many people as a poor man's crop and mainly cultivated by women (Brito, Brouwer, & Falcao, 2012). OFSP promotion as a post-disaster crop to combat food insecurity could also be another reason (Kapinga et al., 2005). Again, low utilization of the crop could also be a factor (Karim et al., 2016). This reputation about OFSP is, however, community-specific and not general (Jenkins, Shanks, & Houghtaling, 2015).

2.3.2 Uses of Sweet Potato

Sweet potato has a variety of uses in various part of the world ranging from flour preparation, starch production and whole tuber consumption. The various parts of the crop can also be fed to farm animals. Notwithstanding the diverse use of the crop, its actual utilisation is community or country-specific. Sweet potato is processed into flour, which is used in the preparation of cakes, bread, biscuit and other pastries and cookies (Mais & Brennan, 2008). Flour produced from sweet potato is reported to be a good industrial stabilizer for the processing of ice cream (Amante, 1995). It also serves as a sweetener in the production of some Ghanaian local drinks such as ‘Burukutu' and ‘Kunu-Zaki' (Tewe, Ojeniyi, & Abu, 2003). In Nigeria, sweet potato flour is used as a sweetener in porridge preparation. Flour produced from orange-fleshed sweet

potato has higher economic value as compared to flour produced from other varieties of sweet potato because of the higher beta-carotene of the orange-fleshed sweet potato (Agbo & Ene, 1994; Odebode, 2010). Sweet potato is dried and prepared into flour in South Africa and used in soups and breakfast foods for children (Laurie, 2004).

Sweet potato, apart from being prepared into flour, is also used for the production of a high-quality starch for both human consumption and industrial purposes (Rahman, Wheatley, & Rakshit, 2003). Starch from sweet potato has found its significant use in Japan and China where it is used for bread, alcoholic drinks, isomerized glucose syrup and pasta (Laurie, 2004; Odebode, Egeonu, & Akoroda, 2008; Prain, Wheatley, & Nguyen, 1997). The starch can also be used industrially as an adhesive and gelling agent (Ashun, 2018; Eleazu & Ironua, 2013; Iheagwara, 2013).

Most of the use of sweet potato in the developing countries is in the consumption of the whole tuber. In Ghana and Nigeria, the tubers are peeled, washed, boiled, and eaten with a sauce or vegetable stew. The tubers are also sliced and deep-fried in vegetable oil and eaten with fried fish and stew or sauce in these countries (Agbo & Ene, 1994; Grant, 2017). In South Africa, eating of boiled sweet potato with stew is no different from that of Ghana and Nigeria. However, South Africans would occasionally eat boiled sweet potato roots with tea (Domola, 2003; Van Oirschot, Rees, & Aked, 2003). Sweet potato roots are sometimes boiled and mashed and eaten (Domola, 2003). The tubers are cut into chips and dried to preserve them for use later (Van Oirschot et al., 2003). Sweet potato can also be prepared into gari in a like manner as cassava is prepared into gari. Sweet potato processing into gari helps in the

preservation of the tubers and the product stores well (Egeonu, 2004; Ellis, Oduro, Fianko, & Otoo, 2001). Not only are the tubers of sweet potato useful, but the leaves are also a good source of minerals, proteins and carotenoids including provitamin A carotenoids which make them nutritious for human consumption (Domola, 2003).

Moreover, sweet potato is used in the preparation of non-alcoholic drinks with citrus, pineapple or ginger flavour with beta-carotene. It can be used in the production of wine, liquor, vinegar, and sugar (Ellong, Billard, & Adenet, 2014; Truong & Fementira, 1990; Wireko-Manu, Ellis, & Oduro, 2010). In the United States, sweet potato is processed in purees in large scale which are sold in cans or the frozen form (Kays, 1985; Walter & Schwartz, 1993). Purees from sweet potato especially the orange-fleshed variety are used as ingredients in a variety of food preparations (Truong & Avula, 2010).

Aside from human and industrial use, sweet potato serves well as animal feed. This is particularly practised in Asia and the United States where the tubers are dried or fermented in silos or drenches and fed to farm animals (Scott, 1992; Woolfe, 1992). Studies report that in Asia, 50% of the total sweet potato produced is used in feeding livestock (Bouis, Graham, & Welch, 2000). Adding to the above, the leaves of sweet potato are used directly in feeding ruminants, poultry and other monogastric animals (Laurie, 2004).

Due to the high beta-carotene content of the orange-fleshed variety of sweet potato, several studies are focused on its addition to human diets and the different orange-fleshed sweet potato food preparations. This is to deal particularly with the worldwide health issues with micronutrients.

2.3.3 Health Benefit of Sweet Potato

The nutritional value of orange-fleshed sweet potato is high providing 90% of nutrients requirements of the body with 100% and 49% of Recommended Daily Allowance of vitamins A and C_4, 10% iron, 15% vitamin C (Kumoro, Retnowati, & Budiyati, 2012). Sweet potato is rich in complex carbohydrate, iron, dietary fibre, beta-carotene (a pro-vitamin A carotenoid) and other forms of vitamins. High beta-carotene is present in the orange-fleshed cultivar. In research conducted by Shih, Yeh, and Yen (2007), sweet potato was tested to contain; carbohydrates, protein, dietary fiber, vitamins A (beta-carotene), vitamins C and E, calcium, phosphorus, magnesium, iron, potassium, sodium and zinc in respective quantities as 20.1g, 1.6g, 3.0g, 709µg, 850 µg, 2.4mg, 0.26mg, 30.0mg, 47.0mg, 25.0mg, 0.6mg, 337mg, 55mg, 0.3mg.

Orange-Fleshed Sweet Potato (OFSP) has enormous health benefits including its high beta-carotene content, which makes it a very good source of vitamin A in the diet. Due to its high beta-carotene content, it plays a great role in the body as antioxidant and greatly improves the vitamin A status of children and people with low vitamin A in their serum (Burri, 2011; Hotz et al., 2012; Laurie et al., 2018; Li & Mu, 2012). A number of studies have confirmed sweet potato to have the potential of raising vitamin A levels of blood, mostly the case in infants (Chan et al., 2009; Garzón, Riedl, & Schwartz, 2009; Kolawole & Agbetoye, 2007). A 100 g tuber provides 8509l g of beta-carotene and 14187 IU of vitamin A, being the highest in the root-tuber category. These compounds are dominant natural antioxidants. Vitamin A, a key requirement of the body to maintain healthy mucus membrane and

skin forms an integral composition of OFSP (Ahmed, Akter, & Eun, 2010). The vitamins act as co-factors for several enzymes in metabolism. The beta-carotene is an interceptor of free radicals. Carotenoids contain antioxidant potentials and limits mutagenesis in cells; terpenoids moderate low-density lipoprotein (LDL) cholesterol levels and function as anti-carcinogens, cause for the cancer prevention qualities of beta-carotene. Orange-fleshed sweet potato is tested to contain 100 µg – 1,600 µg of Retinol Activity Equivalent (RAE) of vitamin A in each 100 g on an average to meet 35% of all vitamin A needs of the body.

It is also reported that orange-fleshed sweet potato contains adequate RAE to meet 90% of vitamin A requirements (Tsoyi et al., 2008). Both the leaves and roots of orange-fleshed sweet potato are edible. The leaves contain high levels of proteins, minerals, vitamins (A, B and K) and dietary fibre (Bowser, Ojwang, Sahs, & Brandenberger, 2017). Apart from the leaves providing these important nutrients in the diet, the roots also compare favourably with fruits in terms of their polyphenol contents and oxygen radical capacity (Bowser et al., 2017; Rautenbach, Faber, Laurie, & Laurie, 2010).

Purple flesh sweet potatoes have genetic factor IbMYB1 and IbMYB2, which are activated to generate purple anthocyanin colours responsible for the purple colour of the root. This variety has anthocyanins - primarily peonidin and cyanidin which have anti-inflammatory and antioxidant properties as it goes through the digestive system (Tsoyi et al., 2008). They lower the risk of oxygen radicals and heavy metals. Purple-fleshed sweet potatoes contain rich minerals, nutrients and functional polyphenols, thus are used as functional

food materials. They are produced in Asia, Africa and islands of the Pacific Ocean (Montagnac et. al., 2009).

Sweet potato is a significant source of carbohydrates for many manual workers with rich minerals and vitamins. Sweet potato diets are helpful for stomach ulcer patients. It also helps in lowering the risks of free radicals. The root has its greater percentage as starch with simple sugars; fructose, glucose and sucrose. Sweet potato is an average calorie starch food with 90% having no cholesterol or saturated fats but a rich source of minerals, antioxidants, vitamins, dietary fibre, amylose to the amylopectin ratio relative to *Solanum tuberosum* (Kurata, Adachi, Yamakawa, & Yoshimoto, 2007). The blood sugar level in the body is increased slowly by amylose in comparison to simple sugars, thus, is a highly recommended food substance for diabetic patients. Sweet potato has nutrients for visual acuity. As natural vegetables with flavonoids, they help protect the immune system and fight against infectious diseases. The roots are filled with essential vitamins; pyridoxine (vitamin B_6), pantothenic acid (vitamin B_5), and thiamin (vitamin B_1), riboflavin and niacin replenish the body (Yamakawa & Yoshimoto, 2001). Sweet potato provides a rich source of minerals such as iron, calcium, manganese, magnesium, and potassium that are vital for protein, carbohydrate and enzyme metabolism. The root contains phytochemicals such as chlorogenic acid and quercetin that function to protect the heart and fight cancer (Garzón et al., 2009).

2.4 Production and Utilization Challenges of OFSP

The orange-fleshed sweet potato (OFSP) is a special variety of sweet potato that has cultivars specifically released due to their potential nutritional

benefits. The OFSP has acceptable storage root shapes and root yields, above 10.0t/hectare compared to the national average for storage root yield of 4.0t/hectares. China is the highest producer of sweet potato in the world and produces about 89% of the total world production (Chan et al., 2009). Famers normally opt for the white and yellow flesh potato due to its dominance and market availability (Fermont, Babirye, Obiero, Abele, & Giller, 2010). Orange-fleshed Potato, however, has been produced in smaller quantities as customers' knowledge on nutritional potency of the variety was not adequately widespread. The International Potato Center (CIP) promoted the production and commercialization of OFSP in Sub-Sahara Africa (Malawi) in 2017 and spread to increase the production of OFSP in many growing areas across the globe. Production method and climate are the same for other varieties of sweet potato but different in nutrient composition. Prior to the intervention of CIP, OFSP was developed by conventional breeding in 1995, caused by attempts to eliminate Vitamin A Deficiency (VAD) among pregnant women and children (Burns, Gleadow, ZacariCumbana, Miller, & Cavagnaro, 2012).

OFSP has emerging attention in health for having high levels of vitamin A, which can provide a cure for VAD in developing countries in Asia and Africa. OFSP has nutritional and chemical composition influenced by climatic and environmental conditions and genotype. More than 40 cultivars of OFSP have been introduced in Africa. Some varieties such as "vitaa", "pumpin", "kabode" and many more have been tested in Kenya where "vitaa" and "kabode" have been exploited into purees (Owade, Abong & Okoth, 2018). The density of the orange-coloured varies positively with the volume of beta-carotene. OFSP was tested to have calorie-rich potency that can eliminate

Protein-Energy Malnutrition (PEM) (Kolawole & Agbetoye, 2007). Beta-carotene in its form of 13-cis, all-trans and 9-cis comprise 10 - 93% of overall carotenoid in OFSP. Studies have reported beta-carotene ranging between 0.03 and 13.63mg/100g fresh weight for different types of OFSP roots (Fermont et al., 2010; Kolawole & Agbetoye, 2007). A study conducted by Boonnop, Wanapat, Nontaso and Wanapat (2009) compared beta-carotene content of OFSP and the white, yellow and cream varieties where OFSP had 19.31-61.39µg/g and others were 1.02, 3.28 – 5.64 and 3.7839µg/g respectively. Padda and Picha (2008) reported that beta-carotene retention after cooking of exotic and indigenous varieties of sweet potato grown in India as 76.56 - 87.76% offers beta-carotene content of 4060-9740 µg/100g of fresh weight, but as the beta-carotene content increases in OFSP the dry matter content decreases. In another study, the acceptability of OFSP root is not only positively influenced by appealing colour and taste but also higher dry matter content (Abidin et al., 2015). Additionally, Bechoff et al. (2009) reported an increase of up to 46% in the in-vitro bioaccessibility of beta-carotene for OFSP roots prepared with fats as compared to just 41% for OFSP roots with a lower dry matter but a higher beta-carotene content as a functional ingredient in bread baking. OFSP, compared with other varieties of sweet potato, has the highest nutritional component in the dry matter; 38.56g, carbohydrates; 22.86g, protein; 4.19g, fats; 2.22g, fibre; 3.0g, starch; 16.9g.

Sweet potatoes, in general, are excellent sources of vitamins, and minerals including phosphorus, potassium, vitamins B, C, K, E, and dietary fifibre (Bengtsson, Namutebi, Almingera, & Svanberg, 2008). The inside of sweet potato roots (flesh) comes in a variety of colours— cream, white, orange,

yellow and purple. Only the orange ones, however, have considerable amounts of the antioxidant (cancer-fighting) beta-carotene, which the body converts into vitamin A, vital for a strong immune system, good vision and healthy skin. The pigmentation was researched to influence the presence of beta-carotene, the shade of orange colour. Ray and Tomlins (2010) established that 100g of medium intensity OFSP variety is adequate for daily vitamin A needs of an infant. Boiling as a basic preparation method of OFSP allows for maintenance of 80% of beta-carotene volumes relative to other crops with higher nutritional loss during preparation (Achir et al., 2014). OFSP is being projected as suitable for improved health (Abidin et al., 2015), making per capita consumption of OFSP in the United States rise from 1.9kg in 2000 to 3.4kg in 2014 (Johnson, Wilson, Worosz, Fields & Bond, 2015).

Vitamin A Deficiency (VAD) has been an issue for about 19 million women and 190 million pre-school children globally (World Health Organisation (WHO), 2009). Fermont et al. (2010) found that VAD is common among 40% of children under five in a global perspective. Suitable dietary means of vitamin A supply was seen to be OFSP. The crop is easier to cultivate relative to varieties such as the white-fleshed variety. Cultivation of OFSP in Central, Eastern and South Africa is dominated by women and children who are the victims of VAD. Due to the high beta-carotene content of OFSP, 500 m^2 of a variety producing 10 tonnes per hectare is adequate to provide vitamin A to meet the nutritional needs of a five-member family for a whole year (Boonnop et al., 2009). OFSP is not only a good source of vitamins but also dietary fibre (2.5–3.3 g/100 g). It is noted for its slow digestible characteristics relative to other boiled roots with a medium glycemic

index of score of 61 and glycemic load of 10.7 per 100 g (Kolawole & Agbetoye, 2007).

Some challenges have been recorded in the production and commercialization of OFSP globally. Processor supply issues and uncertain market demands are characteristic of the production of OFSP as farmers are unable to deal with postharvest losses resulting from market conditions (Burri, 2011). A study conducted by Nassar and Ortiz (2009) on market conditions of OFSP in Maputo, Mozambique, revealed that households demonstrated a preference for the OFSP but low purchasing power was the reason for poorly enhanced dietary supplementation with the produce.

Market development initiatives that encourage home consumption was still permitting surplus for sale on the market. Farmers produce high and above their household consumption. As farms were 10 times larger than domestic consumption, a slight increase in price resulted in a decrease in utility for potential consumers (Lippman & Lotan, 2000). Storage and processing have affected the production and utilization of OFSP. Seasonality is a limitation to consumption or utilization as OFSP is available from March to August in Sub-Sahara Africa. Mangoes, which are a vital complementary source of beta-carotene are available in December and February.

Cooking, processing methods and other forms of processing have been recorded to minimize beta-carotene retention. While protected pits can serve as storage for fresh roots for up to five months, some varieties of OFSP begin to depreciate within 12 weeks under indoor storage and others have 22 weeks in underground storage (Tanumihardjo, 2002). A study conducted by De Moura, Miloff and Boy (2015) showed high losses in carotenoids during

storage of dry OFSP chips. This creates difficulty in the storage of the root for more than 2 months, particularly for certain varieties. Some researchers argued that staggering planting seasons have the potential of reducing storage inconveniences (Burri, 2011). Achir et al. (2014) also found that processors have no adequate guarantee for supply to encourage business in the area.

Studies conducted in most growing areas indicate 10% thorough decay and 35% chemical damage. Eighteen growing districts in Rwanda have experienced significant postharvest losses (Rodriguez-Amaya, Nutti, & de Carvalho, 2011; Tanumihardjo, 2002). Other researches established that storage practice is key among challenges in OFSP production. Farmers use traditional storage means of covering the roots on the ground since other enhanced methods such as a CIP Model Storage solution are expensive. Unsuitable postharvest handling causes the development of bruise and damaged skins. Farmer cash flow leads to early harvesting and reduction of quality in the product. Transportation challenges also affect the scale of production and handling (Failla, Thakkar, & Kim, 2009; Lippman & Lotan, 2000).

Bechoff (2010) argued that OFSP has remained a significant source of vitamin A for health and wellbeing; however, production and utilization of the crops are characterized by a number of challenges, which create a low level of motivation for its production. OFSP like other varieties of sweet potato requires adequate field preparation; development of mounds, transporting the plant stems, cutting the stems and weeding among other activities. Its production is rather labour intensive and requires a large labour force for the cultivation of the crop. Planting materials must be transferred to the most

lowland during the dry season for preservation. The vine becomes yellowish in drought, therefore, needs to be kept in a moisture-laden environment to keep the stem live for propagations. Limited humid lowland zones for vine preservation, with the delicate nature of OFSP vines, prevent continuous planting (WHO, 2009). Other researches indicated that drought in the growing areas does not affect the White Flesh Sweet Potato (WFSP) but OFSP. As flooding is usually followed by insufficient rains, there is low yield from the OFSP roots, while WFSP is more drought resistant (Jenkins, Shanks, Brouwer & Houghtaling, 2018). As OFSP is considered intolerant to unpredictable climatic patterns, production levels are affected.

Farmer education on the nutrition on OFSP technology is inadequate in most growing areas in Ethiopia Burundi, Rwanda, Tanzania, Kenya, Madagascar, Malawi, Zambia, Mozambique, Burkina Faso South Africa, Nigeria and Ghana (Bengtsson et al., 2008). Farmers who have lately begun to produce OFSP have to confirm it as a useful technology. Scepticisms about the viability of the producing OFSP have remained a challenge among most new farmers. Studies conducted on the production bottlenecks in OFSP growing areas indicate that there is little consumer knowledge on the nutritional composition of OFSP relative to other varieties of sweet potato. Also, some consumers are concerned about taste rather than nutritional information as OFSP due to its texture was reported to have a relatively unsuitable taste and firmness when compared to other varieties of sweet potato (Muzhingi et al., 2008).

2.5 Cassava

Cassava (*Manihot esculenta* Crantz) is a root tuber known for its high starch content. It is referred to as yucca in the United States, Brazilian arrowroots or manioc. Cassava is considered an inherent of South America. It is eaten in whole, floured or grated to make crackers, bread, gari among other products (John, Ravindran, & George, 2005).

2.5.1 Geographical Distribution of Cassava

Cassava has its geographical evolution dated in the tropics. As the basic source of staple food for over 5 million people in the growing regions particularly in the South of the Sahara, cassava is placed sixth in the World's cultivation of food crops. Research has largely been focused on crops that thrive in temperate latitudes rather than in the tropics, limiting the development of the potential benefits of cassava to the population of the tropic regions (Lebot, 2009). A key question on the cultivation of the crop, which has remained uncertain in literature, has been on the development stages of cassava. Ninety-eight identified species in the genus Manihot, one of the widely cultivated types of cassava is spread in the Neotropics. Pedigrees of wild species of cassava have been identified and spread in the Neotropical eras. Some researchers proposed that the original domestication of the crop made from a multiplex of varieties of cassava from Central Africa or Mexico, thus making it "compilospecies" (Allem, 2002). Discovery has been made on a remote number of the cassava species, which are exact progenitors in South America. The relationship among the various wild species of cassava is limitedly examined. There is an increasing assumption that the roots of the evolutions of the crop spread further than *M. esculenta* and the crossbred

Manihot variety as remote types that have been identified in Brazil and Eastern Peru (Duputié, Massol, David, Haxaire, & McKey, 2009).

The species in these regions are referred to as *M. esculenta* subsp. flabellifolia (Pohl) Ciferri, commonly found in the transitional forest belts and the Savanna Scrubs of Brazilian plateau and the Amazon Basin. Cassava grows in the transitional forest zone as climbing undergrowth. Mato Grosso, Tocantins and Goias states located in the eastern and southern borders of the Amazon Basin experience thriving yields of the commonest species of cassava (Duputié et al., 2009). The sub-variety flabellifolia grows well within its regions including areas where other species cannot grow, the remote varieties are known to exhibit introgression following their domestication. Cassava is propagated by the stem and planted in depth of 10 cm with a maturity period of 6 – 24 months influenced by soil factor, altitude and climatic conditions (Hillocks, 2002). The planting depth aids the newly sprout roots to reach humidity and micronutrients in the soil. The crop thrives in marginal lands due to its low land preparation requirements. It however, experiences inhibited growth in rocky grounds where its roots have little penetration into the soil. Cassava was cultivated by over 1.9 million hectares worldwide in 2010, approximately 57% of fresh roots for consumption by humans and 32% industrial and other purposes (Montagnac, Davis, & Tanumihardjo, 2009). Over 500 cassava species are discovered across the world's cassava growing regions with different degrees of nutrient content (Mtunda, 2009).

2.5.2 The Role of Cassava in Nutrition and Health

Cassava is largely nutritional relative to its location, age, species, part of the plant used and natural factors in the growing area (FAOSTAT, 2010).

Carbohydrate is a keen energy source contained in the root, with starch variation between 80 – 95% for desiccated roots and 32-35% for freshly harvested roots (Balagopalan, 2002). Cassava has 85% and 17% of amylopectin and amylose respectively with a low amount of glucose, sucrose and fructose, but 17% sucrose in sweet varieties (Bellotti, 2002). The stage of growth and type determine the amount of fibre contained in the root. Fibre content varies around 1.7% for young roots and 4% in flour. Protein tested in cassava is minute, comprising 1.5mg/100g of the fresh root and 1 – 3% of its dry stock, low amino acid, moderate to high glutamic acid, arginine and aspartic acid (Mtunda, 2009).

Bourdoux and others in 1982 studied nutritional values of cassava in Mozambique and found 8 – 24mg/kg of iron, 3 – 140pm of zinc, 15 – 45mg/100g of vitamin C in the edible part. Other vitamins and minerals were found to be available in varying degrees (Bourdoux et al., 1982). Nutrition test conducted on the crop by Hillocks and Wydra (2002) revealed the presence of copper, calcium, potassium, zinc, iron, manganese and magnesium in the root as is available in some leguminous crops. Cassava has a relatively high calcium component among some commonly cultivated staple crops in the tropics like maize. The calcium component is about 15 – 35mg/100g of the root and leaves and ascorbic acid about 15 – 45mg/100g lost during processing activities. Cassava is recorded as the fourth source of carbohydrate sugar in roots, after rice, sugar cane and maize (Gleadow, Evans, McCaffery, & Cavagnaro, 2009). The freshly harvested root of the plant was tested to have 85 – 90% carbohydrates with 125 – 140kcal/100g. Cereal crops like sorghum and maize have higher vitamin and mineral composition than cassava (Duputié

et al., 2009). Cassava root peel was tested to contain fibre, minerals and fats in greater volumes than peeled roots, whereas peeled roots had a high concentration of carbohydrates that result from nitrogen-free extracts (Gil & Buitrago, 2002). Some researches established high calories but low proteins, minerals and fats in the fleshy cassava roots, which make the nutritional quality of cassava lower than leguminous crops, cereals, tubers and other root crops (Endris, 2007).

The World's production and consumption of cassava have risen among 230 million to 276.7 million people across the world from 2010 to 2015 with a projected increase to about 291 million in 2020 (Mtunda, 2009). Developing countries in Africa and Asia account for 51.3% and 29.4% consumption rates respectively. Countries such as Angola, Mozambique and DR Congo have the highest consumption rate of 787g, 680g and 653g respectively with Ghana being the fifth-highest with 543g per day, constituting a remarkable energy element for proper body function and health of people in these regions (Nhassico, Muquingue, Cliff, Cumbana, & Bradbury, 2008). Fresh roots are processed into gari, *miondo*, fufu and other food varieties. The energy needs of cassava cultivation regions positively vary with a daily consumption rate of cassava. Brazil has 900% lower consumption rate than Angola, which is the leading producer and consumer. This discovery illustrates the significance of cassava among low-income regions. According to International Fund for Agricultural Development (IFAD) and FAO study, many African countries have 600kcal daily intake per person (Bellotti, 2002). Cassava is used for chips, gari, cassava cake, French fries, tapioca and some medications due to its nutritional content and mild taste (Hillocks, 2002). Cassava was also

discovered to generate alcohol and is being used for beer and related products across the world. As a source of vitamin C and riboflavin, a measurable intake of cassava meals aids normal cell growth in the human body. Diets rich in riboflavin reduce migraine, some types of cancers and muscle cramps. Recent researches found tapioca starch as a gluten-free flour source, which can be used for bread for people with high gluten intolerance (Cavagnaro, 2008). Kolapo and Sanni (2009) in their research on the nutrition profile of cassava also found out that a cup of cassava flour contains; 42.4mg vitamin C, 78.4g carbohydrates, 330 calories, 3.7g fibre, 558mg potassium, 43.0mg magnesium, 2.8g proteins, 33.0mg calcium and niacin, thiamine and riboflavin. These micronutrients have diverse impacts on health and wellbeing. Vitamin C (ascorbic acid) available in cassava has an indirect influence of the function of the nerve tissues in the human body, converting dopamine into noradrenaline. The adrenal gland and the brain, which are tissues with high ascorbic acid experience biosynthesis of catecholamine. High volumes of vitamin C acts as stress sedative and anti-ageing effects. A balanced intake of Vitamin C in cassava acts like other citrus fruits in protecting against cataract and oxidation of molecular oxygen. An important biological function of vitamin C is its reaction with oxygen-driven unrestricted radicals (Gleadow et al., 2009). The high carbohydrate composition of cassava made of sugars, starches and fibre are the primary source of energy in humans, power agents for the kidney, nervous system, muscles and heart. Cassava fibre in young roots support digestion and limits blood cholesterol levels. Carbohydrates in cassava like grains and legumes are stored in the liver and muscles and released to the body in energy deficiency periods, thus preventing fatigue, headaches, nausea and

mineral deficiencies (Balagopalan, 2002). According to the United States Department of Agriculture cited in Hillocks and Wydra (2002), healthy carbohydrate foods contain more than 12grams per serving, where examples include cassava meals (Allem, 2002). Recommended Dietary Allowance (RDA) for carbohydrate, according to FAO (2010), are 130g, 175g, 210g for adults, pregnant women and lactating mother respectively. This classification endorses cassava meals as one key source of meeting these nutritional needs. As calories volumes in food describe the magnitude of potential energy it contains, 1g of carbohydrate in cassava has 4 kcal. This confirms that a cup of cassava flour of 78.4g of carbohydrates has 19.5 kcal, which in multiples is adequate for an adult energy need ranging from 2,200kcal – 2,700kcal daily. Dietary fibres in cassava are tested to be therapeutic but most of these fibres are removed during processing. Magnesium present in cassava plays a key role in the body's metabolism, reducing oxidation and regulation ions (Endris, 2007). Montagnac et al. (2009) in their research on food nutrients found a positive correlation between the intake of magnesium and calories. High caloric rich food like cassava has high volumes of magnesium. High potassium and calcium component of cassava is argued to limit the risk of high blood pressure, stroke and maintains the mineral density of the bone.

2.5.3 Nutritional Problems Associated with Cassava Consumption

Several pieces of research have been conducted on the nutritional value of cassava alongside dangers associated with its consumption. Cassava has anti-nutritional and toxic components that inhibit the breakdown and absorption of nutrient (Nhassico et al., 2008). Key among these components is cyanide. Cassava consumption has been linked with some diseases and

pathological conditions, revealed in epidemiological studies. The presence of cyanogenic glucoside in cassava limits consumption rates due to the multiplicity of health challenges related to it. Cyanide content in root parenchyma is about 10 – 500mg HCN equivalents/kg. Intake of 50 – 100mg of cyanide is related to severe poisoning and has been described to be harmful to adults. Cyanide causes severe eye problem, ulcers due to acid, carbohydrates causing weight gain and obesity (Møller, 2010). Prolonged intake of cyanide in small doses causes tropical neuropathy, glucose intolerance, cretinism and goitre. "Konzo", a widespread paralytic infection associated with consumption of toxic cassava is recorded in some parts of Nigeria where consumption among women between the ages of 60 – 69 is 24%. "Konzo" is related to geography and climatic conditions of the plant. "Konzo" is highly recorded in the savanna areas than forest regions, associated with complicated urinary thiocyanate. In Africa, cassava toxicity is worsened in the population that experiences deficiency in sulfur-containing amino acid (Morant et al., 2007). Anti-nutrients such as oxalate, nitrate, saponins and polyphenols, limit nutrient bioavailability, though serving as antioxidants and anti-carcinogens subject on the quantity consumed. Vetter (2000) found the volume of phytate in the root of cassava determined at 624 mg/100 g, inhibiting the absorption of minerals such as iron, calcium, molybdenum, and zinc. Phytate interferes with processes of enzymes in breaking protein in the gut. Other studies have reported decreased thiamin absorption, digestion of starch, lipid and protein, and the absorption of non-haem iron by tannins present in cassava. Cyanogenic glycosides have been found by other researchers as present in cassava roots as well as the leaves. Natural factor in

the environment such as climate, soil and genotype of the crop determines the level of toxic substances in the root (Nhassico et al., 2008). Though, fatality is rare in the consumption of toxic roots of cassava, marasmus, undernourishment and kwashiorkor are some reported cases (Montagnac et al., 2009).

According to FAO Report (2010), recommended cyanide volumes should not exceed 10mg per consumption in humans in order to limit toxicity and related complications. There is, however, reported case on high cyanide consumption in many cassava growing regions ranging from 14 - 70 times per person based on body weight. The consumption rate far exceeded the recommended rate by the World Health Organization cited in Liasu, Atayese, and Osonubi (2006). Prolonged consumption of cassava with cyanogenic glycoside resulting in chronic poisoning has been recorded in countries with high consumption of cassava, especially those particularly in the tropics. The highest record was in Mozambique. Konzo is most common in Mozambique, first recorded in 1981 by the Health Ministry (Cliff, Muquingue, Nhassico, Nzwalo & Bradbury, 2011). Women and children have been the most vulnerable groups. Reported cases were associated with bitter cassava, which was harvested in prolonged drought and poorly processed. Bitter cassava was found to be deficient in sulfur and amino acid (Nassar & Ortiz, 2009). High volumes of thiocyanate were tested in the urine of patients with konzo. As cyanide was detoxified, thiocyanate remains in the body and stores in the stomach. Patients with konzo have a high risk of stomach cancer.

Suitable processing methods have the potential of reducing anti-nutrients such as cyanogenic glycosides by soaking, drying, fermentation, roasting, wetting

and boiling. A combination of the processing methods can include detoxification, which provides a better quality of nutrients, or the process can be used singularly. Genetic manipulation was found by Vetter (2000) as a sustained method of eliminating concentrated cyanogenic glycosides from cassava.

According to Balagopalan (2002), cassava roots are low in fats, proteins, vitamins and minerals. Cassava is argued to have lower nutritional elements relative to yam, legumes and cereals. Protein content in cassava is as low as 1-2% and lacks essential amino acids; tryptophan, lysine and methionine. Peeling, significant processing stage of cassava was found to reduce the protein content in the root as cassava peel is higher in protein than in the flesh. Other authors established that fermentation of cassava root enriches protein content by 6 - 8 factors (Cavagnaro, 2008). Calcium and vitamin C present in cassava are high; however, niacin, thiamine and riboflavin were in a minute, with a considerable quantity lost in processing. Cassava leaves were found to be rich in proteins and many researchers recommended it as a source of protein to supplement the root (Hillocks, 2002). Fermentation of cassava for about 24 hours creates health dangers for consumers of products, which uses such processes where gari forms a typical example. Cyanogens, which are residues contained in cassava have severe health hazards such as tropical ataxic neuropathy, hyperthyroidism and konzo. Indigested cyanide is transformed into thiocyanate, an antiphon catalyzed by the enzyme rhodanese (John et al., 2005). Cassava has limited amino acid, which inhibits synthesis resulting in stunting growth among children. In a study conducted by Balagopalan (2002) in Mozambique on child nutrition, it

revealed that an estimated intake of cassava flour among children in a konzo prone area was 700 - 900g fresh for each child daily. A lower rate of 20 - 140g was discovered in non-konzo areas.

Some methods of processing can remove cyanogens from cassava to make the crops more nutritionally relevant to human consumption (Allem, 2002). Combination of Cassava foods such as leaf-meat, methionine and other nutrients would considerably enhance the organic value. The combination has been the practice in industrial food processes that use cassava as raw material (Bellotti, 2002).

2.5.4 Utilization of Cassava

Utilization of cassava ranges from pharmaceutical, industrial and domestic products, where domestically the root is primarily made into flour. Citric acid is made from cassava starch using some strains of *Aspergillus niger*. Starch content referred to in World trade as tapioca is used for baked products, dextrin and glucose. As starch is one key staple food for the human diet, cassava has been one vital raw material aside potatoes, maize, wheat and rice (Taiwo, 2006). Starch from cassava is used in several food preparations and non-food industries for chemical raw materials. Sizing, coating, adhesive, which are nonfood products for cassava starch constitutes 75% productivity of commercial starch. Though resin glue has largely replaced starch, there is continuous development in the production of starch (Gbadegesin & Beeching, 2011). Food products account for the highest utilization of cassava. Glucose and unmodified starch are used directly for custard, baby foods, gravies, sauces, and bakery products. Cassava starch is used in Malaysia in unsweetened and sweetened biscuit and cream sandwiches at the rate of 5-

10% to soften their texture, which adds taste and makes the biscuit non-sticky. Cassava is also used for certain types of candies and soft gums.

Developing countries in Africa and elsewhere in the world have high bread consumption made from cassava (FAOSTAT, 2010). In the tropics, cassava is used for a wide variety of animal and poultry feed. Cassava peels are feed to goats, sheep, pigs while boiled or raw roots mixed with protein extracts are fed to livestock. Cassava alcohol is one rich product of cassava made by fermentation. Fresh cassava root contains 5% and 30% sugars and starch respectively, whereas dry roots containing 80% fermentable substance as a source of alcohol. Ethyl alcohol is made from various carbohydrate materials (John et al., 2005).

A research conducted by Appiah, Nortey and Kagya-Agyeman (2003) further revealed utilities of cassava. Cassava is the raw ingredient for a number of staples in the world, particularly in Africa. Examples include cassava pudding, *polvilhoazedo*, *manicuera*, *pappad*, *gatot*, *kapokpogari*, wafers, *dumby*, *peujeum mingao*, farina, *oyek*, cassareep, *wayana* cassava flakes, *tiwul*, flour, *lafun* cassava rice, cassava bread, fried chips, *ampesi*, *attieke*, *fufuo* (fufu) and gari (Vetter, 2000).

The various food products are patronized across their dominant borders. Cassava rice is eaten by the people of Indonesia and the Philippines, Farina and Mingo in Brazil and West Indies. Dominant cassava foods in Central and West Africa are attieke, tapioca, ampesi, fufuo (fufu) and gari in Cameroon, Guinea, Nigeria, Benin, Togo and Ghana. Gari is a common staple food in these regions, particularly in Nigeria and Ghana. Gari is made from fermented part-dried pulp from cassava sieved into fibre granules and roasted into crispy

and creamy yellow coloured grains. Gari is eaten with soup and stew or made into porridge or several other forms (Hillocks & Wydra, 2002).

2.6 Gari

Cassava being one of the starch-rich foods in the world has gained increased nutritional and economic importance due to the multiple functions of starch in domestic and industrial use. A number of processing and storage means have been adopted for cassava roots due to its physiological and microbial deterioration usually between 2 - 3 and 3 - 5 days of harvesting respectively (Sanni, Adebowale, Awoyale, & Fetuga, 2008). Nigeria, being the largest cassava producer in the world, with production levels at 80% among rural farmers, is unable to adopt modernized storage methods (Sanni et al., 2008). Gari, a primary fermented product of cassava gained grounds as a form of cassava storage.

Gari is made by peeling of roots of cassava, washing and mashing into cassava pulp. The pulp is drained in a porous bag with an adjustable machine or exerted pressure blocks. The par-dried pulp is sieved and roasted to form granular gari, which can be stored for a longer period. Other food varieties such as 'eba' and 'kokoro', made from gari with a combination of other food products are staple foods in Nigeria and Ghana (Phillips, Taylor, Sanni, & Akoroda, 2004).

There are two variations of gari determined by colour; white and yellow. The yellow coloured is roasted with palm oil and the white coloured is without palm oil. Quality of gari made in Ghana is determined by the size of grains and taste. Finer grains and sweeter ones are preferred over sour large grains. Retailers and food vendors prefer one with higher starch content as it has a

high swelling ability. Crispier grains define freshness. Gari is eaten with or without extra cooking by soaking with condiments and making eba usually eaten with soup or gravy (Sanni, 1990).

2.6.1 Nutrient and Health Benefits of Gari

It is important to note that consumption of gari has both constructive and adverse impact of the human body. However, a balanced consumption with other food varieties and right quantities provides good nutritional and health needs for the body. Suitable processing method also enhances the nutritional and health benefits. Cassava, the raw material for gari is copper, fibre and magnesium-rich. A number of health benefits are derived from gari, which are beyond its energy giving ability (Oduro, Ellis, Dziedzoave, & Nimako-Yeboah, 2000).

Gari contains manganese, iron, calcium, thiamin, ascorbic acid, sodium and dietary fibre. Due to the high fibre content digestion is aided. The fibre also helps in weight loss, reduced the risk of heart conditions and cardiovascular diseases. The resistant starch which does not get fully absorbed in the digestive system acts like soluble fibre in removing cholesterol present in the system and also aids the reduction of glucose in the blood (Ikujenlola & Opawale, 2007).

Vitamins and minerals in gari though in lower quantities help in the healthy maintenance of the immune system, healthy bones and nerves. The presence of copper in gari facilitates the functions of the nervous system and reduces the risk of osteoporosis. High amount of calories in gari estimated as 360kcal that is 99% of carbohydrates offers the human body its daily energy need. Some researchers have argued that vitamin B_{17} (amygdalin) and fibre

contained in gari prevent the growth of cancerous cells in the stomach (Maziya-Dixon, Dixon, & Adebowale, 2007). Some other studies showed that one cup of gari has 15% and 47% folate and calcium respectively, which are daily requirements of the body. Foetal development among pregnant women is enhanced with reduced age-related macular deterioration by the presence of folate in the body (Akingbala, Oyewole, Uzo-Peters, Karim, & Baccus-Taylor, 2005). Gari known to be gluten-free in the absence of protein combinations, which are common in grain foods, serves as a healthy diet for celiac patients or people with high gluten intolerance as it prevents guts irritation and harm to the small intestine (FAO, 2000). Nutritional test conducted by Kolawole and Agbetoye (2007) found the following compositions in gari; iron, carbohydrates, calcium, protein, calories, fat and fibres in respective quantities; 1.5g, 80g, 40mg, 1.1g, 330kcal, 1g and 48g.

2.6.2 Gari Processing in Ghana

Production of gari in Ghana has originally been associated with the Ewe ethnic group. An attempt to provide calories for the increasing population led to the discovery of the traditional food, gari. Processing is done on small scale thus, there is little or no quality control. Gari was produced on small to medium scale by individuals and cooperative groups (Sanni et al., 2008). Preparation method such as fermentation is variable from one location to another. Gari was not preferred by a large population in Ghana particularly among the Ashantis; however, through increased commercialization in late 2000, production includes other locations; Awutu-Efutu-Senya, Suhum-Kraboa-Coaltar, Beposo, Pokuase, Central Gonja and Ho Districts and various regions in Ghana (Maziya-Dixon et al., 2007). In a survey conducted by

Phillips and others (2004), methods of production of gari from freshly harvested cassava root involve flaking or peeling, washing, grating, draining of water by pressing mechanisms, fermentation, sieving and roasting. Conventionally, cassava peels are removed by knives, washed and grated by brass rubbing or the use of perforated galvanized metal piece on a wooden board. The pulp is bagged in a jute sack and drained by squeezing the starchy water with the weight of a block. Fermentation occurs in the draining process for about two days. The par-dried dough is sieved on a raffia tray to remove the fibre. The sieved flour grains are roasted in a large open pan by stirring till fully roasted and crispy. The final product is again sieved to remove lumps and then packed for storage or market (Appiah et al., 2003). Gari that is processed by hand may not keep well on shelve due to high moisture content. Improvements in technology have replaced the labour-intensive processes with the invention of the mechanized cassava grater and the wing-nut screw press or hydraulic press. Additives such as palm oil, soya beans are sometimes used to enrich the look, feel and taste of gari and protein content of the product (Kolawole & Agbetoye, 2007).

2.6.3Economic Importance of Gari

Gari is one key marketable product from cassava that has its price continually varied from 2008 where the price per 1kg increased at an increasing rate than the price of maize (Dziedzoave, Graffham, & Boateng, 2004). In 2015, the price of gari increased by 7.2 times from 2005 whilst maize stood at 5.7 times within the same period. The prize hype was attributed to increased consumption among students and urban societies and export avenues. Gari was exported at US$ 443 per tonne in 2008 where the countries

total export stood at 3404 tonnes, contributing US$1,679,719 to Gross Domestic Product (FAO., 2010). Though there were high fluctuations in the export price of the commodity, the total tonnage exported has continuously increased. Export price dropped from US$ 746 per tonne in 2007 to US$ 493 in 2008 and US$ 343 in 2015 (WAAPP, 2009). ISSER (2000) indicated that fluctuations in export prices are unfavourable for policy development, as Ghana continues to be a price taker than giver. High domestic prices of raw materials, limited supply and poor quality of the cassava products are limiting factors for Ghana entering the world market (WAAPP, 2009). According to Quaye and others (2009), cost-benefit ratios for gari production at the small scale ranged from 2.9 – 3.9, and average net profit per month for gari was 50% to total monthly revenue in the Gonja District (Yidana, Osei-Kwarteng, & Amadu, 2013). This indicates that cassava processing was cost-effective and profitable and accounts for high living standards in the Gonja District. Processing of cassava into gari provides job opportunities, enables value addition, reduces waste caused by spoilage of cassava, improves the suitability and enhances technical and commercial skills of the rural people. Gari, fermented, gelatinized and roasted cassava is most of the derivative of cassava in Ghana, a convenient and inexpensive carbohydrate. Gari forms part of the weekly menu of all high schools in Ghana. It has a large developing export market within and outside Africa, particularly in Europe (Sanni et al., 2008). Though a number of processing centres in Ghana are still underdeveloped and at the elementary level, its income-generating potentials are significant. The prolonged shelf life of cassava through gari processing enhances convenience and value and enforces domestic trade for the product in Ghana (Akingbala et

al., 2005). Gari production also requires investment in fuel, transport, labour, packaging and marketing which are rippled economic activities. The emphasis of the Root and Tuber Improvement and Marketing Programme (RTIMP) in Ghana, which is geared towards improving rural livelihoods and reducing poverty using cassava as one of the product chains is in line with the Millennium Development Goal (MDG) - 1. Continuance of its goal therefore, the RTIMP has reinforced the creation of about ten Good Processing Centres (GPC) between 2010 and 2012 to support the processing (FAO, 2010).

2.7 Fermentation

2.7.1 Fermentation in Food Preparation

Fermentation is an important reaction that involves the breakdown of sugar, occurring in the absence of oxygen to release carboxylic acids, gases or alcohol (Mani, 2018). It is the basic means of ATP production by the breaking down of organic substances by microorganisms in the absence of oxygen. The main living organisms involved in the breaking down of sugar are bacteria and yeast (Mani, 2018). It is believed that fermentation has been used essentially in the preservation of food products by employing the actions of organic acids and alcohols. Fermentation has also been employed to develop food aroma, improve texture, detoxify foods and reduce the time for cooking food (Rolle & Satin, 2002). Fermentation is used in the preparation of foods through the application of beneficial microorganisms or the enzymes they secrete (Geis, 2006). Foods over which harmless microorganisms grow or are cultured are referred to as fermented foods. Beneficial microbes or their enzymes hydrolyse sugars, starch, proteins and fats in these food substrates into

products that are not toxic, have more nutrients and have desirable sensory characteristics to humans (Steinkraus, 1996).

Research into the process of fermentation dates back to the works of the French chemist, Louis Pasteur, who in 1857 connected yeast to fermentation and defined fermentation as respiration without air; the winner of the 1907 Nobel Prize in chemistry, Eduard Buchner (German), who determined that fermentation was actually caused by a yeast secretion termed zymase and the Danish Carlsberg scientists, who greatly accelerated the gain of knowledge about yeast and brewing and are identified with the early study of microbiology (Mani, 2018).

Although, before these scientists studied into fermentation, the process was used traditionally in the preparation and fermentation of foods, especially in drinks and fruits. It is reported that over 5000 years ago, people were drinking fermented beverages (Dirar, 1993). Bread, which is also prepared through the process of fermentation, was eaten in Egypt as far back as 1500 BC (Suhigara, 1985). Today, fermentation is still used in the preparation and preservation of a variety of foods and food products. It is used in foods such as pickled cucumber, yoghurt, beer, wine, fufu (Nigeria) and gari (Mani, 2018,).

2.7.2 Effects of Fermentation on Biochemical Properties of Gari

Oboh and Akindahunsi (2003) concluded in their studies that fermentation of cassava mash leads to an increase in the protein and fat content of cassava products. Their study showed a 10.9% increase in protein and 4.5% increase in the fat content of flour produced from fermented cassava mash while a 6.3 % increase in the protein and 3.0% increase in the fat contents were observed in gari produced from fermented cassava mash. In

addition, their study revealed that after fermentation the magnesium and iron contents of gari increased significantly. However, a decrease in the cyanide content was observed in both fermented and unfermented cassava mash products, which, could be attributed to the pressing of the mash, which led to leaching of the anti-nutritional content of the cassava mash (Oboh & Akindahunsi, 2003). A decrease in carbohydrates was also observed in the study by Oboh and Akindahunsi (2003). This decrease could, however, be attributed to the breakdown of sugars and starch by useful microorganisms as stated by Steinkraus (1996) or as a result of high roasting temperature as reported by Eggleston and Vercellotti (2000).

Escobar et al. (2018) observed in their study that though fermentation had some influence on the biochemical characteristics of gari produced from fermented cassava dough, it did not have any considerable effect on the macroscopic properties of the gari. Thus, the moisture content, the grain size and solid volume fraction of the gari were not affected. The microscopic properties of the gari, such as the starch content, sugar content, pH and cyanide content, however, decreased while lactic acid content increased. In addition, Escobar et al. (2018) reported a higher swelling capacity of gari produced from a fermented dough as compared to gari produced from unfermented dough.

2.8 Effects of Storage on Sweet Potato and Beta-carotene

2.8.1 Effects of storage on sweet potato

Beta-carotene discovered in nutrition research, as being present in OFSP confers pro-vitamin A activity that is affected in the processing and storage of OFSP in various forms. The presence of carotenoids in sweet

potato, in general, has combination with phenolic compound; hydroxycinnamic acids, which embodies the main phenolic antioxidant in most marketable sweet potato cultivars. Free radicals scavenging ability and antioxidants in sweet potato are largely attributed to phenolic contents (Burri, 2011). Low et al. (2007) indicated accumulated research evidence supporting cardio-protective, anti-diabetic, hepatoprotective, anti-mutagenic properties and physiological functions of anthocyanins in purple-fleshed sweet potato.

It was further indicated that these compositions in sweet potato are affected by the diverse transformational stages that the root is presented. Similarly, the phytochemical contents of sweet potato are affected by postharvest and management or handling procedures including curing time, temperature, irradiation time, and exposure to light due to biochemical responses of tissues (Padda & Picha, 2008). Many fruits and vegetables are vastly perishable, however, unlike fruits that have short consumption lapse, time from harvest to consumption of sweet potato ranges from days to months. In the temperate latitudes such as United States, tubers are preserved in a well-ventilated facility at a temperature sustained at 29°C and relative humidity ranging between 85 – 90% from 4 – 5 days (Bengtsson et al., 2008). The effects of preservation and storage on sweet potato have been investigated in a number of researches, with attention focused on carotenoid and vitamin C. WHO (2009) noted inadequate documentation and postharvest management effects on sweet potato and its compositions. Limited researches indicated that radical scavenging ability and polyphenols in sweet potato increased during 37-day cold storage, but the degree of increase was not known. The farming site, age of tuber and boiling have been recorded to affect carotenoid content of sweet

potato, with no adequate data on the effect on storage on the photochemical composition such as chlorogenic acid and quercetin that function to protect the heart and fight cancer (Garzón et al., 2009). As OFSP has been largely researched to contain high levels of beta-carotene, traditional storage methods – open pit and shade, heap method; slide and dry – are recorded to present biochemical changes in appearance and composition of the root, particularly the slide and dry method (Shih et al., 2007). In some studies, pit storage was indicated to have retained beta-carotene than other ambience methods as it contained high moisture and low temperature (Shih et al., 2007).

Bioaccessibility, which gives an estimated amount of beta-carotene that would be absorbed by the body, is influenced by the crude storage methods. Carotenoids and provitamins are recorded to be influenced by the tissue microstructure of the sweet potato roots. Other physiological changes such as loss of moisture and texture modification also take place. Starch is degraded into sugar during storage by the action of enzymes amylase thus affecting the microstructure of the sweet potato root (Shih et al., 2007). The level of amylase moderates microstructure changes in relation to temperature and water. Variations of the components of OFSP as established in many studies vary with duration of storage (Wholey & Booth, 1979).

According to Tumuhimbise, Namutebi and Muyonga (2010), higher temperatures were recorded to increase respiration, which causes lignification of the sweet potato cell wall during storage. Slide and dry methods are the major method adopted in northern Ghana in addition to the covered pit. Potato stored by this method stays up to four months as long as its moisture content is reduced, however, taste, appearance and quality of the products are reduced

drastically (Chan et al., 2009). In a study conducted by Bengtsson et al. (2008), detrix decreased from 53 – 37 constituting a 30.2% increase in 3 months period of storage. Other researchers have however established that long duration of storage causes the largest increase in detrix. Fructose and glucose reduce while non-reducing sugars increase; carotenoids are exposed to oxidation and isomerization during processing and storage due to unsaturated nature (Padda & Picha, 2008). Postharvest handling methods that cause degrading of these materials are not worth adopting.

2.8.2 Effects of storage on beta-carotene

There is an increasing interest in the relation between storage temperature and beta-carotene levels in processed OFSP. Several studies relied on OFSP flour that has been stored for a long time at variable temperatures. One major concern is the probability that long-term freezer storage may reduce micronutrient concentrations to such low levels that they cannot be evaluated or that variances between cases and controls will become very small as to be unreliable (Lai, Huang, Chan, Lien, & Liao, 2013). Until definite studies are conducted, a review of the experiments relevant to long-term storage effects will indicate the effects of storage duration and temperature on beta-carotene in OFSP. Curing duration, temperature, radiation and exposure to light have been observed to influence the physicochemical content and biomedical responses of beta-carotene (Grace et al., 2014). Few experiments have recorded notable changes in beta-carotene at various stages of storage (Vimala, Nambisan, & Hariprakash, 2013). Chattopadhyay, Chakraborty, Kumar, Nanda, and Sen (2006) observed an increase of up to 50th day of storage and afterwards decline in beta-carotene. Pugliese et al. (2013) in their

study on long term freezer effects on micronutrients found out that retinol (vitamin A) is stable at storage temperatures of -20°C for at least 15 years, only moderate losses of α-tocopherol occur at temperatures above -40°C in the period and a minute proportion of beta-carotene persists at storage temperatures above -40°C. A decrease in carotenoids has been extensively studied in nutrition science.

Key factors affecting carotenoid oxidation, causing reduced content value are light, temperature, oxygen and acidity (Garzón et al., 2009). In addition, moisture is a very important parameter to evaluate the quality of dried foods or powdery products (Lavelli, Zanoni, & Zaniboni, 2007). Research on freeze-dried sweet potato cubes has shown high levels of beta-carotene decrease at lower water activities (Haralampu & Karel, 1983). Decreasing carotenoids are known to have high oxygen concentrations in dried sweet potato flakes (Emenhiser, Watkins, & Simunovic, 1999).

Storage temperature (4 °C; 25°C; 40°C) has also been confirmed to affect the variability of carotenoid pigments of freeze-dried sweet potatoes having greater losses at high temperatures (Çinar, 2004). Largely, the reduction of carotenoids in a dried food system, under the influence of many factors has been verified to be a first order kinetics reaction (Lavelli et al., 2007). Production of aroma compounds from carotenoids has also been extensively studied due to the application in the flavour industry (Dutta, Raychaudhuri, & Chakraborty, 2005). Other authors have defined volatile products causing degradation of pure beta-carotene to be naturally present in oak wood and paprika powder (Vimala et al., 2013). The highly unsaturated chain of the beta-carotene molecule makes it react easily with any radical species present

(Garzón et al., 2009). Carotenoid disintegration can be caused by autoxidation (air), heating and enzymatic activity (Padda & Picha, 2008). The chain response is characteristic of a free-radical reaction where a product is oxidised into secondary products that are themselves oxidised into other products (Bengtsson et. al., 2008) It is established that beta-carotene given-up to oxidation is degraded into epoxides, apocarotenal and apocarotenoid. At the final oxidation stage, they are self-oxidised into lighter carbonyl compounds, which are explosive. Trans-beta-carotene, 70-80 and 90-100, which are two types of asymmetric cleavages lead to the β-apo-80 and β-cyclocitral carotenal respectively. These unequal cleavages were achieved using xanthin oxidase (Boonnop et al., 2009).

Bechoff and others (2009) and other researchers on carotenoid loss in OFSP again established availability of 80% carotenoid in OFSP, which is a trans-beta-carotene. There were efforts by the HarvestPlus Challenge Program to develop the use of OFSP with a high amount of β-carotene. The programme was targeted at incorporating OFSP in some African recipes (Bechoff et al., 2009). Incorporating OFSP into many food products to achieve high nutritional quality has been discussed in other literature. There is, however, a paucity of data on the retention of carotenoid in OFSP in a slide and dry storage method, or direct sun and oxygen exposure (WHO, 2009). In another study on the retention qualities of beta-carotene during processing, it was recorded that beta-carotene levels were not significantly different after processing. On the contrary, OFSP chips stored at room temperature within the same duration resulted in highly significant losses of provitamin of 70% (Lavelli et al., 2007). Treatment interventions: blanching, antioxidant and

salting did not significantly help in the retention of beta-carotene during storage. In another controlled experiment, dried OFSP chips were stored in temperatures of 40°C, 30°C, 20°C and 10°C. Pro-vitamin levels were variously recorded; lowest temperature, oxygen and high humidity had the least lost (Cinar, 2004). Effect of storage; light, temperature and oxygen was investigated in other fruits to examine parity in the stability rate relative to OFSP products. Changes in quality retinol equivalents (RE) in provitamins A carotenoids in fresh-cut stored for 7 days at 5°C in controlled atmosphere of 12% CO_2, 2% O_2, and in the air. 2% O_2 and 12% CO_2 had no effect on quality attributes of slide peaches over the 7 days storage (Maiani et al., 2009). The appearance of the slides was improved by the treatment containing 12% CO_2, resulting in appreciable differences in pigmentation. Peach slides stored in air and 12% CO_2 had lesser content of beta-carotene and beta-cryptoxanthin, causing lower RE than the other treatment. Various carotenoids observed in permission slides differently responded to tested atmospheres; storage in 2% O_2 or air and 12% CO_2 tended to result in lower RE after 8 days. The loss was not substantial for fruits stored in less than 2% O_2 or air and 12% CO_2. The limit of shelf life was reached before major losses of carotenoids occurred in sliced peaches and persimmons (Pénicaud, Peyron, Bohuon, Gontard, & Guillard, 2010). Variability of beta-carotene, being a carotenoid with vitamin A level rated highest, has been examined under laboratory conditions to complement discoveries in processing and storage. Beta-carotene was tested to be relatively invariable over 24 hours with a total loss below 4% and less than 15% loss over 48 hours after micellar solutions in aqueous medium of this

carotene were nurtured at 37°C, in the dark, in a five percent carbon dioxide in the atmosphere to facilitate incubation conditions (Scita, 1992).

Ultraviolent and florescent lights effect on solutions of beta-carotene in toluene was greatly damaging. Fifty percent loss was observed after 8 hours exposure to UV light and 24 hours sunlight experience. Two well-known anti-oxidants; Alpha-tocopherol and Butylated hydroxytoluene (BHT) reduced the degradation of beta-carotene drastically under light exposure. Alpha-tocopherol had a much stronger relative potency to inhibit the loss of pigment under the same concentration of 1nM. OFSP flakes are largely inexpensive, self-regulated source of provitamin A (beta-carotene) (Chilungo et al., 2019).

Due to the susceptibility of beta-carotene to oxidative degradation, mostly in dehydrated food materials in the presence of atmospheric oxygen, many packaging conditions were examined for the improvement of beta-carotene preservation in OFSP. The flakes packed in polypropylene film, which had high oxygen penetrability with air headspace and laminate film, which had limited oxygen permeability with air headspace, under vacuum or with an enclosed sachet of fresh oxygen absorber. The packaged flakes were preserved in a dark ambience laboratory temperature (~23°C). Beta-carotene content was measured from 0 – 210 days of storage with the adoption of reversed-phase liquid chromatography. From the packaging conditions tested at the given temperature, beta-carotene retention was improved significantly as the presence of oxygen decreased as air headspace< vacuum< oxygen absorber < polypropylene< nylon. The collective adoption of flexible oxygen barrier films and oxygen absorbers provided significant retention of beta-carotene in the 210-day trial (Emenhise et al., 1999).

As indicated in the foregoing literature, a considerable number of studies have outlined various media through which beta-carotene is degraded in storage under variable conditions. Some studies have established carotenoid losses during storage of dried processed products of OFSP. Kosambo (2004) reported 50% loss of beta-carotene in OFSP chips at 25°C room temperature and chips stored in a freezer for three months at a temperature of -20°C had retained beta-carotene levels. Temperature influence on beta-carotene was tested to be due to isomerization, with limited heat concentration causing less damage than high heat concentration. Dried, flakes and powdery products of OFSP at 45°C, 40°C and 20°C temperatures demonstrated remarkable variation in carotenoid contents (Çinar, 2004; Tang & Chen, 2000). A study by Woolfe (1992) however, recorded no influence of storage temperature of 21, 14, 7, 0°C on beta-carotene composition of OFSP. Provesi and others (2011) in their research on determinants of beta-carotene degradation found that 180 days storage in various temperatures had no significant effects on beta-carotene levels. From the dominant cases in previous studies, temperatures and durations of storage have a negative correlation with beta-carotene content in OFSP food products. Varying oxygen concentration at storage has direct and indirect effects on product contents. Head-space oxygen present in storage space or bag was found to influence beta-carotene contents (Bengtsson et al., 2008). Six-week stored samples in 2% oxygen showed an average loss of 4.4% of beta-carotene higher than that of samples stored under 0% oxygen. Higher losses were anticipated with a prolonged period of storage. In storage media, where levels of oxygen concentrations were high, carotenoids degradation was observed to be higher in dried flakes of OFSP,

pasteurized mango puree and tomato source (Emenhise et al., 1999; Vásquez-Caicedo, Schilling, Carle, & Neidhart, 2007).

Water-resistant packaging with oxygen absorber was found to be effective at inhibiting carotenoids degradation by oxidation (Emenhise et al., 1999). Economically, Low-density polyethylene (LDPE) with high oxygen permeability has been highly used as alternative for packaging of beta-carotene than laminate paper, which is more suitable and however scarce. Light was classified as one key determinant of beta-carotene variability in the stored product. Carotenoid degradation was caused by photo-oxidation. Light increases isomerization of beta-carotene, lutein standards and α-carotene, relative to samples stored in the dark (Tang & Chen, 2000). Average effects of light on beta-carotene isomerization relative to temperature have been reported.

According to Chen and Huang (1998) isomerization of hexane at a temperature of 70°C reached 40 minutes in the dark, compared to a temperature of -50°C in 12 hours at 2000 lux. On the contrary, studies and observations have been made on the effect of light on beta-carotene loss. In a study conducted by Rodriguez and Rodriguez-Amaya (2007), beta-carotene degradation was not influenced by light in 21-day storage. Photooxidation in beta-carotene rich foods like potato flakes and gari can be reduced by limiting light exposure on the produce and engagement of opaque packaging materials in storage (Chilungo, 2019).

2.9 Summary

Bio-fortification of sweet potato provides considerable options in solving Vitamin A deficiency among women and children in Africa as well as

provides more commercial avenue for producers, which are predominantly low-income groups in the tropic latitudes. Cassava, which has been used traditionally for flour, tapioca, cassava flakes and gari has been researched to be characterized by nutrient gap relative to OFSP. A number of studies conducted on the nutritional viability of OFSP have confirmed its suitability for vitamin A supply. Processes in the transformation of the fresh root have been hypothesized to influence its nutritional value. Confirmation in literature presents variable cases of nutrient loss through processing. The key focus in the foregoing chapters was the influence of storage on beta-carotene (vitamin A) content of the processed product. Among many views presented, temperature and light are dominants determinants of beta-carotene variability in food products during storage

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sample Preparation

Mature and healthy "Afisiafi" cassava and orange-fleshed sweet potato (OFSP) roots were selected for processing into the OFSP–cassava composite gari. The selected cassava roots were peeled and any discoloured parts removed. The peeled cassava roots were washed twice in clean water to removed dirt and other impurities. They were then placed in big baskets lined with jute sack to drain off water prior to weighing and grating. The unpeeled OFSP roots were also washed in clean water with a rubber sponge to remove all dust or soil particles and other impurities and placed in another container with clean water after each washing to prevent enzymatic browning. To ease grating, the OFSP roots were cut into slice prior to weighing and subsequent grating. Before grating, the cassava and OFSP roots were weighed and mixed. The grated mash had 10% OFSP: 90% cassava, 20% OFSP: 80% cassava and 30% OFSP and 70% cassava. Eleven combinations were made according to the experimental design. The different composite mashes were put in nylon bags and pressed using a screw press to dewater, remove and simultaneously ferment the mash. The gari preparation flow chart followed is shown in figure 1.

3.2 Fermentation of Mixed Dough or Mash

In a typical gari processing, the dough is fermented for up to 3 days. In this study, because of the fortification with OFSP, the effect of fermentation duration from 1 to 3 days on the responses was assessed. The flow chart for the preparation and fermentation of the dough from the fresh roots before

roasting is shown in Figure 1. Roasting of the gari was done after 1 day, 2 days and 3 days of fermentation.

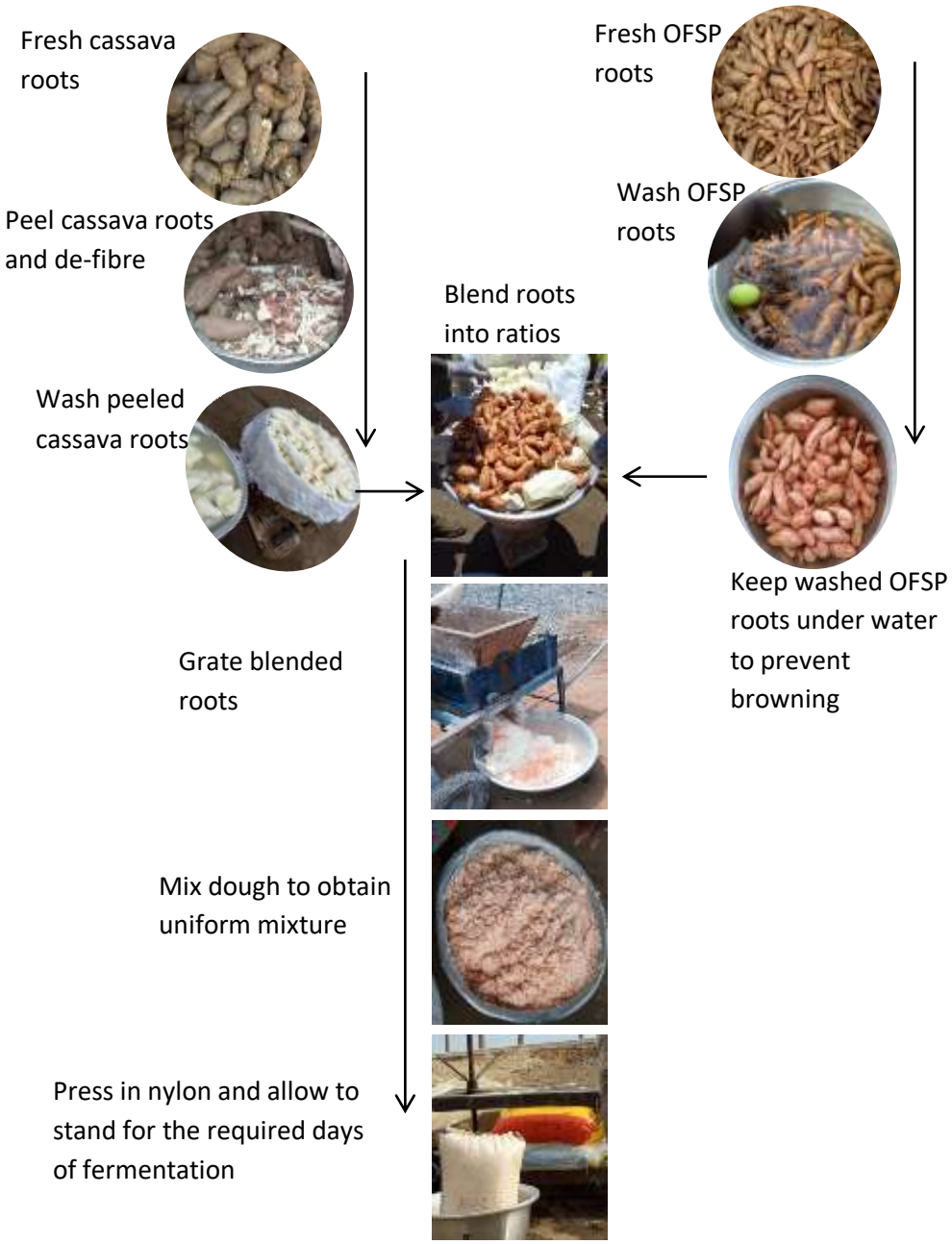

Figure 1: Flow chart of OFSP–cassava composite gari processing line

3.3 Experimental Design

A 2 factor, 3 level factorial response surface method was used for this study. This design was chosen due to its robustness for optimization studies involving many responses and few factors. The effects of different proportions of OFSP from 10% to 30% (Nzamwita, Gyebi, & Minnaar, 2017) and fermentation days from 1 to 3 days were investigated. As high as 46% of OFSP puree has been used for bread (Awuni, Alhassan & Amagloh, 2018). This combination yielded 11 experimental runs with 2 central points using Design Expert statistical software with each run triplicated (Table 1). The effects of the factors on the beta carotene content, colour of gari (whiteness, L* redness, a* yellowness, b*), swelling ability, appearance, colour preference, aroma, taste, texture and overall acceptability were investigated and used for the optimization.

Table 1: Runs Showing the OFSP Percentage (X_1) and Fermentation Duration (X_2) as Generated by Design Expert

Run	X_1	X_2
1	10	3
2	20	1
3	10	1
4	20	3
5	30	2
6	20	2
7	30	3
8	20	2
9	20	2
10	10	2
11	30	1

3.4 Optimization Studies

The data obtained for beta carotene, colour, swelling ability, appearance, colour, flavour, taste, texture, consistency and overall acceptability for each experimental run were optimized using the overall desirability techniques in Design-Expert software version 11.0.

3.5 Roasting of OFSP-gari

The various OFSP and cassava mash were screened after 1, 2 and 3 days of fermentation and roasted in stainless steel pans fixed into the fireplace on mud stove at three successive points. The first roasting was done to remove most of the moisture and the second and third were done to further dry the mash to very low moisture content and to allow for gelatinization of the gari. This was done to produce the normal crispiness of gari as it is usually done in various communities of Ghana. The roasted gari was poured into a clean dry bowl and allowed to cool. After 20 minutes of cooling the cooled OFSP–cassava composite gari was sifted to ensure uniformity of particle size of the final gari product. The sifted final gari product was then put in airtight rubber bags following laboratory analysis and sensory evaluation. The flow chart shown in Figure 2 was followed in the roasting of the OFSP–cassava composite gari.

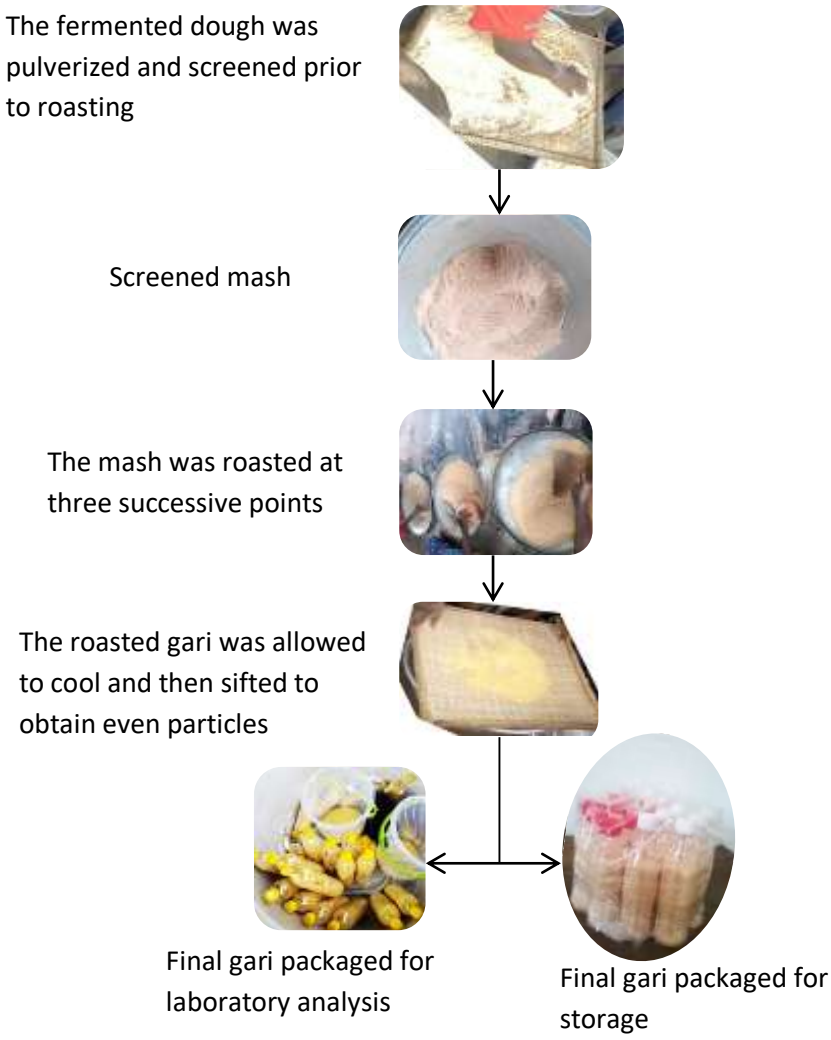

Figure 2: Flow chart of roasting of OFSP-Gari

3.6 Determination of Quality Parameters

3.6.1 Determination of Beta-carotene

The beta-carotene of the roasted gari was determined following the method reported by Sadaf et al. (2013) and Rodriguez-Amaya (2001) with slight modification. One gram of the roasted OFSP–cassava composite gari was weighed and transferred into porcelain mortar and 5 ml of absolute ethanol added to it and manually ground with a pestle to extract the carotene. The extract was then poured into a volumetric flask. This was repeated twice for each sample until the gari sample showed no colour of carotenoids. After

the extraction, 15 ml of petroleum ether was added to the filtrate and the mixture was separated into two layers with the carotenoid substance moving up. The top layer with the carotene was then pipetted for the absorbance reading at a wavelength of 450 nm against a blank of petroleum ether using UV mini-1240 spectrophotometer. The concentration of beta-carotene was calculated from the Beer-Lambert law, which states that the absorbance is directly proportional to the concentration of the pigment as represented by Equation 1. The average of duplicate readings was calculated.

$$Total\ carotenoids\ (\mu g/ml) = \frac{ABS\ X\ V\ (ml) X 10{,}000}{2592 * W(g)} \qquad (1)$$

Where ABS is the absorbance; V (ml) is the volume of solvent used for extraction; W (g) is the weight/volume of sample initially taken; 2592 is the extinction coefficient of beta-carotene in petroleum ether.

3.6.2 Colour Measurements

The colour of the OFSP-gari was measured in Hunter parameters with an ocean optic spectra suit, which uses a USB 4000 ocean optic detector with D65° luminance lamp. The machine was first calibrated by using white and black calibration plates. After standardization, three random readings were recorded; the colour brightness coordinates, L*, measures the whiteness value of the gari and ranges from black (0) to white (100). The Chromaticity coordinates, a*, measure the redness when positive (+60) and greenness when negative (-60), and the chromaticity coordinate, b*, measures yellow when positive and blue when negative. The L*, a* and b* values were used to describe the gari after processing.

3.6.3 Swelling Ability

The swelling index was determined according to the method of Iwuoha (2004). Three grams (3 g) of each sample of gari according to the various OFSP percentage and fermentation duration was transferred into clean, dry, and graduated (50 ml) cylinders. The samples were gently levelled and its volume noted before the addition of 30 ml distilled water. The cylinder was swirled and allowed to stand for 60 min while the final volume of gari in the distilled water was recorded. The swelling power of each gari sample was calculated as a multiple of the original volume.

3.6.4 Bulk Density

To determine the bulk density of the gari, an empty container was weighed and its volume determined. The gari samples were then poured into the container and weighed again. The bulk density was then calculated using Equation 2 below.

$$\text{Bulk Density } (\text{g}/\text{cm}^3) = \frac{\text{weight of gari and container} - \text{weight of empty container}}{\text{volume of gari}} \quad \ldots (2)$$

3.6.5 Sensory Analysis

A sensory panel was formed from among the staff and students of the University of Cape Coast, Ghana. The criteria for selection of the panellists were based on whether (a) they were available and willing to participate in the sensory evaluation tests, (b) they were regular consumers of gari, and (c) they were of sound health, no allergies or infections and dentures (d) they were not colour blind and could taste sweet, bitter and umami tastes, and (e) they could identify roasted gari flavours.

A sensory panel consisting of 50 members (both males and females) was selected after the preliminary test for the analysis (Appendix B). After the

selection, the panellists were trained to recognize and score different quality attributes of the gari samples including appearance (which includes colour), flavour, taste, texture and overall acceptability. The fortified gari samples were served at room temperature conditions at 11: 00 in the morning to the panellists. Prior to the sensory testing**,** the panellists were asked to stay away from any food for at least two hours. The samples were served in transparent plastic cups in separate booths in a well-lit sensory evaluation room (the conference room of School of Agriculture, University of Cape Coast) maintained at a temperature of 20°C to allow for candid observation of the colour. The panellists were also served with water in-between sample testing to rinse their mouth. For the evaluation of the gari, the panellists were trained to assess the samples using a 9-point hedonic scale denoted as like extremely 9; like very much 8; like moderately 7; like slightly 6; neither like nor dislike 5; dislike slightly 4; dislike moderately 3; dislike very much 2; dislike extremely 1.

3.7 Storage of Gari

The gari samples were put in airtight low-density polyethylene (LDPE) bottles and stored for six (6) months. The replicated samples were kept in four storage conditions; ambient condition, supermarket condition, gari sale point condition and refrigeration condition. The average temperatures were 31.0°C and 32.2°C in the morning and afternoon respectively for ambient condition, 31.3°C and 33.1°C in the morning and afternoon respectively for supermarket condition and 34.2°C and 38.8°C in the morning and afternoon respectively for gari sale point condition. Refrigeration condition was 5°C throughout the storage period, which begun in November and ended in May. The effects of

the storage conditions on the beta-carotene, swelling capacity, bulk density and colour were determined after every 30 days (one month).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Incorporation of orange-fleshed sweet potato into varying food preparation has been proven feasible. Due to the high beta-carotene content of the orange-fleshed sweet potato, several studies on its acceptability and its contribution to the nutritional needs of people have risen. In this study, the incorporation of orange-fleshed sweet potato into gari was studied and the overall desirability index was used for the optimization. The influence of OFSP amount and fermentation duration on gari, optimization for OFSP–cassava composite gari production and the effects of storage conditions and durations on the quality of OFSP–cassava composite gari as well as the profitability of OFSP–cassava composite gari production are presented and discussed in this section.

4.2 The Influence of OFSP Amount and Fermentation Duration on the Quality of OFSP–Cassava Composite Gari

The effects of the amount (in percentage) of OFSP incorporated into gari and the fermentation duration of the composite dough of cassava and orange-fleshed sweet potato before roasting were investigated. Table 2 shows the regression coefficients of the two factors: X_1 (amount of OFSP) and X_2 (fermentation duration) and their interactions.

Table 2: Regression Coefficient of OFSP Amount (X_1) and Fermentation Duration (X_2)

	β_0	X_1	X_2	X_1X_2	X_1^2	X_2^2
Beta-Carotene	23.3074	4.3625**	10.7933**	0.145	-1.38592	-1.3384
p-values		0.0212	0.0004	0.9319	0.5248	0.5386
L*	79.4682	-3.6445**	0.6592**	0.351**	0.295974	0.9060**
p-values		< 0.0001	0.0009	0.0291	0.0978	0.0016
a*	7.47474	2.02733**	0.2345	-0.67725**	-0.117842	-0.7713**
p-values		< 0.0001	0.2083	0.0191	0.6571	0.0273
b*	40.297	0.9093	-0.7232	0.5898	2.644**	-3.2585**
p-values		0.1824	0.2732	0.4498	0.0329	0.0155
Swelling Capacity	3.0021	-0.0483	-0.3717**	0.1375	0.2497*	0.0397
p-values		0.5003	0.0025	0.1525	0.0588	0.7140
Appearance	5.5736	-1.1167**	0.1333	-0.25*	0.0658	-0.6842**
p-values		< 0.0001	0.2145	0.0815	0.6677	0.0052
Taste	5.0737	-0.7**	0.5**	-0.45**	-0.0842	-0.7842**
p-values		0.0002	0.0010	0.0039	0.4840	0.0009
Texture	5.5368	-0.4833**	-0.0667	-0.05	-0.1921	-0.1421
p-values		0.0028	0.4839	0.6630	0.2163	0.3432
Smell/ flavour	4.6473	-0.7**	0.0333	-0.375**	-0.2684*	0.1316
p-values		0.0002	0.6675	0.0086	0.0627	0.2949
Overall Acceptability	4.8	-0.5667**	0.35**	0.05	0.5**	0.35
p-values		0.0061	0.0373	0.7558	0.0474	0.1268

**significant at p<0.05, *significant at p<0.1, β_0 is the intercept of the model

4.2.1 Beta-carotene content

From Table 2, both the amount (percentage) of OFSP used in the preparation of the gari and the duration of fermentation of the composite dough before roasting had a significant effect on the beta-carotene content of the final gari produced. As one would expect, the addition of OFSP increased the beta-carotene content of the gari. The combined effect is shown in Figure 3. As the percentage of OFSP increased, so was the beta-carotene content of the gari with a positive coefficient of 4.3625 at a p-value of 0.0212. This means that there is only 2.12% probability that this correlation was due to chance. Phorbee, Olayiwola and Sanni (2013) found no beta-carotene in white cassava used in their study when they compared the white and yellow cassava varieties. It therefore means that the positive correlation between OFSP and beta-carotene content of the gari in this study was due to the incorporation of OFSP into the gari. This confirms the reports on the high beta-carotene content of orange-fleshed sweet potato (Laurie et al., 2015; Leighton, 2007; Sanni et al., 2008). It also confirms the possibility of incorporating orange-fleshed sweet potato in the diet of humans with the potential to reduce the incidence of vitamin A deficiency (Hotz et al., 2012; Laurie et al., 2015; Li & Mu, 2012).

People who live in poor communities have gari as one of their regular staple foods while they usually live on less diversified diets. Incorporating orange-fleshed sweet potato into the regular food of people in such communities would deal with hidden hunger (which is an issue related to a deficiency of micronutrients especially vitamin A). OFSP–cassava composite gari if used as a vehicle for improving vitamin A consumption and preventing

vitamin A deficiency would compare effectively with vegetable oil used for the same purpose in vitamin A risk communities. This is because gari is eaten more in such communities in Ghana than vegetable oil (Ghana Micronutrient Survey [GMS], 2017).

Fermentation duration also had a positive correlation with the amount of beta-carotene retained in the final gari. A correlation coefficient of 10.7933 was determined for the impact of fermentation on beta-carotene with a p-value of 0.0004. This means that there is only 0.04 per cent probability that this estimation was due to chance. It also means that as the composite dough is allowed to ferment for a longer period, more beta-carotene is released and retained in the final gari product. Fermentation has been reported to increase the vitamin content of cereal foods and this has been by the activities of microorganisms (Ekinci & Kadakal, 2005). Research has shown that food processes which break down the cell wall and the matrix of plants make carotenoids available in the final food product (Hedren, Diaz, & Svanberg, 2002; Phorbee et al., 2013). De Almeida Siqueira and his colleagues, as well as Howe and his colleagues, also reported on the food matrix disruption effect of fermentation making beta-carotene available in the final food (De Almeida Siqueira et al., 2007; Howe et al., 2009).

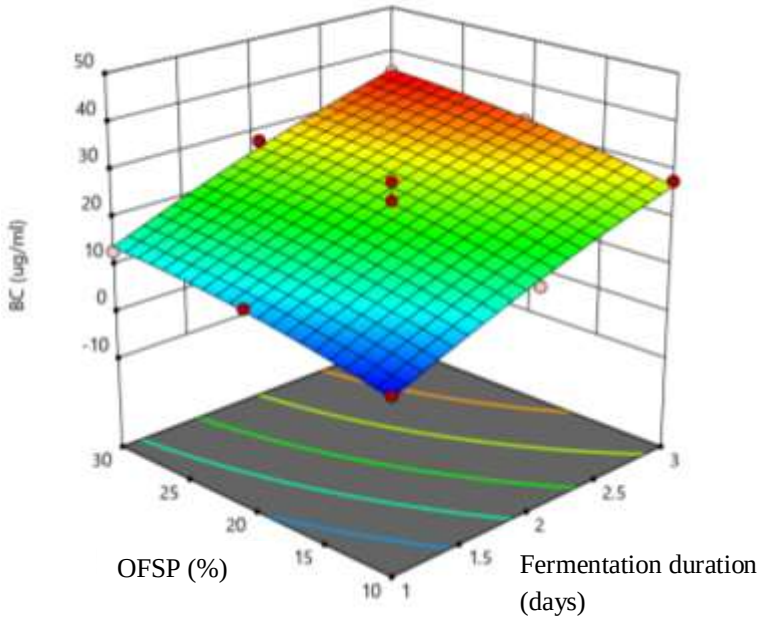

Figure 3: surface response of beta-carotene

The positively high correlation between fermentation duration and beta-carotene content of OFSP–cassava composite gari in this study could be due to the disruption of the cell wall of the orange-fleshed sweet potato making its beta-carotene readily accessible. It, therefore, means OFSP should be available for breakdown by microorganisms during fermentation. The combined effect of OFSP amount and fermentation duration as shown in Figure 3 depicts that an increase in both factors increases the beta-carotene content of the OFSP–cassava composite gari. Both factors used in this study, therefore, had positive effects on beta-carotene content in gari.

4.2.2 Swelling capacity

From Table 2 and Figure 4, it is seen that OFSP had no significant impact on the swelling capacity of the OFSP–cassava composite gari. However, a negative correlation coefficient suggests that the incorporation of OFSP in gari could lower its swelling capacity. This finding, however, contradicts the findings of Karim et al. (2016). Karim and his colleagues reported that the addition of sweet potato into gari increased or improved the

swelling capacity of gari. In their study, all gari prepared from sweet potato and cassava mixes at different levels had increased swelling capacity, except gari produced by adding 10% OFSP to the cassava just before grating. They prepared gari from the following mixes: sweet potato roots and cassava roots mixed before grating; sweet potato dough and cassava dough were mixed after grating in different proportions and 100% sweet potato gari and 100% cassava gari mixed after roasting. Their report showed that gari from the sweet potato and cassava mixture had higher swelling capacity than gari from 100% sweet potato or 100% cassava gari.

Conversely, Gari prepared from 100% sweet potato has been reported to have lower swelling index than gari prepared from 100% cassava (Agbara, Masaya, Igwegbe, Bade, & Mohammed, 2018; Karim et al., 2016; Kure, Nwankwo, & Wyasu, 2012). Agnes and others stated that sweet potato starch had a higher swelling index than cassava starch and cocoyam starch(Agnes, Felix, & Ugochukwu, 2017). However, when cassava and sweet potato were mixed, grated and roasted into gari, the swelling index of the final gari was higher than the swelling indices of the gari prepared from either 100% cassava or 100% sweet potato (Karim et al., 2016).

Kure et al. (2012) also found out in their study that gari produced from fermented 100% sweet potato had a higher swelling index than similar gari from unfermented 100% sweet potato dough.

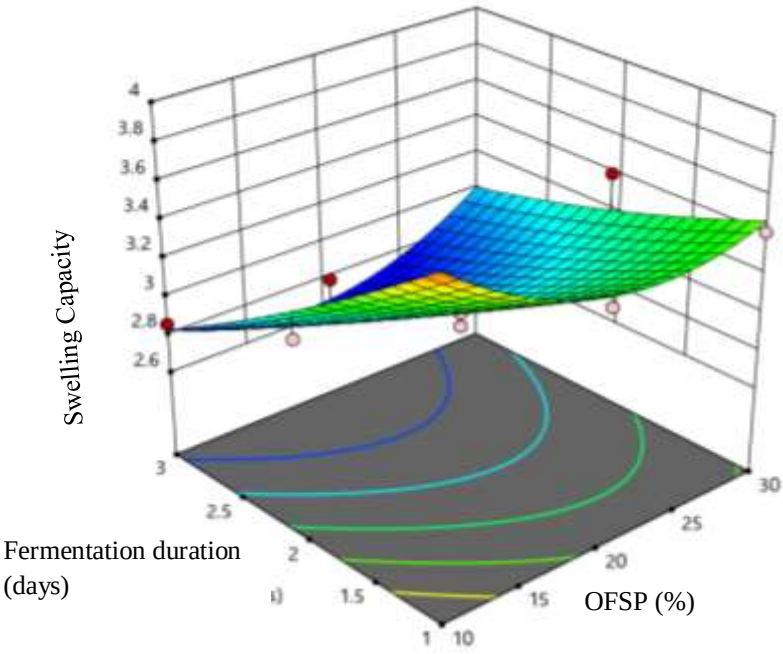

Figure 4: Surface response of swelling capacity

On the other hand, as shown in the correlation coefficient table above (Table 2), fermentation duration, unlike OFSP %, had a significant impact on the swelling capacity of OFSP–cassava composite gari. There was a negative correlation between the fermentation duration and the swelling capacity of the gari. This means that as the composite dough was fermented for a longer period, the swelling capacity of the gari decreased. This may be due to breakdown of starch and fibre, which are known to have higher water absorption and swelling capacities compared to sugars.

4.2.3 Colour

Both OFSP percentage and fermentation duration had a significant ($p<0.05$) influence on the whiteness (L) of the OFSP–cassava composite gari (Table 2 and Figure 5).

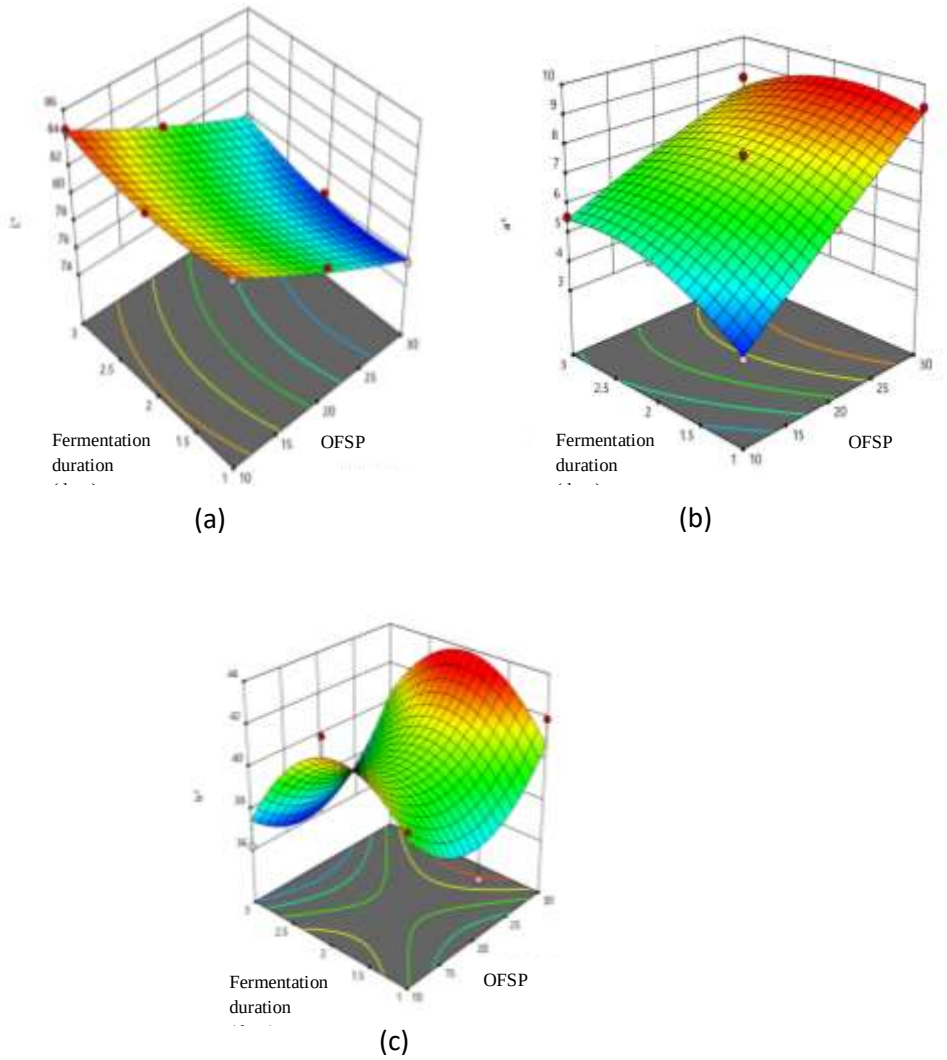

Figure 5: Surface response of colour parameters showing (a) the whiteness of the gari (b) the redness of the gari and (c) the yellowness of the gari

While fermentation duration had a positive correlation with the whiteness of the final gari produced, OFSP percentage had a negative correlation with the whiteness of the gari. This confirms the study by Takahata, Noda and Nagata (1993) indicating that OFSP makes gari darker. Again, considering the redness, a* of the gari, there was a positive correlation between the OFSP percentage and the a* of the gari (Table 2). Fermentation duration, however, had no significant effect on the a* of the OFSP–cassava composite gari. Takahata, Noda and Nagata (1993) reported that among the

colour values, the a* value was closely linked to the beta-carotene content. This could explain why OFSP amount was positively correlated with the a* value, however, their study was based on fresh root analysis. Moreover, neither the OFSP percentage nor the fermentation duration had a significant effect on the b* of the gari (Figure 5).

4.2.4 Sensory attributes

To understand the impact of the incorporation of the OFSP on the sensory attributes of the gari, the solid dry particulate form of the gari was presented to 50 trained panellists made up of students of the University of Cape Coast. The panellists were first screened based on whether they were gari consumers or not, they had strong affinity or aversion for gari, they had cold or any infections that could influence their sensory evaluation and whether they had any allergies related to gari consumption or not. The sensory evaluation results as shown in Table 2 and Figure 6 depict a negatively weak correlation between the OFSP amount and all the sensory attributes evaluated.

Fermentation duration, on the other hand, significantly influenced the taste and overall acceptability of the OFSP–cassava composite gari positively. Which means consumers will like the OFSP–cassava composite gari when it is fermented for a longer period, which also improves the taste. However, the other sensory attributes (appearance, texture and smell) were not significantly influenced by fermentation duration.

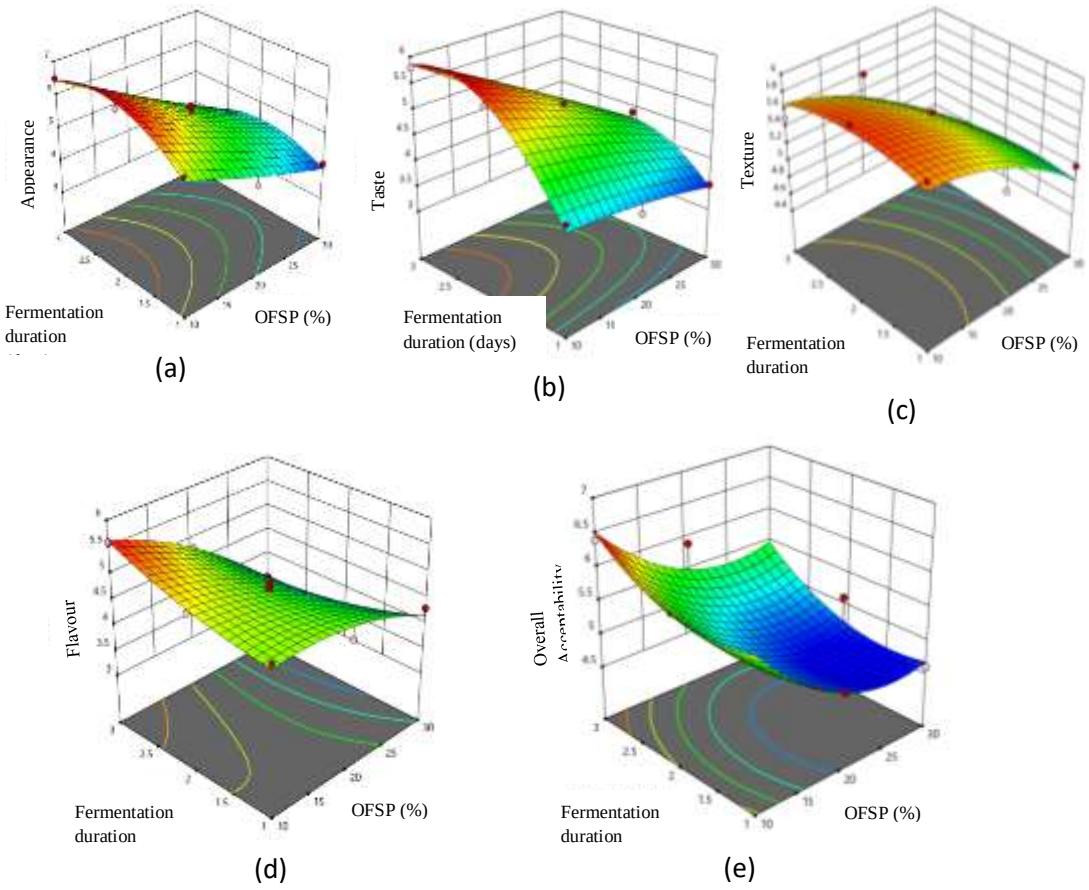

Figure 6: Effect of processing variables on the sensory attributes of OFSP–cassava composite gari

A similar result was found in the work of Karim et al. (2016). In the study by Karim and others, when presented with gari made from 100% cassava, 100% sweet potato and a mixture of cassava and sweet potato in different proportions, panellists ranked the gari made from 100% cassava and gari with 10% sweet potato highest in all the sensory attributes. Conversely, the gari made from 100% sweet potato was ranked the least in all the sensory attributes evaluated. This explains that people will like cassava and sweet potato gari mixture when the sweet potato is added in a moderate amount. The results of the study show that consumers would prefer the sour-tasted gari

since fermentation is positively correlated with the taste of the gari. A finding of this nature is good because fermentation is also found to have a positive impact on the beta-carotene of the OFSP–cassava composite gari. In this light, a moderate addition of OFSP into gari fermented for a longer period would not only improve the nutritional quality of the gari but also improve the taste of the OFSP–cassava composite gari.

On the other hand, the role of the appearance of food should not be overlooked since it has a significant impact on the acceptability and consumption of food products. The result of this study reveals that as OFSP amount affects the acceptability of the gari, fermentation duration improves acceptability of the gari. If consumers are therefore educated on the health benefit and the nutritional content of the gari, their acceptance of the product will be improved.

4.3 Optimization of OFSP–cassava composite gari

The results of the factor location for the optimization of OFSP–cassava composite gari (Table 3) show that based on the nutritional and sensory quality of OFSP–cassava composite gari the optimum OFSP–cassava composite gari is obtained by incorporating 10% OFSP into gari and fermenting for about 2.21 days (Table 3). This confirms the suggestion made by Owuamanam, Hart, Barimalaa, Barber, and Achinewhu (2010) that gari should be fermented for a period of 48 or more hours.

Fermentation was positively correlated with the taste of gari from Table 2 and this may explain why more than two days is determined by the model used in this study.

Table 3: Factor Location for Optimization of OFSP–cassava composite gari

	Factor	Level	Low level	High level	Std. dev	coded
X_1	OFSP	10.00	10.00	30.00	0.0000	Actual
X_2	Fermentation Duration	2.21	1.0000	3.00	0.0000	Actual

Table 4: Point Prediction for Optimization of OFSP–cassava composite gari

RESPONSE	Mean	Std Dev
Beta-Carotene	19.7584	3.22866
Swelling Capacity	3.19391	0.163037
L*	83.5149	0.231787
a*	5.48831	0.397726
b*	41.6063	1.43928
Appearance	6.80668	0.229798
Taste	5.85576	0.177408
Texture	5.81813	0.216106
Smell/ flavour	5.17153	0.179057
Overall Acceptability	5.94609	0.304412

P < 0.05, L*=whiteness, a*=redness, b*= yellowness, std dev= standard deviation

Conversely, a relatively small amount of the beta-carotene provider (OFSP) is required for the production of OFSP–cassava composite gari. OFSP–cassava composite gari with smaller OFSP amount looks lighter in

colour and a bit closer to the market gari (100% cassava) and this may explain why people preferred it. Karim et al. (2016) recommended 10% OFSP incorporation into gari. They reported that 10% OFSP–cassava composite gari was rated highest by panellists in terms of its sensory qualities while the same panelist rated 100% sweet potato gari poor. In this light, it could be mentioned that consumers would like the OFSP–cassava composite gari but not with a higher percentage of the OFSP in it.

This gives a beta-carotene yield of 19.8 µg/ ml and a gari with a swelling capacity of 3.2 (Table 4). When converted to the daily intake of gari, the optimized OFSP–cassava composite gari contributes to 67 % retinol activity equivalent (RAE) in children between 4 – 8 years and 20% RAE in pregnant women for every 100 g of OFSP–cassava composite gari consumed. Since these values are higher (in children) or equal to 20 % (in pregnant women), OFSP–cassava composite gari is considered as a high source of vitamin A (National Institute of Health (NIH), 2019). This confirms that OFSP–cassava composite gari could contribute immensely to dealing with vitamin A deficiency in Sub-Saharan Africa where cassava and gari form part of their regular diet. It must be stated however that, this does not translate directly into the bioavailability of vitamin A in an individual, since bioavailability of vitamin A depends on other factors such as the health status, nutrient status and other factors related to the individual taking in the food (Castenmiller & West, 1998; Failla, Huo, & Thakkar, 2008). Moreover, the presence of beta-carotene in gari improved the vitamin A status and maintained growth in subjects used in the work of Phorbee et al. (2013) and De Almeida Siqueira et al. (2007).

The swelling capacity of 3.2 of the optimized OFSP–cassava composite gari is lower than that found by Karim et al. (2016) and Agbara et al. (2018). However, it falls within the range (3.01 – 4.30) reported by Ojo and Akande (2013) and it is slightly above the swelling index of 3.0 recommended by Akingbala et al. (2005) and Almazan (1992). Moreover, this result is similar to that of Teye, Amoah, Adu, and Darko (2017). Teye and others determined the swelling capacity of gari to range from 3.0 – 3.2. In their study, they collected gari samples from 7 out of 10 regions in Ghana (as at 2017) and their results showed no significant difference in the various gari samples in Ghana. Swelling capacity is a strong determinant of good quality gari and it should be at least three times the original volume of the gari when in water (IITA, 1990; Teye et al., 2017). This means the OFSP–cassava composite gari developed in this study is of good quality in terms of its swelling capacity and it can make an individual feel similar satiety, as would feel with gari produced from 100% cassava. It will, therefore, be a good substitute in areas of high vitamin A risk and be able to reduce vitamin A deficiency in these areas because of its extra beta-carotene content.

The optimized gari has the following colour properties: L* = 83.51, a* = 5.49 and b* = 41.61 for lightness, redness and yellowness. Its appearance, taste, texture, flavour and overall acceptability were 6.8, 5.9, 5.8, 5.2 and 6.0 respectively.

4.4 Effect of Storage Condition and Duration on the Nutritional Quality of OFSP–cassava composite gari

To study the effects of storage condition and storage duration on the nutritional qualities of the optimized OFSP–cassava composite gari developed,

samples of the optimized gari were put into airtight plastic bottles and kept for 6 months under ambient condition, refrigeration, supermarket conditions and local gari sale's point. Some samples were taken every 30 days for analysis. The results of storage effects on the nutritional quality of OFSP–cassava composite gari are shown in Figures 7, 8 and 9 and discussed in the subsections that follow.

4.4.1 Beta-carotene content

The results show that the degradation of beta-carotene was quite rapid and progressive throughout the six months storage period. The beta-carotene content of the OFSP–cassava composite gari fell steadily within the first three months; it then stabilized in the fourth and fifth months and fell again to very low amounts by the sixth month as shown in figure 7.

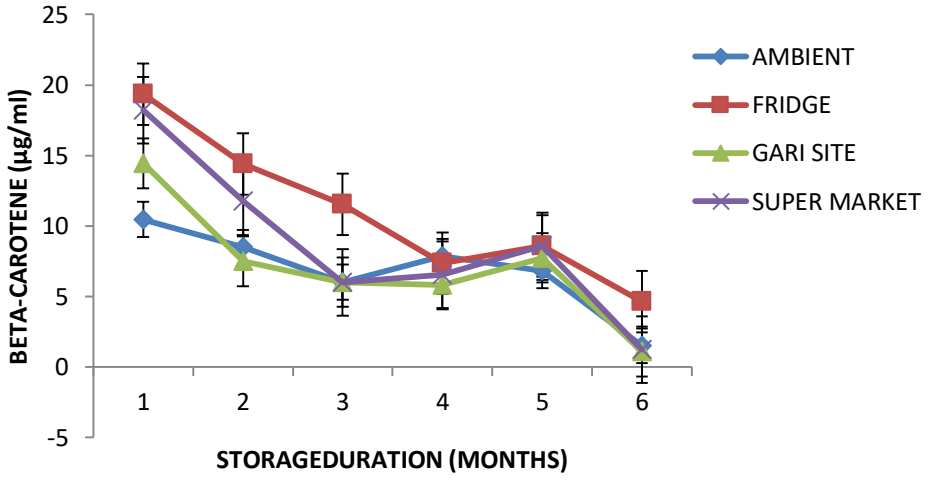

Figure 7: Effect of storage on beta-carotene content of OFSP–cassava composite gari

By the sixth month, there was no significant ($p<0.05$) difference in the beta-carotene content of the gari samples stored under conditions ambient, supermarket, refrigeration and gari sale point.

Even though the degradation of the beta-carotene followed a similar decreasing pattern for all the conditions studied, it was slower under refrigeration condition than the others. Within 30 days of storage (first one month), the beta-carotene content was similar for OFSP–cassava composite gari stored under supermarket condition, refrigeration and gari sale point and this was significantly different from that of the ambient condition.

4.4.2 Swelling capacity

The results of the effects of storage condition and storage duration on the swelling capacity of OFSP–cassava composite gari are shown in Figure 8 below. There were no significant differences in the swelling capacities of OFSP–cassava composite gari stored in all the samples except those stored under ambient conditions, which were significantly different from the rest in the first and fifth months.

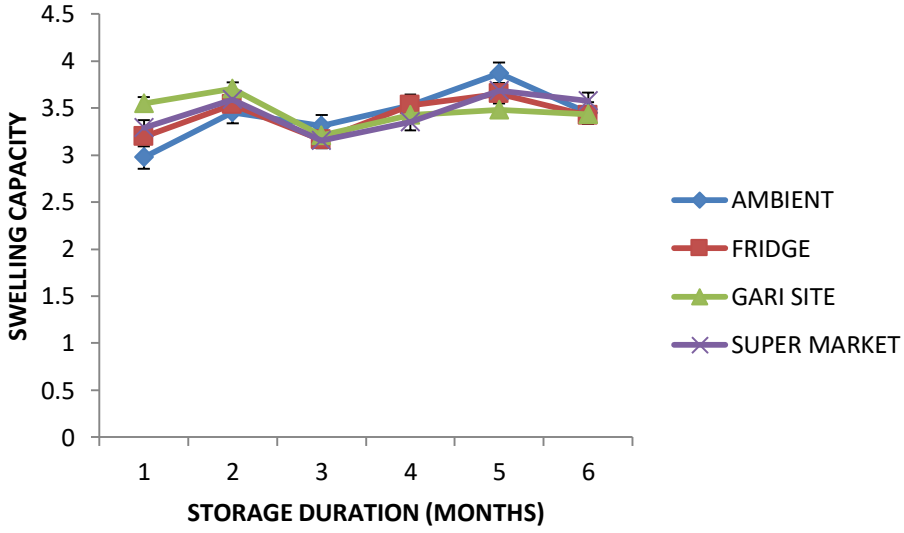

Figure 8: Effect of storage on the swelling capacity of OFSP–cassava composite gari

Under the ambient conditions, OFSP–cassava composite gari showed a significant lower swelling capacity in the first month than the rest of the samples while it showed a significant higher swelling capacity in the fifth

month. The swelling capacity of the OFSP–cassava composite gari at storage ranged from 2.98 to 3.87 under the various conditions in this study. These values except 2.98 are within the recommended swelling capacity range for gari and storage conditions and duration did not have a significant effect on the swelling capacity of gari.

4.4.3 Bulk density

The bulk density of the OFSP–cassava composite gari ranged from 0.53 g/cm^3 for samples stored for a month under the supermarket condition to 0.61 g/cm^3 for samples stored for five months under refrigeration condition (Figure 9). There were significant differences in the bulk densities among the samples stored under the various conditions.

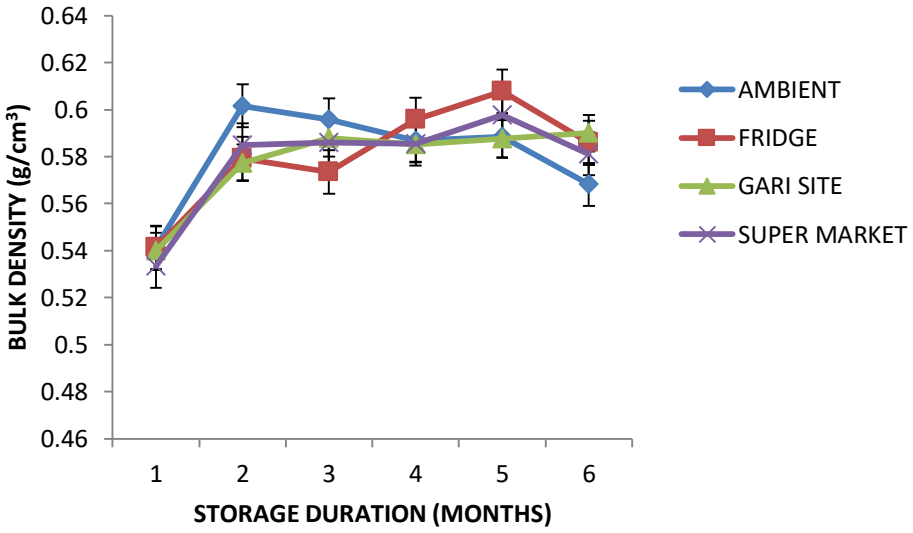

Figure 9: Effect of storage on the bulk density of OFSP–cassava composite gari

At month one of storage, there was no significant difference among the four storage conditions in terms of their impact on the bulk density of OFSP–cassava composite gari. At month 2 of storage, OFSP–cassava composite gari stored at ambient condition had the highest bulk density, which was

significantly different from the gari samples under refrigeration, supermarket condition and gari sale point.

At month three, the bulk densities of gari sample under ambient condition, supermarket condition and gari sale point were similar and were significantly different from that under refrigeration condition. The bulk density of the gari samples under refrigeration was lower than the rest. At month four of storage, there was no significant difference in the bulk density of all the samples under the various conditions. Their bulk densities were similar to that of month three and these were maintained till month six except for samples under refrigeration at month five and samples under ambient at month six.

In terms of duration of storage, samples stored under ambient conditions had higher bulk densities at month 2, 3, 4 and 5. Month 1 and 6 had similar values, which were significantly different from the rest.

4.4.4 Colour parameters

The effects of storage on the L*(brightness/whiteness), a* (redness) and b* (yellowness) of the gari are shown in Figure 10 (a), (b) and (c) respectively. There was no significant difference between the storage conditions in terms of the brightness (L*) and the over the six months storage period except the fifth month. Moreover, the ambient, gari sale point, supermarket and the refrigeration conditions had a similar effect on the yellowness (b*) of the OFSP–cassava composite gari up to the 3rd month. At month 3, 4 and 5 the refrigeration condition had significantly higher b* values than the ambient, gari sale point and supermarket conditions which were statistically similar in their effects.

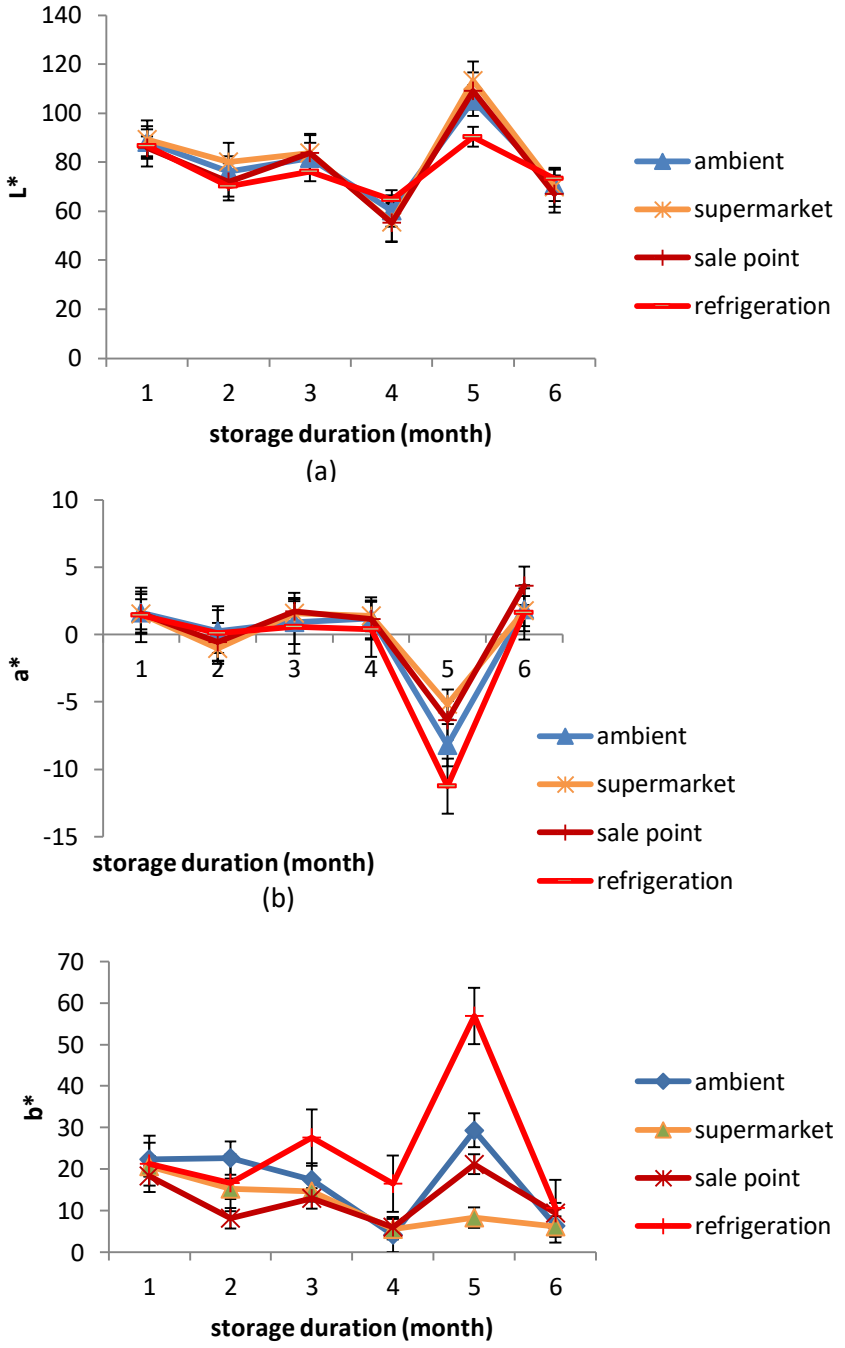

Figure 10: The effects of storage on (a) lightness, L* (b) redness, a* and (c) yellowness, b*

Even though Takahata et al. (1993) found a close relationship between the beta-carotene content and redness (a* value) of gari, which has been explained earlier in this study to have a positive correlation, such correlation

was not seen after storage of the samples. During the storage of the OFSP–cassava composite gari, all the samples over the 6 months of storage maintained close a* values which were significantly similar over the period except that of the fifth month.

4.5 Profitability of OFSP–Cassava Composite Gari

The total cost and profit of processing both 100% cassava gari and OFSP–cassava composite gari are shown in Table 5. In both cases, 100 kg of cassava was used but the OFSP–cassava composite gari had an additional 10% of OFSP. Gari is sold in "Olonka" in Ghana. "Olonka" was weighed to be approximately 2.0 kg and this has been confirmed by Teye and others to be 2.21kg in their study. The market price for an "Olonka" of gari as at the time of the study was GHS 10.00.

From Table 5, it is shown that when OFSP is sold at this price the processor would run at a loss. However, a market survey showed that gari consumers were willing to purchase an "Olonka" of OFSP–cassava composite gari at a price between GHS12.00 and GHS15.00 after knowing the health benefit of OFSP–cassava composite gari. This price range gives an OFSP–cassava composite gari processor a profit between GHS77.85 – GHS126.18 for processing cassava and 10 kg OFSP.

Addition of OFSP to gari, therefore, gives the processor extra income of GHS8.10 – GHS56.43 for every 100kg of cassava processed as compared to 100% cassava gari.

Table 5: The Processing Cost and Profit for 100% Cassava Gari and OFSP–cassava composite gari

ITEM		100% CASSAVA GARI	OFSP–CASSAVA COMPOSITE GARI
OFSP			23.81
Transportation			
Washing of OFSP			1.43
Sub-total cost on OFSP			**25.24**
Cassava		44.25	44.25
Transportation			
sub-total cost on cassava		**44.25**	**44.25**
Peeling		7.00	7.00
Grating		5.00	5.00
Pressing		4.00	4.00
Roasting		10.00	10.00
Fire wood		20.00	20.00
Sub-total cost of processing		**46.00**	**46.00**
Total processing cost		**90.25**	**115.49**
Yield/ kg		**32**	**32.22**
Price	(at GHS 10.00 per 2kg)	**160.00**	161.11
	(at GHS 12.00 per 2kg)	192.00	**193.33**
	(at GHS 15.00 per 2kg)	240.00	241.66
Profit	**at GHS10.00**	**69.75**	45.63
	at GHS12.00	101.75	**77.85**
	at GHS15.00	149.75	126.18

This means the processing of OFSP–cassava composite gari can increase the income of processors. Farmers who cultivate OFSP would also have good returns on their crop since the incorporation of OFSP in gari will promote the marketing of the crop. Issues associated with the storage of OFSP

roots would also be decreased if roots are incorporated and processed into gari.

It should also be noted that consumers would purchase OFSP at a higher price if they know the health benefit. It is therefore important that consumers are educated on the health benefit of OFSP–cassava composite gari.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of the study was to optimize the incorporation of OFSP into gari based on the nutritional composition and sensory quality. The study also sought to investigate the influence of OFSP amount and fermentation duration on the nutritional and sensory qualities, to establish the optimum cassava-OFSP ratio and fermentation duration for OFSP–cassava composite gari, to determine the effect of storage conditions and duration on the nutritional quality of the OFSP–cassava composite gari and to determine the profitability of OFSP–cassava composite gari. Multivariate desirability index of the Response Surface Method was used for the optimization of the OFSP–cassava composite gari.

From the study, beta-carotene content of OFSP–cassava composite gari increased with increasing OFSP amount and fermentation duration. Whilst OFSP amount did not influence the swelling capacity of OFSP–cassava composite gari, longer fermentation duration decreased the swelling capacity. Incorporation of OFSP into gari lowered the sensory attributes of the gari, however, fermentation improved the taste and overall acceptability of the OFSP–cassava composite gari. Fermentation, however, had no significant influence on the appearance, texture and flavour of the gari. Again, reduced amount of OFSP and prolonged duration of fermentation increased the lightness or brightness of the gari, a higher amount of OFSP increased the redness of the gari but had no significant influence on the yellowness, while fermentation duration had no impact on the redness and yellowness of the gari.

The study showed the optimum amount of OFSP to be incorporated into gari as 10% of the total mash and fermentation duration of 2.21 days. Thus, beta-carotene nutritious gari with acceptable sensory attributes can be obtained by combining cassava and OFSP in the ratio 9:1 (90% cassava and 10% OFSP). This gave gari with 19.8 µg/ml of beta-carotene and 3.2 swelling capacity.

The beta-carotene content of the OFSP–cassava composite gari decreased within 6 months of storage in ambient, gari sale point, supermarket and refrigeration conditions. However, storage conditions and storage duration did not affect the swelling capacity of OFSP–cassava composite gari. Production of OFSP fortified gari was found to generate a higher profit than 100% cassava gari if sold at a slightly higher price.

Incorporation of orange-fleshed sweet potato (OFSP) into gari, therefore, can be adopted especially in vitamin A risk communities to eliminate vitamin A deficiency. Also, since OFSP–cassava composite gari generates higher returns than 100% cassava gari its production can improve the economic status of gari processors while improving the nutritional value of gari. However, people must be well educated on the health benefit of the OFSP–cassava composite gari to improve its acceptance.

5.2 Recommendations

1. Further studies should be carried out on the bioavailability and bioaccessibility of the beta-carotene of the OFSP–cassava composite gari in the body.
2. Based on the findings of this study, further study on the effect of storage on ‘trans’ and ‘cis’ forms of beta-carotene of the OFSP is required to fully understand the beta-carotene dynamics at storage.

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APPENDIX A

SENSORY EVALUATION FORM

SENSORY EVALUATION PARAMETERS	ABC	BCD	CDE	DEF	EFG	GHI	IJK	BAC	CDB	EDF	GFE
APPEARANCE (colour)											
TASTE (how nice it is in mouth)											
TEXTURE (how it feels in mouth)											
SMELL (how it smells during eating)											
OVERALL ACCEPTABILITY											

REFERENCE SCALE	INTERPRETATION
1	Dislike extremely
2	Dislike very much
3	Dislike moderately
4	Dislike slightly
5	Neither like or dislike
6	Like slightly
7	Like moderately
8	Like very much
9	Like extremely

COMMENTS……..……

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APPENDIX B

SOME PICTURES OF SENSORY PANEL DURING EVALUATION

APPENDIX C

ANOVA FOR QUADRATIC MODEL (RESPONSES)

RESPONSE 1: BETA-CAROTENE

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	826.07	5	165.21	15.85	0.0044	significant
A-OFSP	114.19	1	114.19	10.95	0.0212	
B-FDuration	698.98	1	698.98	67.05	0.0004	
AB	0.0841	1	0.0841	0.0081	0.9319	
A^2	4.87	1	4.87	0.4668	0.5248	
B^2	4.54	1	4.54	0.4353	0.5386	
Residual	52.12	5	10.42			
Lack of Fit	7.26	3	2.42	0.1079	0.9480	not significant
Pure Error	44.86	2	22.43			
Cor Total	878.19	10				

FIT STATISTICS FOR BETA-CAROTENE

Std. Dev.	3.23	**R^2**	0.9406
Mean	21.82	**Adjusted R^2**	0.8813
C.V. %	14.80	**Predicted R^2**	0.8182
		Adeq Precision	12.7118

RESPONSE 2: L*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	85.66	5	17.13	318.89	< 0.0001	significant
A-OFSP	79.69	1	79.69	1483.37	< 0.0001	
B-FDuration	2.61	1	2.61	48.52	0.0009	
AB	0.4928	1	0.4928	9.17	0.0291	
A²	0.2219	1	0.2219	4.13	0.0978	
B²	2.08	1	2.08	38.70	0.0016	
Residual	0.2686	5	0.0537			
Lack of Fit	0.2686	3	0.0895			
Pure Error	0.0000	2	0.0000			
Cor Total	85.93	10				

RESPONSE 3: a*

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	28.62	5	5.72	36.18	0.0006	significant
A-OFSP	24.66	1	24.66	155.90	< 0.0001	
B-FDuration	0.3299	1	0.3299	2.09	0.2083	
AB	1.83	1	1.83	11.60	0.0191	
A²	0.0352	1	0.0352	0.2224	0.6571	
B²	1.51	1	1.51	9.53	0.0273	
Residual	0.7909	5	0.1582			
Lack of Fit	0.7909	3	0.2636			
Pure Error	0.0000	2	0.0000			
Cor Total	29.41	10				

RESPONSE 4: b*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	44.98	5	9.00	4.34	0.0664	not significant
A-OFSP	4.96	1	4.96	2.40	0.1824	
B-FDuration	3.14	1	3.14	1.51	0.2732	
AB	1.39	1	1.39	0.6716	0.4498	
A^2	17.71	1	17.71	8.55	0.0329	
B^2	26.90	1	26.90	12.98	0.0155	
Residual	10.36	5	2.07			
Lack of Fit	10.36	3	3.45			
Pure Error	0.0000	2	0.0000			
Cor Total	55.34	10				

RESPONSE 5: Swelling Capacity

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-value**	**p-value**	
Model	1.11	5	0.2215	8.33	0.0181	significant
A-OFSP	0.0140	1	0.0140	0.5273	0.5003	
B-FDuration	0.8288	1	0.8288	31.18	0.0025	
AB	0.0756	1	0.0756	2.85	0.1525	
A^2	0.1580	1	0.1580	5.94	0.0588	
B^2	0.0040	1	0.0040	0.1505	0.7140	
Residual	0.1329	5	0.0266			
Lack of Fit	0.1100	3	0.0367	3.21	0.2466	not significant
Pure Error	0.0229	2	0.0114			
Cor Total	1.24	10				

RESPONSE 6: Appearance

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	9.06	5	1.81	34.32	0.0007	significant
A-OFSP	7.48	1	7.48	141.68	< 0.0001	
B-FDuration	0.1067	1	0.1067	2.02	0.2145	
AB	0.2500	1	0.2500	4.73	0.0815	
A^2	0.0110	1	0.0110	0.2076	0.6677	
B^2	1.19	1	1.19	22.46	0.0052	
Residual	0.2640	5	0.0528			
Lack of Fit	0.2440	3	0.0813	8.13	0.1114	not significant
Pure Error	0.0200	2	0.0100			
Cor Total	9.33	10				

RESPONSE 7: Taste

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	7.04	5	1.41	44.75	0.0004	significant
A-OFSP	2.94	1	2.94	93.41	0.0002	
B-FDuration	1.50	1	1.50	47.66	0.0010	
AB	0.8100	1	0.8100	25.74	0.0039	
A^2	0.0180	1	0.0180	0.5708	0.4840	
B^2	1.56	1	1.56	49.50	0.0009	
Residual	0.1574	5	0.0315			
Lack of Fit	0.1507	3	0.0502	15.07	0.0629	not significant
Pure Error	0.0067	2	0.0033			
Cor Total	7.20	10				

RESPONSE 8: Texture

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.63	5	0.3268	7.00	0.0261	significant
A-OFSP	1.40	1	1.40	30.01	0.0028	
B-FDuration	0.0267	1	0.0267	0.5710	0.4839	
AB	0.0100	1	0.0100	0.2141	0.6630	
A^2	0.0935	1	0.0935	2.00	0.2163	
B^2	0.0512	1	0.0512	1.10	0.3432	
Residual	0.2335	5	0.0467			
Lack of Fit	0.2268	3	0.0756	22.68	0.0425	significant
Pure Error	0.0067	2	0.0033			
Cor Total	1.87	10				

RESPONSE 9: Smell

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	3.70	5	0.7403	23.09	0.0018	significant
A-OFSP	2.94	1	2.94	91.70	0.0002	
B-FDuration	0.0067	1	0.0067	0.2079	0.6675	
AB	0.5625	1	0.5625	17.54	0.0086	
A^2	0.1825	1	0.1825	5.69	0.0627	
B^2	0.0439	1	0.0439	1.37	0.2949	
Residual	0.1603	5	0.0321			
Lack of Fit	0.1536	3	0.0512	15.36	0.0617	not significant
Pure Error	0.0067	2	0.0033			
Cor Total	3.86	10				

RESPONSE 10: Overall Acceptability

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3.94	5	0.7884	8.51	0.0173	significant
A-OFSP	1.93	1	1.93	20.79	0.0061	
B-FDuration	0.7350	1	0.7350	7.93	0.0373	
AB	0.0100	1	0.0100	0.1079	0.7558	
A^2	0.6333	1	0.6333	6.83	0.0474	
B^2	0.3103	1	0.3103	3.35	0.1268	
Residual	0.4633	5	0.0927			
Lack of Fit	0.4567	3	0.1522	45.67	0.0215	significant
Pure Error	0.0067	2	0.0033			
Cor Total	4.41	10				