UNIVERSITY OF CAPE COAST

DRYING KINETICS OF CASSAVA AND ORANGE-FLESHED SWEET POTATO AND THE PHYSICO-NUTRITIONAL CHARACTERIZATION OF THEIR COMPOSITE 'FUFU' FLOURS

SAMUEL YOUNGE

2022

UNIVERSITY OF CAPE COAST

DRYING KINETICS OF CASSAVA AND ORANGE-FLESHED SWEET POTATO AND THE PHYSICO-NUTRITIONAL CHARACTERIZATION OF THEIR COMPOSITE 'FUFU' FLOURS

BY

SAMUEL YOUNGE

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

DECEMBER 2022

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: ……..

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: .....

Co-Supervisor's Signature …….....Date …….....

Name: ……

Co-Supervisor's Signature ……..... Date …….....

Name: …….

ABSTRACT

In an effort to address illnesses caused by a lack of vitamin A, the orange-fleshed sweet potato (OFSP) is being pushed for eating as a public health tool in Ghana. As a staple diet in many households, 'fufu' can be suitably fortified with OFSP for the delivery of its essential micronutrients for health improvement. In this study, the drying characteristics of cassava pulp and orange-fleshed (OFSP) sweet potato chips for processing into 'fufu' flours and the moisture sorption behaviour of the composite flour blends were investigated. Also, the nutritional and functional characteristics of composite cassava/OFSP flour blends were examined. The composite flour blends were then cooked into 'fufu' and subjected to sensory evaluation using the nine-point hedonic scale. The pulverized cassava pulp was dried at 70 ^{o}C while the OFSP chips were dried at 60 ^{o}C. The initial average moisture content of the pulverized cassava pulp was 0.07 kg water/kg dry matter and was dried to 8.9 x 10^{-5} kg water/kg dry matter in 6 h while the OFSP chips was also dried from 0.6 kg water/kg dry matter to 9.0 x 10^{-5} kg water/kg dry matter in 9 h. The drying curves showed a single falling rate period for both samples. The effective moisture diffusivity for cassava was 2.36 x 10^{-8} m^2/s and that for OFSP was 4.60 x 10^{-8} m^2/s, both being within the range for drying agricultural food commodities. The Page model best described the drying characteristics of both cassava and OFSP samples. The moisture sorption isotherm curves for the various composite flour blends showed a sigmoidal plot that was typical of type II isotherms for starchy foods. The GAB model also best described the moisture sorption behaviour of the various composite blends. OFSP significantly ($p < 0.05$) enriched the nutritional and functional properties as its

substitution levels for cassava increased. However, the elastic texture and pasting properties degraded. Beyond 5% substitution of cassava with OFSP, sensory panelists disliked the organoleptic properties of the 'fufu' due to the high soluble sugar and fat in OFSP which affected the 'fufu' texture (elasticity). The low level of microbial count with no detection of aflatoxin strains in the flours signified how the fortified 'fufu' flour was safe for consumption. Shelf-life analysis after six months also showed that beta-carotene content in the most preferred flour sample packaged in the polyethylene-laminated paper bag was high to serve its nutritional purpose. Overall, this study showed a high potential of OFSP substitution for cassava in the production of 'fufu' to improve its nutritional value. The adoption of this OFSP-based food product will help diversify the uses of OFSP and also provide an alternative healthy and nutritious food for addressing vitamin A deficiency diseases in Ghana and Africa at large.

KEY WORDS

Beta-carotene

Cassava

Drying kinetics

Fufu

Orange-fleshed sweet potato

Vitamin A deficiency

ACKNOWLEDGEMENTS

Praise to the Holiest in the height and in the depth be praise; in all His words most wonderful, most sure in all His ways. I am most grateful to God Almighty for granting me the wisdom, knowledge and strength to complete this work successfully. Glory be to God.

My profound gratitude to my supervisors, Prof. Robert Sarpong Amoah, Prof. Ernest Ekow Abano and Dr. Francis Kumi for their support and guidance throughout the work and also to the other lecturers and staff of Agricultural Engineering Department for their support as well.

I also wish to express my profound gratitude to Mr. Eric Seddy-Kutortse (Chairman, First Sky Group), Nana Otu Esson and Prof. Richard Jinks Bani for their encouragement and immense support to enable me complete this work successfully.

Special thanks to all my senior friends, Prof. Agyeman Badu Akosa, Nana Safohene Acquaah-Harrison, Dr. Kofi Ankomah Dadzie, Mr. K. T. Dadzie, Mr. Kofi Ayensu, Mr. K. B. Annan, Mr. and Mrs. Obeng, Mr. Alfred Bonney, Major Acquaah-Harrison, Captain Fordjoe, Mr. Bernard Cofie, Mr. Kwame Kyei, Mr. B. B. Apenteng, Mr. Ato Waters and all G-Side members including the G-Side ladies. Special thanks to Dr. Sabi for his immerse support.

I wish to express my sincere gratitude to my uncle, Mr. Mahama Seidu for his support, motivation and encouragement. Finally, I am most grateful to all my siblings especially, Valentine Younge, Charlotte Younge, Jacqueline Younge, and Joseph Kwame Younge as well as my wife, Priscilla Mensah and my lovely children, Maame Benie, Joseph and Nana Amanor Younge for their prayers, encouragement, support and love for me. May God richly bless you all.

DEDICATION

I dedicate this work to God Almighty and to my late parents, Mr. Joseph Cobbinah Younge and Mrs. Philomena Younge, to my wife – Priscilla Mensah and my lovely children – Maame Benie Afiba Younge, Joseph Cobbinah Younge Jr., and Nana Amanor Younge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AGRA	Alliance for Green Revolution in Africa
AHA	American Heart Association
AOAC	Association of Official Analytical Chemists
BET	Brunauer-Emmett-Teller
CIP	International Potato Centre
CRI	Crops Research Institute
CSIR	Council for Scientific and Industrial Research
EDIF	Export Development and Investment Fund
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistic
g	Gram
GAB	Guggenheim-Anderson-de Boer
MDGs	Millennium Development Goals
Mg	Milligram
mL	Milliliter
OFSP	Orange Fleshed Sweet Potatoes
RDA	Recommended Daily Allowance
RE	Retinol Equivalent
RTIMP	Root and Tuber Improvement and Marketing Programme
USAID	United States Agency for International Development
VAD	Vitamin A Deficiency
VEPAG	Vegetable Producers Association of Ghana
WAC	Water Absorption Capacity
WHO	World Health Organization
WIADD	Women in Agricultural Development Directorate

µg	Microgram
µg/dL	Microgram per deciliter
µg/g	Microgram per gram
NMKL	National Museum Kuala Lumpur

CHAPTER ONE

INTRODUCTION

1.0 Background to the study

The nutritional and health requirements of the growing population keep on changing and therefore the processing and formulation of new food products with the aim of enhancing the nutritional value and palatability is critical (Wall and Winger, 2006). However, the main global concern is how these new food products affect the nutritional and health needs of the growing population (De Benoist *et al*., 2006). Current trends in agri-food systems require growers, distributors, agro-processors, retailors as well as other important stakeholders along the supply and value chain to improve the efficiency of their operations to meet the demands of consumers and global regulatory frameworks (Wall and Winger, 2006). As part of the world food bowl, root and tubers are very important food commodities that are considered as dietary energy sources for the growing population due to their high caloric content with a global average per capita consumption of about 19.4 kg per year which is expected to increase to 21 kg by 2025 (Petsakos *et al*., 2019).

Cassava (*Manihot esculenta Crantz*) and sweet potatoes (*Ipomea batatas, Lam*) are essential agricultural staple root tuber crops cultivated for their nutritional, medicinal, industrial and economic purposes. They can be processed into other new food products to meet the growing demand of the population and also to reduce postharvest losses. These root tubers play an essential role in food security in most developing countries especially in Africa. Cassava and sweet potato are of significant importance to most Sub-Saharan African countries as they have nutritional advantage for both urban

and rural dwellers due to their increased rate in cultivation and consumption (Rose and Vasanthakaalam, 2011).

As the third most important source of carbohydrate food in the tropics, behind rice and maize (Bayata, 2019), cassava is one of the most important staple root crops in Ghana. Many businesses use it as a raw ingredient in making bread and alcohol. Raw cassava starch is used in the pharmaceutical industry to create various medications (Ziska *et al*., 2009). The yearly supply of cassava for industrial usage generates an estimated US$20 million in revenue, which has a significant economic and social effect on the nation. Projection also shows that if Ghana is able to increase the industrial processing capability through investing in cassava production, the country is likely to double its economic income and this will improve production yields and the standard of living of the farmers (Koyama *et al*., 2015). Processing cassava has varying industrial applications that includes; food, pharmaceutical, cardboard or paper, ethanol, starch, chips, textiles, and adhesives/glues (Research and Markets, 2019). According to Koyama *et al*. (2015), ethanol is the major industrial product from cassava for local consumption and this is followed by starch, and cassava flour. Over 90% of cassava available for human consumption in Ghana is prepared into 'fufu', 'ampesi' or processed into other food products like 'kokonte', 'gari', 'agbelema' or 'fufu' flour (Agyepong, 2013).

Sweet potato on the other hand is considered globally as a food security root crop because it contains substantial amounts of bioactive compounds like β-Carotene (provitamin A carotenoids), polyphenols, ascorbic acid, minerals, vitamins, dietary fibre, proteins and also minimal in fat and

cholesterol (Ngoma *et al*., 2019). It also serves as the major sources of carbohydrates in the temperate regions (Ware, 2019). The most common ones are the varieties that have orange, purple, yellow and white flesh due to the distinct pigments and phenolic compound contents in their root tubers (Tang *et al*., 2015). Sweet potato is also considered to be very nutritious with other health benefits such as improving insulin sensitivity levels among diabetic patients, stabilization of blood sugar levels, maintaining blood pressure levels, minimizing the risk of cancer, improving digestion and regularity, boosting the human immunity and minimizing inflammation (Neela and Fanta, 2019). Due to the high beta-carotene content in the orange-fleshed variety, its consumption in diet has the tendency of counteracting poor vision among vitamin A deficient and malnourished children in developing countries (Tuffour, 2013). Staple root tubers like cassava and sweet potato contribute significantly to global food supply for human consumption and animal feed. They can also be processed into flour for the formulation of composite flours in the production of 'fufu' as well as other bakery and pastry food products (Chandrasekara and Kumar, 2016).

One critical reason for processing these root tubers is because of the excessive postharvest losses which is a major problem in Ghana. Produce losses in Ghana is so high along the postharvest supply chain causing much financial losses to the farmer and state as well as depriving consumers of the essential nutrients and nourishment needed for proper health and growth (Dadzie, 2018). During storage, these root tubers are left at ambient conditions resulting in undesirable colour changes and moisture loss (weight loss) which causes the root tubers to shrivel. This compromises the quality of the produce

thereby affecting its marketability and consumption. Furthermore, high tropical temperature also contributes to the fast deterioration rate of these root tubers after harvesting. Hence, the need to process them into other food products like flour to extend their shelf-life and also to improve on the nutritional value of the new food product formulated. Therefore, it is believed that by combining cassava with OFSP, a tasty 'fufu' flour product may be developed that can be preserved for extended periods of time and also offer a crucial avenue for the administration of prioritised micronutrients for health improvement of the consumer.

1.1 Rationale

United Nations Sustainable Development Goals 2 and 3 focus on ending hunger and improving health for all people by 2030 (Sachs *et al*., 2019). One of the most effective strategies for achieving these goals is to improve people's access to nutritious food. To achieve this goal, it is necessary to devise methods for distributing certain food-based micronutrients to the general populace. Micronutrient malnutrition, sometimes known as hidden hunger, is one of the most pressing public health issues in many nations of the developing world. This is because food consumed in most parts of Africa are mostly starchy food products which are predominantly root and tubers as well as cereal grains (Olapade *et al*., 2014). There are an estimated 161 million children under the age of 5 who are stunted because of hidden hunger caused by insufficient intake of several important nutrients in their diet (Narayanan *et al*., 2019). In particular, vitamin A deficiency, a form of micronutrient malnutrition, is a major cause of blindness and mortality in African children, with annual estimates ranging from 250,000 to 500,000

(Mayer *et al*., 2008; Kerac *et al*., 2014). According to Abano *et al*. (2019), vitamin A deficiency prevalence in Ghana for children below age 5 was estimated at 76% which is almost twice the average figure quoted for Africa (41.9%). When compared to other countries across the world, Sao Tome and Principe (95.6%) and Kenya (84.4%) rank top and second worst for vitamin A insufficiency severity, respectively (Abano *et al*., 2019). Preventable blindness, infant death, and negative birth outcomes are only some of the consequences of severe vitamin A deficiency in Ghana (USAID, 2016). This calls on the government of Ghana and other African nations to take action and implement measures to reduce the impact of the illness. One way is the adoption of biofortified food crops with enhanced micronutrient density in the fortification and enrichment of new food products during processing (food-to-food fortification). This can be achieved through the fortification of some major staple foods that are widely consumed in Ghana on daily or weekly basis with the biofortified food crop.

'Fufu' is a staple meal in West Africa and is consumed in many households on daily or weekly basis especially in Ghana. A meal like 'fufu' derived from cassava alone does not give a full nutrition, according to Olapade *et al*. (2014), since it contains roughly 85% carbohydrates, about 1-2% protein, and very minute other critical micronutrients. Therefore, its use has been linked to protein and micronutrient malnutrition owing to its poor nutritional value, notably in protein, vitamins, and minerals. Recent advancements have led to alternate processing methods, such as processing the components into composite flour that is simpler and quicker to prepare than the traditional technique of 'fufu' preparation, which entails heat and hand

pounding. Commercially available composite "fufu" flour is made by grinding together ground cassava, plantain, cocoyam, and yam, but not sweet potato (Egyir and Yeboah, 2010).

Using orange-fleshed sweet potatoes (OFSP) to make composite 'fufu' flour has grabbed the curiosity of scientists looking for a novel food product enriched with beta-carotene to treat disorders caused by vitamin A deficiency (RTIMP, 2008). The orange-fleshed form of sweet potato has established itself as the leading contender for satisfying the vital nutritional demands of patients afflicted with vitamin A deficiency disorders due to its large composition of pro-vitamin A, -carotene, and other necessary micronutrients. The International Potato Centre (CIP) and the Consultative Group on International Agricultural Research (CGIAR) developed the OFSP as a biofortified root crop with the potential to greatly improve human health, particularly the vitamin A status of children and reproductive mothers if consumed on a regular basis. It is therefore surprising that sweet potato remained an underutilized crop in Africa over the years. However, in recent years, several African nations have promoted OFSP as a public health strategy for better infant and maternal nutrition (Amoah, 2014; Amoah and Terry, 2018) due to increased understanding of its benefits. Over 6.8 million people's homes in Africa and South Asia were cultivating and consuming OFSP in 2010 (CGIAR, 2010) because to its high vitamin A content. It has not, however, achieved the projected adoption rate in Africa, measured by the percentage of households included it as a main diet in their food budgets. Reasons for this include the fact that many people in sub-Saharan Africa do not like the flavour of boiling sweet potato and hence avoid eating it straight. As a result,

researchers are looking at other recipes for comfortable administration of OFSP.

Processing these root tubers into composite flour requires adequate drying to reduce moisture for long term storability. Drying as a processing technique is an effective and efficient way of preserving agricultural commodities. It is a unit operation aimed at removing moisture from a food commodity to an appropriate level at which it will be in equilibrium with the atmospheric air and at which physiological deterioration and spoilage by pests would be inhibited (Kiaya, 2014). According to Abano (2020), drying is one of the best-known techniques used to minimize postharvest losses associated with root tubers like cassava and sweet potatoes and can also be used to produce quality flour products that can be used to prepare some delicious local staple foods like 'banku', 'fufu', bread, and 'kenkey'. Conventional hot-air dryers are largely used in the industries for the drying process. Abano *et al*. (2011) reported that during drying, heat damage experienced by a food product is mostly directly proportional to the applied temperature and the drying period. As a consequence, despite the fact that hot-air drying is the commonest technique used to preserve food products, most researchers are of the view that it contributes to the degradation of food nutrients, colour, flavour and case hardening because of the high temperatures and extended drying periods. Hence, drying of food products needs be done at an appropriate temperature and within a time interval that will not affect the nutritional composition of the food product (Sanni *et al*., 2012). According to Jahanbakhshi *et al*. (2020), an essential and technical way of explaining and

controlling the drying process of a produce is through mathematical modeling to permit control of the drying parameters.

1.2 Purpose of the Study

There are investigations into the ways of administering OFSP as a convenient diet to fully derive its potentials. Mitra (2012) claims that several initiatives have been launched by international health organisations to combat widespread vitamin A deficiency across the world. These are based on three methods: the distribution of vitamin A capsules through supplementation programmes, the bio-fortification of crops through agronomic breeding programmes to create new crop varieties, and the enrichment and fortification of some local food crops during processing with essential micronutrients to improve dietary quality. Supplements to the diet might be costly and out of reach for the poor. In recent times, biofortified food crops with enhanced micronutrient density that contains substantial amounts of β-carotene (pro-vitamin A carotenoids) and some essential nutrients as well as other antioxidants have been one of the major interventions aimed at minimizing micronutrient malnutrition in most developing countries in Africa (Bouis and Saltzman, 2017). The creation of composite food products in which nutrients from one crop are utilised to fortify the primary product as an alternative to agronomic bio-fortified foods is one example of how innovations in food processing have contributed to an increase in dietary diversity (Olapade *et al*., 2014).

Several food enrichment and fortification schemes have been launched in recent years by the World Health Organisation (WHO) and the Food and Agriculture Organisation (FAO) to combat worldwide issues of food

insecurity and poor nutrition. The term "food enrichment and fortification" refers to the practise of adding certain ingredients to processed foods with the goal of reducing nutritional deficiencies among consumers (Olapade et al., 2014). Food-to-food fortification, as proposed by Dary and Hurrel (2006), is crucial in enhancing the quality and nutritional value of processed food items to promote people's healthy development. OFSP may be combined with other crops to make a wide range of composite food items, adding to its already impressive list of benefits. The use of OFSP in 'fufu' formulation has not been researched, according to a review of the relevant literature. In order to better the health of the general people, this research looked into the potential for processing 'fufu' with OFSP as a nutrient fortifying component and determining the processing needs and channels for distributing it as a nutrient-rich, acceptable product. The study provided information on the hot-air drying characteristics of cassava and OFSP samples, the moisture sorption behaviours of the composite flour blends, the physico-nutritional, functional, pasting properties, microbial composition of the composite 'fufu' flour blends as well as sensory evaluation of the cooked 'fufu' from the composite cassava and OFSP flour blends.

1.3 Aim and Objectives

1.3.1 Main Aim

The main aim of this study is to develop a new nutritionally-enhanced 'fufu' product from composite cassava and orange-fleshed sweet potato flours.

1.3.2 Specific Objectives

To meet the main objective of this study, the following sub-objectives were defined. The specific objectives are to:

1. Use mathematical drying models to determine the drying characteristics of cassava and OFSP samples.
2. Determine the formulation ratios of composite cassava and OFSP flour suitable for processing into 'fufu'.
3. Use mathematical moisture sorption isotherm models to determine the moisture sorption behaviours of composite flour blends from cassava and OFSP flours.
4. Determine the physico-chemical, functional and pasting properties, microbial composition of the composite flour blends and the stability of beta-carotene in shelf-life analysis.
5. Perform sensory analysis to evaluate consumer perception of the new prepared food product.

1.4 Significance of the Study

'Fufu' is a major staple meal in Ghana and it is consumed in many households on daily or weekly basis due to its palatability and affordability. It is normally eaten with different kinds of soup prepared with fish, meat or chicken. However, 'fufu' prepared from cassava fortified with plantain, yam or cocoyam is limited in β-carotene, a precursor of vitamin A. The prevalence of vitamin A deficiency in Ghana is very high (Abano *et al*., 2019) and one of the major ways of addressing this issue is to fortify some of our major staple foods that are consumed almost on daily or weekly basis with some biofortified food crops which are rich in beta-carotene (a pro-vitamin A

carotenoid). It is for this reason that the OFSP is considered as a biofortified crop to meet the critical dietary needs of the people plagued with vitamin A deficiency diseases. Due to the high β-carotene in the OFSP, its consumption in diet especially in the formulation of composite 'fufu' flour has the tendency of counteracting poor vision among vitamin A deficient children and reproductive women. Furthermore, due to the elaborate traditional method of preparing 'fufu', there is an increasing demand for composite 'fufu' flour which is easy and fast to cook with desirable nutritional composition. The adoption of this OFSP-based food product will help diversify its uses and provide an alternate healthy and nutritious food for the growing population. Due to the relatively high vitamin A content, it will help with efforts to minimize Vitamin A deficiency and also, its diversification and utilization to achieve food and nutrition security in Ghana and other parts of Africa.

1.5 Delimitations

The study sought to consider the use of local varieties of both cassava and bio-fortified orange-fleshed sweet potato. The cassava variety '*Capevars bankye*' was bred by the Crop Science Department, School of Agriculture, University of Cape Coast. The '*Apomuden*' variety of OFSP was also bred by the Crops Research Institute of the Council for Scientific and Industrial Research, Kumasi – Ghana. The study was to adopt the food-to-food method of fortification using the biofortified OFSP as the food fortifier to address the issue of vitamin A deficiency in children and reproductive mothers.

1.6 Limitations

Due to the Covid-19 pandemic, sample collection on the field and experimental analysis at the laboratory was somehow problematic due to the

lockdown and public restrictions on movement. Technicians responsible for operating some key equipment or instruments were not available to run test samples and this affected the work schedule as planned.

1.7 Organization of the Study

The study was organized into five chapters. Chapter one covered the introduction which included the background to the study, rationale, purpose of the study, main aim and specific objectives, significance of the study, delimitation, and limitation of the study. Chapter two is the literature review which covered the theoretical framework and conceptual bases of the study. It reviewed the key concepts, theories and conceptual evaluations that provided relevant information to guide the studies. Chapter three also covered the research methodology which included the experimental design, sample materials, sample preparation, research methods, data collection instruments and data processing and analysis. Chapter four dealt with the results and discussion of findings. Finally, chapter five covered the research summary which included the key findings, conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 Background

Agricultural commodities such as root and tubers are essential starchy foods in the world food bowl. They contribute effectively to nutrition and food security in most developing countries. In terms of carbohydrate content, roots and tubers are second to cereal grains (Chandrasekara and Kumar, 2016). Starchy root tubers contribute a substantial amount of global food supply as they serve as a major source of food for human consumption, livestock feed and for industrial purposes for processing into other food products (Chandrasekara and Kumar, 2016). The Organization for Economic Co-operation and Development, OECD and Food and Agriculture Organization, FAO (2016) stated that as part of the world food bowl, root and tubers are considered as dietary energy given food for the growing population due to their high caloric content with a global average per capita consumption of about 19.4 kg per year from 2013 to 2015. And this is anticipated to increase to 21.0 kg per year by the year 2025.

According to FAOSTAT (2020), world output of roots and tubers rose sharply from 704.3 million metric tonnes in 2006 to 841 million metric tonnes (MT) between 2016 and 2018. With an annual output of 178 million metric tonnes (MT), China accounts for almost 20% of global production of roots and tubers. Next in line are Nigeria (116 MT), India (54.2 MT), the Democratic Republic of the Congo (33 MT), and Thailand (31 MT). In 2017, Ghana produced a total of 27.8 million metric tonnes (MT) of roots and tubers, making it the seventh biggest producer in the world. Roots and tubers account

for 76% of global output, with the majority coming from Asia (43%), followed by Africa (33%) (FAOSTAT, 2020). The edible starchy material is stored in the roots, stems, corms, tubers, and rhizomes of root and tuber crops. Vegetative propagation is used to spread sweet potato and cassava, both of which are used as store roots (Chandrasekara and Kumar, 2016). However, because to its expanded production, high nutritional value, and consumption rate in most developed and undeveloped nations worldwide, sweet potato is regarded to be among the most vital staple root crops (Neela and Fanta, 2019).

2.1 Sweet potato

2.1.1 Classification and description of sweet potato

Sweet potato is a perennial dicotyledonous crop usually grown in subtropical and tropical lowland agro-ecological zones. It is classified as a storage root vegetable crop and belongs to the Convolvulaceae family, also called the "morning glory family". The *Convolvulaceae* family has over 1000 species that are grouped into 50 genera, with *Ipomoea* as the largest genus of the family (Lebot, 2009; Amoah, 2014). Although it is often produced in the Caribbean, Asia, and Africa, sweet potatoes are said to have originated in tropical Central America. Large, delicious, fleshy adventitious storage roots (Figure 2.1) emerge at the nodes of the subterranean stem, which may be twinned or trailed and can grow up to 4 metres in length. Like morning glory's herbaceous vines, sweet potato plants produce halberd- or heart-shaped leaves with white edges or violet throat flowers (Lebot, 2009). The skin on the storage roots is typically smooth and long. Various varieties of it are available. The carotenoids and phenolic compounds in sweet potatoes are responsible for differentiating the colours of the skin and flesh, which could be white, yellow,

cream, purple, or orange as shown in Figure 2.2 (Laryea *et al.*, 2018; Neela and Fanta, 2019).

Figure 2.1: Orange-fleshed sweet potato root tuber

Botanically, sweet potato is very different from potato even though their physical appearance, usage and postharvest handling are similar. Again, potato (*Solanum tuberosum*) is a member of the *Solanaceae* family and morphologically, whereas sweet potato grows as an adventitious storage root, potato tuber grows at the tip of the stem (Loebenstein and Thottappilly, 2009; Amoah, 2014).

Figure 2.2: Different types of sweet potatoes

2.1.2 Cultivation and global production of sweet potato

Due to its adaptation mode, the crop is widely distributed and cultivated worldwide in temperate and tropical regions as a staple root crop

(Lebot, 2009). Propagation of the crop is by vegetative means, and it is reproduced in three different ways. Propagation could occur through the botanical seed, which is usually used during breeding programs, crop vines, or the actual storage roots. But with all these modes of propagation, the crop vine system grows quickly and covers the soil within the shortest possible time (IPC, 2019). Sweet potato crop grows well at a temperature of 24 °C and above with a minimum rainfall of 500 mm. The crop grows well in a wide range of soils but does well in a well-drained, slightly acidic soil like sandy loam with a pH ranging between 4.5 to 7. Therefore, sweet potato production is destroyed by frost and cannot withstand temperatures below 10 °C (Oishimaya, 2017).

The cultivation cycle of sweet potato occurs in 3 phases. During phase 1 which is the time of planting to approximately 10 weeks, fibrous roots of the crop grow extensively with moderate vine growth. The period between 10 weeks to 16 weeks is the second phase and at this stage, extensive vine growth occurs with an enhanced area of leaf size as well as initial development of the storage root. The third and final phase before maturity is bulking the storage root with minimal fibrous root and vine growth (Amoah, 2014). Among the various tropical root crops, the production cycle of sweet potato is the shortest, so it is mostly described as a famine crop (IPC, 2019). The crop maturity period is between 2 to 7 months but some early maturing cultivars take 2 months to grow. The fleshy roots of the sweet potato differ in shape and size depending on the variety and soil type. The crop can grow in infertile soils and even in drought season with relatively less labour and little or no pesticides or fertilizer application (IPC, 2019). The orange-fleshed sweet potato (OFSP) is a

special type of variety that is biofortified with high amounts of β-carotene (provitamin A carotenoids) and other essential micronutrients (Srivastava *et al*., 2012).

Figure 2.3: The orange-fleshed sweet potato

Data showed that as of 2020, world production of sweet potato had decreased significantly with a total production of about 106.44 million MT in 2006 to about 89.43 million MT in 2020 (Scott, 2021). Even though the global production of sweet potato declined drastically, China still remained the leading producer of sweet potato in the world with a total production of 48.95 million MT in 2020, accounting for about 54.74% of the world total production. This was followed by Malawi – 6.92 million MT (7.74%), Tanzania – 4.44 million MT (4.96%), Nigeria – 3.87 million MT (4.33%), and Angola – 1.73 million MT (1.93%) respectively. The International Potato Center, CIP (2021) documented that globally, China is the largest producer and consumer of sweet potatoes as they process the root crop for food, starch, and animal feed. According to Observation of Economic Complexity, OEC (2022), in 2021, the top exporter of sweet potatoes whether fresh or dried was the United States of America ($213M), and the top importer of the same crop, whether fresh or dried, was the Netherlands ($151M). The total sweet potato production in Ghana is about 151,420 MT as of 2018 and it is ranked 37th in

the world in terms of production. Statistics shows that Asia (77.9%) and Africa (18.4%) still remain the major producers of sweet potato representing 96.3% of the world's production Most of the sweet potato produced in Africa collectively came from Malawi, Nigeria, Ethiopia, Uganda, Mozambique and Ghana (FAOSTAT, 2020; Scott, 2021).

Asafu-Agyei (2010) reported that based on the new local varieties developed and the increasing cultivation area (hectares) by the small-scale farmers, the Crops Research Institute (CRI) of the Council for Scientific and Industrial Research (CSIR) in Ghana made projection on the total production of sweet potato to reach 200,000 MT by 2020. But this projection did not materialize. According to Nyarko *et al*. (2022), annual sweet potato production in Ghana decreased from 151,420 MT in 2018 to 132,000 MT as of 2021. Nyarko *et al*. (2022) also stated that sweet potato is the fourth major essential root crop in Ghana which is largely grown in the Upper East, Northern, Upper West Savannah, Volta, and Central Regions of Ghana usually by small-scale farmers. Sweet potato has a wide genetic variability with respect to the number of varieties available. However, the development could be through breeding efforts or by hybridization and mutation activity. The crop varies extremely in their chemical and physical characteristics as a result of their varying utilization. Cultivar variation is based on the colour of the flesh, skin or cooked texture (Amoah, 2014). According to Loebenstein and Thottappilly (2009), the colour of the skin could be orange, yellow, red, tan, whitish or reddish purple while the colour of the flesh could also be orange, red, salmon orange, white or yellowish-orange.

Table 2.1: Varieties of sweet potato in Ghana with their characteristics and uses

Name of variety	Root skin colour	Flesh colour	Root yield (t/ha)	Dry matter (%)	Uses and products in Ghana and Sub-region
Apomuden	Reddish	Orange	30	21.9	High β-carotene; preferred by exporters; used for baby foods; good for flour.
Otoo	White	Light orange	23	32.2	Medium β-carotene; deep-fried and boiled; crop is exported
Ogyefo	Pink	White	20	40.1	Fried and boiled as chips; good for extraction of starch.
Hi-Starch	Dark cream	Cream	18	40.0	Starch content is high (21%); mild sweetness; better flour production.
Sauti	White	Yellow	19	40.2	Fried and boiled as chips; sugar content is low.
Faara	Pink	White	22	36.1	Boiled as *ampesi* and better for frying chips.
Okumkom	Light pink	White	20	30.7	Matures early; excellent for *ampesi.*
Santom pona	Dark cream	Light yellow	17	34.4	Matures early; taste like yam; excellent for *ampesi.*
Jukwa orange	Dark cream	Light orange	30	35.0	Higher dry matter; excellent for chips *ampesi*.

Source: Asafu-Agyei (2010) and Amoah (2014)

In recent years, the Crops Research Institute (CRI) of Council for Scientific and Industrial Research (CSIR) in Ghana has come up with new cultivars of sweet potato which is of excellent food value with better-quality starch yield and nutrient content for the Ghanaian domestic market through genetic engineering and back crossing techniques. With its excellent

nutritional content, sweet potato is gradually becoming Ghana's third most essential root tuber after cassava and yam (Tuffour, 2013). Some of the new cultivars developed by the CRI of Ghana include CRI-*Sauti*, CRI-*Ogyefo* (Mugande), CRI-Hi-Starch (fufu santum), CRI-*Apomuden* and CRI-*Faara* as shown in Table 2.1. For the purpose of this study, the CRI-*Apomuden* variety was used.

2.1.3 Utilization and nutritional benefits of sweet potato

Sweet potato has a global significance in terms of its consumption by humans, as a livestock feed for animals or industrial purpose and research. But basically, it could be considered based on its significance as a food security crop or as a health-promoting agricultural commodity with reference to its increased nutritional value (Terry, 2008). With regards to sweet potato industrial uses, many foreign industrial companies mostly in Japan, USA, China and Europe process them into alcohol, industrial starch, and bioplastics (Amoah, 2014). Also, because of the increased agronomic merits of sweet potato due to its high production yield, nutritional content and its ability to survive in different ecological conditions, the crop is seen to have an enhanced capacity in alleviating hunger and poverty in most underdeveloped countries especially in Africa (Islam, 2006; Brinley *et al*., 2008; Amoah, 2014). The fresh sweet potato, also described as a vegetable root crop, is rich in complex carbohydrates and simple starches. It also contains some substantial amounts of β-carotene (especially in the orange-fleshed variety), dietary fiber, vitamins (predominantly vitamin B_5 and B_6) and other minerals. The versatile storage root is used in a wide variety of cuisines. They are often prepared in the oven or microwave and eaten as a sweet treat or snack. Vegetative components of

vines, such as young leaves and vine tips, are also consumed for their nutritional value (Oishamaya, 2017). Vitamin C, potassium, and beta-carotene may all be found in high concentrations in OFSP. According to Bjarnadottir (2019), the abundant minerals and vitamins in this root vegetable include: pro-vitamin A (β-carotene), potassium, vitamin C, vitamin B_5, vitamin B_6, vitamin E and manganese (Table 2.2)

The human body is able to convert the β-carotene into vitamin A to address the issue of vitamin A deficiency that leads to blindness. Vitamin C, a vital antioxidant, shortens the duration of the common cold and improves skin health. Potassium's ability to lower blood pressure and protect against cardiovascular illness is well-documented. When it comes to metabolism, development, and efficient growth, the trace mineral manganese is crucial. Vitamin E, a powerful fat-soluble antioxidant, protects cells from oxidative damage and heals wounds caused by free radicals (Bjarnadottir, 2019). For non-culinary industrial uses, the OFSP might have its juice extracted and used with lime to create a textile dye. Once again, the crop's components have potential as ingredients in animal feed. Oishamaya (2017) suggests that the vine formation might be exploited in home aquarium manufacturing due to its growth pattern in water under improved light conditions.

Table 2.2: Nutrients in sweet potato and their recommended daily intake for consumers

Nutrient	Amount in 124g Serving of Mashed Sweet Potato	Recommended Daily Intake for consumers
Energy (calories)	108	1,600 – 3,000
Protein (g)	2	46 - 56
Fat (g)	3	360 – 1,050 g, depending on energy needs
Carbohydrate (g)	18.7, of which 6.77 g is sugar	130
Fiber (g)	2.48	22.4 – 33.6
Iron (mg)	0.70	8 – 18
Calcium (mg)	50.80	1,000 – 2,000
Magnesium (mg)	19.80	310 - 420
Phosphorous (mg)	50.80	1,000 – 1,200
Potassium (mg)	259	4,700
Sodium (mg)	306	2,300
Selenium (µg)	0.90	55
Vitamin C (mg)	12.80	75 – 90
Folate (µg)	7.44	400
Choline (mg)	14.40	425 – 550
Vitamin A, RAE (µg)	823	700 – 900
Beta-carotene (µg)	9,470	No data
Vitamin K (µg)	5.10	90 – 120
Cholesterol (mg)	1.24	No data

Source: Ware (2019)

Currently, on-going studies on how to produce a particular cultivar that could be used for biofuel production is being carried out. During the last decade, there has been an immense focus on global sweet potato research to realize the crop's potential as a source of food for the growing population, livestock feed products, industrial food manufacturing products, and its marketability (Amoah, 2014).

The nutritional, functional and biochemical characteristics of sweet potato gives it an economical and potential competitive advantage in its utilization as a source of food for human nutrition, livestock feed systems and industrial systems. It also can act as a key role in future renewable energy sources (Bovell-Benjamin, 2007).

Sweet potato has antioxidative, antidiabetic, antimutagenic, and radical scavenging properties that positively impact human health (Islam, 2006). These properties have the potential to minimize blood sugar levels and enhance glucose tolerance, minimise liver damage, and also limit blood pressure activity (Islam, 2006).

When consumed, the young leaves and stems of the crop contain bioactive phytochemicals like chlorogenic acids, which contain substantial quantities of polyphenolics that prevent cancer and cardiovascular diseases and improve glucose tolerance in man. In livestock feed systems, the leaves serve as a source of protein for rearing goats, poultry and pigs as well as enhancing the utilization of ruminant urea (Bovell-Benjamin, 2007). The OFSP is considered as a very important source of vitamin A as its continuous consumption plays a major role in eradicating vitamin A deficiency, especially in children in most developing countries (Girard *et al*., 2017; Kurabachew,

2015; Neela and Fanta, 2019). According to Chandrasekara and Kumar (2016), scientific research has established that OFSP has a good nutritional attribute of possessing anticarcinogenic properties in preventing heart-related (cardiovascular) and cancer diseases. Current scientific research also reports that the free radical scavenging and antioxidative activity of the phenolic acid compounds in OFSP enhance its health-promoting functions in reducing liver damage and blood pressure levels (Bovell-Benjamin, 2007; Teow *et al*., 2007).

2.2 Cassava

2.2.1 Classification and description

Cassava (*Manihot esculenta* Crantz) belongs to the family *Euphobiaceae* and considered as one of the most essential root crops globally as it provides food for over a billion people and plays a significant role in providing food security for most African countries (Teye *et al*., 2011). Through their commerce with coastal African countries in the 16th and 17th centuries, the Portuguese are often credited for bringing the cassava crop to Africa from South America. The significance of the crop as a source of food security on the continent has led to its cultivation by most African countries at the present time (Lebot, 2009). Guira *et al*. (2017) reported that the cassava is the third most vital source of carbohydrate Africa after rice and maize.

Figure 2.4: Cassava

Cassava is a perennial wood crop with a height of about 2-4 m (Figure 2.4). Generally, there are two kinds and these are sweet and bitter cassava. The sweet cassava is more preferred and widely cultivated due to its massive production yields. The texture and colour of the storage root peel as well as the flesh mainly differentiate the various cultivars (Guira *et al*., 2017). The storage root flesh is normally firm, tuberous, tapered and long, and covered with a rough brown outer skin (rind) that is usually 1 mm thick. The flesh is either yellowish or chalk-white colour. The cassava stem is normally erect and it emits from the tuber. The leaves are palmate-like with 5-7 lobes on a long slender petiole. The important and economic parts of the cassava plant are the leaves and tubers (Lebot, 2009). Cassava is a typical drought-resistant agricultural crop that can grow well in poor soils (Naziri *et al*., 2014).

2.2.2 Cultivation and global production of cassava

Cassava is an essential food commodity in many households and its cultivation is very flexible due to its environmental adaptability with respect to its tolerance to drought conditions, resistance to crop pests and diseases as well as its management practices or requirements (Bayitse *et al*., 2017; Meridian Institute, 2009). In Ghana, the growing period is usually around the rainy season which is from April to November. The maturity period for the crop is within 12-14 months but with the introduction of enhanced new local cultivars, the crop can be harvested within 12 months after planting (Sam and Deppah, 2009).

Root output may be increased by providing the crop with the proper growing conditions, which include a humid but warm environment with temperatures between 25 and 27 degrees Celsius and an annual rainfall of 500

to 5,000 millimetres (Bayitse *et al*., 2017). Like sweet potato, Cassava is killed by frost and will not survive temperatures below 10 °C (Lebot, 2009). The plant may thrive in a wide range of soil conditions, but it is particularly happy in sandy loams or loamy sand that's damp, deep, and nutrient-rich. Howeler (2001) states that the crop can survive under high levels of exchangeable aluminium in the soil matrix, low pH, and low phosphorus content. In Ghana, the average annual rainfall ranges between 800-2,200 mm with a soil pH varying between 3.5-7.8. This makes it very appropriate for the cultivation of cassava (SRID-MoFA, 2016). Propagation of the crop is by vegetative means through stem cuttings and the total number of cassava plants per hectare is usually between 10,000 to 15,000 with a planting distance of 80-100 cm (Lebot, 2009). According to FAOSTAT (2020), worldwide output of cassava surged dramatically from around 175.8 million metric tonnes (MT) in 2000 to over 293 million MT in 2015 before progressively declining from about 288.5 million MT in 2016 to around 282 million MT in 2018. Three countries in Africa—Nigeria, the Democratic Republic of the Congo, and Ghana—are responsible for the vast majority of Africa's cassava output. Scott (2021) estimates Nigeria's annual cassava output is 59.4 million metric tonnes, making it the world's greatest producer. About 60% of the world's total output occurs in Africa, making about 21.4% of the total. After that comes Thailand (31.6 million MT), the Democratic Republic of the Congo (29.9 million MT), Ghana (20.8), Brazil (17.6), and Indonesia (16.1). When it comes to producing cassava, Ghana ranks third in Africa and fourth in the globe. Worldwide, 99.9 percent of cassava is grown, with the majority of that crop coming from Africa

(54.9 percent), Asia (30.4 percent), and the Americas (13.6 percent) (FAOSTAT, 2020).

In Ghana, cassava is the most essential storage root crop that is being cultivated on over 900,000 hectares of land (GEPA, 2017). Approximately 70% of the farmers in Ghana are involved in cassava cultivation, contributing about 22% of Ghana's agricultural GDP growth. About 18 cassava varieties have been certified for commercial use in Ghana (GEPA, 2017).

Table 2.3: Summary of the characteristics of some of the improved cultivars of cassava in Ghana

Cultivar	Period of Maturity (Months)	Mean root yield (t/ha)	Total dry matter (%)	Utilization (uses)	CMD Resistance	Appropriate Ecologies
CSIR-CRI Ampong	12	59	36	Flour, starch, poundable (fufu)	Resistant	Forest, Transition and Savannah
CSIR-CRI Buroni bankye	12	40	33	Flour and bakery products	Resistant	Forest, Transition and Savannah
CSIR-CRI Sika bankye	12	56	36	Hi – Starch	Tolerant	Forest, Transition and Savannah
CSIR-CRI Otuhia	12	65	39	Starch and flour	Resistant	Forest, Transition and Savannah
Capevars bankye	8-12	64	39	Starch, flour, poundable (fufu)	Resistant	Forest, Transition, and Savannah

Source: Acheampong *et al*. (2021)

The CRI has developed superior cultivars of these crops with increased nutritional content and starch production for sale in both the local Ghanaian market and abroad. Capevars bankye, Nkabom, IFAD, Afisiafi, Tekbankye,

Abasafitaa, Sikabankye, CRI-Agbelifia, CRI-Essam bankye, CRI-Bankye hermaa, CRI-Doku duade, etc. are just a few examples of the many varieties available (MOFA, 2015). The Capevars bankye was utilised for this analysis (Table 2.3).

2.2.3 Utilization and nutritional benefits of cassava

The economical and industrial uses of cassava in Ghana is very promising as there has been a significant investment on the root crop and research has shown that in the coming years there will be an increase in industrial demand of the commodity. In 2015, food industries in Ghana processed an estimated amount of 66,000 MT of cassava, mainly for producing packaged local foods and drinks. This industrial demand of the root crop was expected to rise to 1.6 million MT by the year 2020 (Koyama *et al*., 2015). Processing of cassava on the international market increased by 2.6% from 2011 to 2018. Majority of the growing population of Asia, South America and Africa relied on cassava production for food and employment for the traders and farmers (Research and Markets, 2019). The economic and social impact of cassava on Ghana's economy is enormous with an estimated amount of US$ 20 million as proceeds from the supply of annual cassava for industrial use. Projection also shows that if Ghana can increase the industrial processing capability through investing in cassava production, the country is likely to double its economic income and this will improve production yields and the farmers' standard of living (Koyama *et al*., 2015).

Table 2.4: Crop production information on the root tubers used in the study

Name of Variety	National Code	Origin/ Source	Breeder/ Institution	Applicant	Distinctness, Uniformity & Stability	Value for Cultivation & Use	Preferred Ecology	Pedigree/ Line	Year of Release	Year of Registry
Capevars bankye	GH/Me/014/ 15	Central Region, Ghana	J. P. Tetteh et al., Univ. of Cape Coast	University of Cape Coast, Ghana	Green young and old leaves, purplish petioles, 1-9 leaf lobes per petiole. Young stem is green with purplish stripes. Mature stem is light brown, and may produce3-5 tiers of branches. Height of first branching may be 120 cm and above. Roots: The skin is dark brown, the rind is light purple, and the flesh is white. Roots are relatively cylindrical in shape with distinct neck. The plant grows vigorously and closes canopy within 3-4 months. It is also resistant to the Cassava Mosaic virus.	Maturity: Quite early maturing, within 8-12 months, but can remain in the soil up to 18 months. High yielding (20-64 t/ha). Roots are mealy all year round. Besides it is relatively sweet, hence it is highly preferred for 'fufu' and 'ampesi'. Starch yield relatively high (above 25%). It is recommended for food uses (fufu, gari, ampesi, agbelima) and for industrial starch production.	Savanna transitional Deciduous forest, Evergreen rain forest.	Selection out of 514 local collections made from Central and Western Regions of Ghana.	2005	2015
CRI-Apomuden	GH/Ib/006/ 15	CIP	H. Dapaah/ K. Adofo CSIR-CRI	CSIR-CRI	Plant type: Spreading; Foliage color: Green; Petiole pigmentation: Green and pigmented close to the leaf; Storage root shape: Long irregular or Curved; Storage root skin color; Predominant color: Purple-red with interspersed Cream; Storage root flesh color: Orange with yellow; Storage root shape variability: Moderately Viarable; Storage root size variability: Moderately Variable.	Storage root DM percentage: 21.9; Storage root starch percentage: 10; very high storage root carotene content; Pest reaction: Susceptible to sweet potato weevil after 3MAP; Excellent for baby-foods and fortification of dairy products (potaghurt), good for flour, potential root yield 30 ton/ha, Starch 47.01% (DWT), total sugars 36.67%.	Guinea savannah, Forest transition and coastal savannah	Kamala sundari	2005	2015

Source: MOFA (2015)

Cassava has become Ghana's main staple food that is being consumed by almost all the ethnic groups in the country either fresh or processed into other forms. It is the main dietary carbohydrate source for many developing African countries (Bayitse *et al*., 2017). The essence of processing cassava is to get rid of the toxins, extend storage life, reduce size to enhance its transportation to market, add nutritional value, and reduce postharvest damage and losses. Processing cassava has varying industrial applications that includes: food, pharmaceutical, cardboard or paper, ethanol, starch, chips, textiles, and adhesives/glues (Research and Markets, 2019). According to Koyama *et al*. (2015), ethanol is the major industrial product from cassava for local consumption, followed by starch and cassava flour. The leaves and roots are the most often used portions for human consumption. Large amounts of poisonous and harmful cyanohydrin cyanide may be found in the roots. It also makes the meal taste bitter when eaten. Cultivars are often classified as bitter or sweet based on the amount of cyanide they contain. The cultivars classified as sweet are meant for human consumption since there is less or negligible cyanide content. But the bitter cultivars have higher cyanide content and are usually used for livestock feed and industrial purposes due to their high starch content (Research and Markets, 2019). The storage root is rich in carbohydrates and vitamin C. The leaves are also rich in lysine, β-carotene and some other compounds that are useful for human metabolism and skin health (Wong, 2019; Montagnac *et al*., 2009). Even though cassava is known to be rich in carbohydrates and lower in protein as well as other important nutrients, it contains some essential compounds believed to possess antioxidant and inflammatory properties. These properties have the potential of treating and

preventing some health conditions such as arthritis, diabetes, cancer, hair loss, infertility etc. Research studies have shown that the root crop contains folic acid and phytoestrogens that can improve fertility (Wong, 2019).

2.3 Food processing innovations

For countries to realize effective economic returns from agricultural production, there is the need to develop the agro-manufacturing food sector and encourage commercial farming and agri-business systems. Improving the agrifood system through innovative food product development strategies is the surest way to meet consumers' increasing demand for food (Winger and Wall, 2006). Food product development is all about creating a new food product or enhancing an existing one by adding nutrients and other beneficial ingredients to make it more appealing to consumers (Laryea *et al*., 2018). Food product development may be considered the methodical process and market-driven innovation of creating and refining new food items to meet customer demand (Winger and Wall, 2006).

As the global population has increased over the last four decades, so has the importance placed on new food product development by the food production industry (Earle et al., 2001; Laryea et al., 2018). According to Stewart-Knox and Mitchell (2003), a food manufacturing business must invest in food product innovation and development to maintain competitiveness in both domestic and foreign markets. According to the literature on business innovation strategy and management in the food manufacturing sector (Winger and Wall, 2006), product development is the industry's lifeblood. Consumers' demand for food constantly changes with time; for that matter, the growing population's increase in global food demand has led to the

development of new food products or reformulating the existing ones. Some factors that affect food product development include environmental and health concerns, convenience and nutritional benefits, industry marketability and profitability as well as technology (methods) for processing (Earle *et al*., 2001).

Winger and Wall (2006) documented that there are four basic essential stages for the process of every food product development and these stages are:

- Strategy for developing the product
- Design of product and development
- Commercialization of product
- Launching of product and post-launch

Activities carried out in each stage produces certain information (outcomes) with which management of the food industry depends on to take some critical decisions. Winger and Wall (2006) stated that the only way to determine the success of a new developed food product on the market is only when its commercialization, launching, promotion and marketability is effective. According to Winger and Wall (2006), in developing a new food product, there is the need to make some considerations, including enhancing the food's safety, its palatability, storage life, addition of nutritional value and minimize wastage.

A well-developed food product which is appealing to the growing population is most likely to survive on both domestic and international markets (Costa and Jongen, 2006). According to Carpenter *et al*. (2000), sensory evaluation is a vital and critical feature of developing a food product. Hence, the new product developed must be very nutritious with significant

health benefits and safe and convenient for consumption. And so far, as it is appealing to the consumer, such food product will never fail on the market. Rudder *et al*. (2001) included idea/concept generation, screening, research/development, product testing, product launch, and product marketing as phases in the creation of a food product. These steps streamline the product development process and increase its effectiveness.

2.4 Development and processing of composite flour

Most food scientists and researchers are paying close attention to the rising trend of creating novel food items via the synthesis of composite flour. The goal of this research is to generate composite flour with improved nutritional content, complete with all the functional and rheological qualities necessary for use in the production of nutrient-rich food items such pastries or snacks, bakery goods, and supplementary meals (Noorfarahzilah *et al*., 2014). To create a novel food product with improved nutritional value, scientists combine the flours of many food sources, often cereal grains, legumes, or root tubers (Shittu *et al*., 2007). Some of the benefits of using composite food flour in both developed and developing countries are the promotion and production of high-yielding crop varieties, the reduction of food imports (especially wheat flour), the improvement of the nutritional value of the processed composite flour, and the proper utilisation of locally grown agricultural commodities (Hasmadi *et al*., 2014). Most developing countries have turned domestic agricultural commodities into flour to supplement or reduce reliance on wheat flour (Abdelghafor *et al*., 2011).

In 1964, the Food and Agriculture Organisation (FAO) introduced the idea of composite flour technology to encourage the use of locally prepared

composite food flours from crops like cereals, legumes, and root tubers (maize, rice, millet, sorghum, cocoyam, cassava, yam, potato, etc.) as a partial substitution for wheat flour. The Food and Agriculture Organisation (FAO) has indicated that if wheat flour imports into developing countries are reduced or abolished, using composite flour in various food items would be economically sensible (Noorfarahzilah *et al*., 2014). Jisha *et al*. (2008) state that composite flour has financial and nutritional benefits in the food industry. Because of the plant protein and other considerable nutrients, the legume crop provides, composite flour created from a cereal and a legume has an improved nutritional value and quality, for example. Bread made from a combination of cassava and groundnuts or cassava and soya has a higher nutritional content than wheat flour bread, as revealed by Nilufer *et al*. (2008). This is due to the soya or groundnut's ability to boost the bread's protein and nutritious content.

According to Chadare *et al*. (2018), the nutritional needs of children and the vulnerable population in the rural settings of most Sub-Saharan African countries can be met through the careful combination of indigenous food crops that complement each other to improve on the nutritional contents of the new food product developed. The cereal proteins in wheat are low in threonine and lysine, two important amino acids (Dhingra and Jood, 2002; Noorfarahzilah *et al*., 2014), leading to the widespread belief that wheat is nutritionally inadequate. As a result, the nutritional content, quality, and palatability of the new food product may be enhanced by replacing wheat flour with low-cost staple food crops such as maize, rice, millet, sorghum, cowpea, soy, cassava, yam, sweet potato, or cocoyam in the formulation of composite food flour.

Processing of food crops represents a significant part of the food production and value chain (Papageorgiou and Skendi, 2018). The prime objective of processing agricultural food products is to convert them into a well stabilized food products that could be stored for longer periods and also limit postharvest losses. The act of processing also retains the products' nutritional values and extends its availability year-round (Gunathilake *et al*., 2018). Processing agricultural food commodities into other food products is a widespread activity involving artisanal small-scale commercial processing groups (Egyir and Yeboah, 2010). The local or industrial techniques for processing these agricultural food crops involves the combinations of various unit processes like peeling, washing, cutting into chips or grating, dewatering, fermenting, drying, roasting and milling. According to Egyir and Yeboah (2010), agro-processing involves every unit operation right from harvest till the food commodity gets to the consumer in a well packaged material for proper marketability. Processing transforms the agricultural food commodity from a high perishable state to a more convenient, marketable, extended storage life that meets consumer demand and preference. Egyir and Yeboah (2010) again reported that the act of processing enhances the nutritional status and palatability of the formulated food product. For instance, cassava processing minimizes the cyanogenic glucoside levels, thereby detoxifying the cassava food product to improve the taste and sensory attributes. Drying and milling (size reduction) are the two major unit operations in processing agricultural food commodities into flours.

2.5 Drying of agricultural commodities

Drying is a time- and energy-saving method for maintaining the high quality of harvested foods. Abano *et al*. (2019) found that doing so reduces water activity, inhibiting microbial growth, and biochemical degradative processes, increasing product stability. The process of drying is a unit operation that aims to remove as much moisture as possible from the food item. Because of this, the product may be kept for a longer period. Sun drying and mechanical systems are two common methods (Hii *et al*., 2012) for completing the task. Drying in the sun, solar drying, oven drying, hot air drying, tunnel drying, microwave drying, and cabinet drying are all examples of traditional drying methods (Ashun, 2018). Solar, sun, or oven drying processes are often utilised in low-volume manufacturing. Traditional sun drying methods are widely used, but they have their drawbacks. For example, dried items may get contaminated with insects, dust, or animal faeces, which may compromise their quality and safety and possibly cause them to deteriorate (Ashun, 2018). Drying is an integral part of the commercial food processing process, and traditional hot-air dryers are often employed for this purpose. Applying heat during drying causes the food product's moisture to evaporate. The nutritional profile of a food item inevitably shifts as drying progresses due to a number of changes that take place. For instance, depending on factors like drying temperature and drying duration, the concentration of certain nutrients may either grow by increasing their availability or decrease (Hassan *et al*., 2007). Heat damage to food during drying is typically proportional to the drying temperature and time (Abano *et al*., 2011). Ashun (2018) and Krokida and Maroulis (2001) found that the drying procedures and

processing conditions significantly impacted the food's texture, colour, nutritional content, porosity, density, and sorption qualities. Most scientific researchers believe that hot-air oven drying contributes to the degradation of food nutrients, colour, flavour, and case hardening, although it is the most common technique used to preserve food products (Abano *et al*., 2011). According to Ashun (2018), the quality of dried items is affected by the physico-chemical and structural changes that occur during drying.

Sablani (2006) asserts that using pretreatments, including blanching, food chemicals (citric acid), choosing the preferred drying process, and optimising the drying conditions may reduce nutritional losses. The removal of moisture from the food sample during the drying process should be done correctly and quickly at an appropriate and recommended temperature and time interval that will not affect the nutritional status of the food product, and as such, the use of a conventional hot-air dryer is advised (Abano *et al*., 2011). Agyei-Poku (2018) documented that some of the factors that usually influence the drying process include:

- shape, size and produce staking arrangement (thinly and evenly spread on tray for drying),
- raw material composition,
- air velocity, temperature and relative humidity,
- pressure and transfer of heat to product surfaces.

The drying technique is made up of two processes which include heat transfer and mass transfer. Mass transfer occurs when moisture is removed from the inside of the produce to the surface and then evaporates from the surface of the produce to the surrounding atmosphere (Hii *et al*., 2012). Heat

occurs to alter the temperature of the product to be dried. External factors such as temperature, relative humidity, and air velocity, and internal factors such as the surface texture of the produce (rough or smooth), physical structure (porosity and density), chemical composition (starches or sugar), shape, size, and colour all influence the rate at which heat and mass transfer processes occur during drying (Hii *et al*., 2012). Therefore, for the drying process to be successful, there must be enough heat to draw out water (moisture) from the produce without cooking it, and also enough dry air circulation (with low relative humidity) within the system to carry away the released moisture from the produce to the surrounding atmosphere (Sanni *et al*., 2012).

2.6 Milling (size reduction)

Milling process can also be referred as grinding. Milling is a unit operation that converts food solid particles into smaller particles by applying forces which include compression, shear, collusion, friction and impact forces (Walker and Eustace, 2016). The milling process is used to develop food flours or for gluten and starch extraction (wet milling) usually from cereal grains and root tubers (Walker and Eustace, 2016). In the food manufacturing sector, raw materials or intermediate food products normally undergo grinding or milling resulting in size reduction of the food product (Walker and Eustace, 2016). According to Gruber and Sarkar (2012), some of the kinds of milling equipment available include; attrition, hammer, roller, ball and pin mills. The milling operation is an important process of reducing large particles into small and fine particles (flour) or flaked. Milling of root and tubers begins with peeling, washing, grating or chipping, drying and milling. Selecting the appropriate milling equipment and conditions for milling depends largely on

the kind of cereal grain or root tuber, the targeted end product and the particles size required and among other factors. According to Walker and Eustace (2016), some of the primary objectives for milling include:

- maximizing the surface area of raw materials,
- enhancing heat and mass transfer,
- enhancing aromas and flavours by improving on the quality and palatability of the food product,
- procurement of a desirable end-product texture,
- enhancing mixing and formulation of composite flours.

Standard milling process can result in finished product with fine particle sizes ranging between 50-750 µm. Flour particles usually range between 50-180 µm. Milling is capable of influencing the quality, palatability and baking performance of the food flour. Characteristics like amount and rate of water absorption of flour, starch damage, and ash content (with bran inclusion) all depend on the nature and kind of milling process applied (Gruber and Sarkar, 2012). Papageorgiou and Skendi (2018) reported that milling indicate the principal procedure in the food processing industry and it is classified into two categories which include wet and dry milling with their associated basic characteristics. In the wet milling, water is used to mix the flour which results in a dough-like mass or the sample is soaked in water before milling. While in the dry milling, the dried and processed food product is crushed or milled directly to obtain the flour (Udoro *et al*., 2021).

2.7 Formulation of composite flour using indigenous food crops

Most developing nations see the formulation of composite flour as economically crucial since it increases the flour's nutritional content while

reducing the importation cost of wheat flour. Hasmadi, *et al*., 2014; Noorfarahzilah, *et al*., 2014) state that this is a good reason to use locally grown crops in the production of composite flour. There has been a shifted away from wheat flour and towards composite flour made from locally grown cereals, as reported by Noor-Aziah and Komathi (2009). This has motivated certain Sub-Saharan African nations to implement national programmes and policies to assess the viability of employing locally cultivated cereals in the creation of composite flour as a substitute for wheat flour (Abdelghafor *et al*., 2011). There has been a lot of research on the impact of using different indigenous food crops in the formulation of composite flour and its impact on functional and physico-nutritional characterization because of the rising rate of its use in most developing countries (Chadare *et al*., 2018).

Recent advances in the use of composite flour have demonstrated the importance of including nutrient-rich and biofortified crops like OFSP, yellow cassava, biofortified maize, and legumes in its formulation in order to improve the nutritional quality and palatability of the new food product (Mepba *et al*., 2007). Due to its nutritious characteristics, wheat flour may also be used into the creation of composite flour. According to Noorfarahzilah *et al*. (2014), the amount of gluten present in the source crops affects the quality of the composite flour. In other words, the pastry or bakery product should have the same attributes as those created with wheat flour if made using composite flour from local crops. The proteins glutenin and gliadin combine to form gluten, which is used as a binding agent (Biesiekierski, 2017). It gives baked goods their characteristic flexibility and chewiness. Most composite flour is created from wheat flour that has been fortified with other nutrient-rich food

crops due to wheat's high gluten content (Noorfarahzilah *et al*., 2014). Baked goods using legume proteins have been shown to have a more ideal ratio of amino acids, as stated by Mohammed *et al*. (2012). Legume proteins have a lot of the important amino acid lysine, which is a great quality. To balance out the other cereal proteins that lack lysine but have abundant sulphur-containing amino acids, legume proteins are low in sulphur-containing amino acids. Ampofo (2009) claims that the soy legume crop has the potential to enhance composite flour due to its high protein content and considerable levels of trace elements including zinc, copper, and manganese.

According to Ware (2019), sweet potatoes may be useful for composite flour formation since they provide high levels of dietary fibre and other key elements. Protein is present in sweet potato in addition to the carbs that make up its main nutritional value (Loebenstein and Thottappilly, 2009). Sweet potatoes have many health benefits, including but not limited to: increased insulin sensitivity in diabetics; normalised blood sugar; maintained blood pressure; reduced risk of cancer; enhanced digestion and regularity; increased immunity; and reduced inflammation (Ware, 2019). Faustat-Lola *et al*. (2017) also showed that a formulation of OFSP and moringa seeds composite flour in a ratio of 80:20 respectively for complementary food produced a result with enhanced β-carotene, protein, lycopene contents and acceptable sensory characteristics. Table 2.5 shows some of the formulation of sweet potato composite flour products developed by other researchers with its nutritional and sensory characteristics.

Table 2.5: Formulation of sweet potato composite flour products developed with their nutritional characteristics

No.	Composite Flour	Best Formulation Ratio (%)	Physico-nutritional Characteristics	New Food Product	Reference
1	Sweet potato/Avocado pear/ Turkey berry	40:35:15	Improved mineral composition (increase in Fe, K, P, Cu and Mg), higher swelling capacity and bulk density, higher fibre content and low percent carbohydrate.	Snack foods Porridge (weaning-mix)	Teye *et al*., 2018
2	Cassava/OFSP	90:10	Improved taste, aroma, and texture due to fermentation duration, increase in β-carotene	Gari	Abano *et al*., 2019
3	OFSP/Wheat	48:52	Significantly improved β-carotene, protein and carbohydrate.	Spaghetti	Atuna *et al*., 2020
4	OFSP/Sclerotium (edible mushroom)	70:30	Increased in β-carotene, minerals (Fe and Zn) and water-soluble vitamins, appreciable increased in protein, fibre, fat and carbohydrate content.	Cookies	Kolawole *et al*., 2020
5	Bulla/Kocho/OFSP/Finger millet	50:30:10:10	Enhanced protein and β-carotene content, increase in proximate composition and mineral content (Ca and Mg).	Porridge (Complementary food)	Cholo (2020)
6	Yellow maize/OFSP/African yam bean	65:20:15	Significant increase in energy, carotenoids, fibre, total starch, protein, fat, Ca and Fe contents with improved functional properties.	Ogi Porridge	Ukom *et al*., 2019
7	Wheat/OFSP/African yam bean	50:20:30	Significant increase in carotenoids, protein, fibre and fat contents.	Noodles	Effiong *et al*., 2018
8	Wheat/OFSP	90:10	Improved fibre, carbohydrate, protein and carotenoid contents.	Swahili buns (Maandazi)	Mongi *et al*., 2015
9	OFSP/Moringa seed	80:20	Enhanced β-carotene, protein, lycopene and fat contents.	Complementary food (porridge)	Fausat Lola *et al*., 2017
10	Wheat/OFSP	60:40	Increased in β-carotene, fat, ash, fibre, energy and iron content.	Cookies	Laelago *et al*., 2015
11	Wheat/Soybean/Rice	70:15:15	Increased in protein, fat and fibre content.	Biscuits	Mishra and Chandra, 2012
12	Wheat/OFSP	70:30	Increased fibre, ash, β-carotene and improved mineral content.	Bread	Kidane *et al*., 2013

Table 2.5 continued

13	Soybean/Wheat	10:90	Higher protein, fat and crude fibre content	Soy-Bread	Ndife *et al*., 2011
14	OFSP/Wheat	40:60	Higher moisture content, ash content affecting product colour, average protein content, softer/tender texture, and higher adhesiveness.	Noodles	Ginting and Yulifianti, 2015
15	Cowpea/Sweet potato	90:10	Higher values for proximate and functional properties	Fried cowpea paste ("Akara")	Moutaleb *et al*., 2017
16	Cowpea/Wheat	10:90	Higher fibre, protein, ash, fat, contents, water absorption, dough stability and development time.	Cowpea-Bread, Cake	Masood *et al*., 2011
17	Rice (R)/African yam-bean (AYB) /OFSP	90% RAYB:10% OFSP	Increase in provitamin A carotenoid content and high protein content.	Noodles	Okoronkwo *et al*., 2020
18	Wheat/Rice/OFSP/Soybean	60:10:15:15	Substantial increase in protein, vitamin A, iron and zinc contents.	Cake Bread Biscuits	Oduro-Obeng and Plahar, 2017
19	Rice/Cassava/sweet Potato/Soybean/Xanthan gum	30:40:15:14.5: 0.5	Increase in fibre content, enhanced water and oil absorption index and swelling power, functional, physicochemical and pasting properties comparable to that of wheat flour.	Bread, Noodles	Tharise *et al*., 2014
20	Sweet potato/Wheat	15:85	The difference in crumb holes, crust colour, elasticity, stability, firmness, appearance and shape regularity of bread with control was not significant	Potato-Bread	Oluwalana *et al*., 2012
21	Cassava/sweet potato	50:50	Increased in protein, ash, fat and crude fibre content. Carbohydrate content decreased due to increase in sweet potato.	Gari	Ojo and Akande, 2013
22	Sweet potato/Maize starch/Soybean/Xanthan gum	40:40:19.5:0.5	Decrease in viscosity of the composite flour and increase in bread firmness	Bread	Julianti *et al*., 2015

2.8 'Fufu' as a major staple in Ghana

'Fufu' also known as 'fufuo' in the local dialect (Twi) is a soft, sticky and doughy food which is a major staple in both rural and urban households in Ghana. This staple is believed to originate from the Akan ethnic groups in Ghana which includes the Ashanti, the Guans, Akuapem, Akyem, Fante, and Bono. But it has generally been accepted across the nation as it is consumed on daily or weekly basis in most households in Ghana. The ingredients involved in preparation includes raw cassava, unripe plantain, cocoyam or yam. The raw cassava, unripe plantain, cocoyam, or yam is peeled, washed, and cut into portable sizes, put in sauce pan with water, and boiled. 'Fufu' is prepared from boiled cassava, usually fortified with plantain, cocoyam or yam (Ipatenco, 2018). The boiled ingredients are pounded in a wooden mortar with a pestle (Figure 2.5).

Figure 2.5: Pounding of 'fufu' in wooden mortar with wooden pestle

The 'fufu' mixture is turned by hand in and out between the strikes of the pestle with the addition of water to make it soft and tender until gradually, the 'fufu' becomes uniformly mixed, soft and sticky (Ipatenco, 2018). The 'fufu' mixture with good elasticity is then rounded into 'fufu' bowls, usually

into earthenware pot (Figure 2.6) and served with soup. The soup could be light soup, palm nut soup, groundnut soup or kontomire soup with fresh/dried/smoked fish, fresh or smoked meat, bushmeat, snail, crab, chicken or pork (Figure 2.7).

Figure 2.6: Rounded 'fufu' in earthenware pot

Figure 2.7: 'Fufu' served with different kinds of soup with fish and meat

In recent times, the innovation of motorized 'fufu' pounding machine was also introduced to the local market for commercial and domestic purposes. With this machine, you could make your 'fufu' effortlessly within some few minutes depending on the quantity of the 'fufu' ingredients used. This novel

'fufu' making machine is highly recommended for restaurants, hotels, and chop bars (Darko-Koomson *et al*., 2020).

There is no doubt that the traditional method of preparing 'fufu' is very tedious and time consuming. Recent advances have led to alternate processing methods, such as processing the components into composite flour that is simpler and quicker to prepare than the traditional technique of 'fufu' preparation, which entails heating and manually crushing the ingredients. Commercially manufactured composite 'fufu' flour made from the combination of cassava and plantain, cassava and cocoyam, or cassava and yam is offered on both foreign and local markets (Egyir and Yeboah, 2010).

Figure 2.8: Some brands of commercial 'fufu' flour on the market

One major innovative business amongst young Ghanaian entrepreneurs is the production of commercial 'fufu' flour for mainly the international market and some local supermarkets. Most Ghanaians in the diaspora or

Europe finds it difficult to prepare ‘fufu’ using the traditional method of mortar and pestle and so are more comfortable with the composite ‘fufu’ flour which is easier and faster to cook. In Ghana, some corporate mothers also find it difficult to use the traditional method to pound ‘fufu’ for their families and have resorted to the use of the ‘fufu’ flour which is fast and easy to cook. This has encouraged several food processing companies to explore the production of composite ‘fufu’ flour. Some of the brands of composite ‘fufu’ flour on the market are shown in Figure 2.8. This includes Neat ‘fufu’ flour, African Queen ‘fufu’ flour, Mother Africa ‘fufu’ flour, Heritage Africa ‘fufu’ flour, and Food Search ‘fufu’ flour from CSIR.

Cooking ‘fufu’ is arduous and time-consuming, thus Egyir and Yeboah (2010) claim that only upper-middle-class or corporate working couples in metropolitan areas regularly eat it. The reason being that they (corporate mothers) are busy at work and have no time in coming back from work to pound ‘fufu’. Research has shown that even domestic housewives have joined the crusade of preparing ‘fufu’ for their families using the ‘fufu’ flour instead of pounding. Due to this reason, there has been a high demand gap for lovers of ‘fufu’ to accept the ‘fufu’ prepared for composite ‘fufu’ flour (Egyir and Yeboah, 2010). The production of composite ‘fufu’ flour has now become a major substitution in the absence of pounded ‘fufu’ which is the most preferred by Ghanaians especially the men (Egyir and Yeboah, 2010). Currently, there is a high demand for ‘fufu’ flour on both the domestic and international markets and therefore, there is the need to increase production as well as develop innovative ways of varying the ingredients used in the production of composite ‘fufu’ flour to address some of the major

micronutrient malnutrition deficiency diseases. Therefore, this study seeks to use OFSP to fortify cassava flour in the production of composite 'fufu' flour which aims at addressing vitamin A deficiency diseases in Ghana and Africa.

2.9 Utilization of OFSP in composite flour production

Modern research in most developing nations has placed a significant emphasis on the hunt for important necessary but under-utilized food commodities as a possible profitable food security crop for the food manufacturing business (Tuffour, 2013). One of the world's most important, but underappreciated, crops is the sweet potato. It is a staple crop in the region of Sub-Saharan Africa where it's grown for subsistence, famine relief, and food security. (Srivastava *et al*., 2012). OFSP is a variety of sweet potato that is biofortified with enhanced micronutrient density that contains substantial amounts of β-carotene (provitamin A carotenoids) and some essential nutrients as well as other antioxidants. Because of its high beta-carotene content, OFSP is being studied as a potential intervention food crop for addressing vitamin A insufficiency in young children throughout Africa (Teye *et al*., 2018). Table 2.6 shows the nutritional breakdown of an orange-fleshed sweet potato (OFSP), which is rich in β-carotene (provitamin A carotenoids), vitamins B, C, and E, as well as minerals K and P, and dietary fibre (Bovell-Benjamin, 2010; Talsma *et al.*, 2016).

Products produced with OFSP have a natural sweetness, aroma, and colour (Mitra, 2012). Educating the public about the root crop's potential uses necessitates the creation of a tasty designed food product made with or from OFSP (Dako *et al*., 2016). In terms of its ability to improve food security in

underdeveloped regions, the sweet potato is regarded as the world's second-best vital root crop and the seventh-most important food crop overall.

Table 2.6: Nutritional composition of orange-fleshed sweet potato as compared to cassava

Nutrients	Units/100 g	Orange-fleshed sweet potato		Cassava	
		Raw roots	Leaves	Raw roots	leaves
Vitamin A	µg	300 – 1,300	51 – 230	1	115
Iron	mg	0.32 – 0.88	1.01	0.27	7.6
Zinc	mg	0.18 – 0.57	0.29	0.34	0.4
Thiamin (B1)	mg	0.08	0.16	0.09	N/A
Riboflavin (B2)	mg	0.06	0.34	0.05	N/A
Niacin (B3)	mg	0.56	1.13	0.85	2.4
Vitamin B6	mg	0.21	0.19	0.09	N/A
Vitamin E	mg	0.26	N/A	0.19	N/A
Vitamin C	mg	22.7	11.0	20.6	310
Protein	g	1.6	4.0	1.4	7.0
Fibre	mg	3.0	2.0	1.8	4.0
Phytate	mg	10.0	42.0	54	42.0

Source: Low *et al*. (2009)

Few decades ago, the orange-fleshed variety of sweet potato emerged as one of the most significant tropical root crops in Africa that is gradually being accepted in the food systems of the consumer food chain to address key micronutrient deficiencies (Mitra, 2012).

Table 2.7: Vitamin A recommended dietary allowance (RDA) in micrograms (µg) Retinol Activity Equivalents (RAE)

Group	Vitamin A: Recommended Dietary Allowance (RDA) in micrograms (µg) Retinol Activity Equivalents (RAE)
CHILDREN	
1 – 3 Years	300 µg /day
4 – 8 Years	400 µg /day
9 – 13 Years	600 µg /day
FEMALES	
14 Years and up	700 µg /day
Pregnant Women	14 – 18 Years: 750 µg /day 19 Years and over: 770 µg /day
Breastfeeding	Under 19 Years: 1,200 µg /day 19 Years and over: 1,300 µg /day
MALES	
14 Years and up	900 µg /day

Source: National Institute of Health (2022)

The regular consumption of OFSP in the consumer food chain has the tendency of counteracting poor vision among vitamin A deficient and malnourished children in developing countries (Tuffour, 2013). According to Low (2013), a piece of OFSP (100g) can meet the daily vitamin A needs of a child (400µg Retinol Activity Equivalents, RAEs). Table 2.7 shows the vitamin A recommended dietary allowance (RDA) in micrograms (µg) Retinol Activity Equivalents (RAE).

In recent developments, sweet potato (especially the OFSP variety) has been used as food-to-food fortifier in the formulation of complementary foods to increase the nutritional status of the product (Teye *et al*., 2020). Amagloh and Coad (2014) note that over 44% of children in Sub-Saharan Africa are vitamin A deficient, raising serious concerns about the prevalence of vitamin A insufficiency among many children and babies in that region. According to Abano et al. (2019), there is a severe public health issue with the incidence of vitamin A insufficiency in Ghana among children under the age of five, which is around 76%. Weanimix (baby foods) made from cereal-based

complementary foods fortified with mixtures of legumes (soybean or cowpea) and groundnut that were enriched with fish powder could not meet the recommended dietary requirements for vitamin A, zinc, or iron due to the high phytate level and low β-carotene levels; phytate is an anti-nutrient inhibitor (Mitra, 2012). According to Gibson *et al*. (2010), the anti-nutrient inhibitor phytate restricts the absorption of zinc and non-heme iron from cereal grains, legumes, and cereal-legume mixtures. Many studies have suggested the orange-fleshed form of sweet potatoes as an option to help counteract the primary nutritional deficits by increasing the β-carotene, zinc, and iron levels (Amagloh *et al*., 2012).

Teucher *et al*. (2004) also reported that sweet potato contains some appreciable amount of ascorbic acid that is capable of countering the adverse effect of the phytate on iron and zinc bioavailability.

In addition to being an established, low-cost, and long-term source of provitamin A carotenoid, OFSP also contains significant amounts of phytochemicals like phenols, flavonoids, and anthocyanins, all of which can affect the stability and quality of the processed food product (Abong *et al*., 2020). Phytochemicals are a class of antioxidants found in many plant-based meals; they can protect humans against a variety of chronic illnesses, including Type II diabetes, cardiovascular disease, cognitive decline, and many malignancies (Del Rio *et al*., 2013). Ghasemzadeh and Ghasemzadeh (2011), Panche *et al*. (2016), and Abong *et al*. (2020) all agree that phytochemicals play an important role in the pharmaceutical, cosmetic, medical, and nutraceutical industries. Bovell-Benjamin (2007) claims that eating sweet potatoes, particularly those with orange or purple flesh, is always

associated with excellent health and increased human nutrition. More and more pastry and baking enterprises are springing up in Ghana due to the country's insatiable need for baked goods. However, wheat flour is the primary ingredient in most of these foods. Due to this, the processing and utilization of composite flour prepared from indigenous crops in most pastry, bakery, and other complementary foods have prompted an increasing number of studies on the effect of varying the food commodities used in the manufacture of these composite food flours and their physical-nutritional and sensory characterization (Teye *et al*., 2018).

The quality and nutritional status of the composite flour is very significant with the single aim of improving the nutritional security of the consumer. OFSP is one major root crop gaining significance in the Ghanaian food system (Amagloh *et al*., 2012). For instance, "gari" is a major staple food for Ghanaians, and Abano *et al*. (2019) reported that increasing the fermentation time of the cassava pulp and enriching it with OFSP in the production of "gari" improved the taste, aroma, texture and the overall acceptability from sensory evaluation with increased β-carotene levels of the new "gari" product. Noodles prepared from wheat flour enriched with OFSP according to Ginting and Yulifianti (2015) also showed an increase in β-carotene and average protein content with an overall acceptability of sensory evaluation. Teye *et al*. (2018) also noted that the mineral composition (Fe, K, P, Cu, and Mg) and fibre content were both enhanced by the manufacture of composite flour from sweet potato (40%) augmented with 35% avocado pear and 15% Turkey berry. Cholo (2020) found that by using a formulation ratio of 50:30:10:10 while making children's supplemental food (porridge), the

protein, beta-carotene, and mineral (Ca and Mg) levels were all improved. According to Ukom *et al*. (2019), preparing ogi porridge with a mixture of yellow maize, OFSP, and African yam bean in a formulation ratio of 65:20:15 significantly increased the energy, carotenoids, fibre, proteins, and mineral content (Fe and Ca), and also improved on the functional properties. As a result of its low cost and quick preparation time, noodles or spaghetti have quickly become a popular staple cuisine in Ghana and Nigeria, as well as across the rest of Africa. Once made using wheat flour, studies have indicated that fortifying it with OFSP flour or another indigenous food crop rich in minerals, vitamins, and other micronutrients is a viable option for improving its nutritional profile. Atuna *et al*. (2020) reported that a combination of wheat and OFSP flours in a formulation ratio of 52:48 in the preparation of spaghetti significantly improved the beta-carotene, protein, and carbohydrate content with a good consumer acceptability. Effiong *et al*. (2018) also reported that a combination of wheat, OFSP, and African yam bean in a formulation ratio of 50:20:30 in the preparation of noodles greatly enhanced the carotenoids (beta-carotene), proteins, fibre, and fat contents with a high consumer acceptability.

Therefore, the health benefits and nutritional qualities OFSP has made the crop a very significant nutrient rich food fortifier in the preparation of composite flour for bakery, pastry and complementary food products for domestic households in the rural settings of most developing countries (Amagloh *et al*., 2012). It is in this light that this study seeks to enrich and fortify cassava flour with OFSP flour in the formulation of a composite 'fufu' flour for consumption by the Ghanaian population with the single aim of addressing VAD. Table 2.5 shows the formulation of different composite flour

produced and the development of a particular food product with its nutritional and functional characteristics.

2.10 Micronutrient bioavailability in OFSP and its retention after processing and storage

Many people living in rural areas are malnourished, particularly children, due to a lack of sufficient nutrition and a balanced diet. Hess *et al*. (2005) and Teye *et al*. (2018) found that a lack of vitamin A, zinc, or iron increases a person's risk of stunted development, infections, mental impairment, and anorexia. In order to combat vitamin A, zinc, and iron deficiencies among the rural impoverished population, it was decided to implement a biofortification strategy aimed at improving the nutritional content of agricultural food crops. Maize, sweet potato, cassava, cowpea, and beans are only some of the biofortified food crops that have been successfully developed via conventional plant breeding and are now eaten in most Sub-Saharan African nations and Asia (Table 2.8). Maximising provitamin A, zinc, or iron content in crops by biofortification is possible, but quantifying the bioavailability of these nutrients as the absorbed and used fraction is difficult (Bechoff & Dhuigue-Mayer, 2016). The nutritional advantages of OFSP, a biofortified root crop, may be broken down into many categories. Beta carotene (Pro-vitamin A carotenoids), in addition to other vitamins and minerals, is present in high concentrations. The ultimate benefit, however, comes from the micronutrients remaining in the food after processing, storage, and consumption, as well as the body's ability to absorb and use them (Low *et al*., 2009). There are some factors that affect carotenoids and mineral bioavailability and these include dietary factors (the matrix with which the

carotenoid is integrated), absorption and bioconversion effectors as well as nutrient status and genetic factors of the host.

Table 2.8: Provitamin A carotenoids and mineral retention from some indigenous biofortified crops during processing.

Micronutrient	Biofortified Crops	Processing Methods	Retention (%)	References
Provitamin A carotenoids (pVACs)	Orange-fleshed sweet potato (OFSP)	Boiling or steaming	80 – 90	Bengtsson *et al.* (2008) Van Jaarsveld *et al.* (2006) Kidmose *et al.* (2007)
		Roasting or frying	70 – 80	Vimala *et al.* (2011) Kidmose *et al.* (2007)
		Solar or sun drying	60 – 80	Bechoff *et al.* (2011) Mulokozi *et al.* (2003)
		Storage of dried product for 4 months at ambient temperature	20 – 30	Bechoff *et al.* (2009) Bechoff *et al.* (2011)
	Yellow cassava	Boiling	80 – 90	Thakkar *et al.* (2009) Failla *et al.* (2012) Carvalho *et al.* (2012)
		Gari processing	40 – 50	Thakkar *et al.* (2009) Failla *et al.* (2012)
		Flour processing	50	Oliveira *et al.* (2010)
		Gari storage for 4 months at ambient temperature	20 – 30	Bechoff *et al.* (2015)
	Maize	Boiling of fermented or unfermented porridge	75	Li *et al.* (2007) Pillay *et al.* (2014)
		18 months storage of dried grain at ambient temperature	60	Burt *et al.* (2010)
		6 months storage of dried grain at ambient temperature	40	Mugode *et al.* (2014)
Zince and Iron	Cowpea and beans	Boiling	90	Carvalho *et al.* (2012) Pereira *et al.* (2014)

Source: Bechoff and Dhuigue-Mayer (2016)

Earlier studies showed that it was difficult to study β-carotene conversion to vitamin A from vegetables sources due to unavailability of precise procedures or protocols (Bovell-Benjamin, 2007). Bioconversion of

provitamin A carotenoids, however, may now be determined thanks to the development of stable isotope technique using food crops (Tang, 2010). Because of the strong correlation between micronutrient retention and bioavailability, understanding the impact of processing on this characteristic is crucial. Preformed vitamin A of animal origin or preformed vitamin A from crops are the two main dietary sources of vitamin A. In contrast to plant-based carotenoids, those of animal origin (meat, for example) are easily absorbed by the body (FAO/WHO, 2002). Bengtsson *et al*. (2008) find that processing time and circumstances affect the preservation of provitamin A carotenoids in OFSP. β-carotene's time retention (TR) varies from 70-92%, according to research published by Van Jaarsveld et al. (2006), depending on the length of time the food is cooked. As cooking times are longer, less -carotene is retained in the dish. The retention of provitamin A carotenoids, for example, is highest during boiling/steaming (80-90%), then during frying/roasting (70-80%), and finally during solar/sun drying (60-80%), depending on the processing time (Table 2.8).

2.11 Bioactive compounds in sweet potato cultivars and their potential health benefits

Sweet potato possesses phytochemicals such as phenolic compounds, anthocyanins and carotenoids that are found in the roots and leaves and have the potential of minimizing possible health risks (Amagloh *et al*., 2021). It has been revealed that red-fleshed sweet potatoes have a greater phenolic content and antioxidant activity than blueberry fruit, which is often believed to have significantly higher antioxidant levels. This is according to research conducted by Cevallos-Casals *et al*. (2003). According to studies, the high carotenoids

content of OFSP may also have antioxidant effects. According to research done by Alam *et al*. (2016), OFSP cultivars cultivated in Bangladesh provided a dual purpose by providing both a dietary antioxidant and protection against vitamin A deficiency. According to research by Amagloh *et al*. (2021), the antioxidant activity present in purple-fleshed sweet potatoes (PFSP) has a significant role in warding against degenerative illnesses including cardiovascular disease and cancer. Studies conducted by Xu *et al*. (2015) and Asadi *et al*. (2017) revealed that PFSP contains protective properties against the bladder, breast and pancreatic cancers, colorectal disease and high blood pressure.

2.11.1 Phenolic compounds

Researchers have observed that sweet potatoes contain a greater concentration of phenolic chemicals than other foods including coffee, tea, cereals, and vegetables (Musilova *et al*., 2017; Amagloh *et al*., 2021). Sweet potatoes contain a variety of phenolic components, including phenolic acid, polyphenols, flavonoids, tanins, lignans, and stilbenes (Gonzalez-Samas *et al*., 2020). In addition to their fundamental role in preventing oxidative damage and providing protection against peroxidation, the phenolic compounds found in fresh produce also have the ability to scavenge free radicals (Visioli *et al*., 2011). Epidemiological research done by Amagloh *et al*. (2021) suggests that eating foods high in polyphenols may reduce the risk of developing numerous chronic illnesses. This has triggered recent research interest in antioxidant effects of polyphenol and its beneficial health effects in relation to plant-based food products especially in sweet potato.

2.11.2 Anthocyanin compounds

The flesh of sweet potatoes is often a light pink to purple coloration due to the presence of anthocyanin, a bioactive molecule that is a member of the flavonoids. It is found in significant concentrations in the roots of purple-fleshed sweet potatoes (PFSP), but in negligible amounts in those of yellow, white, and orange types (de Albuquergne *et al*., 2019; Fernandes *et al*., 2019). When compared to other highly pigmented vegetables like purple asparagus, red onion or aubergine, the PFSP comes out on top in terms of antioxidant activity (Li *et al*., 2012). Multiple studies have demonstrated that the anthocyanin in PFSP may improve cognition, limit cancer cell proliferation, scavenge free radicals, lessen liver dysfunction, lessen insulin resistance, and reduce blood sugar levels, as reported by El-Sheikha *et al*. (2017). The hypo-glycemic effects of the anthocyanins in PFSP have been connected to their inhibitory effects towards -glucosidase and -amylase activity, which may lead to a lower blood glucose level (Amagloh *et al*., 2021). Again, PFSP anthocyanin extracts can enhance metabolic parameters that is closely linked to obesity and also minimizes injury to the liver (Mahadita *et al*., 2016; Ju *et al*., 2017). Asadi *et al*. (2017) also reported that extracts of anthocyanin from PFSP when used to treat human colonic SW480 cancer cells minimize the number of colonic cells and this result suggested that anthocyanin had the capacity to fight against colorectal cancer.

According to Amagloh *et al*. (2021), all these health-promoting effects of these bioactive compounds are widely dependent on the extracts of the raw sweet potato but the consumer usually consumes the sweet potato by cooking (boiling) and not in the extract form. And so, the research question still

remains as "how much of the bioactive compounds are present and bioavailable in the cooked sweet potato and how much is needed to produce a favorable response"? Amagloh *et al*. (2021) therefore reiterated that it is critical to develop data on the functional characteristics and the potential health benefits of the cooked sweet potato roots as the food matrix will certainly influence how the gastrointestinal tract processes these bioactive compounds or nutrients.

2.12 Dietary sources, uptake and transportation of vitamin A to target cells/tissues

Vitamin A is an important nutrient best known for its purpose of aiding good vision. Apart from this general function, it also regulates differentiation and growth of cells. Vitamin A can be absorbed from food consumed as provitamin A carotenoids or preformed vitamin A. The provitamin A carotenoids (α-carotene, β-carotene and β-cryptoxanthin) are normally obtained from vegetables like spinach, carrots, collards, squash, sweet potato and pumpkins. The preformed vitamin A are obtained in foods like liver, eggs, butter, fortified cereals or milk and are absorbed as retinyl esters (long-chained fatty acids of retinol). Intestinal mucosal cells (enterocyts) absorb free retinol from the digestive tract after it has been hydrolyzed by pancreatic and intestinal enzymes (Figure 2.9). Retinol in the enterocyte is bound by cellular retinol binding protein (CRBP) II as retinol is insoluble in water (Conaway *et al*., 2013).

According to Harrison (2012), nearly 50% of provitamin A carotenoids are taken up by mucosa cells and 50% is also oxidized to retinal which is later reduced to retinol. Retinol obtained from provitamin A carotenoids and retinyl

esters are both esterified into long-chain fatty acids. Hence, the carotenoids and retinyl esters together with other lipids are incorporated into chylomicrons and carried by the lymphatics in the blood. The availability of fat in the diet helps in the absorption of vitamin A as it stimulates enzymes in charge of hydrolyzing dietary retinyl esters, thereby, enhancing the formation of micelle for solubilization of carotenoid and retinol in the intestinal lumen as well as increasing the formation of chylomicron (Conaway *et al*., 2013). The chylomicron remnants are capable of delivering retinoids straight to targeted cells or tissues but it has to be sent to the liver since the liver is the main organ for chylomicron remnant clearance. Here, retinyl esters are hydrolyzed within the hepatocytes to retinol and bounded to RBP and later the retinol-RBP is combined with transthyretin and delivered through the blood to target tissues or cells (Figure 2.9). In the case where the retinol is unwanted by the body, it is re-esterified and remains in the liver stellate cells or tissues (D'Ambrosio *et al*., 2011). According to Harrison (2012), it is believed that the absorption of carotenoids and retinyl esters transported by chylomicrons and all-trans-retinoic acid (ATRA) bound to albumen is also likely to occur. Conaway *et al*. (2013) also reported that the liver function as the major storage organ for vitamin A.

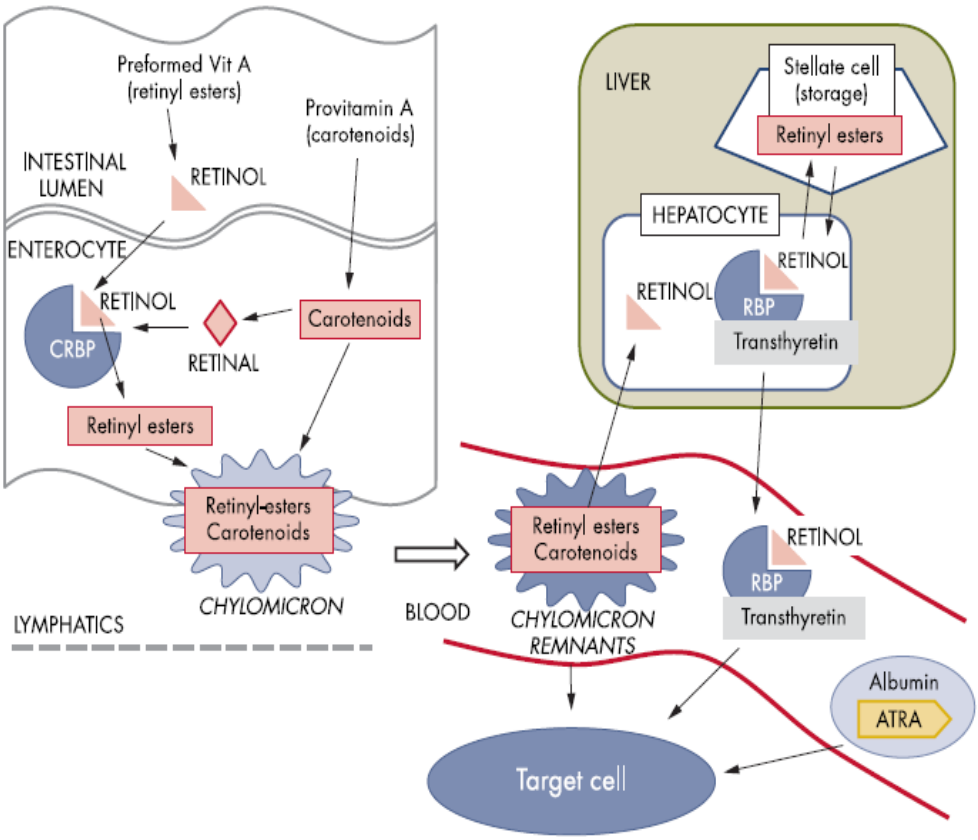


Figure 2.9: Dietary uptake and transport of vitamin A to target cells
Source: Conaway *et al*. (2013)

2.13 Degradation of β-carotene during processing and storage

β-carotenes are carotenoids that are synthesized by plants and mostly found in food crops. β-carotene is found in high concentrations in most vegetables and fruits as well as some root crops like spinach, carrot, apricot, sweet potato, orange, tomato, palm fruits etc. β-carotene is lipophilic, soluble in organic solvents like hexane and petroleum ether but insoluble in water. Its substantial sequence of conjugated double bonds, which gives it its biological, chemical, and physical properties, is the main source of these properties (Pénicaud *et al*., 2011). In the visible spectrum, at a wavelength of 450 nm, β-carotene absorbs purple and blue light and has a vivid red and orange hue (Pénicaud *et al*., 2011). Recent years have seen an increase in the usage of -

carotene as a food additive, mostly in the food production sectors to replace artificial colour additives (Dutta *et al.*, 2006). Therefore, β-carotene is regarded as a vital component of food's organoleptic quality, not only because of its colour but also because it serves as a precursor to aromatic chemicals like monoterpene and norisoprene when fruits develop (Lewinsohn *et al.*, 2005). According to Pénicaud *et al*. (2011), along with beta-cryptoxanthin and alpha-carotene, β-carotene is always regarded as a vitamin A precursor due to its distinctive structure of vitamin A dimers. The function of carotenoids is dependent on their nutritional activity as provitamin A.

By its structure, the number of double bonds in β-carotene makes it very sensitive to degradation especially to oxidation (Liu *et al.*, 2009). Usually, some amount of β-carotene is lost during crop processing. i.e., when the tissues come in contact with light and oxygen with an increase in temperature during processing (thermal treatment), the degradation rate of reactions increases resulting in a loss of β-carotene (Bechoff *et al.*, 2010). β-

In summary, processing of food greatly minimizes the quality of some micronutrients in the food product and this is of great concern to the food manufacturing industry. β-carotene degradation is one of the effects of food processing due to the application of heat. The main pathways of beta-carotene degradation are well documented and some of the major degradation products includes isomers, epoxides, apocarotenones, apocarotenals and short-chain cleavage compounds of which some are flavour compounds as shown in Figure 2.10.

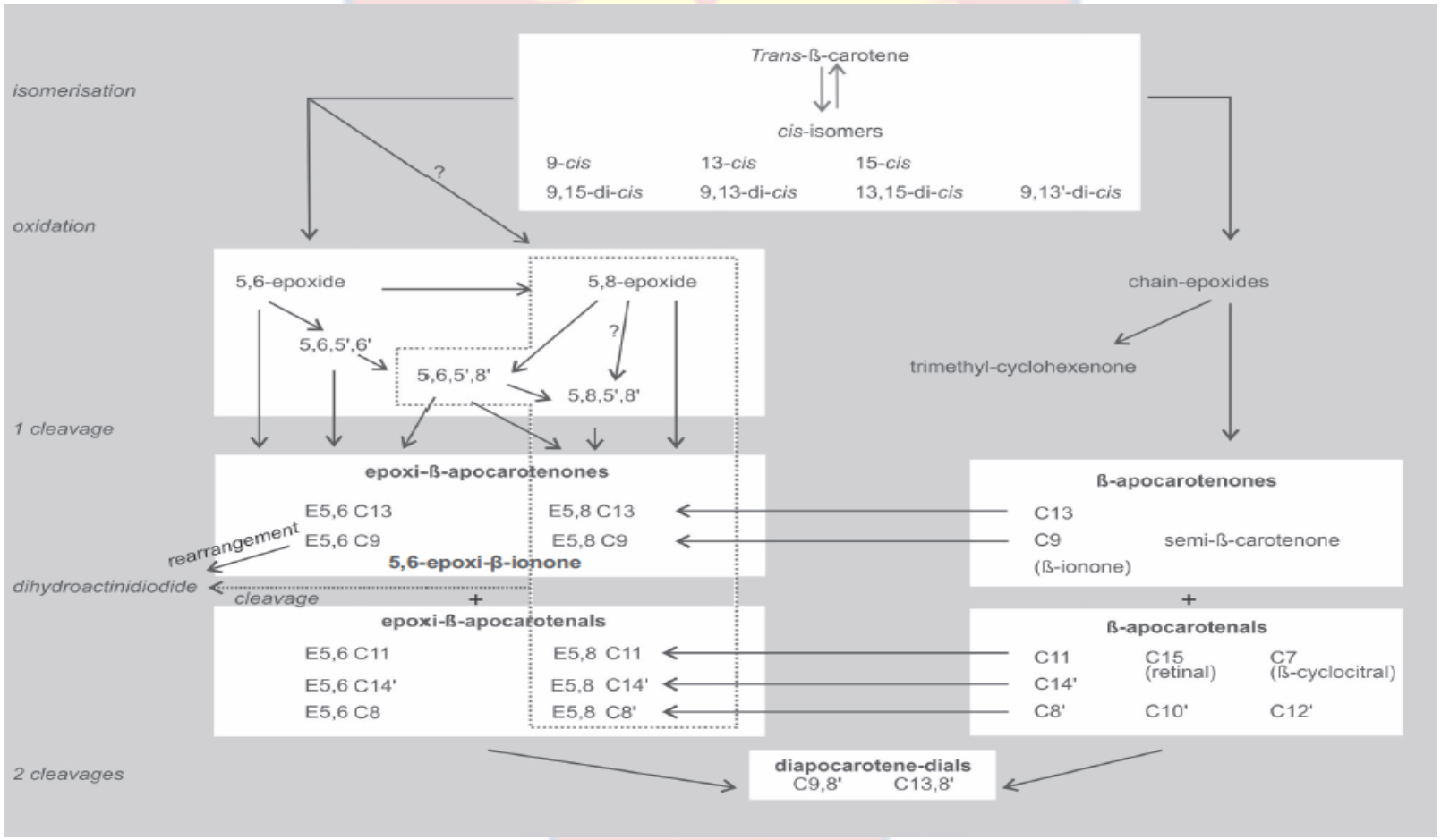


Figure 2.10: Schematic diagram of the general overview of beta-carotene degradation
Source: Pénicaud *et al*. (2011)

2.14 Physical and functional properties of flours and other food products

Functional qualities are the physicochemical traits that characterise the intricate relationships between content, structure, and molecular conformation in flours and other food items. Functional characteristics are required to help with the precise prediction of how proteins, fibre, lipids, and carbohydrates (sugars and starch) may function in certain food systems. These qualities, in accordance with Awuchi *et al*. (2019), demonstrate how ingredients behave during preparation and cooking as well as how they affect the flavour, texture, and appearance of the finished food product.

Water absorption capacity (WAC), swelling index or capacity, foam capacity, emulsion capacity, oil absorption capacity, emulsion stability, bulk density, gelatinization, denaturation, dextrinization, coagulation, plasticity, gluten formation, sensory attributes, shortening etc. are some of the examples of functional properties that can be analyzed (Awuchi *et al*., 2019). According to Suresh and Samsher (2013), the quality, structure, nutritional content, appearance, texture, and acceptance of a flour or other food product all contribute to its functional properties. According to Awuchi *et al*. (2019), the functional quality of a flour or other food product depends on its physical, chemical, or organoleptic qualities. The contents of the food material, particularly the moisture content, proteins, carbohydrates, lipids, fibre, ash, and other food additives added to the flour, have an impact on the functional properties of flour and other food items.

2.14.1 Water absorption capacity (WAC)

The amount of water or moisture that flour can absorb to get the right consistency for improving a food's quality. WAC can also be described as the

optimum quantity of water needed for mixing a flour into dough to avoid it being extremely sticky to process. Too much or very minimal water absorbed by the flour mixture could negatively influence the food product quality and texture (Awuchi *et al*., 2019). Table 2.8 shows the common issues that are likely to occur when there is under-absorption or over-absorption of water. WAC is normally defined by the weight of the flour or food product. According to Awuchi *et al*. (2019), some of the factors that affect WAC of a flour or other food product include:

- Starch: nearly 46% of total water absorbed is linked with the starch in the food product
- Proteins: nearly 31% of total absorbed water is linked with proteins
- Pentosans: nearly 23% of total absorbed water is linked with the pentosans in the food product or flour.
- Availability of other water binding ingredients like eggs, fibre, bran hydrocolloids (gums), etc.

Butt and Rizwana (2010) stated that the variation observed in WAC of different food flours could be attributed to different concentrations of protein, their extent of interaction with water as well as their conformational characteristics. In handling doughs for development of food products, the determination of WAC as functional property is very significant (Iwe *et al*., 2016). Sweet potato flours are reported to have high WAC and this is useful in food flour formulation for processing bakery food products, meat sausages, or processed cheese (Suresh, 2013).

Table 2.9: Issues associated with over and under-absorption of water in bakery products and other food formulations

Over-absorption of water		
No.	**Dough**	**Finished/cooked product**
1	Clean-up time extended	Open crumb grain with large cells.
2	Sticky and wet	Poor symmetry
3	Reduced tolerance to handling (poor machinability)	Large volume
4	Susceptible to over-fermentation	Susceptible to mould infestation
Under-absorption of water		
No.	**Dough**	**Finished/cooked product**
1	Insufficient water to moist, hydrate, and disperse dry ingredients	Firm and dense internal structure (crumb)
2	Dry and stiff	Volume is low
3	Final development cannot occur	Corner edges are white
4	Pan flow is insufficient	Stales very fast
5	Proofs slower	

Source: Awuchi *et al*. (2019)

2.14.2 Bulk density

To calculate bulk density, we divide the mass of the flour particles by the total volume occupied, where the volume includes the volume of the internal pores, the volume of the particles themselves, and the volume of the spaces between them. Powders, flours, granules, and other small particles all have one important defining feature: their bulk density. This aspect is not an essential quality of food. The bulk density of a food item might change depending on how it is processed. Bulk density is typically reported as "poured (freely settled) density" or "tapped density." For example, if flour is placed in a measuring cylinder, it will have a certain bulk density; however, if

the cylinder is disturbed or tapped on the bench, the particles of the flour will simply settle close together, resulting in a higher bulk density. The tapped method is done after a specified compaction process is carried out by tapping the measuring cylinder or container on the bench or the cylinder is vibrated (Awuchi *et al*., 2019).

The difference in food flour's bulk density could be as a result of difference in the starch content of the flours. Increase in starch content could result in higher bulk density (Awuchi *et al*., 2019). According to Iwe *et al*. (2016), bulk density describes the capacity of the needed packaging material to use. This implies that the higher the bulk density, the denser the required packaging material. Seresh and Samsher (2013) reported that some research studies have shown that flours' bulk density could be affected by the initial moisture content of the flour. Higher bulk density of food flours is a function of its appropriateness for use in food processing. Edema *et al*. (2005) reported bulk density values of 0.38 g/mL and 0.55 g/mL for commercially sold soyabean flour and maize soya blend respectively. Ngoma *et al*. (2019) documented a higher bulk density for all the treated sweet potato samples at varying pretreatment concentrations that ranged between 0.81 g/mL to 0.87 g/mL. Similarly, Eleazu and Ironua (2013) also reported a bulk density of 0.92 g/mL for cream-fleshed sweet potato. According to Phuthego (2014), higher bulk density is considered to be a better indicator for mixing purposes in composite flour formulation. Ikpeme *et al*. (2010) also stated that higher bulk density was a better physical property in determining the mixing quality of composite flour formulation. Chandra *et al*. (2015) also reiterated that high bulk density depicts flour heaviness which makes it useful for food processing

as it minimizes the thickness of paste in food products. But on the contrary, Ngoma *et al*. (2019) reported that increase in bulk density is undesirable in packaging due to its minimal ability for flour compression resulting in increased cost for purchasing more packaging materials.

2.14.3 Swelling index

Swelling index which is also referred to as swelling capacity is defined as the volume in milliliter (mL) taken during the swelling of one gram of food flour upon addition of specified amount of water or swelling agent as described in the test procedure (Awuchi *et al*., 2019). Iwe *et al*. (2016) also described it as the measure of the ability of the flour starch to take up water and swell. In most food products like bakery products, swelling index or capacity is considered as a food quality parameter. It also describes the covalent bonding between starch granule molecules. The swelling index of most food flours increases with increasing starch concentration. Awuchi *et al*. (2019) state that the crop type, particle size, and processing technology all have an impact on the swelling index of food flours.

2.15 Microbial loads in composite flour and their effect on human health

Recent research studies on microbial quality and safety of most complementary or composite food flours and the potential risk of hazardous microorganisms contained in these food flours has increased the awareness for reducing the prevalence of foodborne diseases especially in infants and children (Myoda *et al*., 2019). According to Los *et al*. (2018), microbial contamination sources can be determined along the crop production chain which includes preharvest and the postharvest chain (handling, storage, transportation and processing). Microorganisms or pathogens that cause food

contamination could be transmitted by different agents like air, dust, animals, man, water or contaminated processing machines or equipment. Some of the pathogens that are likely to cause this contamination in food flours include; *Esherichia coli* (E. coli), *Salmonella spp, Bascillus cereus*, yeast and moulds, *Aspergillus, Penicillium, Fusarium, Shigella spp, Staphylococcus aureus, Clostridium perfringens, Listeria monocytogenes* and others. The pathogens or microbes are found on the grains or tubers and are usually redistributed into the developed flour during the preparation and processing of the ingredients which involves improper washing or cleaning, grating or milling and this increase the microbial load in the processed food flour (Ware *et al*., 2018).

The rate of consumption of wheat flour, complementary food flours as well as other composite flours has increased due to changes in food habits and improving the nutritional status of consumers and because of this, the potential risk of increasing microbial contamination is critical if these flours are not hygienically produced or stored under appropriate storage conditions. Effective drying methods are required to reduce the moisture content or water activity of the flour to enhance the storage life of the flour and also to prevent microbial growth during storage (Magallanes-Lopez and Simsek, 2021). Magallanes-Lopez and Simsek (2021) again reported that flours with water activity less than 0.6 (a_w < 0.6) do not encourage microbial growth. It is therefore important to properly dry food crops meant for flour production to reduce the moisture content or water activity thereby preventing microbial growth during storage. Again, drying and milling equipment should be well cleaned and disinfected to avoid contamination from microorganisms or pathogens (Eglezos, 2010).

Magallanes-Lopez and Simsek (2021) reported that foodborne diseases and outbreak are linked to contaminated complementary or composite food flours and this could be avoided if proper safety measures are developed with respect to consumers' eating habits or behaviours. According Ware *et al*. (2018), handling and processing treatments like washing, cleaning, sorting, grading, drying or roasting if not properly done could enhance the growth of microbes/pathogens in the food flour developed. Tou *et al*. (2007) stated that the safety of formulated complementary or composite food flours are not often guaranteed since the ingredients used to produce the flour could be contaminated with mycotoxins or other pathogens/microorganisms. It is therefore critical to note that based on the type or kind of microbial contamination in the complementary/composite food flour, the effect could be catastrophic or disastrous to the consumer who are most likely to be infants or children of fragile immune system. Again, the presence of fungal or bacterial organisms in the food flour consumed could cause chronic or acute diarrhoea infections that could be injurious to the health of consumers (Magallanes Lopez and Simsek, 2021). Recent research studies have shown that the presence of mycotoxins in these complementary or composite food flours for consumption could be detrimental to health of consumers, especially with the Aflatoxin B strains that are very carcinogenic (Ware *et al*., 2018).

2.16 Aflatoxin contamination in food crops and their effect on human health

Various moulds and fungi produce mycotoxins, which are secondary metabolites. They infect a great deal of agricultural food crops under favourable conditions, such as high temperature, relative humidity, and

wetness, which occurs during production and postharvest handling and storage (Kumar *et al*., 2021). Aflatoxin is the main mycotoxin that is injurious to human health as a result of its carcinogenic property. Aflatoxin contamination in agricultural food commodities is a universal problem that compromises food safety as well as influencing the agricultural sector economy (Ofori *et al*., 2016a). The process and method by which composite flour from root tubers are produced could result in aflatoxin contamination and aflatoxin contaminants in food products is a major health issue in Ghana (Ofori *et al*., 2016a). Contamination of food crops can occur during pre- and postharvest handling, storage, and distribution by these fungal species leading to the production of numerous mycotoxins. Aflatoxins are chiefly synthesized as a result of several fungal species which include; *Penicillium, Alternaria, Aspergillus* and *Fusarium* (Kumar *et al*., 2021). But according to Quadri *et al*. (2012), aflatoxin secreted by *Aspergillus flavus* and *Aspergillus parasiticus* produces the most toxigenic strains of aflatoxin. There is also a third one called *Aspergillus nomius*. The aflatoxin producing organisms normally contaminate the food crop and secretes the toxin as metabolites in the presence of low protein and high carbohydrate levels (Essono *et al*., 2009).

Quadri *et al*. (2012) also reported that there were six different kinds of aflatoxins which included; Aflatoxin B_1 (AFB_1), Aflatoxin B_2 (AFB_2), Aflatoxin G_1 (AFG_1), Aflatoxin G_2 (AFG_2), Aflatoxin M_1 (AFM_1) and Aflatoxin M_2 (AFM_2). Kumar *et al*. (2021) explained that aflatoxin B_1, B_2, G_1, and G_2 are the ones present in agricultural food commodities and processed food product. The M_1 and M_2 are present in animals' by-products like dairy products. Aflatoxin B_1 and B_2 is synthesized by *Aspergillus flavus* while

Aspergillus parasiticus produces aflatoxin G_1 and G_2. Some of the food crops that are largely contaminated by these aflatoxins include; cereals (rice, maize, wheat, pearl millet, and sorghum), nuts (Brazil nut, almond, coconut, walnut, and pistachio), spices (black pepper, chiles, ginger, coriander, and turmeric) and oilseeds (soybean, peanut, cotton, and sunflower). Root tubers are rarely contaminated by aflatoxin with the exception of yam. Animal by-products that are mostly contaminated by aflatoxins are the various milk products (Rajarajan *et al*., 2013). Qureshi *et al*. (2015) reported that aflatoxin B_1 is the most detrimental to human health due to its carcinogenic effect linked with hepatocellular carcinoma that results in liver cancer. Aflatoxin in the human body overpowers the immune system and by this means, interfere with the capriciousness of the cells responsible for boosting immunity. Extreme quantities of aflatoxin in the system are very detrimental to human health and eventually results in death while minimal quantities in the system leads to immunologic effect or nutritional effect resulting in liver cancer due to its gradual accumulation (Marroquin-Cardona *et al*., 2014; Kumar *et al*., 2021). Zhang *et al*. (2015) reported that children were more susceptible to aflatoxin toxicity as it enhances the risk of early infections by reduced immunization. Zhang *et al*. (2015) also explained that the carcinogenic effect of aflatoxin is as a result of its ability to destroy the DNA either by oxidation or lipid peroxidation. Kumar *et al*. (2021) also reported that aflatoxin can have adverse effect on the heart, kidney, liver, brain and the testis.

To curtail or prevent aflatoxin contamination in agricultural food commodities, most developing countries have enacted different policy framework, strategies and laws with respect to the level of these toxins

(aflatoxins) permissible in food crops for consumption. The international standards according to the United States Food and Drug Administration (USFDA) states that aflatoxin level in food crops and products should not exceed 20 µg/kg while the European Union (EU) also stated that aflatoxin levels in milk products should not exceed 0.5 µg/kg (Gurtler and Keller, 2019). According the European Union, generally, for safe consumption of agricultural food commodities, aflatoxin levels should range between 4-30 µg/kg but for aflatoxin B_1 (AFB_1) which is very toxic to the human body (carcinogenic), the EU has strict permissible limit or standard that should range between 2-4 µg/kg for the food product to be safe for consumption (Mahato *et al*., 2019). According to Ofori *et al*. (2016b), some of the factors responsible for aflatoxin contamination are light, pH, temperature, relative humidity, moisture, and atmospheric gases. These aflatoxin producing organisms can grow within a pH range of 1.7 – 9.3. Eshelli *et al*. (2015) reported that while a lower pH reduces the growth of the fungi, higher pH promotes aflatoxin and fungal production. The presence of light affects the fungal growth and production. Increase in moisture content enhances aflatoxin contamination while a high relative humidity range of 85 – 95 % is very conducive and maximizes aflatoxin contamination, an optimum temperature range of 28 – 37 °C is favorable for fungal growth and production (Cotty *et al*., 2007). Siahmoshteh *et al*. (2017) also reported that the optimal temperature range for aflatoxin growth and production is within 25 – 35 °C.

2.17 Drying kinetics of agriculture food commodities

The proper way of preserving and storing agriculture food products for an extended period is to employ good drying methods to ensure that moisture

content is reduced to the minimum to prevent microbial contamination and deterioration of the food product, especially for cereal grains and root tubers (Cosme-De Vera *et al*., 2021). These foods may be dried either by the sun or in mechanical dryers. Sunlight may be used for either direct or indirect drying of food commodities such as yam, potato, cassava, cocoyam, sweet potato, and cereal grains such as maize, millet, sorghum, etc., when transparent plastics or films are used to cover the food items. The food processing industries utilise artificial mechanised dryers to dry huge volumes of food samples for commercial purposes. It is generally agreed that drying quality (defined as the efficient elimination of moisture content) is strongly influenced by the dryer that is used. The initial moisture content of the raw food sample and the temperature of the drying air medium are two primary factors that determine the complexity of heat and mass transfer processes during a typical drying process (Souza *et al*., 2018). Muhlbauer and Muller (2020) state that the quality market value and packaging of a dried food product are affected by the amount of moisture content in the final dried food product. According to research by Cosme-De Vera *et al*. (2021), root tuber crops with a high moisture content are less than ideal. Root tubers undergo both chemical and physical changes throughout the drying process. Evaporation of water from the sample's surface is the first step in the drying process. Since there is a pressure gradient between the air and the surface of the food sample, the air absorbs the moisture that has been removed. As a result, water and vapour moisture move from inside the sample to its outside. Some reactions occur during moisture evaporation, resulting in physicochemical changes in the dried food product. Therefore, in order to dry the food samples, it is necessary to

have an understanding of the physico-chemical properties and related factors, such as temperature, specific heat capacity, relative humidity, air velocity, density, and thermal conductivity, of the air medium. The physical morphological properties of the food samples, such as their form and size, structure, dimension, porosity, and the kind of root tuber to be dried, are also crucial to know. These features are very important in drying kinetics and drying process (Muhlbauer and Muller, 2020).

Quantitative control over the physicochemical changes that occur during drying is made possible by the creation of a better drying kinetic model. A thorough comprehension of the drying mechanism's response level is made possible by using suitable drying models. Optimising the dryer's process design with improved assumptions and parametric consideration might lead to less energy consumption and higher profits (Inyang *et al*., 2018). The pace at which root tubers dry is largely determined by the ambient air temperature. Recent studies on the drying characteristics of some root tubers have shown that temperatures within the range of 30 to 75 °C have been used for the drying of potato and sweet potato chips, with the results showing that drying time decreased and drying rate increased as drying temperature increased (Naderinezhad *et al*., 2016). Drying air temperature increases lead to a reduction in food product moisture content, as previously documented by Duangchuen *et al*. (2021). The explanation for this is that drying the food sample at a higher temperature had a more significant impact. Again, drying was aided at the lowest possible temperature by the low humidity of the air being used for drying. In addition, Taiwo *et al*. (2010) found that the food sample's moisture content decreases due to the rapid removal of water

molecules from the sample's pores when drying air temperature rises. And according to Pornpraipech *et al*. (2017), the time needed to minimize the moisture content to a certain level is dependent on the temperature of the drying air (Figure 2.11).

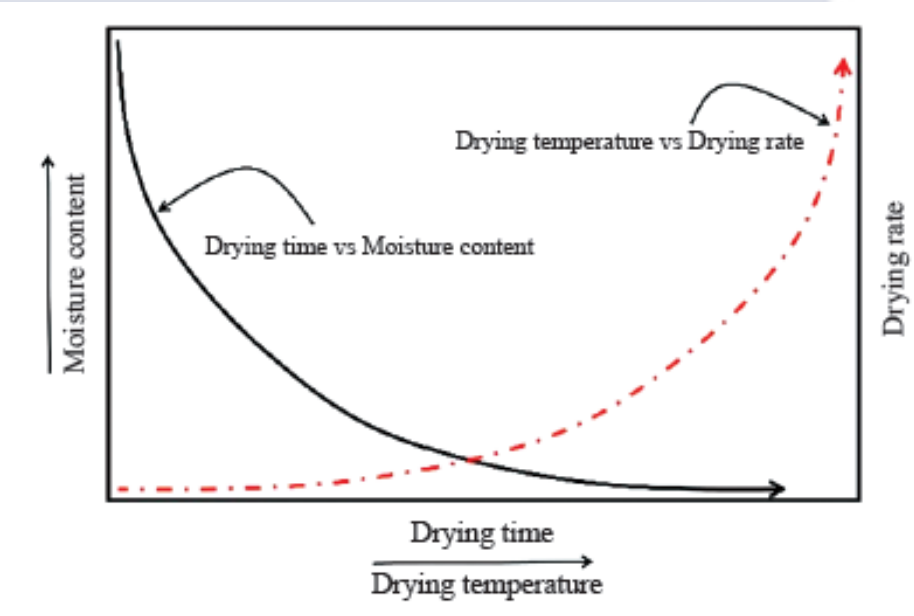


Figure 2.11: A typical graph of drying temperature and drying time versus drying rate and moisture content

2.17.1 Drying kinetics modeling of some root tubers

Understanding the principles of the drying characteristics of some root tubers during the drying process is very complex and cumbersome. The drying process of some agricultural food commodities is influenced by the selection, design and optimization of the process of drying and the type of equipment used. Drying kinetics modeling is a useful parameter in describing quantitatively the physico-chemical changes during the drying process and also its determination is very significant in the processing of root tuber-derived food commodities (Argo *et al*., 2018). In modeling the drying kinetics of some root tubers like cassava and sweet potato, the determination of

effective moisture diffusivity is considered using the Fick's second law of diffusion (equation 1).

$$MR = \frac{M_t}{M_0} = \frac{8}{\pi^2} exp\left[-\frac{\pi^2 Dt}{4L^2}\right] \quad \text{..... (1)}$$

Where: MR – Moisture ratio

D – Effective moisture diffusivity (m^2/s)

t – Drying time (s)

L – Half of the slice thickness (m)

M_t – Moisture content after time, t at % dry basis (db)

M_0 – Initial moisture content at % dry basis (db)

Taking the natural log of both sides:

$$\ln MR = \ln\frac{8}{\pi^2} - \frac{\pi^2 Dt}{4L^2} \quad \text{.....(2)}$$

From Equation 2, plotting a graph of ln MR against the drying time, t results in a straight line with a negative slope (Figure 4.21 and 4.22) where the slope, K (Equation 3), relates to the effective moisture diffusivity, D (Equation 4).

$$K = \frac{\pi^2 D}{4L^2} \quad \text{..... (3)}$$

$$D = \frac{K4L^2}{\pi^2} \quad \text{..... (4)}$$

The study of drying kinetics and determining the best fit kinetic model equation can help in knowing the suitable drying techniques and also to monitor the process of drying (Cosme-De Vera *et al.*, 2021). Some of the drying kinetic models used for root tubers like potato, cassava, sweet potato, yam and cocoyam are listed in Table 10.

Table 2.10: Drying kinetic models used for some root tubers

Name of model	Model equation
Page	$MR = \exp(-kt^n)$
Henderson and Pabis	$MR = a \exp(-kt)$
Modified Page model	$MR = a \exp(-(kt)^n)$
Wang and Singh	$MR = 1 + at + bt^2$
Newton	$MR = \exp(-kt)$
Midilli-Kucuk / Midilli et al.,	$MR = a \exp(-kt^n) + bt$
Logarithmic	$MR = a \exp(-kt) + c$
Two-term	$MR = a \exp(k_1t) + b \exp(k_2t)$
Two-term exponential	$MR = a \exp(-kt) + (1 + a) \exp(-kat)$

Source: Cosme-De Vera *et al*. (2021); Abano and Amoah (2015)

2.18 Moisture sorption isotherm

2.18.1 Water activity (a_w)

Water or moisture in food commodities is exhibited in different types based on the relationship between the food components and the water molecules. Water activity is the ratio of water vapour pressure in the food commodity to the saturated vapour pressure at constant temperature and pressure (Walstra, 2003). Sahin and Gulum (2006) also described the water activity as the equilibrium relative humidity of the air around the food commodity at the same temperature and expressed as shown in Equation (5).

$$a_w = \frac{P_v}{P_{v,sat}} \quad \text{..... (5)}$$

Where: Pv – vapour pressure (mm Hg), Pv,sat – saturated vapour pressure (mm Hg), a_w – water activity.

Water activity is an essential parameter in the preservation of food products. It is a determinant of microbial growth and probably the release of toxins as well as development of non-enzymatic and enzymatic browning. For

every agricultural food commodity or food products, there is a limit of water activity below which microorganisms or pathogens cannot grow (Hii *et al*., 2012). Most bacteria grow around a water activity of about 0.85, fungi at 0.70 and yeast and mold at 0.61. The microorganisms cannot not grow below these values. Hence, proper drying of the crop to reduce the water activity level will inhibit the growth of these microorganisms (Hii *et al*., 2012).

2.18.2 Food sorption isotherm

The thermodynamic interactions between the equilibrium of the moisture content and the water activity of the food commodity at constant pressure and temperature defines the food sorption isotherm (Andrade *et al*., 2011). Understanding food sorption isotherm is extremely significant in food science technology and engineering for drying equipment design and optimization, food material design for packaging, quality predictions, stability, food product storage life and changes in moisture content calculations during storage and distribution of food products (Al-Muhtaseb *et al*., 2004a). The potential of minimizing moisture content of food products has the capability of enhancing preservation processes thereby extending the storage life of the food products as the effect of microorganisms that cause food deterioration or spoilage is inhibited (Yan *et al*., 2008). According to Andrade *et al*. (2011), the shape of an isotherm typically describes how water binds in the food system. Water molecules interactions that are weak generates a greater water activity making the food product very unstable. Fabra *et al*. (2009) reported that water activity depends on the physical state or form of the compounds, the composition and the temperature of the food components. According to Andrade *et al*. (2011), sorption isotherms can be produced from a desorption

process or adsorption process where the difference between these sorption curves is described as hysteresis (Figure 2.12).

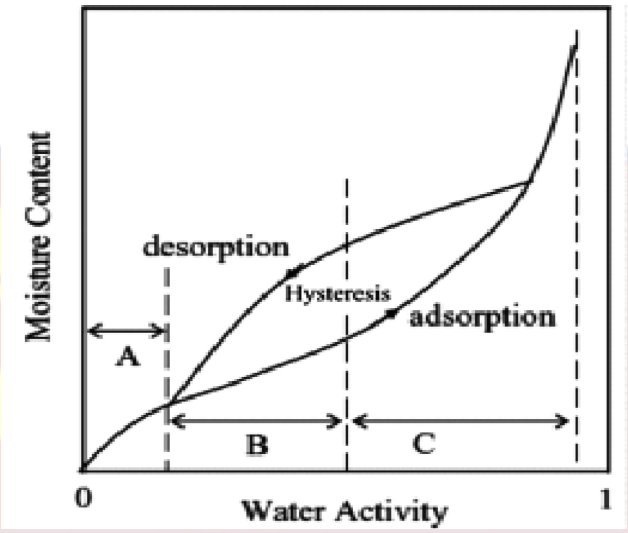


Figure 2.12: A typical sorption isotherm for food commodities

Source: Andrade *et al*. (2011)

The process where water molecules gradually and reversibly blend together with food solids through physical adsorption, multilayer condensation and chemisorption describes the water adsorption of food commodities. Typically, sorption isotherm is grouped into three regions as shown in Figure 2.12 and Figure 2.13. Region A shows strongly bond water where the vaporization enthalpy is substantially higher than that of pure water. The bound water involves two main types of water which are the monolayer water that is sorbed by the hydrophilic and polar groups of the components of the food (proteins and polysaccharides) and the second one is the hydrogen-bounded water referred to as the structural water. The bound water cannot freeze and therefore, it is unavailable for chemical reactions or used as a plasticizer. For region B, the binding for water molecules is not as strong as compared to those in region A. They have less strongly bound water layers. Since they are normally available in small capillaries, its enthalpy of

vaporization is also slightly higher than that of pure water. The water involved here can be seen as gradually transition from bound to free water (Raji and Ojediran, 2011; Andrade *et al*., 2011). For region C, the water there is described as free water that is contained in voids with large capillaries and crevices. The water in this region loosely binds to food materials (Raji and Ojediran, 2011). According to Andrade *et al*. (2011), the hysteresis relates to the state and nature of the food components depicting their potential for conformational and structural rearrangements that changes the availability of actively favourable polar site. Raji and Odediran (2011) again reported that the explanation given to the existence of moisture sorption hysteresis includes the molecular shrinkage theory, the ink bottle theory, the swelling fatigue theory and the capillary condensation.

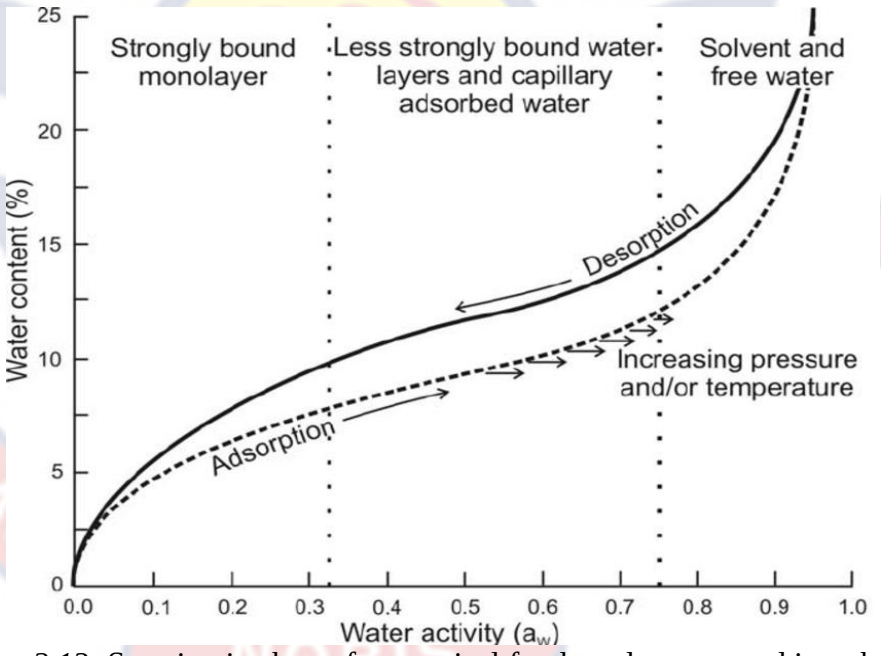


Figure 2.13: Sorption isotherm for a typical food product grouped into three regions

Source: Omolola *et al*. (2015)

2.18.3 Classification of sorption isotherms

Andrade *et al*. (2011) documented that the classification of sorption isotherms according to shape and processes was done by Brunauer *et al*. (1940) where five different kinds of isotherms were established (Figure 2.14).

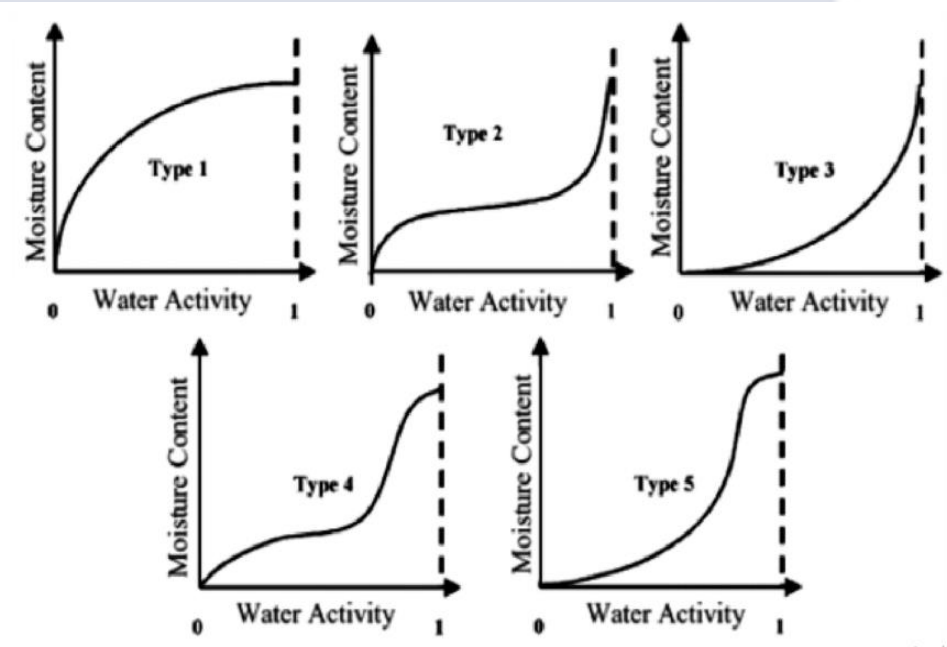


Figure 2.14: Types of sorption isotherms Source: Andrade *et al*. (2011)

Type 1 – is referred to as Langmuir isotherm where comparable isotherms that show a characteristic surge in water activity with respect to increasing moisture content. The shape of this curve is convex upwards. This type of isotherm is applicable in the filling process of water mono-molecular layer at the internal surface of the food commodity.

Type 2 – these are the sigmoidal sorption isotherms where the curves are concave upwards and involves the existence of multilayers at the internal surface of the food produce.

Type 3 – is referred to as the Flory-Huggins isotherm represents a plasticizer or a solvent like glycerol directly above the glass transition temperature.

Type 4 – shows the adsorption of a swellable hydrophilic solid until a final hydration site is reached or obtained.

Type 5 – is referred to as the Brunauer-Emmett-Teller (BET) multilayer adsorption isotherm and this involves the adsorption of water vapour on charcoal. Type 5 is usually related to type 2 and type 3 (Blahovec and Yanniotis, 2009). According Andrade *et al*. (2011), most agricultural food commodities are usually represented by type 2.

Sorption isotherms of food commodities can be determined using three different methods which include manometric, gravimetric and hygrometric techniques. For gravimetric analysis, the weight of the food sample is determined with a weighing balance. For the manometric analysis, the vapour pressure of water is determined at equilibrium with the food sample at a given moisture content. For hygrometric analysis, the equilibrium relative humidity with the food sample at a given moisture content is determined. Research has shown that there have been two additional current methods that can be used to determine the sorption isotherm of food samples. These include the light reflection/attenuation method and the impedance spectroscopy method (Andrade *et al*., 2011).

2.18.4 Mathematical models of moisture sorption isotherms

Using mathematical expression to determine the relationship between the moisture content and water activity of food samples, several mathematical models have been developed and these includes linear, non-linear, regressional models, etc., to explain the sorption isotherm of the food samples. According to Andrade *et al*. (2011), some of the models used in literature include;

1. ***Langmuir model***

$$a_w\left(\frac{1}{M_w}-\frac{1}{M_0}\right)=\frac{1}{CM_0} \quad \text{..... (6)}$$

Where: M_w – equilibrium moisture content (kg water / kg dry matter)

M_o – monolayer sorbate content (kg water / kg dry matter)

C – constant

The monolayer moisture content M_o is very essential because it shows the quantity of water that is strongly adsorbed in specified sites.

2. ***Brunauer-Emmett-Teller (BET) model***

$$M_w=\frac{M_0 C a_w}{[(1-a_w)(1+(C-1)a_w]} \quad \text{..... (7)}$$

Where: M_0 – Monolayer moisture content – is the moisture content (% db) at which water molecules that bind to each ionic and polar groups begin to act as a liquid-like phase.

C – the energy constant (Joules, J) related to the net heat of sorption.

3. ***Oswin model***

$$M_w=C\left(\frac{a_w}{1-a_w}\right)^n \quad \text{..... (8)}$$

Where: C and n are constants

4. ***Smith model***

$$M_w=C_1+C_2\ln(1-a_w) \quad \text{..... (9)}$$

Where: C_1 – the amount of water in the first sorbed fraction

C_2 – the amount of water in the multilayer moisture fraction

5. ***Halsey model***

$$M_w=M_0\left(-\frac{A}{RT\ ln\ a_w}\right)^{1/n} \quad \text{..... (10)}$$

Where: A and n are constants

R – Universal gas constant ($JK^{-1}mol^{-1}$)

T – Absolute temperature (°C)

M_0 – Monolayer moisture content (% db)

6. ***Iglesias – Chirife model***

$$\ln\left[M_w + \left(M_w^2 + M_{w,0.5}\right)^{1/2}\right] = C_1 a_w + C_2 \quad \text{..... (11)}$$

Where: $M_{w,0.5}$ – Moisture content at the water activity of 0.5

C_1 and C_2 – Constants

7. ***Guggenheim-Anderson-de Boer (GAB) model***

$$M_w = \frac{M_0 C K a_w}{(1-Ka_w)(1-Ka_w+CKa_w)} \quad \text{..... (12)}$$

Where: M_0 – the monolayer moisture content (% db)

C and K – the adsorption constants ($Lmol^{-1}$)

The Langmuir's model (equation 6) is based on the intermolecular forces interacting between the water condensed from the vapour or the monomolecular layer at the surface of the food produce like pear and garden mint leaves (Andrade *et al*., 2011). The BET model (equation 7) best describes the type 2 and type 3 isotherms. Arslan and Togrul (2006) reported that BET was an effective model for estimating the quantity of bound water in specified polar sites of dehydrated food commodities. BET is considered useful in the determination of optimum moisture for enhanced storage stability for dehydrated food commodities like dried potato, dried tomato, blueberry, yam, corn flour, etc. The Oswin model (equation 8) is applied in relation to moisture content of freeze-dried tea and fat-free dry milk with water activity of 0.5 and other food produce like dried potato, yam, dried tomato pulp, corn flour, banana pulp, garlic, mango pulp, apple, etc. The Smith model (equation

9) describes the final curved portion of water sorption isotherm of high molecular weight biopolymers. It is applied in food products with water activity range between 0.5 and 0.95 like the case of wheat desorption and other food products like yam, cashew, apple, blueberry, mango pulp, etc (Moraes *et al.,* 2008). Halsey model (equation 10) describes the adsorption data with respect to Type 1, 2 and 3. It also best describes the sorption behaviour of food commodities that contain starch like corn flour, pear, banana pulp, blueberry, etc (Togrul and Arslan, 2007). Iglesias-Chiriefe model (equation 11) also best describes food commodities with high amounts of sugar like grapes, walnut kernels and *chhana podo*. The GAB model (equation 12) is very suitable and best describes the sorption behaviour of almost all food commodities (a_w < 0.9) and some of these food produce includes corn flour, passion fruit peel, dried tomato pulp, yam, banana pulp, walnut kernels, mango pulp, pineapple peel, pear dehydration, etc.

In summary, moisture sorption isotherms are essential thermodynamic tools for describing or predicting the relationship between moisture and components of the food product. Generally, the BET and GAB models best describes the sorption behaviour of almost all agricultural food commodities (Basu *et al*., 2006).

2.19 Promoting the production and consumption of OFSP in Ghana

As part of national efforts to achieve the Millennium Development Goals (MDGs) following the awareness of addressing some micronutrient deficiencies like vitamin A deficiency disease, the government of Ghana in recent times has intensified its campaign to promote the cultivation and utilization of OFSP. This aims to champion the continuous utilization of OFSP

in the domestic households of both rural and urban food budgets. The potential significance of OFSP apart from its nutritional benefits makes it a good source of income generation and employment creation. It is therefore very important as a nation to contribute to the development of OFSP value chains in Ghana.

In Ghana, majority of the reproductive women and children under 5 years of age are malnourished due to insufficient intake of micronutrient rich foods. Abano *et al*. (2019) reported that the prevalence of vitamin A deficiency disease in Ghana is about 76% which is the third highest in Africa and very alarming. Recognizing the significant potential of OFSP as highly nutritious food commodity that is rich in vitamin A and other micronutrients that are capable of fighting stunted growth and minimizing vitamin A deficiency among these vulnerable groups (young children and reproductive mothers), it is important for the government of Ghana to use OFSP as a potential tool to address this devastating problem of vitamin A deficiency in Ghana (Kofi Annan Foundation, 2021). According to Amoah (2014), the Ministry of Food and Agriculture (MoFA) has been supporting research studies that are aimed in promoting the production of sweet potato especially the orange-fleshed variety, its utilization and marketing under the Root and Tuber Improvement and Marketing Programme (RTIMP). Furthermore, the Export Development and Investment Fund (EDIF) in Ghana supported the Vegetable Producers Association of Ghana (VEPAG) with some funds to purchase some farm equipment to enhance the production of sweet potatoes on large-scale for domestic consumption and export. A collaborative project between the University of Ghana, Legon, Tuskegee University and the Crops Research Institute (CRI) of the Council for Scientific and Industrial Research

(CSIR) in Kumasi was funded by USAID to promote the cultivation and consumption of OFSP to address the Vitamin A deficiency malnutrition (Amoah, 2014). The prevalence of vitamin A deficiency malnutrition is very high in the Northern parts of Ghana. To address this problem, the Trax Ghana as the donor and with technical support from Self Help Africa, International Potato Centre (CIP), and the government of Ghana through its Ministry of Food and Agriculture (MoFA) distributed OFSP planting materials (vines) to individual farmers and some schools for cultivation to enhance its production yield. Apart from distributing the planting materials, the Trax Ghana with the technical support from Ministry of Food and Agriculture, CIP and the Women in Agricultural Development Directorate (WIADD) provided technical training for the school pupils and individual farmers on how to conserve the potato planting material (vines) as well as how to prepare a balanced nutritious diet from OFSP to meet their nutritional needs (Taylor, 2015). According Taylor (2015), Trax Ghana and the various collaborators also assisted the farmers by constant engagement and linking them to the open market to help them sell their harvested OFSP produce to make some profit (income) to build a sustainable livelihood for their families and the community. Currently, one major institution that is collaborating with the government of Ghana to champion this course is the Kofi Annan Foundation.

Figure 2.151: Mr. and Mrs. Annan on a field trip with OFSP exhibited

Source: Kofi Annan Foundation (2021)

The Foundation is currently supporting a major project to promote the production and utilization of OFSP in Ghana under the programme "Demand Creation and Impact Scaling Project for Orange-Fleshed Sweet Potato" which is being funded by the Alliance for a Green Revolution in Africa (AGRA). With a market-led and sustainable livelihood approach, this project aims to significantly stimulate the production of OFSP as well as processing it into other food products. This will also ensure high income margins for the farmers to enhance their standard of living and also to address their vitamin A deficiency status with the continuous consumption of the OFSP (Figure 2.15). According to the Foundation, the project also intends to support the government of Ghana flagship programme of "Planting for Food and Jobs" as well as providing raw materials for the "One District One Factory" initiative programme.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Materials

3.1 Acquisition and handling of root tuber samples

Physiologically matured, fresh and undamaged variety of cassava, '*Capevars bankye*' and a local variety of orange-fleshed sweet potato, '*Apomuden*' of known provenance were used for the study. The cassava and sweet potato were grown under standard agronomic practices at the University of Cape Coast's School of Agriculture Research Farm and by an accredited sweet potato farmer at Jukwa, Cape Coast, respectively. The harvested tubers were sorted to discard damaged and rotten roots. Research analyses were conducted at the research laboratory of Agricultural Engineering Department, University of Cape Coast, Cape Coast, Ghana and the research laboratory of Food Research Institute, Council for Scientific and Industrial Research, Accra, Ghana. All analyses were done in triplicate. Pictures of some of the equipment or instruments used for the study are shown in Appendix C. Ethical clearance from the Institutional Review Board Secretariat of University of Cape Coast for the implementation of this study was obtained (Appendix A).

3.2 Sample preparation

3.2.1 Preparation of cassava flour

Dada *et al*. (2017) provided a technique for making cassava flour, which was followed. Cassava roots were picked when they were eleven months old, then peeled using a stainless-steel knife, cleaned with running water, and grated using a machine made in the area.

The pulp was dewatered for 4 h using a locally designed double screw press, pulverized with the hand and dried at 70 °C for 6 h using a convective hot-air dryer (Gourmia Food Dehydrator, Intertek 4001069, China). The dried cassava samples were then milled using a multi-purpose grinder (QE-100, Zhejiang YiLi Tool Co., Ltd., Longquan, China) and sieved (300 µm) into fine powder. The flour produced in Figure 3.16 (white flour) was kept in air-tight moisture-proof polyethylene bags and stored at -18 °C pending further analysis.

3.2.2 Preparation of OFSP flour

OFSP flour was prepared using the method described by Adeleke and Odedeji (2010). Freshly harvested OFSP roots at maturity age of three months were peeled, washed, chipped and dried at 60 °C for 9 h using a convective hot-air dryer (Gourmia Food Dehydrator, Intertek 4001069, China). The dried OFSP chips were also milled using the above multi-purpose grinder (QE-100, Zhejiang YiLi Tool Co., Ltd., Longquan, China) and sieved (300 µm) into fine powder. The flour produced in Figure 3.16 (orange flour) was kept in air-tight moisture-proof polyethylene bags and stored at -18 °C until further analysis.

Figure 3.16: Milled and sieved orange-fleshed sweet potato and white cassava flours

3.3 Formulation of composite 'fufu' flour and experimental design

The Mixture Design in Minitab Software (version 19) was used to create five (5) formulation ratios from the cassava and OFSP flours into composite 'fufu' flours, as indicated in Table 3.11 and Table 3.12. With this plan, we investigated the physico-nutritional parameters (responses) three times to ensure statistical significance. The flours were completely combined using a food mixer (FP9071-GS, Anko Co., Ltd, China) as shown in Figure 3.17. Airtight moisture-proof polyethylene bags were used to keep the composite flour mixes in the freezer at -18 °C until further analysis could be performed. Figure 3.18 shows a summary of samples and product (flour) preparation.

Table 3.11: Mixture design sheet for formulation of cassava – sweet potato blends

Simplex Centroid Design

Components: 2 Design points: 15
Process variables: 0 Design degree: 2
No. of Replicates 3

Mixture total: 100

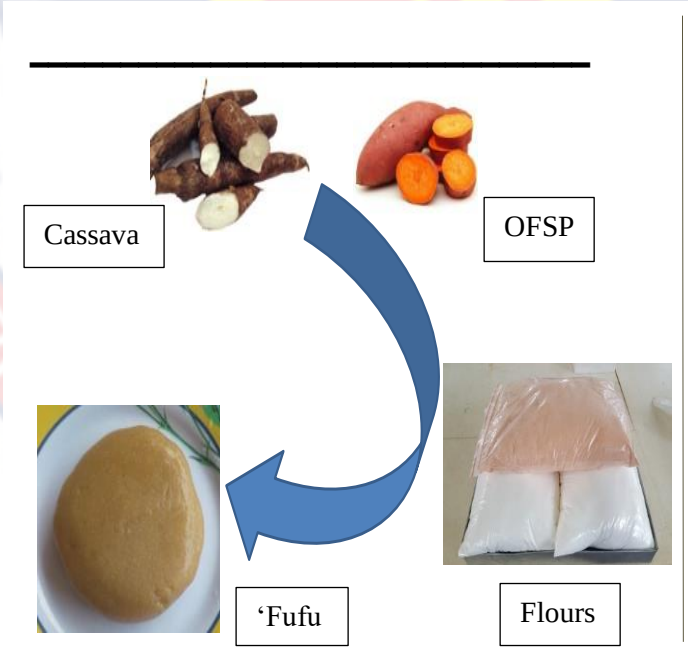
Std Order	Run Order	Pt Type	Blocks	Cassava	OFSP	β-Carotene	Protein	Fat	Iron	Fibre	Ash
13	1	0	1	85	15						
10	2	-1	1	80	20						
2	3	1	1	75	25						
8	4	0	1	85	15						
1	5	1	1	95	5						
5	6	-1	1	80	20						
11	7	1	1	95	5						
14	8	-1	1	90	10						
3	9	0	1	85	15						
9	10	-1	1	90	10						
6	11	1	1	95	5						
7	12	1	1	75	25						
12	13	1	1	75	25						
4	14	-1	1	90	10						
15	15	-1	1	80	20						

Table 3.12: Percentage (%) formulation of composite 'fufu' flour

Sample Code	Formulation Ratio	Cassava Flour (%)	OFSP Flour (%)
CAS100	100% Cassava	100	0
COA	95/5	95	5
COB	90/10	90	10
COC	85/15	85	15
COD	80/20	80	20
COE	75/25	75	25
OFS100	100% OFSP	0	100

Figure 3.17: Mixing and bagging composite flour blends using the food mixer

3.4 Graphical methodology



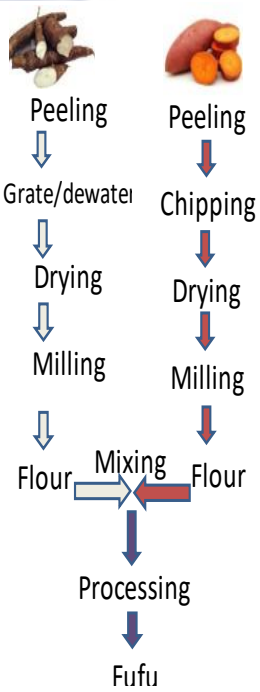


Figure 3.18: Summary of sample and product preparation

3.5 Methods

3.5.1 Determination of initial moisture content

The initial moisture content of the fresh root crops (cassava and OFSP) on wet basis (wb) were estimated according to the method of AOAC (2016). Samples of approximately 200 g were dried in the hot-air drier.

3.5.2 Drying process

While drying, the samples' weight was measured at hourly intervals using an electronic weighing balance (3200 g/0.01 g, A & D Company Ltd, Japan) until a constant weight was obtained to indicate an equilibrium moisture condition. The drying temperature was recorded. The moisture contents of the drying samples with respect to time were calculated and used to estimate the moisture ratios (MR). Different kinds of mathematical models have been used to predict the drying behaviour of food commodities, ranging from theoretical models based on classical diffusion theory to purely empirical models (Addo *et al*., 2009). According to Addo *et al*. (2009), one major equation that has been used to predict successfully the drying behaviour of most food commodities is Page's equation.

$$MR = \frac{M_t - M_e}{M_o - M_e} = exp(-kt^n) \quad \text{..... (13a)}$$

Where:

MR – dimensionless moisture ratio (-)

M_t – moisture content at any moment (% dry basis, db)

M_o – initial moisture content of product (% db)

M_e – equilibrium moisture content

k – rate constant (h^{-1})

t – drying time (h)

n - constant

Since the equilibrium moisture content (M_e) values are relatively small compared to M_t or M_o, equation (13a) can be simplified to equation (13b)

$$MR = \frac{M_t}{M_0} \quad \text{..... (13b)}$$

3.5.3 Effective moisture diffusivity

The effective moisture diffusivity (D) was expressed in terms of Fick's Second Law of Diffusion (Abano and Amoah, 2015) as shown in equation 14:

$$MR = \frac{M_t}{M_0} = \frac{8}{\pi^2}\sum_{n-1}^{\infty}\frac{1}{(2n-1)^2}exp\left[-\frac{(2n-1)^2\pi^2 Dt}{4L^2}\right] \text{..... (14)}$$

Where n = 1, 2, 4 and 8 are the number of terms in the equation taken into consideration, t is the time of drying, D is the effective moisture diffusivity (m^2/s), and L is half the thickness of the slice/chips (m). For long-term drying, equation (13b) can be simplified to equation 15.

$$MR = \frac{M_t}{M_0} = \frac{8}{\pi^2}exp\left[-\frac{\pi^2 Dt}{4L^2}\right] \text{..... (15)}$$

Taking the natural log of both sides (equation 16):

$$\text{In } MR = \text{In}\frac{8}{\pi^2} - \frac{\pi^2 Dt}{4L^2} \text{..... (16)}$$

Plotting a graph of ln MR against the drying time, t results in a straight line with a negative slope where the slope, K, relates to the effective moisture diffusivity, D as shown in equation 17 and 18 respectively.

$$K = \frac{\pi^2 D}{4L^2} \text{..... (17)}$$

$$D = \frac{K4L^2}{\pi^2} \text{..... (18)}$$

3.5.4 Mathematical drying models

The drying characteristics of the samples were determined by fitting the experimental data into four (4) different drying models (Newton, Page, Logarithmic, and Henderson & Pabis) as shown in Table 3.13. The drying models describes the relationship between moisture loss and drying time with the different coefficients in the various drying models (Ajala, 2012).

Table 3.13: Mathematical models to fit experimental data

Model Name	Model Equation	References
Newton	MR = exp (-kt)	Junqueira *et al*. (2017)
Page	MR = exp ($-kt^n$)	Patil and Gawande (2018)
Henderson & Pabis	MR = a exp (-kt)	Gull *et al*. (2017)
Logarithmic	MR = a exp (-kt) + c	Zhang *et al*. (2016)

MR = moisture ratio, a, c, k, n = model constants and t = drying time

3.6 Moisture sorption behaviour

The equilibrium moisture content of samples was determined following the gravimetric method described by Rosa *et al*. (2010) with slight modifications. The experiments were setup in 7 hermetically closed jars, each filled to a quarter of the jar's height with different concentrations of sulphuric acid solution, to keep a water activity of range of 0.1 to 0.9 (Table 3.14). One gramme of composite flour samples was carefully suspended in the jar at an appreciable height above the acid solution to prevent contact. The jars were placed under controlled temperature conditions in a laboratory oven at 30 °C.

The weight of the suspended flour samples was measured at one week interval until a constant weight was attained (after nearly 8 weeks). To minimize atmospheric moisture sorption during weighing, removing, weighing and placing samples back into jar was done in less than 45 s. At the point of

equilibrium, the moisture content, expressed as g water/100 g of flour, was determined as the equilibrium moisture content (EMC).

Table 3.14: Water activity of sulfuric acid solution at 30 °C

Concentration (%)	Water activity, a_w
15	0.9245
25	0.8252
35	0.6693
40	0.5711
50	0.3574
55	0.2563
65	0.0972

Source: (Sahin and Sumnu, 2006)

3.6.1 Modeling sorption data

The water sorption data was fitted to four different moisture sorption models as shown in Table 3.15.

Table 3.15: Moisture sorption models

Model	Expression	Reference
GAB	$M = M_o C k a_w/(1-ka_w)(1-ka_w+Cka_w$	Van den Berg & Bruin, (1981)
BET	$M = M_o C a_w/(1-a_w)(1+a_w(C-1))$	Brunauer *et al.* (1938)
Oswin	$M = a \times a_w/(1-a_w)^b$	Oswin (1946)
Smith	$M = A + Blog(1-a_w)$	Smith (1947)

Where M – Moisture content, Mo – Monolayer moisture content, C, k, A and B – constants, a_w – water activity

3.7 Statistical analysis for drying and moisture sorption characteristics

The constants of the drying model equations and moisture sorption equations were estimated by subjecting them to a non-linear regression analysis using the Statistical Package for Social Scientists (SPSS version 25.0) software and the Origin Pro software (version 18.0), respectively. The

coefficient of determination (R^2), reduced chi-square (χ^2) and Root Mean Square Error (RMSE) were used to test the reliability of the models (Equations 19-21). The model equation with the highest coefficient of determination and the lowest reduced chi-square and RMSE best described the drying characteristics and the moisture sorption isotherm as well.

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{pre,i} - MR_{pre,i})^2}\right] \quad \text{..... (19)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2} \quad \text{..... (20)}$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{(exp,i)} - MR_{pred,i})^2}{N-z} \quad \text{..... (21)}$$

3.8 Determination of physico-nutritional, functional, microbial and sensory evaluation

3.8.1 Proximate composition of composite flour

Dry basis (db) analyses of moisture, crude protein, crude fat, crude fibre, and ash were performed on the composite flours using AOAC (2016) accredited procedures. The overall energy content was assessed using the Atwater factor in kcal/100g, and the total carbohydrates were calculated by subtracting the addition of moisture, ash, protein, and fat from 100% (Bamidele *et al*., 2015).

3.8.1.1 Determination of moisture content

The moisture content of the composite flour samples was determined using the air oven method according to the method of AOAC 32.1.03 (2016). Clean labeled moisture dishes were placed in an oven at 105 °C for 20 minutes

and then transferred to a desiccator using tongs to cool. Immediately upon chilling, the dishes were weighed. Approximately 3 grammes of each composite flour sample was weighed and spread evenly over the bottom of the plate. The samples were subsequently dried in a 105 °C for 24 h. After collection, the samples were put into a desiccator for further analysis. After allowing the samples to cool, they were weighed right away. The moisture content was calculated as the percentage moisture evaporated on dry basis using equation 22.

Calculation:

$$Moisture\ Content = \frac{Loss\ in\ sample\ weight}{Initial\ sample\ weight}\ x\ 100\% \quad \text{..... (22)}$$

3.8.1.2 Determination of ash content

The ash content of the composite flour samples was determined using the muffle furnace method according to the method of AOAC 32.1.05 (2016). Clean labelled porcelain crucibles were ignited, cooled in a desiccator and weighed. An amount of 3 g of the sample was accurately weighed into the crucibles and placed into the muffle furnace and ashed at 550 °C for 8 h. The remaining ash was cooled in the desiccator and weighed. The percent ash content was calculated using equation 23.

Calculation:

$$Ash\ Content = \frac{Weight\ of\ ash}{Weight\ of\ sample}\ x\ 100\% \quad \text{..... (23)}$$

3.8.1.3 Determination of crude fat content

The Gerhardt Soxtherm Apparatus was used to measure the crude fat content of the composite flour samples in accordance with AOAC 4.5.01 (2016). The sample was weighed out at 3 grammes, transferred to filter paper, folded, and then packed into a thimble with grease-free cotton. The thimble was added to the extraction beaker with the sample. The weight of a dry, clean extraction beaker was secured to the extraction unit's base. Next, around 200 mL of petroleum ether were added to the extraction beaker, and the soxtherm was set to run continuously for 5 hours. The flask was dried in a 105 °C oven for 1 hour to remove any remaining moisture from handling. The flask and contents were then transferred to the desiccator to cool and later weighed. A blank was carried out using the same procedure. The percent fat (ether extract) was calculated using equation 24.

Calculation:

$$Fat\ (Ether\ Extract) = \frac{Weight\ of\ fat\ extracted - Blank}{Weight\ of\ sample\ taken}\ x\ 100\% \quad \text{.....(24)}$$

3.8.1.4 Determination of crude protein content

The crude protein was determined using the Kjedahl procedure for the determination of nitrogen using the Tecator Kjecltec systems (Kjeltec 8400, FOSS Analytical Co. Ltd., Sweden) based on the AOAC 4.2.09 (2016). Exactly 0.2 g of the homogenous composite flour samples was weighed onto a piece of filter paper and placed into a 250 mL digestion tube. A 0.1 g ammonium sulphate was weighed into a weighing boat and transferred into a digestion tube and 80 mL of water was then added for Tecator Kjeltec Systems.

In-House control sample: About 0.2 g of in-house control sample was weighed onto a piece of filter paper, folded and placed into a 250 mL digestion tube and digested.

Digestion: one Kjeltab Cu (3.5 g) was added to 15 mL concentrated H_2SO_4 and shook gently to 'wet' the sample with the acid. The exhaust was positioned well and the aspirator was turned on. Digestion was done until green-blue color was attained. The rack with the exhaust was then removed and allowed to cool.

Neutralization and Distillation: Distillation was done in the 'Analyse' or 'Manual' mode. A 25 mL receiver solution (4% Boric acid) was added to the receiver flask. Between 2-3 drops of screened methyl indicator were added to the receiver solution. Exactly 80 mL of water was used to dilute the cooled digest and 80 mL NaOH was added to the diluted digest and the reaction was allowed to settle. This was allowed to stand for 5 min to obtain a distillate of about 150 mL.

Titration: The distillate was titrated with 0.1M HCl until a pink end-point was achieved and the volume of acid used in the titration (titre) was recorded.

Standardization of HCl: Standardization of HCl was done by checking the concentration of the HCl against a pre-determined solution of sodium carbonate. An analytical reagent-quality grade sodium carbonate (Na_2CO_3) of 99% purity was heated to 260-270 °C for 30 min. It was then cooled in a desiccator and the solid was transferred to a warm, dry, glass stoppered tube and kept in the desiccator. A 0.2 g of the pure Na_2CO_3 was weighed into a 250 mL conical flask and dissolved in 50-75 cm^3 distilled water. About 2-3 drops

of methyl orange indicator were added and titrated with the 0.1 M HCl. The estimation of crude protein, w/w is estimated from equation 25-26.

Calculation:

$$\%\ Nitrogen, \frac{w}{w} = \frac{(T-B)\ x\ N\ x\ 14.007}{10\ x\ weight\ of\ sample} \quad \text{..... (25)}$$

$$\%\ Crude\ Protein, w/w = \%\ Nitrogen\ x\ 6.25 \quad \text{..... (26)}$$

Where:

T – Titration volume for sample (mL)

B – Titration volume for blank (mL)

N – Normality of acid to 4 decimal places.

3.8.1.5 Determination of crude fibre content

The crude fibre content of the composite flour sample was determined using the Wende method according to the method of AOAC 4.6.01 (2016). Exactly 2.5 g of the composite flour sample was weighed and transferred to an extraction apparatus and extracted with light petroleum ether by stirring, settling and decanting three times. The extracted sample was air dried and transferred to a dry 1000 mL conical flask. A 200 mL 0.255N H_2SO_4 measured at ordinary room temperature was added and brought to boiling point. The flask was rotated every few minutes to mix the contents and remove particles from the edges, and then it was boiled gently for 30 minutes to keep the volume constant. Suction was used to secure a circular drain to the inside of a Buchner funnel that had been outfitted with a perforated plate by adjusting a sheet of filter paper to cover the holes in the plate. After 30 minutes, we removed the pot from the heat and let the mixture remain for 1 minute before pouring it into the Buchner funnel. Particles from the sample were washed back into the first flask using a wash bottle containing 200 mL

0.313M NaOH solution. It was then boiled for 30 min and allowed to stand for 1 min and filtered immediately through a suitable dried and pre-weighed filter paper and washed with ethanol. The filter paper with the content was then dried at 100 °C to a constant weight. The filter paper and content were then ashed at 550 °C for 4 h. The weight of the ash was subtracted from the increase in weight of the filter paper due to insoluble material and the difference was reported as crude fibre (equation 27).

Calculation:

$$Crude\ fibre = \frac{Weight\ of\ insoluble\ material - Weight\ of\ ash}{Weight\ of\ sample}\ x\ 100\%$$

..... (27)

3.8.1.6 Estimation of total carbohydrate and energy

Carbohydrate content was derived by the difference while energy was also estimated by Atwater factor in kcal/100 g as described by Capuano *et al*. (2018) using equations 28 and 29 respectively.

$$Total\ Carbohydrate = 100 - (Moisture\ + Ash\ + Protein\ + Fat)$$

..... (28)

$$Total\ Energy = [4(Protein) + 4(Carbohydrate) + 9(Fat)]$$ ..... (29)

3.8.2 Mineral and vitamin composition

Zinc and iron levels in the composite flours were measured using AOAC (2016) accredited techniques. The International Organisation for Standardisation (ISO) BS EN 12823:1-2014 established the spectrophotometric technique for the quantitative measurement of vitamin A. Vitamin A content was used to determine β-carotene content.

3.8.2.1 Determination of Iron

The iron content was determined using the 2,2-dipyridyl spectrophotometric method. A volume of 10 mL of ash solution was pipetted into a 50 mL volumetric flask. An amount of 30-40 mg of crystalline ascorbic acid was added to the solution in the flask. After letting the solution sit for 10 minutes, all of the iron III had been reduced to the ferrous form. To a volume of 50 mL, 10 mL of an ammonium acetate solution and 2 mL of a dipyridyl solution were added. For a complete colour development, the solution was left in the dark at room temperature for 1 hour. The absorbance at 520 nm was determined using a spectrophotometer (model CECILCE 7400; Cecil Instruments; Cambridge, England). The ash-dissolving acid was included in the blank solution used to calibrate the spectrophotometer. Absorbances were determined after preparing standard iron solutions of different concentrations. The absorbances were plotted against concentration (in g/mL). The corresponding concentration for the absorbance of the sample was read from the calibration curve and converted to mg/100g using equation 30.

Calculation:

$$Iron\ (Fe)\ content\ (mg/100g) = \frac{Concentration\ of\ Fe\ \left(\frac{ug}{mL}\right) \times 250\ mL}{Weight\ of\ sample(g)\ \times\ volume\ \ of\ aliquot\ taken\ (mL)}$$

..... (30)

Where:

250 mL – is the volume of iron solution and ash solution

3.8.2.2 Determination of Zinc

The zinc content of the composite flour sample was determined using the Atomic Absorption Spectrophotometric method as described by AOAC (2016). A mass of 3 g of each composite flour sample was weighed into a pre-heated crucible and placed in a furnace for 8 h to burn into ash. The ash sample was then digested by adding 10% HNO_3 and boiled on a hot plate for 15 min. The solution was allowed to cool and filtered into a 50 mL volumetric flask. It was then topped up to the 50 mL mark with 0.1N HNO_3. The absorbance was then measured using the atomic absorption spectrophotometer (BUCK Scientific, Buck 2010 VGP, USA) at a wavelength setting of 213.9 nm. The spectrophotometer was set with a blank solution containing the 0.1N HNO_3 used. In the same way, standard zinc solutions at varying concentrations were -prepared and the absorbances measured. A calibration curve of absorbance versus concentration was plotted. The corresponding concentration for the absorbance of the sample was read from the calibration curve and converted to mg/100g. Zinc content was then calculated using equation 31.

Calculation:

$$Zinc\ Content\ (mg/100g) = \frac{Concentration\ of\ Zn\ (\mu g/mL) \times 50\ mL}{Weight\ of\ sample\ (g) \times volume\ of\ aliquot\ taken\ (mL)}$$

…….. (31)

Where:

50 mL – is the volume of ash solution.

3.8.2.3 Determination of Vitamin C

Vitamin C content in each composite flour sample was determined using 2,6-dichlorophenolindophenol method (AOAC, 2016). An amount of 10

g of the composite flour sample was weighed and 5 mL of 20% meta-phosphatic acid was added. A volume of 2 mL acetone was then added and the dye solution, 2,6-dichlorophenolindophenol was titrated against the test sample to a pink red end point (for at least 15 s). The concentration of vitamin C was calculated using equation 32 and expressed as mg/100g.

Calculation:

$$Vitamin\ C\ content\ (\frac{mg}{100g}) = \frac{Titre\ of\ sample\ (mL)\ \times\ Mass\ of\ pure\ vitamin\ C\ (mg) \times\ 100}{Titre\ of\ pure\ vitamin\ C\ (mL)\ \times\ Weight\ of\ sample\ (g)}$$

…...…….. (32)

3.8.2.4 Determination of Vitamin A

The vitamin A content in the composite flour was determined using the spectrophotometric method according to ISO BS EN 12823:1-2014. An amount of 5 g of the sample was weighed into a flat bottom flask and 300 mg of ascorbic acid was added. An aliquot of 15 mL of KOH (60%) was added followed by the addition of 50 mL ethanol. The flat bottom flask was sealed with a stopper and shaken vigorously. The reaction mixture was heated to boiling point under reflux in a water bath to 80-90 °C for 30 min. The solution was then allowed to saponify. The saponified solution was transferred quantitatively into a separating funnel. A volume of 50 mL ethanol to be added to the saponified solution in the separating funnel was used to rinsing the flask before it was transferred into the separating funnel. A volume of 120 mL of distilled water was then added and 50 mL petroleum ether was also added to the solution in the separating funnel and shaken from time to time to allow for separation. The tap of the separating funnel was opened to allow the

aqueous phase to drain out. Another 50 mL petroleum ether was added to the extraction solution in the separating funnel and shaken from time to time to allow for separation. Again, the tap of the separating funnel was opened to allow the aqueous phase of the separation to drain out. This was repeated for the third time to obtain a perfect extraction solution free from any other foreign material. The extraction solution was washed with distilled water and the washed phase was allowed to drain after separation. The extraction solution containing the vitamin A content was then filtered through a phase separation filter paper using anhydrous Na_2SO_4 to remove any suspended water droplets. The volume of the extract was measured and recorded after which the solution was evaporated to dryness. The dried extract was then reconstituted with 10 mL ethanol and the absorbance of the solution was measured at 325 nm using the spectrophotometer. The mass concentration, ρ of all-trans retinol in µg/mL were calculated using equations 33-37, respectively.

Calculation:

$$\rho\ (\mu g/ml) = \frac{Asorbance \times 10^4}{1830} \quad \text{.....(33)}$$

Where:

Absorbance – is the absorption maximum at 325 to 326 nm

1830 E_1^1 $cm^{\%}$ is value for retinol in ethanol and 10^4 is a constant

$$\rho\ (mg/mL) = \frac{Absorbance \times 10^4 \times 0.001}{1830} \quad \text{..... (34)}$$

$$\rho\ (mg/100mL) = \frac{Absorbance \times 10^4 \times 0.001}{1830 \times 100} \quad \text{.....(35)}$$

$$Vitamin\ A\ (mg/100g) = \frac{\rho\ (mg) \times 150\ mL \times 10\ mL \times 100}{100\ mL \times sample\ weight\ (g) \times V(mL)}$$

…..……..……(36)

Where:

150 mL – is the total volume of petroleum ether used

10 mL – is the ethanol used for reconstitution

V – is the total volume of petroleum ether evaporated after extraction (mL)

1 µg/100g of retinol (vitamin A) = 6 µg/100g β-Carotene ..... (37)

3.8.3 Degradation of beta-carotene in shelf-life analysis

The most preferred composite 'fufu' flour blend (95/5) after the sensory evaluation was packaged in two different packaging materials and stored on the shelve in food processing laboratory at an ambient temperature of 28 °C for a period of 6 months. The packaging materials used were the plain polypropylene bags and brown laminated kraft paper pouches with a window for product display as shown in Figure 3.19. An amount of 10 g of the 95/5 composite 'fufu' flour blend was put into six pieces of each of the packaging materials, sealed, well labelled and stored on the shelve from January to June. At the end of each month, the samples in each of the packaging materials for that particular month were analyzed for the beta-carotene content. The second most preferred composite 'fufu' flour blend sample (90/10) from the sensory evaluation analysis was also analyzed using the same protocol to compare the trend of results obtained for the 95/5 composite flour sample.

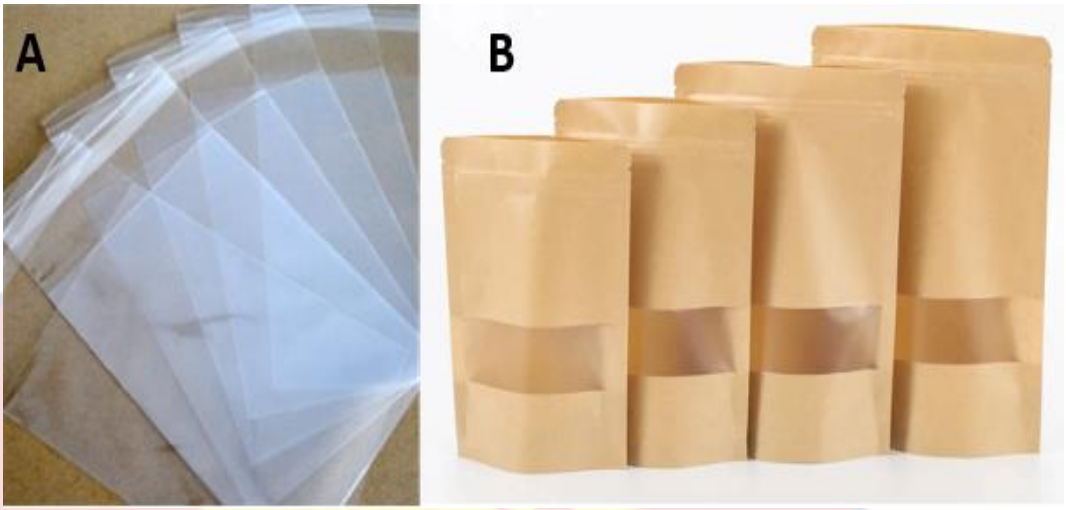


Figure 3.192: Plain polypropylene bags (A) and Brown laminated kraft paper pouches (B)

3.8.4 Physical and functional properties

3.8.4.1 Determination of bulk density

The bulk density was calculated using a modified version of the approach described by Bamidele *et al*. (2015). Five grammes of the composite flour sample were weighed out and transferred to a 10-milliliter graduated cylinder. The sample was levelled by tapping the measuring cylinder for one minute on the bench. After tapping, the volume of the packed sample was measured. After that, we recorded the weight. Equation 38 was used to get the bulk density of the sample under test in units of g/mL.

Calculation:

$$Bulk\ density\ (\frac{g}{mL}) = \frac{mass\ of\ sample\ (g)}{Volume\ of\ sample\ (mL)} \quad \text{.....} \quad (38)$$

3.8.4.2 Determination of water absorption capacity (WAC)

The water-absorbing capacity was calculated using a modified version of the approach given by Bamidele *et al*. (2015). A combination was made by adding exactly 1.0 g of the composite flour to 10 mL of distilled water in a

centrifuge tube and vortexed for 1-2 minutes. The sample was then centrifuged at 3000 rpm (with a centrifugal force of 5.623×10^{-3} N) for 30 min. The supernatant volume was recorded and the water absorbed was computed in percentage of the test sample. Water absorption capacity was calculated using equation 39.

Calculation:

$$WAC\ (\%) = \frac{Volume\ of\ water\ absorbed\ (mL) \times 100}{mass\ of\ sample\ used\ (g)} \quad \text{..... (39)}$$

3.8.4.3 Determination of swelling index

Each composite flour sample's swelling index was calculated using a modified version of the procedure outlined by Awuchi *et al*. (2019). The first sample volume (V1) was measured by pouring the composite flour sample into a 100 mL measuring cylinder till the 10 mL mark and then gently levelling it off. After filling the measuring cylinder with distilled water, it was gently spun to ensure full blending. Afterwards, 50 mL of more water was added, and the mixture was let to sit for an additional hour. The new volume of the sample was then recorded (V_2). The swelling index of each flour sample was calculated using equation 40.

Calculation:

$$Swelling\ index = \frac{V_2}{V_1} \quad \text{..... (40)}$$

3.8.4.4 Determination of pasting properties

The pasting characteristics of the composite flour blends were determined using the Brabender Visco-Amylograph as described by Tortoe *et al*. (2017). The pasting characteristics of the composite flour formulations were determined on an 8% slurry of flour using the Brabender

Viscoamylogragh (Viskograph-E, Brabender Instrument Inc., Duiburg, Germany) equipped with a 1,000 cmg sensitivity cartridge. The suspension was heated from 50 – 95 °C at a rate of 1.5 °C/min within a holding time of 15 min and cooled to 50 °C at a rate of 1.5 °C/min within a holding period of 15 min. The viscosity profile indices recorded included the pasting temperature, peak viscosity, trough viscosity, final viscosity, breakdown viscosity, setback viscosity and pasting time.

3.8.4.5 Determination of colour

Colour analysis of the composite flour blends and the cooked 'fufu' were determined in accordance with the CIE L*a*b* colour space system based on the tristimulus value using a color measuring instrument (Chroma Meter CR-410, Konica Minolta Optics Inc., Japan). The colour was determined as described in AOAC (2016). The hue angle, chroma, the whiteness index and the colour difference were all deduced from L*a*b* and calculated using equations 41-45, respectively.

Calculation:

$$Hue\ angle\ (\alpha) = tan^{-1}\left(\frac{b}{a}\right) \quad \text{(41)}$$

$$\boldsymbol{C}hroma\ (C) = \sqrt{a^2 + b^2} \quad \text{(42)}$$

$$Whiteness\ index\ (WI) = \sqrt{(100 - L)^2 + a^2 + b^2} \quad \text{(43)}$$

$$Colour\ difference\ \Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad \text{(44)}$$

$$\Delta E = \sqrt{(L^* - L_o)^2 + (a^* - a_0)^2 + (b^* - b_o)^2} \quad \text{(45)}$$

Where:

ΔE – Delta E (colour difference)

L_o, a_o and b_o are the initial luminance, redness and yellowness of the unmixed flours, respectively, and L^*, a^* and b^* are the luminance, redness and yellowness of the composite flours, respectively.

3.8.4.6 Determination of starch content

The starch content was determined using the Ewer's method and expressed on dry weight basis (DW). The determination of starch content was in two phases; Total optical rotation (P) and optical rotation for substances soluble in ethanol (P*).

Total optical rotation: An amount of 2.5 g of the composite flour sample was weighed into a 100 mL volumetric flask and 25 mL 0.3094M HCl was added and shaken to obtain uniform distribution. Another 25 mL of the HCl was added and immersed in a boiling water bath. The solution was then shaken vigorously for 3 min and kept in the water bath for 15 min at boiling point. The sample was then removed and 30 mL distilled water was added and allowed to cool to 20 °C. A volume of 5 mL of Carez I was added and 5 mL of Carez II solution was also added, shaken and allowed to stand for 10 min. The volume was made up to the 100 mL mark with the HCl and filtered. The optical rotation was read using Polartronic N-100 at 589.44 nm.

Optical rotation for substances soluble in ethanol: An amount of 5 g of the test sample was weighed into a 100 mL volumetric flask and 40 mL of 40% ethanol was added and allowed to stand for 1 h at room temperature. The mixture was shaken vigorously and the volume made up to the 100 mL mark and filtered. A volume of 50 mL was pipetted into a 250 mL conical flask and 2.1 mL HCl (7.6M) was added and shaken vigorously. The mixture was then decanted into a 100 mL volumetric flask and reflux for 15 min. The mixture

was decanted again into a 100 mL volumetric flask and clarified using carez I and carez II. The optical rotation for substances soluble in 40% ethanol was measured using the Polartronic N-100 at 589.44 nm. The percentage of starch was calculated using equation 46.

Calculation:

$$Percentage\ of\ Starch\ (\%) = \frac{2000\ (P - P^*)}{[\propto]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (46)$$

Where:

P – Total rotation in degrees

P^* – Rotation in degrees given by substances in 40% ethanol

[α] – Specific rotation of pure starch (+184.60) in degrees

2000 – Sample dilution in percentage

3.8.5 Phytochemical composition

3.8.5.1 Total phenolic content

Total phenolic content was measured spectrophotometrically based on a modified method as described by Thaipong *et al*. (2006). A 5 g of the sample was dissolved in 100 mL of 80% ethanol. The ethanolic extract (200 µL) was mixed with 200 µL of 10% Folin-Ciocalteu reagent (FCR) and agitated using a vortex mixer (BPECO, Germany) for a few seconds. The mixture was left to stand for 3 min in the dark. Then, 200 µL of sodium carbonate (7.5 g/100 mL) solution was added to the mixture and topped up to 10 mL with distilled water. The absorbance was measured at 725 nm using a UV–VIS spectrophotometer (PRIM, Secomam, France) against a blank. Total phenolic content was expressed as mg Gallic acid equivalents (GAE) per mL extract in triplicate independent analyses.

3.8.5.2 Total anthocyanin content

Total anthocyanin content was determined using the method described by Connor *et al*. (2002) in which each sample was dissolved (5:95, w/v) in 1% HCl in methanol. The absorbance was measured using a spectrophotometer (PRIM, Secomam, France) at 530 nm against a methanolic blank. The values were expressed as mg cyanidin-3-glucoside (c3g) equivalents per 100 g fresh.

3.8.5.3 Estimation of total flavonoid content

Total flavonoid content was estimated by aluminium chloride colorimetric method as describe by Pekal and Pyrzynska (2014) with slight modification. An aliquot of $AlCl_3$ solution (0.5 mL, 2%, w/v) was added to 1 mL of the test solution (standard or sample) and subsequently 0.5 mL of water, HCl, CH_3COONa or CH_3COONH_4 (each at concentration of 1 M) was added. The concentration of standard solutions of flavonoid stock were 1 mg/mL. The mixture was vigorously shaken and after 30 min of incubation at room temperature, the absorbance was read at 540 nm. The amount of $AlCl_3$ solution substituted by the same amount of water in blank. Quercetin (concentration range of 100-1000 µg/mL) was chosen as standard and the absorbance was read at 540 nm.

3.8.6 Microbiological analyses

3.8.6.1 Homogenization and serial dilution

For all solid samples, 10 g were added to 90.0 mL sterile Salt Peptone Solution (SPS) containing 0.1 % peptone and 0.8 % NaCl, with pH adjusted to 7.2 and homogenized in a stomacher (Lad Blender, Model 4001, Seward Medical, England), for 30 s. From appropriate ten-fold dilutions, a volume of

1 mL aliquots of each dilution was directly inoculated into sterile Petri dish and the appropriate media added for enumeration of microorganisms.

3.8.6.2 Enumeration of yeast and mould

Yeasts and moulds were enumerated by the spread plate method on Dichloran Rose Bengal Chloramphenicol (DRBC) Agar (Oxoid CM0727), pH 5.6, containing Chloramphenicol supplement to prevent bacteria growth and incubated at 25 °C for 3-5 days in an upright position in accordance with ISO 21527-1:2008.

3.8.6.3 Enumeration of *Escherichia coli* (E. coli)

E. coli bacteria was enumerated by pour plate on Trypton Soy Agar (TSA) (Oxoid CM131), pH 7.3. A volume of 1mL of the serial dilution was inoculated into sterile Petri dishes. The inoculum and agar in the Petri plates were well combined by pouring molten TSA over them and swirling the dishes. The plates were pre-incubated at room temperature for 1 to 2 hours to set the mixture. The TSA was incubated at 37 °C for 24 hours for total coliforms and at 44 °C for 24 hours for E. coli, after which pH 7.4 Violet Red Bile Agar (Oxoid CM107) was applied on top and allowed to set at room temperature. Five colonies on the TSA/VRBA plates were identified as possibly being E. coli, and were then subcultured into EC Broth for gas production (Oxoid CM853), pH 6.9. After 24 hours of incubation at 44 degrees Celsius, a positive tube was subcultured into Trypton Water (Oxoid CM87), pH 7.5, and an Indole test was conducted following NMKL No. 125 (2005).

3.8.6.4 Determination of *Staphylococcus spp.*

Staphylococcus aureus was determined using the spread plate method on Baird Parker Agar (BP, CM 275 Oxoid Ltd, Hampshire, England) containing Egg Yolk Tellurite Emulsion (SR54). Colonies suspected of being coagulase-positive have their status validated using the NMKL Method No. 66 (2009) using rabbit coagulase plasma (C14389). Each dilution was added to the surface of the Baird Parker agar in a Petri dish at a volume of 0.1 mL. The inoculum was evenly distributed throughout the agar plate using sterile spreaders. After air drying at ambient temperature, the inoculum was incubated at 37 °C for 48 hours. Colonies were tested for authenticity using a blood agar base and a coagulase assay. Staphylococcus aureus is present if a colony hemolyzes on blood agar and coagulates in rabbit coagulase plasma.

3.8.6.5 Detection of *Salmonella spp*

Detection of *Salmonella* was according to the method NMKL No. 71, (1999). A 25 g of the sample was weighed into a sterile bag and 225 mL of Buffered Peptone Water (CM0509) was added and used as pre –enrichment broth and incubated at 37 °C for 21 h. A volume of 1 mL of the suspension was sub cultured into Rapaport Vaishali's Soya Peptone Broth (CM0866) broth and incubated at 37 °C for 24 h. After incubation, the suspension subsequently streaked on XLD Agar (CM0469 Oxoid Ltd, Hampshire, England) and incubated at 37 °C for 24 h. Suspected *Salmonella* species was confirmed by biochemical test on Triple Sugar Iron Agar (Vm381715 214, Merck KGaA Darmstadt, Germany) and serological test using *Salmonella* Polyvalent Agglutinating Sera (30858501ZD01, UK).

3.8.6.6 Determination of *Enterobacteriaceae*

A volume of 1 mL portions of suitable dilutions of the sample were transferred to sterile petri dishes and about 15 mL violet red-bile-glucose agar was added to each petri dish, allowed to melt and brought to 45 °C in water bath. The inoculums were carefully mixed with the medium by rotating the dishes and agar and was allowed to solidify. A thin layer of the same agar was poured on top of the solidified agar. After solidification of this layer, the inverted plates were incubated at 37.0 °C ± 1.0 °C for 22-26 h.

Plates with 15-150 colonies were selected and all pink to red colonies were counted. At least five representative colonies per plate were selected for biochemical confirmation. Selected colonies were sub-cultured on nutrient agar plates and incubated at 37 °C for 24 ± 3 h. One isolated colony was selected from each subculture for confirmation with oxidase reaction. A plastic loop was used to remove parts of well-isolated colony and streaked out on a filter paper wetted with oxidase reagent. The bacterium was considered as oxidase-negative if the colour of the bacterial material did not change to dark blue-violet within 10 s.

3.8.6.7 Determination of aflatoxin

The analysis was conducted to determine the types and quantity of aflatoxins (AFB_1, AFB_2, AFG_1, and AFG_2) in the cassava and OFSP flour samples.

Sample extraction for aflatoxin analysis: About 25 g each of the cassava and OFSP flour samples were used for the aflatoxin level analysis and the average value calculated. The 25 g of the test portion was weighed using Cobos electronic chemical balance into a 250 mL beaker. Each sample was mixed

thoroughly with 5 g of sodium chloride salt and poured into the Retsch knife mill. The test portion for HPLC analysis, was extracted using 200 mL of 100 % methanol and deionized water (80 mL/20 mL) solution and milled for 3-2 min at 3000 rev/min. The sample extract was filtered using Whatman No 4 (125 mm) filter paper. The filtrate was then collected into a clean 250 mL measuring cylinder for analysis by High Performance Liquid Chromatography (HPLC) method by JAOAC (1991).

Extract dilution: Filtered extracts of the samples were analyzed using the HPLC method (JAOAC, 1991). About 10 mL of the filtered extract was pipetted and transferred into clean 25 mL beakers. It was then diluted with 60 mL of Phosphate Buffered Saline (PBS) and thoroughly mixed with a glass stirrer.

Easi-Extract Immunoaffinity Chromatography: Easi-extract immunoaffinity columns (IACs) were used to clean up the samples. The column was conditioned using 10 mL of PBS. The filtered extract and PBS diluent were loaded into the Immunoaffinity column. The filtrate was passed through the column at a flow rate of approximately 1 drop (approx. 3 mL/min).

Clean-up: Approximately 15 mL of deionized water was used in washing the column. This was applied in little portions of approximately 5 mL at a maximum flow rate of 5 mL/min and dried by passing air through the immunoaffinity column by means of a syringe for 10 s.

Elution: Elution of aflatoxins involved a two-step procedure as follows:

- Aliquots of 0.5 mL methanol was applied on the column and allowed to pass through by gravity. The eluate was collected in a calibrated 5 mL volumetric flask.

- After 1 minute, a second portion of 0.75 mL methanol was applied to the column by passing air through. The eluate was collected in a calibrated 5 mL volumetric flask. The eluate was finally diluted by deionized water before analyzed by HPLC.

Mobile Phase: The HPLC mobile phase was prepared using Methonol/Acetonitrile/Deionized water a formulation ratio of 56:14:30 (V/V/V).

Column: The column used for Agilent 1260 infinity series HPLC system was Agilent column (Eclipse plus C18 150 x 4.60 mm, analytical column 5 µm) at a temperature of 35 °C and flow rate of 1 mL/min.

Derivatization: Aflatoxins B_2 and G_2 are naturally much more fluorescent than aflatoxin B_1 and G_1. Hence, aflatoxin B_1 and G_1 fluorescence were increased for HPLC fluorescence detection by derivatization.

Post Column Derivatization (Pyridine hydro bromide per bromide): About 500 mL of Pyridine hydro bromide per bromide (PBPB) solution was prepared using 20 mg of PBPB at a flow rate of 1 mL/min.

Detector: Fluorescence detector with a wavelength (λ) = 360 nm excitation filter and a wavelength greater than 420 nm cut-off emission filter, or equivalent fluorescence at 360 nm excitation and 440 nm emission was used for the aflatoxin detection. The recommended settings for adjustable detectors are Ex. = 360 nm and Em. = 435 nm for the detector.

The detection limit (LOD) and quantification limit (LOQ) were determined using the formula; LOQ = 2*LOD, where LOD = Standard concentration at which no peak was observed (3*baseline noise/peak height).

3.9 Preparation of cooked 'fufu'

A measured amount of water (500mL) was boiled at 100 °C in a cooking utensil. An amount of 200 g composite flour was added in bits to the boiled water and stirred well to avoid formation of lumps. As the 'fufu' became thicker, measured quantity of water was added till the 'fufu' was finally cooked. The 'fufu' was then rounded in 'fufu' bowl. The total amount of water used for cooking and the time for cooking the 'fufu' were recorded to provide information on the cooking method.

3.10 Sensory evaluation

The composite flour blends were cooked into 'fufu' and subjected to sensory evaluation. Fifty-three untrained panelists who are not allergic to 'fufu' were made to evaluate the 'fufu' paste prepared from the composite flour blends based on the sensory attributes of appearance, colour, aroma, texture, taste, aftertaste and overall acceptability. According to Iwe (2002), we employed a nine-point hedonic scale for the evaluation, with nine indicating an exceptionally positive reaction and one representing an extremely negative reaction (Appendix B). Each panellist received their own unique set of samples, categorised according to Table 3.2. The finished "fufu" was portioned out into individual "fufu" bowls of consistent size. Before analysing each new sample in a specialised sensory facility at CSIR-FRI, panellists were given water to rinse their mouths. The control group ate cooked 'fufu' made with just cassava flour.

3.11 Statistical analyses for physico-nutritional, functional, microbial and sensory analysis

Minitab Statistical Software (Version 19) was used to conduct statistical analysis on data collected during the proximal, physical/functional characteristics, microbiological, and sensory assessment. Tukey's pairwise comparison tests at 95% confidence interval ($p < 0.05$) were used to evaluate significant differences between means after Analysis of Variance (ANOVA) was performed. The linear connection between the physical/functional features and the pasting characteristics of the composite flour blends was also analysed to determine its strength and direction using the Minitab software's correlation analysis. Microsoft Office Excel 2019 was used to create all tables. Means and standard deviations (SDs) were used to summarise the collected data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results obtained from analyses conducted on hot-air drying characteristics of cassava and OFSP samples, the moisture sorption behaviour of the composite flour blends, the physico-nutritional and functional composition of the composite 'fufu' flour blends, microbial analysis on composite flour blends, degradation of beta-carotene in shelf-life analysis, sensory evaluation of 'fufu' prepared from the composite flour blends and the discussion of the findings. Results of ANOVA analysis for the physico-nutritional and functional parameters is shown in Appendix D.

4.1 Drying kinetics of cassava and OFSP samples

4.1.1 Drying process of cassava and OFSP

Drying is the physical removal of moisture during food processing for the extension of product storage life. The application of hot-air drying as an artificial means of drying has a potential advantage of minimum consumption of energy, cost effective and better controlled system as compared to other drying techniques. The drying behaviour of the cassava and OFSP samples is shown in Figure 4.20. Both samples were dried to a specific dry matter at different time periods. It was observed from the drying curves that moisture content significantly decreased continuously with time. The initial average moisture content of the pulverized cassava pulp was 0.07 kg water/kg dry matter and was dried to 8.9 x 10^{-5} kg water/kg dry matter in 6 h at 70 °C at a drying rate of 0.012 kg water/h while that of the OFSP chips was also dried from 0.6 kg water/kg dry matter to 9.0 x 10^{-5} kg water/kg dry matter in 9 h at

60 ℃ at a drying rate of 0.067 kg water/h. The 60 °C used for drying the OFSP chips in this study was also used by Laryea *et al*. (2018), Sebben *et al*. (2017), Risso (2014) and Clifford *et al*. (2014). They explained that, this temperature (60 ℃) was suitable for drying OFSP samples because the drying process is accelerated and prevent burning of samples in order to maintain nutrients and other bioactive compounds. However, Abano (2020) and Moloto *et al*. (2021) also dried the OFSP samples at 70 ℃ using the convective hot air dryer. Wilaipon (2013) as well as Famurewa and Emuekele (2015) also dried cassava sample at 70 ℃.

The moisture curves showed a falling rate period which is typical of many agricultural food commodities as reported by Velic *et al*. (2007) and Ajala *et al*. (2012). Both samples exhibited a single falling rate during drying. The results revealed that there was a higher removal of moisture from the samples within the initial stage of the falling rate period. But according to Ajala *et al*. (2012), this is so because of high moisture percentage in the samples during drying at the initial stage. Drying temperature has a significant effect on agricultural produce. Aghbashlo *et al*. (2009) reported that higher heat transfer to food samples with higher mass transfer of moisture from the samples affects the quality of the food product as it compromises the nutritional composition of the food. According to Mewa *et al*. (2018), the process of drying is enhanced by the temperature used in drying as it shortens the drying time. Decrease in drying time with an increased temperature is credited to high thermal energy which quickens the removal of water molecules within the food sample to be dried. Mwithiga and Olwal (2005) also documented that increase in temperature resulted in more water vapour

pressure deficit which is one of the driving forces for external moisture removal. Afolabi *et al*. (2016) stated that sample thickness is considered as an essential parameter for drying agricultural food commodities especially for root and tubers as it directly influences the distance required for moisture diffusion but also excessive reduction in the sample size or thickness could also cause surface hardening that prevents moisture diffusion. The rate of drying could also be associated with the level of dewatering with respect to time and method used. Well dewatered food sample enhances the rate of drying as the time for drying is reduced. When the method and device for dewatering is very efficient, more food samples could be dried within the shortest possible time (Oladele *et al*., 2011).

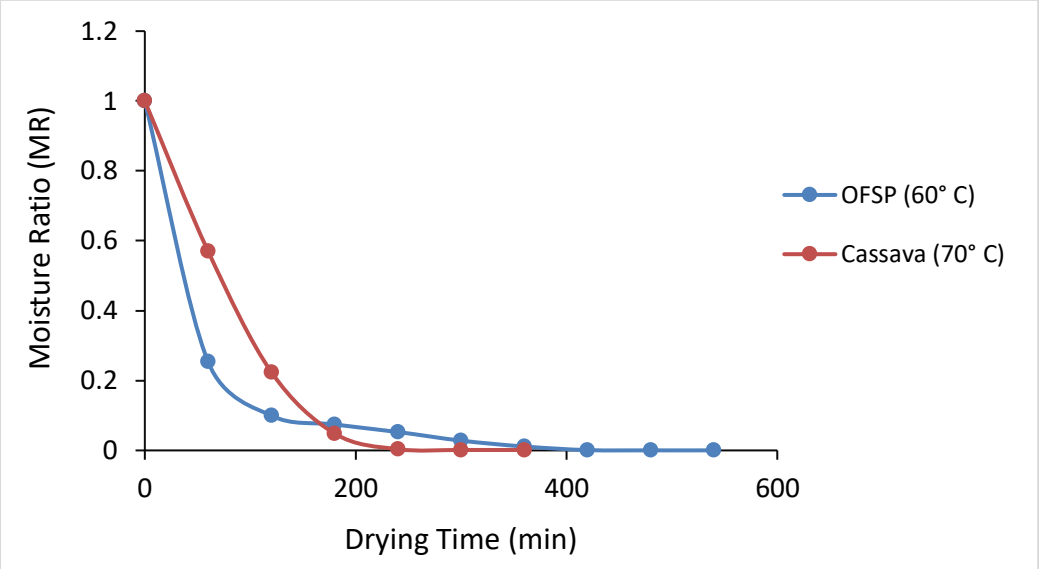


Figure 4.20: Moisture ratio against drying time for OFSP for cassava samples at 60 ℃ and 70 ℃ respectively

4.1.2 Effective moisture diffusivity

In recent times, a lot of scientific research articles are reporting on drying modelling and moisture diffusivity of varying agricultural food commodities as influenced by drying temperature and food sample thickness

(Mewa *et al*., 2018). The relationship between moisture ratio and drying time for the cassava and OFSP samples dried at 70 °C and 60 °C are shown in Figure 4.20. Figure 4.21 and 4.22 showed the influence of temperature on the linear relationship between logarithmic moisture ratio against the drying time of both cassava and OFSP samples. The plots of In (MR) against drying time followed a straight line regression equation with negative slopes.

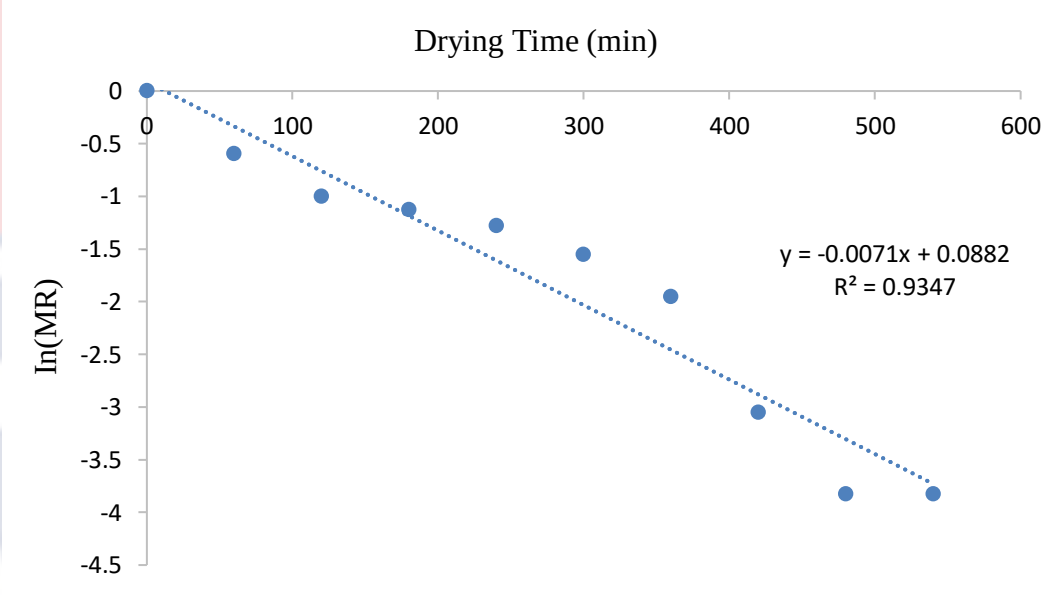


Figure 4.21: Plot of In (MR) against drying time (min) for OFSP sample

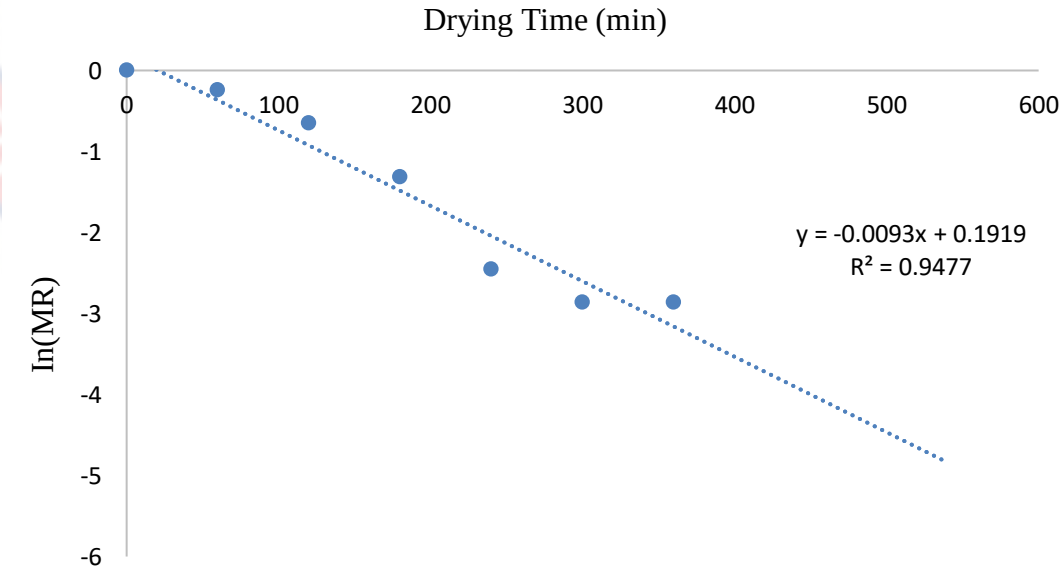


Figure 4.22: Plot of In (MR) against drying time (min) for cassava sample

From the slopes obtained in Figure 4.21 and 4.22, the effective diffusivity for cassava was found to be 2.36 x 10^{-8} m^2/s while that for OFSP sample was 4.60 x 10^{-8} m^2/s respectively. The value recorded for cassava sample in this study was greater than that reported by Ajala *et al*. (2012) which ranged between 2.43 x 10^{-11} m^2/s to 4.52 x 10^{-11} m^2/s but less than that reported by Tunde-Akintunde and Afon (2010) which also ranged from 7.31 x 10^{-7} m^2/s to 8.06 x 10^{-7} m^2/s. Again, the value recorded for OFSP in this study was greater than that reported by Abano (2020) which ranged between 1.5 x 10^{-9} m^2/s to 7.9 x 10^{-10} m^2/s. Ajala *et al*. (2012) reported that the increase or decrease in moisture diffusivity values could be due to the different cultivars used or as a result of the effect of pretreatment induced or applied to samples. According Mewa *et al*. (2018) and Hii *et al*. (2009), the values recorded in this study were within the range of moisture diffusivity for drying agricultural food commodities (10^{-7} to 10^{-12} m^2/s). Touil *et al*. (2014) reported that the determination of effective moisture diffusivity was important in the optimization and stimulation of the drying process since water vapour transfer rate in food commodities is measured by diffusion of moisture toward the outer surface of the food commodities.

4.1.3 Fitting of experimental data into drying models

According to Fudholi *et al*. (2012) as cited in Agyei-Poku (2018), it is very important to control the operating parameters in the process of drying in order to enable proper prediction of the performance of the drying process. And this can be achieved through mathematical modeling of the drying process. It is therefore important to adopt precise models from literature to stimulate the drying curves under varying conditions. Even though predicting

and describing the drying kinetics of a given food commodity continues to be a weakness in the modelling of drying processes, experimentally, drying kinetics has always been determined by measuring the moisture ratio through determination of the weight of a dried food commodity as a function of drying time. Results obtained from fitting the experimental data to the drying models are listed in Table 4.16 and 4.17 for cassava and OFSP respectively. The values of the estimated model constants and the statistical values of coefficient of determination (R^2), root mean square error (RMSE), and the reduced chi-square (χ^2) characterizing each fitting are also listed. Results obtained showed that the correlation coefficients ranged between 1.000 to 0.980.

All the four drying models used in this study showed a good fit as they exhibited coefficient of determination (R^2) values greater than 0.980 under specified drying conditions. The correlation coefficient values recorded for all the drying models considered in this study were very high and close to 1.0. The results obtained indicated that the four drying models used could satisfactorily describe the drying behaviour of the cassava pulp and OFSP chips samples. For the cassava samples, the Page model recorded the highest R^2 value of 0.996 with RMSE value of 0.0239 and chi-square of 0.0008 while the Newton model recorded the least R^2 value of 0.980 with a RMSE value of 0.0548 and chi-square of 0.003 (Table 4.16 and Table 4.17).

Table 4.16: Statistical results for the various drying models for cassava sample

Cassava				
Model Name	**Constants**	**R^2**	**RMSE**	**χ^2**
Page	k= 0.5 n= 0.1	0.996	0.0239	0.0008
Newton	k = 0.05	0.98	0.0548	0.003
Henderson & Pabis	a= 0.03 k = 0.02	0.981	0.0493	0.0034
Logarithmic	a= 0.5 k= 0.5 c= 0.4	0.987	0.0414	0.003

Table 4.17: Statistical results for the various drying models for OFSP sample

OFSP				
Model Name	**Constants**	**R^2**	**RMSE**	**χ^2**
Page	k= 0.1 n=0.5	0.998	0.0141	0.00025
Newton	k = 0.1	0.986	0.0346	0.00133
Henderson & Pabis	a= 0.5 k = 0.1	0.986	0.0346	0.0015
Logarithmic	a= 0.5 k= 0.5 c= 0.4	0.988	0.1	0.0143

On the other hand, the results observed from the drying characteristics of OFSP samples also showed that the Page model recorded the highest R^2 value of 0.998 with RMSE value of 0.0141 and chi-square of 0.00025. But here, Newton model and Henderson & Pabis model recorded similar values for R^2 (0.986) and RMSE (0.0346) but differed slightly in the values for chi-square which is 0.00133 for Newton model and 0.00150 for Henderson and Pabis model. Considering the four drying models applied in this study, the Page model obtained the highest R^2 values with the lowest RMSE and χ^2

values for both the cassava and the OFSP samples. This indicates how reliable and suitable the Page model best described the drying characteristics of cassava and OFSP samples and was therefore selected as the most appropriate model for simulating the drying characteristics of both the cassava and OFSP food samples. Abano (2020) also reported that the Page model best described the microwave-assisted drying of OFSP samples. According to Wilaipon (2013), the drying kinetics of cassava samples dried in a microwave oven were best represented by the Page model. According to Ajala et al. (2012), the drying behaviour of the pulverised cassava pulp was best characterised by the Logarithmic model. The drying behaviour of cassava chips for two types investigated was best characterised by the Modified Henderson and Pabis, as recorded by Famurewa and Emuekele (2015). Recently, similar research was conducted by Vidal et al. (2021), who used four distinct drying models and drying temperatures (40 °C, 50 °C, and 60 °C) to investigate the drying features on the functional qualities of purple-fleshed sweet potato. Based on the findings, the Page model was deemed to be the most suitable model for reproducing the drying properties of the purple-fleshed sweet potato.

4.2 Moisture sorption behaviour for composite flour blends

4.2.1 Fitting of experimental data into moisture sorption isotherm models

The equilibrium moisture content against the water activity for the composite flour blends at 25-28 ℃ is shown in Figure 4.23. The results obtained showed that the equilibrium moisture content increased with increasing water activity for all the varying composite blends. The isotherm showed a sigmoidal shape which is typical with foodstuffs as reported by Koua *et al*. (2014). The sigmoidal plot was typical of type II isotherms for

starchy foods like potato as reported by McMinn and Magee (2003), rice flour and oat flour reported by Brett *et al*. (2009) as well as yellow dent corn reported by Samapundo *et al*. (2007). According to Al-Muhtaseb *et al*. (2004b), the dependence of temperature with respect to equilibrium moisture content has an essential practical effect on both microbiological and chemical reactions associated with food deterioration. Koua *et al*. (2014) reported that increase in water activity at a given temperature subsequently increased the equilibrium moisture content. It is therefore important to maintain an appropriate temperature to lower water activity in order to minimize the effect of deterioration of the food product.

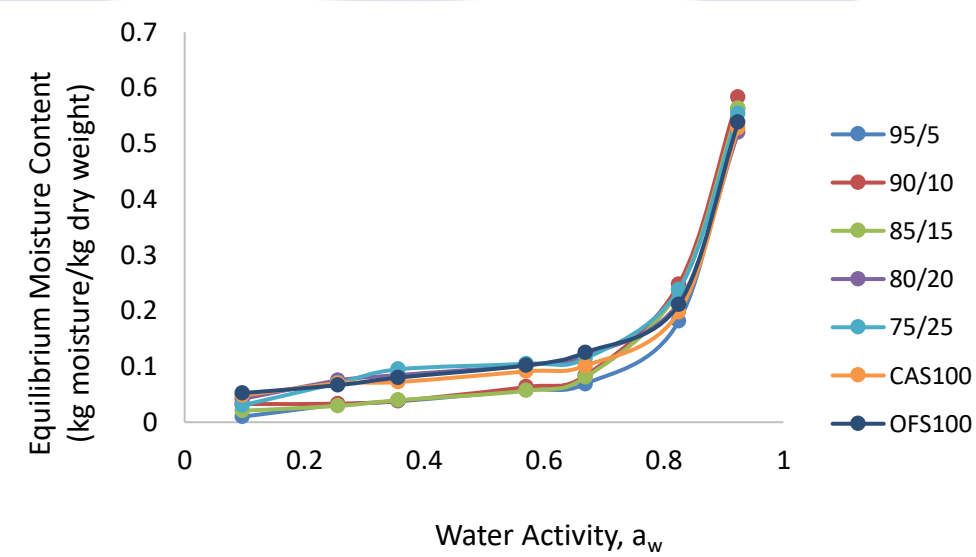


Figure 4.23: Equilibrium moisture content against water activity for the composite flour blends at ambient storage temperature

Results obtained from fitting the experimental data to the sorption isotherm models using the Origin Pro software (version 18.0) presented in Tables 4.18 and 4.19 showed that the correlation coefficients of all the models ranged between 0.807 to 1.000. This implied that all the four moisture sorption models applied in this study could also satisfactorily describe the moisture sorption behaviours of the various composite flour blends. The correlation

coefficient values recorded for all the moisture sorption models for the varying composite flour blends were highly significant. Results observed from the moisture sorption characteristics of the composite flour blends showed that the GAB model recorded the highest R^2 values for almost all the flour blends within the range of 0.98019 to 0.99712 whilst the RMSE values range from 0.11547 to 0.13851 and the Chi-square values range from 0.000111 to 0.000641.

Table 4.18: Parameters and statistical results for the GAB and BET moisture sorption models

	GAB					BET				
Sample	Model Constants	Value	R^2	RMSE	χ^2	Model Constants	Value	R^2	RMSE	χ^2
CAS100	m	2.45324	0.97728	0.11547	0.000657	m	2.96271	0.94581	0.1706	0.00157
	c	0.06241				c	0.03505			
	k	1.05569								
95/5	m	0.16988	0.99712	0.11987	0.000111	m	9.22784	0.98943	0.179	0.000408
	c	0.3806				c	0.00971			
	k	1.0332								
90/10	m	0.0574	0.99045	0.13851	0.000397	m	6.89625	0.99236	0.2078	0.000318
	c	0.94879				c	0.01514			
	k	0.99352								
85/15	m	0.04173	0.99334	0.12837	0.000261	m	8.16657	0.99465	0.1926	0.00021
	c	1.11194				c	0.01212			
	k	0.99172								
80/20	m	3.39598	0.98049	0.11797	0.000534	m	1.48848	0.93878	0.1738	0.00168
	c	0.05206				c	0.08575			
	k	1.05446								
75/25	m	1.93097	0.98019	0.1331	0.000641	m	1.66492	0.95326	0.1972	0.00151
	c	0.08856				c	0.08004			
	k	1.04254								
OFS100	m	3.57777	0.98304	0.12424	0.0005	m	1.81368	0.94217	0.1831	0.00171
	c	0.0493				c	0.06771			
	k	1.05716								

Table 4.19: Parameters and statistical results for the Smith and Oswin moisture sorption models

	Smith					Oswin				
Sample	Model Constants	Value	R^2	RMSE	χ^2	Model Constants	Value	R^2	RMSE	χ^2
CAS100	a	-0.02068	0.80862	0.16068	0.00553	a	0.06581	0.95162	0.17102	0.0014
	b	-0.40525				b	0.82959			
95/5	a	-0.07099	0.80747	0.16148	0.00742	a	0.0313	0.99456	0.17951	0.00021
	b	-0.46767				b	1.14717			
90/10	a	-0.06474	0.8537	0.19334	0.00608	a	0.05463	0.99221	0.20774	0.000324
	b	-0.49675				b	0.94849			
85/15	a	-0.06711	0.86067	0.17941	0.00547	a	0.05106	0.9945	0.19254	0.000216
	b	-0.48408				b	0.96078			
80/20	a	-0.01228	0.85127	0.16785	0.00407	a	0.08821	0.95178	0.17472	0.00132
	b	-0.4025				b	0.70858			
75/25	a	-0.02194	0.86162	0.18975	0.00447	a	0.08956	0.96275	0.19793	0.0012
	b	-0.43968				b	0.72901			
OFS100	a	-0.01551	0.83952	0.17553	0.00473	a	0.08308	0.95304	0.1839	0.00139
	b	-0.41553				b	0.74557			

Results obtained also indicated that the Smith model recorded the least R^2 values for all the flour blends ranging between 0.80747 to 0.86162 with RMSE ranging between 0.16068 to 0.19334 and the reduced chi-square ranging between 0.00407 to 0.00742. Considering all the four models used, results showed that the GAB model presented the highest correlation coefficients and the lowest RMSE and reduced chi-square values. This was followed by the Oswin model, BET model and the Smith model, respectively. This means that the GAB model best described the sorption isotherm of the various composite flour blends. Koua *et al*. (2014) also reported that the GAB model best described the sorption isotherm of cassava samples.

4.3 Physico-nutritional and functional characterization of composite flour blends

4.3.1 Proximate composition of composite 'fufu' flour blend

Proximate analysis in food samples can be described as a method that determines the nutritional facts of the moisture content, ash content, crude protein, crude fat, crude fibre as well as carbohydrate and energy content in the food product and its mostly shown on the food product labels (Kassegn, 2018). Both the manufacturer and the consumer have a vested interest in a product's proximate analysis to ensure that it complies with all relevant laws and regulations pertaining to food hygiene and safety before it is shipped to the end user or consumer. Proximate analysis provides a reasonable estimate of food content and provides a straightforward, low-cost method of confirming the accuracy of nutrition facts panels (Grabowski *et al*., 2008). In Table 4.20, we see the proximate composition (moisture, ash, protein, fat, fibre,

carbohydrates, and energy) of both pure cassava and OFSP flours and their composite flour blends, as given on a dry weight basis.

The range of 7.68–10.45 percent moisture found in this research is suitable for long-term preservation of flour. Moisture levels and storage conditions affect the quality of flour (van Hal, 2000). Reduced moisture content improves the flour's quality and functionality by preventing caking (Tortoe *et al*., 2017). The shelf life of flours is extended because moisture levels below 14% kill off microorganisms (Teye *et al*., 2018). The moisture content of the purely cassava flour (CAS100) was 10.45%, which was substantially ($p < 0.05$) greater than the moisture content of the purely sweet potato flour (OFS100), which was 7.68%. This moisture content fell proportionally as the amount of replacement of cassava flour with OFSP flour rose. Therefore, the inclusion of OFSP improves the shelf life of flours by reducing their moisture content. Teye *et al*. (2018) state that most flours' capacity to be stored is reliant on their moisture content. The results of moisture content analysis as shown in Table 4.20 indicates that all the composite flour blends could be stored for a longer period due to the low moisture content recorded. The moisture contents for the composite flour blends recorded in this study were below the 14.5% level recommended by the Approved Methods of American Association of Cereal Chemists, AACC (2000) for flour storage. According AACC (2000), moisture content of flour that is above the 14.5% encourages microbial growth that result in flour deterioration. Shahzardi *et al*. (2005) as cited in Ashun (2018), reported that food flour products containing less than 13% moisture content are very stable for storage and has lower rate of deterioration. According to Dery (2012), the

Apomuden and *Capevars bankye*, the two local varieties of root and tuber used in this study are known to have high moisture content, hence, processing and drying them to obtain these low moisture content values indicate that the drying technique and temperatures used for the drying process were efficient. OFS100 flour recorded a higher compositional content of ash (2.64%), protein (4.76%), fat (0.40%), and fibre (3.55%) as compared to the compositional content in CAS100 flour (ash-1.14%, protein-2.21%, fat-0.20% and fibre-1.42%) on dry weight basis. These composition levels in sweet potato were similar to that reported by Fana Haile and Fisseha (2015), Tortoe *et al*. (2017), and Obomeghei *et al*. (2020). Thus, increase in the compositional content of the composite flour blends indicated that the addition of OFSP flour also improved the nutritional composition of the composite flour blending ratios.

The ash content ranged between 1.14% and 2.64%. The results showed a significant increase ($p < 0.05$) in ash content as the incorporation of OFSP levels increased in the blending ratios. The ash content of a composite flour can be described as the burning away of the organic matter, leaving the inorganic minerals (iron, zinc, phosphorus, calcium, etc.), which are essential components in food quality and nutrition (Nascimento *et al*., 2014). Shovon *et al*. (2013) also reported that determination of the ash content was an important measure of the mineral elements contained in the food product. Ash content recorded for OFS100 in this study was comparable to the 2.80% reported by Obomeghei *et al*. (2020) and that for CAS100 was also comparable to the 1.18% reported by Bamidele *et al*. (2015). However, the ash content of OFSP flour recorded in this study was higher than the 1.3% and 0.7% documented for the two different varieties of OFSP tested by Sanoussi *et al*. (2013). The

importance of ash in food analysis is primarily for proximate composition analysis in nutritional evaluation. Marshall (2010) explained that ash analysis is the first step in preparing food samples for analyzing specific minerals in food products.

The protein content varied from 2.21% to 4.76% as the OFSP flour increased. OFS100 had a higher protein content of 4.76% as compared to 2.21% in CAS100. According to Oloo *et al*. (2014), there is a substantial amount of protein content in sweet potatoes as compared to other root tubers like yam and cassava. The protein content of the composite flour blends increased significantly ($p < 0.05$) as the OFSP incorporation levels increased. Laryea *et al*. (2018) reported a higher protein content of 5.17% in OFSP flour. However, results obtained in this study for crude protein content in OFSP flour was very similar to that reported by Rodrigues *et al*. (2016) which was 4.8%. According to Nielsen (2017), protein in food is very critical for nutrition and food quality assurance. Protein is regarded as one of the major macronutrients required in every nutritious diet for consumption as it is needed for rapid growth and development as well as repair of worn-out body tissues of infants and young children (Nandutu and Howell, 2009). The World Bank (2005) report stated that hidden hunger can lead to stunted growth and death. Hence, in line with this statement, the formulated composite food product developed in this study could be utilized as a source of providing essential nutrients for young children and reproductive women to address the issues of hidden hunger which is a major problem in Ghana and Africa at large.

Table 4.20: Results of proximate composition on dry basis

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	CHO (%)	Energy (Kcal/100g)
CAS100	10.45 ± 0.14^{a}	1.14 ± 0.11^{d}	2.21 ± 0.11^{e}	0.20 ± 0.01^{e}	1.42 ± 0.09^{e}	86.00 ± 0.12^{a}	354.63 ± 0.13^{d}
95/5	10.27 ± 0.05^{a}	1.23 ± 0.02^{d}	2.43 ± 0.04^{d}	0.22 ± 0.02^{de}	2.33 ± 0.05^{d}	85.85 ± 0.01^{ab}	355.12 ± 0.16^{cd}
90/10	9.99 ± 0.08^{b}	1.48 ± 0.07^{c}	2.56 ± 0.02^{cd}	0.25 ± 0.02^{cd}	2.43 ± 0.04^{cd}	85.72 ± 0.07^{bc}	355.37 ± 0.15^{cd}
85/15	9.83 ± 0.03^{b}	1.74 ± 0.06^{b}	2.65 ± 0.01^{c}	0.27 ± 0.02^{bc}	2.53 ± 0.03^{cd}	85.51 ± 0.07^{c}	355.56 ± 0.32^{cd}
80/20	9.62 ± 0.05^{c}	1.83 ± 0.02^{b}	2.74 ± 0.05^{c}	0.30 ± 0.02^{bc}	2.60 ± 0.03^{bc}	85.50 ± 0.05^{c}	355.68 ± 0.20^{bc}
75/25	9.44 ± 0.02^{c}	1.86 ± 0.03^{b}	3.17 ± 0.05^{b}	0.31 ± 0.01^{b}	2.82 ± 0.12^{b}	85.22 ± 0.04^{d}	356.34 ± 0.24^{b}
OFS100	7.68 ± 0.03^{c}	2.64 ± 0.18^{a}	4.76 ± 0.12^{a}	0.40 ± 0.02^{a}	3.55^{a} ± 0.14^{a}	84.52 ± 0.03^{e}	360.72 ± 0.80^{a}

** Means in the same column with different letters are significantly different ($p < 0.05$).*
**CHO – Carbohydrate.*

A study conducted by Grantham-McGregor *et al*. (2007) revealed that malnutrition in young children impaired the cognitive functioning which subsequently affected the learning capabilities of these young children which lowered their educational achievement as well as reduction in their capacity for physical work. It is therefore advisable to introduce young children and reproductive women to consume this OFSP nutrient-rich composite 'fufu' flour product which is high in energy with substantial amount of protein to address some of these malnutritional deficiencies.

Fats play an essential role in all living cells and are very important for promoting good health, growth and development. The fat composition of the formulated composite 'fufu' flour blends analyzed recorded very low percentages of fat content as listed in Table 4.20. The fat content varied significantly ($p < 0.05$) from 0.20% to 0.40% as the substitution levels of OFSP flour increased in the blending ratios. CAS100 recorded a lower fat content of 0.20% as compared to OFS100 which recorded 0.40%. Ojo and Akande (2013) reported that cassava and sweet potato just like the other root tubers contain low fat content. Crude fat content of between 0.10% and 0.40% were reported by Oloo *et al*. (2014). Similar result of 0.39% was also documented by Rodrigues *et al*. (2016) for OFSP flour. All these results were similar to the results reported in this research work. Obomeghei *et al*. (2020) and Fana Haile and Fisseha (2015) on the contrary documented a higher range of 0.90 – 2.50% fat content in OFSP. On the other hand, Bamidele *et al*. (2015) reported a higher fat content of 1.32% for cassava as compared to what was reported in this study. The difference in the fat content could be attributed to the different varieties of OFSP and cassava used in the analysis. It is very

important to note that higher fat content in developed food products can have an effect on its storage life (Ohizua *et al*., 2017; Noorfarahzilah *et al*., 2014). High fat or lipid content in food products are likely to undergo oxidative deterioration if not stored properly and this can result in rancidification making it more susceptible to food spoilage (Ashun, 2018). Hence, the lower the fat content, the lower the oxidative deterioration and the lower the rancidification. Ogunlakin *et al*. (2012) confirmed that low fat content in food products enhances the storage life without the food product going rancid. The low-fat content of the composite flour blends reported in this study could also be an advantage for product storage since the shelf-life of the developed food product would be extended with decreased rate of deterioration. Fat serves as depot for energy storage and it is readily available as energy source for basal metabolism. Fats are converted to fatty acids that function in many chemical and biochemical activities like avoiding excessive skin flaking and dryness, providing linoleic acid as well as enhancing proper growth and development in infants and young children (Zhang *et al*., 2021). Dietary lipids in food consumed helps in transporting fat-soluble vitamins (A, D, E, and K) through the digestive process and also enhances their intestinal absorption. It also enhances the bioavailability of phytochemicals which are non-essential plant compounds known to be important to human health and growth (Borel and Desmarchelier, 2018). According to Ravisankar *et al*. (2015), dietary lipids also enhance desirability to consume food as it adds aroma and flavour to the diet, enhance the taste and improve the texture of the food. Because dietary fat digestion and absorption rate is slower as compared to other macro- and micronutrients, dietary fat is considered to contribute to satiety which is the

feeling of being full or satisfied (Ravisankar *et al*., 2015). Lohia and Udipi (2015) reiterated that higher fat content could also be a nutritional advantage as the energy content of the developed food product would increase thereby enhancing its availability for basal metabolism. But on the contrary, Dietz and Robinson (2005) reechoed that excessive intake of dietary lipids predisposes young children to obesity that leads to some cardiovascular diseases that results in child mortality. Recent research studies advocate that consumers should not eat foods containing more than 5-10% of saturated fats as one's daily calories. But the American Heart Association (AHA) on the other hand recommended that the consumption of saturated fats in our diet should be around 5-6% (Rose-Francis, 2021). The fat content in the most preferred composite 'fufu' flour blend (95/5) reported in this study was 0.22% and this was below the recommended threshold by the American Heart Association making it very safe for consumption. The availability of fat in the diet also helps in the absorption of vitamin A as it stimulates enzymes in charge of hydrolyzing dietary retinyl esters, thereby, enhancing the formation of micelle for solubilization of carotenoid and retinol in the intestinal lumen as well as increasing the formation of chylomicron (Conaway *et al*., 2013).

The fibre content of the composite blends also increased significantly ($p < 0.05$) from 1.42% to 3.55% as the OFSP increased. The purely cassava flour (CAS100) recorded a crude fibre content of 1.42% while the purely OFSP flour (OFS100) recorded 3.55%. A similar result was reported by Obomeghei *et al*. (2020) for OFSP flour. According to Amagloh *et al*. (2021), an enhanced dietary fibre content in food is essential for easy digestion and avoidance of constipation. Ellong *et al*. (2014) also reported that dietary fibre

presents a satiety feeling that helps in controlling food ingestion as well as maintaining a healthy digestive tract. Ellong *et al*. (2014) also explained that fibre has the potential of maintaining a healthy bowel and minimizes cholesterol levels in the body system. A higher crude fibre of 4.10% was documented by Ashun (2018) even though the same local variety of OFSP (*Apomuden*) was used. The crude fibre content of the most preferred composite 'fufu' flour blend was low (2.33%) and it meets the target set by CAC/GL 08 (1999) and CAC (2011) that recommends fibre content to be less than 5%. According to CAC (2011), high fibre content in formulated food products makes the food bulky and stimulates flatulence which presents an uncomfortable feeling in most young children. But Ashun (2018) also reported that high crude fibre content could enhance digestion in young children. Ijarotimi and Keshinro (2013) state that young children may be encouraged to increase their intake of nutrient-dense food due to the low fibre content, which may help them achieve their daily nutritional requirements and energy demands. Both Solomon (2005) and Mbaeyi-Nwaoha and Obetta (2016) found that some cereal and legume (millet, pigeon pea, and seedless breadfruit leaf powder blends) dietary supplements had a crude fibre content of 4.76–11.5 percent. According to research published by Rolfes *et al*. (2014), eating foods rich in dietary fibre does not provide any nutritional benefit to the body beyond making the digestive tract and intestines more manageable.

The results also showed that there was a significant ($p < 0.05$) decrease in carbohydrate content as the substitution levels of OFSP increased (86.00% – 84.53%). However, this increased significantly ($p < 0.05$) the total energy levels of the composite flour blends from 354.63–360.72 kcal/100g as the

incorporation of OFSP level increased. Results obtained from this study showed that CAS100 recorded the highest carbohydrate content (86.00%) and this was comparable to the value (87.24%) reported by Bamidele *et al*. (2015). The estimated 84.53% carbohydrate content in this research for OFS100 was likewise similar to the figure 83.29% reported by Laryea *et al*. (2018). The percentages of each ingredient in OFSP flour were consistent with those reported by Tortoe *et al*. (2017). However, the carbohydrate content of OFSP was found to be greater by Dansby and Bovell-Benjamin (2003) and Rodrigues *et al*. (2016). Different OFSP types, production techniques, maturation stage, and environmental factors (such as soil conditions) may all affect the carbohydrate content of the final product, as detailed by Laryea *et al*. (2018). Although sweet potatoes are high in carbs, they have a low glycemic index, which measures the rate of digestion of complex carbohydrates and also reduces the pace at which sugars are absorbed into the blood stream (Ooi and Loke, 2013). Because of this, the carbohydrate in sweet potatoes is a great option for those who are overweight or have diabetes.

It was obvious that the cassava flour provided the bulk of the carbohydrates while the OFSP was the major source of protein and minerals in the composite flour blends. Energy levels in the composite blends increased with increased amounts of protein, fat and carbohydrate in the flour blends. Ashun (2018) also confirmed that the addition of OFSP flour enhanced the energy levels of the composite flour blends as the substitution levels of OFSP flour blends increased. Composite flour blends are usually expected to be energy dense and very nutritious. Therefore, this attribute presents OFSP flour

as a suitable food ingredient for the development of composite flour food products.

4.3.2 Mineral and vitamin composition of composite flour blends

Bio-availability and bio-accessibility are directly related to the mineral content of diet (Drago, 2017). Metabolic processes rely heavily on minerals, which are inorganic components (Neela and Fanta, 2019). The mineral and vitamin content of the composite flour blends studied differed significantly (p 0.05), as shown in Table 4.21. As the proportion of OFSP flour in the composite flours rose, the iron concentration rose sharply, from 1.35 mg/100g to 6.42 mg/100g. OFS100's iron content was measured to be in the same ballpark as that reported by Pobee *et al*. (2017). Collagen and some neurotransmitters rely on iron for respiration and energy metabolism (Bashiri *et al*., 2003).

The zinc content in the composite flour blends also increased significantly ($p < 0.05$) from 1.04 mg/100 g in 95/5 to 1.71 mg/100 g in 75/25. The zinc content in 100% cassava flour (0.85 mg/100 g) was lower as compared to that in pure OFSP flour (0.85 mg/100 g). Similar to what was reported by Chikpah *et al*. (2020), the zinc concentration measured for 100% OFSP flour. Neela and Fanta (2019) state that zinc is crucial to human health for proper immune system activity, wound healing, cell development, and insulin function. Ashun (2018) reported that minerals as a nutrient plays an important function in the lives of young children. The minerals aid in building strong and healthy bones and teeth. Proper functioning of nerves and muscle clotting of blood, boosting the immune system of the body as well as enhancing proper functioning of some vital organs in the body.

The amount of vitamin C in the final product ranged from 14.42 mg/100 g to 22.47 mg/100 g, with a statistically significant increase (p 0.05) occurring at higher levels of OFSP flour replacement in the blending ratios. Ascorbic acid, or vitamin C, is a water-soluble nutrient that degrades when exposed to high temperatures. Vitamin C is severely depleted in the food preparation, cooking, and storing stages (Ejoh *et al*., 2005). Vitamin C impacts the absorption of iron, the immune system, and collagen formation, among other biochemical processes (Iqbal *et al*., 2004). When compared to the figure published by Grace *et al*. (2014), the vitamin C concentration in OFS100 was found to be lower. Possible causes include variances between varieties and the environment.

Beta-carotene is a provitamin A carotenoid and it is an essential nutrient required in the body. The sweet potato root tuber is considered to be an excellent source of beta carotene (a precursor of vitamin A) (Zhang *et al*., 2016). The high level of β-carotene in OFSP could help in combating vitamin A deficiency diseases like blindness as well as child and maternal mortality in most developing nations (Zhang *et al*., 2016). Significant differences ($p < 0.05$) in vitamin A content were recorded between the different substitution levels of OFSP in the composite flour blends except the 15% and 20% substitution levels which were similar (Table 4.21). CAS100 (100% cassava flour) recorded the lowest content of vitamin A (89.34 µg/100g) while 100% OFSP (OFS100) flour recorded the highest content (420.98 µg/100g).

Table 4.21: Results of mineral and vitamin composition on dry basis

Sample	Iron (Fe) (mg/100g)	Zinc (Zn) (mg/100g)	Vitamin C (mg/100g)	Vitamin A (µg/100g)	β-Carotene (µg/100g)
CAS100	1.35 ± 0.14^{e}	0.85 ± 0.02^{e}	14.42 ± 0.18^{f}	89.34 ± 0.98^{f}	536 ± 5.89^{f}
95/5	2.21 ± 0.21^{d}	1.04 ± 0.10^{d}	15.61 ± 0.20^{e}	116.28 ± 0.66^{e}	698 ± 3.94^{e}
90/10	2.54 ± 0.20^{d}	1.22 ± 0.10^{cd}	16.28 ± 0.12^{d}	168.50 ± 1.73^{d}	1,011 ± 10.40^{d}
85/15	3.38 ± 0.11^{c}	1.30 ± 0.03^{c}	16.77 ± 0.18^{d}	190.39 ± 1.29^{c}	1,142 ± 7.77^{c}
80/20	4.08 ± 0.41^{bc}	1.41 ± 0.03^{c}	17.42 ± 0.21^{c}	193.63 ± 1.14^{c}	1,162 ± 6.86^{c}
75/25	4.68 ± 0.42^{b}	1.71 ± 0.10^{b}	18.19 ± 0.20^{b}	219.75 ± 1.12^{b}	1,319 ± 6.71^{b}
OFS100	6.42 ± 0.39^{a}	2.33 ± 0.01^{a}	22.47 ± 0.20^{a}	420.98 ± 2.32^{a}	2,526 ± 13.93^{a}

** Means in the same column with different letters are significantly different ($p < 0.05$).*

The β-carotene and Vitamin A values recorded in this study for OFS100 were within the same range as reported by Alam *et al*. (2020) and Mitra (2012). According to Amagloh *et al*. (2021), the differences in β-carotene levels among sweet potato cultivars could be based on their genotype and environmental conditions.

Iron, zinc and vitamin A deficiency diseases are the three major deficiency-related diseases that are of public health concern globally (Rice *et al*., 2004). Therefore, the need to consume a nutritionally balanced diet containing sufficient amounts of these micronutrients is very critical to prevent related deficiency diseases. The recommended dietary allowance (RDA) of vitamin A for children between the ages of 1-13 yr is 300-600 µg and that for women of reproductive age is 700 µg (National Institute of Health, 2022). Each serving of 'fufu' for children within 9 – 15 yr as well as reproductive women required a preparation with 200 g of the composite flour. Thus, if no losses occurred during cooking, a serving of the 95/5 % (cassava/OFSP) composite flour potentially contributes about 37–75% of the RDA for children within the ages of 1-13 yr and 32% of the RDA for women of reproductive age. According to Amagloh *et al*. (2021), vitamin A is an essential food nutrient required for visual acuity as well as proper maintenance of healthy mucous membrane and skin. The results obtained showed that there was an increase in the mineral and vitamin composition in the composite flour blends as the OFSP level in the flour blends increased. This agrees with the report of Neela and Fanta (2019) that OFSP is rich in minerals and vitamins as compared to the other root tubers. However, these minerals are sensitive to

heat and therefore the method and time for cooking is very critical to enhance their bioavailability after cooking and consumption.

4.4 Phytochemical composition

Different cultivars of sweet potato contain varying levels of bioactive phytochemical compounds that could be based on both environmental and genetic factors. There are various bioactive phytochemical compounds present in sweet potato and this study focused on only three: anthocyanin, flavonoid and phenols. The results of these bioactive compounds analyzed are presented in Table 4.22. From the study, CAS100 had lower amounts of anthocyanin, flavonoid and phenol as compared to OFS100 which recorded higher amounts. CAS100 had 0.07 µg/g of anthocyanin, 1.26 µg/g of flavonoid and 0.01 µg/g of phenol. OFS100 also recorded 1.17, 6.07, and 4.25 µg/g for anthocyanin, flavonoid and phenol respectively. According to Wang *et al*. (2016) and de Albuquerque *et al*. (2019), the quantities of these bioactive compounds could vary with cultivars depending on the skin and flesh colour.

It is evident from the results that the addition of OFSP flour improved the phytochemical composition of the composite flour blends as the percentage levels of OFSP flour increased in the blending ratios. Alam *et al*. (2016) and Teow *et al*. (2007) reported that OFSP contained substantial amount of β-carotene and the purple-fleshed sweet potato (PFSP) contain higher levels of anthocyanin compared to the other cultivars. Shekhar *et al*. (2015) also reported that the OFSP cultivars contained higher levels of flavonoids, carotenoids and phenols but had lower quantities of anthocyanins. Fernandes *et al*. (2018) confirmed that anthocyanin content was predominantly high in the PFSP roots but very small or none in the orange-fleshed as well as

the yellow or white-fleshed sweet potato. The results obtained in this current study confirmed that OFSP recorded a lower anthocyanin value of 1.17 µg/g as compared to 6.07 µg/g and phenol 4.25 µg/g of flavonoids and phenols respectively.

Table 4.22: Phytochemical compounds composition in composite 'fufu' flour blends

Sample	Anthocyanin (µg/g)	Flavonoid (µg/g)	Phenol (µg/g)
CAS100	0.07 ± 0.01^{e}	1.26 ± 0.07^{g}	0.01 ± 0.02^{f}
95/5	0.08 ± 0.01^{e}	2.20 ± 0.02^{f}	0.38 ± 0.01^{e}
90/10	0.15 ± 0.01^{d}	2.52 ± 0.02^{e}	0.54 ± 0.01^{e}
85/15	0.19 ± 0.01^{d}	3.02 ± 0.07^{d}	0.76 ± 0.01^{d}
80/20	0.23 ± 0.01^{c}	4.17 ± 0.09^{c}	1.30 ± 0.05^{c}
75/25	0.39 ± 0.01^{b}	4.58 ± 0.01^{b}	1.65 ± 0.04^{b}
OFS100	1.17 ± 0.04^{a}	6.07 ± 0.06^{a}	4.25 ± 0.13^{a}

**Means in the same column with different letters are significantly different ($p < 0.05$).*

According to Lebot *et al*. (2016) and Sun *et al*. (2019), the antioxidant activities of sweet potato is linked to its phenolic compounds, carotenoid and anthocyanin contents. Anthocyanins are nutritionally essential based on their antioxidant activities, anticarcinogenic activities, protection against heart disease, and anti-inflammatory effect. In sweet potatoes, flavonoids, phenolic acids and polyphenols are the main phenolic compounds present. Even though OFSP recorded appreciably high levels of flavonoids and phenols, Wang *et al*. (2016), Ooi *et al*. (2021) and Gabilondo *et al*. (2022) reported that PFSP contained higher concentrations of the phenolic compounds than that recorded for OFSP in this study.

4.5 Physical and functional composition of composite flours

4.51 Bulk density

The bulk density of a flour is an indicator of its heaviness (Ohizua *et al.*, 2017) and is determined by the particle size distribution of the flour. It may also be used as a gauge of food product porosity (Tortoe *et al.*, 2017). Table 4.23 displays the bulk density (in grammes per millilitre) of several composite flour blends, which vary from 0.56 g/mL for CAS100 to 0.75 g/mL for OFS100. Therefore, when OFSP flour replacement levels rose in blending ratios, the flour bulk density increased considerably ($p < 0.05$). The OFSP has higher fibre content which makes it more porous to absorb more water, and this is reflected in the increase in bulk density as the substitution of OFSP increased in the flour blends.

Table 4.23: Results of physical and functional properties of flours and composite flour blends

Sample	Bulk Density (g/mL)	Swelling Index	WAC (%)	Starch (g/100g)
CAS100	0.56 ± 0.01^{e}	1.23 ± 0.06^{e}	136.12 ± 5.93^{d}	88.03 ± 0.26^{a}
95/5	0.57 ± 0.02^{e}	1.37 ± 0.06^{e}	142.90 ± 5.62^{e}	82.35 ± 0.22^{b}
90/10	0.61 ± 0.02^{d}	1.50 ± 0.10^{de}	152.92 ± 5.62^{de}	81.08 ± 0.34^{c}
85/15	0.65 ± 0.02^{c}	1.70 ± 0.10^{dc}	165.99 ± 5.72^{d}	76.33 ± 0.30^{d}
80/20	0.68 ± 0.01^{bc}	1.87 ± 0.12^{c}	186.10 ± 5.69^{c}	74.72 ± 0.79^{e}
75/25	0.72 ± 0.03^{ab}	2.23 ± 0.15^{b}	222.82 ± 5.74^{b}	71.02 ± 0.35^{f}
OFS100	0.75 ± 0.02^{a}	3.03 ± 0.15^{a}	299.22 ± 0.35^{a}	50.90 ± 0.12^{g}

** Means in the same column with different letters are significantly different ($p < 0.05$).*
**WAC – Water Absorption Capacity.*

According to Ohizua *et al.* (2017), bulk density measurement is an indication of product handling, its heaviness, and the kind of packaging material appropriate for product storability and transport. The values recorded

for bulk density for the composite flour blends were higher than that of CAS100 flour. The high bulk densities observed shows that flour blends were heavy and could occupy lesser space with less packaging materials per unit weight which will result in minimum cost of packaging. Ashun (2018) reported that an increase in bulk density is preferable since it presents a better packaging advantage per quantity packed within the packaging container at constant volume.

4.5.2 Water absorption capacity

Water absorption capacity describes the ability of flour to absorb water (moisture) and swell, which is a critical measure of food product consistency and yield (Dereje *et al*., 2020). The water absorption capacity varied significantly ($p < 0.05$) from 136.12% to 299.22%, representing 2-fold increase from that of CAS100 to that of OFS100 (Table 4.23). It was observed that the composite flour blend's ability to absorb water increased as the OFSP incorporation levels increased in the blending ratios. According to Ohizua *et al*. (2017), this could be attributed to the protein and carbohydrate levels of OFSP as reports reveals that carbohydrates have much influence on water absorption capacity in food flours. Olapade *et al*. (2014) also reported that the ability of flour blends to absorb more water is most times attributed to their protein content. Hence, the increase in water absorption capacity observed in this study as the substitution levels of OFSP increased could be attributed to the protein content provided by the OFSP. The results also showed that all the composite flour blends exhibited favorable water absorption capacity, which makes them suitable functional materials (raw material) for composite flour development. However, the value recorded for CAS100 (136.12%) and

OFS100 (299.22%) were all lower than that reported by Ohizua *et al*. (2017). This variation could be due to the varietal differences.

4.5.3 Swelling index

Swelling index of composite flour blends increased significantly ($p < 0.05$) as the OFSP substitution levels increased in the blending ratios. The swelling index ranged from 1.23 to 3.03 as the OFSP flour content was increased (Table 4.23). Thus, OFS100 flour had 2.5-fold higher swelling index than CAS100 flour. The higher swelling capacity of OFSP may be explained by its higher water absorption capacity. This means that there could be about 2.5-fold yield in the volume of 'fufu' prepared from OFSP than from cassava flour alone. Chandra (2013) reported that swelling index of flours are usually influenced by crop varieties, flour particle size and processing technique or operation. This study showed that swelling index of composite flour blends were highly influenced by the addition of OFSP which could be attributed to the high fibre content, its porosity and higher water absorption capacity.

4.5.4 Starch content

Starch content varied from 50.90 g/100g to 88.03 g/100g. CAS100 flour had the highest starch content as compared to OFS100 flour which had the lowest starch content (Table 4.23). Zhang *et al*. (2002) reported that the starch content of different sweet potato genotypes varied between 46.8% and 73.6% of the root dry weight (DW), which is comparable to the value of 50.90 g/100 g DW in OFS100 in the current study which increased to 88.03 g/100g (dry weight) in CAS100. Thus, there was a significant decrease ($p < 0.05$) in starch content as the OFSP flour substitution levels increased in the blending ratios. Starches are the natural carbohydrates which form the nutrient

reservoirs of food crops (Mishra *et al*., 2012). According to Amoah (2014), the carbohydrate in sweet potato constitutes approximately 80-90% of the dry matter and consists of various proportions of starch and soluble sugars. Sweet potatoes have a higher proportion of soluble sugars to total carbs than cassava. This explains why OFS100 has a sweeter taste and far less starch than CAS100. Because of this, 'fu' made using composite flour that contains a high percentage of OFSP is likely to have a different flavour, aftertaste, and texture. The elasticity (texture) of the 'fufu' could be enhanced by increasing the starch level of the composite flour. According to Ketnawa *et al*. (2019), sweet potato starch may be manipulated to show desirable properties, increasing its potential worth in the food industry. The processing of sweet potato starch, however, alters its functional properties due to the presence of additional components such as amylases, sugars, and lipids. According to Moloto *et al*. (2021), these functional characteristics could be standardized by monitoring the heating rate during processing that activates endogenous amylolytic enzymes present in the sweet potato to convert part of the starch to dextrin.

4.5.5 Colour

Colour has the ability to influence consumer perception of a developed food product. According to Tortoe *et al*. (2017), flour colour is considered as an important physical property which influences food quality and consumer preference and acceptability of the food product as well as its marketability. The inclusion of OFSP flour in cassava flour greatly influenced the colour shades of the composite flour blends which showed shades of green and yellow (Table 4.24). This subsequently influenced the colour of the cooked 'fufu' and consumer preference.

Table 4.24: L*a*b* colour characteristics of flour and composite flours

Sample	L*	a*	b*	Hue	Chroma	Whiteness Index (WI)	Delta E (ΔE)
CAS100	99.99 ± 0.02^{a}	6.08 ± 0.08^{f}	-0.92 ± 0.06^{g}	-8.64 ± 0.55^{g}	6.15 ± 0.08^{g}	6.15 ± 0.08^{g}	0.09 ± 0.08^{g}
95/5	96.95 ± 0.08^{b}	7.47 ± 0.06^{e}	2.39 ± 0.15^{f}	17.75 ± 0.92^{f}	7.85 ± 0.11^{f}	8.42 ± 0.06^{f}	4.71 ± 0.20^{f}
90/10	95.07 ± 0.25^{c}	8.23 ± 0.16^{d}	3.97 ± 0.18^{e}	25.75 ± 0.62^{e}	9.14 ± 0.22^{e}	10.38 ± 0.31^{e}	7.26 ± 0.38^{e}
85/15	93.84 ± 0.12^{d}	8.85 ± 0.10^{c}	5.10 ± 0.19^{d}	29.95 ± 0.65^{d}	10.22 ± 0.18^{d}	11.93 ± 0.20^{d}	9.07 ± 0.22^{d}
80/20	92.76 ± 0.09^{e}	9.03 ± 0.25^{bc}	6.26 ± 0.37^{c}	34.72 ± 0.84^{c}	10.99 ± 0.42^{c}	13.16 ± 0.39^{c}	10.61 ± 0.32^{c}
75/25	91.51 ± 0.15^{f}	9.41 ± 0.29^{b}	7.37 ± 0.20^{b}	38.07 ± 0.12^{b}	11.96 ± 0.35^{b}	14.67 ± 0.21^{b}	12.33 ± 0.13^{b}
OFS100	79.71 ± 0.28^{g}	14.01 ± 0.11^{a}	19.83 ± 0.16^{a}	54.77 ± 0.08^{a}	24.28 ± 0.19^{a}	31.64 ± 0.25^{a}	30.09 ± 0.21^{a}

** Means in the same column with different letters are significantly different ($p < 0.05$).*

Anthocyanins and carotenoids make up the colour pigments in OFSP flour and they affect the b^* and a^* colour indices. The lightness or darkness of the flour is indicated by the L^* values, and this showed a significant difference ($p < 0.05$) for 100% cassava flour (99.99) and 100% OFSP flour (79.71) indicating that the cassava flour had a lighter (whiter) colour than the OFSP flour which was darker (orange). While the L^* values decreased, a*, b*, hue, chroma, whiteness index and colour difference (delta E) increased significantly ($p < 0.05$) as the substitution levels of OFSP flour increased in the blending ratios, and this was confirmed by Singh *et al*. (2013). The whiteness index is a measure of how close the surface ties with the properties of a perfect reflecting diffuser. The lower the whiteness index the lighter the flour colour. Whiteness index which varied from 6.15 to 31.64 increased significantly ($p < 0.05$) as the OFSP flour substitution levels increased (Table 4.24). The delta E (ΔE) is the total colour difference and it determines the colour change in samples as measured using the three-dimensional axes L*, a*, b* in the Hunter Lab colour space. According to Finn (2021), the significance of determining the colour difference (ΔE) is to match colours to ensure accuracy and also to measure the degree of colour change over time. The delta E varied significantly ($p < 0.05$) from 0.09 to 30.09 as the OFSP flour substitution levels increased.

4.5.6 Pasting characteristics of composite flour

Pasting qualities is an essential criterion in identifying food application for flour development (Moloto *et al*., 2021). When cooked, ‘fufu’ has a certain texture that customers enjoy, which varies with the quality of the ingredients and the technique of preparation. A crucial quality parameter that foretells the

reliability of the 'fufu' and, by extension, the approval of consumers is the flour's pasting qualities. The 'fufu' paste gets its signature texture (its elasticity) from the starch that gives it both elastic and viscous qualities. Physical interactions occur between starch granules because they absorb and bind with water during pasting analysis, reducing the amount of intergranular water accessible (Kumar and Khatkar, 2017). These interactions, known as pasting, cause the viscosity of the starch and water solution to increase dramatically. During both the heating and chilling phases, we found that the pasting capabilities of the cassava-OFSP composite flour blends altered considerably ($p < 0.05$) with increasing amounts of OFSP flour replacement (Table 4.25). Pasting starch at different temperatures results in different degrees of swelling and water absorption in the starch granules (Bamidele *et al*., 2015). The pasting temperature, as defined by Iwe *et al*. (2016), is the point at which heating causes a noticeable rise in viscosity. The peak temperature of the composite 'fufu' flour blends increased significantly ($p < 0.05$) between 100% cassava flour (85.45 °C) and 100% OFSP (94.90 °C) as the substitution levels of OFSP flour increased in the composite blending ratios. High pasting temperature of starches is an indication of higher resistance to swelling and rupture (Kumar and Khathar, 2017). Pasting temperature depends on the size of granules with smaller granules being more resistant to rupture and loss of molecular order (Singh *et al*., 2007; Kumar and Khatkar, 2017).

Peak viscosity which is the highest viscosity reached prior to disintegration of the starch granules decreased significantly ($p < 0.05$) from 358.00 BU to 54.50 BU as the incorporation of OFSP flour levels increased in

the composite flour blending ratios. Olapade *et al*. (2014) explained that the variation observed in the pasting viscosities could be attributed to the varying rates at which water is absorbed by the starch granules of the various composite flour blends and subsequent swelling during the heat processing. Furthermore, high peak viscosity according to Moloto *et al*. (2021) is suitable for manufacturing of food products that require maximum gel strength, thick paste and elasticity. It also shows the presence of high starch content. The CAS100 which was 100% cassava flour recorded a higher starch content of 88.03 g/100g, and when cooked into 'fufu' gave a good texture with an enhanced elasticity that looked like the pounded 'fufu'. From the formulated composite flour blends, the 95/5 blend 'fufu' was most preferred after the sensory evaluation, which also recorded a high starch content of 82.35 g/100g. This gave a 'fufu' with fairly good texture and elasticity that was comparable to the CAS100 'fufu'.

Trough viscosity refers to the reduction in pasting viscosity caused by the rupture of starch granules (Kumar and Khatkar, 2017). Another name for the trough viscosity is "the beginning of the cooling period." The capacity of a paste to resist disintegration during cooling is measured by its trough viscosity (Olapade *et al*., 2014). As the percentage of OFSP flour in the mix grew, the trough viscosity changed dramatically ($p < 0.05$), falling from 106.00 BU to 51.00 BU. As the percentage of OFSP flour used rose, the ultimate viscosity dropped dramatically ($p < 0.05$), from 181.50 BU to 63.00 BU. Since OFSP flour contains less starch than cassava flour, it has a lower viscosity. The aggregation of amylose molecules in the paste, as suggested by Oluwamukomi *et al*. (2005), may account for the variation in final viscosity values. The lower

viscosity of OFSP is further evidenced by the observation that the breakdown viscosity, which is a measure of the resistance to heat and shear stress of the composite flour samples, decreased significantly ($p < 0.05$) from 252.00 BU (CAS100) to 3.50 BU (OFS100) as the substitution levels of OFSP flour content increased.

The breakdown viscosity can also be defined as the difference between the peak viscosity and the trough viscosity. The breakdown viscosity decreased significantly ($p < 0.05$) from 252.00 BU (CAS100) to 3.50 BU as the substitution levels of OFSP flour increased in the composite blending ratios. Breakdown viscosity indicates the resistance of the paste to the disintegration of starch granules (Bamidele *et al*., 2015; Olapade *et al*., 2014). Since flour with lower peak viscosities has a better resistance to starch granules disintegrating, the breakdown viscosity is inversely proportional to the starch granules' stability (Lewu *et al*., 2010). Therefore, the peak, final, and breakdown viscosities of the composite blends were drastically decreased due to the incorporation of OFSP. Contrary to what was found when cocoyam was combined with cassava flour (Bamidele *et al*., 2015), this was not the case. According to research by Singh *et al*. (2006), high breakdown values indicate that the flour's starches are unlikely to result in stable pastes.

Setback viscosity measures the viscosity of the flour when the paste is cooled to 50 ^{o}C after heating (Zaidul *et al*., 2007). The setback viscosity of CAS100 decreased significantly ($p < 0.05$) from 75.00 BU to 16.50 BU as the incorporation levels of OFSP flour increased in the composite blending ratios

Table 4.125: Results of pasting characteristic of cassava and OFSP composite 'fufu' flour blends

Sample	Peak Temperature (°C)	Peak Viscosity (BU)	Trough Viscosity (BU)	Final Viscosity (BU)	Breakdown Viscosity (BU)	Setback Viscosity (BU)	Peak Time (min)
CAS100	85.45 ± 0.50^{a}	358.00 ± 14.10^{a}	106.00 ± 12.73^{a}	181.50 ± 6.36^{a}	252.00 ± 9.70^{a}	75.00 ± 7.07^{a}	24.40 ± 0.14^{c}
95/5	87.00 ± 0.14^{b}	298.50 ± 4.95^{a}	94.50 ± 0.71^{ab}	154.50 ± 0.71^{b}	204.00 ± 5.66^{b}	67.50 ± 2.12^{a}	25.23 ± 0.11^{bc}
90/10	88.05 ± 0.78^{b}	214.00 ± 12.73^{b}	79.50 ± 4.95^{bc}	126.00 ± 5.66^{c}	134.50 ± 7.78^{b}	52.00 ± 4.24^{b}	25.85 ± 0.64^{bc}
85/15	89.00 ± 0.71^{bc}	168.50 ± 9.19^{bc}	68.50 ± 3054^{cd}	107.00 ± 5.66^{d}	100.00 ± 5.66^{bc}	40.00 ± 4.24^{bc}	26.38 ± 0.25^{bc}
80/20	89.40 ± 0.57^{bc}	136.50 ± 9.19^{c}	60.00 ± 2.83^{d}	90.50 ± 4.95^{de}	76.50 ± 6.36^{d}	31.50 ± 0.71^{c}	26.75 ± 0.50^{b}
75/25	90.00 ± 0.14^{cd}	111.00 ± 7.07^{cd}	51.50 ± 0.71^{d}	76.00 ± 2.83^{ef}	59.50 ± 6.36^{e}	28.50 ± 0.71^{cd}	27.23 ± 0.04^{b}
OFS100	94.90 ± 0.42^{d}	54.50 ± 4.95^{d}	51.00 ± 2.83^{e}	63.00 ± 1.41^{f}	3.50 ± 2.12^{f}	16.50 ± 0.71^{d}	34.23 ± 1.09^{a}

** Means in the same column with different letters are significantly different ($p < 0.05$).*

The setback viscosity is a measure of the tendency of starch granules to retrograde (Owuamanam *et al*., 2010). An increase in the setback viscosity value increases the tendency of retrogradation of the starch granules of the product with increased staling rate. The results of this study showed that apart from 100% cassava flour which had the highest retrogradation tendency value of 75.00 BU, the 5% level of OFSP sample had the next highest retrogradation tendency value of 67.50 BU and this decreased gradually as the substitution levels of OFSP flour increased in the composite blending ratios. According to Zaidul *et al*. (2007), this could be credited to an increase in hydrogen bonding during cooling and can be used to predict the shelf-life of the flour product. Okafor and Ugwu (2013) also documented that lower setback values are an indication of better gelling characteristics and high setback values indicated a lower ability to withstand heat and shear stress during cooking resulting in a weak gel.

Pasting time indicates the response of the starch granules during heating. It varied slightly from 24.40 min to 34.23 min for CAS100 and OFS100 respectively. With the exception of the 100% OFSP flour sample, all the composite flour blends had similar pasting time just as the 100% cassava flour.

4.6 Correlation between physical/functional and pasting properties of composite 'fufu' flour blends

The results of Pearson correlation matrices between the physical/functional properties and pasting properties of the composite flour blends are listed in Table 4.26. Although statistically significant at the 0.05 level (2-tailed), the findings demonstrated a positive or negative association between physical/functional features and the pasting characteristics of the

composite flour blends. The peak, trough, final, breakdown, and setback viscosities were all positively linked with starch content. The flour's pasting qualities are a significant quality measure since they indicate how consistent the 'fufu' will be. The starchy paste used to make 'fufu' has a distinctive viscosity thanks to the starch used to make it. Cause for this is found in the starch's positive association with all measures of viscosity (peak, trough, final, breakdown, and setback). According to Bamidele *et al*. (2015), the ability of the starch granules to absorb water and swell is positively correlated with the bulk density, swelling index, water absorption capacity, and pasting temperature. Because of the high soluble sugar in OFSP, the findings in Table 4.26 also demonstrated that the composite flour blends' propensity to absorb water and swell increased with increasing levels of OFSP inclusion, which in turn influenced the starch concentration in the composite flour blends.

Increasing pasting temperature and time decreased significantly the peak viscosity, trough viscosity, final viscosity, breakdown and setback viscosities and this showed a positive correlation. According to Abdel-Aal *et al*. (2018), Ragaee and Abdel-Aal (2006), Olapade *et al*. (2014) and Tortoe *et al*. (2017), the variation observed in the pasting viscosities could be credited to the varying rates at which water was absorbed by the starch granules of the composite flour and subsequent swelling during the heating process. An increase in the pasting temperature and time resulted in the disintegration of the starch granules thereby reducing the viscosities of the flour paste and this could be attributed to the negative correlation between the peak temperature and time with the peak viscosity, trough viscosity, final viscosity, breakdown and setback viscosities.

Table 4.136: Pearson correlation matrices between physical/functional and pasting characteristics of composite flour blends

	BD	SI	WAC	Starch	PT	PV	TV	FV	Breakdown	Setback
SI	**0.936**									
WAC	**0.917**	**0.997**								
Starch	-0.927*	-0.992*	-0.982*							
PT	**0.913***	**0.979***	**0.967***	-0.994						
PV	-0.962	-0.876	-0.841	**0.894***	-0.902					
TV	-0.970	-0.843	-0.809	**0.849***	-0.846	**0.987***				
FV	-0.976	-0.878	-0.846	**0.888***	-0.888	**0.996***	**0.996***			
Breakdown	-0.969	-0.896	-0.864	**0.912***	-0.921	**0.998***	**0.981***	**0.993***		
Setback	-0.983	-0.898	-0.868	**0.907***	-0.908	**0.991***	**0.986***	**0.993***	**0.994***	
Peak time	**0.809***	**0.956***	**0.958***	-0.964	**0.968***	-0.767	-0.693	-0.750	-0.798	-0.785

*Correlation is significant at the 0.05 level (2-tailed)
PT = Peak temperature, PV = Peak viscosity, TV = Trough viscosity, FV = Final viscosity, BD = Bulk density, SI = Swelling index, WAC = Water absorption capacity
Highlighted values = positive correlation.

4.7 Microbial composition in composite flour blends

Generally, the levels of microbial load in the composite 'fufu' flour blends were very low. Results listed in Table 4.27 showed that most of values recorded for all the microbes analyzed were lower than the Ghanaian standards beyond which the food flour will not be wholesome for consumption. The results showed that the level of microbial load for *E. coli* ranged between 0.0 – 1.0×10^1 cfu/g whilst *Enterobacteria* ranged between 0.0 – 4.8×10^2 cfu/g. *Staphylococcus spp* varied between 0.0 – 1.2×10^1 cfu/g whilst Yeast varied between 0.0 – 44.0×10^3 cfu/g, and Mould ranged between 2.0 – 16.0×10^3 cfu/g. *Salmonella* was not detected in any of the composite flour blends. Even though there were some values recorded for all the microbes analyzed, they were significantly low and could not have caused any food contamination that would have been injurious to human health after consumption. According to Rajkovic *et al*. (2010), most of these microbes would have also been destroyed or killed during cooking (application of heat) to minimize their fatal effect. From the sensory evaluation conducted, the most preferred composite flour blend of 95/5 had 0.6×10^1 cfu/g for *E. coli*, 1.6×10^2 cfu/g for *Enterobacteria*, 0.4×10^1 cfu/g for *Staphylococcus*, 0.0×10^1 cfu/g for Yeast, 9.0×10^1 cfu/g for Mould. The low level of these microbial count signifies that the most preferred composite flour blend was also safe for consumption. According to Malavi *et al*. (2018), adhering to good and hygienic practices during processing and drying (Good Manufacturing Practices) helped reduce the microbial load in the processed food product. Abano *et al*. (2019) also reported that the heat applied during the drying process could also help minimize the level of microbial load in the dried samples.

Table 4.147: Microbial composition in composite 'fufu' flour blends (cfu/g*)

Sample	Microbial Analysis					
	E. coli	***Enterobacteria***	***Staphylococcus***	**Yeast**	**Mould**	***Salmonella***
CAS100	0.0×10^1	0.0×10^1	0.0×10^1	0.0×10^1	2.0×10^1	Not Detected
95/5	0.6×10^1	1.6×10^1	0.4×10^1	0.0×10^1	9.0×10^1	Not Detected
90/10	0.5×10^1	2.0×10^1	0.7×10^1	0.0×10^1	14.0×10^1	Not Detected
85/15	0.7×10^1	2.8×10^1	0.5×10^1	11.0×10^1	13.0×10^1	Not Detected
80/20	1.0×10^1	2.3×10^1	0.6×10^1	23.0×10^1	14.0×10^1	Not Detected
75/25	0.8×10^1	4.8×10^1	0.8×10^1	41.0×10^1	15.0×10^1	Not Detected
OFS100	0.9×10^1	3.3×10^1	1.2×10^1	44.0×10^1	16.0×10^1	Not Detected
STANDARDS*	$\mathbf{1.0 \times 10^1}$	$\mathbf{1.0 \times 10^2}$	$\mathbf{1.0 \times 10^1}$	$\mathbf{1.0 \times 10^3}$	$\mathbf{1.0 \times 10^3}$	**No Detection**

*Standards from Ghana Standard Authority (GSA)
*cfu/g – Colony-forming unit per gram

4.7.1 Aflatoxin composition in cassava and OFSP flours

Table 4.28 and Table 4.29 show the results obtained for aflatoxin analysis using the HPLC. The results showed that the two flour samples of cassava and orange-fleshed sweet potato did not contain aflatoxin B_1, B_2, G_1, and G_2 at detectable levels. This could be attributed to better drying and processing methods used. For aflatoxin B_1 and B_2, the limit of detection (LOD) is 0.15 µg/kg while the detection limit for aflatoxin G_1 and G_2 is 0.13 µg/kg. The limit of quantification (LOQ) for aflatoxin B_1 and B_2 was 0.16 and 0.30 µg/kg respectively while that for aflatoxin G_1 and G_2 was also 0.28 and 1.08 µg/kg respectively (Ofori *et al*., 2016a).

Results obtained from this study conform to the results reported by Ofori *et al*. (2016b) for aflatoxin content in sweet potato flour, cocoyam flour, and water yam flour samples where there were no detection of aflatoxins B_1, B_2, G_1, and G_2 in all the flour samples analyzed. Furthermore, the finding of this current study was similar to the work carried out by Ofori *et al*. (2016a) on aflatoxin content in High Quality Cassava Flour (HQCF) where there was no detection of aflatoxin B_1, B_2, G_1, and G_2 in the HQCF samples analyzed. The absence of aflatoxin B_1, B_2, G_1, and G_2 gives a strong indication and conviction that the newly developed nutritionally-rich composite 'fufu' flour poses no health threat and therefore, safe for public consumption. Figure 4.24 and 4.25 shows the HPLC chromatograms for aflatoxin detection in OFS100 and CAS100 flour samples respectively.

The peaks show whether there was detection of aflatoxin B_1, B_2, G_1, and G_2. The results obtained from the graphs showed that the peak heights do

not show any sign of detection of the various aflatoxin strains for both cassava and OFSP flour samples.

Table 4.158: Aflatoxin measurement for OFS100 flour sample

Aflatoxin Analysis for 100% OFSP				
Time (min)	Area (LU)	Amount/Area	Amount (µg/kg)	Group name
2.117	0	0	0	Aflatoxin G2
2.232	0	0	0	Aflatoxin G1
2.505	0	0	0	Aflatoxin B2
2.967	0	0	0	Aflatoxin B1
		Totals:	0.00000	

Table 4.169: Aflatoxin measurement for CAS100 flour sample

Aflatoxin Analysis for 100% Cassava				
Time (min)	Area (LU)	Amount/Area	Amount (µg/kg)	Group name
2.117	0	0	0	Aflatoxin G2
2.232	0	0	0	Aflatoxin G1
2.505	0	0	0	Aflatoxin B2
2.967	0	0	0	Aflatoxin B1
		Totals:	0.00000	

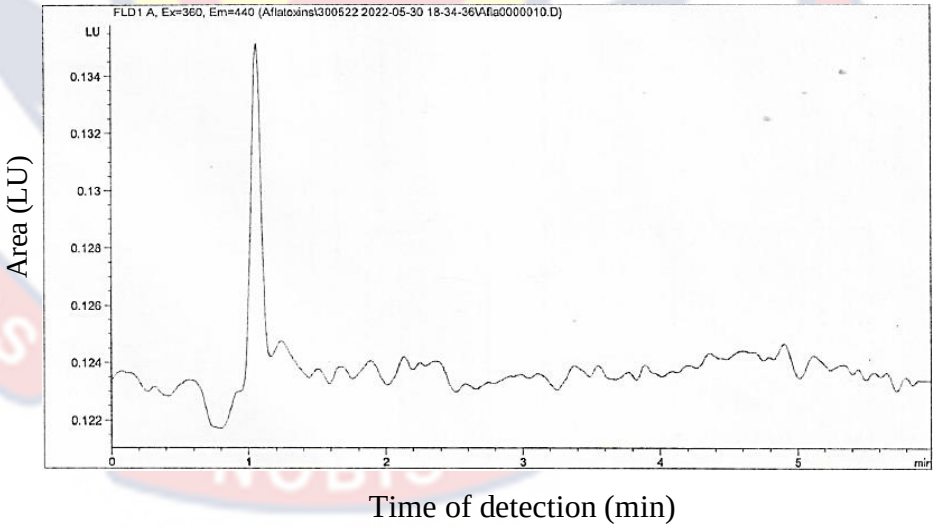


Figure 4.24: HPLC graph for aflatoxin detection in OFS100 flour sample

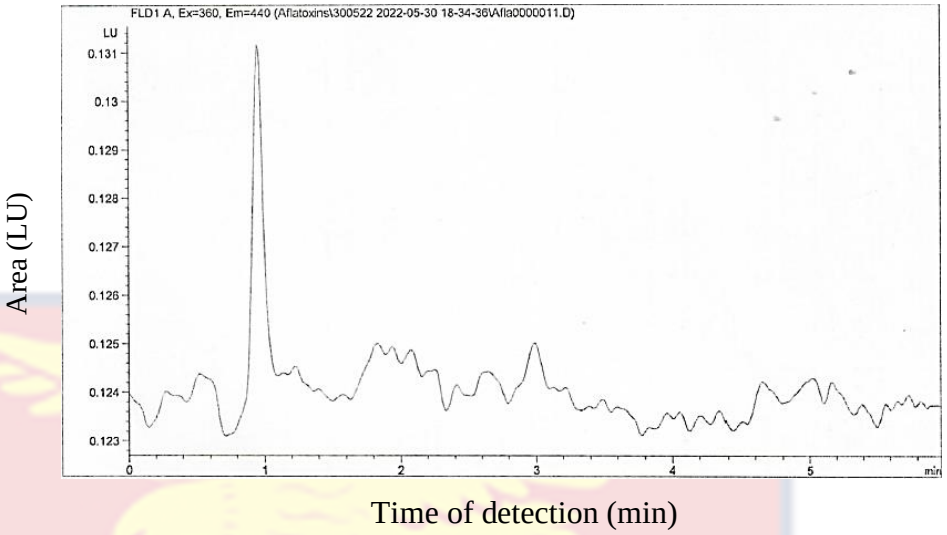


Figure 4.25: HPLC graph for aflatoxin detection in CAS100 flour sample

4.8 Sensory evaluation of cooked 'fufu'

The sensory evaluation scores for cooked 'fufu' from composite cassava and OFSP flour blends is listed in Table 4.30. Cooked 'fufu' samples from composite flour blends are also shown in Figure 4.26. The 100% cassava flour (CAS100) which was used as the control was rated the highest with sensory scores of 7.51, 7.30,7.38, 7.21, 7.04, 7.08 and 7.49 for appearance, aroma, colour, texture, taste, after-taste and overall acceptability, respectively on the hedonic scale. 'Fufu' is commonly cooked from cassava which is usually off-white to slightly yellow colour. The addition of plantain or cocoyam enriches its nutritional value with uniform consistency but with a characteristic colour depending on the additive. The consistency, as influenced by the texture, is very critical for consumers of 'fufu' in Ghana. The 'fufu' product is characterized by its elasticity. The substitution of cassava flour with 5% OFSP flour did not have any profound difference in consumers' perception of the appearance, colour, aroma and taste compared to the wholly cassava 'fufu'.

Table 4.30: Results of sensory attributes and overall acceptability of cassava flour and composite flour 'fufu'

Sample	Appearance	Aroma	Colour	Texture	Taste	After Taste	Overall Acceptability
CAS100	7.51 ± 1.09^{a}	7.30 ± 1.12^{a}	7.38 ± 1.18^{a}	7.21 ± 1.32^{a}	7.04 ± 1.21^{a}	7.08 ± 1.00^{a}	7.49 ± 0.89^{a}
95/5	6.66 ± 1.33^{ab}	6.70 ± 1.01^{ab}	6.77 ± 1.19^{ab}	5.53 ± 1.49^{b}	6.22 ± 1.25^{ab}	6.07 ± 1.22^{b}	6.55 ± 1.15^{b}
90/10	5.91 ± 1.32^{bc}	6.17 ± 0.98^{bc}	5.96 ± 1.27^{bc}	4.64 ± 1.79^{bc}	5.77 ± 1.58^{bc}	5.62 ± 1.39^{bc}	5.64 ± 1.21^{c}
85/15	5.38 ± 1.85^{cd}	5.57 ± 1.79^{cd}	5.70 ± 1.64^{cd}	4.02 ± 2.08^{c}	5.23 ± 1.79^{c}	5.11 ± 1.82^{c}	5.23 ± 1.40^{cd}
80/20	4.92 ± 2.10^{d}	5.25 ± 1.71^{d}	4.96 ± 1.82^{de}	3.96 ± 2.04^{c}	5.02 ± 1.98^{c}	4.89 ± 2.01^{c}	4.91 ± 1.75^{cd}
75/25	4.58 ± 2.13^{d}	5.57 ± 1.73^{cd}	4.64 ± 1.84^{e}	3.91 ± 2.02^{c}	5.15 ± 2.02^{c}	5.08 ± 2.07^{c}	4.49 ± 1.98^{d}

** Means in the same column with different letters are significantly different ($p < 0.05$).*

The 5% OFSP 'fufu' had a preferable good elastic texture and a light brown/orange colour that was preferred by consumers as compared to the other blends. The increase in OFSP level in the composite flour blends could be a reason for the browning (orange colour) of the cooked 'fufu' samples (Figure 4.26) which also could have been initiated by milliard reaction of protein in OFSP and some carbohydrates of cassava during cooking. Again, the sweetness of OFSP could be due to the monosaccharides or disaccharides and these readily undergo caramelization during heating and could be contributing more to the colour development in the cooked 'fufu' (Laryea *et al*., 2018). The results of the study showed, however, that increase in the substitution level of OFSP flour beyond 5% negatively affected consumers' likeness of all the sensory attributes, particularly the texture and hence, the overall acceptability. The high soluble sugar and the fat (lipid) content in OFSP affected the texture during cooking and this made 'fufu' prepared from the composite flour blends lose its elasticity as the addition of OFSP flour increased. On the contrary, the high soluble sugars in OFSP accounted for the nice taste and aroma of 'fufu' which possibly affected consumer's likeness. From Table 4.21, the vitamin A content in 5% OFSP substituted composite flour blend was 116.28 µg/100 g. This implies that each serving of 'fufu' per person prepared from 200 g of 5% OFSP substituted composite flour blend would provide 232.56 µg/200 g of vitamin A. Barring any losses during cooking, this could potentially contribute 38 to 77% of the Recommended Dietary Allowance (RDA) of vitamin A for children between the ages of 1-13 years and 33% that for women of reproductive age, respectively.

Figure 4.36: Cooked 'fufu' samples from the composite flour blends

4.9 Degradation of β-Carotene in shelf-life analysis

β-carotene is a reactive compound because its structure is highly unsaturated and that makes it electronically rich by delocalization of π-electrons. Furthermore, β-carotene is also prone to degradation at high temperature and oxidation as a result of the occurrence of oxygen in the food products (Pericaud *et al*., 2011). Figure 4.27 and Figure 4.28 show the graphical representation of the results obtained for beta-carotene degradation in shelf-life analysis for the 95/5 and 90/10 composite 'fufu' flour blends conducted within six (6) months of storage. The shelf-life analysis for β-carotene degradation in the 90/10 composite blend was also done to compare the trend of β-carotene degradation to that of 95/5 composite flour blend.

Two different packaging materials were used in packaging the composite flour samples and storage at ambient temperature which ranged between 25 ℃ and 28 ℃. Results showed that for the two different composite flour blends used in the analysis, β-carotene content remained slightly constant until the third month when it began to degrade slightly till the sixth month.

The β-carotene content for the 95/5 cassava-OFSP composite flour blend which was the most preferred sample after sensory evaluation varied slightly from 683.82 µg/100g to 573.10 µg/100g by the end of the sixth month for the plain polypropylene bag. The results also showed a slight variation from 690.33 µg/100g to 592.64 µg/100g for the 95/5 sample in the paper polyethylene laminated bags or pouches. Comparing the two results obtained from the two different packaging materials used, it was found that degradation of β-carotene in the paper polyethylene laminated bags or pouches was lower than that in the plain polypropylene and this showed a significant difference ($p < 0.05$) in the two packaging materials. The 90/10 cassava-OFSP composite flour blend that was added to the analysis to compare the trend of degradation of β-carotene in the 95/5 flour blend also showed a similar rate of degradation as compared to the 95/5 flour blend (Figure 4.27 and Figure 4.28). The difference in the rate of degradation could be attributed to some physical and biochemical factors like temperature, light and oxygen. Kidmose *et al*. (2006) reported that some of the physical and biochemical factors that enhances the degradation of β-carotene are temperature, light and oxygenation. Increasing the effect of these factors enhances the degradation of β-carotene in the sample. The plain polypropylene bags absorb more light because of its transparent nature and also due to the pores in the plain polypropylene bags allow some amount of atmospheric oxygen transmission to increase the rate of degradation of β-carotene.

On the contrary, there is an inner liner of plain polyethylene inside of the paper pouches. The brown paper serves as an opaque body and prevents the penetration of light. It also has much reduced air spaces and together with

the inner polyethylene liner reduces the amount of oxygen transmission through the packaging material and this minimizes the rate of β-carotene degradation.

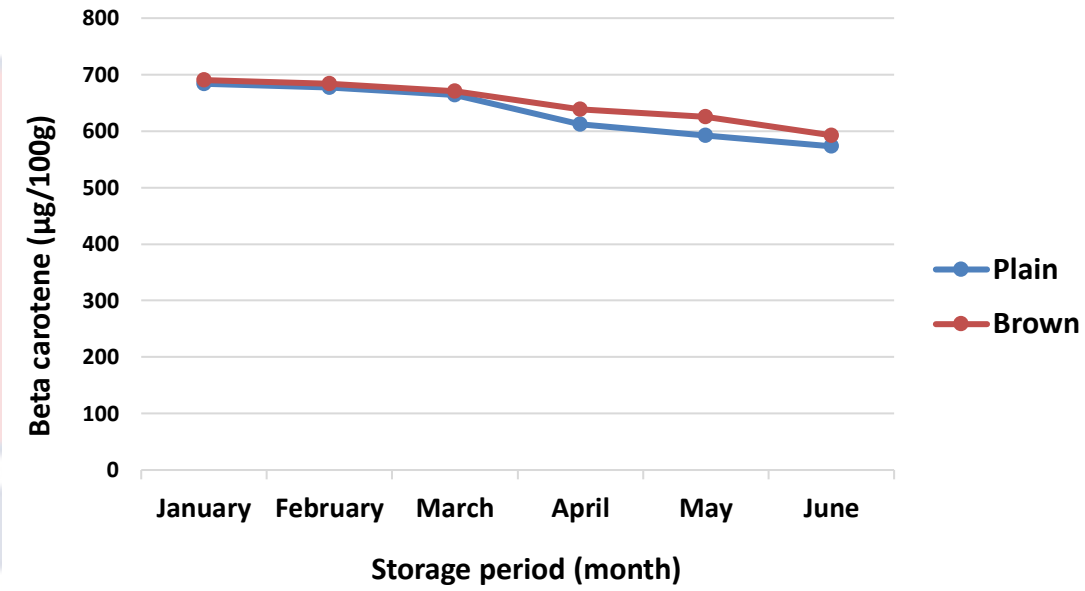


Figure 4.47: Stability of beta-carotene in shelf-life analysis for composite flour 95/5

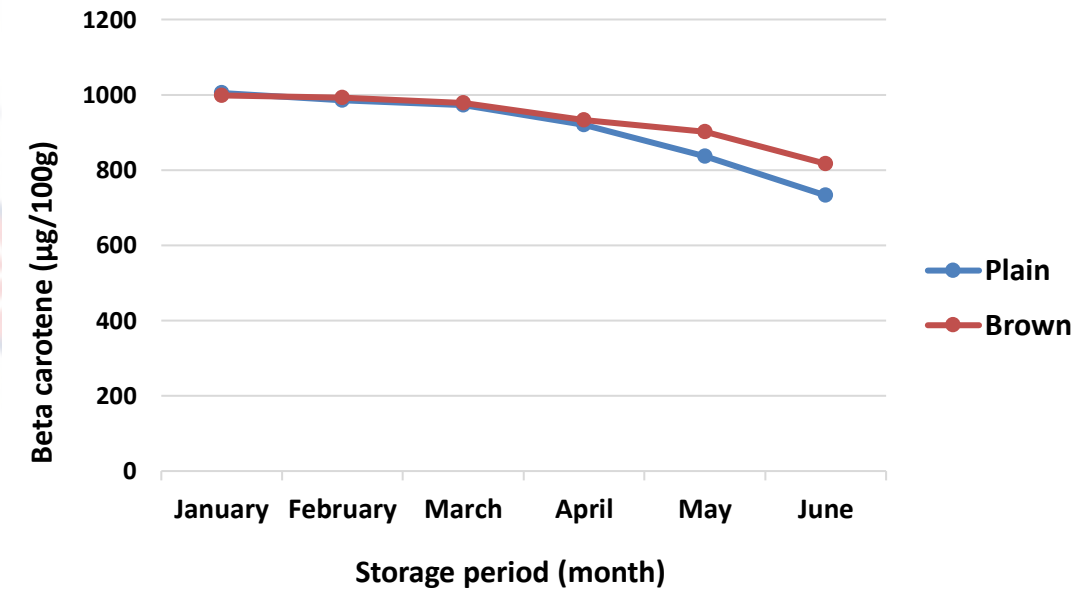


Figure 4.58: Stability of beta-carotene in shelf-life analysis for composite flour 90/10

The light and oxygen are two main factors that help to speed up the degradation rate of β-carotene and this could be the reason why the rate of degradation in the plain polypropylene packaging material was higher than that of the paper polyethylene laminated packaging material. Kidmose *et al.* (2006) reported that it is very essential to control these factors (temperature, light and oxygen) so as to improve the retention of β-carotene in the processed food crop or product throughout the storage life period. Egyir and Yeboah (2010) reported that most of the commercially processed composite 'fufu' flour even though are packaged in opaque polypropylene bags are also put in paper cartoons to prevent the effect of light and oxygen so as to enhance its storability and marketability.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

Innovations in food processing have led to expansions in dietary varieties developed from composite food products in which nutrients from one crop is used to fortify the main product as an alternative to agronomic bio-fortified foods. The OFSP is being pushed for consumption as a public health tool to treat vitamin A deficiency, and the technique of food-to-food fortification technique was employed in this research to improve the nutritional content and quality of processed food items for healthy population development. The OFSP was used as the food fortifier in this study. Hence, this study investigated the opportunities for processing 'fufu' with OFSP as a nutrient fortifying ingredient and established the processing requirements and pathways for delivering it as a nutrient-rich, acceptable food product to the consuming public to improve their health especially with respect to their vitamin A status. The study provided information on the hot-air drying characteristics of locally bred cassava (*Capevars bankye*) and OFSP (*Apomuden*) samples, the moisture sorption behaviours of the composite flour blends from these two samples, the physico-nutritional, functional, pasting properties, degradation of beta-carotene in shelf-life analysis, microbial composition of the composite 'fufu' flour blends as well as sensory evaluation of the cooked 'fufu' from the composite cassava and OFSP flour blends.

5.1 Summary of key findings

The application of hot-air drying resulted in a significant decrease in moisture content with time. The temperature for drying the cassava and OFSP samples (70 °C and 60 °C respectively) was appropriate for drying these root tubers. The moisture curves of both cassava and OFSP samples exhibited a single falling rate during drying. The values recorded for moisture diffusivity in this study were 2.36 x 10^{-8} m^2/s and 4.60 x 10^{-8} m^2/s for cassava and OFSP samples, respectively. These values were within the range of moisture diffusivity for drying agricultural food commodities. Results obtained from fitting the experimental data to the drying models used in this study showed that all four drying models used could satisfactorily describe the drying kinetics of the cassava and OFSP samples, but the Page model best described the drying kinetics of both samples and was therefore selected as the most appropriate model for simulating the drying characteristics of both the cassava and OFSP samples.

The moisture sorption isotherm analyses showed that the equilibrium moisture content increased at room temperature with increasing water activity for all the varying composite blends. The isotherms showed a sigmoidal shape which was typical of foodstuffs. Results obtained from fitting the experimental data to the sorption isotherm models also showed that all the four moisture sorption models applied in this study could also satisfactorily describe the moisture sorption behaviour of the various composite flour blends analyzed. However, the GAB model best described the sorption isotherm of the various composite flour blends and was also chosen as the most appropriate model for

simulating the moisture sorption behaviour for the composite 'fufu' flour blending ratios.

For proximate analysis, the moisture content of the individual flours analyzed on a dry weight basis (db) showed that both samples (cassava and OFSP) were well-dried. The values recorded for moisture content were below the 14.5% (db) level recommended by the American Association of Cereal Chemists (AACC, 2000) for all flour samples. The OFSP flour recorded higher values in ash, protein, fat, and fibre contents, resulting in higher energy content for all the composite flour blends with cassava flour as the substitution levels of OFSP flour increased in the blending ratios. The mineral and vitamin composition in the composite flour samples showed a similar trend since there was a significant increase in iron, zinc, vitamin C and A as the incorporation levels of OFSP flour increased in the blending ratios. Thus, the addition of OFSP flour improved the phytochemical composition of the composite flour blends as the percentage levels of OFSP flour increased in the blending ratios, especially with the phenol and flavonoids.

The physical and functional composition in the composite flour blend also showed a significant increase in the bulk density, water absorption capacity, and swelling index as the substitution levels of the OFSP flour increased, but it was the reverse in the case of the starch content, and this was attributed to the soluble sugars in the sweet potato. The colour of the cooked 'fufu' also had an effect on consumer likeness on sensory evaluation. Increasing the substitution levels of OFSP in the flour blends significantly affected (decreased) the pasting characteristics of the 'fufu' flour with respect to an increase in pasting temperature and time. The low level of microbial

count for the various microorganisms analyzed with no detection of the major aflatoxin metabolites signified the safeness of the most preferred fortified 'fufu' for consumption. The sensory evaluation also showed that the 95/5% (cassava/OFSP) composite 'fufu' was the most preferred by the sensory panelists as it exhibited good consistency and elasticity. Taking into consideration any losses of β-carotene during cooking, the most preferred composite 'fufu' blend (95/5) could potentially contribute about 38–77% of the recommended dietary allowance (RDA) for children within the ages of 1-13 years and 33% of the RDA for women of reproductive age. Finally, shelf-life analysis to evaluate the effect of beta-carotene degradation also showed that the most preferred composite 'fufu' flour product could stay on the shelve for at least six months to serve it nutritional purpose.

5.2 Conclusions

Processing root tubers into composite food flour requires adequate drying to reduce moisture for long term storability. This study showed a high potential of OFSP substitution for cassava in the production of 'fufu' to improve its nutritional value. Thus, OFSP flour exhibited the potential of replacing plantain, cocoyam or yam flour in the preparation of 'fufu' as it possesses more desirable nutritional composition. Sensory evaluation revealed that a substitution level of not more than 5% OFSP flour was the acceptable limit for cooking 'fufu' with good consistency (elastic texture) and desirable sensory attributes. The newly developed fortified composite 'fufu' flour product enriched with vitamin A can help fight the tenacious vitamin A malnutrition disease, a major problem in Ghana and Africa.

5.3 Recommendations

The following recommendations are made based on the findings of this study;

1. Future work could focus on adopting different drying methods for drying the root tubers used in developing the composite ‘fufu’ flour product.
2. Further work can be conducted by determining the microbial load or growth during shelf-life analyses of the most preferred flour product.
3. It is suggested that nutritional studies be performed by feeding a group of individuals (children or reproductive women) with the newly developed food product to evaluate the vitamin A status of the individuals used.
4. To evaluate the cost analysis to ascertain the economic gains in commercial production of the new developed food product.
5. To optimize the nutrition analyses and sensory evaluation of the desirable composite ‘fufu’ flour blend.

REFERENCE

AACC (2000). Approved Methods of American Association of Cereal Chemists. (10th ed.). NewYork: AACC International Press.

Abano, E. E. (2020). Microwave and blanching pretreatments for hot air drying of orange fleshed sweet potato slices (*Ipomoea batatas*). *International Journal of Food Science*, p. 2020.

Abano, E. E., & Amoah, R. S. (2015). Microwave and blanch-assisted drying of white yam (*Dioscorea rotundata*). *Food Science & Nutrition*, 3(6), 586-596.

Abano, E. E., Amoah, R. S., & Opoku, E. K. (2019). Temperature, microwave power and pomace thickness impact on the drying kinetics and quality of carrot pomace. *Journal of Agricultural Engineering*, 50(1), 28-37.

Abano, E. E., Ma, H. and Qu, W. (2011). Influence of Air Temperature on the Drying Kinetics and Quality of Tomato Slices. *J. Food Process Technology* 2:123

Abano, E. E., Quayson, E. T., Bosompem, M., & Quarm, M. (2019). β-Carotene-fortified gari: Processing variables effect on nutritional and sensory qualities. *Journal of Food Process Engineering*, 43(2), e13322.

Abdel-Aal, E. S. M., Ragaee, S., Rabalski, I., Warkentin, T., & Vandenberg, A. (2018). Nutrient content and viscosity of Saskatchewan-grown pulses in relation to their cooking quality. *Canadian Journal of Plant Science*, 99(1), 67-77.

Abdelghafor, R. F., Mustafa, A. I., Ibrahim, A. M. H., & Krishnan, P. G. (2011). Quality of bread from composite flour of sorghum and hard white winter wheat. *Advance Journal of Food Science and Technology*, 3(1), 9-15.

Abong, G. O., Muzhingi, T., & Okoth, M. W. (2020). Phytochemicals in Leaves and Roots of Selected Kenyan Orange Fleshed Sweet Potato (OFSP) Varieties. *International Journal of Food Science*, 2020.

Acheampong, P. P., Danquah, E. O., Agyeman, K., Dankwa, K. O., & Addison, M. (2021). Research and Development for Improved Cassava Varieties in Ghana: Farmers' Adoption and Effects on Livelihoods. *In Cassava-Biology, Production, and Utilization*. IntechOpen.

Adeleke, R. O. & Odedeji, J. O. (2010). Functional properties of wheat and sweet potato flour blends. *Pakistan Journal of Nutrition*, 9(6): 535-538.

Addo, A., Bart-Plange, A., & Boakye, D. M. (2009). Drying characteristics of cap and stem of mushroom. *Journal of Science and Technology* (Ghana), 29(2).

Afolabi, M. T., Black, A. G., & Adekunbi, T. K. (2016). The influence of drying on the physical properties of sweet potato slices. Agricultural Engineering International: *CIGR Journal*, 18(1), 301-313.

Aghbashlo, M., Kianmehr, M. H., Khani, S., & Ghasemi, M. (2009). Mathematical modelling of thin-layer drying of carrot. *International Agrophysics*, 23(4), 313-317.

Agyei-Poku, B. (2018). The Effect of pre-treatment and oven drying temperatures on the nutritional, antinutritional values and colour properties of the fruits of *Solanum torvum*. Kwame Nkrumah University of Science and Technology, Ghana (Doctoral dissertation).

Agyepong, J. K. (2013). Extraction of cassava (*Manihot Esculenta* Cranz) starch with the aid of pectolytic enzymes from *Saccharomyces cerevisiae* (ATCC 52712): Effects of cassava varietal differences on the process. Kwame Nkrumah University of Science and Technology, Ghana (Doctoral dissertation).

Ajala, A. S., Aboiye, A. O., Popoola, J. O., & Adeyanju, J. A. (2012). Drying characteristics and mathematical modelling of cassava chips. *Chemical and Process Engineering Research*, 4(2012), 01-09.

Alam, M. K., Rana, Z. H., & Islam, S. N. (2016). Comparison of the proximate composition, total carotenoids and total polyphenol content of nine orange-fleshed sweet potato varieties grown in Bangladesh. *Foods*, 5(3), 64.

Alam, M. K., Sams, S., Rana, Z. H., Akhtaruzzaman, M., & Islam, S. N. (2020). Minerals, vitamin C, and effect of thermal processing on carotenoids composition in nine varieties orange-fleshed sweet potato (*Ipomoea batatas* L.). *Journal of Food Composition and Analysis*, 92, 103582.

Al-Muhtaseb, A. H., McMinn, W. A. M., & Magee, T. R. A. (2004a). Water sorption isotherms of starch powders: part 1: Mathematical description of experimental data. *Journal of Food Engineering*, 61(3), 297-307.

Al-Muhtaseb, A. H., McMinn, W. A. M., & Magee, T. R. A. (2004b). Water sorption isotherms of starch powders. Part 2: Thermodynamic characteristics. *Journal of Food Engineering*, 62(2), 135-142.

Amagloh, F. K. & Coad, J. (2014). Orange-fleshed sweet potato-based infant food is a better source of dietary vitamin A than a maize-legume blend as complementary food. *Food and Nutrition Bulletin*, 35(1), 51–59.

Amagloh, F. K., Hardacre, A., Mutukumira, A. N., Weber, J. L., Brough, L., & Coad, J. (2012). Sweet potato-based complementary food for infants in low-income countries. *Food and Nutrition Bulletin*, 33(1), 3-10.

Amagloh, F. K., Weber, J. L., Brough, L., Hardacre, A., Mutukumira, A. N., & Coad, J. (2012). Complementary food blends and malnutrition among infants in Ghana: A review and a proposed solution. *Academic Journals*, 7,9.

Amagloh, F. C., Yada, B., Tumuhimbise, G. A., Amagloh, F. K., & Kaaya, A. N. (2021). The Potential of Sweetpotato as a Functional Food in Sub-Saharan Africa and Its Implications for Health: A Review. *Molecules*, 26(10), 2971.

Amoah, R. S. (2014). The effects of ethylene on sweet potato storage. PhD Thesis. Cranfield University, United Kingdom.

Amoah, R.S., & Terry, L.A. (2018). 1-Methylcyclopropene (1-MCP) effects on natural disease resistance in stored sweet potato. *Journal of the Science of Food and Agriculture*, 98, 4597-4605.

Ampofo, V. (2009). Production and sensory analysis of soybean and wheat flour composite cake. HND Dissertation, Cape Coast Polytechnic, Cape Coast, Ghana, 1, 5-7.

Andrade, R. D., Lemus, R., & Perez, C. E. (2011). Models of sorption isotherms for food: uses and limitations. *Vitae*, 18(3), 325-334.

AOAC (2016). *Official Methods of Analysis*, 16th Edition. Washington, DC: Association of Analytical Chemists, USA.

Argo, B. D., Sandra, S., & Ubaidillah, U. (2018). Mathematical modeling on the thin layer drying kinetics of cassava chips in a multipurpose convective-type tray dryer heated by a gas burner. *Journal of Mechanical Science and Technology*, 32(7), 3427-3435.

Arslan, N., & Togˇrul, H. (2006). The fitting of various models to water sorption isotherms of tea stored in a chamber under controlled temperature and humidity. *Journal of Stored Products Research*, 42(2), 112-135.

Asadi, K., Ferguson, L. R., Philpott, M., & Karunasinghe, N. (2017). Cancer-preventive properties of an anthocyanin-enriched sweet potato in the APCMIN Mouse Model. *Journal of Cancer Prevention*, 22(3), 135.

Asafu-Agyei, J. N. (2010). Ghana Sweet potato Improvement Programme. CSIR-CRI Conference on Research for Development, Cape Coast, Ghana. April, 2010.

Ashun, E. K. (2018). Orange fleshed sweet potato: its use in complementary infant formula. University of Cape Coast, Ghana (Doctoral dissertation).

Atuna, R. A., Deborah, N., & Amagloh, F. K. (2020). Composite spaghetti has good consumer acceptability and a significant source of dietary vitamin A. *Food Proc Nutr Sci*, 1(1), 25-30.

Awuchi, C. G., Igwe, V. S., & Echeta, C. K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research*, 5(11), 139-160.

Bamidele, O. P., Fasogbon, M. B., Oladiran, D. A., & Akande, E. O. (2015). Nutritional composition of fufu analog flour produced from Cassava root (Manihot esculenta) and Cocoyam (Colocasia esculenta) tuber. *Food Science & Nutrition*, 3(6), 597-603.

Bashiri, A., Burstein, E., Sheiner, E., & Mazor, M. (2003). Anaemia during pregnancy and treatment with intravenous iron: review of the literature. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 110(1), 2-7.

Basu, S., Shivhare, U. S., & Mujumdar, A. S. (2006). Models for sorption isotherms for foods: A review. *Drying Technology*, 24(8), 917-930.

Bayata, A. (2019). Review on nutritional value of cassava for use as a staple food. *Science Journal of Analytical Chemistry*, 7(4), 83-91.

Bayitse, R., Tornyie, F., & Bjerre, A. B. (2017). Cassava cultivation, processing and potential uses in Ghana. Handbook on Cassava. *Nova Science Publishers, Inc*, 313-333.

Bechoff, A., Chijioke, U., Tomlins, K. I., Govinden, P., Ilona, P., Westby, A., & Boy, E. (2015). Carotenoid stability during storage of yellow gari made from biofortified cassava or with palm oil. *Journal of Food Composition and Analysis*, 44, 36-44.

Bechoff, A., Dufour, D., Dhuique-Mayer, C., Marouzé, C., Reynes, M., & Westby, A. (2009). Effect of hot air, solar and sun drying treatments on provitamin A retention in orange-fleshed sweetpotato. *Journal of Food Engineering*, 92(2), 164-171.

Bechoff, A., Tomlins, K., Dhuique-Mayer, C., Dove, R., & Westby, A. (2011). On-farm evaluation of the impact of drying and storage on the carotenoid content of orange-fleshed sweet potato (*Ipomea batatas* Lam.). *International Journal of Food Science & Technology*, 46(1), 52-60.

Bechoff, A., & Dhuique-Mayer, C. (2016). Factors influencing micronutrient bioavailability in biofortified crops. *Annals of the New York Academy of Sciences*, 1390, 74-87.

Bechoff, A., Dhuique-Mayer, C., Dornier, M., Tomlins, K. I., Boulanger, R., Dufour, D., & Westby, A. (2010). Relationship between the kinetics of β-carotene degradation and formation of norisoprenoids in the storage of dried sweet potato chips. *Food Chemistry*, 121(2), 348-357.

Bengtsson, A., Namutebi, A., Alminger, M. L., & Svanberg, U. (2008). Effects of various traditional processing methods on the all-trans-β-carotene content of orange-fleshed sweet potato. *Journal of Food Composition and Analysis*, 21(2), 134-143.

Biesiekierski, J. R. (2017). What is gluten. *Journal of gastroenterology and hepatology*, 32, 78-81.

Bjarnadottir, A. (2019). Sweet potatoes: Nutrition facts and health benefits. Retrieved from: https://www.healthline.com/nutrition/foods/sweet-potatoes. Accessed on August 8, 2021

Blahovec, J., & Yanniotis, S. (2009). Modified classification of sorption isotherms. *Journal of Food Engineering*, 91(1), 72-77.

Borel, P., & Desmarchelier, C. (2018). Bioavailability of fat-soluble vitamins and phytochemicals in humans: effects of genetic variation. *Annual Review of Nutrition*, 38, 69-96.

Bovell-Benjamin, A. C. (2007). Sweet potato: a review of its past, present, and future role in human nutrition. *Advances in Food and Nutrition Research*, 52, 1-59.

Brett, B., Figueroa, M., Sandoval, A. J., Barreiro, J. A., & Müller, A. J. (2009). Moisture sorption characteristics of starchy products: oat flour and rice flour. *Food Biophysics*, 4(3), 151-157.

Brinley, T.A., Truong, V.D., Coronel, P. Simunovic, J. and Sandeep, K.P. (2008). Dielectric properties of sweet potato puree at 915 MHz as affected by temperature and chemical composition. *International Journal of Food Properties*, 11: 158-172.

Brunauer, S., Deming, L. S., Deming, W. E., & Teller, E. (1940). On a theory of the van der Waals adsorption of gases. *Journal of the American Chemical Society*, 62(7), 1723-1732.

Brunauer, S., Emmett, P. H., & Teller, E. (1938). Adsorption of gases in multimolecular layers. *Journal of the American Chemical Society*, 60 (2), 309-319.

Burt, A. J., Grainger, C. M., Young, J. C., Shelp, B. J., & Lee, E. A. (2010). Impact of postharvest handling on carotenoid concentration and composition in high-carotenoid maize (*Zea mays* L.) kernels. *Journal of Agricultural and Food Chemistry*, 58(14), 8286-8292.

Butt, M. S., & Rizwana, B. (2010). Nutritional and functional properties of some promising legumes protein isolates. *Pakistan Journal of Nutrition*, 9(4), 373-379.

Bouis, H. E. & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security*, 12: 49-58.

CAC (2011), Guidelines on formulated supplementary foods for older infants and young children, Proposed Draft Revision, Codex Alimentarius Commission, Joint FAO/WHO Food Standards Programme, Codex Committee on Nutrition and Foods for Special Dietary Uses, CX/NFSDU 11/33/8.

CAC/GL 08 (1999). Codex Alimentarius: Guidelines on Formulated Supplementary Foods for Older Infants and Young Children. Vol. 4, FAO/WHO Joint Publications: 144.

Carpenter, R.P., Lyon, D.H. & Hasdell, T.A. (2000), Guidelines for sensory analysis in food product development and quality control, 2nd edition, Maryland: Aspen Publishers, pp 1-6.

Carvalho, L. J., Oliveira, A. G., Godoy, R. O., Pacheco, S., Nutti, M., de Carvalho, J. V. & Fukuda, W. (2012). Retention of total carotenoid and β-carotene in yellow sweet cassava (Manihot esculenta Crantz) after domestic cooking. *Food & Nutrition Research*, 56(1), 15788.

Capuano, E., Oliviero, T., Fogliano, V., & Pellegrini, N. (2018). Role of the food matrix and digestion on calculation of the actual energy content of food. *Nutrition Reviews*, 76(4), 274-289.

Cevallos-Casals, B. A., & Cisneros-Zevallos, L. (2003). Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweetpotato. *Journal of Agricultural and Food Chemistry*, 51(11), 3313-3319.

CGIAR (The Consultative Group on International Agricultural Research) (2010). Biofortified orange-fleshed sweet potato. Retrieved from: https://www.cgiar.org/innovations/biofortified-orange-fleshed-sweetpotato/ Accessed on March 18, 2021

Chadare, F. J., Madode, Y. E., Fanou-Fogny, N., Kindossi, J. M., Ayosso, J. O., Honfo, S. H. & Hounhouigan, D. J. (2018). Indigenous food ingredients for complementary food formulations to combat infant malnutrition in Benin: A review. *Journal of the Science of Food and Agriculture*, 98(2), 439-455.

Chandra, S., Singh, S., & Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Journal of Food Science and Technology*, 52(6), 3681-3688.

Chandrasekara, A., & Kumar, J. T. (2016). Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. *International Journal of Food Science*, 2016: 1–15.

Chikpah, S. K., Korese, J. K., Hensel, O., & Sturm, B. (2020). Effect of sieve particle size and blend proportion on the quality properties of peeled and unpeeled orange fleshed sweet potato composite flours. *Foods*, 9(6), 740.

Cholo, A. (2020). Evaluation and demonstration of new food product of enset, orange fleshed sweet potato and finger millet blends for alleviation of nutritional insecurity. Retrieved from: https://www.alliedacademies.org/articles/evaluation-and-demonstration-of-new-food-product-of-enset-orange-fleshed-sweet-potato-and-finger-millet-blends-for-allev.pdf. Accessed on April 13, 2021.

CIP-International Potato Centre (2021). Sweet potato facts and figures. International Potato Centre, Lima, Peru. Retrieved from: https://cipotato.org/sweetpotato/sweetpotato-facts-and-figures/ Accessed on May 16, 2021.

Clifford, I. O., Kingsley, E., Chika, C. O., & Chinyere, I. I. (2014). Effects of osmotic dewatering and oven drying on β-carotene content of sliced light yellow-fleshed sweet potato (*Ipomea batatas* l.). *Nigerian Food Journal*, 32(2), 25-32.

Conaway, H. H., Henning, P., & Lerner, U. H. (2013). Vitamin a metabolism, action, and role in skeletal homeostasis. *Endocrine Reviews*, 34(6), 766-797.

Connor, A. M., Luby, J. J., & Tong, C. B. (2002). Variation and heritability estimates for antioxidant activity, total phenolic content, and anthocyanin content in blueberry progenies. *Journal of the American Society for Horticultural Science*, 127(1), 82-88.

Cosme-De Vera, F. H., Soriano, A. N., Dugos, N. P., & Rubi, R. V. C. (2021). A comprehensive review on the drying kinetics of common tubers. *Applied Science and Engineering Progress*, 14(2), 146-155.

Costa, A.I.A. & Jongen, W.M.F. (2006). New insights into consumer-led food product development. *Trends in Food Science and Technology*, 17: 457-465.

Cotty, P. J., & Jaime-Garcia, R. (2007). Influences of climate on aflatoxin producing fungi and aflatoxin contamination. *International Journal of Food Microbiology*, 119(1-2), 109-115.

Dada, T. A., Barber, L. I., Ngoma, L., & Mwanza, M. (2017). Formulation, sensory evaluation, proximate composition and storage stability of cassava strips produced from the composite flour of cassava and cowpea. Journal of *Food Science & Nutrition*, 6(2), 395-399.

Dadzie, R. (2018). Effect of edible coatings on the postharvest quality of eggplant (*Solanum aethiopicum* L.) Fruits during low temperature storage. University of Cape Coast, Ghana (Doctoral dissertation).

Dako, E., Rotta, N. & Desse, G. (2016). Effect of Blending on selected sweet potato. *Global Journal of Science Frontier Research: D Agriculture and Veterinary*, 16 (4): 31-41.

D'Ambrosio, D. N., Clugston, R. D., & Blaner, W. S. (2011). Vitamin A metabolism: an update. *Nutrients*, 3(1), 63-103.

Dansby, M. Y., & Bovell-Benjamin, A. C. (2003). Production and proximate composition of a hydroponic sweet potato flour during extended storage. *Journal of Food Processing and Preservation*, 27(2), 153-164.

Darko-Koomson, S., Aidoo, R., & Abdoulaye, T. (2020). Analysis of cassava value chain in Ghana: implications for upgrading smallholder supply systems. *Journal of Agribusiness in Developing and Emerging Economies*, 10(2), 217-235.

Dary, O., & Hurrell, R. (2006). Guidelines on food fortification with micronutrients. Geneva: World Health Organization, Food and Agricultural Organization of the United Nations.

de Albuquerque, T. M. R., Sampaio, K. B., & de Souza, E. L. (2019). Sweet potato roots: Unrevealing an old food as a source of health promoting bioactive compounds–A review. *Trends in Food Science & Technology*, 85, 277-286.

De Benoist, B., Dary, O., & Hurrell, R. (2006). Guidelines on food fortification with micronutrients (Vol. 126). L. Allen (Ed.). Geneva: World Health Organization.

Del Rio, D., Rodriguez-Mateos, A., Spencer, J. P., Tognolini, M., Borges, G., & Crozier, A. (2013). Dietary (poly) phenolics in human health: structures, bioavailability, and evidence of protective effects against chronic diseases. *Antioxidants & Redox Signaling*, 18(14), 1818-189 2.

Dereje, B., Girma, A., Mamo, D., & Chalchisa, T. (2020). Functional properties of sweet potato flour and its role in product development: a review. *International Journal of Food Properties*, 23(1), 1639-1662.

Dery, E. K. (2012). The Effect of Drying Methods (Catalytic Flameless Infrared—CFIR, Oven and Solar Drying) on the Quality of Sweet Potato Flour. Department of Biochemistry and Biotechnology, College of Science, Kwame Nkrumah University of Science and Technology, Ghana (Doctoral dissertation).

Dietz, W. H., & Robinson, T. N. (2005). Overweight children and adolescents. *New England Journal of Medicine*, 352(20), 2100-2109.

Dhingra, S., & Jood, S. (2002). Organoleptic and nutritional evaluation of wheat breads supplemented with soybean and barley flour. *Food Chemistry*, 77(4), 479-488.

Drago, S. R. (2017). Minerals. In Nutraceutical and functional food components (pp. 129-157). Academic Press.

Duangchuen, J., Pathaveerat, S., Noypitak, S., & Jermwongruttanachai, P. (2021). Effect of spray drying air temperature to the changes of properties of skimmed coconut milk powder. *Applied Science and Engineering Progress*, 14(2), 187-195.

Dutta, D., Dutta, A., Raychaudhuri, U., & Chakraborty, R. (2006). Rheological characteristics and thermal degradation kinetics of beta-carotene in pumpkin puree. *Journal of Food Engineering*, 76(4), 538-546.

Earle, M., Earle, R. & Anderson, A. (2001), Food product development, Cambridge England: Wood Head Publishing Limited, pp. 1-2.

Effiong, B. N., Maduka, N., & Essien, A. G. (2018). Evaluation of wheat and orange-fleshed sweet potato composite flour fortified with African yam bean flour for instant noodle production. *Archives of Current Research International*, 1-15.

Egyir, I. & Yeboah, B. (2010). "Fufu" flour processing in Ghana: Costs, returns and institutional support expected to encourage young entrepreneurs. *Ghana Journal of Agricultural Science*, 42: 1-2.

Edema, O., Sanni, O., & Sanni, I. (2005). Evaluation of Maize- Soybean Flour for Sour Maize Bread Production in Nigeria. *African Journal of Biotechnology*, 4(9), 911-918.

Eglezos, S. (2010). Microbiological quality of wheat grain and flour from two mills in Queensland, Australia. *Journal of Food Protection*, 73(8), 1533-1536.

Eleazu, C. O., & Ironua, C. (2013). Physicochemical composition and antioxidant properties of a sweetpotato variety (Ipomoea batatas L) commercially sold in South Eastern Nigeria. *African Journal of Biotechnology*, 12(7).

Ejoh, A. R., Tanya, A. N., Djuikwo, N. V., & Mbofung, C. M. (2005). Effect of processing and preservation methods on vitamin C and total carotenoid levels of some Vernonia (bitter leaf) species. *African journal of food, Agriculture, Nutrition and Development*, 5(2).

Ellong, E. N., Billard, C., & Adenet, S. (2014). Comparison of physicochemical, organoleptic and nutritional abilities of eight sweet potato (*Ipomoea batatas*) varieties. *Food Nutrition and Science*, 5(2), 196- 210.

El-Sheikha, A. F., & Ray, R. C. (2017). Potential impacts of bioprocessing of sweet potato. *Critical Reviews in Food Science and Nutrition*, 57(3), 455-471.

Eshelli, M., Harvey, L., Edrada-Ebel, R., & McNeil, B. (2015). Metabolomics of the bio degradation process of aflatoxin B_1 by actinomycetes at an initial pH of 6.0. *Toxins*, 7(2), 439-456.

Essono, G., Ayodele, M., Akoa, A., Foko, J., Filtenborg, O., & Olembo, S. (2009). Aflatoxin producing Aspergillus spp. and aflatoxin levels in stored cassava chips as affected by processing practices. *Food Control*, 20(7), 648-654.

Fabra, M. J., Talens, P., Moraga, G., & Martínez-Navarrete, N. (2009). Sorption isotherm and state diagram of grapefruit as a tool to improve product processing and stability. *Journal of Food Engineering*, 93(1), 52-58.

Failla, M. L., Chitchumroonchokchai, C., Siritunga, D., De Moura, F. F., Fregene, M., Manary, M. J., & Sayre, R. T. (2012). Retention during processing and bioaccessibility of β-carotene in high β-carotene transgenic cassava root. *Journal of Agricultural and Food Chemistry*, 60(15), 3861-3866.

Famurewa, J. A., & Emuekele, P. O. (2015). Modelling of drying pattern of cassava chips at different air velocity and temperature using fluidized bed dryer. *International Journal of Agricultural Sciences*, 5(3), 54-65.

Fana Haile, S. A., & Fisseha, A. (2015). Effects of pre-treatments and drying methods on chemical composition, microbial and sensory quality of orange-fleshed sweet potato flour and porridge. *American Journal of Food Science and Technology*, 3(3), 82-88.

FAOSTAT. (2020). Roots and tubers. Rome: FAO. Retrieve from: http://www.fao.org/faostat/en/#data/QC Accessed on March 3, 2022

FAO/WHO (2002). Vitamin A in human vitamin and mineral requirements: 87–107. Report of joint FAO/WHO expert consultation. Rome: FAO Food and Nutrition Division.

Fausat Lola, K., Mutiat Adebanke, B., & Halimat Olamide, S. O. (2017). Physical and chemical characteristics of moringa-fortified orange sweet potato flour for complementary food. Hrvatski časopis za prehrambenu tehnologiju, biotehnologiju i nutricionizam, 12(1-2), 37-43.

Fernandes, I., Marques, C., Évora, A., Faria, A., Calhau, C., Mateus, N., & de Freitas, V. (2019). Anthocyanins: Nutrition and health. *In Bioactive Molecules in Food* (pp. 1097-1133). Springer, Cham.

Finn, J. (2021). How is colour measured – Calculating Delta E. Retrieved from: https://www.alpolic-americas.com/wp-content/uploads/20 21/05/ FinalCalclulating-DE-Color-White-Paper-041221.pdf Accessed on March 9, 2022.

Fudholi, A., Ruslan, M. H., Haw, L. C., Mat, S., Othman, M. Y., Zaharim, A., & Sopian, K. (2012). Mathematical modeling of brown seaweed drying curves. *In Proceedings of the WSEAS International Conference on Applied Mathematics in Electrical and Computer Engineering,* pp. 207-211.

Gabilondo, J., Corbino, G., Chludil, H., & Malec, L. (2022). Bioactive compounds of two orange fleshed sweet potato cultivars (*Ipomoea batatas* (L.) Lam.) in fresh, stored and processed roots. *Applied Food Research*, 2(1), 100061.

GEPA (2017). Ghana Export Promotion Authority sector capabilities – Cassava from Ghana. Retrieved from: https://www.gepaghana.org/ import/ ghana-product/cassava-from-ghana/ Accessed on September 21, 2021.

Ghasemzadeh, A., & Ghasemzadeh, N. (2011). Flavonoids and phenolic acids: Role and biochemical activity in plants and human. *Journal of Medicinal Plants Research*, 5(31), 6697-6703.

Gibson, R. S., Bailey, K. B., Gibbs, M., & Ferguson, E. L. (2010). A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. *Food and Nutrition Bulletin*, 31(2_suppl2), S134-S146.

Ginting, E., & Yulifianti, R. (2015). Characteristics of noodle prepared from orange-fleshed sweet potato, and domestic wheat flour. *Procedia Food Science*, 3, 289-302.

Girard, A. W., Grant, F., Watkinson, M., Okuku, H. S., Wanjala, R., Cole, D., Carol, L. & Low, J. (2017). Promotion of orange-fleshed sweet potato increased vitamin A intakes and reduced the odds of low retinol-binding protein among postpartum Kenyan women. *Journal of Nutrition*, 147(5), 955–963.

Grabowski, J. A., Truong, V. D., & Daubert, C. R. (2008). Nutritional and rheological characterization of spray dried sweetpotato powder. LWT-*Food Science and Technology*, 41(2), 206-216.

Grace, M. H., Yousef, G. G., Gustafson, S. J., Truong, V. D., Yencho, G. C., & Lila, M. A. (2014). Phytochemical changes in phenolics, anthocyanins, ascorbic acid, and carotenoids associated with sweetpotato storage and impacts on bioactive properties. *Food Chemistry*, 145, 717-724.

Grantham-McGregor, S., Cheung, Y. B., Cueto, S., Glewwe, P., Richter, L., & Strupp, B. (2007). Child development in developing countries 1 - Developmental potential in the first 5 years for children in developing countries. *Lancet*, 369(9555), 60-70.

Gruber, W., & Sarkar, A. (2012). Durum wheat milling. In Durum Wheat (pp. 139-159). AACC International Press.

Grune, T., Lietz, G., Palou, A., Ross, A. C., Stahl, W., Tang, G. & Biesalski, H. K. (2010). Beta- carotene is an important vitamin A source for humans. *The Journal of Nutrition*, 140(12), 2268S-2285S.

Guira, F., Some, K., Kabore, D., Sawadogo-Lingani. H., Traore, Y. & Savadogo, A. (2017). Orignis, production and utilization of cassava in Burkina Faso, a contribution of a neglected crop to household food security. *Food Science and Nutrition*, 5 (3): 415-423.

Gull, A., Prasad, K., & Kumar, P. (2017). Drying kinetics of millet, pomace and wheat-based pasta and its effect on microstructure, color, water absorption and pasting properties. *Journal of Food Measurement and Characterization*, 11(2), 675-684.

Gunathilake, D. M. C. C., Senanayaka, D. P., Adiletta, G., & Senadeera, W. (2018). Drying of agricultural crops. *In Advances in Agricultural Machinery and Technologies*, (pp. 331-365). CRC Press.

Gurtler, J. B., & Keller, S. E. (2019). Microbiological safety of dried spices. *Annual Review of Food Science and Technology*, 10, 409-427.

Harrison, E. H. (2012). Mechanisms involved in the intestinal absorption of dietary vitamin A and provitamin A carotenoids. Biochimica et Biophysica Acta (BBA)-Molecular and Cell Biology of Lipids, 1821(1), 70-77.

Hasmadi, M., Siti Faridah, A., Salwa, I., Matanjun, P., Abdul Hamid, M. & Rameli, A. S. (2014). The effect of seaweed composite flour on the textural properties of dough and bread. *Journal of Applied Phycology*, 26:1057–1062.

Hassan, S.W., Umar, R. A., Maishanu, H. M., Matazu, I. K., Faruk, U. Z., & Sanni, A. A. (2007). The effects of drying method on nutrients and non-nutrients composition of leaves of *Gynandropsis gynadra* (*Capparaceae*). *Asian Journal of Biochemistry*, 2, 349-353.

Hess, S. Y., Thurnham, D. I., & Hurrell, R. F. (2005). Influence of provitamin A carotenoids on iron, zinc, and vitamin A status. *Harvest Plus Technical Monography*, 6.

Hii, C. L., Jangan, S. V., Ong, S. P., and Mujumdar, A. S. (2012). Solar Drying: Fundamentals, Applications and Innovations. Transport Phenomena Group, Singapore.

Hii, C. L., Law, C. L., & Cloke, M. (2009). Modeling using a new thin layer drying model and product quality of cocoa. *Journal of Food Engineering*, 90(2), 191-198.

Hiranvarachat, B., Suvarnakuta, P., & Devahastin, S. (2008). Isomerisation kinetics and antioxidant activities of β-carotene in carrots undergoing different drying techniques and conditions. *Food Chemistry*, 107(4), 1538-1546.

Howeler, R. H. (2001). Cassava mineral nutrition and fertilization. *In Cassava: Biology, Production and Utilization* (pp. 115-147). Wallingford UK: CABI.

Ijarotimi, S. O., & Keshinro, O. O. (2013). Determination of nutrient composition and protein quality of potential complementary foods formulated from the combination of fermented popcorn, African locust and Bambara groundnut seed flour. *Pol. J. FoodNutr. Sci.*, 63(3), 155-166.

Ikpeme, C., Osuchukwo, N., & Oshiele, L. (2010). Functional and Sensory Properties of Wheat (*Aestium triticium*) and taro flour (*Colocasia esculanta*) Composite Bread. *Africa Journal of Food Science*, 14(5), 248-253.

Inyang, U. E., Oboh, I. O., & Etuk, B. R. (2018). Kinetic models for drying techniques—food materials. *Advances in Chemical Engineering and Science*, 8(02), 27.

Ipatenco, S. (2018). Nutrition in 'fufu' Ghana. Retrieve from: https:// healthyeating.sfgate.com/nutrition-fufu-ghana-9856.html. Accessed on June 25, 2022

IPC (International Potato Centre) (2019). How sweet potato grows. International Potato Centre, Lima, Peru. Retrieved from: https://cipotato.org /sweetpotato /how-sweetpotato-grows/ Accessed on February 7, 2022.

Iqbal, K., Khan, A., & Khattak, M. M. A. K. (2004). Biological significance of ascorbic acid (Vitamin C) in human health-a review. *Pakistan Journal of Nutrition*, 3(1), 5-13.

Islam, S. (2006). Sweetpotato leaf: Its potential effects on human health and nutrition. *Journal of Food Science, 71,* 13-21.

Iwe, M. O. (2002). Handbook of Sensory Methods and Analysis. First Edition. Enugu: Rejoint Communication Ltd, pp 71.

Iwe, M. O., Onyeukwu, U., & Agiriga, A. N. (2016). Proximate, functional and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Cogent Food & Agriculture*, 2(1), 1142409.

Jahanbakhshi, A., Kaveh, M., Taghinezhad, E., & Rasooli Sharabiani, V. (2020). Assessment of kinetics, effective moisture diffusivity, specific energy consumption, shrinkage, and color in the pistachio kernel drying process in microwave drying with ultrasonic pretreatment. *Journal of Food Processing and Preservation*, 44(6), e14449.

JAOAC (1991). Quality assurance for microbiology laboratories. *Journal of Association of Analytical Chemists. Volume. 74* No. 1-3, 6th Edition. Washington, DC.

Jisha, S., Padmaja, G., Moorthy, S. N., & Rajeshkumar, K. (2008). Pre-treatment effect on the nutritional and functional properties of selected cassava-based composite flours. *Innovative Food Science and Emerging Technologies*, 9: 587–592.

Ju, R., Zheng, S., Luo, H., Wang, C., Duan, L., Sheng, Y., ... & Huang, K. (2017). Purple sweet potato attenuate weight gain in high fat diet induced obese mice. *Journal of Food Science*, 82(3), 787-793.

Julianti, E., Rusmarilin, H., & Yusraini, E. (2015). Functional and rheological properties of composite flour from sweet potato, maize, soybean and xanthan gum. *Journal of the* Saudi *Society of Agricultural Sciences*, 16(2), 171-177.

Junqueira, J. R., Corrêa, J. L. G., de Oliveira, H. M., Avelar, R. I. S., & Pio, L. A. S. (2017). Convective drying of cape gooseberry fruits: Effect of pretreatments on kinetics and quality parameters. LWT-*Food Science and Technology*, 82, 404-410.

Kassegn, H. H. (2018). Determination of proximate composition and bioactive compounds of the Abyssinian purple wheat. *Cogent Food & Agriculture*, 4(1), 1421415.

Kerac, M., Postels, D. G., Mallewa, M., Jalloh, A. A., Voskuijl, W. P., Groce, N., Gladstone, M., & Molyneux, E. (2014). The interaction of malnutrition and neurologic disability in Africa. In Seminars in pediatric neurology (Vol. 21, No. 1, pp. 42-49). WB Saunders.

Ketnawa, S., Kaur, L., Ogawa, Y., & Singh, J. (2019). Sweet potato microstructure, starch digestion, and glycemic index. In Sweet Potato (pp. 243-272). Academic Press.

Kiaya, V. (2014). Post-harvest losses and strategies to reduce them. Technical Paper on Postharvest Losses, Action Contre la Faim (ACF), 25.

Kidane, G., Abegaz, K., Mulugeta, A., & Singh, P. (2013). Nutritional analysis of vitamin A enriched bread from orange flesh sweet potato and locally available wheat flours at Samre Woreda, Northern Ethiopia. *Current Research in Nutrition and Food Science Journal*, 1(1), 49-57.

Kidmose, U., Christensen, L. P., Agili, S. M., & Thilsted, S. H. (2007). Effect of home preparation practices on the content of provitamin A carotenoids in coloured sweet potato varieties (*Ipomoea batatas* Lam.) from Kenya. *Innovative Food Science & Emerging Technologies*, 8(3), 399-406.

Kidmose, U., Yang, R. Y., Thilsted, S. H., Christensen, L. P., & Brandt, K. (2006). Content of carotenoids in commonly consumed Asian vegetables and stability and extractability during frying. *Journal of Food Composition and Analysis*, 19(6-7), 562-571.

Kofi Annan Foundation (2021). Combating hunger: New Project – Promoting orange-fleshed sweet potato (OFSP) in Ghana. Retrieved from: https://www.kofiannanfoundation.org/combatting-hunger/orange-fleshed-sweet-potato-ghana/. Accessed on March 25, 2022

Kolawole, F. L., Akinwande, B. A., & Ade-Omowaye, B. I. (2020). Physicochemical properties of novel cookies produced from orange-fleshed sweet potato cookies enriched with sclerotium of edible mushroom (*Pleurotus tuberregium*). *Journal of the Saudi Society of Agricultural Sciences*, 19(2), 174-178.

Koua, B. K., Koffi, P. M. E., Gbaha, P., & Toure, S. (2014). Thermodynamic analysis of sorption isotherms of cassava (*Manihot esculenta*). *Journal of Food Science and Technology*, 51(9), 1711-1723.

Koyama, N., Kaiser, J., Ciugu, K. & Kabiru, J. (2015). Market opportunities for commercial cassava in Ghana, Mozambique and Nigeria. IDH-The Sustainable Trade Initiative, 6: 1-77.

Krokida, M. K., & Maroulis, Z. (2001). Quality changes during drying of food materials. *Journal of Food Science and Technology*, 49(2), 33-39.

Kumar, R., & Khatkar, B. S. (2017). Thermal, pasting and morphological properties of starch granules of wheat (*Triticum aestivum* L.) varieties. *Journal of Food Science and Technology*, 54(8), 2403-2410.

Kumar, A., Pathak, H., Bhadauria, S., & Sudan, J. (2021). Aflatoxin contamination in food crops: causes, detection, and management: a review. *Food Production, Processing and Nutrition*, 3(1), 1-9.

Kurabachew, H. (2015). The role of orange fleshed sweet potato (Ipomea batatas) for combating vitamin A deficiency in Ethiopia: A review. International *Journal of Food Science and Nutrition Engineering*, 5(3): 141–146.

Laelago, T., Haile, A., & Fekadu, T. (2015). Production and quality evaluation of cookies enriched with β-carotene by blending orange-fleshed sweet potato and wheat flours for alleviation of nutritional insecurity. *International Journal of Food Science and Nutrition Engineering*, 5(5), 209-217.

Laryea, D. Wireko-Manu, F. & Oduro, I. (2018). Formulation and characterization of sweet potato-based complementary food. *Cogent Food and Agriculture*, *4*(1): 1-15.

Lebot, V. (2009). Tropical roots and tuber crops: cassava, sweet potato, yams and aroids. Crop production science in horticulture (17), CAB Books, CABI Wallingford, UK.

Lebot, V., Michalet, S., & Legendre, L. (2016). Identification and quantification of phenolic compounds responsible for the antioxidant activity of sweet potatoes with different flesh colours using high performance thin layer chromatography (HPTLC). *Journal of Food Composition and Analysis*, 49, 94-101.

Lewinsohn, E., Sitrit, Y., Bar, E., Azulay, Y., Ibdah, M., Meir, A., Yosef, E., Zamir, D. & Tadmor, Y. (2005). Not just colors—carotenoid degradation as a link between pigmentation and aroma in tomato and watermelon fruit. *Trends in Food Science & Technology*, 16(9), 407-415.

Lewu, M. N., Adebola, P. O., & Afolayan, A. J. (2010). Comparative assessment of the nutritional value of commercially available cocoyam and potato tubers in South Africa. *Journal of Food Quality*, 33(4), 461-476.

Li, H., Deng, Z., Zhu, H., Hu, C., Liu, R., Young, J. C., & Tsao, R. (2012). Highly pigmented vegetables: Anthocyanin compositions and their role in antioxidant activities. *Food Research International*, 46(1), 250-259.

Li, S., Tayie, F. A., Young, M. F., Rocheford, T., & White, W. S. (2007). Retention of provitamin A carotenoids in high β-carotene maize (Zea mays) during traditional African household processing. *Journal of Agricultural and Food Chemistry*, 55(26), 10744-10750.

Liu, L. H., Zabaras, D., Bennett, L. E., Aguas, P., & Woonton, B. W. (2009). Effects of UV-C, red light and sun light on the carotenoid content and physical qualities of tomatoes during post-harvest storage. *Food Chemistry*, 115(2), 495-500.

Loebenstein, G., & Thottappilly, G. (Eds.). (2009). The sweet potato. Springer Science & Business Media.

Lohia, N., & Udipi, S. (2015). Use of fermentation and malting for development of ready-to use complementary food mixes. *International Journal of Food and Nutritional Sciences*, 4(1), 2320 –7876.

Los, A., Ziuzina, D., Akkermans, S., Boehm, D., Cullen, P. J., Van Impe, J., & Bourke, P. (2018). Improving microbiological safety and quality characteristics of wheat and barley by high voltage atmospheric cold plasma closed processing. *Food Research International*, 106, 509-521.

Low, J. W. (2013). Biofortified crops with a visible trait: the example of orange-fleshed sweet potato in sub-Saharan Africa. *In Handbook of Food Fortification and Health*, (pp. 371-384). Humana Press, New York, NY.

Low, J., Kapinga, R., Cole, D., Loechl, C., Lynam, J., & Andrade, M. (2009). Challenge theme paper 3: nutritional impact with orange-fleshed sweet potato (OFSP). Unleashing the Potential of Sweetpotato in Sub-Saharan Africa: Current Challenges and Way Forward, 73-105.

Magallanes-López, A. M., & Simsek, S. (2021). Pathogens control on wheat and wheat flour: A review. *Cereal Chemistry*, 98(1), 17-30.

Mahadita, G. W., Jawi, M., & Suastika, K. (2016). Purple sweet potato tuber extract lowers mallondialdehyde and improves glycemic control in subjects with type 2 diabetes mellitus. *Glob. Adv. Res. J. Med. Med. Sci*, 5, 208-213.

Mahato, D. K., Lee, K. E., Kamle, M., Devi, S., Dewangan, K. N., Kumar, P., & Kang, S. G. (2019). Aflatoxins in food and feed: an overview on prevalence, detection and control strategies. *Frontiers in Microbiology*, 10, 2266.

Malavi, D. N., Muzhingi, T., & Abong, G. O. (2018). Good manufacturing practices and microbial contamination sources in orange fleshed sweet potato puree processing plant in Kenya. *International Journal of Food Science*, 2018.

Marroquín-Cardona, A. G., Johnson, N. M., Phillips, T. D., & Hayes, A. W. (2014). Mycotoxins in a changing global environment–a review. *Food and Chemical Toxicology*, 69, 220-230.

Marshall, M. R. (2010). Ash analysis. In Food analysis (pp. 105-115). Springer, Boston, MA.

Masood, S. B., Javaid, I., Ambreen, N., Hafiz, A. R. S., Mir, M. N. Q., Faiza, S. & Ahmar M. J. (2011). Effect of flour blending on bread characteristics. *Journal of Food Safety*, 13: 142-149.

Mayer, J. E., Pfeiffer, W. H., & Beyer, P. (2008). Biofortified crops to alleviate micronutrient malnutrition. *Current Opinion in Plant Biology*, 11(2), 166-170.

Mbaeyi-Nwaoha, I. E., & Obetta, F. C. (2016). Production and evaluation of nutrient-dense complementary food from millet (*Pennisetum glaucum*), pigeon pea (*Cajanus cajan*) and seedless breadfruit (*Artocarpus altillis*) leaf powder blends. *African Journal of Food Science*, 10(9), 143-156.

McMinn, W. A. M., & Magee, T. R. A. (2003). Thermodynamic properties of moisture sorption of potato. *Journal of Food Engineering*, 60 (2), 157-165.

Mepba, H. D., Eboh, L., & Nwaojigwa, S. U. (2007). Chemical composition, functional and baking properties of wheat-plantain composite flours. *African Journal of Food, Agriculture, Nutrition and Development*, 7(1).

Meridian Institute. (2009). Science and Innovation for African Agricultural Value Chains: Lessons learned in transfer of technologies to smallholder farmers in Sub-Saharan Africa. New Growth International.

Mewa, E. A., Okoth, M. W., Kunyanga, C. N., & Rugiri, M. N. (2018). Drying modelling, moisture diffusivity and sensory quality of thin layer dried beef. *Current Research in Nutrition and Food Science*, 6 (2), 552-565.

Mishra, N., & Chandra, R. (2012). Development of functional biscuit from soy flour & rice bran. *International Journal of Agricultural and Food Science*, 2(1), 14-20.

Mishra, S., Hardacre, A., & Monro, J. (2012). Food structure and carbohydrate digestibility. *Carbohydrates-Comprehensive Studies on Glycobiology and Glycotechnology*, 289-316.

Mitra, S. (2012). Nutritional Status of Orange-Fleshed Sweet Potatoes in Alleviating Vitamin A Malnutrition through a Food-Based Approach. *Journal of Nutritional and Food Sciences*, 2 (8): 6-9.

MOFA (2015). Ministry of Food and Agriculture: Catalogue of crop varieties released and registered in Ghana, 1: 2-44

Mohammed, I., Ahmed, A. R., & Senge, B. (2012). Dough rheology and bread quality of wheat chickpea flour blends. *Industrial Crops and Products*, 36(1), 196-202.

Moloto, P. I., Mosala, M., Omolola, A. O., Jideani, A. I. O., & Laurie, S. M. (2021). Optimization of hot-air drying conditions on functional properties of flour from dried South African sweet potato cultivars (Impilo and Bophelo) using the response surface methodology. *Food Science and Technology*, 41, 39-46.

Mongi, R. J., Simbano, M., Ruhembe, C., & Majaliwa, N. (2015). Development and assessment of frying characteristics, chemical composition, descriptive sensory properties and preference mapping of wheat-orange fleshed sweet potato composite swahili buns (maandazi). *Tanzania Journal of Agricultural Sciences*, 14(2).

Montagnac, J. A., Davis, C. R., & Tanumihardjo, S. A. (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. Comprehensive reviews in *Food Science and Food Safety*, 8(3), 181-194.

Moraes, M. A., Rosa, G. S., & Pinto, L. A. (2008). Moisture sorption isotherms and thermodynamic properties of apple Fuji and garlic. *International Journal of Food Science & Technology*, 43(10), 1824-1831.

Moutaleb, O. H., Amadou, I., Amza, T., & Zhang, M. (2017). Physico-functional and sensory properties of cowpea flour-based recipes (akara) and enriched with sweet potato. *Journal of Nutritional Health and Food Engineering*, 7(4), 00243.

Mugode, L., Ha, B., Kaunda, A., Sikombe, T., Phiri, S., Mutale, R., Davis, C., Tanumihardjo, S., & De Moura, F. F. (2014). Carotenoid retention of biofortified provitamin A maize (Zea mays L.) after Zambian traditional methods of milling, cooking and storage. *Journal of Agricultural and Food Chemistry*, 62(27), 6317-6325.

Muhlbauer, W. and Muller, J. (2020). Drying Atlas. Woodhead Publishing, Cambridge, England.

Mulokozi, G., & Svanberg, U. (2003). Effect of traditional open sun-drying and solar cabinet drying on carotene content and vitamin A activity of green leafy vegetables. *Plant Foods for Human Nutrition*, 58(3), 1-15.

Musilová, J., Bystrická, J., Árvay, J., & Harangózo, L. (2017). Polyphenols and phenolic acids in sweet potato (*Ipomoea batatas* L.) roots. Potravinárstvo: *Slovak Journal of Food Sciences*, 11(1), 82-87.

Mwithiga, G., & Olwal, J. O. (2005). The drying kinetics of kale (Brassica oleracea) in a convective hot air dryer. *Journal of Food engineering*, 71(4), 373-378.

Myoda, S. P., Gilbreth, S., Akins-Lewenthal, D., Davidson, S. K., & Samadpour, M. (2019). Occurrence and levels of Salmonella, enterohemorrhagic Escherichia coli, and Listeria in raw wheat. *Journal of Food Protection*, 82(6), 1022-1027.

Naderinezhad, S., Etesami, N., Poormalek Najafabady, A., & Ghasemi Falavarjani, M. (2016). Mathematical modeling of drying of potato slices in a forced convective dryer based on important parameters. *Food Science & Nutrition*, 4(1), 110-118.

Nandutu, A. M., & Howell, N. K. (2009). Nutritional and rheological properties of sweet potato based infant food and its preservation using anti-oxidants, *African Journal of Food, Agriculture, Nutrition and Development*, 9(4) 76-1090.

Narayanan, N., Beyene, G., Chauhan, R. D., Gaitan-Solis, E., Gehan, J., Butts, P., Siritunga, D., Okwuonu, I., Woll, A., Jimenez-Aguilar, D. M., Boy, E., Grusak, M. A., Anderson, P. and Taylor, N. J. (2019). Biofortification of field-grown cassava by engineering expression of an iron transporter and ferritin. *Nature Biotechnology*, 37: 144-151.

Nascimento, A. C., Mota, C., Coelho, I., Gueifão, S., Santos, M., Matos, A. S., & Castanheira, I. (2014). Characterization of nutrient profile of quinoa (*Chenopodium quinoa*), amaranth (*Amaranthus caudatus*), and purple corn (*Zea mays* L.) consumed in the North of Argentina: Proximates, minerals and trace elements. *Food Chemistry*, 148, 420-426.

National Institute of Health (2022). Vitamin A and carotenoids. Retrieved from: https://ods.od.nih.gov/factsheets/VitaminA-HealthProfessional/. Accessed on July 20, 2022

Naziri D, Quaye W, Siwoku B, Wanlapatit S, Tu VP, Ben B (2014). The diversity of postharvest losses in cassava value chains in selected developing countries. *J Agric Rural Dev Trop Subtrop* 115:111–123.

Ndife, J., Abdulraheem, L. O., & Zakari, U. M. (2011). Evaluation of the nutritional and sensory quality of functional breads produced from whole wheat and soya bean flour blends. *African Journal of Food Science*, 5(8), 466-472.

Neela, S., & Fanta, S. W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. *Journal of Food Science & Nutrition*, 7(6), 1920-1945.

Ngoma, K., Mashau, M. E., & Silungwe, H. (2019). Physicochemical and functional properties of chemically pretreated Ndou sweet potato flour. *International Journal of Food Science*, 2019.

Nielsen, S. S. (2017). Introduction to food analysis. *In Food Analysis* (pp. 3-16). Springer, Cham.

Nilufer, D., Boyacioglu, D. & Vodovotz, Y. (2008). Functionality of soy-milk powder and its components in fresh soy bread. *Journal of Food Science*, 73: 275– 281.

NMKL No. 66 (2009). Coagulase-positive *Staphylococci* enumeration in foods. 5th Ed. National Museum Kuala Lumpur – NMKL.

NMKL No. 71 (1999). *Salmonella* detection in foods. 5th Ed. National Museum Kuala Lumpur – NMKL.

NMKL No. 125 (2005). Thermo-tolerant coliform bacteria and *Escherichia coli* in food and feed. 4th Ed. National Museum Kuala Lumpur – NMKL.

Noor-Aziah, A. A., & Komathi, C. A. (2009). Acceptability attributes of crackers made from different types of composite flour. *International food research journal*, 16(4).

Noorfarahzilah, M., Lee, J. S., Sharifudin, M. S., Mohd-Fadzelly, A. B. & Hasmadi, M. (2014). Applications of composite flour in development of food products. *International Food Research Journal*, 21(6): 2061-2074.

Nyarko, A., Sarkodie-Addo, J., Adofo, K., Quaye, M. O., & Adu, J. (2022). Growth and yield characteristics of two sweet potato (*Ipomoea batatas* L.) varieties as influenced by organic and inorganic fertilizer application. *International Journal of Plant and Soil Science*, 34(17): 98-104.

Obomeghei, A. A., Olapade, A. A., & Akinoso, R. (2020). Evaluation of the chemical composition, functional and pasting properties of four varieties of Nigerian sweet potato [*Ipomoea batatas* L. (Lam.)] flour. *African Journal of Food, Agriculture, Nutrition and Development*, 20(3), 15764-15778.

Oduro-Obeng, H., & Plahar, W. A. (2017). Development, quality evaluation and estimated contribution of composite flour snack foods to nutrient requirements of young children aged 2 to 6 years. *African Journal of Food Science*, 11(9), 318-329.

OEC (Observation of Economic Complexity) (2022). Sweet potatoes, fresh or dried. Retrieved from: https://oec.world/en/profile/hs/sweet-potatoes-fresh-or-dried/. Accessed on January 24, 2022

OECD/FAO (2016). Organization for Economic Co-operation and Development -FAO Agricultural Outlook 2016-2025, OECD Publishing, Paris. Retrieve from: http://dx.doi.org/10.1787/agr_outlook-2016-en. Accessed on May 7, 2022.

Ofori, H., Akonor, P. T., & Dziedzoave, N. T. (2016a). Variations in trace metal and aflatoxin content during processing of High-Quality Cassava Flour (HQCF). *International Journal of Food Contamination*, 3(1), 1-5.

Ofori, H., Tortoe, C., Akonor, P. T., & Ampah, J. (2016b). Trace metal and aflatoxin concentrations in some processed cereal and root and tuber flour. *International Journal of Food Contamination*, 3(1), 1-6.

Ogunlakin, G. O., Oke, M. O., Babarinde, G. O., &Olatunbosun, D. G. (2012). Effect of drying methods on proximate composition and physichochemical properties of cocoyam flour. *American Journal of Food Technology*, 7(4), 245-250.

Ohizua, E. R., Adeola, A. A., Idowu, M. A., Sobukola, O. P., Afolabi, T. A., Ishola, R. O. & Falomo, A. (2017). Nutrient composition, functional, and pasting properties of unripe cooking banana, pigeon pea, and sweetpotato flour blends. *Journal of Food Science & Nutrition*, 5(3), 750-762.

Oishimaya, S. N. (2017). World leaders in sweet potato production. Retrieved from: https://www.worldatlas.com/articles/world-leaders-in-sweet-potato-production.html. Accessed on February 24, 2022.

Ojo, A., & Akande, E. A. (2013). Quality evaluation of 'gari' produced from cassava and sweet potato tuber mixes. *African Journal of Biotechnology*, 12(31).

Okafor, C. C., & Ugwu, E. E. (2013). Comparative study of pasting properties of high fibre plantain-based flour intended for diabetic food (Fufu). *World Academy of Science. Engineering and Technology International Journal of Nutrition and Food Engineering*, 7, 494-498.

Okoronkwo, N. C., Mgbakogu, C. D., & Mbaeyi-Nwaoha, I. E. (2020). Production and Evaluation of Breakfast Cereals from Rice, African Yam-bean and Orange-fleshed Sweet Potato. *Asian Food Science Journal*, 1-17.

Oladele, P. K., Leo, A. S. A., & Agboola, S. O. (2011). Evaluation of cassava mash dewatering methods. *Journal of Bioinformatics and sequence Analysis*, 3(2), 23-30.

Olapade, A. A., Babalola, Y. O., & Aworh, O. C. (2014). Quality attributes of fufu (fermented cassava) flour supplemented with bambara flour. *International Food Research Journal*, 21(5), 2025.

Oliveira, R. A., De Carvalho, M. L., Nutti, R. M., De Carvalho, L. J., & Fukuda, W. G. (2010). Assessment and degradation study of total carotenoid and ß-carotene in bitter yellow cassava (Manihot esculenta Crantz) varieties. *Africa Journal Food Science*, 4: 148–155.

Oloo, B. O., Shitandi, A., Mahungu, S., Malinga, J. B., & Ogata, B. R. (2014). Effects of lactic acid fermentation on the retention of beta-carotene content in orange-fleshed sweet potatoes. *International Journal of Food Studies*, 3, 13-33.

Oluwalana, I. B., Malomo, S. A., & Ogbodogbo, E. O. (2012). Quality assessment of flour and bread from sweet potato wheat composite flour blends. *International Journal of Biological and Chemical Sciences*, 6(1), 65-76.

Oluwamukomi, M. O., Eleyinmi, A. F., & Enujiugha, V. N. (2005). Effect of soy supplementation and its stage of inclusion on the quality of ogi–a fermented maize meal. *Food Chemistry*, 91(4), 651-657.

Omolola, A. O., Jideani, A. I., & Kapila, P. F. (2015). Drying characteristics and kinetics of banana (Musa spp., AAA group, cv.'Mabonde'). *Tropical Agriculture*, 92(3).

Ooi, C. P., & Loke, S. C. (2013). Sweet potato for type 2 diabetes mellitus. Cochrane Database Systems.

Ooi, S. F., Sukri, S. A. M., Zakaria, N. N. A., & Harith, Z. T. (2021). Carotenoids, phenolics and antioxidant properties of different sweet potatoes (Ipomoea batatas) varieties. *In IOP Conference Series: Earth and Environmental Science*, 756(1), 012077.

Oswin, C. R. (1946). The kinetics of package life. III. The isotherm. Journal of the Society of Chemical Industry, 65(12), 419-421.

Owuamanam, C. I., Ihediohanma, N. C., & Nwanekezi, E. C. (2010). Sorption isotherm, particle size, chemical and physical properties of cocoyam corm flours. *Researcher*, 2(8), 11-19.

Panche, A. N., Diwan, A. D., & Chandra, S. R. (2016). Flavonoids: an overview. *Journal of Nutritional Science*, 5.

Papageorgiou, M., & Skendi, A. (2018). Introduction to cereal processing and by-products. In Sustainable Recovery and Reutilization of Cereal Processing By-Products (pp. 1-25). Woodhead Publishing.

Patil, R. C., & Gawande, R. R. (2018). Drying characteristics of amla candy in solar tunnel greenhouse dryer. *Journal of Food Process Engineering*, 41(6), e12824.

Pękal, A., & Pyrzynska, K. (2014). Evaluation of aluminium complexation reaction for flavonoid content assay. *Food Analytical Methods*, 7(9), 1776-1782.

Pénicaud, C., Achir, N., Dhuique-Mayer, C., Dornier, M., & Bohuon, P. (2011). Degradation of β-carotene during fruit and vegetable processing or storage: reaction mechanisms and kinetic aspects: A review. *Fruits*, 66(6), 417-440.

Pereira, E. J., Carvalho, L. M., Dellamora-Ortiz, G. M., Cardoso, F. S., Carvalho, J. L., Viana, D. S., & Rocha, M. M. (2014). Effects of cooking methods on the iron and zinc contents in cowpea (Vigna unguiculata) to combat nutritional deficiencies in Brazil. *Food & Nutrition Research*, 58(1), 20694.

Petsakos, A., Prager, S. D., Gonzalez, C. E., Gama, A. C., Sulser, T. B., Gbegbelegbe, S., Enoch, M. K. & Hareau, G. (2019). Understanding the consequences of changes in the production frontiers for roots, tubers and bananas. Global food security, 20, 180-188.

Phuthego, B. L. (2014). Physico-Functional Properties of Wheat-Morama Bean Composite Flour and its Performance in Food Systems (Mphil dissertation, University of Ghana).

Pillay, K., Siwela, M., Derera, J., & Veldman, F. J. (2014). Provitamin A carotenoids in biofortified maize and their retention during processing and preparation of South African maize foods. *Journal of Food Science and Technology*, 51(4), 634-644.

Pobee, R. A., Akonor, P. T., & Bonsi, E. (2017). Orange-fleshed sweet potato based complementary food provides sufficient vitamin A for infants aged 6-12 months. *African Journal of Food Science*, 11(7), 215-222.

Pornpraipech, P., Khusakul, M., Singklin, R., Sarabhorn, P., & Areeprasert, C. (2017). Effect of temperature and shape on drying performance of cassava chips. *Agriculture and Natural Resources*, 51(5), 402-409.

Quadri, S. H., Ms, N., Kc, C., Shantaram, U., & Hs, E. (2012). An overview on chemistry, toxicity, analysis and control of aflatoxins. *Int. J. Chem. Life Sci*, 2, 1071-1078.

Qureshi, H., Hamid, S. S., Ali, S. S., Anwar, J., Siddiqui, A. A., & Khan, N. A. (2015). Cytotoxic effects of aflatoxin B1 on human brain microvascular endothelial cells of the blood-brain barrier. *Medical Mycology*, 53(4), 409-416.

Ragaee, S., & Abdel-Aal, E. S. M. (2006). Pasting properties of starch and protein in selected cereals and quality of their food products. *Food Chemistry*, 95(1), 9-18.

Rajarajan, P. N., Rajasekaran, K. M., & Devi, N. A. (2013). Aflatoxin contamination in agricultural commodities. *Indian Journal of Pharmaceutical and Biological Research*, 1(04), 148-151.

Raji, A. O., & Ojediran, J. O. (2011). Moisture sorption isotherms of two varieties of millet. *Food and Bioproducts Processing*, 89(3), 178-184.

Rajkovic, A., Smigic, N., & Devlieghere, F. (2010). Contemporary strategies in combating microbial contamination in food chain. International Journal of Food Microbiology, 141, S29-S42.

Ravisankar, P., Reddy, A. A., Nagalakshmi, B., Koushik, O. S., Kumar, B. V., & Anvith, P. S. (2015). The comprehensive review on fat soluble vitamins. *IOSR Journal of Pharmacy*, 5(11), 12-28.

Research and Markets (2019). Global cassava processing market report 2019: Industry trends, share, size, growth, opportunity and forecasts 2011-2018 and 2019-2024. Retrieved from: https://www.globenewswire.com/news-release/2019/02/21/1739470/0/en/Global-Cassava-Processing-Market-Report-2019-Industry-Trends-Share-Size-Growth-Opportunity-and-Forecasts-2011-2018-2019-2024.html. Accessed on March 15, 2022.

Rice, A. L., West Jr, K. P., & Black, R. E. (2004). Vitamin A deficiency. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors, 1, 0211-0256.

Risso, R. D. S. (2014). Etanol de batata-doce: otimização do pré-processamento da matéria-primae da hidrólise enzimática. Universidade Federal do Rio Grande do Sul. Escola de Engenharia (Masters Dissertation).

Rodrigues, N. R., Barbosa, J. L., & Barbosa, M. I. M. (2016). Determination of physico-chemical composition, nutritional facts and technological quality of organic orange and purple-fleshed sweet potatoes and its flours. *International Food Research Journal*, 23(5), 2071-2078.

Rolfes, S. R., Pinna, K., & Whitney, E. (2014). Understanding normal and clinical nutrition. Cengage Learning. 10th Edition, Library of Congress, Stamford, USA.

Rosa, G. S., Moraes, M. A., & Pinto, L. A. (2010). Moisture sorption properties of chitosan. LWT-*Food Science and Technology*, 43(3), 415-420.

Rose-Francis, K. (2021). Recommended daily intake of saturated fats. Retrieved from: https://www.medicalnewstoday.com/articles/how-much-saturated-fat-per-day Accessed on July 5, 2022

Rose, I. and Vasanthakaalam, H. (2011). Comparison of the nutrient composition of four sweet potato varieties cultivated in Rwanda. *American Journal of Food and Nutrition*, 1 (1): 34-38.

RTIMP (2008). Developing efficient and cost-effective postharvest storage technology for fresh sweetpotato roots through farmer participatory approach. Ghana's Ministry of Food and Agriculture Competitive Grant for Agricultural Research under the Root and Tuber Improvement and Marketing Programme.

Rudder, A., Ainsworth, P. & Holgate, D. (2001), new food product development: strategies for success. *British Food Journal*, 103, 657–671.

Sablani, S. S. (2006). Drying of Fruits and Vegetable: Retention of Nutritional/Functional Quality. *Drying Technology*, 24, 123-125.

Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nature Sustainability*, 2(9), 805-814.

Sahin, S., & Sumnu, S. G. (2006). Physical properties of foods. Springer Science & Business Media.

Sam, J. & Dapaah, H. (2009). Baseline Survey Report-*West African Agricultural Productivity Programme*-WAAPP-GHANA.

Samapundo, S., Devlieghere, F., De Meulenaer, B., Atukwase, A., Lamboni, Y., & Debevere, J. M. (2007). Sorption isotherms and isosteric heats of sorption of whole yellow dent corn. *Journal of Food Engineering*, 79(1), 168-175.

Sanni, L. O., Onadipe-Phorbee, O., & Alenkhe, E. B. (2012). Low-cost sustainable cassava drying technologies in West Africa: A compendium of information, design, fabrication and pilot testing. Abuja, Nigeria: *International Institute of Tropical Agriculture*, Project Report, Pp. 28

Sanoussi, A. F., Dansi, A., Bokossa-Yaou, I., Dansi, M., Egounlety, M., Sanni, L. O., & Sanni, A. (2013). Formulation and biochemical characterization of sweet potato (Ipomoea batatas) based infant flours fortified with soybeanand sorghum flours. *International Journal of Current Microbiology and Applied Sciences*, 2(7), 22-34.

Scott, G. J. (2021). A review of root, tuber and banana crops in developing countries: Past, present and future. *International Journal of Food Science & Technology*, 56(3), 1093-1114.

Sebben, J. A., Trierweiler, L. F., & Trierweiler, J. O. (2017). Orange-fleshed sweet potato flour obtained by drying in microwave and hot air. *Journal of Food Processing and Preservation*, 41(1), e12744.

Shahzadi, N., Butt, M. S., Rehman, S. U., & Sharif, K. (2005). Rheological and baking performance of composite flours. *International Journal of Agriculture and Biology*, 7(1), 100-104.

Shekhar, S., Mishra, D., Buragohain, A. K., Chakraborty, S., & Chakraborty, N. (2015). Comparative analysis of phytochemicals and nutrient availability in two contrasting cultivars of sweet potato (*Ipomoea batatas* L.). *Food Chemistry*, 173, 957-965.

Shittu, T., Raji, A. O. & Sanni, L. O. (2007). Bread from composite cassava-wheat flour: I. Effect of baking time and temperature on some physical properties of bread loaf. *Food Research International,* 40: 280–290.

Shovon, B., Abida, S., Muhammad, H. S., Muhammed, A. I., & Ahtashom, M. M. A. (2013). Analysis of the proximate composition and energy values of two varieties of onion (Allium cepa L.) bulbs of different 136 origin: A comparative study. *International Journal of Nutrition and Food Sciences*, 2(5), 246-253.

Siahmoshteh, F., Siciliano, I., Banani, H., Hamidi-Esfahani, Z., Razzaghi-Abyaneh, M., Gullino, M. L., & Spadaro, D. (2017). Efficacy of Bacillus subtilis and Bacillus amyloliquefaciens in the control of Aspergillus parasiticus growth and aflatoxins production on pistachio. *International Journal of Food Microbiology*, 254, 47-53.

Singh, J., Kaur, L., & McCarthy, O. J. (2007). Factors influencing the physico-chemical, morphological, thermal and rheological properties of some chemically modified starches for food applications—A review. *Food Hydrocolloids*, 21(1), 1-22.

Singh, J., McCarthy, O. J., & Singh, H. (2006). Physico-chemical and morphological characteristics of New Zealand Taewa (*Maori potato*) starches. *Carbohydrate Polymers*, 64(4), 569-581.

Singh, S., Riar, C. S., & Saxena, D. C. (2013). Effect of incorporating sweet potato flour to wheat flour on the quality characteristics of cookies. *African Journal of Food Science*, 2(6), 065-072.

Smith, S. E. (1947). The sorption of water vapor by high polymers. *Journal of the American Chemical Society*, 69(3), 646-651.

Solomon, M. (2005). Nutritive value of three potential complementary foods based on cereals and legumes. *African Journal of Food Agriculture Nutrition and Development*, 6, 1684-5378

Souza, A., Steward, B., & Bern, C. (2018). A modelica library for thin-layer drying of agricultural products. In *Proceedings of the American Modelica Conference* (pp. 227-235).

SRID-MoFA. (2016). Agriculture in Ghana (Facts and Figures in 2015). Statistics, Research and Information Directorate – Ministry of Food and Agriculture. Retrieved from: https://mofa.gov.gh/site/images/pdf/ AGRICULTURE-IN-GHANA-Facts-and-Figures-2015.pdf. Accessed on June 16, 2022.

Srivastava, S., Genitha, T. R., & Yadav, V. (2012). Preparation and Quality Evaluation of Flour and Biscuit from Sweet Potato. *Journal of Food Processing and Technology*, 3 (12): 1-6

Stewart-Knox, B., & Mitchell, P. (2003). What separates the winners from the losers in new food product development? *Trends in Food Science & Technology*, 14(1-2), 58-64.

Sun, Y., Pan, Z., Yang, C., Jia, Z., & Guo, X. (2019). Comparative assessment of phenolic profiles, cellular antioxidant and antiproliferative activities in ten varieties of sweet potato (*Ipomoea Batatas*) storage roots. *Molecules*, 24(24), 4476.

Suresh, C. (2013). Assessment of functional properties of different flours. *African Journal of Agricultural Research*, 8(38), 4849-4852.

Suresh, C. and Samsher, S. (2013). Assessment of functional properties of different flours. *African Journal of Agricultural Research*.8(38); 4849-4852.

Taiwo, A. F., Abowei, M. F. N., Puyate, Y. T., & Achinewhu, S. C. (2010). Effects of drying parameters on the drying kinetics of fermented ground cassava using a rotary dryer. *International Journal of Food Engineering*, 6(6).

Talsma, E. F., Brouwer, I. D., Verhoef, H., Mbera, G. N., Mwangi, A. M., Demir, A. Y., & Melse-Boonstra, A. (2016). Biofortified yellow cassava and vitamin A status of Kenyan children: a randomized controlled trial. *The American Journal of Clinical Nutrition*, 103(1), 258-267.

Tang, G. (2010). Bioconversion of dietary provitamin A carotenoids to vitamin A in humans. *The American Journal of Clinical Nutrition*, 91(5), 1468S-1473S.

Tang, Y., Cai, W., & Xu, B. (2015). Profiles of phenolics, carotenoids and antioxidative capacities of thermal processed white, yellow, orange and purple sweet potatoes grown in Guilin, China. *Food Science and Human Wellness*, 4(3), 123-132.

Taylor, R. (2015). Promoting orange-fleshed sweet potato (OFSP) in Northern Ghana – The contribution of Trax Ghana and its collaborators. Retrieved from: https://traxghana.com/2015/09/01/promoting-orange-fleshed-sweetpotato-ofsp-in-northern-ghana-the-contribution-of-trax-ghana-and-its-collaborators Accessed on May 23, 2023.

Teow, C. C., Truong, V. D., McFeeters, R. F., Thompson, R. L., Pecota, K. V., & Yencho, G. C. (2007). Antioxidant activities, phenolic and β-carotene contents of sweet potato genotypes with varying flesh colours. *Food Chemistry*, 103(3), 829–838.

Terry, L.A. (2008). Health-promoting Properties of Fruit and Vegetables. CAB International. MPG Books Group, Bodmin and King's Lynn, UK.

Teucher, B., Olivares, M., & Cori, H. (2004). Enhancers of iron absorption: ascorbic acid and other organic acids. *International Journal for Vitamin and Nutrition Research*, 74(6), 403-419.

Teye, E., Asare, A. P., Amoah, R. S. and Tetteh. J. P. (2011). Determination of the dry matter content of cassava (*Manihot esculenta*, Crantz) tubers using specific gravity. *ARPN Journal of Agricultural and Biological Science*. 6(11): 23-28

Teye, E., Agbemafle, R. & Lamptey, F. (2018). Development and examination of sweet potato flour fortified with indigenous underutilized seasonal vegetables. *Beverages*, 4 (1): 5.

Teye, E., Deha, C. I., Dadzie, R., & MacArthur, R. L. (2020). Delivering the Nutritional Needs by Food-to-Food Fortification of Staples Using Underutilized Plant Species in Africa. *International Journal of Food Science*, 2020.

Thaipong, K., Boonprakob, U., Crosby, K., Cisneros-Zevallos, L., & Byrne, D. H. (2006). Comparison of ABTS, DPPH, FRAP, and ORAC assays for estimating antioxidant activity from guava fruit extracts. *Journal of food composition and analysis*, 19(6-7), 669-675.

Thakkar, S. K., Huo, T., Maziya-Dixon, B., & Failla, M. L. (2009). Impact of style of processing on retention and bioaccessibility of β-carotene in cassava (Manihot esculanta, Crantz). *Journal of Agricultural and food chemistry*, 57(4), 1344-1348.

Tharise, N., Julianti, E., & Nurminah, M. (2014). Evaluation of physico-chemical and functional properties of composite flour from cassava, rice, potato, soybean and xanthan gum as alternative of wheat flour. *International Food Research Journal*, 21(4), 1641.

Toğrul, H., & Arslan, N. (2007). Moisture sorption isotherms and thermodynamic properties of walnut kernels. *Journal of Stored Products Research*, 43(3), 252-264.

Tortoe, C., Akonor, P. T., & Buckman, E. S. (2017). Potential uses of sweet potato-wheat composite flour in the pastry industry based on proximate composition, physicochemical, functional, and sensory properties of four pastry products. *Journal of Food Processing and Preservation*, 41(5), 13206.

Tou, E. H., Mouquet-Rivier, C., Picq, C., Traoré, A. S., Trèche, S., & Guyot, J. P. (2007). Improving the nutritional quality of ben-saalga, a traditional fermented millet-based gruel, by co-fermenting millet with groundnut and modifying the processing method. LWT-*Food Science and Technology*, 40(9), 1561-1569.

Touil, A., Chemkhi, S., & Zagrouba, F. (2014). Moisture diffusivity and shrinkage of fruit and cladode of Opuntia ficus-indica during infrared drying. *Journal of Food Processing*, 2014.

Tuffour, E. (2013). Evaluation of starch from Ghanaian sweet potato varieties as excipients for solid oral dosage forms (Doctoral dissertation). Department of Pharmaceutics, Kwame Nkrumah University of Science and Technology, Ghana.

Tunde-Akintunde, T., & Afon, A. A. (2010). Modeling of hot-air drying of pretreated cassava chips. *Agricultural Engineering International: CIGR Journal*, 12(2), 34-41.

Udoro, E. O., Anyasi, T. A., & Jideani, A. I. O. (2021). Process-induced modifications on quality attributes of cassava (Manihot esculenta Crantz) flour. *Processes*, 9(11), 1891.

Ukom, A. N., Adiegwu, E. C., Ojimelukwe, P. C., & Okwunodulu, I. N. (2019). Quality and sensory acceptability of yellow maize ogi porridge enriched with orange-fleshed sweet potato and African yam bean seed flours for infants. *Scientific African*, 6, e00194.

USAID. (2016). Nutrition strategy counter vitamin A deficiency in Ghana. Accra: The Borgen Project.

Van den Berg, C. and Bruin, S. (1981). Water activity and its estimation in food systems: Theoretical aspects. In L. B. Rockland & G. F. Stewart (Eds). Water Activity: Influences on food quality. Academic Press, New York, USA. pp. 1-61.

Van Hal, M. (2000). Quality of sweet potato flour during processing and storage. *Food Reviews International*, 16(1), 1-37.

Van Jaarsveld, P. J., Marais, D. W., Harmse, E., Nestel, P., & Rodriguez-Amaya, D. B. (2006). Retention of β-carotene in boiled, mashed orange-fleshed sweet potato. *Journal of Food Composition and Analysis*, 19(4), 321-329.

Velić, D., Bilić, M., Tomas, S., Planinić, M., Bucić-Kojić, A., & Aladić, K. (2007). Study of the drying kinetics of "Granny Smith" apple in tray drier. *Agriculturae Conspectus Scientificus*, 72(4), 323-328.

Vidal, H. G., Araujo, L. F. D., & Barbosa Junior, J. L. (2021). Drying temperatures on the functional properties of purple-fleshed sweet potato. *Ciência Rural*, 52.

Vimala, B., Nambisan, B., & Hariprakash, B. (2011). Retention of carotenoids in orange-fleshed sweet potato during processing. *Journal of Food Science and Technology*, 48(4), 520-524.

Visioli, F., Lastra, C. A. D. L., Andres-Lacueva, C., Aviram, M., Calhau, C., Cassano, A., D'Archivo, M., Foria, A., Fave, G., Fogliano, V., Llorach, R., Vitaglione, P., Zoratti, M. & Edeas, M. (2011). Polyphenols and human health: a prospectus. *Critical Reviews in Food Science and Nutrition*, 51(6), 524-546.

Walker, C.E., & Eustace, W.D. (2016). Milling and Baking: History Encyclopedia of Food Grains. 2nd edition, *Elsevier Limited*, 3, 299–305.

Wall, G., & Winger, R. (2006). Food product innovation: A background paper. Food and Agriculture Organization of the United Nations, Rome.

Walstra, P. (2003). Physical chemistry of foods. Marcel Dekker, Inc. New York, United States of America. pp. 253-255.

Wang, S., Nie, S., & Zhu, F. (2016). Chemical constituents and health effects of sweet potato. *Food Research International*, 89, 90-116.

Ware, M. (2019). Nutritional Composition and Health Benefits of Sweet Potato. Retrieved from: https://www.medicalnewstoday.com/articles/ 2814 38.php. Accessed on April 12, 2022.

Waré, L. Y., Nikièma, A. P., Meile, J. C., Kaboré, S., Fontana, A., Durand, N., Montet, D. & Barro, N. (2018). Microbiological safety of flours used in follow up for infant formulas produced in Ouagadougou, Burkina Faso. *AIMS Microbiology*, 4(2), 347.

Wilaipon, P. (2013). Cassava chip drying by using a small-scale hot-air microwave oven. *American Journal of Engineering and Applied Sciences*, 6(2), 211-215.

Winger, R. & Wall, G. (2006). Food product innovation: A background paper. Food and Agriculture Organization of the United Nations, Rome.

Wong, C. (2019). The health benefits of cassava. Retrieved from: https://the-health-benefits-of-cassava-88619/ Accessed on December 8, 2021

World Bank (2005). Repositioning Nutrition as Central to Development: A Strategy for Large Scale Action. Washington D.C: The World Bank.

Xu, J., Su, X., Lim, S., Griffin, J., Carey, E., Katz, B., Tomich, J., Smith, J. S., & Wang, W. (2015). Characterization and stability of anthocyanins in purple-fleshed sweet potato P40. *Food Chemistry*, 186, 90-96.

Yan, Z., Sousa-Gallagher, M. J., & Oliveira, F. A. (2008). Effect of temperature and initial moisture content on sorption isotherms of banana dried by tunnel drier. *International Journal of Food Science & Technology*, 43(8), 1430-1436.

Zaidul, I. S. M., Yamauchi, H., Kim, S. J., Hashimoto, N., & Noda, T. (2007). RVA study of mixtures of wheat flour and potato starches with different phosphorus contents. *Food Chemistry*, 102(4), 1105-1111.

Zhang, Q. A., Song, Y., Wang, X., Zhao, W. Q., & Fan, X. H. (2016). Mathematical modeling of debittered apricot (Prunus armeniaca L.) kernels during thin-layer drying. *CyTA-Journal of Food*, 14(4), 509-517.

Zhang Z., Wheatley, C. and Corke H. (2002). Biochemical changes during storage of sweet potato roots differing in dry matter content. *Postharvest Biology and Technology*, 24, 317-325.

Zhang, K., Wu, Z., Tang, D., Lv, C., Luo, K., Zhao, Y., Liu, X., Huang, Y., & Wang, J. (2016). Development and identification of SSR markers associated with starch properties and β-carotene content in the storage root of sweet potato (Ipomoea batatas L.). *Frontiers in plant science*, 7, 223.

Zhang, Y., Zhang, T., Liang, Y., Jiang, L., & Sui, X. (2021). Dietary bioactive lipids: a review on absorption, metabolism, and health properties. *Journal of Agricultural and Food Chemistry*, 69(32), 8929-8943.

Zhang, J., Zheng, N., Liu, J., Li, F. D., Li, S. L., & Wang, J. Q. (2015). Aflatoxin B1 and aflatoxin M1 induced cytotoxicity and DNA damage in differentiated and undifferentiated Caco-2 cells. *Food and Chemical Toxicology*, 83, 54-60.

Ziska, L. H., Runion, G. B., Tomecek, M., Prior, S. A., Torbet, H. A., & Sicher, R. (2009). An evaluation of cassava, sweet potato and field corn as potential carbohydrate sources for bioethanol production in Alabama and Maryland. *Biomass and Bioenergy*, 33(11), 1503-1508.

APPENDICES

APPENDIX A

ETHICAL CLEARNCE

UNIVERSITY OF CAPE COAST

INSTITUTIONAL REVIEW BOARD SECRETARIAT

TEL: 0558093143 / 0508878309
E-MAIL: irb@ucc.edu.gh
OUR REF: UCC/IRB/A/2016/970
YOUR REF:
OMB NO: 0990-0279
IORG #: IORG0009096

3RD JUNE, 2021

Mr. Samuel Younge
Department of Agricultural Engineering
University of Cape Coast

Dear Mr. Younge,

ETHICAL CLEARANCE – ID (UCCIRB/CANS/2021/16)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted Provisional Approval for the implementation of your research **Drying Kinetics and Physico-nutritional Characterization of Composite 'Fufu' Flour from Cassava and Orange-Fleshed Potato.** This approval is valid from 3rd June, 2021 to 2nd June, 2022. You may apply for a renewal subject to submission of all the required documents that will be prescribed by the UCCIRB.

Please note that any modification to the project must be submitted to the UCCIRB for review and approval before its implementation. You are required to submit periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

Always quote the protocol identification number in all future correspondence with us in relation to this protocol.

Yours faithfully,

Samuel Asiedu Owusu, PhD
UCCIRB Administrator

ADMINISTRATOR
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST

APPENDIX B

SENSORY EVALUATION FORM

ACCEPTABILITY TEST

Name ..... Date .....

Instruction: You have been served with instant 'fufu' samples. Please examine and give your degree of likeness using the scale below. Please remember to rinse your mouth with water before tasting each sample. Thank you.

Scale	Interpretation
9	Like Extremely
8	Like Very Much
7	Like Moderately
6	Like Slightly
5	Neither Like nor Dislike
4	Dislike Slightly
3	Dislike Moderately
2	Dislike Very Much
1	Dislike Extremely

Attributes	Sample Code					
Appearance						
Aroma						
Color						
Texture (Hand feel)						
Taste						
After Taste						
Overall Acceptability						

APPENDIX C

SOME EQUIPMENT AND INSTRUMENT USED FOR ANALYSES

Cassava grater for milling the cassava into pulp

Peeled and washed cassava to be milled

Feeding the hopper of the cassava grater with cassava sample for milling

Double screw press – for removing water from the milled cassava pulp

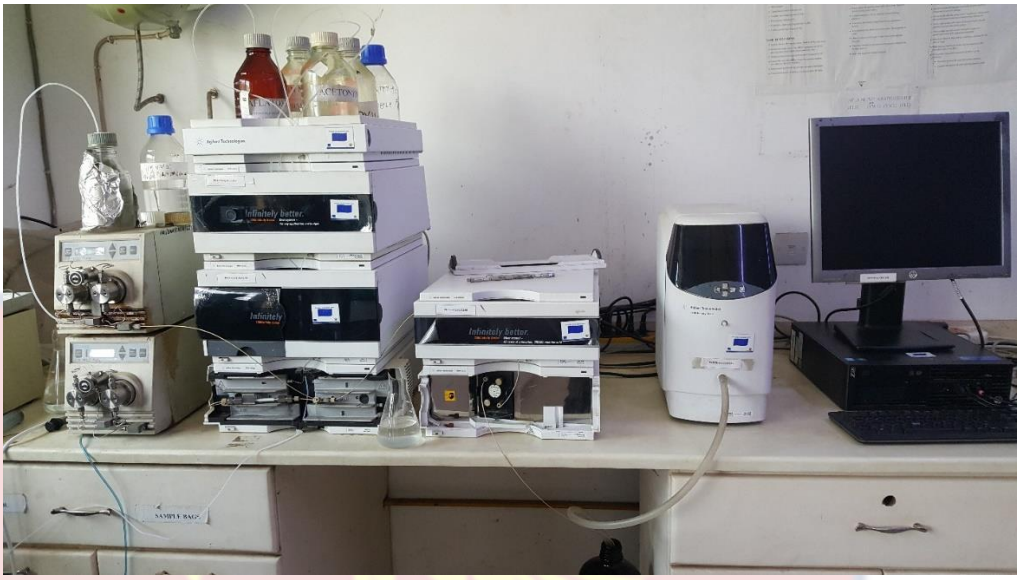
Convective hot-air dryer

Locally design chipping machine – cut sweet potatoes into chips

Chipped orange-fleshed sweet potato

Power grinder – for milling dried cassava pulp

Food mixer – for mixing the OFSP flour and the cassava flour into a composite flour blend



HPLC equipment – for analyzing aflatoxin in cassava flour and OFSP flour samples

Tecator Kjecltec systems (Kjeltec 8400) – for protein content determination

APPENDIX D

ONE-WAY ANOVA ANALYSES OF SOME MEASURED PARAMETERS

Moisture (%) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	15.3201	2.55335	581.57	0.000
Error	14	0.0615	0.00439		
Total	20	15.3816			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0662607	99.60%	99.43%	99.10%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	7.6767	0.0321	(7.5946, 7.7587)
100/0	3	10.4533	0.1358	(10.3713, 10.5354)
75/25	3	9.4433	0.0208	(9.3613, 9.5254)
80/20	3	9.6200	0.0458	(9.5379, 9.7021)
85/15	3	9.8333	0.0306	(9.7513, 9.9154)
90/10	3	9.9900	0.0755	(9.9079, 10.0721)
95/5	3	10.2700	0.0458	(10.1879, 10.3521)

Pooled Standard Deviation = 0.0662607

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
100/0	3	10.4533	A		
95/5	3	10.2700	A		
90/10	3	9.9900		B	
85/15	3	9.8333		B	
80/20	3	9.6200			C
75/25	3	9.4433			C
0/100	3	7.6767			D

Means that do not have the same letter are significantly different.

Ash (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	4.5513	0.758557	99.76	0.000
Error	14	0.1064	0.007604		
Total	20	4.6578			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0871982	97.71%	96.74%	94.86%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	2.639	0.177	(2.531, 2.747)
100/0	3	1.1352	0.1085	(1.0273, 1.2432)
75/25	3	1.8626	0.0341	(1.7546, 1.9705)
80/20	3	1.82931	0.01597	(1.72133, 1.93728)
85/15	3	1.7449	0.0613	(1.6369, 1.8529)
90/10	3	1.4776	0.0667	(1.3696, 1.5856)
95/5	3	1.2296	0.0226	(1.1216, 1.3376)

Pooled Standard Deviation = 0.0871982

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
0/100	3	2.639	A		
75/25	3	1.8626		B	
80/20	3	1.82931		B	
85/15	3	1.7449		B	
90/10	3	1.4776			C
95/5	3	1.2296			D
100/0	3	1.1352			D

Means that do not have the same letter are significantly different.

Protein (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	13.2806	2.21343	446.76	0.000
Error	14	0.0694	0.00495		
Total	20	13.3499			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0703872	99.48%	99.26%	98.83%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	4.7586	0.1184	(4.6715, 4.8458)
100/0	3	2.2112	0.1194	(2.1240, 2.2984)
75/25	3	3.1730	0.0453	(3.0858, 3.2601)
80/20	3	2.7366	0.0496	(2.6494, 2.8237)
85/15	3	2.65064	0.01021	(2.56348, 2.73780)
90/10	3	2.5590	0.0190	(2.4718, 2.6461)
95/5	3	2.4258	0.0379	(2.3386, 2.5129)

Pooled Standard Deviation = 0.0703872

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping			
0/100	3	4.7586	A			
75/25	3	3.1730		B		
80/20	3	2.7366			C	
85/15	3	2.65064			C	
90/10	3	2.5590			C	D
95/5	3	2.4258				D
100/0	3	2.2112				E

Means that do not have the same letter are significantly different.

Fat (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	0.078501	0.013084	44.02	0.000
Error	14	0.004161	0.000297		
Total	20	0.082662			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0172395	94.97%	92.81%	88.67%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	0.3972	0.0226	(0.3758, 0.4185)
100/0	3	0.19730	0.01315	(0.17595, 0.21865)
75/25	3	0.31288	0.00630	(0.29153, 0.33423)
80/20	3	0.29505	0.01676	(0.27370, 0.31639)
85/15	3	0.27357	0.01701	(0.25222, 0.29492)
90/10	3	0.24812	0.01693	(0.22677, 0.26947)
95/5	3	0.2229	0.0223	(0.2015, 0.2442)

Pooled Standard Deviation = 0.0172395

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
0/100	3	0.3972	A		
75/25	3	0.31288		B	
80/20	3	0.29505		B	C
85/15	3	0.27357		B	C
90/10	3	0.24812			C D
95/5	3	0.2229			D E
100/0	3	0.19730			E

Means that do not have the same letter are significantly different.

Fibre (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	7.23195	1.20532	181.97	0.000
Error	14	0.09273	0.00662		
Total	20	7.32468			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0813858	98.73%	98.19%	97.15%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	3.5527	0.1360	(3.4520, 3.6535)
100/0	3	1.4220	0.0875	(1.3212, 1.5228)
75/25	3	2.8159	0.1195	(2.7151, 2.9167)
80/20	3	2.6001	0.0281	(2.4993, 2.7009)
85/15	3	2.5324	0.0346	(2.4316, 2.6331)
90/10	3	2.4294	0.0351	(2.3286, 2.5302)
95/5	3	2.3292	0.0522	(2.2284, 2.4300)

Pooled Standard Deviation = 0.0813858

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping			
0/100	3	3.5527	A			
75/25	3	2.8159		B		
80/20	3	2.6001		B	C	
85/15	3	2.5324			C	D
90/10	3	2.4294			C	D
95/5	3	2.3292				D
100/0	3	1.4220				E

Means that do not have the same letter are significantly different.

Carbohydrate (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	4.3596	0.726599	100.78	0.000
Error	14	0.1009	0.007210		
Total	20	4.4605			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0849103	97.74%	96.77%	94.91%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	84.5282	0.1443	(84.4231, 84.6334)
100/0	3	86.0029	0.1230	(85.8978, 86.1081)
75/25	3	85.2083	0.0386	(85.1031, 85.3134)
80/20	3	85.5191	0.0544	(85.4139, 85.6242)
85/15	3	85.4975	0.0725	(85.3924, 85.6027)
90/10	3	85.7253	0.0694	(85.6202, 85.8305)
95/5	3	85.8517	0.0033	(85.7466, 85.9569)

Pooled Standard Deviation = 0.0849103

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping			
100/0	3	86.0029	A			
95/5	3	85.8517	A	B		
90/10	3	85.7253		B	C	
80/20	3	85.5191			C	
85/15	3	85.4975			C	
75/25	3	85.2083				D
0/100	3	84.5282				E

Means that do not have the same letter are significantly different.

Energy (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	79.016	13.1694	103.54	0.000
Error	14	1.781	0.1272		
Total	20	80.797			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.356641	97.80%	96.85%	95.04%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	360.722	0.791	(360.280, 361.163)
100/0	3	354.632	0.125	(354.191, 355.074)
75/25	3	356.341	0.242	(355.899, 356.782)
80/20	3	355.678	0.200	(355.236, 356.120)
85/15	3	355.055	0.316	(354.613, 355.496)
90/10	3	355.370	0.154	(354.929, 355.812)
95/5	3	355.116	0.162	(354.674, 355.558)

Pooled Standard Deviation = 0.356641

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
0/100	3	360.722	A		
75/25	3	356.341		B	
80/20	3	355.678		B	C
90/10	3	355.370		B	C D
95/5	3	355.116			C D
85/15	3	355.055			C D
100/0	3	354.632			D

Means that do not have the same letter are significantly different.

Bulk Density vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	0.092295	0.015383	82.83	0.000
Error	14	0.002600	0.000186		
Total	20	0.094895			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.0136277	97.26%	96.09%	93.84%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	0.75333	0.01528	(0.73646, 0.77021)
100/0	3	0.56333	0.00577	(0.54646, 0.58021)
75/25	3	0.71667	0.00577	(0.69979, 0.73354)
80/20	3	0.68000	0.01000	(0.66312, 0.69688)
85/15	3	0.65333	0.01528	(0.63646, 0.67021)
90/10	3	0.6133	0.0208	(0.5965, 0.6302)
95/5	3	0.57333	0.01528	(0.55646, 0.59021)

Pooled Standard Deviation = 0.0136277

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping				
0/100	3	0.75333	A				
75/25	3	0.71667	A	B			
80/20	3	0.68000		B	C		
85/15	3	0.65333			C		
90/10	3	0.6133				D	
95/5	3	0.57333					E
100/0	3	0.56333					E

Means that do not have the same letter are significantly different.

Swelling Index vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	6.9190	1.15317	93.14	0.000
Error	14	0.1733	0.01238		
Total	20	7.0924			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.111270	97.56%	96.51%	94.50%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	3.0333	0.1528	(2.8955, 3.1711)
100/0	3	1.2333	0.0577	(1.0955, 1.3711)
75/25	3	2.2333	0.1528	(2.0955, 2.3711)
80/20	3	1.8667	0.1155	(1.7289, 2.0045)
85/15	3	1.7000	0.1000	(1.5622, 1.8378)
90/10	3	1.5000	0.1000	(1.3622, 1.6378)
95/5	3	1.3667	0.0577	(1.2289, 1.5045)

Pooled Standard Deviation = 0.111270

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
0/100	3	3.0333	A		
75/25	3	2.2333		B	
80/20	3	1.8667			C
85/15	3	1.7000			C D
90/10	3	1.5000			D E
95/5	3	1.3667			E
100/0	3	1.2333			E

Means that do not have the same letter are significantly different.

WAC (%) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

AN0VA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	60037.0	10006.2	236.82	0.000
Error	14	591.5	42.3		
Total	20	60628.6			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
6.50013	99.02%	98.61%	97.80%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	299.22	9.95	(291.17, 307.27)
100/0	3	136.12	5.93	(128.07, 144.17)
75/25	3	222.82	5.74	(214.77, 230.87)
80/20	3	186.10	5.69	(178.05, 194.15)
85/15	3	165.99	5.72	(157.94, 174.04)
90/10	3	152.92	5.62	(144.87, 160.97)
95/5	3	142.90	5.65	(134.85, 150.95)

Pooled Standard Deviation = 6.50013

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
0/100	3	299.22	A		
75/25	3	222.82		B	
80/20	3	186.10			C
85/15	3	165.99		D	
90/10	3	152.92		D	E
95/5	3	142.90			E
100/0	3	136.12			E

Means that do not have the same letter are significantly different.

Starch (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	2577.14	429.523	2795.35	0.000
Error	14	2.15	0.154		
Total	20	2579.29			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.391990	99.92%	99.88%	99.81%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	50.9044	0.1243	(50.4190, 51.3898)
100/0	3	88.032	0.259	(87.547, 88.518)
75/25	3	71.020	0.349	(70.535, 71.505)
80/20	3	74.718	0.785	(74.232, 75.203)
85/15	3	76.333	0.297	(75.847, 76.818)
90/10	3	81.076	0.343	(80.591, 81.562)
95/5	3	82.351	0.220	(81.865, 82.836)

Pooled Standard Deviation = 0.391990

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
100/0	3	88.032	A
95/5	3	82.351	B
90/10	3	81.076	C
85/15	3	76.333	D
80/20	3	74.718	E
75/25	3	71.020	F
0/100	3	50.9044	G

Means that do not have the same letter are significantly different.

Vitamin C (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	119.998	19.9997	582.98	0.000
Error	14	0.480	0.0343		
Total	20	120.478			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.185218	99.60%	99.43%	99.10%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	22.468	0.196	(22.239, 22.698)
100/0	3	14.421	0.175	(14.191, 14.650)
75/25	3	18.191	0.204	(17.962, 18.421)
80/20	3	17.489	0.207	(17.260, 17.719)
85/15	3	16.773	0.181	(16.543, 17.002)
90/10	3	16.2759	0.1174	(16.0465, 16.5053)
95/5	3	15.614	0.200	(15.384, 15.843)

Pooled Standard Deviation = 0.185218

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	22.468	A
75/25	3	18.191	B
80/20	3	17.489	C
85/15	3	16.773	D
90/10	3	16.2759	D
95/5	3	15.614	E
100/0	3	14.421	F

Means that do not have the same letter are significantly different.

Vitamin A (µg/100g db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	208816	34802.7	17376.18	0.000
Error	14	28	2.0		
Total	20	208844			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.41524	99.99%	99.98%	99.97%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	420.98	2.32	(419.23, 422.74)
100/0	3	89.338	0.982	(87.585, 91.090)
75/25	3	219.752	1.118	(217.999, 221.504)
80/20	3	193.627	1.143	(191.875, 195.380)
85/15	3	190.388	1.294	(188.636, 192.141)
90/10	3	168.50	1.73	(166.75, 170.25)
95/5	3	116.275	0.657	(114.522, 118.027)

Pooled Standard Deviation = 1.41524

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	420.98	A
75/25	3	219.752	B
80/20	3	193.627	C
85/15	3	190.388	C
90/10	3	168.50	D
95/5	3	116.275	E
100/0	3	89.338	F

Means that do not have the same letter are significantly different.

β-Carotene (db) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	7517377	1252896	17376.18	0.000
Error	14	1009	72		
Total	20	7518387			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
8.49142	99.99%	99.98%	99.97%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	2525.91	13.93	(2515.39, 2536.42)
100/0	3	536.03	5.89	(525.51, 546.54)
75/25	3	1318.51	6.71	(1308.00, 1329.03)
80/20	3	1161.76	6.86	(1151.25, 1172.28)
85/15	3	1142.33	7.77	(1131.81, 1152.84)
90/10	3	1011.00	10.40	(1000.49, 1021.52)
95/5	3	697.65	3.94	(687.13, 708.16)

Pooled Standard Deviation = 8.49142

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping				
0/100	3	2525.91	A				
75/25	3	1318.51		B			
80/20	3	1161.76			C		
85/15	3	1142.33			C		
90/10	3	1011.00				D	
95/5	3	697.65					E
100/0	3	536.03					F

Means that do not have the same letter are significantly different.

Peak Temperature (PT) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	106.767	17.7945	65.91	0.000
Error	7	1.890	0.2700		
Total	13	108.657			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.519615	98.26%	96.77%	93.04%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	85.450	0.495	(84.581, 86.319)
COA	2	87.000	0.141	(86.131, 87.869)
COB	2	88.050	0.778	(87.181, 88.919)
COC	2	89.000	0.707	(88.131, 89.869)
COD	2	89.400	0.566	(88.531, 90.269)
COE	2	90.000	0.141	(89.131, 90.869)
OFS100	2	94.900	0.424	(94.031, 95.769)

Pooled Standard Deviation = 0.519615

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
OFS100	2	94.900	A		
COE	2	90.000		B	
COD	2	89.400		B	
COC	2	89.000		B	C
COB	2	88.050		B	C
COA	2	87.000			C D
CAS100	2	85.450			D

Means that do not have the same letter are significantly different.

Final viscosity (H50) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	21973.4	3662.24	183.77	0.000
Error	7	139.5	19.93		
Total	13	22112.9			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
4.46414	99.37%	98.83%	97.48%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	181.50	6.36	(174.04, 188.96)
COA	2	154.500	0.707	(147.036, 161.964)
COB	2	126.00	5.66	(118.54, 133.46)
COC	2	107.00	5.66	(99.54, 114.46)
COD	2	90.50	4.95	(83.04, 97.96)
COE	2	76.00	2.83	(68.54, 83.46)
OFS100	2	63.00	1.41	(55.54, 70.46)

Pooled Standard Deviation = 4.46414

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping			
CAS100	2	181.50	A			
COA	2	154.500		B		
COB	2	126.00			C	
COC	2	107.00				D
COD	2	90.50				D	E
COE	2	76.00					E	F
OFS100	2	63.00						F

Means that do not have the same letter are significantly different.

Setback vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	5489.43	914.90	69.61	0.000
Error	7	92.00	13.14		
Total	13	5581.43			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
3.62531	98.35%	96.94%	93.41%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	75.00	7.07	(68.94, 81.06)
COA	2	67.50	2.12	(61.44, 73.56)
COB	2	52.00	4.24	(45.94, 58.06)
COC	2	40.00	4.24	(33.94, 46.06)
COD	2	31.500	0.707	(25.438, 37.562)
COE	2	28.500	0.707	(22.438, 34.562)
OFS100	2	16.500	0.707	(10.438, 22.562)

Pooled Standard Deviation = 3.62531

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
CAS100	2	75.00	A		
COA	2	67.50	A		
COB	2	52.00		B	
COC	2	40.00		B	C
COD	2	31.500			C
COE	2	28.500			C D
OFS100	2	16.500			D

Means that do not have the same letter are significantly different.

Peak Time vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	127.560	21.2600	76.51	0.000
Error	7	1.945	0.2779		
Total	13	129.505			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.527122	98.50%	97.21%	93.99%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	24.400	0.141	(23.519, 25.281)
COA	2	25.2250	0.1061	(24.3436, 26.1064)
COB	2	25.850	0.636	(24.969, 26.731)
COC	2	26.375	0.247	(25.494, 27.256)
COD	2	26.750	0.495	(25.869, 27.631)
COE	2	27.2250	0.0354	(26.3436, 28.1064)
OFS100	2	34.225	1.096	(33.344, 35.106)

Pooled Standard Deviation = 0.527122

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
OFS100	2	34.225	A		
COE	2	27.2250		B	
COD	2	26.750		B	
COC	2	26.375		B	C
COB	2	25.850		B	C
COA	2	25.2250		B	C
CAS100	2	24.400			C

Means that do not have the same letter are significantly different.

Peak viscosity (PV) versus Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	136961	22826.9	71.65	0.000
Error	7	2230	318.6		
Total	13	139191			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
17.8486	98.40%	97.02%	93.59%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	358.0	42.4	(328.2, 387.8)
COA	2	298.50	4.95	(268.66, 328.34)
COB	2	214.00	12.73	(184.16, 243.84)
COC	2	168.50	9.19	(138.66, 198.34)
COD	2	136.50	9.19	(106.66, 166.34)
COE	2	111.00	7.07	(81.16, 140.84)
OFS100	2	54.50	4.95	(24.66, 84.34)

Pooled Standard Deviation = 17.8486

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
CAS100	2	358.0	A		
COA	2	298.50	A		
COB	2	214.00		B	
COC	2	168.50		B	C
COD	2	136.50			C
COE	2	111.00			C D
OFS100	2	54.50			D

Means that do not have the same letter are significantly different.

Trough viscosity (H95) vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	5458.0	909.67	29.48	0.000
Error	7	216.0	30.86		
Total	13	5674.0			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
5.55492	96.19%	92.93%	84.77%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	106.00	12.73	(96.71, 115.29)
COA	2	94.500	0.707	(85.212, 103.788)
COB	2	79.50	4.95	(70.21, 88.79)
COC	2	68.50	3.54	(59.21, 77.79)
COD	2	60.00	2.83	(50.71, 69.29)
COE	2	51.500	0.707	(42.212, 60.788)
OFS100	2	51.00	2.83	(41.71, 60.29)

Pooled Standard Deviation = 5.55492

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
CAS100	2	106.00	A		
COA	2	94.500	A	B	
COB	2	79.50		B	C
COC	2	68.50			C D
COD	2	60.00			C D
COE	2	51.500			D
OFS100	2	51.00			D

Means that do not have the same letter are significantly different.

Breakdown vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	CAS100, COA, COB, COC, COD, COE, OFS100

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	88401	14733.6	94.45	0.000
Error	7	1092	156.0		
Total	13	89493			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
12.4900	98.78%	97.73%	95.12%

Means

Sample	N	Mean	StDev	95% CI
CAS100	2	252.0	29.7	(231.1, 272.9)
COA	2	204.00	5.66	(183.12, 224.88)
COB	2	134.50	7.78	(113.62, 155.38)
COC	2	100.00	5.66	(79.12, 120.88)
COD	2	76.50	6.36	(55.62, 97.38)
COE	2	59.50	6.36	(38.62, 80.38)
OFS100	2	3.50	2.12	(-17.38, 24.38)

Pooled Standard Deviation = 12.4900

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
CAS100	2	252.0	A		
COA	2	204.00	A		
COB	2	134.50		B	
COC	2	100.00		B	C
COD	2	76.50			C
COE	2	59.50			C
OFS100	2	3.50			D

Means that do not have the same letter are significantly different.

L* vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	744.652	124.109	4526.37	0.000
Error	14	0.384	0.027		
Total	20	745.036			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.165587	99.95%	99.93%	99.88%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	79.710	0.284	(79.505, 79.915)
100/0	3	99.9900	0.0173	(99.7850, 100.1950)
75/25	3	91.5067	0.1531	(91.3016, 91.7117)
80/20	3	92.7600	0.0854	(92.5550, 92.9650)
85/15	3	93.8433	0.1193	(93.6383, 94.0484)
90/10	3	95.073	0.246	(94.868, 95.278)
95/5	3	96.9533	0.0764	(96.7483, 97.1584)

Pooled Standard Deviation = 0.165587

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
100/0	3	99.9900	A
95/5	3	96.9533	B
90/10	3	95.073	C
85/15	3	93.8433	D
80/20	3	92.7600	E
75/25	3	91.5067	F
0/100	3	79.710	G

Means that do not have the same letter are significantly different.

a* vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	110.205	18.3674	640.94	0.000
Error	14	0.401	0.0287		
Total	20	110.606			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.169284	99.64%	99.48%	99.18%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	14.0067	0.1097	(13.7970, 14.2163)
100/0	3	6.0767	0.0764	(5.8670, 6.2863)
75/25	3	9.413	0.286	(9.204, 9.623)
80/20	3	9.033	0.251	(8.824, 9.243)
85/15	3	8.8500	0.0985	(8.6404, 9.0596)
90/10	3	8.2267	0.1550	(8.0170, 8.4363)
95/5	3	7.4733	0.0643	(7.2637, 7.6830)

Pooled Standard Deviation = 0.169284

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping				
0/100	3	14.0067	A				
75/25	3	9.413		B			
80/20	3	9.033		B	C		
85/15	3	8.8500			C		
90/10	3	8.2267				D	
95/5	3	7.4733					E
100/0	3	6.0767					F

Means that do not have the same letter are significantly different.

b* versus Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	775.832	129.305	3075.91	0.000
Error	14	0.589	0.042		
Total	20	776.421			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.205032	99.92%	99.89%	99.83%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	19.8333	0.1557	(19.5794, 20.0872)
100/0	3	-0.9233	0.0586	(-1.1772, -0.6694)
75/25	3	7.373	0.203	(7.119, 7.627)
80/20	3	6.263	0.367	(6.009, 6.517)
85/15	3	5.100	0.185	(4.846, 5.354)
90/10	3	3.970	0.184	(3.716, 4.224)
95/5	3	2.3933	0.1518	(2.1394, 2.6472)

Pooled Standard Deviation = 0.205032

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	19.8333	A
75/25	3	7.373	B
80/20	3	6.263	C
85/15	3	5.100	D
90/10	3	3.970	E
95/5	3	2.3933	F
100/0	3	-0.9233	G

Means that do not have the same letter are significantly different.

Hue vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	6953.08	1158.85	3025.85	0.000
Error	14	5.36	0.38		
Total	20	6958.44			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.618856	99.92%	99.89%	99.83%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	54.7695	0.0814	(54.0032, 55.5358)
100/0	3	-8.640	0.553	(-9.407, -7.874)
75/25	3	38.0727	0.1177	(37.3063, 38.8390)
80/20	3	34.715	0.840	(33.948, 35.481)
85/15	3	29.947	0.645	(29.180, 30.713)
90/10	3	25.751	0.623	(24.985, 26.517)
95/5	3	17.749	0.920	(16.983, 18.516)

Pooled Standard Deviation = 0.618856

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	54.7695	A
75/25	3	38.0727	B
80/20	3	34.715	C
85/15	3	29.947	D
90/10	3	25.751	E
95/5	3	17.749	F
100/0	3	-8.640	G

Means that do not have the same letter are significantly different.

Chroma vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	639.157	106.526	1753.08	0.000
Error	14	0.851	0.061		
Total	20	640.007			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.246506	99.87%	99.81%	99.70%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	24.281	0.187	(23.975, 24.586)
100/0	3	6.1466	0.0759	(5.8414, 6.4519)
75/25	3	11.957	0.349	(11.652, 12.263)
80/20	3	10.993	0.415	(10.688, 11.298)
85/15	3	10.215	0.176	(9.910, 10.520)
90/10	3	9.135	0.219	(8.830, 9.440)
95/5	3	7.8479	0.1066	(7.5426, 8.1531)

Pooled Standard Deviation = 0.246506

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	24.281	A
75/25	3	11.957	B
80/20	3	10.993	C
85/15	3	10.215	D
90/10	3	9.135	E
95/5	3	7.8479	F
100/0	3	6.1466	G

Means that do not have the same letter are significantly different.

Whiteness Index vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	1266.78	211.130	3569.26	0.000
Error	14	0.83	0.059		
Total	20	1267.61			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.243213	99.93%	99.91%	99.85%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	31.643	0.251	(31.342, 31.944)
100/0	3	6.1466	0.0758	(5.8455, 6.4478)
75/25	3	14.669	0.207	(14.368, 14.970)
80/20	3	13.164	0.392	(12.862, 13.465)
85/15	3	11.927	0.200	(11.626, 12.228)
90/10	3	10.379	0.309	(10.078, 10.680)
95/5	3	8.4187	0.1141	(8.1175, 8.7199)

Pooled Standard Deviation = 0.243213

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	31.643	A
75/25	3	14.669	B
80/20	3	13.164	C
85/15	3	11.927	D
90/10	3	10.379	E
95/5	3	8.4187	F
100/0	3	6.1466	G

Means that do not have the same letter are significantly different.

Delta E vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	7	0/100, 100/0, 75/25, 80/20, 85/15, 90/10, 95/5

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	6	1623.90	270.651	4687.56	0.000
Error	14	0.81	0.058		
Total	20	1624.71			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
0.240288	99.95%	99.93%	99.89%

Means

Sample	N	Mean	StDev	95% CI
0/100	3	30.087	0.212	(29.789, 30.384)
100/0	3	0.0933	0.0814	(-0.2042, 0.3909)
75/25	3	12.3300	0.1308	(12.0325, 12.6275)
80/20	3	10.610	0.322	(10.312, 10.908)
85/15	3	9.070	0.220	(8.772, 9.368)
90/10	3	7.260	0.377	(6.962, 7.558)
95/5	3	4.710	0.203	(4.412, 5.008)

Pooled Standard Deviation = 0.240288

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping
0/100	3	30.087	A
75/25	3	12.3300	B
80/20	3	10.610	C
85/15	3	9.070	D
90/10	3	7.260	E
95/5	3	4.710	F
100/0	3	0.0933	G

Means that do not have the same letter are significantly different.

Appearance vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	322.8	64.562	22.72	0.000
Error	312	886.7	2.842		
Total	317	1209.5			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.68580	26.69%	25.51%	23.84%

Means

Sample	N	Mean	StDev	95% CI
284	53	6.660	1.329	(6.205, 7.116)
474	53	4.585	2.125	(4.129, 5.041)
592	53	7.509	1.085	(7.054, 7.965)
651	53	5.377	1.853	(4.922, 5.833)
733	53	5.906	1.319	(5.450, 6.361)
908	53	4.925	2.102	(4.469, 5.380)

Pooled Standard Deviation = 1.68580

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.509	A		
284	53	6.660	A	B	
733	53	5.906		B	C
651	53	5.377			C D
908	53	4.925			D
474	53	4.585			D

Means that do not have the same letter are significantly different.

Aroma versus Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	164.7	32.939	16.02	0.000
Error	312	641.7	2.057		
Total	317	806.4			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.43409	20.42%	19.15%	17.33%

Means

Sample	N	Mean	StDev	95% CI
284	53	6.698	1.011	(6.311, 7.086)
474	53	5.566	1.792	(5.178, 5.954)
592	53	7.302	1.119	(6.914, 7.689)
651	53	5.566	1.727	(5.178, 5.954)
733	53	6.170	0.975	(5.782, 6.557)
908	53	5.245	1.709	(4.858, 5.633)

Pooled StDev = 1.43409

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.302	A		
284	53	6.698	A	B	
733	53	6.170		B	C
651	53	5.566			C D
474	53	5.566			C D
908	53	5.245			D

Means that do not have the same letter are significantly different.

Color vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	289.0	57.807	25.16	0.000
Error	312	716.9	2.298		
Total	317	1006.0			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.51588	28.73%	27.59%	25.96%

Means

Sample	N	Mean	StDev	95% CI
284	53	6.774	1.187	(6.364, 7.183)
474	53	4.642	1.841	(4.232, 5.051)
592	53	7.377	1.180	(6.968, 7.787)
651	53	5.698	1.636	(5.288, 6.108)
733	53	5.962	1.270	(5.553, 6.372)
908	53	4.962	1.818	(4.553, 5.372)

Pooled Standard Deviation = 1.51588

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.377	A		
284	53	6.774	A	B	
733	53	5.962		B	C
651	53	5.698			C D
908	53	4.962			D E
474	53	4.642			E

Means that do not have the same letter are significantly different.

Texture vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	446.7	89.334	27.18	0.000
Error	312	1025.5	3.287		
Total	317	1472.2			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.81301	30.34%	29.22%	27.63%

Means

Sample	N	Mean	StDev	95% CI
284	53	5.528	1.488	(5.038, 6.018)
474	53	3.906	2.022	(3.416, 4.396)
592	53	7.208	1.321	(6.718, 7.698)
651	53	4.019	2.080	(3.529, 4.509)
733	53	4.642	1.788	(4.152, 5.132)
908	53	3.962	2.038	(3.472, 4.452)

Pooled Standard Deviation = 1.81301

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.208	A		
284	53	5.528		B	
733	53	4.642		B	C
651	53	4.019			C
908	53	3.962			C
474	53	3.906			C

Means that do not have the same letter are significantly different.

Taste vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	161.2	32.248	11.56	0.000
Error	311	867.5	2.790		
Total	316	1028.8			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.67019	15.67%	14.32%	12.38%

Means

Sample	N	Mean	StDev	95% CI
284	53	6.226	1.250	(5.775, 6.678)
474	53	5.151	2.023	(4.700, 5.602)
592	53	7.038	1.208	(6.586, 7.489)
651	53	5.226	1.794	(4.775, 5.678)
733	53	5.774	1.577	(5.322, 6.225)
908	52	5.019	1.985	(4.564, 5.475)

Pooled Standard Deviation = 1.67019

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.038	A		
284	53	6.226	A	B	
733	53	5.774		B	C
651	53	5.226			C
474	53	5.151			C
908	52	5.019			C

Means that do not have the same letter are significantly different.

After Taste vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	180.1	36.018	13.52	0.000
Error	312	831.3	2.664		
Total	317	1011.4			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.63233	17.81%	16.49%	14.61%

Means

Sample	N	Mean	StDev	95% CI
284	53	6.057	1.216	(5.615, 6.498)
474	53	5.075	2.065	(4.634, 5.517)
592	53	7.075	0.997	(6.634, 7.517)
651	53	5.113	1.815	(4.672, 5.554)
733	53	5.623	1.390	(5.181, 6.064)
908	53	4.887	2.006	(4.446, 5.328)

Pooled Standard Deviation = 1.63233

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.075	A		
284	53	6.057		B	
733	53	5.623		B	C
651	53	5.113			C
474	53	5.075			C
908	53	4.887			C

Means that do not have the same letter are significantly different.

Overall Acceptability vs Sample

H_o – All means are same
H_a – All means are not the same
$p < 0.05$

For the analysis, same variances were assumed

Factor	Levels	Values
Sample	6	284, 474, 592, 651, 733, 908

ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Sample	5	330.9	66.181	31.79	0.000
Error	312	649.6	2.082		
Total	317	980.5			

Summary of Model

S	R-sq	R-sq(adj)	R-sq(pred)
1.44296	33.75%	32.69%	31.18%

Means

Sample	N	Mean	StDev	95% CI
284	53	6.547	1.153	(6.157, 6.937)
474	53	4.491	1.977	(4.101, 4.881)
592	53	7.491	0.891	(7.101, 7.881)
651	53	5.226	1.396	(4.836, 5.616)
733	53	5.642	1.210	(5.252, 6.031)
908	53	4.906	1.746	(4.516, 5.296)

Pooled Standard Deviation = 1.44296

Tukey Pairwise Comparisons at 95% Confidence level

Sample	N	Mean	Grouping		
592	53	7.491	A		
284	53	6.547		B	
733	53	5.642		C	
651	53	5.226		C	D
908	53	4.906		C	D
474	53	4.491			D

Means that do not have the same letter are significantly different.