UNIVERSITY OF CAPE COAST

ENRICHING ROASTED MAIZE PORRIDGE TO ENHANCE INTAKE OF PROTEIN AND VITAMIN A USING LOCALLY AVAILABLE STAPLE FOODS

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BY

GIFTY SERWAA OTOO (MRS)

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 fulfilment of the requirements for the award of Doctor of Philosophy degree in Food and Postharvest Technology

JULY, 2024

DECLERATION

Candidate's Declaration

I hereby declare that this submission is my own work toward the PhD and that, to the best of my knowledge, it contains no material previously published by another person or material which has been presented for the award of another degree in this university or somewhere else, except where due acknowledgment has been made in the text.

Candidate's signature ……………………………..…….. Date …………….

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Supervisor's Declaration

I 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 ………………..

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ABSTRACT

Protein deficiency, particularly among youngsters, is widespread in most developing nations. An effective approach to address this insufficiency is to integrate regionally abundant staple foods, such as Bambara groundnut and soybean, into current and widely consumed meals, like porridge made from roasted maize flour. For addressing issue related to vitamin A deficiency among expectant mothers and infants, the use of staple foods such as ripe plantain and orange-fleshed sweet potatoes, which abound in Vitamin A, can be explored. Thus, in this study, the properties of composite flours made from roasted maize, Bambara groundnut, and ripe plantain (MBP), roasted maize, Bambara groundnut, and orange-fleshed sweet potatoes (MBO), and roasted maize, soybean, and ripe plantain (MSP) were investigated. Additionally, the study assessed the consumer preference for porridge made from the ingredients. Increasing the quantities of Bambara groundnut, soybean, orange-fleshed sweet potatoes, and ripe plantain resulted in an augmentation in protein and β-carotene levels, respectively, while having no impact on the physicochemical quality. The iron content was enhanced by increasing the amount of ripe plantain, while the zinc content was enhanced by increasing the amount of orange flesh sweet potatoes. Nevertheless, elevated concentrations of the Bambara groundnut and soybean resulted in an augmentation of the tannin content. Hedonic sensory scores indicated no significant changes in acceptability in terms of aroma, appearance, texture, and taste. Therefore, the porridges from the composite flours from this study could easily be accepted by consumers because their attributes were similar to those of roasted maize porridge that they are familiar with.

KEY WORDS

Protein deficiency

Vitamin A deficiency

Roasted Maize flour

Ripe plantain flour

Orange fleshed sweet potato flour

Bambara groundnuts flour

Soybeans flour

Composite flour

Nutrient content

Mineral content

Phytochemical content

Anti-nutritional content

Functional properties

Physicochemical properties

Sensory evaluation

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DEDICATION

To my late dear mother, Mrs. Elizabeth Serwaa Boateng

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ABBREVIATIONS

WHO	World Health Organization
FAO	Food and Agriculture Organization
UNICEF	United Nations International Children's Emergency Fund
MRC	Medical Research Council
NCD	Non-Communicable Diseases
SSA	Sub-Sahara Africa
PEM	Protein Energy Malnutrition
VAD	Vitamin A Deficiency
RDA	Recommended Dietary Allowance
NVAP	National Vitamin A Supplementation Programme
DHS	Demographic and Health Survey
µgRE/day	Microgram per gram Retinol equivalent per day
g/day	Gram per day
µg/100g	Microgram per 100 gram
mL	Millilitres
BU	Brabender Unit
RVU	Rapid Visco Analyzer
ANOVA	Analysis of Variance

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The lack of proper nutrient intake poses significant health hazards, particularly among individuals in developing countries who are vulnerable to vitamin A deficiency (Song et al., 2023) and protein (Schönfeldt et al., 2012; Vissamsetti et al., 2024). Vitamin A insufficiency is a significant issue in public health, leading to avoidable blindness in children and women (Bastos Maia et al., 2018). Approximately 33.3% of preschool-aged children, which accounts for one-third of the global preschool population, are predicted to be deficient in vitamin A (WHO, 2009). According to the World Health Organisation (WHO) in 2009, around 44% of pre-school children in Africa are known to be deficient in vitamin A. In Ghana, around 20.8% of children below five years are believed to suffer from vitamin A insufficiency, and 1.5% of women are affected as well (Wegmüller et al., 2020). Additionally, an estimated 7.7% of pregnant women in Ghana are deficient in vitamin A (Song et al., 2023).

Recommended treatments for alleviating vitamin A deficiency include supplementation, fortification, and boosting the consumption of vitamin A-rich foods (Mendes et al., 2016; Olson et al., 2021). Supplementation and fortification schemes effectively address vitamin A and other dietary deficiencies. However, their high cost poses a hurdle to their long-term sustainability (Booth et al., 1992). A comprehensive examination of using food as a means to address vitamin A insufficiency has been thoroughly studied and determined to have a favourable potential (Ruel, 2001).

According to Blomme et al. (2020), the most sustainable strategy to prevent vitamin A deficiency is the use of staple foods that abound in vitamin A or its precursors. Hence, incorporating staple foods that are rich in vitamin A into pre-existing diets can help mitigate issues of vitamin A deficiency. In this regard, combining locally available raw materials in food production has been commended as an alternative system to tackle nutrient deficiencies including vitamin A, compared to the use of expensive food supplements which are considered more expensive (Affonfere et al., 2021; Neela & Fanta, 2019)

In most developing countries such as Ghana, the diet of children consists primarily of cereals and grains, even though these foods are limited in nutritional quality (Annor & Nagai, 2009). Among the cereal foods, maize is one of the most popular and can be consumed as porridge after roasting and milling. Roasted maize porridge is a soft food prepared by boiling roasted maize flour in water and adding sweeteners such as sugar to enhance the taste. This type of porridge is also consumed as a breakfast meal and can additionally be used as infant-weaning foods (Nagai et al., 2009; Oladeji et al., 2016). However, because maize is low in several essential nutrients such vitamin A (Annor & Nagai, 2009; Ejoh & Onyeulo, 2022; Oladeji et al., 2016), supplementation of maize products using vitamin-rich staples could be helpful for improving nutritional outcomes. Indeed, the popularity of roasted maize porridge along with the fact that it is consumed by people of all ages means that it can be used as a target to help tackle issues of vitamin A deficiency. This can be done by supplementing maize porridge with staples such as ripe plantain and orange flesh sweet potatoes (OFSP) that are rich in vitamin A.

Plantain (*Musa paradisiaca* L.) abounds in Ghana but usually shows a quick post-harvest deterioration during the seasons of bumper because of the limited processing technologies at the pre-climacteric phase of ripening (Serwah Ayeh et al., 2023). At this stage, the fruit is rich in both β-carotene (a vitamin A precursor) and iron (Kwofie et al., 2020) and although the composition is sufficient to satisfy the requirements for vitamin A in both infants and women (Agbemafle et al., 2017a; Blomme et al., 2020), innovative strategies for integrating ripe plantain into infant foods, such as maize porridge, are still needed.

In addition to ripe plantain, orange flesh sweet potato, which is also rich in β-carotene can be used to supplement roasted maize porridge to boost vitamin A intake. Additionally, orange flesh sweet potato is known to contain a high concentration of ascorbic acid and can be utilised to raise the nutritional value of cereal-based foods (Pessu et al., 2020). Indeed, as a component of the worldwide endeavour to combat vitamin A deficiency, the intake of orange-fleshed sweet potatoes has been promoted (Girard et al., 2017).

Both ripe plantain and orange flesh sweet potato, however, contain low protein levels, thus, additional protein sources may be needed to enhance protein consumption. Considering that protein-energy malnutrition is still prevalent among infants in Ghana and most developing countries (Amoah et al., 2024; Müller & Krawinkel, 2005; Pedroza Velandia et al., 2016) adding a protein-rich source to roasted maize containing either ripe plantain or orange flesh sweet potato can help achieve a nutritionally balanced meal. Indeed, having recognised the nutrient limitation of maize and other cereals, Marcel et al.

(2022) recommended that grain products must be supplemented with other staples to make complimentary foods with improved nutrient density.

To address the low protein of roasted maize porridge, which because of the high-rate of consumption in Ghana and many parts of Africa, could be a useful vehicle for improving protein-energy malnutrition, readily available legume-based plant protein sources such as Bambara groundnut and soybeans can be investigated. This is especially important due to the increasing interest in the utilization of locally grown and readily accessible foods (Fetriyuna et al., 2023) to help end hunger and malnutrition (United Nations Sustainable Development Goal 2), while eradicating poverty (United Nations Sustainable Development Goal 1). Indeed, the Government of Ghana realised the importance of supplementing cereals, launched a campaign to encourage women to prepare weaning meals at home by adding specified portions of readily available legumes (Amagloh et al., 2012).

Among the leguminous crops, Bambara groundnut is considered nutritious, rich in protein, and underutilized. With a protein content of 18-24 %, Bambara groundnut shows a comparable or higher content than several other legumes (Mayes et al., 2019; Mi et al., 2018). The groundnut is abundant in essential amino acids and can be utilized as an additional composite to enhance the nutritional worth of food products (Yao et al., 2015). In addition to Bambara groundnut, the possibility of using soybeans to enhance the intake of protein also needs to be investigated. This is especially important considering that soybeans are readily available and is also rich in lipids, fibre and minerals. Hence, in this study, the possibility of enhancing the intake of vitamin A and protein by the addition of Bambara groundnut or soybeans, and ripe plantain or orange flesh sweet potatoes to roasted maize porridge was investigated.

1.2 Problem Statement and Justification

To help address issues of nutritional deficiencies and improve public health, food supplementation and fortification are the two main strategies employed. While supplementation involves providing individuals with specific nutrients in the form of syrups, pills, caplets, capsules, powders and tablets, fortification is the process of incorporating required or important nutrients into commonly consumed foods during processing (Olson et al., 2021). Although supplementation and fortification programs are effective, they are expensive, therefore, undermining their sustainability (Mannar & Wesley, 2016). According to Olson et al. (2021), a food-based approach to vitamin A fortification, using vitamin A-rich staples has a promising role in reducing the deficiency. Thus, to help promote community nutrition, there is an increasing interest in the utilization of locally available foods which are easily accessible and affordable to the general population in food fortification (Booth et al., 1992; Kruger et al., 2020; Olson et al., 2021).

Considering the continuing prevalence of protein and vitamin A deficiencies in developing countries, using local available food staples offers a sustainable strategy to help combat the deficiencies. Taking into account the challenges that may be encountered with the adoption and usage of newly developed foods, already existing and popular foods must be used as conduits to help address nutritional deficiencies. In this regard, using roasted maize porridge as a conduit to help tackle issues of vitamin A and protein deficiency can be considered as it is a popular meal consumed by all people.

However, the addition of both a protein-rich (Bambara groundnut or soybeans) and vitamin A-rich (ripe plantain or orange flesh sweet potatoes) food staples to roasted maize may affect the quality of the flour and the acceptability of porridges produced thereof. Therefore, it was important that in addition to analysing the changes in protein and vitamin A levels, the effect on other nutritional attributes was investigated. Also, other quality attributes which could affect appearance, aroma and taste when the new flours were developed needed to be determined. In addition, the consumer sensory acceptability of porridge prepared from the new flours was investigated.

The adoption and usage of foods with improved nutritional content which have been developed from more traditional foods such as roasted maize porridge could encounter challenges among consumers. This could be related to changes in the cooking conditions, sensorial properties and high cost of the newly developed foods, and the (un)willingness of consumers to forego traditional foods. In this regard, the possible changes in price when Bambara groundnut/soybeans and ripe plantain/orange flesh sweet potatoes were added to roasted maize needed to be evaluated.

1.3 Aims and Objectives

The study investigated the effect of incorporating protein—and vitamin A-rich staples to help improve the nutritional quality of roasted maize porridge by adding either Bambara groundnuts or soybeans and ripe plantain or orange flesh sweet potatoes, respectively, to form composite flours.

The specific objectives were to:

1. Investigate the quality (nutritional content, functional, physicochemical and phytochemical quality, anti-nutrient content, and sensory property) of composite flours prepared using roasted maize flour by adding:
   - Bambara groundnut and ripe plantain
   - Bambara groundnut and orange flesh sweet potatoes
   - Soybeans and ripe plantain.
2. Evaluate consumer acceptability of porridge prepared from the various composite flours.
3. To analyse the changes in cost/price of the composite flours compared to roasted maize flour.

1.4 Significance of the study

As part of measures taken by the Ghana Health Service to eradicate malnutrition and vitamin A deficiencies, mothers are advised to use locally available staples in the preparation of foods for their households (Amagloh et al., 2012). Besides, the combination of locally available raw materials in food production has been recommended as an alternative to expensive commercial foods (Badejo et al., 2020; Odebode et al., 2018). In addition, many developing nations like Ghana, have a lot of interest in creating nutritious foods using locally and easily accessible raw resources (Amankwah et al., 2009).

The significance of this study is to provide scientific information that will contribute to the adoption and usage of nutrient-rich locally available staple foods that can form a part of existing foods to meet specific nutritional requirements. This can contribute to the nutritional well-being of the general populace and children, especially, thus helping Ghana to achieve the United Nations Sustainable Development Goal 2 of ending hunger and malnutrition.

Additionally, the usage of Bambara groundnuts, soybeans, ripe plantain and orange flesh sweet potatoes in roasted maize porridge can help diversify the usage of these foods which can lead to increased production, thus enabling farmers to obtain additional income which can help Ghana meet United Nations Sustainable Development Goal 1 of eradicating poverty.

CHAPTER TWO

LITERATURE REVIEW

2.1 Malnutrition in Ghana

Proper nutrition is important for the physical and cognitive development as well as the overall well-being of a child. Adequate nutrition serves the energy and nutrients needs necessary to sustain life and promote physical, social, emotional, and cognitive development (Roberts et al., 2022; Salama et al., 2014).

Malnutrition is a major public health issue that affects both children and adults globally (WHO, 2020). It is not just a public health concern; it also impedes productivity, economic expansion, and the fight against world poverty. When the requirements of the body for nutrients and how those nutrients are used are out of balance, malnutrition ensues. Malnutrition comes in a variety of ways, with undernutrition and overnutrition being the two major subtypes. Indicators of undernutrition include wasting or low weight, stunting and excess or deficiency of vitamins and minerals. Overnutrition is linked to obesity, overweight, and dietary-related non-communicable diseases (NCDs) such as diabetes mellitus, and heart disease, among others (WHO, 2020).

In sub-Saharan Africa (SSA), malnutrition accounts for the death of one in seven children before they turn five years (Dukhii, 2020). In Ghana, one in every ten children under the age of five are underweight and nearly one in every five children under the age of five are stunted. From six months to two years of age, about 2 in 3 children do not receive nutrients that support their fast-developing bodies and brains (UNICEF, 2020). As a result, they run the danger of impaired brain growth, poor learning abilities, low immunity, increased infections, and, in many cases, death. In 2019, the World Health Organisation reported that 462 million adults were underweight, 1.9 billion adults were overweight, 155 million children were stunted, 52 million children were wasted, 17 million severely wasted, and 41 million children under five were overweight or obese. People, especially those from underdeveloped nations, are at risk of vitamin A and protein deficiencies which are health concerns linked with insufficient consumption of nutrients.

Deficiency in vitamin A is one of the global public health issues (Carey & Low, 1998.). It is a known public health concern that contributes significantly to avoidable blindness in children and women of reproductive age (WHO, 2009; Burri, 2011). Approximately 250 million preschool-aged children globally need vitamin A, and between 150,000 and 2,500 of them pass away within a year after losing their vision (WHO, 2011). Vitamin A is needed for the formation and maintenance of mucous membranes, skin, and bone. It repairs damaged cells due to oxidation and prevents diseases like Xerophthalmia, blindness, vision impairment etc (Feroze & Kaufman, 2022).

2.2 Protein Energy Malnutrition

In developing and impoverished countries, protein-energy malnutrition (PEM), also known as protein-energy undernutrition, is a serious public health concern. Protein-energy malnutrition (PEM), as defined by the World Health Organisation (2007), is a condition characterised by an inadequate supply of both protein and energy, which hinders optimal growth and functioning of the body. Despite the name used, individuals who are affected do not necessarily have a protein deficiency; rather, they may have a deficiency in all types of energy. Proteins obtained from food, which are frequently utilised for tissue growth or repair, are also employed as a source of energy (Singh et al., 2021). PEM, also known as protein-energy malnutrition, is infrequent in affluent countries and is usually associated with neglected children or elderly individuals who live in isolation and suffer from inadequate nutrition (Dhulse et al., 2023). There are two (2) main types of PEM, Primary and Secondary PEM.

Primary PEM results from an inadequate diet or the consumption of protein of low quality, which is unable to provide the required nutrients to maintain the body's metabolism (Lavoe, 2015). Children who have primary PEM can develop several pathological disorders, including kwashiorkor and marasmus. The two severe types of primary PEM may share many determinants and clinical characteristics, but the kwashiorkor condition is distinguished by oedema, irritability, slow in growth, and discoloured hair (Benjamin & Lappin, 2022). Protein, energy, or both deficits are included in severe PEM. This leads to kwashiorkor, marasmus, and marasmic kwashiorkor, where the latter is caused by a combination of acute or chronic protein deficiency and chronic energy deficiency. Protein, energy, or both deficits are included in severe PEM. This leads to kwashiorkor, marasmus, and marasmic kwashiorkor, where the latter is caused by a combination of acute or chronic protein deficiency and chronic energy deficiency (Titi-Lartey & Gupta, 2020).

Secondary PEM develops when an illness or other conditions that are already affecting the body creates barriers to the body's ability to absorb and utilise nutrients, making it difficult for it to meet its protein or energy requirements, or when metabolic losses increase and pass the level at which nutrients are available (Gangadharan et al., 2017). This is more prevalent in developed nations, where it typically happens because of cancer, chronic kidney failure and others that hinder the body's ability to absorb or utilise nutrients or make up for nutrient losses (Iorember, 2018).

2.2.1 "Kwashiorkor"

The word "kwashiorkor," which means "the sickness of the weaning," comes from the Ga language in Ghana (Batool et al., 2015). It is believed that eating too little protein, but relatively normal amounts of calories cause kwashiorkor. Children on diets high in maize were the first to report it. (Grover et al., 2009). Most of the time, older infants and young children are involved in kwashiorkor, and is common in underdeveloped nations. Most often, it happens in locations where there is hunger or a shortage of food, especially in nations where the staples of the diet are corn and rice (Batool et al., 2015; Edhborg et al., 2000). The defining feature of kwashiorkor is oedema, which comes from a confluence of low blood albumin, increased cortisol, and limited activation of antidiuretic hormone (Coulthard, 2015). The balance of bodily fluids is maintained by proteins. Lack of protein leads fluid to move to unnatural parts of the body where it accumulates in the tissues. Oedema, or the retention of fluid, can be caused by an imbalance of fluid on the capillary walls (Benjamin & Lappin, 2022). In addition to oedema, clinical characteristics include dermatoses, hypopigmented hair, an enlarged abdomen, and hepatomegaly. Typically, hair is reddish yellow in colour, sparse, brittle, and dry (Benjamin & Lappin, 2022; Coulthard, 2015; Grover et al., 2009).

2.2.2 Marasmus

The most prevalent form of acute malnutrition syndrome is marasmus (Grover et al., 2009). Which is taken from the Greek word "marasmus," which denotes wasting or withering. Marasmus results from a lack of energy over months to several years. It is characterised by the wasting of bodily tissues, particularly muscles and subcutaneous fat, and is usually brought on by severe calorie restriction. It is the body's physiologically appropriate response to hunger brought on by severe food and energy shortages. The most affected are children under the age of five because of their higher calorie needs and greater vulnerability to illnesses (Batool et al., 2015; Grover et al., 2009). Marasmus has several causative factors, and it include inadequate nutrition or insufficient food intake, nutritional imbalances (eating too much of one nutrient while not getting enough of another), and medical conditions that impair the body's ability to properly absorb or utilize nutrients (Batool et al., 2015; Gangadharan et al., 2017; Titi-Lartey & Gupta, 2022). It is characterised by persistent dizziness, lack of energy, dry skin, and brittle hair (Grover et al., 2009). Under severe conditions, Marasmic kwashiorkor which combines characteristics of both marasmus and kwashiorkor can occur. Severe wasting and oedema usually occur simultaneously in children with marasmic kwashiorkor.

2.2.3 Health Implications of Protein Energy Malnutrition (PEM)

PEM causes a significant rate of mortality and morbidity in children in underdeveloped nations (Bentley, 2003). It is uncommon in adults. The intensity and clinical characteristics of PEM point to two signs of dietary deprivation which are marasmus and kwashiorkor. PEM becomes fatal when a person develops an increased sensitivity to infections that are not typically fatal (Dhulse et al., 2023). This interferes with the child's growth at a critical stage and could result in lifelong disabilities (Bentley, 2003; Bhutia, 2014). PEM is determined by three factors: wasting, stunting, and underweight (De & Chattopadhyay, 2019; Siddiqa et al., 2023). According to UNICEF (2013), stunting (moderate and severe) affects 48 % of children under five, wasting (moderate and severe) affects 20 %, and underweight (moderate and severe) affects 43 % (moderate and severe).

2.3 Vitamin A Deficiency (VAD)

One of the main public health problems that are recognised to be a major cause of avoidable blindness in children and women of reproductive age is vitamin A deficiency (Burri, 2011; Grover & Ee, 2009). Approximately 250 million preschool-aged children globally show vitamin A deficiency, and between 150,000 and 2,500 of them pass away within a year (WHO, 2011; Xu et al., 2021).

Vitamin A deficiency comes about when dietary intake of vitamin A is inadequate to satisfy physiological needs (Hodge & Taylor, 2023). High rates of infection, particularly measles and diarrhoea, may make it worse. It is hardly seen in developed countries, but very common in developing countries (WHO, 2011; Abrha et al., 2016). Inadequate intake of vitamin A is a global public health concern, particularly in Africa and South-East Asia (Akhtar et al., 2013). Small children and expectant mothers in low-income nations are most negatively impacted by this deficiency (Burri et al., 2011; Alaefe, Burney, Naylor & Taren, 2017; Sahile et al., 2020) despite all the effort being made by WHO to minimize the effect of the epidemic (Keats et al., 2019).

Approximately 33.3% of preschool-age children, which accounts for one third of the global kid population, are lacking in Vitamin A, according to the World Health Organisation (WHO, 2009). According to Keats et al. (2019), this leads to one million deaths annually. Exploring sustainable solutions: underdeveloped a nutritious supplemental food for newborns in underdeveloped nations using sweet potatoes, which are high in vitamin A, zinc, and iron. In Africa, it is estimated that 44.4 % of children at preschool level are deficient of Vitamin A (WHO, 2009; Sahile et al., 2020). A reliable indicator of the nutritional status of vitamin A is serum retinol levels. Retinol concentrations below 20 micrograms/dL are deficient (Hodge & Taylor, 2023). Deficiency of vitamin A in humans is caused by:

a) consuming insufficient quantities of vitamin, A (or vitamin A precursors) foods; and / or
b) due to ill health brought on by illnesses like malaria, measles, intestinal parasites, and other conditions during which vitamin A is not properly absorbed during digestion (Carey et al., 1995) and so retinol is excreted in significant amounts in the urine.
c) insufficient fat in the diet can also decrease the absorption of precursors to vitamin A (Mccauley et al., 2015).

2.3.1 Vitamin A Intake

Vitamin A is a fat-soluble vitamin essential for cell growth, metabolism, immunological functions, eyesight, and reproductive processes (D’Ambrosio et al., 2011; Wiseman et al., 2017). Some sources of vitamin A include leafy vegetables, orange-coloured vegetables, dairy products, liver, and fish (Hombali et al., 2019).

Vitamin A is typically found in animal products, but provitamin A (vitamin A precursors), the most prevalent of which is the carotenoid pigment ß-carotene, is found in plants (Carazo et al., 2021; Khalid et al., 2020). Beta-carotene contributes to an individual's growth, prevents illness from infectious diseases and maintains the health of the epithelial tissues and skin (Anand et al., 2022; Marzęda & Łuszczki, 2019). A reliable indicator of the nutritional status of vitamin A is serum retinol levels. Retinol concentrations below 20 micrograms/dL are deficient (Hodge &Taylor, 2023; Wright, 1934). Retinol, which is the animal form of vitamin A is normally called preformed vitamin A and is found in animal tissues, especially liver oil, liver, eggs and dairy products whereas β-carotene and its precursor are derived from plant-based foods (Carazo et al., 2021; Booth et al., 1992). Examples of plant -based foods of vitamin A are leafy vegetables, yellow vegetables and tubers, coloured fruits, juices and red palm oil (Booth et al., 1992a; Carazo et al., 2021; Marzęda & Łuszczki, 2019).

According to estimates, the median diet in the developed countries contains about 25% provitamin A and 75% preformed vitamin A, with fortified foods being the main contributors (Marzęda & Łuszczki, 2019; Booth et al., 1992). Conversely, research from poor nations indicates that food sources high in provitamin A account for as much as 80% of the vitamin A consumed through diet (Haskell, 2012; Persson, 2001).

Vitamin A requirements in human diet vary with age and sex. The vitamin A recommended dietary allowance (RDA) for healthy adults is approximately 700 micrograms/day for women and 900 micrograms/day for men (Buzigi et al., 2022). According to Green et al. (2024) the RDA is 300 to 900, 770, and 1300 micrograms/day for children, pregnant women, and breastfeeding women, respectively. However, to prevent symptomatic vitamin A deficiency in children aged 1 to 5 years a minimum of 200 micrograms/day is needed (Green et al., 2024). The basal or mean requirement is the amount of vitamin A needed to prevent clinical deficiency. People who meet this requirement have normal growth and reproduction but have very low or no reserves. Therefore, infection can easily cause them to be susceptible to vitamin A deficiency. On the other hand, safe level intake is the level of intake which maintains both health and reserves (Sommer & Vyas, 2012; Adetola et al., 2020). The recommended dietary intake of vitamin A according to FAO/WHO (2002) which includes both the basal or mean and safe requirement is shown in Table 2.1.

Table 2.1: Recommended dietary intake of vitamin A in RE

Group (µgRE/day)	**Basal or Mean (µgRE/day)**	**Safe intake**
Infants		
0.5-1 yr	180	350
Children		
1-6 yrs	200	400
Pregnancy	370	600
Lactation	450	850

Source: FAO/WHO (2002)

2.3.2 Health implications of Vitamin A deficiency

Severe morbidity and mortality from common paediatric infections are associated with vitamin A deficiency, which is the main cause of preventable childhood blindness in the world. (WHO, 2014). Additionally, it causes more than a million children to pass away annually (Keats et al., 2019). Inadequate intake of vitamin A also raises the possibility of maternal death rate and other undesirable consequences during pregnancy and breastfeeding (Mccauley et al., 2015). It also reduces their ability to fight infections. Since it may raise a child's risk of respiratory and diarrhoeal infections, slow or stunted growth, sluggish bone development, and lessen their probability of surviving an acute sickness, subclinical or mild deficiency can even be serious (Sahile et al., 2020; WHO, 2009). Vitamin A is needed for the formation and maintenance of mucous membrane, skin, and bone. It repairs damaged cells due to oxidation and prevents diseases like Xerophthalmia, blindness, vision impairment etc (WHO, 2014). Night blindness is one of the first signs of a vitamin A deficiency. In a more serious case, it causes cornea to become extremely dry, which harms the retina and cornea (WHO, 2014).

About two hundred and fifty thousand to five hundred thousand pre-school children worldwide who are vitamin A deficient become blind and pass away within a year of becoming blind (WHO, 2011 & UNICEF, 2007). In Ghana, the prevalence of vitamin A deficiency is as high as 76 % among children under five years of age (DHS, 2009). According to Ghana Micro-nutrient Survey (UNICEF, 2017), a deficit in iron and vitamin A affects about 30 % of pre-schoolers. Meanwhile, proper nutrition in the first twenty-four (24) months of children is critical for their physical and mental development (Journal, 2023). According to Tariku et al. (2016), enhancing the vitamin A status of deficient children considerably lowers the risk of measles mortality by 50%, diarrhoea mortality by 40%, and overall mortality by 25–35%.

It has been established in human and animal studies that, there is a relationship between vitamin A effect and iron (Gutowska et al., 2022; Khan, 2006). Vitamin A is necessary for the process of hemopoiesis and is involved in the metabolism of iron (Al-Mekhlafi et al., 2013; Gutowska et al., 2022). Studies conducted by Mendes et al. (2016) and Zimmermann et al. (2006), suggested that Vitamin A deficiency affects the production of red blood cells (erythropoiesis) and mobilization of iron from the iron storage in the body into the blood circulation. According to Umbreen et al. (2021), a study on rats that were deficient in vitamin A indicated that supplementation with vitamin A and iron was more effective in restoring iron status to normalcy than with iron alone. In addition, research has shown that vitamin A decreases the inhibition of iron absorption by the occurrence of phytate and polyphenols in foods (Khan, 2006; Piskin et al., 2022). Also, haemoglobin concentration was improved during pregnancy, when vitamin A was added to iron supplements for women in Indonesia (Ani et al., 2023).

2.4 Strategies to help combat vitamin A deficiency and Protein Energy Malnutrition

Deficiency of vitamin A has been tackled by three of the most common strategies. These distribution of vitamin A supplements, food fortification, and food-based approaches are methods used to promote the consumption of vitamin A-rich foods (Jemberu et al., 2016; Alashry & Morsy, 2021; Blaner, 2020). Recently, a food-based approach has also been recommended to help tackle issues of protein deficiency.

2.4.1 Food-Based approach

Biofortification, dietary diversification and food-to-food fortification are the food-based approaches that promote the use of utilising local crops to fight against micronutrient deficiencies (Desire et al., 2021). Food-to-food fortification is more sustainable among rural dwellers because it promotes independence and creates a market for their farm produce (Kruger et al., 2020). Of all the strategies, the food-based approaches are more sustainable, feasible, and most accepted culturally (Jemberu et al., 2016).

The food-based approach is one of the low-cost techniques that are applicable in dealing with malnutrition and micronutrient deficiency in deprived or low-income regions. Conventional industrial food fortification, biofortification, and dietary diversification are used to address micronutrient insufficiency. According to Siwela et al. (2020), there has been several fortification programs in developing countries, but they failed. This was because locally available crops which were well endowed with essential micronutrients were neglected.

2.4.2 Food fortification

According to the Codex Alimentarius Commission (1987) fortification is "the addition of one or more essential nutrients to a food whether it is normally contained in the food, to prevent or correct a demonstrated deficiency of one or more nutrients in the population or specific population groups." World Health Organization (2022) also defined food fortification as the process of intentionally enhancing a food's vitamins, minerals, and other critical micronutrients, to provide a public health benefit by increasing the nutritional quality of the food supply while posing the fewest risks to consumer health. Food fortification is one of the low-cost strategies that can be applied to deal with malnutrition and micronutrient deficiency in the rural areas. Conventional industrial food fortification, biofortification, and dietary diversification are used to address micronutrient insufficiency (Kruger et al., 2020).

According to Darnton-Hill et al. (2002), there has been several fortification programs in the developing countries, but they failed. This is because locally available crops which are well endowed with essential micronutrients are neglected (Ofosu et al., 2017; Teye et al., 2020). To integrate food fortification into the systems of food production and distribution, it is necessary to identify commonly consumed foods. This implies that fortification within current food patterns does not alter population dietary practices and does not necessitate individual adherence. Given their regular consumption by significant portions of the population, staple foods and condiments make the most sense as fortifiers (Olson et al., 2021). The selection of food vehicles is typically restricted to a few basic meals and condiments, such as cereals, oils and fats, sugar, salt, and sauces, in underdeveloped nations. Usually, folic acid and other B-complex vitamins, vitamins A, D, iodine, iron, and zinc are the vitamins and minerals utilised for fortification (Mannar & Wesley, 2016). The advantages of fortification can last a person's whole life. For this reason, it might be among the most economical ways to treat micronutrient deficiencies (Mannar & Wesley, 2016).

2.4.2.1 Bio-fortification

The World Health Organization defines biofortification as “the practice of deliberately increasing the content of an essential micronutrient, that is, vitamins and minerals (including trace elements) in a food crop through agronomic practices, conventional plant breeding, or modern biotechnology, so as to improve the nutritional quality of the food supply and provide a public health benefit with minimal risk to health” (WHO, 2019). Biofortification is the technique of growing food crops to increase their nutritional worth. Biofortification primarily focuses on increasing provitamin A carotenoid, iron, and zinc levels in various food crops by means of plant breeding or agronomic techniques (mineral fertilizer) (Olson et al., 2021). Additionally, several experiments have used protein and amino acids as biofortifiers. Iron and zinc were used to fortify rice, beans, maize and sweet potatoes, and vitamin A used for sweet potatoes, corn and cassava (Foley et al., 2021). Studies on biofortification have determined the benefits of this strategy. It primarily targets low-income households who have little to no access to industrially fortified foods and live in isolated rural locations. These families who mostly practice subsistence farming are able to cultivate, eat, and market their own fortified crops (Olson et al., 2021). Furthermore, food systems can supply more nutritious foods more affordably when biofortification is implemented correctly. According to Low et al. (2007) and De Brauw et al. (2019), vitamin intake was increased among children and women of reproductive age when farmers were introduced to orange-fleshed sweet potatoes (OFSP).

2.4.2.2 Dietary diversification

Dietary diversification refers to the act of expanding the variety of foods consumed and a number of foods high in micronutrients that are consumed through diet planning and conventional food processing and preservation techniques (FAO/WHO, 2006). The key factors in the effectiveness of dietary diversification are food availability and the ability of the household to buy a variety of food types, including enough animal-based meals (Madhavan-Nair & Augustine, 2018). Rather than aiming to broaden the variety of food groups in the diet, the goal of dietary diversification is to enhance the quantity and bioavailability of nutrients by employing methods to enhance the meal composition or formulation (Kruger et al., 2020).

2.4.2.3 Food to food fortification

According to Chadare et al. (2019) and Kruger et al. (2020), food-to-food fortification is a method of improving the micronutrients of food with another food that is well-dense with nutrients, which is readily available and can easily be assessed locally. The goal of this approach is to improve the population’s nutritional status by leveraging nutrient-dense food (Kruger et al., 2020), and to increase the values of both micronutrients and macronutrients in food products (Tenagashaw et al., 2017). This strategy is to improve the number of micronutrients in food throughout its formulation, processing, and preparation.

2.4.3 Distribution of supplements

Because vitamin A status in underdeveloped nations is precarious, high-dose supplements were created as a reliable means of preventing the harmful effects of vitamin A deficiency (Sommer & Davidson, 2002). In Ghana, a policy and strategy implemented by the Ministry of Health to combat vitamin A deficiency is to give vitamin A supplements to every child within the age range of 6 to 59 months every 6 months (Lartey & Armah, 2019). According to studies by David (2003), the severity of diarrhoea and measles among children was reduced when The National Vitamin A Supplementation Programme (NVAP) started distributing supplements in large quantities to the three northern Ghanaian regions most lacking in vitamin A (Northern, Upper East and Upper West) in 1996 and 1997. Even though vitamin A supplementation has been successful, its sustainability is a challenge due to the following: erroneous assumptions about the supplement, neglecting to take it, misplacing it, travelling, lack of enthusiasm, imagined adverse effects, worries that the supplement is family planning or may complicate delivery, superstitious beliefs (Hill et al., 2007) and expensive (Underwood, 2004).

2.4.4 Food-based approach to reducing PEM

Among the common protein sources, legumes offer the opportunity to address PEM due to their ease of accessibility and cost compared to other protein sources. The importance of legumes as a crop for human nourishment is second only to that of cereal grains (Ebert et al., 2017). Legumes are highly nutritious, rich in proteins and essential amino acids like lysine and tryptophan and are considered an alternative and cheaper source of proteins compared to animal protein around the world (Da Silva et al., 2020). The chemical composition of some legumes is shown in Table 2.2. Indeed, protein levels of between 18-45 g/100g have been reported in several leguminous crops (Mune et al., 2007; Maphosa & Jideani, 2017; Subuola et al., 2012). These led to calls for the incorporation of legumes in commonly consumed foods to help fight protein energy malnutrition in developing countries (Maphosa & Jideani, 2017). Among the legumes, the most consumed in Ghana is soybeans and cowpea. Legumes are also an affordable source of protein for people on a budget. For example, a cup of cooked lentils contains about 18 grams of protein, which is about the same as a three-ounce serving of chicken.

Legumes that are not used to their full potential are also referred to as underutilised legumes, orphan crops, neglected crops, or inferior crops. Examples of underutilised legumes that deserve to be given more attention are Bambara groundnut, African locust bean, African yam, kidney bean, pigeon pea, lima, and Mārama beans (Ebert, 2014). Many of these neglected legumes are more nutritious, produce more than ordinary legumes, and can survive in harsh conditions. (Ebert 2014). For the ever-increasing population in developing/poor nations like those in sub-Saharan Africa, there is an urgent need for widely available, inexpensive, nutrient-rich dietary supplements. The solution to this requirement might be underutilised legumes. Most are only grown as supplemental crops at the household level. Due to their great nutritional value, these beans might significantly help fight malnutrition (Ebert.

2014). Underutilised legumes are thought to contain many unidentified bioactive substances that might be used to create therapeutic, cost-effective, functional meals (Abberton et al., 2022; Adedayo et al., 2021; Popoola et al., 2023). Increasing usage of underutilised legumes may help to minimise overuse of more widely available legumes like soybean and cowpea.

Table 2.2: Chemical composition of some legumes (g/100g)

Legume	Botanical Name	Protein	Fat	Carbohydrate	Fibre	Ash
Soybean	*Glycine max*	37 - 41	18-21	30 – 40	4 - 6	4 - 5
Cowpea	*Vigna unguiculata*	22 - 26	1 - 2	60 – 65	4 - 5	3 - 4
Groundnut	*Arachis hypogaea*	20 - 33	42-48	22 – 25	3 - 4	2 - 3
Hyacinth bean	*Lablab purpureus*	24 - 28	1 - 2	5 – 70	7 - 9	4 - 5
Common bean	*Vigna sinensis*	20 - 27	1 - 2	60 – 65	4 - 5	4 - 5
Pigeon pea	*Cajanus cajan*	15 - 29	1 - 3	60 – 66	5 - 10	3 - 4
Lima bean	*Phaseolus lunatus*	19 - 25	1 - 2	70 – 75	4 - 6	3 - 5
Winged bean	*Psophacarpus tetragonolobus*	30 - 40	15-20	35 – 45	6 - 7	3 - 5
Bambara groundnut	*Vigna subterranea*	16 -18	6-8	50 – 57	3 - 6	3 - 4

Source: Borget (1992)

2.4.4.1 Soybeans

Soybean (*Glycine max*) which belongs to the family and sub-family of Leguminosae and Papilionoidea, respectively is a food staple in many cultures. Comparing soybeans to other legumes, it is characterized as a unique vegetable with high protein content and lower carbohydrate content (Rizzo & Baroni, 2018). Soybeans are packed with nutrients and have many health benefits, making them a popular food among health-conscious consumers (Key et al., 1999; Messina, 1999). They are rich sources of protein, containing all the essential amino acids required by humans for healthy function (Michelfelder, 2009). In fact, soybeans are one of the few plant-based sources of complete protein, making them an important food for vegetarians and vegans (Qin et al., 2022). When soybeans (30 - 50 g) are consumed daily in place of an equivalent number of animal-based proteins, detrimental low-density cholesterol is significantly reduced and healthy high-density cholesterol is increased (Appiah et al., 2017). Several meat and dairy substitutes and analogues are made from soybeans and might be utilized as an alternative, particularly when switching to a vegetarian diet (Kumar et al., 2017).

According to USDA (2017), one hundred grams serving of soybeans contain 36g of protein, 30.16g of carbohydrate, 19.94g of fat, 9.3g of fiber, 15.7mg of iron and 277mg of calcium. The high fiber in soybeans makes it crucial for digestive health and can lower the chance of certain chronic diseases (Messina, 1999). Depending on cultivars, the amount of protein in soybeans ranges between 36 and 46 % (Grieshop et al., 2003; Grieshop & Fahey, 2001) . According to McClements et al. (2021) soy's protein content has been examined and was discovered that it is very much comparable to the proteins present in cow's milk and eggs, which are often used as benchmarks.

Additionally, it serves as a valuable reservoir of essential vitamins and minerals. They are particularly rich in folate, magnesium, calcium, iron, vitamin K, and potassium (Agyenim-Boateng et al., 2023). Folate is important for healthy fetal development and may reduce the risk of certain birth defects (Greenberg et al., 2011). Vitamin K is important for blood clotting, while potassium helps regulate blood pressure and can reduce the risk of stroke.

Soybeans contain compounds called isoflavones, which are a type of phytoestrogen (Setchell, 1998). Phytoestrogens are substances derived from plants that can imitate estrogen's physiological effects (Desmawati & Sulastri, 2019). Some studies suggest that consuming soy isoflavones may reduce the possibility of developing breast cancer and improve bone health in postmenopausal women (Carbonel et al., 2022; Zhao et al., 2019).

Due to their high unsaturated fat content and low saturated fat content, soybeans can help lower cholesterol and lower the risk of heart disease. (Messina et al., 2021). The American Heart Association recommends consuming soy protein as part of a heart-healthy diet (Zhao et al., 2019). Soybeans contain a type of carbohydrate called oligosaccharides, which can cause digestive discomfort in some people (Nawaz et al., 2020; Rackis, 1981). However, soaking, boiling, or fermenting soybeans can reduce the levels of oligosaccharides and make them easier to digest (Cichońska & Ziarno, 2022)

2.4.4.2 Bambara groundnut

Bambara groundnut (*Vigna subterranean (L) verd*) belongs to the family of legumes. It is an annual herbaceous crop plant with small leaves that grow about 15 cm high and has many nitrogen-fixing nodules on the roots, which help to improve the soil (Onuche, 2020; Yakubu et al., 2010). Bambara Groundnut is one of the neglected underutilized legumes (NULs) (Azam-Ali et al., 2001). When compared to other important cash crops, it is relatively underutilized, and it is often associated with small-scale subsistence farming, where women are the main producers and processors. (Mbosso et al., 2020; Mubaiwa et al., 2018).

When compared to other legumes, Bambara groundnut has advantages; It can withstand both drought and hot temperatures (Abejide et al., 2020).

Because of this, Feldman et al. (2019) suggested it should be promoted in regions that are currently prone to drought, where predictions of climate change indicate a rise in the frequency and severity of droughts. Even in regions with little or variable rainfall, Bambara groundnut is not vulnerable to the possibility of a complete harvest failure (Berchie et al., 2016; Mayes et al., 2019; Nautiyal et al., 2017) . The crop is also resistant to pest and disease invasion (Agyeman et al., 2021) and it makes little demand from the soil.

Among the leguminous seeds, Bambara groundnut has been reported to be a cheap source of protein Mubaiwa et al. (2016), with Soumare et al. (2022), recommending its incorporation into cereal-based diets. The Bambara groundnut crop is recognized as a source of a balanced and full diet. It is mostly composed of 51–71% of carbohydrate, 18–24% of crude protein, 4–12% of oil, 3–12% of fibre, and 3–12% of ash (Mayes et al., 2019). This nutrient-dense bean is commonly referred to as a "complete food," due to its optimal distribution of macronutrients. According to Azman Halimi et al. (2019), around 64.4% of the Bambara groundnut's composition is carbohydrates, followed by 23.6% of protein, 6.5% of fat, 5.5% of fibre, and a wealth of minerals. Additionally, it contains 32.72 % and 67.28 % of essential amino acids and non-essential amino acids per 100 g of grain, respectively (Koubala et al., 2013). A nearly balanced meal is produced by bambara groundnut, according to a biochemical examination of its protein, fat, carbohydrate, and mineral composition. Having an 80% protein score as opposed to groundnut's 65% (Nderitu et al., 2013), 64% for cowpeas and 74% for soybeans, the nut was shown to contain more essential amino acids than groundnut (Schaafsma, 2002).

Bambara groundnut is a perfect meal to supplement many cereal-based diets in Sub Sahara Africa because of its high quantities of protein and amino acids (Alake et al., 2017). According to Yao et al. (2015), Bambara groundnut is abundant in essential amino acids, like leucine (102.1 mg/g crude protein) and lysine (80.2 mg/g crude protein) as well as isoleucine, methionine, phenylalanine, threonine and valine. Bambara Groundnuts are rich in the crucial amino acids lysine and tryptophan, which are typically limited in maize, which is widely used in Sub-Sahara Africa (Arise et al., 2023), while methionine, an essential amino acid, is often abundant in maize but deficient in legumes (Arise et al., 2020; Tan et al., 2020). The Bambara groundnut grain contains about 10.3% of lysine which is one of the major essential amino acids (Majola et al., 2021). The Bambara groundnut grain provides the most energy boost when consumed comparing to other legumes such as cowpeas, pigeon peas, and lentils (Ojuederie et al., 2021). The recommended daily protein intake based on age is shown in Table 2.3.

Table 2.3: Recommended Daily Allowance of Protein based on age

Age	**Protein g/kg body weight**		**Reference weight kg**		**g/day**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
Infant						
4 to 12 months	1.2		8.6	7.9		
Children and adolescents						
1 to 4 years	1.0		13.9	13.2	14	
4 to 7 years	0.9		20.2	20.1	18	
Adults						
19 to 25 years	0.8		70.8	60.5	57	48
25 to 51 years	0.8		70.7	60.0	57	48
51 to 65 years	0.8		68.7	58.2	55	47
65 and older	1.0		66.8	57.1	67	57
Pregnant women						
Lactating women		1.2		60.5		71

Source: (Richter et al., 2019)

2.4.5 Food-based approach to reducing Vitamin A deficiency

The food-based approach to addressing issues of vitamin A deficiency includes adding foods which are rich in vitamin A to already existing meals. In this regard, the use of locally available staples rich in vitamin A such as ripe plantain and orange flesh sweet potatoes can go a long way to meeting vitamin A requirement.

2.4.5.1 Ripe plantain

Plantains (*Musa paradisiacal normalis*) are species of plants that produce starchy fruits that need processing before ingestion (Marian et al., 2018; Tsazeu Judicaël Boris et al., 2023). Plantain (*Musa paradiciaca*) is a staple food cultivated mostly in the tropical and subtropical regions of the world. Africa produces 61.1% of the world supply of plantain followed by South America (25.4 %) and Asia (13.5 %) (FAO, 2017). Ghana is the second largest producer of plantain in the world (FAO, 2018).

The stages of ripeness of plantain are judged primarily by colour of the plantain peel using a 1–7 scale common in the industry. At colour No. 1, the plantain is hard and completely green. Colour No. 2, the plantain is green with some yellow traces. At colour No.3, the plantain peel is more green than yellow and at colour No. 4 it has more yellow than green. At colour No. 5 the peel is more yellow with green traces. The plantain is fully yellow at stage No. 6 ant at No 7 it is yellow with black spots (Sogo-Temi et al., 2014).

It is very versatile with good nutritional value. It has high amount of vitamin A, B6, C, folic acid, iron, magnesium and potassium (Joy et al., 2022; Ayodeji, 2016). It contains 8207 μg/100g of β-carotene (Englberger et al., 2006). The amount of vitamin A in the fruit depends on the colour. The yellower the flesh, the more vitamin A it contains (Blomme et al., 2020). Plantain has an advantage over other starchy foods because it has a low glyceamic index (Adu-Gyamfi, 2022). Starches with low glyceamic index release glucose at a slow rate therefore plantain starch may be a healthier choice for diabetics (Oladele & Williamson, 2016). It is found to have 17.50% resistant starch and 56.29% accessible starch (Pacheco-Delahaye et al., 2008), which tends to boost digestion, encourage weight loss, promote high levels of insulin sensitivity (Mirabelli et al., 2020).

The plantain fruit is very versatile as each phase of ripeness has different characteristic and culinary possibilities. Due to this it is consumed almost every day by both the people in the urban and rural areas. In Ghana, when the skin is green and nearly yellow and the plantain is solid and starchy, it is used in preparing a variety of dishes like *ampesi* (boiled), *fufu* (thick Paste), *3to* (mashed) and when ripe it is roasted or fried. The fully ripped plantain is mashed and mixed with maize flour and spices and baked to prepare a cake-like product called *ɔfam* and this same mixture when packaged in leaves and boiled is called *akankyeɛ* in Ghanaian language. It has been made into chips as well. If plantain is not used for the afore-mentioned dishes, it perishes due to short storage life which is about eleven (11) day under ambient conditions (Sugri et al., 2010).

2.4.5.2 Orange fleshed sweet potatoes

Orange flesh sweet potato is a variety of the *Ipomea batatas* [L.] Lam species, which is cultivated in tropical and semi-tropical areas around the globe as a dietary staple and source of income, particularly in rural areas (Hendebo et al., 2022; Pessu et al., 2020). Orange flesh sweet potatoes are starchy vegetables that provide the amino acid lysine and ascorbic acid., in addition to significant amounts of beta-carotene (β-carotene) (Babatunde et al., 2019). β-carotene is necessary for immune system stimulation, development, and clear vision. β-carotene, which is highly bioavailable and transforms into vitamin A (retinol) in the human body, is known to be present in orange flesh sweet potato in great amounts (Haskell et al., 2012; Jamil et al., 2012).

To lessen frequent health issues linked to vitamin A deficiency in low-income communities, orange flesh sweet potato variants have recently attracted a lot of attention (Babatunde et al., 2019). It is known that OFSP offers low-income families the most economical dietary source of vitamin A (Laurie et al., 2018). Most poor households choose to rely on plant sources, such as OFSP, because they are unable to regularly afford to consume highly bioavailable animal foods (Babatunde et al., 2019).

Including carotene-rich plant-based foods like OFSP in your diet is one of the simplest methods to increase a person’s intake of vitamin A (Greiner, 2013). According to (Vollmer et al., 2017) at the International Potato Center, adding 100–150 g of OFSP to the diet can significantly lower maternal mortality and prevent VAD in children. According to (Fetuga et al., 2014), increase in production and consumption of the OFSP enhanced consumers' nutritional status in African nations, particularly in Nigeria.

It is one of the crops that has been biofortified as a part of an international initiative to lower vitamin A deficiency (Mwanga & Ssemakula, 2011). Orange flesh sweet potato is valued for its contribution to the elimination of vitamin A deficiency in underdeveloped countries (Girard et al., 2021). Orange flesh sweet potato comprises of 10-93% of β-carotene of total carotenoid in the roots (Faber et al., 2013). According to various research, some types of orange flesh sweet potato roots have β-carotene contents ranging from 0.03 to 13.63 mg/100g fresh weight (Ashun, 2018; Mbusa et al., 2018). A comparison of the β-carotene content of various sweet potato varieties revealed that OFSP roots had a higher amount of (19.31–61.39µg/g) than those of white, yellow, and cream fleshed sweet potatoes (1.02, 3.28–5.64, and 3.7839µg/g, respectively) (Islam et al., 2016).

According to a study conducted by Vimala et al. (2011), heating does not reduce the amount of β-carotene found in the OFSP roots. A family diet can be supplemented with small amounts of OFSP to help prevent vitamin A deficits in both adults and children. (Neela & Fanta, 2019). About 300 µg RE to over 3,000 µg RE per 100g of fresh weight can be found in a small amount of orange flesh sweet potatoes (Gurmu et al., 2014). This is a good source of additional nutrients and can readily meet the necessary intake. Studies on bio-efficacy of OFSP in South Africa indicated that a daily addition of as little as 100g of it to diet could prevent VAD in children (Anderson P et al., 2007). India promoted OFSP roots as a functional food and it has proven to be a successful technique for eradicating VAD while maintaining cost-effectiveness (Merckel, 2020; Owade et al., 2018). Apart from using OFSP to alleviate vitamin A deficiency, its high calorie content can be used to combat protein and energy deficiency. (Honi et al., 2018).

In an investigation conducted by the Medical Research Council (MRC), pupils who had a school lunch that included OFSP for almost two months saw an improvement in their vitamin A level, when it was successfully incorporated into the school feeding program during a trial period (van Jaarsveld et al., 2005); Leighton, 2007).

2.5 Common Foods that can be Supplemented

According to Fatemi et al. (2023), it is necessary to identify commonly consumed foods to integrate food fortification into systems of food production and distribution. Examples Millet porridge has been fortified with carrots in a study by Ndiaye et al. (2020), Moringa leaves were used to fortify fermented sorghum porridge (Nago et al., 2020), Orange fleshed sweet potatoes has been used to fortify several foods (Kruger et al., 2020; Kruger et al., 2018; Bechoff et al., 2011 & Chilungo et al.,2019). Baobab has been used to fortify porridge (Gabaza et al., 2018; Oluyimika et al., 2019). Palm oil was used to fortify tortillas (Canfield et al., 2001) and wheat base cookies (Ranjan, Passi and Singh, 2019). Starchy staples were fortified with legumes (Hurrell, 2021).

2.5.1 Roasted maize porridge

Generally, roasted maize porridge is popularly known as "Tom Brown" in Ghana. It is frequently eaten by adults for breakfast and by kids as a supplemental meal. It is frequently eaten by adults for breakfast and by children as a supplemental meal. in most African countries (Annor & Nagai, 2009; Oladeji et al., 2016) Like a lot of other cereal-based foods in the area, "Tom Brown" has a low protein content (Nagai et al., 2009; Oladeji et al., 2016). Cereals are the primary components of most traditional supplementary foods in West Africa (Oladeji et al., 2016). However, little children virtually never get enough calories and protein from the quantity they consume because of the low nutrient density of these supplemental foods (Oladeji et al., 2016). According to a study by Ejoh and Onyeulo, (2022), roasted maize contained 7.05 % of crude protein, 2.50 % of ash, 2.01 of crude fibre, 2.20 % of fat and 79.85 % of total carbohydrate. Therefore, fortifying plant-based complementary foods can be a useful tactic for combating childhood malnutrition in underdeveloped nations, if most of the population can afford it (Lartey et al., 1999; Oladeji et al., 2016). Since powdered milk (dry whole milk) contains a significant amount of protein up to 37.0%, it would have been a perfect fortifier for maize meal porridge (Oladeji et al., 2016). However, in areas where PEM is common, this can be too costly for the low-income population and so one potential strategy to reduce PEM is to fortify typical cereal-based diets with high-protein legumes (Faber et al., 2005). As a result, it is imperative to employ locally accessible, inexpensive protein sources as substitutes. Several legumes have been used to fortify roasted maize. example of such is soybean (Annor & Nagai, 2009; Nagai et al., 2009; Oladeji et al., 2016) and ground nuts (Annor & Nagai, 2009; Oladeji et al., 2016), etc.

2.6 Antinutritional factors

The plant kingdom is full of antinutrients, yet due to conventional food processing, foods containing them may be ingested without risk (Messina, 2014). Edible crops are primarily composed of antinutritional substances such as tannins, phytic acid, oxalate, gossypol, lectins, protease inhibitors, amylase inhibitors, and goitrogens (Duraiswamy et al., 2023; Majola et al., 2021; Mayes et al., 2019).

Antinutrients are a significant cause of decreased bioavailability for many components found in grains and legumes (Samtiya et al., 2020). Legumes typically exhibit some undesirable characteristics, including deficiencies in methionine and cysteine, as well as significant levels of antinutritional agents such as protease inhibitors, lectins, phytic acid, and tannins, oxalate, metal chelators, saponins, cyanogens, isoflavonoids among others (Banti & Bajo, 2020)

Antinutrients are compounds that reduce the nutritional quality of food, bioavailability and digestibility of nutrients and therefore cause micronutrient, malnutrition, and mineral deficiencies (Duraiswamy et al., 2023; Samtiya et al., 2020). Beans have several molecules that have been labelled as antinutrients, which are substances that can prevent the body from properly absorbing and using nutrients. They consist of lectins, phytates, oxalates, and protease inhibitors (PIs) (Bouchenak et al., 2013; Campos-Vega & Oomah, 2010) and polyphenolic compounds such as tannins, phenolic acids, and flavonoids (Marathe et al., 2011)

Both phytates and oxalates, predominantly impacts calcium, and have a negative impact on mineral absorption. A large range of cooked dry beans had oxalate concentrations of between 4-80 mg/100 g in a study by Chai & Liebman (2005). The chelating effect of phytate affects the bioavailability of calcium and other minerals, such as iron, copper, and zinc (Kaushik et al., 2018). Other elements, such as polyphenols, and oxalates, are regarded as antinutrients that can reduce the bioavailability of dietary minerals.

According to Campo-Vega et al. (2010) and Chitra et al. (2005), beans have a phytate level that varies from 0.1 percent to 2 percent. Phytate is not dissolved by heat, therefore it has a significant impact on how well micronutrients like zinc, which is often low in plant-based diets, are absorbed from beans (Campo-Vega et al., 2010). The effects of phytate may be lessened by soaking and fermentation for zinc absorption to increase (Gupta et al., 2015).

Additionally, the iron absorption from beans and other plant meals is decreased by phytate. This explains why the RDA of iron for vegetarians 18 times greater than the RDA for non-vegetarians (Petri et al., 2016). Tannin is one antinutrient that could be advantageous. It has antioxidant properties (Messina, 2014) and may reduce the risk of some malignancies and kidney stones (Sharma et al., 2021).

2.6.1 Phytate

Food has varying quantities of phytates, ranging from 0.1% to 6.0%. They are sometimes referred to as myo-inositol-1,2, 3,4,5,6-hexakis dihydrogen phosphate (Gupta et al., 2015). Due to its predominantly negative charge, phytic acid readily forms complexes with positively charged metal ions such as zinc, iron, magnesium, and calcium. These complexes lessen these ions' bioavailability. Phytic acid is considered one of the most powerful antinutrients in food because of its chelating activity. It also contributes to mineral ion deficit in animal and human nutrition (Kumar et al., 2021; Nissar et al., 2017). According to a study by Lee et al. (1988), giving phytate to female rats had a negative impact on their ability to metabolize calcium, zinc, and phosphorus. Soaking, cooking, roasting, germination and fermentation are traditional methods that can be employed to reduce the amount of phytate (Petroski & Minich, 2020). Phytate levels in millet, maize, rice, and soybeans could be lowered by 28, 21, 17, and 23%, respectively, by soaking the seeds in fresh water (Petroski & Minich, 2020).

2.6.2 Tannins

Tannins are phenolic compounds and have the properties of precipitating proteins. Plant leaves, fruits, and bark all produce tannins, which are secondary compounds. (Timotheo & Lauer, 2018). Tannins frequently decrease the digestibility of proteins and result in a depletion of crucial amino acids due to the formation of both reversible and irreversible tannin-protein complexes. These complexes are formed between the hydroxyl group of tannins and the carbonyl group of proteins (Raes et al., 2014). There are two types of tannin groups in nature: hydrolysable (examples are gallotannins and ellagitannins) and condensed (example proanthocyanins) (de Camargo & da Silva Lima 2019). Legumes and some seeds mostly contain condensed tannins. Since tannins are concentrated in the bran part of the legumes, peeling, and boiling the legume can lower their phenolic content by up to 90% (Petroski & Minich, 2020; Karamać 2009). When ingested, tannins react with proteins to create compounds that reduce the digestibility of proteins and deactivate a number of digestive enzymes (Joye, 2019). Tannins have the potential to reduce iron absorption in humans (Petroski & Minich, 2020).

2.6.3 Oxalate

Many foods from plants that people eat contain oxalates. The highest oxalate-containing plant foods are raw beans, amaranth, taro, sweet potatoes, almonds, baking chocolate, and tea (Petroski & Minich, 2020). Oxalate concentration varies greatly in raw legumes. The highest concentration is found in soybeans (370 mg/100 g) (Shi et al., 2018; Petroski & Minich, 2020). Variations in the total oxalate content are related to growing conditions, season, and cultivars (Shi, Mou & Correll, 2016). For example, Horner et al. (2005) in their studies discovered a more than twofold disparity in oxalate content among 116 cultivars of soy, ranging between 82 and 285 mg/100 g dry weight. Additional factors that may affect oxalate concentrations include the time of harvest (Hönow et al., 2010). Most foods like legumes and greens are boiled before consumption, oxalate levels in raw food items are not indicative of the actual content consumed (Petroski & Minich, 2020). It has been shown that using traditional preparation techniques can effectively reduce the amount of oxalate present. There is only a 50–200 mg daily limit for dietary oxalate intake (Siener et al., 2013).

2.6.4 Processing methods for reducing antinutrients in legumes or cereals

When present in excess, antinutrients can become hazardous in addition to reducing the bioavailability of nutrients. For this reason, it is critical to lower the amounts of antinutritional components in edible crops to avoid toxicity and the health issues that come with it (Gemede & Ratta, 2014). It is feasible to decrease the amount of antinutrients in meals by utilizing a variety of techniques alone or in combination. The amounts of these antinutrient components can be decreased using a variety of conventional techniques and modern technology. To lower the antinutrient content of foods, a variety of processing procedures and technologies that are utilized include Milling, fermentation, germination, de-branning, autoclaving, soaking, cooking, or boiling, roasting.

2.6.4.1 Milling

Milling is a widely used, conventional technique employed to extract the bran layer from the grains. Grains are ground into flour by this process. One major drawback of this approach is that it also removes important minerals. The milling process removes antinutrients such as phytic acid, lectins, and tannins that are present in the bran of grains (Gupta et al., 2015).

In a study by Suma and Urooj (2014), They milled the grains of pearl millet to create whole flour, bran-rich section, and semi-refined flour, then compared the antinutrients and mineral bioavailability. The findings of the nutritional content revealed that there was no distinction between whole pearl millet and semi-refined flour. However, it was found that semi-refined flour had lower levels of phytate and oxalate than whole flour because the bran portion had been removed.

2.6.4.2 Soaking

Soaking is a preferred technique for eliminating antinutrient content from foods because, it reduces the duration required for cooking. After soaking, certain enzymes, such as natural phytases found in plant-based foods such as almonds, pecans, and cereals, are liberated more readily (Samtiya et al., 2020).

In general, soaking gives legumes, cereals, and other consumable kernels the necessary wet conditions for germination, with corresponding decreases in the levels of enzyme inhibitors and other antinutrients to improve nutritional value and digestibility (Ranabhat, 2020). Furthermore, the process of soaking is essential for fermentation as it aids in reducing the levels of particular antinutrients present in food (Gupta et al., 2015). Because a lot of anti-nutrients are naturally soluble in water, this makes it easier for them to seep out of legumes.

Soaking legumes and grains increase their hydration, resulting in a softer texture. This technique also triggers the activation of an internal enzyme called phytase, which facilitates subsequent cooking or boiling. However, soaking normally reduces the antinutrient phytochemicals like phytate, tannins, etc. Due to these advantages, it was advised that some grains and legumes be ingested after being soaked for 12 to 24 h (Gupta et al., 2015; Ertas & Türker 2014; Onwuka, 2006).

According to Coulibaly et al. (2011), the concentration of minerals and the availability of protein are both improved by soaking grains and beans, which also results in lower levels of phytic acid. Another study found that increasing the soaking period from 2 to 12 hours decreased the amount of phytic acid in chickpeas by 47.45 to 55.71 percent (Ertaş et al., 2014).

2.6.4.3 Cooking/ Boiling

This procedure removes heat-sensitive antinutritional components like trypsin inhibitors (Bhasin et al., 2018). According to Vadivel and Biesalski (2012), the amount of phytic in legume grain significantly reduced by soaking and boiling. Prior to eating, legumes are typically boiled or pressure-cooked. Additionally, studies by Patterson et al. (2017) showed that lowering foods' antinutritional factors like tannins and trypsin inhibitors by boiling or heating them significantly increased their nutritional content. Again, Vadivel et al. (2012) found that cooking and soaking legume grains significantly reduced the amount of phytic acid present in those grains.

2.6.4.4 Blanching

Blanching refers to a gentle application of heat to food. Normal methods for blanching legumes include soaking them in hot water or briefly boiling them. Food enzymes and several antinutritional elements in the legumes are destroyed during this procedure. Blanching help the dehulling procedure as well (Oyeyinka et al., 2021).

2.6.4.5 Germination

Germination is a highly effective approach for decreasing the antinutritional content of plant-based foods (Nkhata et al., 2018). During the process of seed germination, the enzyme phytase is often activated, leading to a reduction in the quantity of phytic acid in the samples through the breakdown of phytate.

During germination, food often changes in morphological features, biochemical properties, and nutritional value. Typically, this technique is employed to reduce the antinutritional levels in cereals (Oghbaei & Prakash, 2016; Onyango et al., 2013). Decreasing antinutrients like tannin and phytic acid in sprouted grains enhances the absorption of various minerals and boosts the nutritious content of food items (Ogbonna et al., 2012; Oghbaei & Prakash, 2016).

2.6.4.6 Fermentation

Fermenting food is essential because it effectively reduces the levels of anti-nutrients found in cereal, such as phytic acid, tannins, and polyphenols (Simwaka & Masamba, 2017). Fermentation is a metabolic process that produces energy by oxidising carbohydrates and improving the absorption of nutrients from plant-based diets. Since cereals are difficult to ingest in their natural or raw forms, one of the processing methods utilised in Africa is fermentation. It makes cereal grains digestible and improves the nutritional content and safety aspect of these foods (Galati et al., 2014).

In grains, proteins and metal cations like zinc, iron, and calcium often form complexes with phytic acid. Enzymes are typically used to break down these complexes, and they need the ideal pH that fermentation maintains. Therefore, this type of degradation raises the nutritional value of dietary grains by releasing soluble iron, zinc, and calcium and lowering the amount of phytic acid (Gibson et al., 2010).

2.6.4.7 Roasting

Legumes are roasted on an open frying pan, regardless of whether salt or ash is present or not. Legumes taste more palatable after roasting. It is crucial for lowering and getting rid of antinutritional factors. The distinctive flavours of roasted legumes can boost their sensory appeal (Subuola et al., 2012; Oyeyinka et al., 2021). Additionally, the roasting method significantly decreased the trypsin inhibitor activity in soybean meals. according to a study by Vagadia et al. (2017).

2.7 Effects of the processing methods on the functional properties of food

The essential physicochemical attributes of foods are their functional qualities, which depict the complex connections between the compositions, structures, and molecular arrangement of food components and the surrounding environment and settings in which they are evaluated and correlated (Godswill et al., 2019; Suresh & Samsher, 2013).

The functional features of food components describe their behaviours throughout the process of preparation and cooking, as well as their impact on the ultimate appearance, texture, structure, and flavours of food items (Godswill et al., 2019a). A food's organoleptic, physical, and/or chemical characteristics frequently dictate its functional characteristics (Omowonuola et al., 2017). Among the flour’s functional qualities are their solubility, water retention, elasticity, foaming ability, absorptive capacity for fat and foreign particles, emulsification, water binding (hydration), viscosity, cohesion, and adhesion (Suresh & Samsher, 2013).

The quality and suitability of flours for use in diverse food applications depend greatly on their functional qualities (Dereje et al., 2020; Godswill, 2019). Every component that goes into a food has a unique purpose, which frequently affects the food’s functional attribute. Starch is the main factor that causes gelatinization, browning, dextrinization, gelation, etc. Proteins are largely responsible for processes like foaming, browning, emulsification, coagulation, denaturation, and others. Fat is the main cause of several processes, including emulsification, aeration, and shortening. A food's functional qualities begin to emerge from most of the procedures it goes through. An example is heating (Godswill et al., 2019; Awuchi & Echeta, 2019).

2.7.1 Water absorption capacity (Hydration)

Water Absorption Capacity (WAC), sometimes called water binding capacity, is the amount of moisture or water that food or flour can absorb to get the right consistency and high-quality food product (Dereje et al., 2020; Li et al., 2023). The quality of food products might be negatively impacted by either very low or very high-water absorption. Water absorption is often determined by the weight of the food or flour. When flour and water are combined, the water molecules hydrate the proteins and starch, including other components. The hydration process is accomplished when water molecules form hydrogen bonds and hydrophilic interactions with starch and protein molecules (Chandra et al., 2015). Through friction and interaction with water molecules, particles hydrate. Pressure, water flow, mixer type, and other process variables cause the hydrated surface layer to be removed and new particle layers to be exposed to excess water, allowing the water diffusion process to continue. The following metrics can be affected by water absorption of products: viscosity of porridge, consistency of porridge, proofing of bread dough, fracture stress of bread crumb, loaf volume, yield, characteristics of the finished product, and shelf life (Godswill et al., 2019; Zghal et al., 2001).

Many hydrophilic ingredients included in food, like carbohydrate and protein, particularly polar amino acid residues, which have a strong attraction to water molecules, are responsible for the food's high WAC value (Sreerama *et al.,* 2012). The loss of starch's crystalline structure, increased amylose solubility, and leaching are also contributing factors to the rise in flour's WAC. Certain composite flours have high WAC values which indicate that combining several flours can be utilized to produce a wide variety of foods. Butt and Batool, (2010) reported that the variation in water absorption capacity (WAC) of different foods and flours can be attributed to variations in protein quantities, their structural features, and the extent of their interaction with water. The water-absorbing capacity of flour is essential for achieving the desired volume and texture, particularly in baking processes (Iwe et al., 2016). The decreased presence of polar amino acids in certain types of flour could potentially explain the reduced ability to absorb water.

2.7.1.1 Factors that affect the water absorption capacity of flour

Factros that affect the water absorption capacity of flour includes:

1. Starch**:** The flour's starch content accounts for around 46% of the total water absorbed.
2. Pentosans**:** Pentosans in the flour are linked to around 23% of the total water absorbed.
3. Proteins**:** It is estimated that proteins account for 31% of the total amount of water absorbed.

4. Vital wheat gluten (VWG): The addition VWG enhances dough's stability and boost its absorption of water in the case of breadmaking. (Sumnu & Sahin, 2008).
5. Additional water-binding ingredients like fibre, bran hydrocolloids (gums), eggs, etc. also boost its ability to absorb water.

   (Adapted from Godswill et al., 2019)

2.7.2 Oil absorption capacity

Oil absorption capacity (OAC) is also known as oil binding capacity (OBC), and it occurs when fat binds to flour or food through the non-polar side chain of proteins (Chandra et al., 2015; Godswill Awuchi et al., 2019). Protein-rich foods exhibit a significantly elevated propensity for absorbing oil (Zhang et al., 2021). The ability of food protein to bind water and oil depends on its inherent qualities, such as the amino acid composition and surface polarity or hydrophobicity, and protein structure (Suresh & Samsher, 2013). Flours are beneficial in culinary applications where excellent oil absorption is needed because of their capacity to bond with oil, causing flour to have prospective uses in foods such as production of pastries, sausage, porridge. The flour's capacity to absorb oil enhances mouthfeel and preserves the flavour when used in food preparation (Suresh & Samsher, 2013; Iwe et al., 2016). High OAC flours may aid in the structural interactions of food, especially in terms of enhancing taste, prolonging the duration of freshness, and maintaining flavour, particularly in meat products and baked goods where it is desirable for fat to be absorbed (Godswill et al., 2019). Protein is the primary chemical constituent affecting OAC because it has both hydrophobic and hydrophilic parts (Jitngarmkusol et al., 2008; Godswill et al., 2019).

2.7.3 Bulk density (volumetric density or apparent density)

Bulk density is defined as the mass of several powdered material particles divided by the total volume, they occupy (Godswill et al., 2019). It is alternatively referred to as apparent density or volumetric density. The total volume consists of the volume occupied by particles, the volume of internal pores, and the volume of voids between particles (Webb, 2001). It is a useful characteristic of food ingredients such as flour, powders, fine particles, granules, and other split materials. The bulk density of food can vary based on its handling, indicating that it is not a constant characteristic.

Food variations in starch content may be the cause of variations in bulk densities (Godswill et al., 2019; Godswill, 2019). An increased starch content is more likely to lead to an elevated bulk density. Furthermore, increasing bulk density with smaller particles is possible since bulk density is influenced by various aspects, including the shape, measurement technique, particle size, surface characteristics, and the density of the materials. Furthermore, bulk density increases with appropriate packaging material, properly tapped/vibrated and compatible (Iwe et al., 2016: Godswill Awuchi et al., 2019). The bulk density indicates the proportional volume or capacity of the necessary packing material. A higher bulk density of the flour requires denser packaging material. The porosity of a food product is demonstrated, which has an impact on the package's design and helps identify the kind of packing material needed (Iwe et al., 2016). According to Joshi et al. (2015), flour's initial moisture content might have an impact on its bulk density. Flours are appropriate for use in culinary preparations when they have high bulk density. Conversely, low bulk density might be advantageous for formulating complimentary food for babies (Suresh & Samsher, 2013).

2.7.4 Swelling index (swelling capacity)

The volume in millilitres that one gramme of food material will take up to swell under specific conditions is known as the swelling index (SI), often called the swelling capacity (SC) (Godswill et al., 2019). The measurement of starch's ability to swell after absorbing water is called its swelling capacity. It also demonstrates how strong the associative forces are within the starch grains. When it comes to some food items, such porridge and baked goods, the swelling index is regarded as a quality indicator. Particle size, species diversity, processing technique, and unit operations are factors that affect the flour swelling index (Ahmed et al., 2016). Foods and flours with a high starch content have a higher swelling index, particularly those with a greater branching amylopectin concentration. A chain of glucose molecules, which could be branched (amylopectin) or linear chains (amylose), makes up starch. Starch is present in little structures called granules. Plant sources vary in the composition and proportions of amylose and amylopectin in starch. This explains why flours made from different plant species and sources have different swelling capabilities (Godswill et al., 2019).

2.7.5 Solubility index

Solubility in foods is a chemical and functional characteristic that pertains to the capacity of a specific food component to dissolve in a solvent., usually water or oil (Godswill et al., 2019). The solubility of a material is primarily determined by the physical and chemical characteristics solute and solvent, as well as by temperature, pressure, pH, and the presence of other substances in the solution (Godswill, 2019). According to Opong et al. (2021), foods (flours) with lipids have a lower ability to absorb water, which can diminish their swelling capacity and, ultimately, their solubility. Foods with high solubility can also be highly digestible, which suggests that they make good baby formula and foods. Food materials are specifically categorized as insoluble when their solubility is less than 0.1 g per 100 milliliters of the solvent (Godswill et al., 2019)

2.8 Viscosity and pasting properties of flours

Pasting is the outcome of several steps that occur after starch is heated and cooled, leading to granule rupture during gelatinization and then polymer alignment because of mechanical shear (Amagloh, 2022).

Gelatinization occurs when heat and water cause the intermolecular bonds between starch molecules to weaken, enabling the hydrogen bonding sites to absorb a significant amount of water. Consequently, the starch granules undergo irreversible dissolution in water. Water functions as a plasticizer. Starch granules absorb moisture, swell, and rupture when heated in a liquid, like water. This increases the viscosity or stickiness of the starch, which causes the mixture to thicken. When heating, the mixture must be stirred gently to avoid lumps and to ensure consistency (Hasmadi et al., 2020). The three primary steps that the starch granules go through are granule swelling, crystal or double helical melting, and amylose leaching (Hasmadi et al., 2020). The amylose concentration in flour, as well as the quantity of non-starchy ingredients like protein and fat, and processing methods, all affect the pasting properties of starch (Amagloh, 2022; Devi et al., 2024; Mauro et al., 2023).

Brabender Viscograph is a worldwide standard instrument for the determination of the gelatinization and retrogradation properties of starch which are indicated by the viscosity of a starch-water suspension during heating and cooling. Viscograph viscosity is the ‘resistance’ measured as torque and expressed in arbitrary units (Brabender Units, BU) of a starch-water suspension heated in the Brabender Viscograph at a constant rate of increase (heating) and decrease (cooling) at a designated constant rotational speed, while being subjected to temperature changes. The viscosity of starch paste measured at different stages during their preparation serves as a guide to their pasting behaviour. Pasting properties are influenced by factors such as starch, stirring, water, temperature, addition of other ingredients, such as protein, sugar, acids, fat, etc (Adebayo-Oyetoro et al., 2016; Dereje et al., 2020; Godswill, 2019).

2.8.1 The stages involved in pasting process

Figure 1.1 show the stages involved in pasting process. The peak viscosity refers to the maximum viscosity exhibited by the paste during the heating process. Peak time refers to the specific moment when viscosity reaches its highest point. It measures the duration of the gelation process of a sample paste while it is being cooked (Alake et al., 2016).

Final viscosity is the viscosity of a paste at the end of the cooling phase at 50 ℃. It is used to show whether starch can form different types of paste or gel when cooled. According to Sanni et al. (2006), final viscosity is utilised to assess the quality of a specific sample of starch-based material.

Setback refers to the disparity between the final viscosity and the peak. It measures the paste's stability following cooking. It is also the cooling phase of the mixture during which re-association between the starches molecules occurs to a greater extent. It consequently influences the starch molecules' retrogression and reorganization (Alake et al., 2016; Sanni et al., 2006). It has been reported by Sanni et al. (2006) that setback pasting property has a correlation with texture and is also associated with synergism and 'weeping'. High stability is indicated by a low setback of paste (Awoyale et al., 2016).

The degree of granule disintegration or paste stability during the viscosity test's holding period is measured by breakdown viscosity. High peak viscosity is linked to high breakdown values, and this in turn is connected to how much the starch granules swell after heating (Ragaee & Abdel-Aal, 2006). According to Adebowale et al. (2005), paste stability increases with decreasing breakdown viscosity.

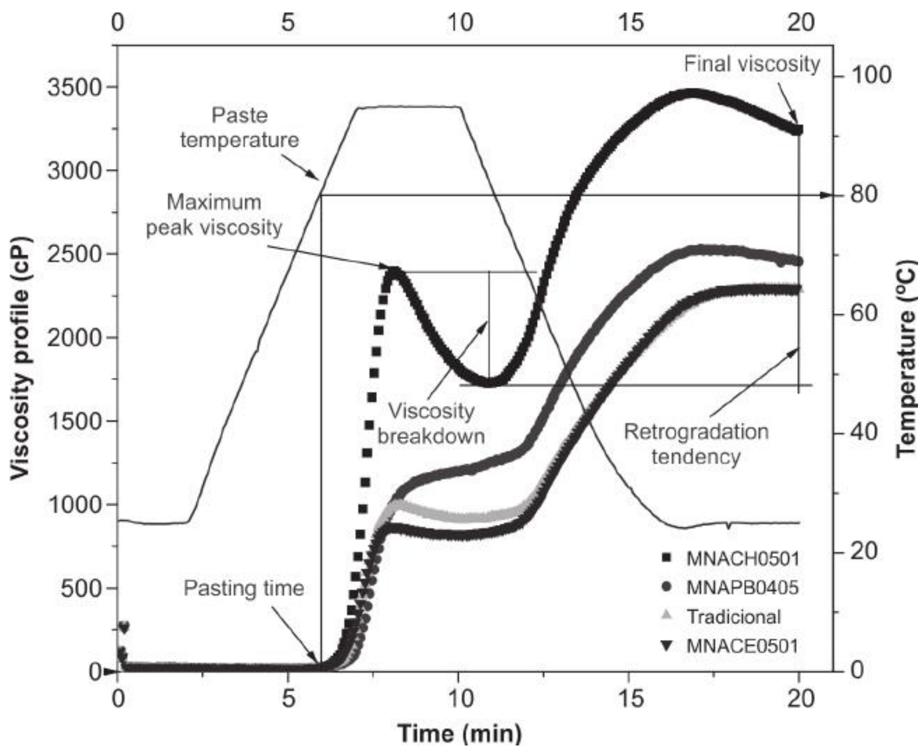


Figure 1.1 The viscosity profile of the paste.

The temperature at which viscosity increases by two (2) BU or RVU in 2 seconds is known as the peak temperature. It indicates the temperature needed to cook the flour paste to the point of gelatinization.

2.9 Sensory Evaluation

Sensory evaluation consists of a collection of methodologies for accurately measuring human responses to foods and minimising the potentially biased impacts of brand identity and other information influences on customer perception (Lawless & Heyman, 2010). Sensory analysis provides detailed information about the sensory properties of food products, from raw materials to finished products. By attempting to separate the sensory qualities of food itself, sensory assessment gives managers, food scientists, and product developers vital and practical information about the sensory qualities of their goods. Sensory tests are frequently used in academic research on foods, materials, and their properties and processing to assess how people perceive changes in the products. According to Stone and Sidel, (2009), sensory evaluation is a scientific approach to elicit, quantify, examine, and evaluate responses to items as experienced by the senses of sight, smell, touch, taste, and hearing.

The procedures used in sensory evaluation include tests intended to find differences between the samples to be evaluated. What kind of difference is there between the samples? There are two primary types of sensory tests: objective sensory tests that focus on humans as detective instruments and subjective (affective) sensory evaluations which place emphasis on customer reactions (likes, preferences, and emotions).

2.9.1 Objective testing

Objective testing uses selected or trained panel to evaluate sensory attributes of a product. Objective testing is classified into two. These are discrimination test which ascertain if variations exist between two or more samples and descriptive tests which also determine the type of sensory variations or the extent of the variations (Lawless & Heymann 2010).

2.9.2 Discrimination or difference test

Discrimination tests can also be termed as difference tests. These are analytical sensory tests used to determine whether two or more samples differ from one another and referring to published significance tables based on the binomial distribution makes it simple to ascertain the results (Drake, Watson & Liu, 2023; Lawless & Heyman, 2010). The discrimination test can be categorised into triangle test, duo-trio test, same difference test, paired comparison test, ranking test, and tetrad test (Drake et al., 2023; Ennis et al. 2014; Inarejos-Garcia et al., 2012; Ramsgaard et al., 2018). The number of panellists or consumers required for these sensory tests range from 20 to over 100, contingent upon the choice of difference test and its ability to identify differences (Drake et al., 2023).

Triangle test is used to ascertain whether two samples differ from one another. Three coded samples are given to assessors, and their task is to identify "the odd one out." To find out if there is a difference between two samples, the duo-trio test is also employed. Three samples are provided to assessors; two are coded, and one is marked as a "reference." They are required to identify the one that most closely resembles the reference sample. Assessors are given two samples in the same-different test, and their task is to decide whether the samples are similar or different. If there are any disparities, they might be asked to explain them in this type of test. Paired comparison is employed to ascertain whether there is a difference between two samples with respect to a particular attribute. The paired comparison test is also called a paired preference test when it is used to determine preference between two samples. A ranking test can also be used to find out if there is a difference in a particular attribute between three or more samples. e.g. thickness (Lawless & Heyman, 2010).

2.9.3 Descriptive test

Another name for a descriptive test is trained panel profiling. This objective sensory approach is a valuable tool for accurately characterising the sensory characteristics of food or any other product. The analysis and interpretation of descriptive test data is conducted as though it originated from an analytical instrument. In this test, panel do not measure likeness and there is no subjective point of view (Drake, 2007; Lawless & Heymann, 2010). The descriptive test is conducted with a group of skilled or trained evaluators, often ranging from 6 to 12, depending on the chosen methodology. These panels are trained to identify sensory characteristics and employ a numerical scale to quantify the intensity of those characteristics. The produced data are statistically analysed, either alone or in conjunction with other analyses, such as instrumental or consumer acceptability evaluations, to address a particular analytical sensory objective (Lawless & Heymann, 2010; Drake et al., 2023; Murray et al., 2001). An essential aspect of panellist training involves the creation or utilisation of a thoroughly established sensory lexicon or vocabulary. (Lawless & Civille, 2013).

Descriptive test methods are of different types. The general outcome remains the same even with varying strategies or tactics used for panel training and/or data gathering. Several frequently employed techniques include the spectrum approach, quantitative descriptive analysis, flavour profile method, and texture profile method (Lawless & Heymann 2010). The spectrum technique and the quantitative descriptive approach differ in their practical approach to panel training (Lawless & Heymann 2010; Murray et al., 2001). To document the intensities of flavours and texture in food products, the spectrum approach uses a universal scale, while quantitative descriptive analysis utilises a scale specific to the product. Panellists in quantitative descriptive analysis are typically chosen based on how well-versed they are in the product and the panel leader abstains from participating in the product review, and neither of these techniques are employed in the spectrum method. Nevertheless, the quantitative descriptive analysis necessitates minimal training time for the panel in contrast to the spectrum method, rendering each approach particularly suitable for distinct aims (Drake et al., 2014).

Free-choice profiling is another approach to descriptive test. Panellists who use this method must come up with their own attributes and then use their own way to scale the intensities of those attributes. Panellists must possess the ability to replicate the attribute profiles of samples. they have, much like in conventional sensory profiling. After collecting the data, another statistical method known as generalised Procrustes analysis is used to produce a consensus map. This method, in theory, does away with training; but panellists need to be able to profile a product using self-generated attribute consistently. Experience is key. Flash profiling is another recommended descriptive analysis method.

Panellists must also be experienced. Panellists are given all the samples and asked to describe all the descriptive attributes instead of evaluating each sample separately and grading intensities as is done with standard sensory analysis or free-choice profiling. Samples are subsequently ranked by panellists based on the designated attributes (Drake et al., 2023).

2.9.4 Subjective testing

Subjective sensory evaluation includes the consumer's emotional, affective, and behavioural responses to the product. In subjective testing the sensory properties of a product are measured by the reaction of consumers. It is also referred to as an affective or consumer test. This test provides subjective data on acceptability, preference or hedonic tests and can be conducted with untrained assessors (Marques et al., 2022). Hedonic or affective test methods are sensory assessments that aim to measure how much a consumer likes or dislikes a product. These tests are considered consumer tests because they are conducted using untrained consumer panels.

According to Weaver & Brittin, (2001), the hedonic scale was established at the U.S. Army Food and Container Institute during the latter part of the 1940s. The approach aimed at generating scale point labels with adverbs that conveyed psychological shifts in hedonic tone and provided a 9-point balanced scale for liking with a neutral category at the center as shown in Figure 2.1 (Lawless & Heymann, 2010). Generally, a group of 75-150 frequent users of the product would be employed in a hedonic test. Through this test, manufacturers can identify consumer segments that would prefer various product designs, such as distinct colours or flavours. It gives producers an opportunity to be informed about why consumers like or dislike a product as well. The variability of responses is controlled by using questionnaires and numerical scales (Stone, 2015).

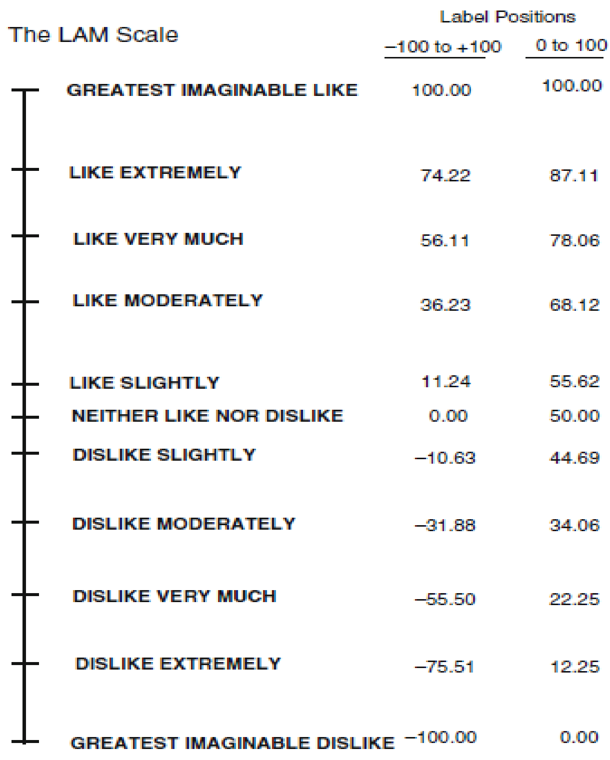


Figure 2.1: The affective magnitude (AM) scale (Lawless and Heymann, 2010)

Combining objective and subjective testing increases the effectiveness of sensory assessment and provides insight into how sensory qualities influence consumers' acceptance (Singh-Ackbarali & Maharaj, 2014). Combining data from sensory and instrumental tests can offer valuable understanding of the chemical and physical characteristics like colour, shape, size, viscosity, and density driving sensory attribute (Saleh & Lee, 2023). For example, (Otoo et al., 2018) used both instrumental and sensory measurement to evaluate quality attribute of fufu. If there is a strong correlation between the sensory data, it may be feasible to replace the sensory panel with a more cost-effective instrumental test (Blaker et al., 2014; Saleh & Lee, 2023). Physical properties, chemical properties, formulation, and process variables linked to sensory properties enable product to be designed to deliver appropriate consumer benefits (Alake et al., 2016; Moss et al., 2023).

Approximately 75% of newly developed products which do not conduct consumer testing do not do well their first year of availability on store shelves (Kemp et al., 2010; Buisson, 1995). According to Lawless and Heymann, (2010), incorporating consumer and sensory testing into the product development process lowers the chance of failure by enabling the cost-effective delivery of items that customers find acceptable.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Acquisition of materials

Fresh plantain and orange-fleshed sweet potatoes were procured from the Jukwa market in the Central Region while maize was purchased at a local market at Abura in Cape Coast. Bambara groundnut and soybeans were purchased from a local market in Tachiman. The plantain was kept in a cool room until the onset of ripening before preparation into flour. Maize, soybeans and Bambara groundnuts were sorted manually by picking immature seeds, stones, unwholesome grains and other foreign materials.

3.2 Preparation of Flours from Raw Materials

Ripe plantain was processed into flour using the process reported by Odebode et al., (2018) with minor modifications. The freshly harvested plantain was stored at ambient temperature in the dark to initiate ripening until a colour equivalence of “No 4” (Sogo-Temi et al., 2014). To prepare the flour, the ripe plantain was peeled and sliced into 0.5 cm thickness and immediately dried in a five-layer food dehydrator (Food Dehydrator, Model No. /TD/OA 420, China) at 60 °C for 12 hours. The dried sample was cooled and milled into flour using a stainless-steel laboratory blender, sieved through a mesh (300 µm) and packed into an airtight zip lock bags and kept in a freezer at -4 °C until analysis (Figure 3.2).

Orange-fleshed sweet potatoes (OFSP) were thoroughly washed with water to remove debris, peeled and sliced with a knife for drying in the dehydrator for 12 hours at 60 °C. After milling and packaging, the flour was stored in a freezer (Figure 3.2).

Maize was roasted in a cast iron pan on a gas cooker 120 °C for 40 min. During roasting, maize was continuously stirred with a wooden spatula until the colour turned golden-brown. The roasted maize was then milled with a hammer mill (Gratis Foundation, Mc Lean, VA, USA), packaged and stored in a freezer (Figure 3.2).

Bambara groundnut flour was prepared according to the technique used by Mbata et al., (2009) with minor modifications. The nuts were steeped in distilled water for 3 hours and boiled at 100 °C for 2 hours. The cooked nuts were de-hulled manually with a wooden mortar and pestle and dried at 60 °C for 12 hours. The dehulling was done to reduce the antinutrient and to enhance the seeds' nutritional content and digestibility. After milling, and packaging, the flour was stored in a freezer (Figure 3.2).

Soybeans were roasted in a cast iron pan on a gas stove and stirred with spatula continuously at 150 °C for 40-45 min. The roasted soybean was allowed to cool, milled, packaged and stored in a freezer.

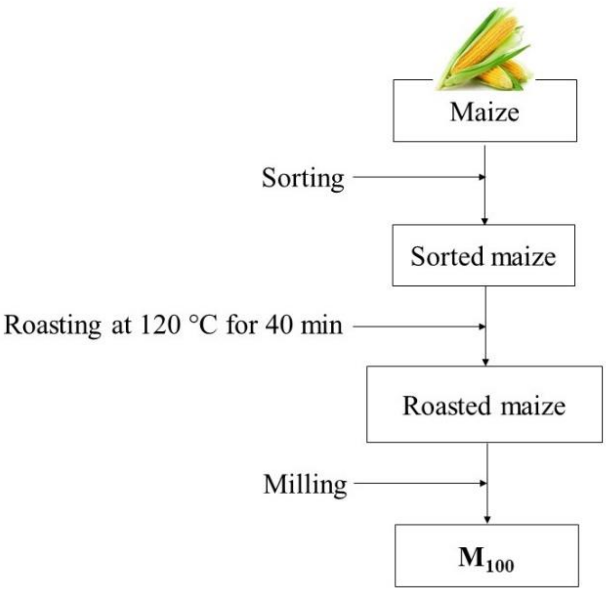


Figure 3.1: The preparation of roasted maize (M_{100}) flour.

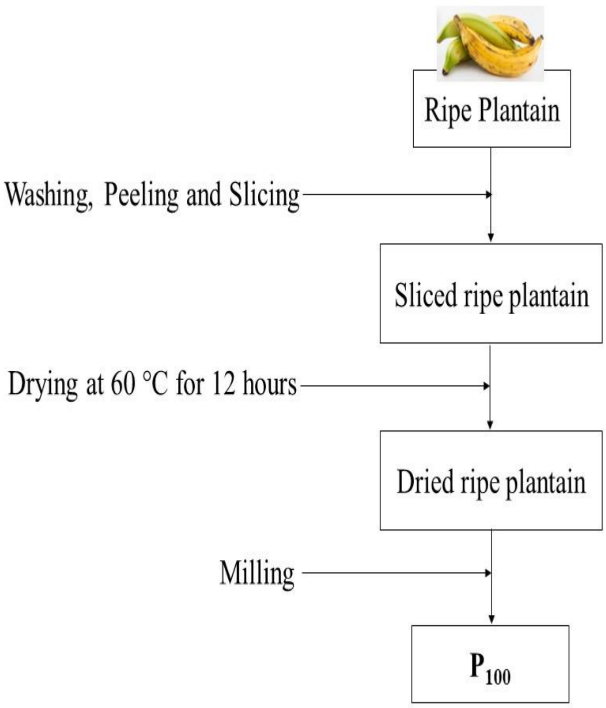


Figure 3.2: The preparation of ripe plantain (P_{100}) flour.

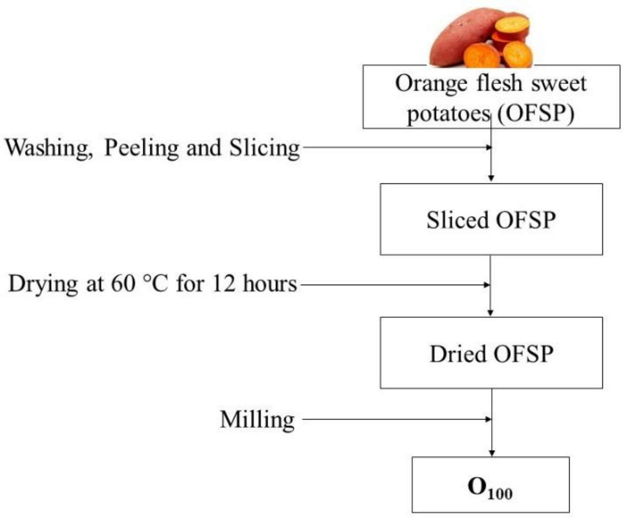


Figure 3.3: The preparation of roasted orange flesh sweet potatoes (O_{100}) flour.

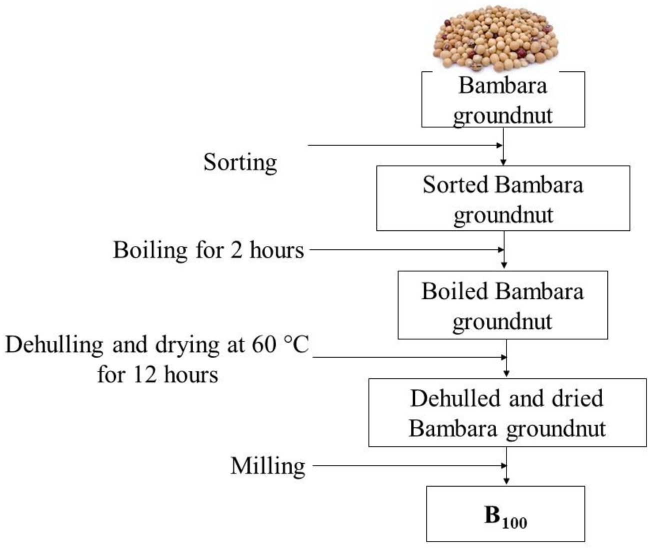


Figure 3.4: The preparation of Bambara groundnut (B_{100}) flour.

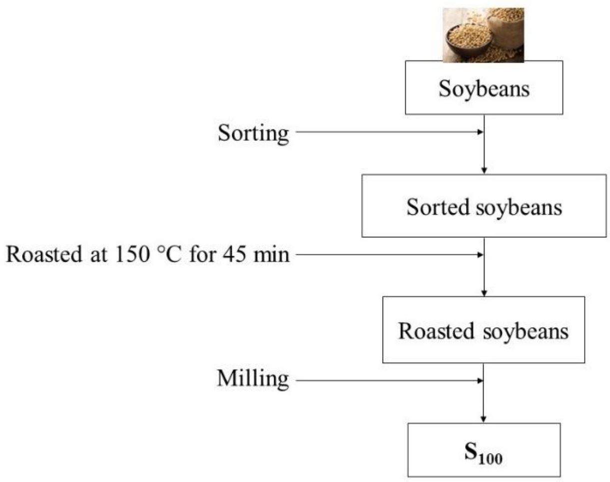


Figure 3.5: The preparation of Soybeans (S_{100}) flour.

3.3 Preparation of composite flours

Three (3) groups of composite flours were prepared from the flours obtained from the raw materials. Each of the three groups contained roasted maize flour (M_{100}), a vitamin A rich source [either ripe plantain flour (P_{100}) or orange flesh sweet potatoes flour (O_{100})] and a protein rich source [either Bambara groundnut flour (B_{100}) or soybeans flour (S_{100})]. The subscript '100' represents the percentage of the sample. The first group of flours were made from roasted maize, Bambara groundnut and ripe plantain flour, while the second group was prepared from roasted maize flour, orange- fleshed sweet potato and Bambara groundnut. The last group of flours were prepared from roasted maize, ripe plantain and soybeans flours.

Composite flours were prepared by mixing the different components according to the ratios shown in Table 3.5. The ratios were generated based on a Simple Lattice Design using Design Expert with an upper and lower limit of 50 and 25%, respectively, for each flour. The composite flours made from roasted maize, ripe plantain and Bambara groundnut flours were designated as $M_XB_YP_Z$, while that prepared from roasted maize flour, orange flesh sweet potatoes flour and Bambara groundnut flour was designated as $M_XB_YO_Z$, and that from roasted maize flour, ripe plantain flour and soybeans flour was designated as $M_XS_YP_Z$, where the subscripts X, Y and Z represents the fraction of each component in the mixture.

Table 3.5: Designation of flour samples and the ratios used in the preparation of composite flours

Designation	Roasted Maize Flour	Bambara Groundnut or Soybeans Flour	Ripe Plantain or OFSP Flour
M_{100}	100	-	-
B_{100}	-	100	-
S_{100}	-	100	-
O_{100}	-	-	100
P_{100}	-	-	100
$M_{29}U_{41}Y_{29}$	29.33	41.33	29.33
$M_{25}U_{50}V_{25}$	25	50	25
$M_{29}U_{29}V_{41}$	29.33	29.33	41.33
$M_{33}U_{33}V_{33}$	33.33	33.33	33.33
$M_{50}U_{25}V_{25}$	50	25	25
$M_{41}U_{29}V_{29}$	41.33	29.33	29.33
$M_{25}U_{25}V_{50}$	25	25	50

U = Bambara groundnut flour or soybeans flour; V = ripe plantain flour or orange flesh sweet potato flour (OFSP)

3.4 Quality analysis of flour samples

3.4.1 Nutrient content of flour

The analysis of the nutrient composition was carried out in accordance with the techniques established by the Association of Official Analytical Chemists (AOAC,2010). The moisture, ash, protein, crude fat, and total fibre were analysed, while the carbohydrate content was estimated based on the difference.

3.4.1.1 Determination of moisture content

Approximately 2 g of the flour sample was weighed before being placed in glass dish that had already been dried and weighed. The glass crucibles and the samples were placed in a thermostatically controlled oven and subjected to heating at a temperature of 105 °C for a duration of 5 hours until they reached a stable weight. The sample and the glass crucibles were taken out, allowed to cool in a desiccator, and then weighed again. Next, the moisture content was ascertained by loss in weight as shown below (AOAC, 2005).

$$Moisture\ content = \frac{weight\ of\ dry\ sample}{weight\ of\ sample} x\ 100 \quad \text{......................Eqn. 1}$$

3.4.1.2 Determination of ash content

For the determination of ash content, 2 g of flour sample was put into a ceramic crucible that had been ignited, allowed to cool, and then weighed. After that, this was kept in a muffle furnace set to 600 °C for two hours. The crucible was taken out and allowed to cool in a desiccator. By measuring the weight of the crucible and its contents, we were able to ascertain the overall ash content, which was subsequently expressed as a percentage as shown below.

$$Ash\ content = \frac{weihgt\ of\ ash}{weight\ of\ sample}\ x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 2}$$

3.4.1.3 Determination of crude fat

The crude fat was determined used the Soxhlet apparatus system. A 250 mL round-bottom flask that had been dried beforehand was precisely weighed. Flour sample (2 g) was moved to a thimble-shaped 22 x 80 mm filter paper. and 100 mL petroleum ether was added and placed in the Soxhlet extractor. Using a heating mantle, a Quick Fit condenser was attached to the Soxhlet extractor and refluxed on low heat for eighteen hours. Next, the flask was taken out and allowed to evaporate in a steam bath. Subsequently, the flask and its contents were subjected to heating at a temperature of 103 °C for a duration of 30 minutes within an oven. Once the flask and its contents were cooled to room temperature in a desiccator, they were weighed. The fat content was expressed as percentage crude fat (AOAC, 1990).

$$Crude\ fat = \frac{weight\ of\ fat}{weight\ of\ sample}\ x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 3}$$

3.4.1.4 Determination of crude fibre

The crude fat sample was placed into a 750 mL Erlenmeyer flask and 200 mL of boiling 1.25 % H_2SO_4 was added, heated for 30 min. After decanting the flask, the contents were promptly strained through a linen cloth in a funnel and meticulously rinsed in copious amounts of boiling water. The remaining substance was moved into a Gooch crucible using distilled water, rinsed with 15 mL of alcohol, and then the crucible and its contents were dried for 1 hour at a temperature of 100 °C. Following the process of cooling in a desiccator, the weight of the crucible was determined. The crucible was subsequently fired in a muffle furnace for a duration of 30 minutes, then cooled in a desiccator and reweighed. The crude fibre content was then calculated as shown below (AOAC, 2005).

$$Crude\ fibre = \frac{weight\ of\ fibre - weight\ of\ ash\ fibre}{weight\ of\ sample}\ x\ 100 \text{……….Eqn. 4}$$

3.4.1.5 Determination of protein

The protein content was quantified using the Kjeldahl method, which entails the digestion of the sample, followed by distillation and titration.

Digestion: Flour sample (2 g) was weighed and placed in a digestion flask. Half of Selenium based catalyst tablet and a little of anti-bumping agents were added. 25 mL of concentrated H_2SO_4 was also added. The flask was agitated until the sample was fully saturated, then positioned on a digesting burner and gradually heated until the bubbling stopped, and the resulting solution became transparent. Subsequently, the solution was allowed to cool to the ambient temperature. The treated sample solution was then transferred into a 100 mL volumetric flask and filled up to the designated level.

Distillation: The apparatus was rinsed with boiled distilled water produced by the steam generator of the distillation apparatus. The connections were set up to circulate the water through the inner decomposition flask and out of the condenser for a minimum of 20 minutes. A volume of 25 mL of a 2% solution of boric acid indicator was positioned beneath the condenser of the apparatus. The conical flask and its contents were positioned beneath the apparatus in a manner that ensured the tip of the condenser was fully submerged in the solution. A volume of 10 mL of the sample solution that had undergone digestion was transferred to a reaction chamber using a trap funnel. NaOH (15-20 mL, 40 %) was added to the decomposition flask, and steam was directed into the decomposition chamber by closing the stopcock on the steam trap exit, causing the freed ammonia to be driven into the collection flask. Upon contact with ammonia, the boric acid promptly underwent a colour change to blue green. Distillation went on for a duration of 1-5 minutes. Subsequently, the receiving flask was lowered such that the tip of the condenser was positioned just above the liquid. The tip of the condenser was washed with a little distilled water and distilled for another 30 seconds. The burner was separated from the steam generator.

Titration: The distillate underwent titration using a 0.1N HCL solution. The acid was added until the solution became devoid of colour. The solution became pink when additional acid was added. The same method was carried out for the blank in the absence of a sample. The protein content was then estimated as shown below.

$$Protein = \frac{(T-B)\ x\ N\ x\ 6.25\ x\ 100}{W\ x\ 10} \text{.....................................Eqn. 5}$$

where,

T = volume in mL of the standard HCl solution used in the titration

B = volume in mL of the HCl acid solution used in the titration

N = Normality of standard HCl

W = Weight in grams of the test material

3.4.1.6 Determination of total carbohydrate

The calculation of the total carbohydrate was done by subtracting all the other proximate determinations from 100% (AOAC, 2005) as shown below.

$$Carbohydrate = 100 - (moisture\ content + ash\ content + crude\ fat + protein + crude\ fibre) \text{.....................................Eqn. 6}$$

3.4.2 Determination of mineral composition

Among the minerals that were analysed in the flour samples included iron, zinc calcium, magnesium and potassium. To conduct the analyses, 20 g of flour were burned in a muffle furnace at a temperature of 550 °C. The resulting ash was then treated with 3 M HCl to make it acidic. After that, it was transferred to a volumetric flask and diluted with distilled water to a final volume of 50 mL.

3.4.2.1 Determination of iron and zinc

The iron and zinc content were measured using an atomic absorption spectrophotometer. (Schimadzu AAS model No. 6401F) (Siong et al., 1989). Standard solutions of zinc or iron concentrations of 1 µg/mL, 2 µg/mL and 5 µg/mL was prepared, and the curves plotted on the AAS.

3.4.2.2 Determination of calcium and magnesium

The concentration of calcium and magnesium was analyzed by transferring 10 mL of solubilised samples into a 250 mL conical flask. The solution was made up to 150 mL using distilled water after which 15 mL of buffer was added. To the solution, one (1) mL each of potassium cyanide, hydroxylamine hydrochloride, potassium ferro-cyanide, and triethanolamine (TEA) were added followed by 5 drops each of Eriochrome Black. The resulting solution was then titrated against 0.005 M EDTA, and the calcium and magnesium estimated as shown below.

$$\%\ Calcium = \frac{0.005\ x\ 40.08\ x\ T}{weight\ of\ sample} \qquad \text{Eqn. 7}$$

$$\%\ Magnesium = \frac{0.005\ x\ 24.31\ x\ T}{weight\ of\ sample} \qquad \text{Eqn. 8}$$

3.4.4 Analysis of β-carotene, phenolic, tannins, oxalate and phytate content

β-carotene was analysed by weighing 1.0 g of flour and after adding 5 mL of cold acetone, incubating at 4 °C with occasional mixing for 15 minutes. The mixture was centrifuged at 1370 ×g for 10 minutes and the supernatant was collected. The, the residue was re-extracted. The supernatant of each re-extraction was pooled and filtered, and the absorbance measured at 449 nm (Bibby Scientific Ltd, UK, Jenway 6400). β-carotene was used as the standard (Biswas et al., 2011). For analysing the phenolic content, methanolic extracts were made by mixing 0.5 g flour with 10 mL absolute methanol. After incubating for 0.5 hours at room temperature, the mixture was centrifuged at 3000 xg for 20 minutes. To 100 µL of the supernatant, 1.0 mL Folin-Ciocalteau and 750 µL, 6 % sodium bicarbonate were added and incubated for 90 minutes. The absorbance was then measured at 725 nm. Gallic acid was used as the standard (Dadzie et al., 2021).

For the analysis of phytate, 3 M HCl (100 mL) was added to 2.0 g of flour and shaken for 3 hours. After filtration, 107 mL of distilled water was added to 50 mL of the filtrate. Subsequently, 10 mL of 0.3 % ammonium thiocyanate was added and titrated against Iron (III) chloride (García-Villanova et al., 1982). Total oxalate was determined by titration of acid-digested samples against potassium per manganite as described by (D'Angelo et al., 2023). For tannin content, 10 mL 70 % acetone was added to 0.2 g flour to form a mixture. The mixture was then incubated in a water bath at 60 °C for 15 minutes. The mixture was allowed to cool to the ambient temperature for 30 minutes, after which it was filtered. Then 0.5 mL filtrate was reacted with an equal volume of Folin's reagent and distilled water, subsequently, 2.5 mL 20 % Na_2CO_3 was added. Absorbance of the mixture was measured at 725 nm. Tannic acid was used as the standard (Samaniego-Sánchez et al., 2020).

3.4.5 The pasting and functional properties of the flours

The pasting qualities was measured using a Brabender viscoamylograph (Type 801203 W.G) with 700 cmg cartridge. After dispersing 40 g flour in 500 mL of water, an aliquot was delivered into the sample tube. It was then heated from 30 °C to 95 °C at a was continuously recorded at a rotational velocity of 75 rpm.

The functional properties of the flours included water absorption capacity, oil absorption capacity, bulk density, swelling power and solubility. The water absorption capacity (WAC) was measured by dispersing 1.0 g of flour into 10 mL of distilled water in a test tube that was weighed beforehand (W1) and mixed by vortex for 30 s. The dispersion was left to equilibrate for 30 minutes and then centrifuged with a force of 2,527 × g for 1 minute. After carefully decanting the supernatant, the content was re-weighed (W_2) and the water absorption capacity was calculated using the equation shown below. For oil binding capacity, water was substituted with oil following a similar procedure as previously described (Adebowale et al., 2002)

$$\% \, WAC = \frac{W_2 - W_1}{weight\ of\ sample} \quad \text{.................................Eqn. 9}$$

The bulk density was measured by placing 100 g of flour into a 250 mL graduated measuring cylinder and compacting it by tapping with the hand to get a uniform volume. The mass of flour and volume was used to compute the bulk density as described by Adebowale et al., (2002).

Swelling power was measured by dispersing 1.0 g flour into a pre-weighed 50 mL graduated centrifuge tubes and adding 40 mL distilled water. The dispersion was mixed by vortex for 30 s and heated at 85 °C with shaking for 30 min. Once the contents had cooled to 28°C, the tubes were centrifuged at a force of 3000 ×g for 15 minutes. The supernatant was then poured out and stored. The mass of sedimented gel to the dry weight of flour was used to estimate the swelling power as shown below. To determine flour solubility, 5 mL supernatant was transferred into a pre-weighed crucible, dried at 105 °C in an oven for 4 hrs and the dry weight was measured. The difference in weight was used to estimate flour solubility (Adebowale et al., 2002).

$$Swelling\ power = \frac{weight\ of\ sedimented\ flour\ paste}{weight} \quad \text{..............Eqn. 10}$$

$$Solubility\ = \frac{weight\ of\ sedimented\ flour\ paste}{weight\ of\ sample}\ x\ 100 \quad \text{.............Eqn. 11}$$

3.4.6 Determination of pH, Brix and colour

pH and Brix of the supernatant were measured using a B10P Benchtop pH meter and an MA871 Milwaukee Refractometer, respectively. For this, a quantity of 1.0 g of flour was evenly distributed in 10 mL distilled water and centrifuged at 3000 ×g for 20 minutes. The supernatant was preserved for further analysis. The colour was measured using a colorimeter (CHN Spec, China, CS-10) using the CIELAB colour space. Colour primaries, L*a*b* values were determined and used to estimate the total colour change (Ampofo-Asiama et al., 2020) and browning index (Kizzie-Hayford et al., 2021) as shown below.

$$Browning\ index = \frac{100(x - 0.31)}{0.17}, x = \frac{a^* + 1.75L}{5.645L + a^* - 3.01b^*}$$

$$Colour\ change = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 12}$$

3.4.7 Sensory evaluation of porridge prepared from flour samples

Sensory analyses were done for three (3) formulations from each group in addition to the porridge prepared from roasted maize flour (M_{100}). The formulations that were selected from each group of composite flour samples included $M_{25}U_{50}V_{25}$, $M_{25}U_{25}V_{50}$ and $M_{33}U_{33}V_{33}$ where U represents either Bambara groundnut flour or Soybeans flour, and V represents either ripe plantain flour or orange flesh sweet potato flour (OFSP).

For preparing porridge, 70 g of each selected flour, 0.5 g table salt and 3.5 g sugar were weighed, transferred into a blender (Binatone, Model No.BLG401-28G, China) and reconstituted with 800 mL water by homogenizing to form a dispersion. After transferring into a stainless-steel pan, the dispersion was heated using an electric cooking plate (Binatone, Model No. ECP – 210, China) to boil with continuous stirring for 12 minutes. The cooked porridge was allowed to cool to 50 °C for sensory analyses.

The consumer preference of the porridges was assessed using a hedonic scale. The panel was allowed to score the attributes of the porridge based on the taste, aroma, appearance, texture, and acceptance from 1 (dislike extremely) to 9 (like extremely).

Sensory evaluation of porridge from roasted maize, Bambara groundnut and ripe plantain flours (M_{100}, $M_{25}B_{50}P_{25}$, $M_{25}B_{25}P_{50}$, and $M_{33}B_{33}P_{33}$), was conducted on 25th September 2020 using 75-member panel (30 males, 45 females, average age: 22.2 years). Similar sensory analysis on porridges prepared from roasted maize flour, Bambara groundnut flour and orange-fleshed sweet potato flour and (M_{100}, $M_{25}B_{50}O_{25}$, $M_{25}B_{25}O_{50}$, and $M_{33}B_{33}O_{33}$) and roasted maize flour, soybeans flour and ripe plantain flour (M_{100}, $M_{25}S_{50}P_{25}$, $M_{25}S_{25}P_{50}$, and $M_{33}S_{33}P_{33}$) was conducted on 18th March and 27th May 2022, using 78-member (42 males, 36 females, average age: 21.8 years) and 93-member panels (57 males, 36 females, average age: 27.12 years), respectively.

3.5 Determination of the cost of the composite flours

The cost and affordability of the composite flours were determined by considering the cost of raw materials (maize, ripe plantain, orange flesh sweet potatoes, Bambara groundnut and soybeans), the different processing steps needed to produce the flour, and the cost of labour.

3.6 Data analysis

All the data obtained from this study was inputted into Microsoft excel and the descriptive statistics were estimated. Analysis of the data based on the determinations of the flour quality investigation was analysed using Analysis of Variance in SPSS at $p<$ of 0.05 (IBM, SPSS Statistics 20). Post-hoc analyses were carried out using the Tukey test. The data obtained from the sensory analysis was also analysed using ANOVA.

CHAPTER FOUR

RESULTS

The result of this study is presented in five sections, with the first three sections focusing on the evaluation of the composite flour quality. The first section covers the results on the quality of flours prepared from the mixture of roasted maize, Bambara groundnut and ripe plantain ($M_XB_YP_Z$), while the second and third sections presents results on mixtures of flours prepared from roasted maize, Bambara groundnut and orange flesh sweet potatoes ($M_XB_YO_Z$), and roasted maize, soybeans and ripe plantain ($M_XS_YP_Z$), respectively. The fourth section presented the results of sensory evaluation of the samples while the fifth sections, presents results on the costing of the composite flours.

4.1 Quality analysis and sensory evaluation of flour mixtures using roasted maize, Bambara ground nut and ripe plantain

4.1.1 Proximate content of flours

The nutrient content of the flours in Table 4.1 showed that the moisture content of the composite flours ranged between 4.05-5.83 g/100g, which were all higher than the control (roasted maize flour, M_{100}). Comparing all the flours, a high moisture content of 6.32 and 7.46 g/100g, respectively, was observed for B_{100} and P_{100}. Apart from M_{25}:B_{25}:P_{50} (2.37 g/100g) which had an ash content of about twice that of the control, all the composite flours had ash contents which were insignificantly different from that of the control. The highest ash content among all the flours was observed for $P_{100.}$

The protein content of P_{100} was 6.04 g/100g which was insignificantly different from M_{100}. However, the amount of protein in B_{100} was more than two times that of M_{100}. With respect to the composite flours, the highest and lowest protein content was observed for M_{25}:B_{50}:P_{25} and M_{25}:B_{25}:P_{50}. Each of the composite flours possessed a significantly higher protein content than M_{100} except M_{25}:B_{25}:P_{50}. The fat content for the composite flour ranged from 1.45-2.60 g/100g, which was much lower than M_{100}. Also, the fiber content for the composites varied between 2.84-4.47 g/100g, which was also lower than M_{100}.

Table 4.1: Nutrient content (g/100g) of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), ripe plantain flour (P_{100}), and the composite flours

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)
M_{100}	3.55 ± 0.15^{a}	1.35 ± 0.03^{a}	7.92 ± 0.07^{a}	5.01 ± 0.06^{a}	4.52 ± 0.27^{a}
B_{100}	6.32 ± 0.21^{b}	1.08 ± 0.09^{b}	18.31 ± 0.16^{b}	7.61 ± 0.04^{b}	7.33 ± 0.20^{b}
P_{100}	7.43 ± 0.18^{c}	3.61 ± 0.14^{c}	6.04 ± 0.15^{c}	1.32 ± 0.07^{c}	1.81 ± 0.05^{c}
M_{29}:B_{41}:P_{29}	4.62 ± 0.40^{d}	1.48 ± 0.11^{a}	11.97 ± 0.19^{d}	1.93 ± 0.10^{d}	4.42 ± 0.14^{a}
M_{25}:B_{50}:P_{25}	5.61 ± 0.07^{e}	1.33 ± 0.14^{a}	13.62 ± 0.11^{e}	1.76 ± 0.42^{d}	3.40 ± 0.33^{d}
M_{29}:B_{29}:P_{41}	5.83 ± 0.88^{e}	1.57 ± 0.13^{a}	9.20 ± 0.23^{f}	1.76 ± 0.07^{d}	3.32 ± 0.05^{d}
M_{33}:B_{33}:P_{33}	5.02 ± 0.65^{e}	1.15 ± 0.05^{a}	9.33 ± 0.38^{f}	1.62 ± 0.31^{d}	3.65 ± 0.06^{d}
M_{50}:B_{25}:P_{25}	5.23 ± 0.71^{e}	1.66 ± 0.22^{a}	10.54 ± 0.06^{g}	2.52 ± 0.20^{e}	4.47 ± 0.11^{a}
M_{41}:B_{29}:P_{29}	4.05 ± 0.11^{d}	1.49 ± 0.25^{a}	10.08 ± 0.09^{g}	1.45 ± 0.08^{d}	3.83 ± 0.06^{d}
M_{25}:B_{25}:P_{50}	5.68 ± 0.14^{e}	2.37 ± 0.22^{d}	8.67 ± 0.04^{h}	2.60 ± 0.14^{e}	2.84 ± 0.09^{e}

M – Roasted Maize B – Bambara groundnut P – Ripe Plantain.
Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.1.2 Mineral content of flours

The mineral composition analysis revealed that the composite flours had a greater iron (Fe) content compared to M_{100} (Table 4.2). The composite flours, M_{29}:B_{29}:P_{41} and M_{25}:B_{25}:P_{50}, had higher values of 873.35 and 845.36 mg/100g of Fe content which were more than twice that of the M_{100}. The Ca and Mg content of the composite flours were not significantly different from M_{100}. The potassium content of the composite flours was higher than M_{100} (0.36 g/100g) with M_{25}:B_{25}:P_{50} having the highest concentration of potassium of 0.91g/100g which was about three times more than M_{100}. Even the composite flour, M_{29}:B_{29}:P_{41}, having the lowest concentration of potassium was about twice that of M_{100}.

Table 4.2: Minerals content of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), ripe plantain flour (P_{100}), and the composite flours

Sample	Iron (mg/100g)	Calcium (g/100g)	Magnesium (g/100g)	Potassium (g/100g)
M_{100}	392.82 ± 3.76^a	0.92 ± 0.02^a	0.11 ± 0.01^a	0.36 ± 0.02^a
B_{100}	276.88 ± 11.63^b	0.86 ± 0.03^a	0.08 ± 0.02^a	0.68 ± 0.04^b
P_{100}	1976.8 ± 32.48^c	1.22 ± 0.06^b	0.10 ± 0.01^a	1.21 ± 0.02^c
$M_{29}B_{41}P_{29}$	551.63 ± 22.11^d	0.86 ± 0.01^a	0.10 ± 0.01^a	0.76 ± 0.05^b
$M_{25}B_{50}P_{25}$	467.21 ± 15.05^e	0.78 ± 0.09^a	0.11 ± 0.01^a	0.73 ± 0.10^b
$M_{29}B_{29}P_{41}$	873.35 ± 2.96^f	0.88 ± 0.02^a	0.09 ± 0.03^a	0.72 ± 0.06^b
$M_{33}B_{33}P_{33}$	702.43 ± 11.07^g	0.65 ± 0.04^c	0.10 ± 0.01^a	0.74 ± 0.08^b
$M_{50}B_{25}P_{25}$	487.97 ± 18.56^e	0.91 ± 0.09^a	0.19 ± 0.03^a	0.73 ± 0.10^b
$M_{41}B_{29}P_{29}$	769.86 ± 19.80^h	0.78 ± 0.03^a	0.08 ± 0.01^a	0.72 ± 0.11^b
$M_{25}B_{25}P_{50}$	845.36 ± 7.35^i	0.94 ± 0.08^a	0.11 ± 0.02^a	0.91 ± 0.14^b

M – Roasted Maize B – Bambara groundnut P – Ripe Plantain.
Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.1.3 Phytochemical and anti-nutrient content of the flours

The β-carotene, phenolic content, phytate, oxalate and tannins content of the flours are shown in Table 4.3. The composite flours exhibited a greater quantity of β-carotene than M_{100} (2.65 mg/g) with a range from 3.36 to 5.70 mg/g. The composite flour with a high proportion of ripe plantain (M_{29}:B_{29}:P_{41} and M_{25}:B_{25}:P_{50}) had a 100 percent increase in β-carotene compared to that of M_{100}. Among the raw materials, P_{100} (8.63 mg/g) had the highest β-carotene content which was about four times higher than M_{100} while B_{100} had the least β-carotene of 1.63 mg/g. The phenolic content of the composite flours did not show a significant difference compared to M_{100} (32.25 mg/g). However, B_{100} exhibited the greatest phenolic content of 38.67 mg/g.

Regarding the levels of oxalate and phytate, there were no statistically significant differences seen among all the flours and M_{100}. The composite flours, M_{29}:B_{41}:P_{29} and M_{25}:B_{50}:P_{25}, had the highest phytate content of 0.38 % and 0.42 %, respectively, which were significantly different from M_{100}. (0.23 %). However, the high levels of tannins in Bambara groundnuts caused an increase in the composite flours with M_{33}:B_{33}:P_{33} having the greatest tannin content of 4.01 mg/g compared to the 2.67 mg/g observed in M_{100}.

Table 4.3: Phytochemical and anti-nutrient content of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), ripe plantain flour (P_{100}), and composite flours

Sample	β-Carotene (mg/g)	Phenolic Content (mg/g)	Phytate (%)	Oxalate (%)	Tannins (mg/g)
M_{100}	2.65 ± 1.15[a]	32.25 ± 1.97a	0.23 ± 0.04[a]	0.02 ± 0.00[a]	2.67 ± 0.11[a]
B_{100}	1.63 ± 0.09b	38.67 ± 2.18b	0.77 ± 0.16[b]	0.04 ± 0.01[a]	4.45 ± 0.43[b]
P_{100}	8.63 ± 0.69c	29.82 ± 1.55a	0.09 ± 0.01[c]	0.02 ± 0.00[a]	2.65 ± 0.14[a]
M_{29}:B_{41}:P_{29}	3.72 ± 0.09d	31.50 ± 3.35a	0.38 ± 0.24[a]	0.04 ± 0.01[a]	3.16 ± 0.01[ab]
M_{25}:B_{50}:P_{25}	3.36 ± 0.11d	30.90 ± 2.49a	0.42 ± 0.03[ac]	0.03 ± 0.00[a]	3.17 ± 0.03[a b]
M_{29}:B_{29}:P_{41}	5.34 ± 0.31e	30.40 ± 1.88a	0.29 ± 0.03[a]	0.04 ± 0.00[a]	2.95 ± 0.01[ab]
M_{33}:B_{33}:P_{33}	4.89 ± 0.12e	32.10 ± 2.15a	0.30 ± 0.04[ac]	0.03 ± 0.00[a]	4.01 ± 0.01[b]
M_{50}:B_{25}:P_{25}	3.62 ± 0.53d	31.80 ± 1.65a	0.28 ± 0.04[ac]	0.03 ± 0.01[a]	2.98 ± 0.03[a]
M_{41}:B_{29}:P_{29}	4.45 ± 0.20e	31.20 ± 2.64a	0.24 ± 0.04[ac]	0.03 ± 0.01[a]	3.44 ± 0.02[ab]
M_{25}:B_{25}:P_{50}	5.70 ± 0.57e	32.70 ± 1.99a	0.22 ± 0.03[a]	0.04 ± 0.00[a]	3.12 ± 0.02[ab]

M - Roasted Maize B -Bambara groundnut P – Ripe Plantain.

Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.1.4 Physicochemical quality of the flours

The physicochemical properties (pH, Brix, colour change and browning index) of the flours (Table 4.4) showed that the pH of M_{100} was 5.39, which showed no substantial difference compared to the composite flours. P_{100} had the lowest pH of 4.63. The Brix of the composite flours varied between 1.21-1.88, which were higher than M_{100} (0.40). B_{100} had the highest Brix of 2.30 among the flours. The sample M_{29}:B_{29}:P_{41} had the highest color change among the composite flours compared to M_{100}. The browning index values for the composite flours ranged from 23.43-39.60, which were all lower than the M_{100} (48.70).

Table 4.4: pH, Brix, colour change and browning index of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), ripe plantain flour (P_{100}), and the composite flours

Sample	pH	Brix(◦Brix)	Colour change	Browning index
M_{100}	5.39 ± 0.11^a	0.40 ± 0.08a	-	48.70 ± 6.35^a
B_{100}	6.38 ± 0.08^b	2.30 ± 0.08b	-	10.52 ± 1.52^b
P_{100}	4.62 ± 0.11^c	1.50 ± 0.07^c	-	28.65 ± 3.52^c
M_{29}:B_{41}:P_{29}	5.55 ± 0.11^a	1.74 ± 0.14^c	14.26 ± 1.26^a	25.37 ± 2.37^c
M_{25}:B_{50}:P_{25}	5.38 ± 0.09^a	1.21 ± 0.08^c	7.06 ± 0.97^b	23.43 ± 3.29^c
M_{29}:B_{29}:P_{41}	5.64 ± 0.08^a	1.54 ± 0.07^c	15.69 ± 1.07^a	33.52 ± 3.35^d
M_{33}:B_{33}:P_{33}	5.71 ± 0.11^a	1.88 ± 0.11^c	6.87 ± 0.87^b	29.95 ± 3.20^c
M_{50}:B_{25}:P_{25}	5.55 ± 0.10^a	1.51 ± 0.14^c	7.17 ± 0.92^b	39.60 ± 2.96^e
M_{41}:B_{29}:P_{29}	5.72 ± 0.08^a	1.76 ± 0.09^c	13.81 ± 1.48^a	35.44 ± 2.05^e
M_{25}:B_{25}:P_{50}	5.62 ± 0.09^a	1.56 ± 0.17^c	11.79 ± 1.22^c	36.06 ± 3.16^e

M – Roasted Maize B – Bambara groundnut P – Ripe Plantain.
Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.1.5 Functional properties of the flours

Table 4.5 presents the functional properties of the different flours with the composite flours showing lower water absorption capacity (range of 1.3-1.75 g/g) compared to M_{100} (2.97 g/100g). The control M_{100} exhibited a high oil absorption capacity of 1.96 g/g which was higher than the composite flours (0.71-0.77 g/100g). The bulk density of M_{100} (0.75 mg/L) did not differ significantly from the bulk density of the composite flours ranging from 0.70 to 0.80 mg/L. Both the solubility index (11.65 %) and swelling power (6.07 g/g) of M_{100} were lower compared to the composite flours (solubility index- 13.55-15.38; swelling power- 6.93-8.46 g/g).

Table 4.5: Functional properties of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), ripe plantain flour (P_{100}), and the composite flours

Sample	Water Absorbed (g/g)	Oil Absorbed (g/g)	Bulk Density (mg/L)	Solubility Index (%)	Swelling Power (g/g)
M_{100}	2.97 ± 0.05^{a}	1.96 ± 0.09^{a}	0.75 ± 0.09^{a}	11.65 ± 1.25^{a}	6.07 ± 0.23^{a}
B_{100}	1.47 ± 0.02^{b}	0.34 ± 0.02^{b}	0.67 ± 0.07^{a}	11.36 ± 2.65^{a}	10.69 ± 1.05^{b}
P_{100}	1.32 ± 0.08^{c}	0.58 ± 0.07^{b}	0.79 ± 0.10^{a}	18.56 ± 3.25^{ab}	7.62 ± 1.21^{a}
$M_{29}:B_{41}:P_{29}$	1.75 ± 0.23^{b}	0.71 ± 0.02^{c}	0.78 ± 0.01^{a}	14.70 ± 0.52^{ab}	8.46 ± 0.07^{c}
$M_{25}:B_{50}:P_{25}$	1.71 ± 0.21^{b}	0.76 ± 0.15^{c}	0.70 ± 0.01^{a}	13.71 ± 0.45^{ab}	6.93 ± 0.11^{c}
$M_{29}:B_{29}:P_{41}$	1.52 ± 0.36^{b}	0.77 ± 0.03^{c}	0.80 ± 0.01^{b}	14.58 ± 0.58^{ab}	8.46 ± 0.24^{c}
$M_{33}:B_{33}:P_{33}$	1.43 ± 0.17^{c}	0.76 ± 0.09^{c}	0.73 ± 0.01^{a}	13.44 ± 0.23^{ab}	7.25 ± 0.02^{c}
$M_{50}:B_{25}:P_{25}$	1.60 ± 0.21^{b}	0.76 ± 0.16^{c}	0.78 ± 0.01^{ab}	14.88 ± 0.36^{ab}	6.66 ± 0.14^{a}
$M_{41}:B_{29}:P_{29}$	1.58 ± 0.24^{b}	0.72 ± 0.08^{c}	0.78 ± 0.02^{ab}	14.16 ± 0.18^{ab}	7.67 ± 0.23^{c}
$M_{25}:B_{25}:P_{50}$	1.67 ± 0.19^{b}	0.77 ± 0.11^{c}	0.74 ± 0.01^{ab}	15.38 ± 0.10^{ab}	8.18 ± 0.02^{c}

M - Roasted Maize B -Bambara groundnut P – Ripe Plantain.

Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.1.6 Viscosity and pasting properties of the flours

The viscosity and pasting properties of the flours shown in Table 4.6 reveals that the pasting temperature ranged between 78.62-87 .62 °C with P_{100} having the lowest value. All the composite flours had higher pasting temperature compared to M_{100} (81.25 °C) except M_{25}:B_{25}:P_{50} (79.80 °C). Among the composite flours, M_{41}:B_{29}:P_{29} had the highest pasting temperature of 84.85 °C. The peak viscosity of the composite flours ranged between 1014-1214 BU which were higher than M_{100}. With the exception of M_{33}:B_{33}:P_{33}, M_{50}:B_{25}:P_{25} and M_{41}:B_{29}:P_{29} , the breakdown viscosity of the composite flours was higher than M_{100}. The trough or setback viscosities of the flours ranged between 907-1268 and 296-456, while a final viscosity 1427-2059 BU was observed for the composite flours compared to 1396 observed for M_{100}. The peak time ranged between 8.99-10.53 min, with M_{100} having the highest value.

Table 4.6: viscosity and pasting properties of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), ripe plantain flour (P_{100}) and the composite flours

Sample	Pasting temperature (℃)	Peak viscosity (BU)	Breakdown Viscosity (BU)	Trough Viscosity (BU)	Setback viscosity (BU)	Final viscosity (BU)	Peak Time (min)
M_{100}	81.25	1082	40	1042	354	1396	10.53
B_{100}	87.62	1343	75	1268	294	1654	8.99
P_{100}	78.62	1125	218	907	456	2452	9.25
$M_{29}B_{41}P_{29}$	84.775	1162	121	1041	377	1518	9.635
$M_{25}B_{50}P_{25}$	83.2	1200	248	952	375	1427	10.13
$M_{29}B_{29}P_{41}$	83.225	1185	110	1075	366	1994	9.53
$M_{33}B_{33}P_{33}$	84.8	1014	41	973	349	1765	10.23
$M_{50}B_{25}P_{25}$	81.55	1185	24	1161	350	1921	9.15
$M_{41}B_{29}P_{29}$	84.85	1084	31	1053	412	1965	9.965
$M_{25}B_{25}P_{50}$	79.8	1214	80	1134	405	2059	9.13

M – Roasted Maize B -Bambara groundnut P – Ripe Plantain.

Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.1.7 Sensory acceptability of porridges prepared from the selected flours

The sensory scores of the porridge prepared from M_{100} and the selected flours is shown in Figure 4.1. The sensory scores ranged from 6.85-7.24 for appearance, with $M_{25}B_{25}P_{50}$ having the highest score and $M_{25}B_{50}P_{25}$ having the lowest score of 6.85. The score for taste was between 6.31-6.73 with all the composite flours having higher scores than M_{100}. The scores for texture ranged between 7.01-7.15, while for aroma a range from 6.34 to 7.03 was observed with M_{100} having the lowest score. $M_{25}B_{25}P_{50}$ had the highest score for overall acceptability, range from 6.54 to 6.81. Nevertheless, there was no notable distinctions identified in the sensory scores for the composite flours when compared to M_{100}.

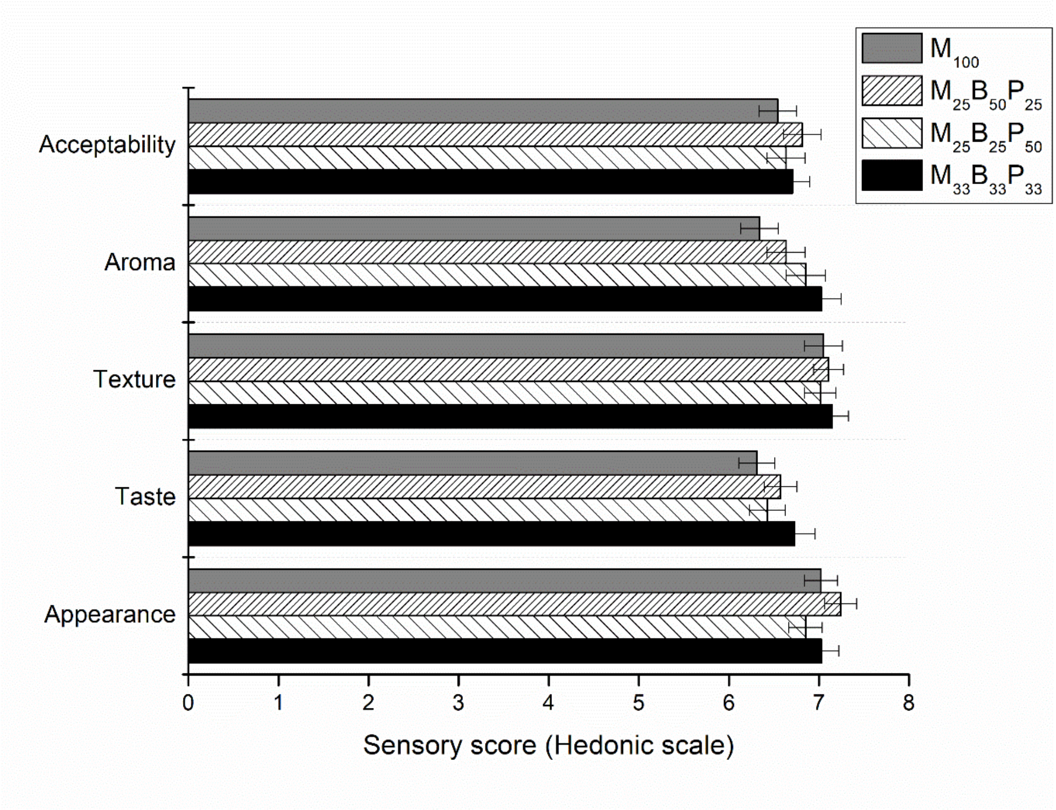


Figure 4.1: Hedonic scale based sensory evaluation scores of porridges prepared from for M_{100}, $M_{25}B_{50}P_{25}$, $M_{25}B_{25}P_{50}$, and $M_{33}B_{33}P_{33}$.

4.2 Quality analysis and sensory evaluation of flours prepared from Bambara groundnut, roasted maize and orange flesh sweet potatoes

4.2.1 Nutrient content of flours

Table 4.7 shows that the moisture content of the flours was higher than M_{100} (3.55 g/100g). Among the composite flours, the highest and lowest observation of the moisture content was M_{25}:B_{50}:O_{25} (7.38 g/100g) and M_{41}:B_{29}:O_{29}.(6.42 g/100g), respectively. The composite flours have an ash content that falls within a certain range of 2.47-4.12 g/100g which were all higher than M_{100} (1.35 g/100g). Even the composite flour M_{41}:B_{29}:O_{29} (2.47 g/100g) with the lowest ash content was almost twice that of M_{100} while the highest ash content which was found in M_{29}:B_{29}:O_{41} (4.12 g/100g) was three times more than that of $M_{100.}$ O_{100} had ash content of 4.79 g/100g which was more than three times that of $M_{100.}$ The protein content of the composite flours (10.79 -13.64 g/100g) was higher than M_{100} (7.92 g/100g), however, most of the composite flours had fat content lower than the M_{100} (5.01 g per100g) except for M_{25}:B_{50}:O_{25} (5.87 g/100g) and M_{41}:B_{29}:O_{29} (5.57 g/100g). The fiber content of the composite flours (6.17-7.49 g/100g) was higher than M_{100} (4.52 g/100g).

Table 4.7: Nutrient content (g/100g) of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), orange flesh sweet potatoes flour (O_{100}) and the composite flours

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)
M_{100}	3.55 ± 0.15[a]	1.35 ± 0.03[a]	7.92 ± 0.07[a]	5.01 ± 0.06[a]	4.52 ± 027[a]
B_{100}	6.32 ± 0.21[b]	1.08 ± 0.09[b]	18.31 ± 0.16[b]	7.61 ± 0.04[b]	7.33 ± 0.20[b]
O_{100}	6.79 ± 0.17[b]	4.79 ± 0.24[c]	5.40 ± 0.12[c]	1.16 ± 0.03[c]	5.23 ± 0.12[a]
M_{29}:B_{41}:O_{29}	6.78 ± 0.23[b]	3.34 ± 0.33[c]	10.79 ± 0.22[d]	3.39 ± 0.04[d]	6.48 ± 0.20[a]
M_{25}:B_{50}:O_{25}	7.38 ± 0.29[b]	2.93 ± 0.07[d]	13.64 ± 0.16[f]	5.87 ± 0.11[f]	7.08 ± 0.06[b]
M_{29}:B_{29}:O_{41}	6.64 ± 0.25[b]	4.12 ± 0.02[c]	11.65 ± 0.14[d]	3.96 ± 0.04[d]	6.36 ± 0.09[a]
M_{33}:B_{33}:O_{33}	6.67 ± 0.18[b]	2.49 ± 0.22[d]	11.69 ± 0.07[d]	4.23 ± 0.03[e]	6.17 ± 0.06[a]
M_{50}:B_{25}:O_{25}	6.64 ± 0.13[b]	2.75 ± 0.29[d]	11.62 ± 0.05[d]	4.62 ± 0.30[e]	6.49 ± 0.09[a]
M_{41}:B_{29}:O_{29}	6.42 ± 0.26[b]	2.47 ± 0.06[d]	12.30 ± 0.36[e]	5.57 ± 0.08[f]	6.80 ± 0.05[a]
M_{25}:B_{25}:O_{50}	6.84 ± 0.12[b]	3.65 ± 0.21[c]	11.08 ± 0.05[d]	3.85 ± 0.13[d]	6.60 ± 0.17[a]

M – Roasted Maize B – Bambara groundnuts O – Orange-fleshed sweet potatoes. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.2.2 Mineral content of the flours

The mineral content of the flours (Table 4.8) showed that the Fe content in the composite flours (269.07-304.88 µg/g) were all lower than M_{100} (392.82 mg/100g). The Ca content of the composite flours (0.69-0.88 g/100g) was also lower than M_{100} (0.92 g/100g), however, no significant difference in magnesium and potassium content was observed when comparing the composite flours to M_{100}.

Table 4.8: Mineral content of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), orange flesh sweet potatoes flours (O_{100}) and composite flours

Sample	Iron (mg/100g)	Calcium (g/100 g)	Magnesium (g/100 g)	Potassium (g/100 g)
M_{100}	392.82 ± 3.76^{a}	0.92 ± 0.02^{a}	0.11 ± 0.01^{a}	0.36 ± 0.02^{a}
B_{100}	276.88 ± 11.63^{b}	0.86 ± 0.03^{a}	0.08 ± 0.02^{a}	0.68 ± 0.04^{b}
P_{100}	268.17 ± 5.62^{b}	0.72 ± 0.03^{b}	0.09 ± 0.01^{a}	0.42 ± 0.02^{a}
$M_{29}B_{41}O_{2}$	285.98 ± 8.52^{b}	0.72 ± 0.08^{b}	0.09 ± 0.03^{a}	0.45 ± 0.03^{a}
$M_{25}B_{50}O_{25}$	269.07 ± 6.15^{b}	0.69 ± 0.09^{b}	0.11 ± 0.01^{a}	0.38 ± 0.02^{a}
$M_{29}B_{29}O_{41}$	272.72 ± 4.03^{b}	0.78 ± 0.09^{b}	0.12 ± 0.03^{a}	0.31 ± 0.02^{a}
$M_{33}B_{33}O_{33}$	275.27 ± 6.08^{b}	0.88 ± 0.08^{ab}	0.10 ± 0.02^{a}	0.25 ± 0.02^{a}
$M_{50}B_{25}O_{25}$	291.46 ± 4.64^{a}	0.79 ± 0.07^{ab}	0.10 ± 0.01^{a}	0.32 ± 0.03^{a}
$M_{41}B_{29}O_{29}$	304.88 ± 6.35^{a}	0.77 ± 0.08^{ab}	0.11 ± 0.01^{a}	0.33 ± 0.02^{a}
$M_{25}B_{25}O_{50}$	284.97 ± 7.65^{b}	0.87 ± 0.08^{ab}	0.10 ± 0.01^{a}	0.47 ± 0.01^{a}

M – Roasted Maize B – Bambara groundnuts O – Orange-fleshed sweet potatoes. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.2.3 Phytochemical and antinutrients content of the flours

The β-carotene content of the composite flours ranged between 7.2-13.23 mg/g which were higher than M_{100} (2.65 mg/g) (Table 4.9). The composite flours, M_{29}:B_{41}:O_{29} (7.21 mg/g), with the lowest concentration of β-carotene was thrice more than of M_{100}. The composite flour sample with the highest β-carotene was M_{25}:B_{25}:O_{50} (13.23 mg/g). The flour with the highest phenolic content was O_{100} (168.37 mg/g) while the phenolic content in the composite flours ranged between 45.65- 86.94 mg/g, which were all higher than M_{100}. The phytate content of the composite flours was between 0.22-0.37 (%). With the exception of M_{33}:B_{33}:O_{33} (0.22 %) all the composite flours exhibited higher levels of phytate content compared to M_{100} (0.23 mg/g), while O_{100} had the lowest phytate of 0.07 mg/100g. The oxalate concentration of the composite flours did not differ significantly from that of M_{100}. However, the composite flours did exhibit high levels of tannins.

Table 4.9: Phytochemical and antinutrient content of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), orange flesh sweet potatoes flours (O_{100}) and the composite flours

Sample	β-Carotene (mg/100g)	Phenolic Content (mg/100g)	Phytate (mg/100g)	Oxalate (mg/100g)	Tannins (mg/100g)
M_{100}	2.65 ± 1.15^{a}	32.25 ± 1.97^{a}	0.23 ± 0.04^{a}	0.02 ± 0.00^{a}	2.67 ± 0.11^{a}
B_{100}	1.63 ± 0.09^{b}	38.67 ± 2.18^{b}	0.77 ± 0.16^{b}	0.04 ± 0.0^{1a}	4.45 ± 0.43^{b}
O_{100}	25.64 ± 2.65^{c}	168.37 ± 0.99^{c}	0.07 ± 0.01^{c}	0.02 ± 0.00^{a}	2.35 ± 0.07^{a}
$M_{29}:B_{41}:O_{29}$	7.21 ± 1.88^{d}	56.43 ± 0.37^{d}	0.31 ± 0.01^{d}	0.02 ± 0.00^{a}	3.95 ± 0.21^{bc}
$M_{29}:B_{29}:O_{41}$	13.00 ± 3.66^{e}	56.33 ± 0.06^{d}	0.28 ± 0.05^{d}	0.03 ± 0.00^{a}	3.04 ± 0.15^{c}
$M_{25}:B_{25}:O_{50}$	13.23 ± 0.98^{e}	63.94 ± 1.30^{e}	0.26 ± 0.03^{d}	0.03 ± 0.00^{a}	2.88 ± 0.14^{a}
$M_{41}:B_{29}:O_{29}$	8.65 ± 1.58^{d}	86.94 ± 0.70^{f}	0.25 ± 0.06^{d}	0.05 ± 0.00^{a}	3.24 ± 0.10^{c}
$M_{33}:B_{33}:O_{33}$	9.43 ± 1.18^{d}	72.46 ± 0.17^{g}	0.22 ± 0.04^{d}	0.03 ± 0.00^{a}	3.01 ± 0.21^{c}
$M_{50}:B_{25}:O_{25}$	8.37 ± 1.58^{d}	45.65 ± 0.11^{h}	0.28 ± 0.04^{d}	0.02 ± 0.00^{a}	2.98 ± 0.17^{a}
$M_{25}:B_{50}:O_{25}$	7.66 ± 0.88^{d}	50.96 ± 1.11^{i}	0.37 ± 0.03^{d}	0.03 ± 0.00^{a}	4.06 ± 0.27^{b}

M – Roasted Maize B – Bambara groundnuts O -Orange-fleshed sweet potatoes. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.2.4 Physicochemical quality of the flours

The pH of the composite flours which ranged between 5.24-6.13 (Table 4.10) was not significantly different from M_{100} (5.39), while the Brix of the composite flours which ranged between (1.60-2.40) were all significantly higher. Among the composite flours, the highest colour change of 12.82 was observed in M_{29}:B_{29}:O_{41}. The browning index of the composite flours which ranged between 53.48-65.52 were all higher than M_{100} (48.70).

Table 4.10: pH, Brix, colour change and browning index of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), orange flesh sweet potatoes flours (O_{100}) and the composite flours

Sample	pH	Brix (◦Brix)	Colour change	Browning index
M_{100}	5.39 ± 0.01^{a}	0.40 ± 0.01^{a}	-	48.70 ± 6.35^{a}
B_{100}	6.38 ± 0.02^{b}	2.30 ± 0.01^{b}	-	10.52 ± 1.52^{b}
O_{100}	5.88 ± 0.01^{c}	3.00 ± 0.01^{c}	-	54.62 ± 3.69^{a}
M_{29}:B_{41}:O_{29}	5.86 ± 0.01^{c}	2.00 ± 0.00^{c}	10.11 ± 1.11^{a}	53.82 ± 8.73^{a}
M_{29}:B_{29}:O_{41}	5.57 ± 0.01^{c}	2.30 ± 0.01^{c}	12.82 ± 1.82^{a}	65.52 ± 6.19^{a}
M_{25}:B_{25}:O_{50}	5.90 ± 0.01^{c}	2.40 ± 0.01^{c}	11.66 ± 1.66^{a}	64.26 ± 10.03^{a}
M_{41}:B_{29}:O_{29}	5.24 ± 0.01^{c}	1.90 ± 0.01^{d}	10.98 ± 1.50^{a}	57.10 ± 8.14^{a}
M_{33}:B_{33}:O_{33}	5.93 ± 0.01^{c}	1.77 ± 0.00^{d}	12.52 ± 1.85^{a}	64.05 ± 9.54^{a}
M_{50}:B_{25}:O_{25}	6.00 ± 0.01^{c}	1.60 ± 0.01^{d}	11.39 ± 1.44^{a}	58.31 ± 8.53^{a}
M_{25}:B_{50}:O_{25}	6.13 ± 0.01^{c}	2.10 ± 0.01^{c}	11.32 ± 1.32^{a}	53.48 ± 6.17^{a}

M – Roasted Maize B – Bambara groundnuts O -Orange-fleshed sweet potatoes. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.2.5 Functional Properties of the flours

The water absorption capacity of M_{100} (2.97 g/g) was higher than the composite flour which ranged between 1.74 -2.31 g/g (Table 4.11). The composite flours had oil absorption capacity of 0.32-0.39 g/g which were lower than M_{100} (1.96g/g). The bulk density of M_{100} was 0.75 mg/L which was not significantly different compared to the composite flours. The solubility index of the composite flours (11.95-12.92 %) were not significantly different compared to M_{100}. Also, the swelling power of composite flours (7.77-9.85 g/g) was not different compared to M_{100} (6.07 g/g).

Table 4.11: Functional properties of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), orange flesh sweet potatoes flour (O_{100}) and the composite flours

Sample	Water Absorbed (g/g)	Oil Absorbed (g/g)	Bulk Density (mg/L)	Solubility Index (%)	Swelling Power (g/g)
M_{100}	2.97 ± 0.05^{a}	1.96 ± 0.09^{a}	0.75 ± 0.09^{a}	11.65 ± 1.25^{a}	6.07 ± 0.23^{a}
B_{100}	1.47 ± 0.02^{b}	0.34 ± 0.02^{b}	0.67 ± 0.07^{a}	11.36 ± 2.65^{a}	10.69 ± 1.05^{b}
O_{100}	2.69 ± 0.03^{a}	0.35 ± 0.03^{b}	0.35 ± 0.05^{b}	13.96 ± 0.89^{a}	9.19 ± 0.32^{b}
$M_{29}:B_{41}:O_{29}$	2.13 ± 0.13^{c}	0.35 ± 0.01^{c}	0.64 ± 0.04^{a}	12.92 ± 0.42^{a}	8.27 ± 0.11^{c}
$M_{29}:B_{29}:O_{41}$	2.26 ± 0.33^{c}	0.36 ± 0.02^{b}	0.63 ± 0.03^{a}	11.15 ± 0.46^{a}	9.83 ± 0.16^{b}
$M_{25}:B_{25}:O_{50}$	2.31 ± 0.28^{c}	0.37 ± 0.03^{b}	0.63 ± 0.03^{a}	12.85 ± 0.30^{a}	9.85 ± 0.17^{b}
$M_{41}:B_{29}:O_{29}$	1.90 ± 0.09^{c}	0.32 ± 0.05^{b}	0.71 ± 0.09^{a}	13.71 ± 0.51^{a}	7.79 ± 0.39^{c}
$M_{33}:B_{33}:O_{33}$	2.11 ± 0.11^{c}	0.38 ± 0.04^{b}	0.67 ± 0.08^{a}	11.45 ± 0.37^{a}	8.05 ± 0.33^{c}
$M_{50}:B_{25}:O_{25}$	2.00 ± 0.11^{c}	0.39 ± 0.01^{b}	0.67 ± 0.07^{a}	12.83 ± 0.53^{a}	7.77 ± 0.18^{c}
$M_{25}:B_{50}:O_{25}$	1.74 ± 0.14^{d}	0.32 ± 0.05^{b}	0.63 ± 0.05^{a}	11.65 ± 0.42^{a}	8.06 ± 0.30^{c}

M – Roasted Maize B – Bambara groundnuts O -Orange-fleshed sweet potatoes. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.2.6 Viscosity and pasting properties of the flours

Table 4.12 showed that the pasting temperature of the composite flours ranged between 82.98-85.98 ℃ which were higher than that of M_{100} (81.25 ℃), however, the peak viscosity of the composite flours (858-1039 BU) was lower than that of M_{100}. The breakdown viscosity of the composite flours varied from 39 to 81 BU, with the M_{25}:B_{25}:O_{50} mixture having the lowest value and the M_{29}:B_{41}:O_{29} mixture having the greatest value. The trough and setback viscosities of the composite flours ranged between 778-998 and 258-287 BU, respectively, were both lower than M_{100}. Similarly, the final viscosity of the composite flours, as well as the peak time, were also lower than the values observed for M_{100}.

Table 4.12: Pasting properties of roasted maize flour (M_{100}), Bambara groundnut flour (B_{100}), Orange Flesh Sweet Potatoes (O_{100}) and the composite flours

Sample	Pasting temperature °C	Peak viscosity BU	Breakdown Viscosity BU	Trough Viscosity BU	Setback viscosity BU	Final viscosity BU	Peak Time min
M_{100}	81.25	1082	40	1042	354	1396	10.53
B_{100}	87.62	1343	75	1268	294	1654	8.99
O_{100}	85.32	550	170	380	182	650	9.86
M_{29}:B_{41}:O_{29}	85.21	973	39	934	272	1251	9.50
M_{25}:B_{50}:O_{25}	85.98	1039	42	998	275	1439	9.49
M_{29}:B_{29}:O_{41}	82.98	894	63	832	263	1181	9.67
M_{33}:B_{33}:O_{33}	84.09	958	73	885	284	1321	9.57
M_{50}:B_{25}:O_{25}	84.61	995	48	947	287	1286	9.99
M_{41}:B_{29}:O_{29}	82.99	966	41	925	285	1247	9.72
M_{25}:B_{25}:O_{50}	84.21	858	81	778	258	1188	9.48

M – Roasted Maize B – Bambara groundnuts O -Orange-fleshed sweet potatoes

4.2.7 Sensory acceptability of porridge prepared from the selected flours

The sensory scores of the selected flours (Figure 4.2) showed that M_{25}:B_{50}:O_{25} had the highest score of 7.32 for appearance with M_{33}:B_{33}:O_{33} (6.78) having the least score. The scores for taste ranged between 6.04-6.45, with M_{100} having the highest score, while the scores for texture and aroma ranged between 6.74-7.12 and 6.24-6.59, respectively. The porridge made from the flours received scores for overall acceptability ranging from 6.71 to 7.01, with M_{100} achieving the highest score.

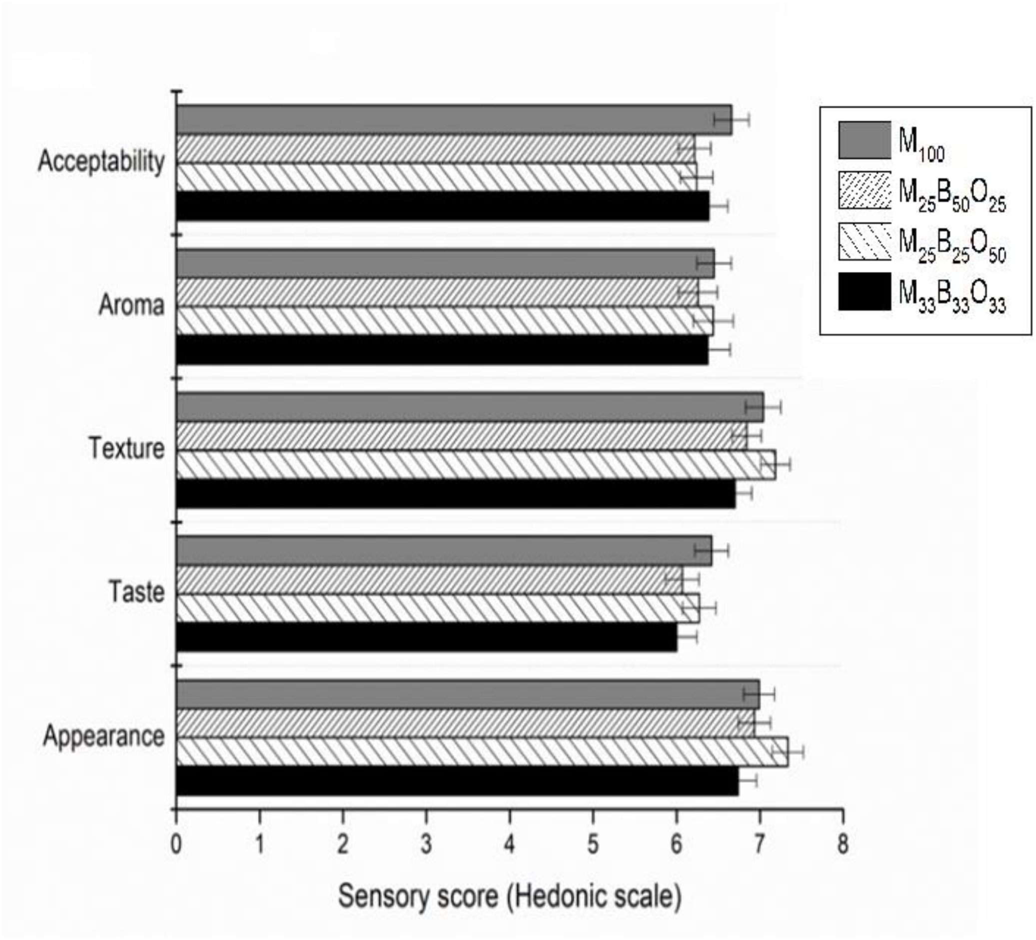


Figure 4.2: Hedonic scale-based sensory evaluation scores of porridges prepared from M_{100}, M_{25}:B_{50}:O_{25}, M_{25}:B_{25}:O_{50}, and M_{33}:B_{33}:O_{33}.

4.3 Quality analysis and sensory evaluation of flours prepared from roasted maize, ripe plantain and Soybeans

4.3.1. Proximate content of flours

The moisture content of the composite flours ranged between 5.49-7.27 g/100g, which were all higher than M_{100} (3.55 g/100g), with the composite M_{25}:S_{25}:P_{50} having the highest moisture content, while M_{25}:S_{50}:P_{25} had the lowest moisture content (Table 4.13). M_{100} (1.35 g/100g) had a lower ash content than the composite flours (2.61-3.35 g/100g). The protein content of the composite flours (15.69-23.53 g/100g) were all higher than the M_{100} (7.29 g/100g). Even the composite sample with the lowest protein M_{29}:S_{29}:P_{41} (15.69 g/100g) had more than twice the protein composition of M_{100}. The fat composition of the composite flours (5.22 g/100g - 9.78 g/100g) were, while that of M_{100} was 5.01 g/100g. The fiber content of M_{100} was 4.52 g/100g, with S_{100} (8.65 g/100g) having about twice the fiber of M_{100}. M_{25}:S_{25}:P_{50} had the lowest fiber of 3.54 g/100g among the composite flours, however, M_{25}:S_{50}:P_{25} (6.29g /100g) which had the highest percentage of soybean had the highest fiber (Table 4.13).

Table 4.13: **Nutrient content (g/100g) of roasted maize flour (M_{100}), soybeans flour (S_{100}), ripe plantain flour (P_{100}), and composite flour**

Sample	Moisture	Ash	Protein	Fat	Fibre
M_{100}	3.55 ± 0.15^a	1.35 ± 0.03^a	7.92 ± 0.07^a	5.01 ± 0.06^a	4.52 ± 027^a
S_{100}	6.89 ± 0.11^b	3.82 ± 0.08^b	31.62 ± 1.0^b	12.45 ± 0.89^b	8.65 ± 1.12^b
P_{100}	7.43 ± 0.18^b	3.61 ± 0.14^b	6.04 ± 0.15^c	1.32 ± 0.07^c	1.81 ± 0.05^c
M_{29}:S_{41}:P_{29}	5.93 ± 0.07^c	3.17 ± 0.02^b	20.31 ± 0.34^d	8.70 ± 0.08^d	4.22 ± 0.20^a
M_{29}:S_{29}:P_{41}	6.36 ± 0.31^b	2.58 ± 0.39^c	15.69 ± 0.27^e	6.78 ± 0.20^e	5.62 ± 0.16^d
M_{25}:S_{25}:P_{50}	7.27 ± 0.34^b	2.61 ± 0.22^c	16.48 ± 0.20^e	6.11 ± 0.00^e	3.54 ± 0.16^e
M_{41}:S_{29}:P_{29}	5.96 ± 0.15^c	2.64 ± 0.09^c	17.59 ± 0.34^e	6.75 ± 0.02^e	5.54 ± 0.27^d
M_{33}:S_{33}:P_{33}	6.11 ± 0.13^b	2.79 ± 0.07^c	17.81 ± 0.16^e	7.39 ± 0.14^e	4.76 ± 0.03^a
M_{50}:S_{25}:P_{25}	5.95 ± 0.16^c	2.77 ± 0.07^c	17.15 ± 0.17^e	5.22 ± 0.05^a	5.38 ± 0.27^d
M_{25}:S_{50}:P_{25}	5.49 ± 0.08^c	3.53 ± 0.03^b	23.53 ± 0.16^f	9.78 ± 0.12^f	6.29 ± 0.36^e

M – Roasted Maize S – Soybean P – Ripe Plantain. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.3.2 Mineral content of flours

The Fe of the composite flours was between 586.83-1190.88 were all higher than M_{100} (Table 4.14). The composite flours had Ca levels between 0.83-1.10 g/100g which were not significantly different from M_{100} (0.92 g/100g), which was similar to that observed for Zn. Nevertheless, the potassium levels in the composite flours were considerably greater than those in M_{100} (0.36 g/100g).

Table 4.14: Mineral composition of roasted maize flour (M_{100}), soybeans flour (S_{100}), ripe plantain flour (P_{100}), and composite flour

Sample	Iron (mg/100g)	Calcium (g/100 g)	Magnesium (g/100 g)	Potassium (g/100 g)
M_{100}	392.82 ± 3.76^a	0.92 ± 0.02^a	0.11 ± 0.01^a	0.36 ± 0.02^a
S_{100}	306.17 ± 4.65^b	0.93 ± 0.01^a	0.08 ± 0.02^a	0.48 ± 0.04^b
P_{100}	1976.8 ± 32.48^c	1.22 ± 0.06^b	0.10 ± 0.01^a	1.21 ± 0.02^c
$M_{29}:S_{41}:P_{29}$	586.83 ± 11.30^d	1.01 ± 0.10^b	0.11 ± 0.01^a	0.55 ± 0.01^b
$M_{29}:S_{29}:P_{41}$	1004.71 ± 27.38^e	0.96 ± 0.09^a	0.10 ± 0.01^a	0.84 ± 0.02^d
$M_{25}:S_{25}:P_{50}$	1190.88 ± 26.18^e	0.97 ± 0.10^a	0.10 ± 0.01^a	0.89 ± 0.02^d
$M_{41}:S_{29}:P_{29}$	752.13 ± 25.46^f	0.95 ± 0.07^a	0.10 ± 0.01^a	0.44 ± 0.02^b
$M_{33}:S_{33}:P_{33}$	787.76 ± 19.38^f	0.99 ± 0.08^a	0.11 ± 0.01^a	0.62 ± 0.01^e
$M_{50}:S_{25}:P_{25}$	683.70 ± 17.19g	0.96 ± 0.08^a	0.11 ± 0.01^a	0.53 ± 0.02^b
$M_{25}:S_{50}:P_{25}$	624.32 ± 33.47^g	0.93 ± 0.08^a	0.11 ± 0.01^a	0.61 ± 0.01^e

M – Roasted Maize S – Soybean P – Ripe Plantain. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.3.3 Phytochemicals and anti-nutrients

The composite flours had a β-carotene level ranging from 3.58 to 5.08 mg/100g which were higher than M_{100} (2.65 mg/g) (Table 4.15). The composite flour with the highest percentage of ripe plantain, M_{25}:S_{25}:P_{50} had the highest amount of β-carotene of 5.08 mg/100g. M_{100} showed a higher phenolic content of 32.25 mg/100g compared to the composite flours (22.26 -28.18 mg/100g). The composite flours had a phytate level ranging from 0.32 to 0.52 mg/g, which were all higher than M_{100} (0.23 mg/g). The oxalate and tannin of the composite flours showed no significant differences compared to M_{100}.

Table 4.15: Phytochemical and antinutrient content roasted maize flour (M_{100}), Soybeans flour (S_{100}), ripe plantain flour (P_{100}), and the composite flours

Sample	β-Carotene (mg/100g)	Phenolic Content (mg/100g)	Phytate (mg/100g)	Oxalate (mg/100g)	Tannins (mg/100g)
M_{100}	2.65 ± 0.15^a	32.25 ± 1.97^a	0.23 ± 0.04^a	0.02 ± 0.01^a	2.67 ± 0.11^a
S_{100}	1.33 ± 0.10^b	22.37 ± 2.11^b	1.02 ± 0.09^b	0.04 ± 0.01^a	2.86 ± 0.10^a
P_{100}	8.63 ± 0.69^c	29.82 ± 1.55^a	0.09 ± 0.01^c	0.02 ± 0.01^a	2.65 ± 0.14^a
$M_{29}:S_{41}:P_{29}$	4.17 ± 0.14^d	28.18 ± 1.43^a	0.35 ± 0.04^a	0.04 ± 0.00^a	2.56 ± 0.13^a
$M_{29}:S_{29}:P_{41}$	4.77 ± 0.19^d	22.26 ± 1.35^b	0.32 ± 0.06^a	0.06 ± 0.00^b	2.78 ± 0.08^a
$M_{25}:S_{25}:P_{50}$	5.08 ± 0.28^d	27.46 ± 1.85^c	0.52 ± 0.11^d	0.02 ± 0.01^a	2.89 ± 0.12^a
$M_{41}:S_{29}:P_{29}$	3.71 ± 0.28^d	23.15 ± 0.81^b	0.37 ± 0.07^e	0.04 ± 0.01^a	2.67 ± 0.10^a
$M_{33}:S_{33}:P_{33}$	4.25 ± 0.34^d	24.38 ± 1.35^b	0.36 ± 0.08^e	0.02 ± 0.01^a	2.97 ± 0.09^a
$M_{50}:S_{25}:P_{25}$	3.58 ± 0.05^d	25.22 ± 1.18^b	0.35 ± 0.08^e	0.02 ± 0.01^a	2.47 ± 0.15^a
$M_{25}:S_{50}:P_{25}$	3.76 ± 0.04^d	23.25 ± 1.29^b	0.52 ± 0.05^d	0.01 ± 0.00^a	2.71 ± 0.11^a

M – Roasted Maize S – Soybean P – Ripe Plantain. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.3.4 Physicochemical properties of flours

The physicochemical characteristics of the flours shown in Table 4.16 reveals no significant differences in pH between the composite flours (5.37-5.79) and M_{100} (5.39). The Brix of M_{100} was 0.40, was significantly lower the range of 1.10-1.40 observed for the composite flours. The observed colour change and browning index of the composite flours range between 8.64-11.65 and 19.54-34.85, respectively.

Table 4.16: pH, Brix, Colour and Browning Index of roasted maize flour (M_{100}), Soybean flour (S_{100}) and ripe plantain flour (P_{100}) and composite flour

Sample	pH	Brix (°Brix)	Colour change	Browning Index
M_{100}	5.39 ± 0.11^a	0.40 ± 0.08^a	-	48.70 ± 6.35^a
S_{100}	6.29 ± 0.08^b	3.02 ± 0.08^b	-	18.54 ± 1.37^b
P_{100}	4.62 ± 0.11^c	1.50 ± 0.07^c	-	28.65 ± 3.52^c
$M_{29}:S_{41}:P_{29}$	5.65 ± 0.01^a	1.30 ± 0.00^c	11.65 ± 1.11^a	21.89 ± 2.31^c
$M_{29}:S_{29}:P_{41}$	5.43 ± 0.01^a	1.40 ± 0.01^c	9.65 ± 0.98^a	19.54 ± 2.62^b
$M_{25}:S_{25}:P_{50}$	5.37 ± 0.01^a	1.40 ± 0.00^c	8.65 ± 0.91^b	28.52 ± 2.48^c
$M_{41}:S_{29}:P_{29}$	5.52 ± 0.01^a	1.30 ± 0.00^c	8.64 ± 0.87^b	24.66 ± 2.14^c
$M_{33}:S_{33}:P_{33}$	5.54 ± 0.01^a	1.30 ± 0.00^c	9.65 ± 0.72^a	29.59 ± 2.23^c
$M_{50}:S_{25}:P_{25}$	5.51 ± 0.02^a	1.20 ± 0.01^c	11.65 ± 1.05^a	34.85 ± 1.63^c
$M_{25}:S_{50}:P_{25}$	5.79 ± 0.01^a	1.10 ± 0.01^d	10.37 ± 1.00^a	31.58 ± 2.91^c

M – Roasted Maize S – Soybean P – Ripe Plantain. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.3.5 Functional properties of flours

Table 4.17 indicated that the composite flours did not exhibit a substantial disparity in water and oil absorption capacity when compared to M_{100}. The composite flours exhibited a water absorption capacity ranging from 2.26 to 2.65 g/g, and an oil absorption capacity ranging from 2.04 to 2.30 g/g. Also, no significant difference was observed when comparing the bulk density of the composite flours, which ranged between 0.70-0.80 mg/L, to M_{100} (0.75 mg/L). Nevertheless, the composite flours exhibited a notably higher solubility index. Regarding swelling power, the composite flours showed greater values, however only M_{29}:S_{29}:P_{41} and M_{25}:S_{25}:P_{50} were considerably higher than M_{100}.

Table 4.17: Functional properties of roasted maize flour (M_{100}), Soybeans flour (S_{100}), ripe plantain flour (P_{100}), and composite flours

Sample	Water Absorbed (g/g)	Oil Absorbed (g/g)	Bulk Density (mg/L)	Solubility Index (%)	Swelling Power (g/g)
M_{100}	2.97 ± 0.05^a	1.96 ± 0.09^a	0.75 ± 0.09^a	11.65 ± 1.25^a	6.07 ± 0.20^a
S_{100}	2.47 ± 0.02^a	2.34 ± 0.02^a	0.67 ± 0.07^a	22.74 ± 0.55^a	5.72 ± 0.16^a
P_{100}	1.32 ± 0.08^b	0.58 ± 0.07^b	0.79 ± 0.10^a	18.56 ± 3.25^a	7.62 ± 0.21^b
$M_{29}:S_{41}:P_{29}$	2.42 ± 0.10^a	2.30 ± 0.15^a	0.78 ± 0.01^a	19.32 ± 0.82^a	6.78 ± 0.32^a
$M_{29}:S_{29}:P_{41}$	2.36 ± 0.13^a	2.11 ± 0.14^a	0.70 ± 0.01^a	16.01 ± 0.65^a	7.15 ± 0.30^a
$M_{25}:S_{25}:P_{50}$	2.35 ± 0.11^a	2.05 ± 0.12^a	0.80 ± 0.01^a	18.54 ± 0.91^a	7.19 ± 0.22^a
$M_{41}:S_{29}:P_{29}$	2.45 ± 0.13^a	2.07 ± 0.15^a	0.73 ± 0.01^a	18.85 ± 0.73^a	6.55 ± 0.40^a
$M_{33}:S_{33}:P_{33}$	2.43 ± 0.16^a	2.04 ± 0.18^a	0.78 ± 0.01^a	17.73 ± 0.74^a	6.12 ± 0.19^a
$M_{50}:S_{25}:P_{25}$	2.65 ± 0.09^a	2.08 ± 0.12^a	0.78 ± 0.02^a	14.01 ± 0.61^a	6.74 ± 0.24^a
$M_{25}:S_{50}:P_{25}$	2.26 ± 0.08^a	2.08 ± 0.10^a	0.74 ± 0.01^a	19.05 ± 0.44^a	6.20 ± 0.19^a

M – Roasted Maize S – Soybean P – Ripe Plantain. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.3.6 Viscosity and pasting properties of the flours

The viscosity and pasting characteristics shown in Table 4.18 reveals that S_{100} had the highest pasting temperature of 85.54 °C whiles P_{100} had the lowest pasting temperature value of 78.62 °C. Among the composite flours, the pasting temperature ranged between 80.99-82.05 °C. The peak viscosity of the flours ranged between 1082-1305 BU with S_{100} and M_{100} having the highest and lowest values, respectively. Also, the flours exhibited a breakdown viscosity ranging from 40 to 218 BU, with M_{100} displaying the lowest value. The trough and breakdown viscosity of the flours ranged between 907-1181 BU, and 325 to 456 BU, respectively. The final viscosity of the composite flours was higher than M_{100}, with M_{25}:S_{50}:P_{25} having the highest final viscosity 1917 BU. However, The peak time of the composite flours exhibited a lower value, ranging from 9.25 to 10.23 minutes, in contrast to the reported value of 10.53 minutes for M_{100}.

Table 4.18: Pasting properties of roasted maize flour (M100), soybean flour (S100), semi-ripe plantain flour (P100) and the composite flours

Sample	Pasting temperature (°C)	Peak viscosity (BU)	Breakdown Viscosity (BU)	Trough Viscosity (BU)	Setback viscosity (BU)	Final viscosity (BU)	Peak Time (min)
M_{100}	81.25	1082	40	1042	354	1396	10.53
S_{100}	85.54	1305	124	1181	325	1561	10.43
P_{100}	78.62	1125	218	907	456	2452	9.25
M_{29}:S_{41}:P_{29}	80.99	1169	127	1042	370	1750	10.41
M_{29}:S_{29}:P_{41}	82.05	1215	153	1062	360	1747	10.09
M_{25}:S_{25}:P_{50}	81.06	1098	89	1009	389	1805	9.92
M_{41}:S_{29}:P_{29}	82.05	1108	86	1023	372	1754	10.36
M_{33}:S_{33}:P_{33}	81.19	1157	112	1045	379	1718	10.08
M_{50}:S_{25}:P_{25}	81.92	1152	123	1029	368	1733	9.99
M_{25}:S_{50}:P_{25}	81.10	1107	97	1010	397	1917	9.98

M – Roasted Maize S – Soybean P – Ripe Plantain. Mean in the same column with different superscript letters are significantly different at $p < 0.05$.

4.3.7 Consumer acceptability of porridge prepared from roasted maize, ripe plantain, and soybean flours

The scores for sensory evaluations between the control sample maize (M_{100}), and the selected composite flours $M_{33}:S_{33}:P_{33}$, $M_{25}:S_{50}:P_{25}$, and $M_{25}:S_{25}:P_{50}$ shown in Figure 4.3, reveals that the scores for appearance ranged between 6.23-7.37 with the composites $M_{25}:S_{25}:P_{50}$ and $M_{25}:S_{50}:P_{25}$ having the highest and the least scores, respectively. The scores for taste were between 6.34-6.73 with M_{100} having the highest score. Also, the scores for texture were between 6.05-6.73 with $M_{33}:S_{33}:P_{33}$ (6.30) and $M_{25}:S_{50}:P_{25}$ (6.04) having lower scores than M_{100}. The scores for aroma were between 6.13-7.03 with M_{100} having the highest score followed by $M_{25}:S_{25}:P_{50}$ (6.66). For overall acceptability, the scores ranged between 6.27-6.88 with M_{100} having the highest score followed by $M_{25}:S_{25}:P_{50}$ (6.63). In general, there were no notable differences found between the M_{100} and the three chosen composite flours in terms of all sensory characteristics.

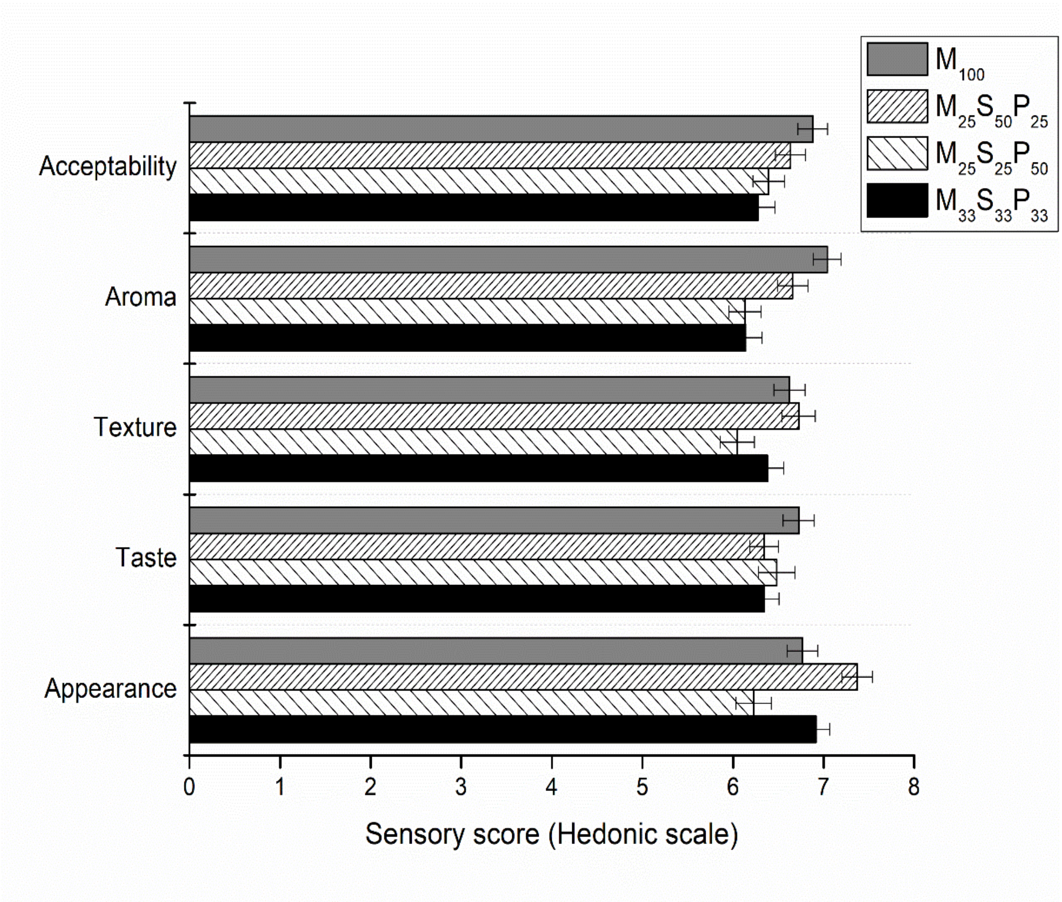


Figure 4.3: Hedonic scale based sensory evaluation scores of porridges prepared from M_{100}, $M_{25}:S_{50}:P_{25}$, $M_{25}:S_{25}:P_{50}$, and $M_{33}:S_{33}:P_{33}$.

4.4 Cost analysis and pricing of the composite flours

Table 4.19 displays the expenses associated with various raw materials and processing techniques necessary for flour porduction. The cost of the different raw materials was obtained on the 10th of September 2022. The estimated cost of the flours (Table 4.20) produced from these raw materials was obtained taking into consideration the cost associated with each unit operation (Table 4.21). Based on estimates for water and electricity usage and labour cost during the period of the study (September 2022), the cost of milling and dehulling was estimated to about 1 ¢/kg, while the cost of roasting, boiling, and drying were estimated to about 1.2, 1.1 and 1.5 ¢/kg, respectively. Based on this information, the price of M_{100} was estimated to be about 10.7 ¢/kg, while B_{100}, P_{100}, O_{100} and S_{100} was estimated to be about 23.2, 14, 36.2 and 11.9 ¢/kg.

Table 4.19: Cost of raw materials and the processing methods (unit operations) used in the preparation of flours

Ingredients	Cost/kg (¢)	Processing method
Maize	6.00	Sorting, Roasting, Milling
Ripe Plantain	8.00	Washing, Peeling, Slicing, Drying, Milling
Orange flesh Sweet Potato	30.00	Washing, Peeling, Slicing, Drying, Milling
Bambara Groundnut	16.00	Sorting, Boiling, Dehulling, Drying, Milling
Soybeans	7.00	Sorting, Roasting, Milling

Table 4.20: Cost of the unit operations associated with the processing of raw materials

Other production costs	Cost (¢)
Milling cost (kg)	1.00
Roasting (kg)	1.20
Dehulling	1.00
Boiling	1.10
Drying	1.50

Table 4.21: Cost of flour obtained from each raw material

Ingredient	Cost of flour (¢/kg)
Maize	10.70
Ripe Plantain	14.00
Orange flesh Sweet Potato	36.20
Bambara Groundnut	23.30
Soybeans	11.90

The estimated cost of composite flours made from roasted maize, Bambara groundnut, and ripe plantain flour would range from 15.50-17.83 ¢/kg.

Similarly, composite flours made from roasted maize, Bambara groundnut, and orange flesh sweet potatoes would be priced between 23.17-23.38 ¢/kg. Lastly, composite flours made from roasted maize, soybean, and ripe plantain flours would be priced between 12.08-12.65 ¢/kg, based on the cost of the raw materials (Table 4.22).

Table 4.22: Cost of roasted maize and some selected composite flours.

Flour	Cost/kg (¢)
M_{100}	10.70
$M_{25}B_{50}P_{25}$	17.83
$M_{25}B_{25}P_{50}$	15.50
$M_{33}B_{33}P_{33}$	18.22
$M_{25}B_{50}O_{29}$	23.38
$M_{25}B_{25}O_{50}$	23.38
$M_{33}B_{33}O_{33}$	23.17
$M_{25}S_{50}P_{25}$	12.13
$M_{25}S_{25}P_{50}$	12.65
$M_{33}S_{33}P_{33}$	12.08

CHAPTER FIVE

DISCUSSION

5.1 The nutritional quality of the composite flours

The nutrient contents of the roasted maize flour, (Dauda et al.,2020; Paterne et al., 2019), Bambara groundnut flour (Azman Halimi et al., 2019; Mayes et al., 2019), orange-fleshed sweet potatoes flour (Babatunde et al., 2019) and ripe plantain flour (Ketiku, 1973) were within the range reported in the literature for these products. Qamar et al. (2016) reported the nutrient composition of several maize germplasms to be between 0.81-1.35 g/100 g for ash, 0.79-2.78 g/100 g for crude fibre and 11.05-12.79 g/100 g crude protein, which are all within the ranges observed in this study. Similarly, the nutrient content of Bambara groundnut was found to consist of 18-25 g/100g of protein 5.6 and 6.7 g/100g, respectively for fat and fibre and 3- 4 g/100g of ash. Bambara groundnut is mostly composed of 51–71g/100 g of carbohydrate, 18–24 g/100 g (Mayes et al., 2019; Mi, 2018). With respect to the nutrient content of orange-fleshed sweet potatoes, protein, ash, fats and fibre contents of 1-2, 0.8-1.2, 0.5-1 and 2.3 g/100g respectively have been reported (Mbame et al., 2021; Neela & Fanta, 2019b) while the levels in ripe plantain were 1.2-1.5 g/100g for protein, and 0.4-0.6, 2.3-3.5 and 0.9 -1.2 g/100g for fats, fibre and ash (Ketiku 1973).

The increase in the moisture content of the flours mixtures, in comparison to the roasted maize flour, can be attributed to the greater levels of moisture found in the Bambara groundnut, soybean, orange skinned sweet potatoes, and ripe plantain flours (Marcel et al., 2022; Gemede, 2020). An increase in hydration level can increase the possibility of microbial growth and onset of moisture-dependent biochemical reactions (Nasir et al., 2003; Ojo et al., 2018). However, according to Nasir et al. (2003) flours with a moisture content of 10 % are considered shelf stable, implying that the composite flours can be stored for extended periods.

The ash concentration of each composite flour exceeded that of the roasted maize flour. Ripe plantain, orange-fleshed sweet potatoes Bambara groundnut and soybean showed higher ash contents, which was reflected in the increase ash content of the composite flours. The rise in the ash level of the composite flours also led to an elevation in the mineral content. The higher ash content in ripe plantain flour correlated with an increase in iron, magnesium, and potassium in the composite flours. Other studies have similarly seen an increase in the ash content of composite flours when orange-fleshed sweet potatoes, was included. Jenfa et al. (2024) and Olugbuyi et al. (2024) observed an increase in ash content when OFSP was added to sorghum and rice bran, respectively.

The protein content of the composite flours exceeded that of roasted maize flour because of the inclusion of legumes such as Bambara groundnut and soybean. Among the composite flours, the addition of soybean led to high protein levels compared to Bambara groundnut. Nevertheless, Bambara groundnut has demonstrated a significant concentration of many crucial amino acids, such as leucine and lysine. (Yao et al., 2015). Considering the low content of protein and lysine in maize (Chassy, 2009) but the most widely consumed cereal in Africa (Erenstein et al., 2022), the addition of legumes to breakfast meal such as roasted maize porridge is highly commendable (Soumare et al., 2022b). This can also help augment the utilization of the nuts for food, improve protein energy nutrition, help consumers meet the dietary essential amino acid requirements and improve access to sufficient and nutritious food. According to Richter et al., (2019), the daily protein intake that is advised for infant and children range from 8 to 14 g, showing that by consuming a 100 g of composite flours, individuals can effectively meet their daily protein requirements.

The fat and fibre content of the composite flours were comparable to that of roasted maize flour, indicating that similar energy levels (calorific intake), compared to roasted maize flour can be achieved when the composite flours are consumed. On the other hand, the addition of soybean led to increase in fat content, which could affect the shelf life with an increase possibility of rancidification. However, this can be avoided when appropriate storage techniques are used to store the composite flours such as keeping it away from oxygen, light and higher temperatures. Similar increase in fat content were observed by Olaniyan and Ademola (2015) and Kulu (2022) when soybeans were added to malted sorghum and cassava flours respectively.

The iron content of the composite flours containing ripe plantain was higher due to the higher levels of iron observed in ripe plantain flour. Similarly, high levels of iron have been observed in ripe plantain in other studies (Agbemafle et al., 2017; Honfo, 2007). This shows that the composite flours containing ripe plantain can be used to tackle issues of iron deficiency anaemia, which is prevalent in several developing countries including Ghana (Shenton et al., 2020). Considering that the suggested daily intake for iron is about 0.27 mg/day for infants up to 6 months, and between 7-18 mg/day (Restrepo-Gallego et al., 2021) for the general population, the composite flours containing ripe plantain can be considered adequate for satisfying the RDA of infants and the general populace.

The levels of calcium and magnesium observed in the composite flours were similar compared to roasted maize flour, showing similar intake levels will be achieved when the composite flours are consumed. However, higher levels of potassium were observed in the composite flours containing ripe plantain, like what has been observed in other studies (Agbemafle et al., 2017; Honfo et al., 2007). Considering the essential role of potassium in helping to maintain fluid and electrolyte balance in humans (Lanham-New et al., 2012), the consumption of the composite flours containing ripe plantain can help to enhance potassium intake to help meet the recommended daily allowance.

5.2 Phytochemical and Antinutrients Content of the Composite flours

The β-carotene of the composite flours were higher than roasted maize flour due to the addition of ripe plantain and orange flesh sweet potatoes flours, with the flour containing higher portion of ripe plantain and orange-fleshed sweet potatoes possess elevated quantities of β-carotene. Higher levels of β-carotene were observed in the composite flours containing orange fleshed sweet potatoes, which showed to have appreciable levels β-carotene that are highly bioavailable and can easily be converted into vitamin A (retinol) within the human body system (Koala et al., 2021). Taking a conversion rate of 12 µg of dietary β-carotene to 1µg retinol (Vitamin A) (Blaner, 2020b), the possible levels of retinol in the composite flours containing orange flesh sweet potatoes and ripe plantain will be between 600.83-1102.50 and 280-475 µgRAE respectively. According to Miller et al., (2001) the recommended daily intake of vitamin A for babies and children is between 400-600 µgRAE. This shows that consuming 100 g of composite flour containing orange fleshed sweet potatoes can help meet the daily requirement of vitamin A, while the consumption of composite flour containing ripe plantain can contribute to half of the recommended requirement. This shows that the observed increase in β-carotene in the composite flours can serve an important purpose in helping to mitigate vitamin A deficiency. Considering the possible health effect of vitamin A deficiency such as night blindness and xerophthalmia, using readily available common food such as ripe plantain and orange fleshed sweet potatoes to supplement foods to combat this deficiency can be considered novel. Additionally, in Ghana and most countries, the use of ripe plantain as food is primarily restricted to hot-oil frying and roasting, thus incorporating ripe plantain into porridge can provide avenues to expand its usage whilst enhancing the economic importance.

The phenolic content of all the composite flours were similar to roasted maize flour apart from the composite flour containing orange flesh sweet potatoes in which higher phenolic content levels were observed. This shows that roasted maize flour can serve as a vital meal for supplementation purposes to meet specific nutritional needs while the use of orange flesh sweet potatoes can help improve the overall intake of phenolic compounds. Similar increase in phenolic content was observed when orange fleshed sweet potatoes were supplemented in other foods (Korese et al., 2021) because of its high phenolic content.

The inclusion of soybeans, ripe plantain, and orange-fleshed sweet potatoes had no impact on the concentrations of anti-nutritional compounds, oxalate, phytate and tannins. However, the incorporation of Bambara groundnut in the composite flours caused an average increase in tannins by about 22 %, without changing the phytate levels. Bambara groundnut exhibits higher concentrations of tannins in comparison to other legumes such as soybeans (Mubaiwa et al., 2016; Pretorius et al., 2023). Although the analyzed anti-nutrients have been observed to play non-beneficial roles in human nutrition, such as mineral bioavailability and protein digestibility (Oyeyinka & Afolayan, 2019), acceptable levels in food have been reported to lower blood glucose and lipids levels, as well as helping to prevent calcium crystallization in renal organs (Oyeyinka & Afolayan, 2019). A safe limit of at most 1.5 g tannin per day was recommended by Rao & Prabhavathi, (1982), which implies that the observed rise in tannin concentration of the composite flours is not likely to have any adverse effects on consumers. Moreover, the heat applied during porridge preparation could further decrease the tannin levels, as Ojo et al. (2023) reported that more than 50 % reduction of anti-nutrients occur when legumes are cooked.

5.3 Physicochemical properties of the composite flours

The pH of the composite flours was not different from that of roasted maize flour, showing that the composite flours may exhibit equivalent levels of sourness. This shows that porridge prepared from the composite flours may taste similar, concerning sourness, to porridge prepared from roasted maize flour. Similarly, no change in pH was observed when orange-fleshed sweet potatoes (Jenfa et al., 2024), Bambara groundnut (Mashau et al., 2022) and soybeans (Olaniyan & Ademola, 2015) were used in the prepare of composite flours.

Although the inclusion of ripe plantain and orange flesh sweet potatoes led to an increase in Brix, sugar is usually added to porridge before consumption. Thus, similar sweetness levels can be achieved when the composite flours are prepared into porridge prepared from roasted maize flour. However, the composite flours may taste sweeter Yusufu et al. (2014) noticed a rise in Brix when ripe plantain flour was added to *fura,* while Ibrahim et al. (2021) and Mamo et al. (2014) also noticed a rise in Brix when orange flesh sweet potatoes were added to sorghum and mango, respectively.

Changes in browning were observed when the composite flours were compared to roasted maize flour with higher values observed in the composite flour containing orange flesh sweet potatoes, while the addition Bambara ground nut, ripe plantain, and soybean led to reduction in browning index. The increase in the browning index upon the addition of orange-fleshed sweet potatoes can be ascribed to the orange colour, which contributes to an increase in brownness. The colour changes observed in the composite flours compared to roasted maize flour were all higher than 6. Based on the colour change scale developed by Cserhalmi et al. (2006). It can be surmised that greatly visible differences in colour can be observed when comparing the composite flour to roasted maize flour.

5.4 Functional Properties of the Composite Flours

The quality and suitability of flours for use in diverse food application depends greatly on their functional qualities. High water absorption capacity, which describes how well flour can hold water is advantageous in many culinary applications. During food preparation, changes in starch can lead to reduction in the capacity of absorb water, causing the release of water and leading to the production of liquid gruels (Sharma et al., 2019; Aderonke et al., 2014). Considering that no major changes in water absorption were observed, similar products may be obtained upon the addition of water when comparing the composite flours to roasted maize flour. In addition, oil absorption capacity is a crucial factor to consider with water absorption capacity, since it indicates the amount of oil that flour can retain when used for frying. Like water absorption capacity, it was expected that the composite flours would behave the same as roasted maize flour in the presence of oil. The observed similarities in water absorption between the roasted maize flour and the composite flours was expected as the different components of the composite flours have been observed in other studies not to have affected water absorption. Bolarin et al. (2022) observed no changes in water absorption when soybeans were added to sorghum, although a comparable observation was noted by Jenfa et al. (2024) and Olugbuyi et al. (2024) when they worked with orange fleshed sweet potatoes.

Another important parameter that influences the cooking properties of flours is bulk density, which measures the density without the influence of compression. According to Sharma et al. (2019), less compact flour may have higher flowability and dispersibility due to a lower bulk density. The addition of Bambara groundnut, ripe plantain, and soybeans did not affect the bulk density of the composite flours compared to roasted maize flour. This is advantageous as the flowability and dispersibility of the composite flours was like roasted maize flour and thus similar conditions can be employed during handling and processing. Although the utilisation of orange-fleshed sweet potatoes led to a reduction in bulk density, these changes were not different compared to roasted maize flour. The similarity in bulk densities of the composite flours compared to roasted maize flours offers other advantages, as the same conditions can be employed for packaging, storage and transportation when working on the composite flours (Olugbuyi et al., 2024). Anosike et al. (2020) also found that a diet with low bulk density lacks the ability to make a thick gruel, which is a desirable functional characteristic for supplementary food.

The composite flours prepared from roasted maize, Bambara groundnut and orange fleshed sweet potatoes did not differ in solubility in water compared to roasted maize flour. Solubility index, which measures the proportion of flour that dissolves in water can affect the texture, consistency and processing behaviour of flours during food preparation (Bello et al., 2021) . The similarities in solubility index shows that similar texture, consistency and processing behaviour can be expected when using these composite flours in place of roasted maize flour. This is important as most consumers may be familiar with the cooking behaviour of roasted maize flour and may not have to adapt new techniques when preparing the composite flours into porridges. However, composite flours made from roasted maize, Bambara groundnut, and ripe plantain had higher solubilities, while even higher solubility indices were observed for composite flours prepared from roasted maize, ripe plantain and soybeans, due to the higher solubility indices of ripe plantain and soybeans. Considering that flour with high solubility indices dissolves more readily in water leading to products with smooth texture with limited lumps (Tas et al., 2022). The composite flours containing ripe plantain and soybeans may lead to the production of porridges that can easily be consumed by infants and children.

The high swelling power of the composite flours compared to roasted maize flour can be attributed to their higher value observed for Bambara groundnut and orange fleshed sweet potatoes flours, with composite flours containing these two having the highest swelling power. Swelling power, measures the ability of starch granules to assimilate water and swell upon heating, gives an indicator of the moisture retention ability of flours. Flours with high swelling power are desired as these affects' mouthfeel due to the smoother and consistent texture upon heating such flours after the addition of water. These shows that the composite flours prepared from roasted maize, Bambara groundnut and orange fleshed sweet potatoes flours can have a higher acceptability, especially among children, as the higher swelling power will enhance the mouthfeel when consumed. The increase in swelling power upon the addition of orange fleshed sweet potatoes has also been observed in other studies (Jenfa et al., 2024; Olugbuyi et al., 2023), with similar observations made Bambara groundnut (Mashau et al., 2022).

5.5 Viscosity and pasting properties of the composite flours

The addition of Bambara groundnut, ripe plantain, orange fleshed sweet potatoes and soybeans to roasted maize flour affected the viscosity and pasting properties. Changes in pasting temperature was observed, with increase and decrease observed in the different composite flours. Pasting temperature refers to the specific temperature at which the initial noticeable rise in viscosity is observed. It is characterized by initial change due to starch swelling, giving an indication of the minimum temperature required for cooking (Julianti et al., 2017). The composite flours from roasted maize, Bambara groundnut and ripe plantain, as well as the composite flours containing soybeans showed low pasting temperature whilst the composite flours from roasted maize, Bambara groundnut and orange fleshed sweet potatoes exhibited high pasting temperature. According to Ikegwu et al. (2010) and Anosike et al. (2020), low pasting temperature indicates shorter cooking time, therefore, porridges prepared from roasted maize and composite flours containing the ripe plantain will cook at a much faster rate than the composite flours containing orange fleshed sweet potatoes, Comparable peak time was observed in between the composite flours and roasted maize flour, showing that similar cooking durations will be observed when preparing the flours into porridges as the peak time gives an estimate of the cooking time of flours.

The composite flours of roasted maize, Bambara groundnuts and orange fleshed sweet potatoes showed low peak viscosities, which meant that upon cooking and cooling, a paste with a low viscosity will be formed. Low peak viscosity also means that the gel will be a high caloric density food per unit volume and so will be good for children. According to the World Health Organisation (2003), a high-quality complementary diet should be rich in nutrients, have a low density, and have the right texture and consistency that make it easy to consume. The lower peak viscosity values recorded for the composite with orange fleshed sweet potatoes were in line with the report by Amagloh (2022) and Jemberu et at. (2016) who observed decreases in viscosity for their formulated porridges as portions of orange-fleshed sweet potatoes increased. Low peak viscosity could be ascribed to the presence of simple sugars in orange-fleshed sweet potatoes, while high peak viscosity in the other composite flours and roasted maize flour gave an indication of high amount of starch (Ikegwu et al., 2010; Anosike et al., 2020).

Breakdown viscosity provides a measure of the extent to which starch granules disintegrate and can also be used as a measure of the starch's stability when subjected to the cooking process (Tijani et al., 2017). According to

Ikegwu et al. (2010), a low breakdown viscosity indicates that the flour has a stronger capacity to endure heating and shear stress during processing. Changes in breakdown viscosity was observed when comparing roasted maize flour to the composite even though no observable pattern was noted.

The setback viscosity which is estimated by taking the difference in final viscosity and trough or paste viscosity is known to affect retrogradation and reordering of starch molecules during heating (Salami et al., 2019; Sanni, 2015). The composite flours containing orange-fleshed sweet potatoes showed lower setback viscosity compared to roasted maize flour indicating the possible resistance to retrogradation. Considering that retrogradation involves the reorganization of starch molecules after gelatinization which can help increase viscosity by thickening porridges (Anosike et al., 2020), the reduction of retrogradation in the composite flours containing orange-fleshed sweet potatoes can lead to the production of less viscous porridges

The final viscosity, which is often the parameter used to characterize a starch-base food, gives an indication of the ability to form a viscos paste after cooking and cooling. The final viscosity of the composite flours containing orange fleshed sweet potatoes were lower than maize flour, which showed that less viscous porridges were obtained in the composite flours containing orange fleshed sweet potatoes. The low viscosity of orange fleshed sweet potatoes composite flours has also been confirmed by previous studies carried out by Jenfa et al. (2024), Olugbuyi et al. (2024) and Ibrahim et al. (2021). This shows that more flour will be needed to prepare porridge to achieve the same viscosity when using composite flours containing orange fleshed sweet potatoes as compared to when using roasted maize flour. However, the composite flours containing ripe plantain had higher final viscosities, which meant that less flour will be needed to achieve comparable viscosities when preparing porridges, compared to roasted maize flour.

5.6 Sensory Acceptability of Porridges Prepared from the Composite Flours

The higher sensory scores for aroma of the porridges prepared from the composite flours containing Bambara groundnuts and ripe plantain can be attributed to the pleasant aroma associated with ripe plantain flour and the reduction of the beany flavour during the preparation of Bambara groundnut by dehulling. Ripe plantain flour has shown to have a pleasant aroma and thus helping to increase the acceptability of foods. In wheat cookies, the incorporation of ripe plantain flour increased the aroma scores leading to higher acceptability (Omowonuola et al., 2016). Similarly, Ogori (2022) and Olaoye et al. (2006) observed that the incorporation of plantain flour into composites for cookies resulted in higher scores for aroma. In addition, the aroma of cake prepared from ripe plantain and wheat flours had high scores according to Ibeanu et al. (2016).

The sensory score for aroma of the porridges prepared from the composite flours containing orange fleshed sweet potatoes were also high. This could be attributed to the high phenolic content of the orange fleshed sweet potatoes. According to Cheynier (2012), phenolic compounds contribute to the flavour characteristics of red and yellow fruits, helping to enhance their aroma and acceptability. The results of the studies agree with the sensory scores for aroma when orange fleshed sweet potatoes were incorporated into porridge prepared from maize and haricot beans flours (Jemberu at al., 2016), and snacks

(Honi et al., 2018). The scores were higher for aroma despite the incorporation of soybeans and Bambara groundnut. This could be due to the preprocessing steps (soaking and boiling for Bambara groundnut and roasting for soybeans) employed prior to the preparation of their flours. According to Jemberu et al. (2016), roasting and boiling improves the flavour and the taste of food, with reductions in beany flavour observed especially in legumes upon boiling and roasting (Ogori et al., 2022; Oyeyinka et al., 2021).

The sensory score for texture of porridges prepared from the composite flours was comparable to roasted maize flour although the composite flours containing orange fleshed sweet potatoes were higher. This may be attributed to the reduced viscosity of the composite flours containing orange-fleshed sweet potatoes, leading to porridges which could easily be swallowed. A similar observation was made in composite flours prepared from quality protein maize, where the addition of orange-fleshed sweet potatoes led to reductions in viscosity of the porridge and helped to improve the scores for texture after sensory evaluation (Amagloh et al., 2012).

The comparable sensory score for texture of porridges prepared from the composite flours containing Bambara groundnut could be attributed to the dehulling of the beans which has been shown to help improve flour particles size and hence the overall texture and mouthfeel. In the composite flours containing soybeans, the acceptability score of texture could be due to the high fat content of soybeans, with fat helping to improve the texture and aroma of foods (Kalumbi et al., 2019).

Comparable sensory scores for taste were observed between the porridge prepared from maize flour and the composite flours. Among the factors that influence the taste of porridge and other similar foods include the degree of sweetness and sourness (Calvin & George, 2018). Considering that no changes in pH was observed between the composite flours and roasted maize flour, it is possible that similar degrees of sourness could be observed in the porridge, contributing to the observed similarity in taste scores. In addition, although the addition of ripe plantain and orange fleshed sweet potatoes led to increase in Brix, it is possible that the porridges may have about the same degree of sweetness as equal quantities of sugar were added during porridge preparation. The similar degree of sweetness may also have contributed to the observed comparable scores for taste. Besides, although Bambara groundnut and soybean were added to the composite flours, the cooking and roasting employed during the flour preparation may have helped to reduce any unpleasant beany taste associated with the use of the two legumes. Similar observations with regards to taste have been made in other studies focusing on the use orange fleshed sweet potatoes when used in a composite flour for porridge preparation (Amagloh, 2022). The effect of roasting on the soybean on helping to reduce beany flavour of soybeans has also been confirmed by Agume et al. (2017), who compared porridges prepared from composite flours containing maize, and either roasted or unroasted soybeans.

The sensory scores for appearance of the porridges were all high, showing their acceptability by the sensory panel. The acceptability of the appearance of the porridges, especially the porridge prepared from the composite flours is important, as according to Spence (2015), the appearance and colour of food plays an important role in acceptability. Also, Singh-Ackbarali and Maharaj, (2014) noted that colour and appearance have the power to stimulate or stifle desirability and are usually used by consumers as indicators of intrinsic quality of food. The acceptability of the appearance of the porridges prepared from the composite flours despite the observable differences in colour compared to roasted maize flour, which is marked by the higher colour change and observable differences in browning index, showed the potential of the composite flours to be consumed by the general populace.

Generally, the overall acceptability of the porridges prepared from the composite flours was high and comparable to roasted maize porridge. This is unsurprising as according to Yang and Lee, (2019), familiarity with food product affects food choices and potential acceptability. Also, Gomes and Lopes (2022) observed that familiarization of consumers to a product already on the market influence their choices. This shows that using an already existing and popular food such as roasted maize porridge as a vehicle to help tackle issues of vitamin A and protein deficiency through supplementation with other stable rich foods can be successful as consumers are already familiar with the taste, appearance, texture and aroma.

5.7 Implications of adding Bambara groundnut/soybeans and ripe Plantain/Orange Flesh Sweet Potatoes on the cost of Roasted Maize Flour

An average price increase of about 50 % was observed when comparing the price of the composite flours prepared from roasted maize, Bambara groundnut and ripe plantain flours to roasted maize flour. Similarly, average price increase of over 100 % and about 16 %, was observed for the composite flours prepared from roasted maize, Bambara groundnut and orange fleshed sweet potatoes, and roasted maize, soybeans and ripe plantain flours, respectively. The rise in pricing of composite flours can be ascribed to the additional processing steps required to convert raw ingredients into flours. The high cost of Bambara groundnut and orange flesh sweet potatoes led to an increase in the price of the composite flours containing them. However, the cost contributed by Bambara groundnut and orange fleshed sweet potatoes could be lower if they find increase usage for food with enhanced production and a corresponding consumer demand.

In developing countries like Ghana, it is difficult to provide for the nutritional needs of children because of the low purchasing capacity of the general populace, with commercial cereal-based foods and supplements out of reach for many people. Furthermore, the higher nutrient richness of these commercial foods which are primarily made from milk and other animal products, encourages needless and lavish nutrient consumption (Smedman et al., 2010). Thus, finding inexpensive nutrient sources from commonly consumed local foods that are considered staples is important (Kahane et al., 2013).

Concerning helping to reduce protein under-nutrition and vitamin A deficiency in vulnerable and economically disadvantaged communities through the introduction of composite flours, it is possible that the composite flours prepared from roasted maize, soybean and ripe plantain flours can be produced at a lower cost than that reported in this study if indigenous processing steps such as sun or solar drying and traditional milling methods are employed. Thus, by incorporating soybean and ripe plantain into roasted maize flour, composite flours with different characteristics can be generated, which can be significant for influencing protein and vitamin A nutrition in Ghana and other developing countries. This shows that a food-based approach to achieving food supplementation by incorporating nutrient-rich staples into already existing diets offers the opportunity to fight malnutrition.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The study sought to improve the nutrition quality of cereal-based breakfast using local sources of staples. Maize which is one of the main sources of calories in the diet of the people of Sub-Saharan Africans was a key ingredient in every formulation used in this investigation. In Ghana, maize is a significant crop that is used in many traditional dietary systems. When combined in the right ratio with legumes, the deficiency of amino acids in cereals can be supplemented. Bambara groundnut and soybean were used to fortify the cereal-based product. Other non-cereals or legume staples that were used to fortify the cereal-based flour were orange-fleshed sweet potato and semi-ripe plantain. They were added because of their high concentration of polyphenols, carotenoids, antioxidants, dietary fibre, vitamins A and C, and minerals like potassium, magnesium, selenium, zinc, manganese, iron, B-complex vitamins, and other nutrients that can help treat anaemia and vitamin A deficiencies.

Three (3) groups of composite flours were prepared from the flours obtained from the raw materials. Each of the three groups contained roasted maize flour (M_{100}), a vitamin A-rich source [either ripe plantain flour (P_{100}) or orange flesh sweet potatoes flour (O_{100})] and a protein-rich source [either Bambara groundnut flour (B_{100}) or soybeans flour (S_{100})]. The first group of composite flours were prepared from roasted maize flour, Bambara groundnut flour and ripe plantain flour, while the second group was prepared from roasted maize flour, orange flesh sweet potato flour and Bambara groundnut flour. The last group of composite flours were prepared from roasted maize flour, ripe plantain flour and soybeans flour.

Composite flours were prepared by mixing the flours according to the ratios that were generated based on a Simple Lattice Design using Design Expert with an upper and lower limit of 50 and 25%, respectively, for each flour. The composite flours prepared from roasted maize flour, ripe plantain flour and Bambara groundnut flour was designated as $M_XB_YP_Z$, while that prepared from roasted maize flour, orange flesh sweet potatoes flour and Bambara groundnut flour was designated as $M_XB_YO_Z$, and that from roasted maize flour, ripe plantain flour and soybeans flour was designated as $M_XS_YP_Z$, where the subscripts X, Y and Z represents the fraction of each component in the mixture.

The nutritional content, functional properties, physicochemical and phytochemical properties, and anti-nutrient content) of the three (3) groups of composite flours were investigated. The consumer acceptability of porridge prepared from the flours was also determined by sensory evaluation. The change in the cost or price of the composite flours was determined.

6.2 Summary of key findings

The combination of cereals and legume-based food helped to increase the protein content because most legumes have high protein contents. Their addition improved the nutritional protein, beta-carotene content and some minerals of the product which can be consumed by people of all ages especially children to lessen the malnutrition cases.

Although most legumes have antinutritional properties like oxalate, phytate, tannins and polyphenolic compounds, they were reduced to levels that are not harmful to human beings by roasting the soybean and by boiling and dulling the Bambara groundnut.

Composite flours containing the ripe plantain cooked at a much faster rate than the composite flours containing orange-fleshed sweet potatoes because they had low pasting temperatures. Upon cooking and cooling, the composite flours of roasted maize, Bambara groundnuts and orange-fleshed sweet potatoes showed low peak viscosities. No observable pattern was seen in changes in breakdown viscosity.

The scores on the sensory attributes (aroma, taste, texture, acceptability, and appearance) were all high. The processing steps in making the flours from raw material and high cost of Bambara groundnut and orange-fleshed sweet potatoes contributed to an increase in prices of the composite flours.

6.3 Conclusion

In this study, roasted maize porridge was used as a medium to help address issues of vitamin A and protein deficiencies through a food-based approach (food-to-food fortification) towards addressing nutritional deficiencies by adding local and available rich sources of vitamin A (ripe plantain or orange flesh sweet potatoes) and protein (Bambara groundnuts or soybeans).

The addition of Bambara groundnut and ripe plantain to roasted maize resulted in composite flours with increased protein, β-carotene (a vitamin A precursor) and iron content that can be used to address concerns related to protein-energy malnutrition, vitamin A deficiency and anaemia, respectively. Also, adding soybeans and ripe plantain to roasted maize flour increased protein, β-carotene, iron and fat content showing the enhanced energy content of these composite flours when using it to address vitamin A and protein deficiencies. No major changes in physicochemical quality, and functional properties were observed, indicating that these composite flours can yield similar flour properties, cooking conditions and porridge outcomes. However, an increase in viscosity was observed in these composite flours showing that less composite flour might be needed to achieve similar viscosities compared to using roasted maize flour.

Adding Bambara groundnut and orange-fleshed sweet potatoes to roasted maize flour led to increases in protein, β-carotene, zinc and phenolic content, showing that in addition to helping to alleviate vitamin A and protein deficiencies, these composite flours may have high antioxidant properties. This shows that the addition of soybeans and ripe plantain to roasted maize flour offers the opportunity to fight vitamin A and protein deficiencies in vulnerable communities.

However, changes in the functional and pasting properties of the composite flours can lead to porridges with different attributes such as a lowered viscosity which may require the use of more composite flours if similar viscosities compared to roasted maize porridge is to be achieved.

Sensory analysis comparing the acceptability of porridges prepared from the composite flours to roasted maize flour revealed no discernible differences in aroma, appearance, texture and taste. The addition of Bambara groundnut and soybean did not impart an unpleasant beany taste to the composite flours which could be attributed to the preprocessing (cooking and roasting) of the legumes before flour preparation. However, an increase in tannins was observed in the composite flours containing Bambara groundnut.

A comparison of the possible selling price of composite flours revealed that the high cost of orange flesh sweet potatoes and Bambara groundnut led to increases in the selling price of the composite flours. While the possible selling price of composite flours prepared from roasted maize, soybeans and ripe plantain increased by approximately 20 % as compared to the price of roasted maize flour, increases of more than 100 % were observed in the composite flours prepared from roasted maize, Bambara groundnut and orange fleshed sweet potatoes.

6.4 Recommendations

Based on the observations made in this study, the following recommendations are suggested:

a. Considering that roasted maize porridge serves as a weaning food for infants, it is recommended that sensory analysis of porridges prepared from the composite flours be carried out on infants and children to determine acceptability.
b. Taking into account that Bambara groundnut has been shown to contain essential amino acids such as lysine, further analysis of the amino acid profile of the composite flours can be carried out to determine the possible contribution towards achieving the recommended daily allowance of these essential amino acids.
c. The addition of the protein and vitamin A sources led to improvement in the nutritional profile of the composite, which can influence the possible growth of microorganisms, thus it is recommended that studies on the possible shelf life of the composite flours be carried out.

- The addition of soybeans led to increases in crude fat content, thus studies on packaging of the composite flours that can limit lipid rancidification is recommended.
- Taking into consideration the potential of the composite flours to help alleviate vitamin A and protein deficiency, studies on the sustainability of adopting the newly developed composite flours and the impact on the nutritional outcomes of consumers could be relevant.

REFERENCES

Abberton, M., Paliwal, R., Faloye, B., Marimagne, T., Moriam, A., & Oyatomi, O. (2022). Indigenous African Orphan Legumes: Potential for Food and Nutrition Security in SSA. *Frontiers in Sustainable Food Systems*, *6*.

Abejide, D. R., Falusi, A., Adebola, M. O., Gana, A. S., Abubakar, A., & Dangana, M. (2020). Effect Of Water Stress On Physiological Parameters of Bambara Groundnut (Vigna Subterranea (L.) Verdc.) Accessions. https://doi.org/10.33628/jpd.2020.27.1.111

Abrha, T., Girma, Y., Haile, K., Hailu, M., & Hailemariam, M. (2016). Prevalence and associated factors of clinical manifestations of vitamin a deficiency among preschool children in asgede-tsimbla rural district, north Ethiopia, a community based cross sectional study. *Archives of Public Health*, *74*(1).

Adebayo-Oyetoro, A. O., Ogundipe, O. O., & Adeeko, K. N. (2016). Quality assessment and consumer acceptability of bread from wheat and fermented banana flour. *Food Science and Nutrition*, *4*(3), 364–369. https://doi.org/10.1002/fsn3.298

Adebowale, K. O., Afolabi, T. A., & Lawal, O. S. (2017). Isolation, chemical modification and physicochemical characterisation of Bambarra groundnut (Voandzeia subterranean) starch and flour. *Elsevier*.

Adebowale, Y. A., Adeyemi, A., & Oshodi, A. A. (2005). Variability in the physicochemical, nutritional and antinutritional attributes of six Mucuna species. *Food Chemistry*, *89*(1), 37–48.

Adedayo, B. C., Anyasi, T. A., Taylor, M. J. C., Rautenbauch, F., Le Roes-Hill, M., & Jideani, V. A. (2021). Phytochemical composition and antioxidant properties of methanolic extracts of whole and dehulled Bambara groundnut (Vigna subterranea) seeds. *Scientific Reports*, *11*(1). https://doi.org/10.1038/S41598-021-93525-W

Aderonke, A. M., Fashakin, J. B., & Ibironke, S. I. (2014). Determination of mineral contents, proximate composition and functional properties of complementary diets prepared from maize, soybean and pigeon pea. *American Journal of Nutrition and Food Science, 1(3), 53-56*. http://dx.doi.org/10.12966/ajnfs.07.01.2014.

Adetola, O. Y., Onabanjo, O. O., & Stark, A. H. (2020). The search for sustainable solutions: Producing a sweet potato based complementary food rich in vitamin A, zinc and iron for infants in developing countries. *Scientific African*, *8*, e00363. https://doi.org/ 10.1016/J.SCIAF.2020.E00363

Adu-Gyamfi, C. A. (2022). An Evaluation of Glycaemic Load in the Assortments of Fufu in Ghana. *Trends Journal of Sciences Research*, *1*(1), 12–32. https://doi.org/10.31586/ujfst.2022.528

Affonfere, M., Chadare, F. J., Fassinou, F. T. K., Talsma, E. F., Linnemann, A. R., & Azokpota, P. (2021). A complementary food supplement from local food ingredients to enhance iron intake among children aged 6–59 months in Benin. *Food Science and Nutrition*, *9*(7), 3824–3835. https://doi.org/10.1002/fsn3.2358

Agbemafle, R., Esinam E., Aggor-Woananu, S., Robert, A., Samira Elsie, A.-W., & Hayford, D. (2017). Effect of Cooking Methods and Ripening Stages on the Nutritional Compositions of Plantain (Musa Paradisiaca). *International Journal of Food Science and Biotechnology*, *10*(2), 134–140.

Agume, A. S. N., Njintang, N. Y., & Mbofung, C. M. F. (2017). Effect of Soaking and Roasting on the Physicochemical and Pasting Properties of Soybean Flour. *Foods 2017, Vol. 6, Page 12*, *6*(2), 12. https://doi.org/10.3390/FOODS6020012

Agyenim-Boateng, K. G., Zhang, S., Zhang, S., Khattak, A. N., Shaibu, A., Abdelghany, A. M., Qi, J., Azam, M., Ma, C., Feng, Y., Feng, H., Liu, Y., Li, J., Li, B., & Sun, J. (2023). The nutritional composition of the vegetable soybean (maodou) and its potential in combatting malnutrition. *Frontiers in Nutrition*, *9*, 1034115. https://doi.org/10.3389/FNUT.2022.1034115/FULL

Ahmed, J., Taher, A., Mulla, M. Z., Al-Hazza, A., & Luciano, G. (2016). Effect of sieve particle size on functional, thermal, rheological and pasting properties of Indian and Turkish lentil flour. *Journal of Food Engineering*, *186*, 34–41.

Akhtar, S., Ahmed, A., Randhawa, M. A., Atukorala, S., Arlappa, N., Ismail, T., & Ali, Z. (2013). Prevalence of vitamin A deficiency in South Asia: causes, outcomes, and possible remedies. *Journal of Health, Population, and Nutrition*, *31*(4), 413–423.

Alake, O. O., Babajide, J. M., Adebowale, A. A., & Adebisi, M. A. (2016). Evaluation of physico-chemical properties and sensory attributes of cassava enriched custard powder. *Cogent Food and Agriculture*, *2*(1). https://doi.org/10.1080/23311932.2016.1246116

Alake, O., Soil, M. A.-V.-S. A. J. of P. and, & 2017, undefined. (2017). Genotypic variation and correlations between yield system traits and yield components in African landraces of bambara groundnut. *Journals.Co.ZaOC Alake, MA Ayo-VaughanSouth African Journal of Plant and Soil, 2017•journals.Co.Za*, *34*(2), 125–137. https://doi.org/10.1080/02571862.2016.1204017

Al-Mekhlafi, H. M., Al-Zabedi, E. M., Al-Maktari, M. T., Atroosh, W. M., Al-Delaimy, A. K., Moktar, N., Sallam, A. A., Abdullah, W. A., Jani, R., & Surin, J. (2013). Effects of vitamin A supplementation on iron status indices and iron deficiency anaemia: A randomized controlled trial. *Nutrients*, *6*(1), 190–206.

Amagloh, F. K. (2022). Sweetpotato-based infant foods produce porridge with lower viscosity and aflatoxin level than cereal-based complementary blends. *PLoS ONE*, *17*(10 October). https://doi.org/10.1371/journal.pone.0275593

Amagloh, F. K., Hardacre, A., Mutukumira, A. N., Weber, J. L., Brough, L., & Coad, J. (2012). A household-level sweet potato-based infant food to complement vitamin A supplementation initiatives. *Maternal & Child Nutrition*, *8*(4), 512–521.

Amankwah, E. A., Barimah, J., Nuamah, A. K. M., Oldham, J. H., & Nnaji, C. O. (2009). Formulation of weaning food from fermented maize, rice, soybean and fishmeal. *Citeseer*, *8*(11), 1747–1752. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=fe9240d540a640079fc542e29e9e73eaf5ed404a

Amoah, W. W., Kobi, D., Tabong, P. T.-N., Kukeba, M. W., Alhassan, Y., Achaliwie, F., Amoah, A., & Adugbire, A. B. (2024). Factors Contributing to Malnutrition among Children Under 5 Years at St. Elizabeth Catholic Hospital, Ahafo Hwidiem. *Clinical Medicine Insights: Pediatrics*, *18*.

Ampofo-Asiama, J., Debrah, D. T., Abakah, B., Thompson Owusu, E., Quansah, A. R., Antwi, B., Ampoforo, K. A., & Acquah, W. (2020).Phytochemical and physicochemical properties of some underutilized tropical fruits. 3(1), 1–8. www.abjournals.org *African Journal of Agriculture and Food Science*

Anand, R., Mohan, L., & Bharadvaja, N. (2022). Disease Prevention and Treatment Using β-Carotene: the Ultimate Provitamin A. In *Revista Brasileira de Farmacognosia* (Vol. 32, Issue 4, pp. 491–501). *Springer Science and Business Media Deutschland GmbH*. https://doi.org/10.1007/s43450-022-00262-w

Anderson P, Kapinga R, Zhang D, & Hermann M. (2007). Vitamin A For Africa (VITAA): An Entry Point For Promoting Orange-Fleshed Sweetpotato To Combat Vitamin A-Deficiency In Sub-Saharan Africa. 711–720.

Ani, L. S., Bakta, I. M., Suryadhi, M. A. H., & Bagiada, N. A. (2023). The comparison of effects of iron supplementation since pre-pregnant and during pregnant period on reducing iron deficiency anemia in pregnant women with mild anemia in Bali. *Bali Medical Journal*, *12*(2), 1585–1588. https://doi.org/10.15562/bmj.v12i2.4149

Annor, G., & Nagai, T. (2009). Locally Processed Roasted-Maize-Based Weaning Foods Fortified with Legumes: Factors Affecting Their Availability And Competitiveness In Accra, Ghana.

Anosike, F. C., Nwagu, K. E., Nwalo, N. F., Ikegwu, O. J., Onyeji, G. N., Enwere, E. N., & Nwoba, S. T. (2020). Functional and pasting properties of fortified complementary foods formulated from maize (Zea mays) and African yam bean (Sphenostylis stenocarpa) flours. *Legume Science*, *2*(4). https://doi.org/10.1002/leg3.62

Arise, A. K., Esan, O. T., & Famakinde, T. R. (2023). Amino acid, pasting and sensory properties of "Poundo" yam enriched with fermented Bambara groundnut flour. *Ceylon Journal of Science*, *52*(1), 83. https://doi.org/10.4038/cjs.v52i1.8107

Arise, A. K., Taiwo, G. O., & Malomo, S. A. (2020). Amino acid profile, pasting, and sensory properties of croissant snacks produced from wheat-fermented Bambara flour. *Legume Science*, *2*(4), e53. https://doi.org/10.1002/LEG3.53

Ashun, E. K. (2018). Orange fleshed sweet potato: its use in complementary infant formula.

Ayodeji, S. P. (2016). Conceptual design of a process plant for the production of plantain flour. *Cogent Engineering*, *3*(1). https://doi.org/10.1080/23311916.2016.1191743

Azam-Ali, S. N., Sesay, A., Karikari, S. K., Massawe, F. J., Aguilar-Manjarrez, J., Bannayan, M., & Hampson, K. J. (2001). Assessing the potential of an underutilized crop – a case study using bambara groundnut. *Experimental Agriculture*, *37*(4), 433–472.

Azman Halimi, R., Barkla, B. J., Mayes, S., & King, G. J. (2019). The potential of the underutilized pulse bambara groundnut (Vigna subterranea (L.) Verdc.) for nutritional food security. *Journal of Food Composition and Analysis*, *77*, 47–59.

Babatunde, R. O., Omoniwa, A. E., & Adeniyi, A. E. (2019). Orange fleshed sweet potatoes (OFSP) and productivity: the case of smallholders in Kwara State, Nigeria. *Agricultura Tropica et Subtropica*, *52*(3–4), 105–111. https://doi.org/10.2478/ATS-2019-0012

Badejo, A. A., Duyilemi, T. I., Falarunu, A. J., & Akande, O. A. (2020). Inclusion of baobab (adansonia digitata l.) fruit powder enhances the mineral composition and antioxidative potential of processed tigernut (cyperus esculentus) beverages. *Preventive Nutrition and Food Science*, *25*(4), 400.

Banti, M., & Bajo, W. (2020). Review on Nutritional Importance and Anti-nutritional Factors of Legumes. *International Journal of Nutrition and Food Sciences*, *9*(6), 138.

Barroso Da Silva, F. L., Carloni, P., Cheung, D., Cottone, G., Donnini, S., Foegeding, E. A., Gulzar, M., Jacquier, J. C., Lobaskin, V., Mackernan, D., Mohammad Hosseini Naveh, Z., Radhakrishnan, R., & Santiso, E. E. (2020). Understanding and Controlling Food Protein Structure and Function in Foods: Perspectives from Experiments and Computer Simulations. *Annual Review of Food Science and Technology*, *11*(Volume 11, 2020), 365–387. https://doi.org/10.1146/ANNUREV-FOOD-032519-051640/CITE/REFWORKS

Bastos Maia, S., Costa Caminha, M. de F., Lins da Silva, S., Rolland Souza, A. S., Carvalho dos Santos, C., & Batista Filho, M. (2018). The Prevalence of Vitamin A Deficiency and Associated Factors in Pregnant Women Receiving Prenatal Care at a Reference Maternity Hospital in Northeastern Brazil. *Nutrients 2018, Vol. 10, Page 1271*, *10*(9), 1271. https://doi.org/10.3390/NU10091271

Batool, R., Butt, M. S., Sultan, M. T., Saeed, F., & Naz, R. (2015). Protein-Energy Malnutrition: A Risk Factor for Various Ailments. Critical Reviews *in Food Science and Nutrition*, *55*(2), 242–253. https://doi.org/10.1080/10408398.2011.651543

Bello, T. O., Bresciani, A. E., Oller Nascimento, C. A., & Brito Alves, R. M. (2021). Systematic Screening of Ionic Liquids for the Hydrogenation of Carbon Dioxide to Formic Acid and Methanol. *Industrial and Engineering Chemistry Research*, *60*(47), 17195–17206.

Benjamin, O., & Lappin, S. L. (2022). Kwashiorkor. *StatPearls*. https://www.ncbi.nlm.nih.gov/books/NBK507876/

Bentley, D. (2003). CHILDREN | Nutritional Problems. *Encyclopedia of Food Sciences and Nutrition*, 1151–1157.

Berchie, J., Dapaah, H., Agyeman, A., Sarkodie-Addo, J., Addo, J., Addy, S., & Blankson, E. (2016). Performance of five bambara groundnut (Vigna subterranea (L.) Verdc.) landraces in the trasition agroecology of Ghana under different sowing dates. *Agricultural and Food Science Journal of Ghana*, *9*, 718–729. https://www.ajol.info/index.php/afsjg/article/view/146729

Bhutia, D. T. (2014). Protein Energy Malnutrition in India: The Plight of Our Under Five Children. *Journal of Family Medicine and Primary Care*, *3*(1), 63. https://doi.org/10.4103/2249-4863.130279

Biswas, A. K., Sahoo, J., & Chatli, M. K. (2011). A simple UV-Vis spectrophotometric method for determination of β-carotene content in raw carrot, sweet potato and supplemented chicken meat nuggets. *LWT-Food Science and Technology*, *44*(8), 1809-1813.

Blaker, K. M., Plotto, A., Baldwin, E. A., & Olmstead, J. W. (2014). Correlation between sensory and instrumental measurements of standard and crisp-texture southern highbush blueberries (Vaccinium corymbosum L. interspecific hybrids). *Journal of the Science of Food and Agriculture*, *94*(13), 2785–2793. https://doi.org/10.1002/jsfa.6626

Blaner, W. S. (2020). Vitamin A and provitamin A carotenoids. *Present Knowledge in Nutrition*, 73–91. https://doi.org/10.1016/B978-0-323-66162-1.00005-6

Blomme, G., Ocimati, W., Nabuuma, D., Sivirihauma, C., Davey, M., Buah, S., Van den Bergh, I., Vutseme, L., Bahati, L., & Ekesa, B. (2020). Pro-vitamin A carotenoid content of 48 plantain (Musa AAB genome) cultivars sourced from eastern Democratic Republic of Congo. *Journal of the Science of Food and Agriculture*, *100*(2), 634–647. https://doi.org/10.1002/jsfa.10058

Bolarin, F. M., Akande, E. A., & Oke, M. O. (2022). Effects Of Processing Methods on The Yield, Functional and Pasting Properties Of "Garri Analogue" Produced From Different Varieties Of Orange Flesh Sweet Potato. *Food Science*, *6*(1), 53-68.

Booth, S. L., Johns, T., & Kuhnlein, H. V. (1992). Natural Food Sources of Vitamin A and Provitamin A. *Food and Nutrition Bulletin*, *14*(1), 1–15. https://doi.org/10.1177/156482659201400115

Buisson, D. (1995). Developing new products for the consumer. *Food choice and the consumer*, 182-215.

Burri, B. J. (2011). Evaluating Sweet Potato as an Intervention Food to Prevent Vitamin A Deficiency. *Comprehensive Reviews in Food Science and Food Safety*, *10*(2), 118–130.

Buzigi, E., Pillay, K., & Siwela, M. (2022). Potential of pumpkin to combat vitamin A deficiency during complementary feeding in low- and middle-income countries: variety, provitamin A carotenoid content and retention, and dietary reference intakes. *Critical Reviews in Food Science and Nutrition*, *62*(22), 6103–6112. https://doi.org/10.1080/ 10408398.2021.1896472

Calvin, O., & George, W. W. (2018). Quality of porridge from sub-Saharan Africa evaluated using instrumental techniques and descriptive sensory lexicon - Part 1: Thick (stiff) porridge. *African Journal of Food Science*, *12*(4), 86–96.

Carazo, A., Macáková, K., Matoušová, K., Krčmová, L. K., Protti, M., & Mladěnka, P. (2021). Vitamin A update: Forms, sources, kinetics, detection, function, deficiency, therapeutic use and toxicity. In *Nutrients* (Vol. 13, Issue 5). MDPI AG.

Carbonel, A. A. F., Simões, R. S., Sasso, G. D. S., Vieira, R. R., Lima, P. A., Simões, M. D. J., & Soares, J. M. (2022). May isoflavones prevent breast cancer risk? *Revista Da Associação Médica Brasileira*, *68*(11), 1487. https://doi.org/10.1590/1806-9282.2EDI TR11

Carey, E., Hangenimana, V., K'Osambo, L., Oyunga, Benesi, I., Smit, N. E. J. M., P'Obwoya, C. O., Turyamureeba, G., Ndolo, P., & Low, J. (2000). Using orange fleshed sweet potato varieties to combat vitamin A deficiency and enhance market opportunities for smallholder farmers in sub-Saharan Africa.

Carey, E. E., Oyunga, M. A., Turyamureeba, G., Hagenimana, V., Region, S. A., Box, P. O., & Agricultural, N. (1995). Using orange-fleshed sweetpotato varieties to combat vitamin A deficiency and enhance market opportunities for smallholder farmers in sub-Saharan Africa. *1995*, 1–16.

Chadare, F. J., Idohou, R., Nago, E., Affonfere, M., Agossadou, J., Fassinou, T. K., Kénou, C., Honfo, S., Azokpota, P., Linnemann, A. R., & Hounhouigan, D. J. (2019). Conventional and food-to-food fortification: An appraisal of past practices and lessons learned. In *Food Science and Nutrition* (Vol. 7, Issue 9, pp. 2781–2795). Wiley-Blackwell. https://doi.org/10.1002/fsn3.1133

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. https://doi.org/10.1007/s13197-014-1427-2

Chassy, B. M. (2009). Global regulation of transgenic crops. *Biotechnology in Agriculture and Forestry*, *63*, 107–124. https://doi.org/10.1007/978-3-540-68922-5_9

Cheynier, V. (2012). Phenolic compounds: From plants to foods. *Phytochemistry Reviews*, *11*(2–3), 153–177.

Cichońska, P., & Ziarno, M. (2022). Legumes and Legume-Based Beverages Fermented with Lactic Acid Bacteria as a Potential Carrier of Probiotics and Prebiotics. *Microorganisms*, *10*(1). https://doi.org/10.3390/MICROORGANISMS10010091

Claudine Mbame, M., Tiencheu, B., Feumba, R., Deffo Tiepma, F., Oben Ashu, A., Aduni Ufuan, A., Gabin Kingue Azantsa, B., & Oben, J. (2021). Formulation of Adequate Complementary Food for Children 6–24 Months Using Local Staple Foods in the South-west Region of Cameroon. *European Journal of Nutrition & Food Safety*, 89–108. https://doi.org/10.9734/ejnfs/2021/v13i1230471

Coulthard, M. G. (2015). Oedema in kwashiorkor is caused by hypoalbuminaemia. *Paediatrics and International Child Health*, *35*(2), 83. https://doi.org/10.1179/2046905514Y.0000000154

Cserhalmi, Z., Sass-Kiss, Á., Tóth-Markus, M., & Lechner, N. (2006). Study of pulsed electric field treated citrus juices. *Innovative Food Science & Emerging Technologies*, *7*(1–2), 49–54.

D'Ambrosio, D. N., Clugston, R. D., & Blaner, W. S. (2011). Vitamin A Metabolism: An Update. *Nutrients 2011, Vol. 3, Pages 63-103*, *3*(1), 63–103. https://doi.org/10.3390/NU3010063

D'Angelo, A., & Goldman, I. L. (2023). Temporal Accumulation of Geosmin, Oxalic Acid, and Total Dissolved Solids in Table Beet. *HortScience*, *58*(9), 974-982.

Dadzie, R. G., Amoah, R. S., Ampofo-Asiama, J., Quaye, B., Kizzie-Hayford, N., & Abano, E. E. (2021). Improving the storage quality of eggplants (solanum Aethiopicum L.) fruit using aloe Vera gel coating. *Journal of Food Technology Research*, *8*(2), 58-66.

Damilola Jenfa, M., Oluwasola, |, Adelusi, A., Aderinoye, | Aderonke, Oluwafemi, |, Coker, J., Itohan, |, Martins, E., Olusegun, |, & Obadina, A. (2024). Physicochemical compositions, nutritional and functional properties, and color qualities of sorghum–orange-fleshed sweet potato composite flour. *Wiley Online Library*, *12*(4), 2364–2378. https://doi.org/10.1002/fsn3.3922

Darnton-Hill, I., Bloem, M. W., De Benoist, B., & Brown, L. R. (2002). Micronutrient restoration and fortification: Communicating change, benefits and risks. *Asia Pacific Journal of Clinical Nutrition*, *11*(SUPPL. 6), S184–S196.

Dauda, A. O., Kayode, R. M. O., & Salami, K. O. (2020). Quality attributes of snack made from maize substituted with groundnut. *Ceylon J. Sci*, *49*, 21-27. https://doi.org/10.4038/cjs.v49i1.7702

David, P. (2003). Evaluating the Vitamin A Supplementation Programme in northern Ghana: Has it contributed to improved child survival. *Micronutrient Initiative and JSI: Boston, MA, USA*.

De Brauw, A., Moursi, M., & Munhaua, A. B. (2019). Vitamin A intakes remain higher among intervention participants 3 years after a biofortification intervention in Mozambique. *British Journal of Nutrition*, *122*(10), 1175–1181.

De, P., & Chattopadhyay, N. (2019). Effects of malnutrition on child development: Evidence from a backward district of India. *Clinical Epidemiology and Global Health*, *7*(3), 439–445. https://doi.org/10.1016/j.cegh.2019.01.014

Dereje, B., Girma, A., Mamo, D., & Chalchisa, T. (2020). Functional properties of sweet potato flour and its role in product development: a review. In *International Journal of Food Properties* (Vol. 23, Issue 1, pp. 1639–1662). Bellwether Publishing, Ltd. https://doi.org/10.1080/10942912.2020.1818776

Desire, M. F., Blessing, M., Elijah, N., Ronald, M., Agather, K., Tapiwa, Z., Florence, M. R., & George, N. (2021). Exploring food fortification potential of neglected legume and oil seed crops for improving food and nutrition security among smallholder farming communities: A systematic review. *Journal of Agriculture and Food Research*, *3*(March 2020), 100117.

Desmawati, D., & Sulastri, D. (2019). Phytoestrogens and Their Health Effect. *Open Access Macedonian Journal of Medical Sciences*, *7*(3), 495. https://doi.org/10.3889/OAMJMS.2019.086

Devi, R., Singh, A., Dutta, D., & Sit, N. (2024). Physicochemical properties of barley starch and effect of substitution of wheat flour with barley starch on texture and sensory properties of bread. *EFood*, *5*(1). https://doi.org/10.1002/efd2.132

Dhulse, P., Maurya, A., & Wanjari, M. B. (2023). Assessment of Serum Vitamin D Status and Its Associated Health Problem Among Children with Protein Energy Malnutrition: A Cross-Sectional Research Study in Central Rural India. *Cureus*, *15*(4). https://doi.org/10.7759/CUREUS.37859

Drake, M. A., Miracle, R. E., & Wright, J. M. (2014). Sensory properties of dairy proteins. In *Milk proteins* (pp. 473-492). Academic Press. https://www.sciencedirect.com/science/article/pii/B9780124051713000167

Drake, M. A., Watson, M. E., & Liu, Y. (2023). *Sensory Analysis and Consumer Preference: Best Practices*.

Dukhi, N., & Dukhi, N. (2020). Global Prevalence of Malnutrition: Evidence from Literature. *Malnutrition*.

Duraiswamy, A., Sneha A, N. M., Jebakani K, S., Selvaraj, S., Pramitha J, L., Selvaraj, R., Petchiammal K, I., Kather Sheriff, S., Thinakaran, J., Rathinamoorthy, S., & Kumar P, R. (2023). Genetic manipulation of anti-nutritional factors in major crops for a sustainable diet in future. In *Frontiers in Plant Science* (Vol. 13). Frontiers Media S.A. https://doi.org/10.3389/fpls.2022.1070398

Ebert, A. W., Chang, C. H., Yan, M. R., & Yang, R. Y. (2017). Nutritional composition of mungbean and soybean sprouts compared to their adult growth stage. *Food Chemistry*, *237*, 15–22. https://doi.org/10.1016/J.FOODCHEM.2017.05.073

Edhborg, M., Seimyr, L., Lundh, W., & Widstrom, A. M. (2000). Fussy child-difficult parenthood? Comparisons between families with a "depressed" mother and non-depressed mother 2 monnths postpartum. *Journal of Reproductive and Infant Psychology*, *18*(3), 225–238. https://doi.org/10.1080/713683036

Ejoh, N., & Onyeulo, C. G. (2022). Roasting's Effects on Proximate and Amino Acid Content of Maize. *Indonesian Journal of Agricultural Research*, *5*(01), 1–10. https://doi.org/10.32734/injar.v5i01.6580

Englberger, L., Schierle, J., Aalbersberg, W., Hofmann, P., Humphries, J., Huang, A., Lorens, A., Levendusky, A., Daniells, J., Marks, G. C., & Fitzgerald, M. H. (2006). Carotenoid and vitamin content of Karat and other Micronesian banana cultivars. *International Journal of Food Sciences and Nutrition*, *57*(5–6), 399–418. https://doi.org/10.1080/09637480600872010

Ennis, J. M., Rousseau, B., & Ennis, D. M. (2014). Sensory difference tests as measurement instruments: A review of recent advances. *Journal of Sensory Studies*, *29*(2), 89-102.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security*, *14*(5), 1295–1319. https://doi.org/10.1007/S12571-022-01288-7

Faber, M., Laurie, S. M., & Jaarsveld, P. J. van. (2013). Total β-carotene content of orange sweetpotato cultivated under optimal conditions and at a rural village. *African Journal of Biotechnology*, *12*(25), 3947–3951. https://doi.org/10.5897/AJB2013.12380

Fatemi, S. F., Irankhah, K., Kruger, J., Bruins, M. J., & Sobhani, S. R. (2023). Implementing micronutrient fortification programs as a potential practical contribution to achieving sustainable diets. *Nutrition Bulletin*, *48*(3), 411–424.

Feldman, A. B., Ho, W. K., Massawe, F., & Mayes, S. (2019). Bambara Groundnut is a Climate-Resilient Crop: How Could a Drought-Tolerant and Nutritious Legume Improve Community Resilience in the Face of Climate Change? *Sustainable Solutions for Food Security: Combating Climate Change by Adaptation*, 151–167. https://doi.org/10.1007/978-3-319-77878-5_8

Feroze, K. B., & Kaufman, E. J. (2022). Xerophthalmia. *StatPearls*. https://www.ncbi.nlm.nih.gov/books/NBK431094/

Fetriyuna, F., Purwestri, R. C., Jati, I. R. A. P., Setiawan, B., Huda, S., Wirawan, N. N., & Andoyo, R. (2023). Ready-to-use therapeutic/supplementary foods from local food resources: Technology accessibility, program effectiveness, and sustainability, a review. In *Heliyon* (Vol. 9, Issue 12). Elsevier Ltd. https://doi.org/10.1016/j.heliyon.2023.e22478

Fetuga, G., Tomlins, K., Henshaw, F., & Idowu, M. (2014). Effect of variety and processing method on functional properties of traditional sweet potato flour ("elubo") and sensory acceptability of cooked paste ("amala"). *Food Science & Nutrition*, *2*(6), 682. https://doi.org/10.1002/FSN3.161

Gangadharan, A., Choi, S. E., Hassan, A., Ayoub, N. M., Durante, G., Balwani, S., Kim, Y. H., Pecora, A., Goy, A., & Suh, K. S. (2017). Protein calorie malnutrition, nutritional intervention and personalized cancer care. *Oncotarget*, *8*(14), 24009. https://doi.org/10.18632/ONCOTARGET.15103

García-Villanova, R., García-Villanova, R. J., & De Lope, C. R. (1982). Determination of phytic acid by complexometric titration of excess of iron (III). *Analyst*, *107*(1281), 1503-1506.

Gemede, H. F. (2020). Nutritional and antinutritional evaluation of complementary foods formulated from maize, pea, and anchote flours. *Food Science & Nutrition*, *8*(4), 2156–2164. https://doi.org/10.1002/FSN3.1516

Girard, A. W., Brouwer, A., Faerber, E., Grant, F. K., & Low, J. W. (2021). Orange-fleshed sweetpotato: Strategies and lessons learned for achieving food security and health at scale in Sub-Saharan Africa. *Open Agriculture*, *6*(1), 511–536. https://doi.org/10.1515/OPAG-2021-0034/HTML

Girard, A. W., Grant, F., Watkinson, M., Okuku, H. S., Wanjala, R., Cole, D., Levin, C., & 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.

Godswill Awuchi, C., Kate Echeta, C., Godswill, C., Somtochukwu, V., & Kate, C. (2019). The Functional Properties of Foods and Flours. In *International Journal of Advanced Academic Research | Sciences* (Vol. 5, Issue 11).

Godswill, C. (2019). Proximate Composition and Functional Properties of Different Grain Flour Composites for Industrial Applications. In *International Journal of Food Sciences* (Vol. 2, Issue 4). www.iprjb.org

Gomes, S., & Lopes, J. M. (2022). Evolution of the Online Grocery Shopping Experience during the COVID-19 Pandemic: Empiric Study from Portugal. *Journal of Theoretical and Applied Electronic Commerce Research*, *17*(3), 909–923. https://doi.org/10.3390/jtaer17030047

Green, M. H., Lopez-Teros, V., Avila-Prado, J., & Green, J. B. (2024). Use of Theoretical Women and Model-Based Compartmental Analysis to Evaluate the Impact of Vitamin A Intake with or without a Daily Vitamin A Supplement on Vitamin A Total Body Stores and Balance During Lactation. *The Journal of Nutrition*. https://doi.org/10.1016/J.TJNUT.2024.06.001

Greenberg, J. A., Bell, S. J., Guan, Y., & Yu, Y. (2011). Folic Acid Supplementation and Pregnancy: More Than Just Neural Tube Defect Prevention. *Reviews in Obstetrics and Gynecology*, *4*(2), 52. https://doi.org/10.18370/2309-4117.2017.34.57-63

Greiner, T. (2013). Vitamin A: Moving the food-based approach forward. *FAO and WHO*. www.fao.org/publications

Grieshop, C. M., & Fahey, G. C. (2001). Comparison of Quality Characteristics of Soybeans from Brazil, China, and the United States. *Journal of Agricultural and Food Chemistry*, *49*(5), 2669–2673. https://doi.org/10.1021/JF0014009

Grieshop, C. M., Kadzere, C. T., Clapper, G. M., Flickinger, E. A., Bauer, L. L., Frazier, R. L., & Fahey, G. C. (2003). Chemical and nutritional characteristics of United States soybeans and soybean meals. *ACS Journal of Agricultural and Food Chemistry, 2003•ACS Publications*, *51*(26), 7684–7691.https://doi.org/10.1021/jf034690c

Grover, Z., & Ee, L. C. (2009). Protein Energy Malnutrition. *Pediatric Clinics of North America*, *56*(5), 1055–1068. https://doi.org/10.1016/j.pcl.2009.07.001

Gupta, R. K., Gangoliya, S. S., & Singh, N. K. (2015). Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of Food Science and Technology*, *52*(2), 676. https://doi.org/10.1007/S13197-013-0978-Y

Gurmu, F., Hussein, S., & Laing, M. (2014). The Potential of Orange-Fleshed Sweet Potato to Prevent Vitamin A Deficiency in Africa. *Https://Doi.Org/10.1024/0300-9831/A000194*, *84*(1–2), 65–78. https://doi.org/10.1024/0300-9831/A000194

Gutowska, K., Formanowicz, D., & Formanowicz, P. (2022). Interrelations between Iron and Vitamin A—Studied Using Systems Approach. *International Journal of Molecular Sciences*, *23*(3). https://doi.org/10.3390/ijms23031189

Haskell, M. J. (2012). The challenge to reach nutritional adequacy for vitamin A: β-carotene bioavailability and conversion - Evidence in humans. In *American Journal of Clinical Nutrition* (Vol. 96, Issue 5). https://doi.org/10.3945/ajcn.112.034850

Haskell, M. J., Jamil, K. M., Jamil, M., Peerson, J. M., Keenan, A. H., Newman, J. W., & Brown, K. H. (2012). Daily consumption of orange-fleshed sweet potato increased plasma beta-carotene concentration but did not increase total body vitamin A pool size in Bangladeshi women. *The FASEB Journal*, *26*(S1), 1031.3-1031.3. https://doi.org/10.1096/FASEBJ.26.1_SUPPLEMENT.1031.3

Hasmadi, M., Noorfarahzilah, M., Noraidah, H., Zainol, M. K., & Jahurul, M. H. A. (2020). Functional properties of composite flour: A review. In *Food Research* (Vol. 4, Issue 6, pp. 1820–1831). Rynnye Lyan Resources. https://doi.org/10.26656/fr.2017.4(6).419

Hendebo, M., Ibrahim, A. M., Gurmu, F., & Beshir, H. M. (2022). Assessment of Production and Utilization Practices of Orange-Fleshed Sweet Potatoes (Ipomoea Batatas L.) in Sidama Region, Ethiopia. *International Journal of Agronomy*, *2022*, 1–10. https://doi.org/10.1155/2022/4922864

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

Hill, Z., Kirkwood, B., Kendall, C., Adjei, E., Arthur, P., & Agyemang, C. T. (2007). Factors that affect the adoption and maintenance of weekly vitamin A supplementation among women in Ghana. *Public Health Nutrition*, *10*(8), 827–833.

Hodge, C., & Taylor, C. (2023). Vitamin A Deficiency. *Clinical and Experimental Optometry*, *77*(2), 76–77.

Hombali, A. S., Solon, J. A., Venkatesh, B. T., Nair, N. S., & Peña-Rosas, J. P. (2019). Fortification of staple foods with vitamin a for vitamin a deficiency. In *Cochrane Database of Systematic Reviews* (Vol. 2019, Issue 5). *John Wiley and Sons Ltd.*

Honfo, Fernande G., A. P. Polycarpe Kayodé, Ousmane Coulibaly, and Abdou Tenkouano. 2007. "Relative Contribution of Banana and Plantain Products to the Nutritional Requirements for Iron, Zinc and Vitamin A of Infants and Mothers in Cameroon." *Fruits* 62(5): 267–77. doi: 10.1051/fruits:2007023

Honi, B., Mukisa, I. M., & Mongi, R. J. (2018). Proximate composition, provitamin A retention, and shelf life of extruded, orange-fleshed sweet potato and bambara groundnut-based snacks. *Journal of Food Processing and Preservation*, *42*(1).

Ibeanu, V., Onyechi, U., Ani, P., & Ohia, C. (2016). Composition and sensory properties of plantain cake. *African Journal of Food Science*, *10*(2), 25–32. https://doi.org/10.5897/AJFS2015.1292

Ibrahim, A. G., Ayo, J. A., & Joseph, H. M. (2021). Effects of orange-fleshed sweet potato supplementation on the phytochemical composition, physicochemical, and sensory properties of sorghum-based kunu-zaki. *Research Journal of Food Science and Nutrition*, *6*(3), 22–29. https://doi.org/10.31248/RJFSN2021.122

Ikegwu, O. J., & Ekwu, F. C. (2010). Use of response surface methodology in predicting the apparent viscosity of 'Achi'Brachystegia spp Flour. *Pakistan Journal of Nutrition*, *9*(7), 720-723.

Iorember, F. M. (2018). Malnutrition in chronic kidney disease. *Frontiers in Pediatrics*, *6*, 379132.

Islam, S. N., Nusrat, T., Begum, P., & Ahsan, M. (2016). Carotenoids and β-carotene in orange fleshed sweet potato: A possible solution to vitamin A deficiency. *Food Chemistry*, *199*, 628-631.

Jamil, K. M., Brown, K. H., Jamil, M., Peerson, J. M., Keenan, A. H., Newman, J. W., & Haskell, M. J. (2012). Daily Consumption of Orange-Fleshed Sweet Potato for 60 Days Increased Plasma β-Carotene Concentration but Did Not Increase Total Body Vitamin A Pool Size in Bangladeshi Women, *The Journal of Nutrition*, *142*(10), 1896–1902. https://doi.org/10.3945/JN.112.164830

Jemberu, Y., Zegeye, M., Singh, P., & Abebe, H. (2016). Formulation of Maize – Based Complementary Porridge Using Orange - Fleshed Sweet Potato and Bean Flour for Children Aged 6-23 Months in Kachabira Woreda, *6*(4), 87–101.

Jitngarmkusol, S., Hongsuwankul, J., & Tananuwong, K. (2008). Chemical compositions, functional properties, and microstructure of defatted macadamia flours. *Food chemistry*, *110*(1), 23-30.

Joshi, A. U., Liu, C., & Sathe, S. K. (2015). Functional properties of select seed flours. *LWT - Food Science and Technology*, *60*(1), 325–331. https://doi.org/10.1016/J.LWT.2014.08.038

Joy, G.-F. F., A, J.-A. Y., Sunday, O. Z., Remilekun, A., & Olusegun, A. D. (2022). Waste-to-wealth; nutritional potential of five selected fruit peels and their health benefits: A review. *African Journal of Food Science*, *16*(7), 172–183.

Julianti, E., Rusmarilin, H., Ridwansyah, & Yusraini, E. (2017). 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. https://doi.org/10.1016/J.JSSAS.2015.05.005

Kahane, R., Hodgkin, T., Jaenicke, H., Hoogendoorn, C., Hermann, M., Dyno Keatinge, J. D. H., D'Arros Hughes, J., Padulosi, S., & Looney, N. (2013). Agrobiodiversity for food security, health and income. *Agronomy for Sustainable Development*, *33*(4), 671–693. https://doi.org/10.1007/S13593-013-0147-8

Kalumbi, M., Matumba, L., Mtimuni, B., Mwangwela, A., & Gama, A. P. (2019). Hydrothermally treated soybeans can enrich maize stiff porridge (Africa's main staple) without negating sensory acceptability. *Foods*, *8*(12). https://doi.org/10.3390/foods8120650

Keats, E. C., Neufeld, L. M., Garrett, G. S., Mbuya, M. N. N., & Bhutta, Z. A. (2019). Improved micronutrient status and health outcomes in low- and middle-income countries following large-scale fortification: evidence from a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*, *109*(6), 1696–1708. https://doi.org/10.1093/AJCN/NQZ023

Ketiku, A. O. (1973). Chemical composition of unripe (green) and ripe plantain (musa paradisiaca). *Journal of the Science of Food and Agriculture*, *24*(6), 703–707.

Key, T. J., Davey, G. K., & Appleby, P. N. (1999). Health benefits of a vegetarian diet. *Proceedings of the Nutrition Society*, *58*(2), 271–275. https://doi.org/10.1017/S0029665199000373

Khalid, S., Aslam, M., Syed, F., Imran, M., Saad, B., & Noreen, S. (2020). An insight to Vitamin A: A neglected vitamin. *EAS Journal of Nutrition and Food Sciences* https://doi.org/10.36349/easjnfs.2020.v02i03.005

Khan, N. C. (2006). The role of plant food sources in controlling vitamin A deficiency in Vietnam. In *Doctoral dissertation*.

Koala, M., Hema, A., Spina, R., Palé, E., Dupire, F., Françoise, C., ... & Laurain-Mattar, D. (2018). Orange-Fleshed Sweetpotato Flour: Characterization of Carotenoids and Conservation. *Agricultural and Food Science Journal of Ghana*, *11*, 909-914.

Korese, J. K., Chikpah, S. K., Hensel, O., Pawelzik, E., & Sturm, B. (2021). Effect of orange-fleshed sweet potato flour particle size and degree of wheat flour substitution on physical, nutritional, textural and sensory properties of cookies. *European Food Research and Technology*, *247*(4), 889–905. https://doi.org/10.1007/s00217-020-03672-z

Koubala, B. B., Gonné, S., Félix-Alain, W., & Benoî, K. B. (2013). Assessment of Twenty Bambara Groundnut (Vigna subterranea (L.) Verdcourt) Landraces using Quantitative Morphological Traits. *International Journal of Plant Research*, *2013*(3), 39–45. https://doi.org/10.5923/j.plant.20130303.04

Kruger, J., Taylor, J. R. N., Ferruzzi, M. G., & Debelo, H. (2020). What is food-to-food fortification? A working definition and framework for evaluation of efficiency and implementation of best practices. In *Comprehensive Reviews in Food Science and Food Safety* (Vol. 19, Issue 6, pp. 3618–3658). Blackwell Publishing Inc.

Kulu, N. N. (2022). Analysis of starch metabolism in South African pigeon pea (Cajanus cajan) varieties.

Kumar, A., Singh, B., Raigond, P., Sahu, C., Mishra, U. N., Sharma, S., & Lal, M. K. (2021). Phytic acid: Blessing in disguise, a prime compound required for both plant and human nutrition. *Food Research International*, *142*, 110193.

Kumar, P., Chatli, M. K., Mehta, N., Singh, P., Malav, O. P., & Verma, A. K. (2017). Meat analogues: Health promising sustainable meat substitutes. *Critical Reviews in Food Science and Nutrition*, *57*(5), 923–932. https://doi.org/10.1080/10408398.2014.939739

Kwofie, M. K., Sarpong, M. A., Anima, F., Bukari, N., & Adeboye, O. (2020). The Use of Ripe Plantain (<i>Musa spp</i>.) and Peppercorns for Beverage Processing as a Pro-Vitamin A Carotenoid and Nutrition Catalyst. *Food and Nutrition Sciences*, *11*(12), 1096–1106. https://doi.org/10.4236/fns.2020.1112077

Lanham-New, S. A., Lambert, H., & Frassetto, L. (2012). Potassium. *Advances in nutrition*, *3*(6), 820-821.https:// advances.nutrition.org/article/S2161-8313(22)01076-6/fulltext

Lartey, S., & Armah, P. (2019). JOJ Ophthalmol Vitamin a Supplementation in Preschool Children. Coverage and Factors Determining Uptake in Three Districts of Ghana. *JOJ Ophthalmol*, *8*(1). https://doi.org/10.19080/JOJO.2019.08.555726

Lavoe, F. (2015). Regional Institute for Population Studies University of Ghana Determinants of Malnutrition Among Children Under the Age of Five in The Three Northern Regions of Ghana. http://ugspace.ug.edu.gh

Lawless, H. T., & Heymann, H. (2010). Sensory evaluation of food: principles and practices. Springer Science & Business Media.

Lawless, L. J. R., & Civille, G. V. (2013). Developing Lexicons: A review. *Journal of Sensory Studies*, *28*(4), 270–281.

Lee, D. Y., Schroeder, J., & Gordon, D. T. (1988). Enhancement of Cu Bioavailability in the Rat by Phytic Acid. *The Journal of Nutrition*, *118*(6), 712–717. https://doi.org/10.1093/JN/118.6.712

Leighton, C. S. (2007). *by*. *July*.

Li, M., Zhang, Y., You, X., Wang, Y., Zhou, K., Wei, P., & Wei, L. (2023). Assessment of Functional Properties of Wheat–Cassava Composite Flour. *Foods*, *12*(19). https://doi.org/10.3390/foods12193585

Low, J. W., Arimond, M., Osman, N., Cunguara, B., Zano, F., & Tschirley, D. (2007). A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *The Journal of Nutrition*, *137*(5), 1320–1327.

Madhavan Nair, K., & Augustine, L. F. (2018). Food fortification and dietary diversification as effective interventions to improve iron status of indian population. In *Proceedings of the Indian National Science Academy* (Vol. 84, Issue 4, pp. 891–897). Indian National Science Academy. https://doi.org/10.16943/ptinsa/2018/49445

Majola, N. G., Gerrano, A. S., & Shimelis, H. (2021). Bambara Groundnut (Vigna subterranea [L.] Verdc.) Production, Utilisation and Genetic Improvement in Sub-Saharan Africa. *Agronomy 2021, Vol. 11, Page 1345*, *11*(7), 1345.

Mannar, M. G. V., & Wesley, A. S. (2016). Food Fortification. In *International Encyclopedia of Public Health* (pp. 143–152). Elsevier Inc. https://doi.org/10.1016/B978-0-12-803678-5.00160-0

Maphosa, Y., & Jideani, V. A. (2017). The Role of Legumes in Human Nutrition. *Functional Food - Improve Health through Adequate Food*. https://doi.org/10.5772/INTECHOPEN.69127

Marathe, S. A., Rajalakshmi, V., Jamdar, S. N., & Sharma, A. (2011). Comparative study on antioxidant activity of different varieties of commonly consumed legumes in India. *Food and Chemical Toxicology*, *49*(9), 2005–2012.

Marcel, M. R., Chacha, J. S., & Ofoedu, C. E. (2022). Nutritional evaluation of complementary porridge formulated from orange-fleshed sweet potato, amaranth grain, pumpkin seed, and soybean flours. *Food Science and Nutrition*, *10*(2), 536–553. https://doi.org/10.1002/fsn3.2675

Marian, D. Q., Adelaide, A., & Beloved, M. D. (2018). Assessment of plantain (Musa sapientum L.) accessions genotypic groups relatedness using simple sequence repeats markers. *African Journal of Biotechnology*, *17*(16), 541–551. https://doi.org/10.5897/ajb2017.16363

Marques, C., Correia, E., Dinis, L. T., & Vilela, A. (2022). An Overview of Sensory Characterization Techniques: From Classical Descriptive Analysis to the Emergence of Novel Profiling Methods. In *Foods* (Vol. 11, Issue 3). MDPI. https://doi.org/10.3390/foods11030255

Marzęda, P., & Łuszczki, J. (2019). Role of vitamin A in health and illness. *Journal of Pre-Clinical and Clinical Research*, *13*(3), 137–142. https://doi.org/10.26444/jpccr/112376

Mashau, M. E., Mukwevho, T. A., Ramashia, S. E., & Siwela, M. (2022). The influence of Bambara groundnut (Vigna subterranean) flour on the nutritional, physical and antioxidant properties of steamed bread. *CyTA - Journal of Food*, *20*(1), 259–270. https://doi.org/10.1080/19476337.2022.2130435

Mauro, R. R., Vela, A. J., & Ronda, F. (2023). Impact of Starch Concentration on the Pasting and Rheological Properties of Gluten-Free Gels. Effects of Amylose Content and Thermal and Hydration Properties. *Foods*, *12*(12). https://doi.org/10.3390/foods12122281

Mayes, S., Ho, W. K., Chai, H. H., Gao, X., Kundy, A. C., Mateva, K. I., Zahrulakmal, M., Hahiree, M. K. I. M., Kendabie, P., Licea, L. C. S., Massawe, F., Mabhaudhi, T., Modi, A. T., Berchie, J. N., Amoah, S., Faloye, B., Abberton, M., Olaniyi, O., & Azam-Ali, S. N. (2019). Bambara groundnut: an exemplar underutilised legume for resilience under climate change. *Planta*, *250*(3), 803–820. https://doi.org/10.1007/S00425-019-03191-6

Mayes, S., Ho, W. K., Chai, H. H., Song, B., Chang, Y., & Massawe, F. (2019). Bambara Groundnut (Vigna Subterranea (L) Verdc)—A Climate Smart Crop for Food and Nutrition Security. *Genomic Designing of Climate-Smart Pulse Crops*, 397–424. https://doi.org/10.1007/978-3-319-96932-9_8

Mbata, T. I., Ikenebomeh, M. J., & Ezeibe, S. (2009). Evaluation of mineral content and functional properties of fermented maize (Generic and specific) flour blended with bambara groundnut (Vigna subterranean L). *African Journal of Food Science*, *3*(4), 107-112.

Mbosso, C., Boulay, B., Padulosi, S., Meldrum, G., Mohamadou, Y., Niang, A. B., Coulibaly, H., Koreissi, Y., & Sidibé, A. (2020). Fonio and Bambara Groundnut Value Chains in Mali: Issues, Needs, and Opportunities for Their Sustainable Promotion. *Sustainability 2020, Vol. 12, Page 4766*, *12*(11), 4766. https://doi.org/10.3390/SU12114766

Mbusa, H. K., Ngugi, K., Olubayo, F. M., Kivuva, B. M., Muthomi, J. W., Felister, &, & Nzuve, M. (2018). Agronomic Performance of Kenyan Orange Fleshed Sweet Potato Varieties. *Journal of Plant Studies*, *7*(2). https://doi.org/10.5539/jps.v7n2p11

Mccauley, M. E., van den Broek, N., Dou, L., & Othman, M. (2015). Vitamin A supplementation during pregnancy for maternal and newborn outcomes. *Cochrane Database of Systematic Reviews*, *2016*(3). https://doi.org/10.1002/14651858.CD008666.pub3

McClements, D., in, L. G.-C. R., & 2021, undefined. (2021). The science of plant-based foods: Constructing next-generation meat, fish, milk, and egg analogs. *Wiley Online Library*, *20*(4), 4049–4100. https://doi.org/10.1111/1541-4337.12771

Mendes, J. F. R., De Almeida Siqueira, E. M., De Brito e Silva, J. G. M., & Arruda, S. F. (2016). Vitamin A deficiency modulates iron metabolism independent of hemojuvelin (Hfe2) and bone morphogenetic protein 6 (Bmp6) transcript levels. *Genes and Nutrition*, *11*(1). https://doi.org/10.1186/s12263-016-0519-4

Merckel, K. R. (2020). Building evidence for nutrition-sensitive agriculture: the experience of introducing orange-flesh sweet potato in India. Cornell University.

Messina, M. J. (1999). Legumes and soybeans: overview of their nutritional profiles and health effects. *The American Journal of Clinical Nutrition*, *70*(3), 439S-450S.

Messina, M., Shearer, G., & Petersen, K. (2021). Soybean oil lowers circulating cholesterol levels and coronary heart disease risk and has no effect on markers of inflammation and oxidation. *Nutrition*, *89*, 111343. https://doi.org/10.1016/J.NUT.2021.111343

Messina, V. (2014). Nutritional and health benefits of dried beans. *American Journal of Clinical Nutrition*, *100*(SUPPL. 1). https://doi.org/10.3945/ajcn.113.071472

Mi, Y., & Ejeh, D. D. (2018). Production of Bambara Groundnut Substituted Whole Wheat Bread: Functional Properties and Quality Characteristics. *Journal of Nutrition & Food Sciences*, *08*(05). https://doi.org/10.4172/2155-9600.1000731

Michelfelder, A. J. (2009). Soy: a complete source of protein. *American Family Physician*, *79*(1), 43–47.

Miller, M., Humphrey, J., Johnson, E., Marinda, E., Brookmeyer, R., & Katz, J. (2002). Why do children become vitamin A deficient? *The Journal of nutrition*, *132*(9), 2867S-2880S.

Mirabelli, M., Chiefari, E., Arcidiacono, B., Corigliano, D. M., Brunetti, F. S., Maggisano, V., Russo, D., Foti, D. P., & Brunetti, A. (2020). Insulin Resistance and Related Diseases. *Nutrients*.

Moss, R., LeBlanc, J., Gorman, M., Ritchie, C., Duizer, L., & McSweeney, M. B. (2023). A Prospective Review of the Sensory Properties of Plant-Based Dairy and Meat Alternatives with a Focus on Texture. In *Foods* (Vol. 12, Issue 8). MDPI.

Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A. R. (2016). Hard-to-cook phenomenon in bambara groundnut (Vigna subterranea (L.) Verdc.) processing: Options to improve its role in providing food security. *Taylor & Francis*, *33*(2), 167–194. https://doi.org/10.1080/87559129.2016.1149864

Mubaiwa, J., Fogliano, V., Chidewe, C., & Linnemann, A. R. (2018). Bambara groundnut (Vigna subterranea (L.) Verdc.) flour: A functional ingredient to favour the use of an unexploited sustainable protein source. *PLOS ONE*, *13*(10), e0205776. https://doi.org/10.1371/JOURNAL.PONE.0205776

Müller, O., & Krawinkel, M. (2005). Malnutrition and health in developing countries. Canadian Medical Association. In *CMAJ. Canadian Medical Association Journal* (Vol. 173, Issue 3, pp. 279–286). https://doi.org/10.1503/cmaj.050342

Mune, M., Alain, M., & René, M. S. (2007). Improving the Nutritional Quality of Cowpea and Bambara Bean Flours for Use in Infant Feeding. *Pakistan Journal of Nutrition*, *6*(6), 660–664.

Murray, J. M., Delahunty, C. M., & Baxter, I. A. (2001). Descriptive sensory analysis: past, present and future. *Food research international*, *34*(6), 461-471.

Mwanga, R. O. M., & Ssemakula, G. (2011). Orange-fleshed sweetpotatoes for food, health and wealth in Uganda. *International Journal of Agricultural Sustainability*, *9*(1), 42–49. https://doi.org/10.3763/IJAS.2010.0546

Nagai, T., Staatz, J., Bernsten, R., Sakyi-Dawson, E., & Annor, G. (2009). Locally processed roasted-maize-based weaning foods fortified with legumes: Factors affecting availability and competitiveness in Accra, Ghana. *African Journal of Food, Agriculture, Nutrition and Development*, *9*(30), 1945–1965.

Nago, E., Agossadou, J. O., Chadare, F. J., Houndji, S., & Hounhouigan, D. J. (2020). Fermented sorghum porridge fortified with Moringa leaf powder and baobab fruit pulp cured children from moderate acute malnutrition in Benin. *African Journal of Food, Agriculture, Nutrition and Development*, *20*(6), 16622-16637.

Nasir, M., Anjum, F. M., Sharif, M. K., Butt, M. S., Anjum, F. M., & Minhas, R. (2003). Effect of Moisture on the Shelf Life of Wheat Flour Characterization and utilization of spirulina for food applications View project Pesticide residues and Heavy metal in vegetables Punjab Pakistan View project Effect of Moisture on the Shelf Life of Wheat Flour. In *International Journal Of Agriculture & Biology*. http://www.ijab.org

Nautiyal, P. C., Kulkarni, G., Singh, A. L., & Basu, M. S. (2017). Evaluation of water-deficit stress tolerance in Bambara groundnut landraces for cultivation in sub-tropical environments in India. *Indian Journal of Plant Physiology*, *22*(2), 190–196. https://doi.org/10.1007/S40502-017-0296-X/METRICS

Nawaz, M. A., Tan, M., Øiseth, S., & Buckow, R. (2020). An Emerging Segment of Functional Legume-Based Beverages: A Review. *Food Reviews International*, 1–39.

Nderitu, A. M., Dykes, L., Awika, J. M., Minnaar, A., & Duodu, K. G. (2013). Phenolic composition and inhibitory effect against oxidative DNA damage of cooked cowpeas as affected by simulated in vitro gastrointestinal digestion. *Food Chemistry*, *141*(3), 1763–1771.

Ndiaye, C., Martinez, M. M., Hamaker, B. R., Campanella, O. H., & Ferruzzi, M. G. (2020). Effect of edible plant materials on provitamin A stability and bioaccessibility from extruded whole pearl millet (P. typhoides) composite blends. *LWT*, *123*, 109109. https://doi.org/10.1016/J.LWT.2020.109109

Neela, S., & Fanta, S. W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. In *Food Science and Nutrition* (Vol. 7, Issue 6, pp. 1920–1945). Wiley-Blackwell. https://doi.org/10.1002/fsn3.1063

Odebode, F. D., Ekeleme, O. T., Ijarotimi, O. S., Malomo, S. A., Idowu, A. O., Badejo, A. A., Adebayo, I. A., Fagbemi, T. N., & Tayo Fagbemi, C. N. (2018). Nutritional composition, antidiabetic and antilipidemic potentials of flour blends made from unripe plantain, soybean cake, and rice bran. *Wiley Online Library*, *42*(4). https://doi.org/10.1111/jfbc.12447

Ofosu, I. W., Ellis, W. O., Nsiah, K., & Oduro, I. N. (2017). Neglected and Underutilized Legumes (NULs): Exposure Assessment, Habitual Cooking and Eating Habits and Consumers' Characteristics. *Journal of Food Security*, *5*(5), 169–175. https://doi.org/10.12691/JFS-5-5-3

Ogori, A. F. (2022). Effects of thermal processing on edible seed plant proteins. *Journal of Nutritional Health and Food Engineering*, *12*(1), 14-21.

Ojo, D. O., & Enujiugha, V. N. (2018). Comparative evaluation of ungerminated and germinated co-fermented instant 'Ogi'from blends of maize (Zea mays) and ground bean (Kerstingiella geocarpa). *J Nutr Health Food Eng*, *8*(1), 00258.

Ojo, O. A., Oshin, A., Obadina, O. A., & Oke, E. K. (2023). Mineral and anti-nutritional properties of pearl millet and pumpkin leaf flour as affected by fermentation. *Acta Universitatis Sapientiae, Alimentaria*, *16*(1), 75–89. https://doi.org/10.2478/ausal-2023-0006

Ojuederie, O. B., Popoola, J. O., Aremu, C., & Babalola, O. O. (2021). Harnessing the Hidden Treasures in African Yam Bean (Sphenostylis stenocarpa), an Underutilized Grain Legume with Food Security Potentials. *Food Security and Safety: African Perspectives*, 1–20. https://doi.org/10.1007/978-3-030-50672-8_1

Oladeji, A. E., Bussie, M.-D., Ibironke, P., Therese, G., & David, C. (2016). Nutritional Evaluation and Consumer Preference of Legume Fortified Maize-meal Porridge. *Journal of Food and Nutrition Research*, *4*(10), 664–670. https://doi.org/10.12691/jfnr-4-10-6

Oladele, E. O., & Williamson, G. (2016). Impact of resistant starch in three plantain (Musa AAB) products on glycaemic response of healthy volunteers. *European Journal of Nutrition*, *55*(1), 75–81. https://doi.org/10.1007/S00394-014-0825-6/METRICS

Olaniyan, S. A, B. I., & Ademola, A. A, A. LO. (2015). Malted Sorghum-Soy Composite Flour: Preparation, Chemical and Physico-Chemical Properties. *Journal of Food Processing & Technology*, *06*(08). https://doi.org/10.4172/2157-7110.1000467

Olson, R., Gavin-Smith, B., Ferraboschi, C., & Kraemer, K. (2021). Food fortification: The advantages, disadvantages and lessons from sight and life programs. In *Nutrients* (Vol. 13, Issue 4). MDPI AG. https://doi.org/10.3390/nu13041118

Olugbuyi, A., Oyinloye, A., Araoye, K., & Ariseloye, O. (2024). Orange fleshed sweet potato-rice bran flour: Optimization, proximate and amino acid composition for dough meal production. *Journal of Agriculture and Food Research*, *15*, 100920. https://doi.org/10.1016/J.JAFR.2023.100920

Onuche, U. (2020). Profitability and efficiency of Bambara groundnut production in Nigeria: a case study. *Review of Agricultural and Applied Economics*, *23*(2), 92–101. https://doi.org/10.15414/RAAE.2020.23.02.92-101

Otoo, G. S., Essuman, E. K., Gyimah, V., & Bigson, K. (2018). Quality attributes of fufu: instrumental and sensory measurement. *Scientific African*, *1*, e00005.

Owade, J. O., Abong, G. O., & Okoth, M. W. (2018). Production, utilization and nutritional benefits of orange fleshed sweet potato (OFSP) puree bread: A review. In *Current Research in Nutrition and Food Science* (Vol. 6, Issue 3, pp. 644–655). Enviro Research Publishers. https://doi.org/10.12944/CRNFSJ.6.3.06

Oyeyinka, A. T., Obilana, A. O., & Siwela, M. (2021). The Potential of Bambara Groundnut for Use in Complementary Feeding. *Food and Potential Industrial Applications of Bambara Groundnut*, 169–187. https://doi.org/10.1007/978-3-030-73920-1_10

Oyeyinka, B. O., & Afolayan, A. J. (2019). Comparative evaluation of the nutritive, mineral, and antinutritive composition of musa sinensis l. (banana) and musa paradisiaca l. (plantain) fruit compartments. *Plants*, *8*(12). https://doi.org/10.3390/plants8120598

Pacheco-Delahaye, E., Maldonado, R., Pérez, E., & Schroeder, M. (2008). Production and characterization of unripe plantain (musa paradisiaca l.) Flours. *Interciencia*, *33*(4), 290–296.

Paterne, djoman, Ginette Gladys, D., Téhi Bernard, S., & Bogui Anicet, E. (2020). Comparative Study on Proximate, Mineral and Anti-Nutrient Content of Composite Roasted Corn Flour with Its Traditional Roasted Corn Counterpart for Homemade. *Publish.Sub7journal.Com*. https://doi.org/10.9734/AFSJ/2019/v9i130002

Pedroza Velandia, S. P., Kissimova-Skarbek, K., & Pedroza, S. P. (2016). The Heavy Burden of Protein and Energy Malnutrition on the Society of Ghana: Urging the Implementation of an Easily Enacted Backyard Poultry Intervention. *Zdrowie Publiczne i Zarządzanie, 14*(4). https://doi.org/10.4467/20842627OZ.16.024.5893

Persson, V. (2001). Vitamin A intake status and improvement using the dietary approach. Studies of vulnerable groups in three Asian countries.

Pessu, P. O., Abel, G. I., Akande, S. A., Ayanda, I. S., Adarabierin, I. G., Olagunju, O. D., & Gbabe, E. K. (2020). Chemical and physico-chemical properties of orange fleshed sweet potatoes (OFSP) chips dried using solar dyers. *Agrosearch*, *20*(1), 144–157. https://doi.org/10.4314/agrosh.v20i1.13s

Petroski, W., & Minich, D. M. (2020). Is there such a thing as "anti-nutrients"? A narrative review of perceived problematic plant compounds. *Nutrients*, *12*(10), 1–32. https://doi.org/10.3390/nu12102929

Piskin, E., Cianciosi, D., Gulec, S., Tomas, M., & Capanoglu, E. (2022). Iron Absorption: Factors, Limitations, and Improvement Methods. In *ACS Omega* (Vol. 7, Issue 24, pp. 20441–20456). American Chemical Society. https://doi.org/10.1021/acsomega.2c01833

Popoola, J. O., Ojuederie, O. B., Aworunse, O. S., Adelekan, A., Oyelakin, A. S., Oyesola, O. L., Akinduti, P. A., Dahunsi, S. O., Adegboyega, T. T., Oranusi, S. U., Ayilara, M. S., & Omonhinmin, C. A. (2023). Nutritional, functional, and bioactive properties of african underutilized legumes. *Frontiers in Plant Science*, *14*. https://doi.org/10.3389/FPLS.2023.1105364

Pretorius, B., Otto, M., & Schönfeldt, H. C. (2023). Antinutrients and metabolomic compounds of Bambara groundnut (Vigna subterranean) as affected by traditional processing by smallholder farmers. *Journal of Food Science*, *88*(8), 3435-3444. https://doi.org/10.1111/1750-3841.16698

Qamar, S., Aslam, M., & Javed, M. A. (2016). Determination of Proximate Chemical Composition and Detection of Inorganic Nutrients in Maize (Zea mays L.). *Materials Today: Proceedings*, *3*(2), 715–718. https://doi.org/10.1016/j.matpr.2016.01.118

Qin, P., Wang, T., & Luo, Y. (2022). A review on plant-based proteins from soybean: Health benefits and soy product development. *Journal of Agriculture and Food Research*, *7*. https://doi.org/10.1016/J.JAFR.2021.100265

Rackis, J. J. (1981). Flatulence Caused. by Soya and Its Control through Processing. *Jol'rnal of the American Oil Chdlists' Society*, *58*(3), 503–510.

Raes, K., Knockaert, D., Struijs, K., & Van Camp, J. (2014). Role of processing on bio accessibility of minerals: Influence of localization of minerals and anti-nutritional factors in the plant. *Trends in Food Science & Technology*, *37*(1), 32–41. https://doi.org/10.1016/J.TIFS.2014.02.002

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.

Ramsgaard, J., Worch, T., & Zacharov, N. (2018). Sensory evaluation methods for sound. In *Sensory Evaluation of Sound* (pp. 107-155). CRC Press.

Ranabhat, T. (2020). Effects of processing techniques on antinutritional factors of black gram (vigna mungo) (Doctoral dissertation, Department of Food Technology Central Campus of Technology Institute of Science and Technology Tribhuvan University, Nepal 2020).

Rao, B. S. N., & Prabhavathi, T. (1982). Tannin content of foods commonly consumed in India and its influence on ionisable iron. *Journal of the Science of Food and Agriculture*, *33*(1), 89–96. https://doi.org/10.1002/JSFA.2740330116

Restrepo-Gallego, M., Díaz, L. E., & Rondó, P. H. (2021). Classic and emergent indicators for the assessment of human iron status. *Critical Reviews in Food Science and Nutrition*, *61*(17), 2827-2840.

Richter, M., Baerlocher, K., Bauer, J. M., Elmadfa, I., Heseker, H., Leschik-Bonnet, E., Stangl, G., Volkert, D., & Stehle, P. (2019). Revised Reference Values for the Intake of Protein. *Annals of Nutrition and Metabolism*, *74*(3), 242–250.

Rizzo, G., & Baroni, L. (2018). Soy, Soy Foods and Their Role in Vegetarian Diets. *Nutrients*, *10*(1).

Roberts, M., Tolar-Peterson, T., Reynolds, A., Wall, C., Reeder, N., & Rico Mendez, G. (2022). The Effects of Nutritional Interventions on the Cognitive Development of Preschool-Age Children: A Systematic Review. *Nutrients*, *14*(3).

Ruel, M. (2001). *Can food-based strategies help reduce vitamin A and iron deficiencies*.https://ageconsearch.umn.edu/record/15902/files/mi01ru01.pdf

Sahile, Z., Yilma, D., Tezera, R., Bezu, T., Haileselassie, W., Seifu, B., & Ali, J. H. (2020). Prevalence of Vitamin A Deficiency among Preschool Children in Ethiopia: A Systematic Review and Meta-Analysis. *BioMed Research International*, *2020*, 1–24. https://doi.org/10.1155/2020/8032894

Salama, A., Elhawary, D., & El-Nmer, F. (2014). Nutritional knowledge, attitude, and practice of parents and its impact on growth of their children. *Menoufia Medical Journal*, *27*(3), 612. https://doi.org/10.4103/1110-2098.145529

Salami, K. O., Olorunlambe, A. A., Adesina, B. O., Akinwande, F. F., Ahmed El-Imam, A. M., & Oyeyinka, S. A. (2019). Physicochemical and sensory properties of corn starch custard soured with tamarind, soursop and lime. *Hrvatski Časopis Za Prehrambenu Tehnologiju, Biotehnologiju i Nutricionizam*, *14*(3–4), 91–97. https://doi.org/10.31895/HCPTBN.14.3-4.4

Saleh, M., & Lee, Y. (2023). Instrumental Analysis or Human Evaluation to Measure the Appearance, Smell, Flavor, and Physical Properties of Food. In *Foods* (Vol. 12, Issue 18). Multidisciplinary Digital Publishing Institute (MDPI).

Samaniego-Sánchez, C., Marín-García, G., & Quesada-Granados, J. J. (2020). A new fermented beverage from sugarcane (Saccharum officinarum L.) molasses: Analysis of physicochemical properties and antioxidant capacity, and comparison with other industrial alcohol products. *LWT*, *128*, 109505.

Samtiya, M., Aluko, R. E., & Dhewa, T. (2020). Plant food anti-nutritional factors and their reduction strategies: an overview. In *Food Production, Processing and Nutrition* (Vol. 2, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s43014-020-0020-5

Sanni, O. (2015). Drying for wealth, food security and nation building funaab inaugural lecture series.

Schaafsma, G. (2002). *Advantages and limitations of the protein digestibility-corrected amino acid score (PDCAAS) as a method for evaluating protein quality in human diets*. https://doi.org/10.1017/S0007114512002541

Schönfeldt, H. C., Hall, N. G., & Smit, L. E. (2012). The need for country specific composition data on milk. *Food Research International*, *47*(2), 207–209. https://doi.org/10.1016/J.FOODRES.2011.05.018

Serwah Ayeh, E., Asiamah, E., Boakye, A. A., Wireko-Manu, F. D., Aryeetey, E., & Oduro, I. N. (2023). Effects of ripening stages and thermal treatment on quality characteristics of the overripe plantain puree. *Journal of Agriculture and Food Research*, *14*. https://doi.org/10.1016/j.jafr.2023.100662

Setchell, K. D. R. (1998). Phytoestrogens: the biochemistry, physiology, and implications for human health of soy isoflavones. *The American Journal of Clinical Nutrition*, *68*(6), 1333S-1346S. https://doi.org/10.1093/AJCN/68.6.1333S

Sharma, S., Singh, B., & Sikka, R. (2015). Changes in some Physico-Chemical characteristics of soils under poplar-based agroforestry. *Agric Res J*, *52*(3), 19-22. https://doi.org/10.5958/2395-146X.2015.00030.7

Shenton, L. M., Jones, A. D., & Wilson, M. L. (2020). Factors Associated with Anemia Status Among Children Aged 6–59 months in Ghana, 2003–2014. *Maternal and Child Health Journal*, *24*(4), 483–502. https://doi.org/10.1007/S10995-019-02865-7

Shi, L., Arntfield, S. D., & Nickerson, M. (2018). Changes in levels of phytic acid, lectins and oxalates during soaking and cooking of Canadian pulses. *Food Research International*, *107*, 660–668. https://doi.org/10.1016/J.FOODRES.2018.02.056

Siddiqa, M., Shah, G. H., Mayo-Gamble, T. L., & Zubair, A. (2023). Determinants of Child Stunting, Wasting, and Underweight: Evidence from 2017 to 2018 Pakistan Demographic and Health Survey. *Journal of Nutrition and Metabolism, 2023*. https://doi.org/10.1155/2023/2845133

Simwaka, J., & Masamba, K. G. (2017). Effect of fermentation on physicochemical and antinutritional factors of complementary foods from millet, sorghum, pumpkin and amaranth seed flours Characterization of a thermostable mannitol dehydrogenase from hyperthermophilic Thermotoga neapolitana DSM 4359 with potential application in mannitol production View project. In *Article in International Food Research Journal*. http://www.ifrj.upm.edu.my

Singh, A., Ghosh, S., Ward, H., Manary, M. J., Rogers, B. L., & Rosenberg, I. H. (2021). Biomarkers of environmental enteric dysfunction are differently associated with recovery and growth among children with moderate acute malnutrition in Sierra Leone. *The American Journal of Clinical Nutrition*, *113*(6), 1556–1564. https://doi.org/10.1093/AJCN/NQAA434

Singh-Ackbarali, D., & Maharaj, R. (2014). Sensory Evaluation as a Tool in Determining Acceptability of Innovative Products Developed by Undergraduate Students in Food Science and Technology at The University of Trinidad and Tobago. *Journal of Curriculum and Teaching*, *3*(1). https://doi.org/10.5430/jct.v3n1p10

Siong, T. E., Choo, K. S., & Shahid, S. M. (1989). Determination of iron in foods by the atomic absorption spectrophotometric and colorimetric methods. *Pertanika*, *12*(3), 313-322.

Siwela, M., Pillay, K., Govender, L., Lottering, S., Mudau, F. N., Modi, A. T., & Mabhaudhi, T. (2020). Biofortified Crops for Combating Hidden Hunger in South Africa: Availability, Acceptability, Micronutrient Retention and Bioavailability. *Foods 2020, Vol. 9, Page 815*, *9*(6), 815. https://doi.org/10.3390/FOODS9060815

Smedman, A., Lindmark-Månsson, H., Drewnowski, A., & Edman, A. K. M. (2010). Nutrient density of beverages in relation to climate impact. *Food & Nutrition Research*, *54*.

Sogo-Temi, C. M., Idowu, O. A., & Idowu, E. (2014). Effect of Biological and Chemical Ripening Agents on the Nutritional and Metal Composition of Banana (Musa spp). *Journal of Applied Sciences and Environmental Management*, *18*(2), 243–246. https://doi.org/10.4314/JASEM.V18I2.14

Sommer, A., & Davidson, F. R. (2002). Assessment and control of vitamin A deficiency: The annecy accords. *Journal of Nutrition*, *132*(9 SUPPL.). https://doi.org/10.1093/JN/132.9.2845S

Sommer, A., & Vyas, K. S. (2012). A global clinical view on vitamin A and carotenoids. *American Journal of Clinical Nutrition*, *96*(5). https://doi.org/10.3945/ajcn.112.034868

Song, P., Adeloye, D., Li, S., Zhao, D., Ye, X., Pan, Q., Qiu, Y., Zhang, R., & Rudan, I. (2023). The prevalence of vitamin A deficiency and its public health significance in children in low- and middle-income countries: A systematic review and modelling analysis. *Journal of Global Health*, *13*. https://doi.org/10.7189/JOGH.13.04084

Soumare, A., Diedhiou, A. G., & Kane, A. (2022). Bambara groundnut: a neglected and underutilized climate-resilient crop with great potential to alleviate food insecurity in sub-Saharan Africa. *Journal of Crop Improvement*, *36*(5), 747–767.

Spence, C. (2015). On the psychological impact of food colour. *Flavour 2015 4:1*, *4*(1), 1–16. https://doi.org/10.1186/S13411-015-0031-3

Stone, H. (2015). Alternative methods of sensory testing: advantages and disadvantages. In *Rapid sensory profiling techniques* (pp. 27-51). Woodhead Publishing.

Stone, H., & Sidel, J. (2009). Sensory Science and Consumer Behavior. *Global Issues in Food Science and Technology*, 67–77. https://doi.org/10.1016/B978-0-12-374124-0.00005-3

Subuola, F., Widodo, Y., & Kehinde, T. (2012). Processing and Utilization of Legumes in the Tropics. *Trends in Vital Food and Control Engineering*. https://doi.org/10.5772/36496

Sugri, I., Norman, J., Egyir, I., Res, P. J. (2010). Preliminary assessment of shea butter waxing on the keeping and sensory qualities of four plantain (Musa aab) varieties. *academicjournals.Org*, Afr. J. Agric *5*(19), 2676–2684.

Tan, X. L., Azam-Ali, S., Goh, E. Von, Mustafa, M., Chai, H. H., Ho, W. K., Mayes, S., Mabhaudhi, T., Azam-Ali, S., & Massawe, F. (2020). Bambara Groundnut: An Underutilized Leguminous Crop for Global Food Security and Nutrition. *Frontiers in Nutrition*, *7*, 601496. https://doi.org/10.3389/FNUT.2020.601496

Tariku, A., Fekadu, A., Ferede, A. T., Mekonnen Abebe, S., & Adane, A. A. (2016). Vitamin A deficiency and its determinants among preschool children: A community based cross-sectional study in Ethiopia. *BMC Research Notes*, *9*(1), 1–8.

Tas, O., Ertugrul, U., Grunin, L., & Oztop, M. H. (2022). An investigation of functional quality characteristics and water interactions of navy bean, chickpea, pea, and lentil flours. *Legume Science*, *4*(1), e136. https://doi.org/10.1002/LEG3.136

Tenagashaw, M. W., Kinyuru, J. N., Kenji, G. M., Melaku, E. T., & Susanne, H.-K. (2017). Nutrient Density of Complementary Foods Formulated from a Blend of Teff, Soybean and Orange-fleshed Sweet Potato. *International Journal of Food Science and Nutrition Engineering*, *7*(4), 61–69.

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*(1), 8826693.

Tijani, A. O., Bakare, H. A., Babajide, J. M., & Omemu, A. M. (2017). The effect of processing parameters on the functional and pasting properties of breadfruit (Artocarpus Altilis) “elubo” flour. *Croatian Journal of Food Science and Technology*, *9*(1), 31–39. https://doi.org/10.17508/CJFST.2017.9.1.05

Titi-Lartey, O. A., & Gupta, V. (2020). Marasmus. *StatPearls*. http://europepmc.org/books/NBK559224

Tsazeu Judicaël Boris, N., Nkot Laurette, N., & Sop Marie Modestine, K. (2023). Plantain (*Musa paradisiaca* L.): Production, Consumption and Processing in Cameroon. *American Journal of Food Science and Technology*, *11*(1), 8–14. https://doi.org/10.12691/ajfst-11-1-2

Umbreen, F., Qamar, K., Shaukat, S., Khan, M., Malik, S., & Ali, H. (2021). Iron Deposition in The Growth Plate of Long Bones Of The Offspring When Given During Pregnancy In Rat Model. *Pakistan Armed Forces Medical Journal*, *71*(4), 1223–1226.

Underwood, B. A. (2004). Vitamin A deficiency disorders; international efforts to control a preventable “pox.” *The Journal of Nutrition*, *134*(1). https://doi.org/10.1093/JN/134.1.231S

Vagadia, B. H., Vanga, S. K., & Raghavan, V. (2017). Inactivation methods of soybean trypsin inhibitor – A review. *Trends in Food Science & Technology*, *64*, 115–125.

Van Jaarsveld, P. J., Faber, M., Tanumihardjo, S. A., Nestel, P., Lombard, C. J., & Benadé, A. J. S. (2005). β-Carotene–rich, orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test1–3. *The American Journal of Clinical Nutrition*, *81*(5), 1080–1087. https://doi.org/10.1093/AJCN/81.5.1080

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. https://doi.org/10.1007/S13197-011-0323-2/METRICS

Vissamsetti, N., Simon-Collins, M., Lin, S., Bandyopadhyay, S., Kuriyan, R., Sybesma, W., & Tomé, D. (2024). Local Sources of Protein in Low- and Middle-Income Countries: How to Improve the Protein Quality? *Current Developments in Nutrition*, *8*. https://doi.org/10.1016/j.cdnut.2023.102049

Vollmer, R., Villagaray, R., Cárdenas, J., Castro, M., Chávez, O., Anglin, N. L., & Ellis, D. (2017). A large-scale viability assessment of the potato cryobank at the International Potato Center (CIP). https://doi.org/10.1007/s11627-017-9846-1

Weaver, M. R., & Brittin, H. C. (2001). Food preferences of men and women by sensory evaluation versus questionnaire. *Family and Consumer Sciences Research Journal*, *29*(3), 288–301. https://doi.org/10.1177/1077727X01293006

Webb, P. A. (2001). Volume and Density Determinations for Particle Technologists.

Wiseman, E. M., Bar-El Dadon, S., & Reifen, R. (2017). The vicious cycle of vitamin a deficiency: A review. *Critical Reviews in Food Science and Nutrition*, *57*(17), 3703–3714.

World Health Organization, & United Nations Children's Fund. (2020). *Levels and trends in child malnutrition: key findings of the 2020 edition. UNICEF/WHO/World Bank Group joint child malnutrition estimates*. World Health Organization.

World Health Organization. (2009). Global prevalence of vitamin A deficiency in populations at risk 1995-2005: WHO global database on vitamin A deficiency.

Wright, E. J. (1934). Vitamin A Deficiency. *British Medical Journal*, *2*(3839), 234. https://doi.org/10.1136/bmj.2.3839.234

Xu, Y., Shan, Y., Lin, X., Miao, Q., Lou, L., Wang, Y., & Ye, J. (2021). Global patterns in vision loss burden due to vitamin A deficiency from 1990 to 2017. *Public Health Nutrition*, *24*(17), 5786-5794.

Yang, J., & Lee, J. (2019). Application of Sensory Descriptive Analysis and Consumer Studies to Investigate Traditional and Authentic Foods: A Review. *Foods 2019, Vol. 8, Page 54*, *8*(2), 54. https://doi.org/10.3390/FOODS8020054

Yao, D. N., Kouassi, K. N., Erba, D., Scazzina, F., Pellegrini, N., & Casiraghi, M. C. (2015). Nutritive evaluation of the Bambara groundnut Ci12 landrace [Vigna subterranea (L.) Verdc. (Fabaceae)] produced in Côte d'Ivoire. *International Journal of Molecular Sciences*, *16*(9), 21428-21441.

Yao, Y., Docter, M., Van Ginkel, J., De Ridder, D., & Joo, C. (2015). Single-molecule protein sequencing through fingerprinting: Computational assessment. *Physical Biology*, *12*(5). https://doi.org/10.1088/1478-3975/12/5/055003

Yusufu, P. A., Mosiko, T. B., & Ojuko, O. O. (2014). Effect of Firm Ripe Plantain Fruit Flour Addition on the Chemical, Sensory and Microbial Quality of Fura Powder. *Nigerian Food Journal*, *32*(1), 38–44. https://doi.org/10.1016/S0189-7241(15)30094-1

Zena Mamo, T., Gebre Mezgebe, A., & Haile, A. (2014). Development of Orange-Fleshed Sweet Potato (Ipomoea batatas) Juice: Analysis of Physico-Chemical, Nutritional and Sensory Property. *International Journal of Food Science and Nutrition Engineering*, *2014*(5), 128–137. https://doi.org/10.5923/j.food.20140405.03

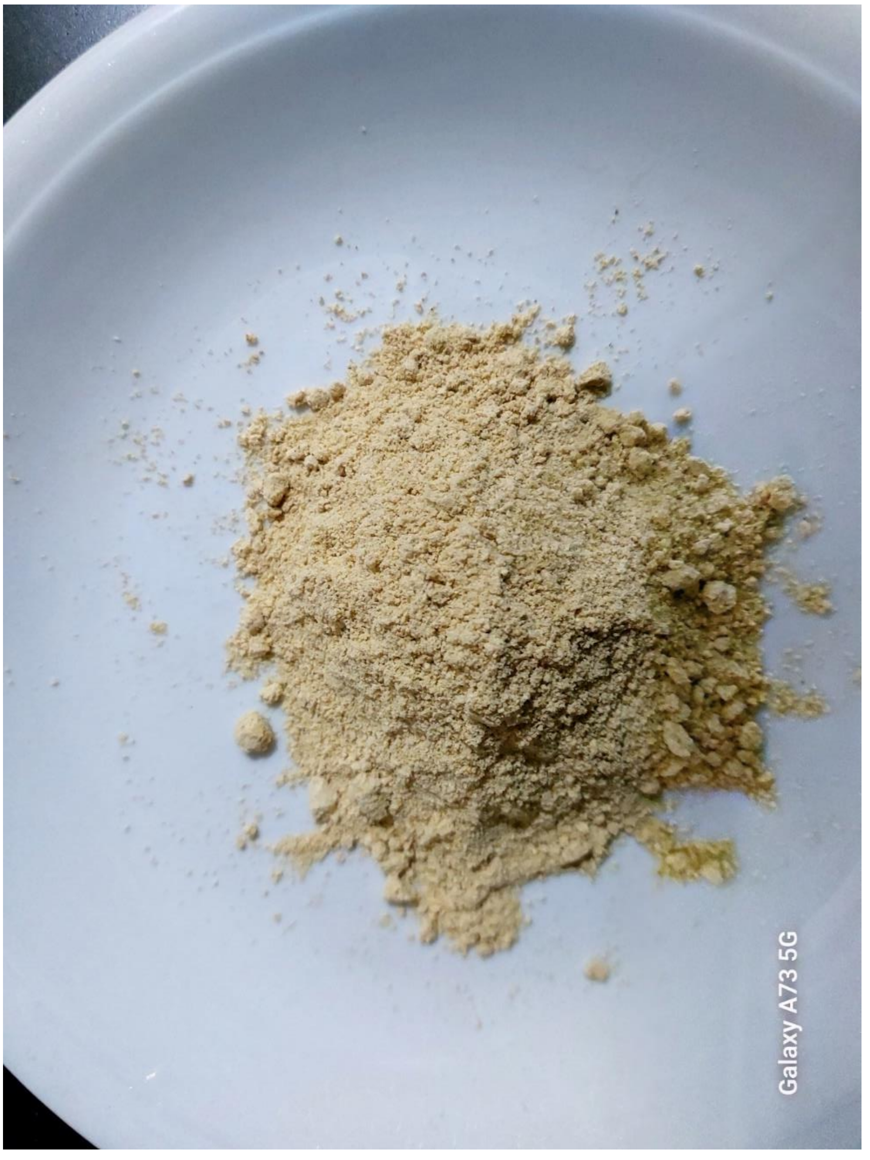
Zhang, Y., Sharan, S., Rinnan, Å., & Orlien, V. (2021). Survey on methods for investigating protein functionality and related molecular characteristics. In *Foods* (Vol. 10, Issue 11). MDPI. https://doi.org/10.3390/foods10112848

Zhao, T. T., Jin, F., Li, J. G., Xu, Y. Y., Dong, H. T., Liu, Q., Xing, P., Zhu, G. L., Xu, H., & Miao, Z. F. (2019). Dietary isoflavones or isoflavone-rich food intake and breast cancer risk: A meta-analysis of prospective cohort studies. *Clinical Nutrition*, *38*(1), 136–145. https://doi.org/10.1016/J.CLNU.2017.12.006

Zimmermann, M. B., Biebinger, R., Rohner, F., Dib, A., Zeder, C., Hurrell, R. F., & Chaouki, N. (2006). *Vitamin A supplementation in children with poor vitamin A and iron status increases erythropoietin and hemoglobin concentrations without changing total body iron 13*.

APPENDICES

APPENDIX A



Roasted Maize Flour

Composite flour of Roasted Maie, Bambara Groundnut, Ripe-Plantain flours

Composite flour of Roasted Maize, Bambara Groundnut, and Orange Fleshed Sweet Potato flours.

Composite flour of Roasted Maize, Soybean, and Ripe Plantain flours.

APPENDIX B

Samples Preparation

A group of prepared samples for sensory evaluation

Freshly sliced plantain to be dry

Dried sliced plantain

A picture of sliced plantain in a dehydrator

Laboratory mill

APPENDIX C

HEDONIC RATING TEST FOR PORRIDGE SAMPLES

ASSESSOR :………………………………… **DATE:………………**

GENDER :……………. **AGE :……………….**

You are presented with four (4) samples of porridge, please rate these according to your preferences by ticking in the appropriate space provided. Please use the water to clean your palate before you taste each sample.

Appearance

Sample code	Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
255									
505									
219									
402									

Taste

Sample code	Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
255									
505									
219									
402									

Texture

Sample code	Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
255									
505									
219									
402									

Aroma

Sample code	Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
255									
505									
219									
402									

Acceptability

Sample code	Dislike Extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
255									
505									
219									
402									

Comments:

Thank you for taking part in this exercise.