UNIVERSITY OF CAPE COAST

OPTIMISATION OF COMPOSITE CASSAVA-YAM GARI, PACKAGING MATERIAL, STORAGE STABILITY AND TECHNO-ECONOMIC ANALYSIS OF OPTIMISED PRODUCT

BY

AMOS MANYO

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

JULY 2024

DECLARATION

Candidate's Declaration

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

Candidate's Signature …………………….. Date ……………………

Name: Amos Manyo

Supervisors' Declaration

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

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

Name: Prof. Ernest Ekow Abano

ABSTRACT

Incorporating *D.praehensilis* into cassava gari could improve the nutritional profile of cassava-yam composite gari. This study investigated the effects of yam quantity (X_1), fermentation duration (X_2), and roasting temperature (X_3) on the physico-nutritional qualities of the cassava-yam composite gari and then evaluated the effects of packaging materials and storage conditions on the quality attributes. A three-factor three-level response surface methodology (RSM) was used for the optimisation study while the storage study was done using $3^2 \times 3$ factorial. Interestingly, an increase in yam quantity, fermentation duration, and roasting temperature resulted in a significant increase in the beta-carotene content. The iron and zinc contents of the cassava-yam composite gari increased significantly when the yam quantity was increased. Swelling capacity was reduced by yam quantity however, the roasting temperature increased the swelling capacity significantly to 3.40. Yam quantity reduced the flavour, taste, texture, and overall acceptability but was positively influenced by fermentation. Roasting temperature affected the brownness more than the other processing variables. All sensory attributes, L*, beta carotene, and swelling capacity were reduced under all packaging materials and storage conditions. However, the reduction was significantly higher under polyethylene (PE) packaging material at 32.22 ± 3.34ºC. The brownness (a*) increased in PE, polyethylene/ polyethylene terephthalate (PE/PET), and polyethylene/polyethylene terephthalate/aluminium (PE/PET/ AL) packaging materials but the increase was significantly higher in PE under open market (OM) condition at 32.22 ± 3.34ºC. PE/PET and PE/PET/AL provided a strong barrier property against temperature (32.22 ± 3.34ºC). Considering fixed and variable costs, producing a tonne of the optimised gari yielded profit.

ACKNOWLEDGEMENT

Sincerely, I am grateful to my supervisor, Professor Ernest Ekow Abano for his patience, guidance, objective criticism, and supervision of my thesis. Under his tutelage, I was able to design an experiment and analyse the results using response surface methodology (RSM), specifically, Box Behnken's design.

I am particularly grateful to Mr. Enoch of the department of Chemistry and Mr. Osei of Technology Village Laboratory for assisting me with my laboratory analysis.

I am grateful to my colleagues, Mr. Joshua Akanson, Mr. Welbeck Joel, and Miss Lawrencia for their support throughout the study.

Special appreciation goes to Madam Esi at Duakror for helping me in processing the gari.

Finally, I would like to express my gratitude to the Bachelor of Agriculture Science level 300 students for assisting me with sensory evaluation.

DEDICATION

This study is dedicated to my mother, Miss Grace Abla Zilevu, and my step-mother, Miss Hunyeametor Segbenu.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Background to the Study

Yam is a root crop that is predominantly consumed by indigenes of sub-Saharan Africa (Adebowale et al., 2018; Faustina Dufie et al., 2013; Leng et al., 2019; Okeke & Oluka, 2019) and some Asian countries. Numerous yam cultivars that are edible cannot be consumed in their raw form because they are bitter, itchy, and contain toxic constituents (Adebowale et al., 2018). Because of this, yams are cooked chiefly by boiling, frying, and steaming (Gong et al., 2021; Maziya-Dixon et al., 2017; Obidiegwu et al., 2020; Tortoe et al., 2017). Additionally, yam varieties grown in Ghana for their economic value are white yam (Dioscorea rotundata), water yam (D. alata), bitter yam (D. dumetorum), Chinese yam (D. esculenta) and yellow yam (D. cayenensis) (Adebowale et al., 2018; Ferraro et al., 2016; Otegbayo et al., 2018; Padhan & Panda, 2020; Tortoe et al., 2017) whereas underutilised varieties such as D. praehensilis (bush yam) also exist.

Bush yam is one of the popular wild yam cultivars which is noted to potentially contribute to reducing food security and poverty in Sub-Saharan Africa. Bush yam tubers are normally about 60 centimetres long, with mostly white flesh stained with yellow and an unpleasant violet layer below the epidermis (Adewumi et al., 2021). Bush yam is underutilized partly due to high flesh enzymatic browning and postharvest losses (Adewumi et al., 2021). In addition, the rate of enzymatic browning in bush yam is higher as compared to other yam varieties. Consequently, bush yam is usually not patronised making it difficult to exploit its nutritional benefits. Interestingly, bush yam contains rich sources of micronutrients such as zinc (5.40±77mg/100g) and iron (9.00±00mg/100g) (Polycarp et al., 2012) which can enhance the nutritional value of food products.

Unfortunately, micronutrient deficiency is an issue of public concern in Sub-Saharan Africa and other African countries, with women, pregnant women, and children being particularly affected. This is a result of the consumption of diets lacking essential minerals (Desire et al., 2021; Maziya-Dixon et al., 2017). One such micronutrient deficiency is vitamin A deficiency. Vitamin A deficiency is regarded to be among the most common nutrient deficiencies worldwide, mainly impacting children in underdeveloped countries such as Ghana. Vitamin A deficiency affects around 30% of children under the age of five globally, accounting for 2% of all deaths in this age range (Timoneda et al., 2018; Wirth et al., 2017).

Similar to vitamin A deficiency are iron and zinc deficiency. Given that iron and zinc play significant roles in several metabolic pathways, a lack of these micronutrients has a deleterious impact on several physiological systems, including the gastrointestinal tract, central nervous system, immunological, skeletal, and reproductive systems. Iron deficiency affects 42% of children under the age of five and 40% of pregnant women globally are anaemic (Demini & Rajagopalan, 2023) whilst zinc deficiency can lead to stunted growth, loss of appetite, late wound healing, and late sexual growth (Gharibzahedi & Jafari, 2017).

To overcome micronutrient deficiency-related ailments, food-to-food fortification employing underused species high in micronutrients is becoming sustainable since it encourages independence and opens up food markets for food produced locally (Desire et al., 2021). Teye et al. (2020) reported that underutilized crops have the potential to reduce undernourishment and the devastating impacts of hidden hunger owing to their rich sources of micronutrients. One such food-to-food initiative intended to fortify gari is the orange-fleshed sweet potato (OFSP) fortified gari (Abano et al., 2020). Additionally, the influence of food-to-food fortification on iron and zinc deficiency reduction has not been fully studied in Ghana. It is against this backdrop that this research sought to incorporate bush yam into a ready-to-eat staple, gari which invariably is deficient in iron and zinc.

Fortunately, there has been an improvement in research related to yam food product development (Leng et al., 2019a). For example, yam was used as a composite for bread (Amandikwa et al., 2015; Chinma et al., 2020), cookies (Christiana & Nkemakonam, 2018; Igbabul et al., 2015), and yam-fortified yoghurt (Siddiqui et al., 2022). However, little research effort has been made to incorporate some proportions of bush yam into gari with the motive of improving its nutritional quality.

Gari is an essential food commodity prepared and consumed by people in Western Africa, especially Nigeria and Ghana. (Abano et al., 2020; Akinoso & Olatunde, 2014; and Atuna et al., 2021). Its convenience and ready-to-eat nature have improved sales to school children, the poor, and the busy in the community (Abano et al., 2020; Atuna et al., 2021). Gari is mainly produced from cassava which can be eaten with water, milk, and sugar as soakings or with hot/cold water to produce ‘eba’ (Abano et al., 2020; Atuna et al., 2021). Gari preparation involves cassava root peeling, washing, grating, dewatering/fermentation, screening, and roasting of fermented cassava mash

(Adinsi et al., 2019; Akinoso & Olatunde, 2014; Escobar et al., 2018; Kehinde AT, 2013; Oyeyinka et al., 2019). Fermentation followed by roasting helps to develop the gari's taste, flavour, and colour (Abano et al., 2020). Cassava dough for gari processing is normally allowed to ferment for a maximum of four days depending on the cassava cultivar and taste preference of the people (Abano et al., 2020). Whereas the roasting causes the gari to gelatinize, dry out, and become crispy.

In view of this, this study aims to examine how proportionate quantity of yam (YQ) mash, fermentation duration (FD), roasting temperature (RT), packaging materials, and storage conditions affect the physico-nutritional qualities and storage stability of cassava-yam composite gari.

Problem Statement

Micronutrient deficiency is a public health concern in countries in Sub-Saharan Africa and other African countries with pregnant women and children severely affected (Desire et al., 2021; Harrison et al., 2022; Maziya-Dixon et al., 2017). This is because many people in our part of the world are exposed to unhealthy diets lacking important minerals including iron and zinc (Desire et al., 2021; Okwuonu et al., 2021). Boateng et al. (2019) and Greffeuille et al. (2023) reported that in Ghana, children below age five are malnourished with differing degrees of anaemia. Studies suggest that eighty-nine percent of anaemic cases in 2013 affected eleven million Ghanaians with iron and other essential nutrient deficiency cited as the fundamental causes. In addition, iron deficiency accounts for about forty-five percent of children of school-going age, and a zinc deficiency of six to ten percent (Wegmüller et al., 2020).

To overcome micronutrient deficits, the Ghanaian government has created compulsory fortification of wheat flour with 58.5 mg/kg of iron and 58.5 mg/kg of zinc. However, studies show that just twenty-three percent of flour samples were sufficiently fortified (Wegmüller et al., 2020).

Bush yam (*D. praehensilis*) which is underutilized is dense in some micronutrients (Zn and iron) (Polycarp et al., 2012) and remains highly perishable and liable to decay in storage. *D. praehensilis* is underutilized partly due to high flesh enzymatic browning and postharvest losses (Adewumi et al., 2021b).

Yam-related food product development has made a profound improvement in research (Leng et al., 2019). However, there is no formulation with bush yam to prepare gari. This study therefore seeks to improve the utilisation of bush yam (D. praehensilis) and also incorporate iron and zinc into gari using bush yam.

Moreover, previous studies examined the effects of storage on the quality of gari. Oluwamukomi & Adeyemi (2015) examined the effects of storage and packaging on the quality of protein-fortified gari and found that the amount of browning and free fatty acid increased under temperature and high-density polyethylene (HDPE) packaging material. However, these studies focused on a single packaging material. A detailed study on the effects of different packaging materials and storage conditions is scanty.

Justification

Gari is a ready-to-eat food prepared chiefly from cassava roots (Oyeyinka et al., 2019). Studies show the possibility of incorporating root tuber crops in gari processing. Abano et al. (2020) and Atuna et al. (2021) substituted up to 30% of cassava mash with orange-fleshed sweet potato mash for gari production and found that there were differences in sensory attributes of the orange-fleshed sweet potato gari with improved vitamin A content from the whole cassava gari. In addition, Amandikwa et al. (2015) examined the sensory properties of wheat-yam flour and found that enhancing wheat flour for bread with 25% yam flour was statistically similar to whole wheat bread. Furthermore, Leng et al. (2019) investigated the nutritional potential of yam flour blended with carrot and groundnut paste and reported that the flour blends met the established requirements for micronutrients.

Meanwhile, bush yam (D. *praehensilis*) remains underutilized with rich micronutrients such as zinc (5.40±77mg/100g) and iron (9.00±00mg/100g) which can be incorporated into gari to improve its nutritional quality. This proves that incorporating bush yam mash into cassava dough will yield gari of sensory qualities similar to OFSP-cassava gari but with improved nutritional characteristics.

General Objectives

This research aims to examine the effects of the proportionate quantity of yam (YQ) mash, fermentation duration (FD), roasting temperature (RT), packaging materials, and storage conditions on the physicochemical and sensory attributes of cassava-yam composite gari.

Specific Objectives

1. To examine the effects of yam quantity (YQ), fermentation duration (FD), and roasting temperature (RT) on the functional (swelling capacity), sensory (colour, flavour, taste, texture, and overall acceptability), and nutritional (beta carotene, iron, and zinc) qualities of cassava-yam gari.
2. To investigate the effects of packaging materials and storage conditions of the optimized gari on its shelf stability.
3. To assess the techno-economic viability of producing 1000kg of the optimized gari.

Research Questions

This study seeks to address the following major concerns:

1. What are the effects of the processing variables, yam quantity (YQ), fermentation duration (FD), and roasting temperature (RT) on the nutritional (vitamin A, zinc, and iron) and sensory (appearance, flavour, taste, texture, overall acceptability, colour) qualities of the cassava-yam composite gari?
2. How do the packaging materials and storage conditions influence the shelf stability of the optimized gari?

3. What will be the techno-economic viability of producing a tonne of the optimized gari?

Delimitations

Numerous varieties of cassava and bush yam exist; nevertheless, in this research, *afisiafi* cassava variety and *D.praehensilis* will be utilised owing to their availability.

Limitations

The petroleum ether utilised in this research could not be separated from the ethanol containing the beta carotene though the exact amount as enshrined in the protocol was used.

Organisation of the Study

This research comprises five chapters. Chapter one focused on the research background, problem statement, justification, research objectives, research questions, delimitations, limitations, and how the research was organised. In the second chapter, studies that have connections with this research including minerals (iron and zinc), beta carotene, cassava, yam, and gari were referenced. The methodology employed in this study, theories and concepts underlying these methods, the rationale behind the application of the methods, and data analysis procedures were itemized in chapter three. Chapter four covers the research results and their discussions. Chapter five concludes the research based on the research results, inferences for practical application, and recommendations for further study.

CHAPTER TWO

LITERATURE REVIEW

Yam

Origin and Cultivation of Yam

Yams is a member of the family *Dioscoreaceae* and genus *Dioscorea* (Shan et al., 2020). It has been determined that yams originated mostly in Sub-Saharan Africa, Southeast Asia, and the arid regions of America (Andres et al., 2016; Otoo, 2017; Zhu, 2015). 95% of the total world production occurs in West Africa with Nigeria, Ghana, Cote d'Ivoire, Benin, and Togo being the region's largest producers representing over sixty million metric tonnes, thus, providing a source of livelihood for over 3000000 people (Adewumi et al., 2021b; Baffour-Ata et al., 2023; Otoo, 2017; Polycarp et al., 2012). There are more than six-hundred yam varieties and of these, ten are staples. Those commonly grown are white yam (*D. rotundata*), water yam (*D. alata*), bitter yam (*D. dumetorum*), Chinese yam (*D. opposita*), and yellow yam (*D. cayenensis*), cush-cush yam (*D. Trifida*), (Adebowale et al., 2018d; Ngwe et al., 2015; Otegbayo et al., 2018; Otoo, 2017; Padhan, Biswas, et al., 2020; Zhu, 2015). Yam varies in shape (long and cylindrical) and colour (yellow, purple, and white) (Andres et al., 2016; Arnau et al., 2017; Obidiegwu et al., 2020; Tortoe et al., 2020; Zhu, 2015). Yams are drought-resistant crops that thrive on poor soils (Tanko & Alidu, 2017).

In Ghana, yam is grown within the Sudan Savannah and forest zones, but *Dioscorea rotundata* (*pona*) grows well in the Guinea Savannah zone. The forest zone is the primary habitat for *Dioscorea alata*, *Dioscorea cayenensis*, *Dioscorea dumentorum*, and *Dioscorea praehensilis* (Anokye et al., 2014).

Similarly, yams are grown across Ghana, except for the Upper East and Greater Accra regions. Brong-ahafo and northern regions are the largest producers of yam, thus, producing 1,337,701MT for the 2009 production year (Kofi Chikpah et al., 2013). Remarkably, a total production of five million eight-hundred and fifty-five thousand, one hundred and thirty-eight metric tonnes with twenty-seven thousand metric tonnes for export in 2011 was recorded (Tortoe et al., 2020). However, production of yam suffers from low yields and productivity due to environmental challenges like drought, pests, diseases (Banson & Danso, 2013), scarcity of high-quality yam seed (Boadu et al., 2018), cost of labour, and high cost of inputs (Baffour-Ata et al., 2023).

In the West African Sub-region, Ghana comes second to Nigeria in terms of world production, with a production capacity of six point three million tonnes in 2011 (Baffour-Ata et al., 2023). However, Ghana exports the largest quantity of yam into the international market (Boadu et al., 2018; Felix et al., 2020, 2020; Wumbei et al., 2023) with exportations amount rising from thirty-two point five nine, nine million US dollars in 2017 to thirty-seven point nine eight six US Dollars in 2018 (Baffour-Ata et al., 2023).

Food Uses of Yam

Compared to other tuber crops, yam is the second most frequently eaten tuber crop and serves as food for people in the Western part of Africa, South America, Asia, and the Caribbean (Andres et al., 2016; Arnau et al., 2017; Obidiegwu et al., 2020; Zhu, 2015). Yams are cooked chiefly by boiling, frying, and steaming (Gong et al., 2021; Maziya-Dixon et al., 2017; Obidiegwu et al., 2020; Tortoe et al., 2017). Similarly, yam can be boiled and eaten with sauces, mashed/pounded into fufu, and fried into yam chips (Amandikwa et al., 2015; Tortoe et al., 2017).

In addition, yams are used as composites in many food products mainly composite flours as a means of enhancing their utilization (Kokoh et al., 2019), boosting the nutritional composition (Leng et al., 2019), and promoting high-yielding native species, strengthening domestic agriculture, and helps rural development (M.O. Iwe1 et al., 2016). For instance, yam was utilized as composite for bread (Amandikwa et al., 2015; Chinma et al., 2020; Q. M. Li et al., 2020; Mingle et al., 2017; Tamaroh & Sudrajat, 2021), cookies (Igbabul et al., 2015), yam-based complementary food (Padhan, Biswas, et al., 2020), and biscuits (Annisa et al., 2023; Nwosu, 2014; Omolayo Fasuan et al., 2017). M.O. Iwe1 et al. (2016) reported that composite flour is a mixture of flour from starchy roots and cereals either containing or lacking wheat. Ultimately, tuber-based formulated foods have a nutritional benefit over cereal-based formulations due to their low phytate content (Leng et al., 2019).

In Ghana, yams are an important food staple for both rural and urban populations' food budgets. On average, 25% of the food expenditure of urban households is expended on yam-based foods (Ayantunde et al., 2019; Wumbei et al., 2023).

A newly harvested yam tuber comprises seventy 20% water, 25% starch, 1.2% protein, and trace amounts of vitamins (Obidiegwu & Akpabio, 2017). Moreover, yam peels are high in micronutrients and can be used in the daily diet of animals (Karya Kate Nanbol & Otsanjugu Aku Timothy Namo, 2019; SHAN et al., 2020). They also offer certain beneficial nutrients including protein and micronutrients (Amandikwa et al., 2015; M. O. & O. O., 2015; Obidiegwu & Akpabio, 2017) thereby contributing significantly to food security and the livelihoods of sixty million people (Karya Kate Nanbol & Otsanjugu Aku Timothy Namo, 2019).

Furtherance to the nutritional value of yams, they have some industrial properties such as starch similar to that extracted from cereals. Amoo. (2014) reported that starch is an essential raw material for industries such as textiles, paper, adhesives, pharmaceuticals, and food. Starch isolated from different varieties was reported to expand the shelf life of fruits (Martins da Costa et al., 2020).

Despite the nutritional and industrial importance of yam, it has numerous cultural, religious, and social values that may differ regionally (Verter & Becvarova, 2014). Obidiegwu & Akpabio (2017) posited that yam ownership and production are primarily associated with gender and class, emphasizing "male achievement" and "social prestige." Among the Nigerian Igbos, yam is the most popular food, and it has a role in social activities such as marriage, burial, and other traditional rites and customs. Similarly, certain households use it at weddings and fertility ceremonies (Verter & Bečvářová, 2015). Cultivating yam is a demanding procedure that emphasizes its importance as a social, economic, and cultural crop, as well as a sign of social rank and authority (Obidiegwu & Akpabio, 2017).

Nutritional and Functional Properties of Yam

Yam contains vitamin B6, vitamin E, manganese, potassium, and diosgenin which has anti-cancer effects (Tortoe et al., 2020). Apart from the importance of yam as food, yam contains anthocyanins, steroidal saponins, and polyphenols, which regulate blood sugar levels and neural functions, prevent heart ailments and build-up of cancer cells (Adebowale et al., 2018; Adomėnienė & Venskutonis, 2022; Gong et al., 2021; Otegbayo et al., 2018; Padhan, Nayak, et al., 2020; Padhan & Panda, 2020).

Moreover, several studies have enumerated the therapeutic, anti-microbial, antimutagenic, and hypoglycaemic potential of species of Dioscorea. Obidiegwu et al. (2020) posited that yam has a considerable number of bioactive compounds including; flavonoids, tannins, saponins, phenols, and alkaloids. In addition, yam contains peptides and proteins that perform pharmacological functions such as antioxidant, immunomodulatory, estrogenic, trypsin inhibiting, and anti-proliferative functions (Obidiegwu et al.,2020).

Similarly, Shan et al. (2020) stated that the health benefits of yam tubers are linked to the presence of bioactive components namely; allantoin and steroidal saponins. Allantoin acts as an anti-irritant, anaesthetic, analgesic, and antibacterial component. In addition, Zhang et al. (2014) posited that Chinese yam contains allantoin which enhances wound healing, cell division, health, and longevity.

Padhan & Panda (2020) reported that the isolates of *D. bulbifera* and *D. alata* possess antifungal effects on *Botryodiploidia theobromae* and the antifungal effects of D. Pentaphylla on *Staphylococcus aureus, Pseudomonas aeruginosa*, and *Streptococcus mutans*. Dutta & Barnali Dutta (2015) reported the consumption of *D. esculenta* for weight gain and powder of *D. pentaphylla* for curing abdominal pain after delivery, tuberculosis, contraceptives, constipation, indigestion, and abdominal pain.

Problems Associated with Yam Production and Processing for Food

Yams contain a considerable number of micronutrients such as vitamins and minerals viz, zinc (5.40±77mg/100g) and iron (9.00±00mg/100g) (Bassey, 2017). It remains a high-caloric food for countries in Sub-Saharan Africa (Abu & Adzigiwe, 2021). In addition, yam is an indicator of wealth and an essential component of social ceremonies and religious activities. However, yam production faces some bottlenecks such as costs of storage and postharvest losses which are estimated to be around 55% under some environmental conditions (Ogbo Frank & Kingsley, 2014). The environmental factors that result in low yields and productivity are drought, pests, and diseases (Banson & Danso, 2013), and other conditions such as scarcity of high-quality yam seed (Boadu et al., 2018), cost of labour, and high cost of inputs (Baffour-Ata et al., 2023).

In addition, Yams are economically produced, however, certain wild species have yet to be cultivated due to lower food quality, limited yield, and the presence of anti-nutritive chemicals (Chen et al., 2017; Padhan & Panda, 2020). Classification of the quality of food attributes inherent in the undomesticated species is necessary for utilization as food and probable cultivation. The quality of food material present in yam involves nutritional and anti-nutritional components (Chen et al., 2017), and physicochemical composition (Otegbayo et al., 2018) which are vital for yam utilization. Otegbayo et al. (2018) posited that classification of the wild varieties in terms of food quality will provide knowledge on the chemical, nutritional constituents, functional, and physicochemical attributes of the several yam cultivars and species that are extensively grown in West Africa, as well as promote the production of shelf-stable products by identifying possible downstream uses for the underutilized yams. In addition, it may offer valuable information that can help plant breeders improve crop nutritional attributes while minimizing antinutritional factors via selection and hybridization (Baiyeri & Samuel-Baiyeri, 2023). Interestingly, the antinutritional components are biosynthesized and act through their reaction with minerals to form complexes that are poisonous to humans and animals as a result reducing nutrient bioavailability (Dogoré Digbeu et al., 2018; Umoh, 2013). Bassey (2017) and Okache et al. (2016) reported that these anti-nutritional factors included phytates, tannins, oxalates, hydrocyanic acid, saponins, and sapogenins acid which exist in low concentrations. Okache et al (2016) defined bioavailability as the degree to which micronutrients are assimilated by the body whereas Dilworth et al (2013) defined bioavailability rather succinctly as the amount of minerals in foods that are accessible for use in normal metabolism.

Phytates have been observed to reduce the bioavailability of minerals through the formation of complex compounds with these minerals. Moreover, iron and zinc deficiency have been linked largely to phytate consumption (Ayele et al., 2015). While oxalates combine with calcium making it unavailable for absorption by the body. Surprisingly, these chemical toxicants are lost through food processing methods such as soaking, cooking, baking, roasting, and oil-frying (Oladebeye et al., 2023) thereby making them harmless with high nutritional availability. Additionally, Processing enhances digestion, taste, and storage quality while also making the yam safer to ingest (Dogoré Digbeu et al., 2018; Kasaye T et al., 2018).

Nonetheless, food processing through cutting and peeling of yams hasten enzymatic browning which occurs as a result of the oxidation of phenols by polyphenol oxidase and peroxidase to quinones which is hydrolysed to produce brown colouration. This browning reaction reduces the nutritional quality, physical appeal, and market value of yams as a result affecting their utilization potential (Chen et al., 2017).

Cassava

Cassava belongs to the *euphorbiaceae* family (Parmar et al., 2017; Perera et al., 2014). Cassava is cultivated through stem cutting that grows into a tiny tree and can be regarded as a semi-perennial crop (Chaweewan & Taylor, 2015; Ferguson et al., 2019; Ikuemonisan et al., 2020). At physiological maturity, cassava plants normally grow to a height of 1 to 4 meters and are harvested between six to ten months for consumption and over twelve months for starch (Ferguson et al., 2019; Legg et al., 2015; S.L. Tan, 2015).

Moreover, the conditions that favour the growth of cassava include a humid hot climate, a temperature of between 25 and 29^{o}C and a yearly rainfall of 1000 to 1500ml (Awoyale et al., 2017; S. Li et al., 2017; Ola & Adedayo, 2020; Perera et al., 2014). Cassava has high adaptation to stresses, pests, and diseases (Adebayo, 2023; Chipeta, 2013a; Ikuemonisan et al., 2020). It grows in marginal soils ranging from medium to high sandy loam fertile soil with enhanced soil porosity (Adebayo, 2023; S.L. Tan, 2015).

Cyanogen is present in every tissue of cassava and is released as hydrogen cyanide by the enzyme linamarase when there is a physical injury. The cyanogen concentration of the storage root pith is used to categorize cassava varieties into two categories: "bitter" and "sweet." "Bitter" varieties are often those with richer starch content in their roots (S.L. Tan, 2015).

Geographical Distribution of Cassava

Cassava is thought to have moved from northern Argentina to the US peninsula of America (S.L. Tan, 2015). Other schools of thought reported that it originated from the south of the Brazilian Rainforest (Ferguson et al., 2019; Ikuemonisan et al., 2020; Otekunrin & Sawicka, 2019). Similarly, studies suggest that the cultivation of cassava began from the northern to the eastern part of South American Countries such as Brazil, Mexico, and Paraguay over a four-hundred-year period (Otekunrin & Sawicka, 2019; Parmar et al., 2017). Studies suggest that the cultivation of cassava crop started ten thousand years ago in the Amazon rainforest making it one of the earliest crops to be grown (Parmar et al., 2017). Though its exact origins are still up for debate, the most recent evidence, according to molecular markers, points to the plant's domestication in the southwestern rim of the Amazon basin (modern-day Brazil(Alene et al., 2018; Edhirej et al., 2017; Tonukari et al., 2015)), where it descended from Manihot. esculenta species, the closest wild relative (Legg et al., 2015).

Incidentally, cassava was propagated to western Africa by Portuguese Merchants in the year 1588 and domesticated around the coast of West Africa and the Congo River (Ferguson et al., 2019; S.L. Tan, 2015). Presently, cassava is cultivated in over a hundred nations, filling the caloric gap of over a million people living in the tropics (Parmar et al., 2017).

Cassava has consistently grown at a rate of more than 3% per year worldwide. In the year 2018, global production reached close to two-hundred and seventy-eight million tonnes with Africa producing one-seventy million tonnes which is equivalent to fifty-six percent of global production (Adebayo, 2023; Alene et al., 2018; Ikuemonisan et al., 2020; Parmar et al., 2017; Visses et al., 2018). Moreover, Nigeria, Thailand, Brazil, and Indonesia, remained the top four largest producers worldwide (Visses et al., 2018) where it serves as a food security crop for close to 800 million people. However, Nigeria (59,411,510 tonnes), DR Congo (40,050,112 tonnes), and Ghana (22,447,635 tonnes) represent the top three producers of cassava in Africa (Adebayo, 2023).

Nutritional and Functional Properties of Cassava

Cassava has starch in large amounts as well as minimal concentrations of protein, fibres, fats, and minerals, and the distribution of nutrients within plant portions varies (Panghal et al., 2021). Li et al. (2017) observed that the amount of starch cassava contains is in the region of 800 g starch per kilogram dry weight and high levels of vitamin C, carotenoids, and minerals, as an ideal energy source for human consumption.

Further, the bulk of cassava's starch is kept in amyloplasts in the swollen root. Interestingly, cassava’s root starch concentration ranges from 70.3% to 80.9% dry weight. However, amylose ranges from thirteen point six to twenty-three-point eight percent, while amylopectin is approximately 83%. Cassava's soluble amylose level was found to be between 10 and 40% of total amylose (Panghal et al., 2021).

Additionally, compared to potatoes, cassava root has a higher carbohydrate content than wheat, rice, yellow maize, and sorghum (Montagnac et al., 2009) per 100g as well as seventy percent moisture, twentyfour percent starch, two percent fibre, one percent protein and three percent minerals (Panghal et al., 2021).

There has been an increased desire to incorporate fibre-rich foods in daily meals, and cassava could potentially be used for this purpose because of its high dietary fibre content. Dietary fibres, particularly those derived from carbs and starch structures, are major factors of low glycaemic index foods (Onodu et al., 2018). Onodu et al (2018) reported that Cassava could be rich in chemicals that are considered hazardous to humans, however roughly 80% of it is eliminated through the processing of the tuber. Studies showed that tuber crops including cassava have a low glycaemic index (GI $<$ 55) and reduced cholesterol levels due to their delayed glucose release into the bloodstream. Further, root crops including cassava are potentially beneficial in reducing the risk of chronic diseases such as cardiovascular disease and diabetes mellitus. Similarly, cassava is dense in resistant starch which helps in managing type 2 diabetes. Resistant starch is described as starch that skips digestion in the small intestine and travels to the large intestine, where it is degraded by gut bacteria (Onodu et al., 2018).

Moreover, cassava remedies digestive ailments (gastritis, gastroduodenal ulcer, and constipation) and liver diseases. Despite being a rich source of calories (610 kJ/100 g fresh weight), cassava is a solution for a host of ailments such as inflammatory, analgesic, and carcinogenic diseases. Additionally, cassava contains calcium, manganese, beta carotene, ascorbic acid, retinol, as well as iron which boosts the red blood cells as a result preventing anaemia (Zekarias Tsige, 2019).

Cassava contains a host of beneficial bioactive substances such as cyanogenic glucosides including but no scopoletin, terpenoids, and flavonoids, which have been observed to possess antioxidant, anti-obesity, antimicrobial, and antidiabetic properties (Chandrasekara & Josheph Kumar, 2016). Besides, cassava has demonstrated a series of pharmacological activities such as antioxidants which fight cancer, inflammation, bacteria, and diabetes; tannins which fight diarrhoea, and catechins which are effective against diabetes and obesity (Mohidin et al., 2023).

Factors Affecting Cassava Utilisation for Food

Several studies opined that cassava utilization has been low over the years due to a myriad of reasons. Among the reasons enumerated is the presence of antinutritional factors in cassava. In general, cassava contains anti-nutrients including phytates, nitrates, oxalates, and saponins that decrease nutrient bioavailability (Bayata, 2019; Zekarias Tsige, 2019). These antinutrients can be synthetic or naturally occurring in cassava and affect micronutrient absorption. The Phytates content of cassava is in the region of 624 mg/100 g of cassava roots which bind to magnesium, iron, calcium, and zinc thereby affecting bioavailability and the utilization of protein. Oxalates on the other hand affect calcium and magnesium availability, and the formation of complex compounds with proteins as a result inhibiting protein digestion (Bayata, 2019).

Besides, cassava contains toxic constituents such as linamarin, and luteotropin which are cyanogenic (Chandrasekara & Josheph Kumar, 2016; Mohidin et al., 2023). These constituents are recognized as harmful to human well-being since they may lead to the development of neurological conditions, particularly when consuming unprocessed cassava. Ferraro et al (2016) reported that cassava has cyanogen in the form of linamarin (ninety-five percent of cyanide) and lotaustralin (five percent of cyanide). Linamarin is found in the flesh of cassava and is produced by valine. Bayata (2019) posited that cyanide is the most poisonous chemical that restricts the eating of cassava roots. Consequently, humans can die of cyanide poisoning after consuming 50 to 100 milligrams of cyanide.

These toxic constituents are toxins and antinutritional in their actions and so cassava must be processed adequately before consumption. Inadequate processing has the potential to leave traces of cyanide which can cause cyanide poisoning and goitre (Alleluyanatha E., 2022; Oluwaniyi & Oladipo, 2017).

Further, the underutilization of cassava has also been due to the preference of cereals for root crops like cassava, small-scale production of casava, and the inaccessibility of cultivars with improved attributes. Cassava cultivation has been the preserve of the peasant farmer in most countries in the global south. This ultimately affects the availability and utilization potential of cassava (Chipeta, 2013b; Mohidin et al., 2023).

In addition, cassava has a short postharvest life. After three to four days following harvest, cassava is liable to decay owing to its bulky nature and high moisture content (Agwu et al., 2015; Alleluyanatha., 2022). Chipeta (2013) reported that decay after the harvest of cassava is shown by an interior colour change which affects the marketability of cassava.

Nevertheless, pests and diseases pose a significant danger to cassava production in Sub-Saharan Africa. The pests of major concern are green mites, mealy bugs, cassava mosaic disease, and bacterial blight (Chipeta, 2013).

Uses of Cassava for Food

Cassava is an essential crop that provides calories for thousands of people as well as providing numerous commercial and industry-related benefits through processing (Awoyale et al., 2017; Edhirej et al., 2017; Legg et al., 2015; Li et al., 2017). Its fibrous root serves as a vital part of the diet of millions of individuals worldwide. Moreover, cassava has been regarded as a "poor man's crop" because it is primarily consumed by those who live in poverty (Otekunrin & Sawicka, 2019; Perera et al., 2014; S.L. Tan, 2015) and those who cannot pay for higher-cost food cereals like rice (Chaweewan & Taylor, 2015; Ferguson et al., 2019; Mezette et al., 2013). Furthermore, cassava can be cooked, roasted, dried, or fermented before consumption, based on the cultivar (Djeni et al., 2015). Most importantly, cassava is boiled and eaten with sauces or sundried and milled into flour (Oluba et al., 2018). Gari is a staple food produced from cassava which is indigenous to people living in the west African sub-region and can be eaten in the form of ‘eba’ and ‘gari’ soakings (Adebayo, 2023; Akingbala et al., 2005; Atuna et al., 2021). Similarly, gari is prepared using a blend of cassava and orange-fleshed sweet potato as a means of fortification with vitamin A (Abano et al., 2020; Atuna et al., 2021). In addition, cassava is processed into fufu, yakayake, tapioca, cassava flour, attieke (Adebayo, 2023; Awoyale et al., 2017), cassava cakes, biscuits, and noodles (Tonukari et al., 2015) and animal feed (Li et al., 2017; Ola & Adedayo, 2020; Visses et al., 2018). Interestingly, cassava is used as an ingredient for poultry, pork, cattle, and fish feed (Tonukari et al., 2015). Cassava flour is free from gluten and can be used wholly to bake bread, as well as a blend of wheat flour to lower the amount of gluten in the product of interest (Adebayo, 2023).

In addition to being a staple meal in tropical and subtropical regions and feed for animals, it is additionally utilized as a basic ingredient in food processing, textile, pharmaceutical, plastic, and detergent industries due to its high level of starch (Panghal et al., 2021). In developed economies, cassava serves as raw materials for starch production, medicines, and biofuels (Alene et al., 2018; Edhirej et al., 2017; S. Li et al., 2017; Tonukari et al., 2015). In the food industry, cassava starch is processed to yield goods with specific chemical and physical properties for items including custard powders, jelly, gravies, confections, glucose, and baby food (Edhirej et al., 2017). Additionally, in the field of pharmacy, cassava starch is used to coat tablets, as a desiccant to absorb moisture from capsules, and to bind powders together (Tonukari et al., 2015)

The utilization of cassava to produce ethanol and biofuel has drawn a lot of attention in the last ten years because fossil oil sources are finite (Li et al., 2017). Hence, Cassava has so gained popularity as a crop for large-scale plantations and small-scale farming due to its minimal time, labour, and financial input requirements. This ultimately ensures the availability of raw materials for the manufacture of bio-ethanol (Li et al., 2017) which in turn can be used to manufacture organic acids (citric acid and enzymes) (Tonukari et al., 2015).

Gari

Gari also called Garri or tapioca is the most eaten cassava-based food in Sub-Saharan Africa. It is a roasted granular product made from cassava after peeling, grinding, fermenting, and roasting. It is a ready-to-eat food due to its low cost, ease of storage, and simple to prepare (Arinola et al., 2017; Ndjouenkeu et al., 2021; Ngoualem Kégah & Ndjouenkeu, 2023). Fermentation before roasting contributes to the development of the gari's taste, flavour, and colour (Abano et al., 2020). In addition, gari is normally consumed in the form of ‘eba’, or ‘gari soaking’ in conjunction with other food products (Adebayo, 2023; Akingbala et al., 2005; Atuna et al., 2021).

The processing of gari has evolved over the years. There is white gari and yellow gari. White gari is prepared wholly from cassava whereas yellow gari is prepared from cassava dough mixed with yellow food colour or palm oil. Gari’s texture, colour, taste, and swelling ability determine its quality. Fine texture, sweet gari, and higher swelling capacity are mostly preferred by customers (Atuna et al., 2021).

Functional Properties of Gari

Consuming gari can have positive and negative effects on the body. The main problem regarding the consumption of gari is the exposure to toxins owing to inadequate processing of cassava with high cyanogenic glucosides. Ingesting gari rich in toxins may lead to the development of neurological conditions including cyanide poisoning and goitre (Alleluyanatha, 2022; Oluwaniyi & Oladipo, 2017).

Studies suggest that the physical and chemical properties of gari include the amount of moisture of 10.3% to 12.4%, percentage ash of 0.69%

and 0.78%, percentage fat of 0.33% and 0.44%, percentage fibre of 0.48% to 0.66%, (Karim et al., 2015). Teye et al (2017) reported that gari is high in carbohydrates, and fibre, as well as some substantial quantity of calcium, phosphorus, and vitamin C.

Furthermore, the main nutrient in gari is carbohydrates with a minimal amount of protein, fibre, fat, and minerals. This indicates that gari lacks some essential nutrients such as iron, and zinc (Atuna et al., 2021). Similarly, Karim et al. (2015) reported that gari contains a considerably small amount of protein, and therefore lacks important amino acids for good health. Hence, it's important to improve the nutritional quality of gari with easily accessible sources of nutrients.

Numerous studies have employed the approach of food-to-food fortification and preparing gari with biofortified cassava. Amongst them are findings made by Abano et al. (2020) and Atuna et al. (2021). Abano et al. (2020) reported fortifying gari with up to 30% orange-fleshed sweet potato rich in beta carotene improved the vitamin A composition of gari which can resolve the vitamin A menace in Africa. Atuna et al. (2021) on the other hand posited that adding up to 27% orange-fleshed sweet potato enhanced the vitamin A content of the gari with reduced cyanogen content. Additionally, Olatunde et al. (2021) substituted up to 30% of beta carotene-fortified cassava with African yam bean and found that the gari has 16.3-23.5% protein and of beta carotene 19.8-20.3%**.**

Gari Processing in Ghana

In Ghana, the processing of gari is a preserve for rural women on a small scale, thus providing a source of livelihood and food security for the underprivileged, and the disadvantaged (Teye et al., 2017). Lately, the gari processing business in Ghana and around the world is receiving more attention due to its critical role in preserving global food security. The majority of Ghanaian processors are rural and small-scale operators, making quality control exceedingly challenging (Bani et al., 2013).

Gari production in Ghana starts with the peeling of cassava roots with a knife. Washing is done with clean water and then grated by a grating machine. Cassava mash is then bagged in polypropylene sacks and pressed to dewater. Fermentation begins during the process of dewatering for the recommended number of days. Sieving is done on raffia trays to remove unwanted fibre, and roasted in aluminium pans by roasting until crispy.

Many Ghanaians, especially Ashantis, did not like gari; but, as a result of growing commercial activities in the late 2000s, consumption has expanded to encompass the rest of Ghana. Processing methods especially fermentation varies from region to region. Fermentation is usually done for a maximum of four days following frying given the type of cassava cultivar and the particular community's preferred flavour. The methods of fermentation and frying determine the taste, flavour, and colour of the gari. Some Ghanaian processors mix white gari with yellow food colour to improve its appearance (Abano et al., 2020)

There is competition in gari marketing centres, neither buyers nor sellers can decide their prices. Many smallholder units produce gari in main gari-producing areas, and they primarily sell it in village markets. Large markets, which are often smaller, serve as a hub for the assembling of gari from the many smallholder units that surround them (Bani R et al., 2013).

Amongst all the by-products of cassava, Gari remains the product most people in West Africa cherish to prepare, eat, and sell (Esheya, 2021). Similarly, in Ghana, close to 70% of all marketable cassava products are gari. The demand for gari has grown in recent years among consumers particularly students, and the working population in the country and outside (Amoah et al., 2022). Opoku-Mensah et al. (2013) posited that gari manufacturers made GH45 per 50kg of gari, GH25 per 50kg of *agbelima*, and GH40 to 50 per 50kg of high-quality cassava flour. Given such marketing conditions, gari is the most cherished by-product to manufacture and market. Nimoh et al. (2020) posited that gari producers make a revenue of sixty-five thousand seven hundred fifty-six pesewas per year for every fifty-two thousand and fifty-two kilograms of cassava processed with a total production cost of fifty-one and forty pesewas and a mean net income of fourteen thousand seven hundred and sixteen cedis seven pesewas making gari production a profitable enterprise.

Effects of Fermentation on the Physicochemical Quality of Gari

Through fermentation, raw food products can be converted into more valuable products that have more nutrients and improved gut health characteristics (Xiang et al., 2019). Abano et al. (2020) posited that a surge in fermentation duration causes an upsurge in beta carotene content of OFSP gari and results in about 2.5 times more than the orange-fleshed sweet potato quantity. This according to the authors could also be due to the reduction in dry matter as microorganisms break down starch and proteins. However, fermentation decreased the swelling power of the OFSP gari as opposed to the potato amount. This is because fermentation degrades the carbohydrate in the

OFSP-cassava mash to produce lactic acid which reduces the amount of carbohydrates.

Additionally, Fermentation had a positive effect on the taste, texture, flavour, and overall acceptability of beta carotene gari than the orange-fleshed sweet potato amount (Abano et al., 2020)

Further, Abiodun et al. (2020) reported an enhancement in the protein amount of gari with the duration of fermentation as well as fibre content. This is due to the loss of dissolvable solids as a result of improving the amount of fibre of the gari. However, the amount of ash decreases as fermentation duration increases. This could be due to the solubility of some minerals during the dewatering process. In contrast, fermentation boosted iron and zinc amounts of whole cassava gari but was higher in gari processed with blended breadfruit. This is because breadfruits are denser in zinc and iron amounts than cassava (Ajifolokun & Adeniran, 2018).

Interestingly, microbes perform an essential function in the conversion of starch to organic acids. For example, in research conducted by Escobar et al. (2018), the PH of a dewatered fermented cassava mash was somewhat more than the PH of a fermented mash. However, gari processed from both mashes had lower PH due to the conversion of starch to acids. In addition, screw-pressing of a grated mash decreased the cyanide content by 84% owing to the *linamarase* activity and dewatering. Moreover, fermentation reduced cyanide by 72%. This is attributable to the actions of lactic acid bacteria *linamarase* and the solubility of cyanogens in water (Escobar et al., 2018).

Effects of Roasting on the Physicochemical Quality of Gari

Roasting as a thermal processing method that increases food's digestibility, flavour, and bioavailability while also enhancing nutrient bioavailability by altering the physical, chemical, and structural characteristics of the food product (Sruthi et al., 2021). Furthermore, roasting imparts colour, flavour, aroma, and antioxidants to food while also causing the food product to gelatinize and expand (Kotsiou et al., 2021; L. Li et al., 2023; Mohamed Ahmed et al., 2020; Sruthi et al., 2021).

Findings by Amoakoah Twum et al. (2021) who worked on the effects of roasting on soybean gari fortified with iron showed that antinutritional amounts such as oxalates (0.048mg per 100g to 0.199mg per 100g), phytates (0.510mg per 100g to 1.512mg per 100g), and tannins (0.0140 mg per 100g to 0.027mg per 100g) of the fortified gari increased due to the increment in amounts of soybean used. However, the unheated soybean flour had the largest amounts of these antinutritional factors but was reduced upon heat treatment at a temperature of 80^{o}C. Moreover, fortification of soybean gari mixed with iron prior to roasting had the highest iron amount (1.90mg/100g) whereas soybean gari fortified with iron post roasting was lower than the former (1.03mg/100g). Other minerals examined in the research saw a similar trend; Ca (.15 - 15.81 mg/100g), Na (0.83 - 11.51 mg/100g), Mg (3.81 - 9.27 mg/100g), and Zn (0.4-1.82 mg/100g). Generally, minerals withstand food processing methods. Moreover, thermal processing has been noted to enhance iron amounts and bioavailability (Arinola & Olanrewaju, 2016). Similarly, the amount of ash in gari was found to increase when roasting was increased though it was less than the allowable limit in gari (Arinola & Olanrewaju, 2016).

Additionally, Amoakoah Twum et al. (2021) indicated that fortifying soybean gari with iron before roasting profoundly affected the colour of the gari. The brightness (L*) and brownness (a*), saw a substantial increase in values. Specifically, the largest L* value of 72.82 was observed when iron was added post roasting while a* value of 2.72 was noted when iron was added before roasting. However, the yellowness (b*) decreased when iron was added.

Arinola & Olanrewaju, (2016) reported that an increase in roasting time enhanced the protein amount. This was attributed to degradation of antinutritional factors bonded the available proteins during the roasting process. However, the amount of fibre decreased substantially with increased roasting time. This was attributed to the thermal degradation of fibres in the food subjected to elevated temperature during roasting.

Storage

Effects of Storage on the Physicochemical Properties of Gari

A host of factors including but not limited to light, oxygen, amount of moisture, temperature and packaging materials could cause the degradation of carotenoids. Numerous studies show the degradation of carotenoids under storage (Dias et al., 2014; Marangoni Júnior et al., 2018; Sonar et al., 2019; Song et al., 2018; Syamila et al., 2019; H. Zhang et al., 2019). Bechoff et al. (2015) reported that the degradation of trans-b-carotene increased with temperature and storage duration of gari packaged in a sewed cotton bag and stored in Kilner jars; this was lowest for the gari made using palm oil and highest for the gari made from yellow cassava. In this study, the Arrhenius model predicted that 13% of trans-b-carotene of the biofortified gari with RAE (retinol activity equivalent) of 301 would have been retained if the biofortified gari was stored at 25 8°C for 6 months. Therefore, when working with biofortified gari, it is not advisable to use traditional gari storage methods.

Similarly, Udemba et al. (2023) mentioned that the total carotenoid counts of gari prepared from yellow-fleshed cassava root decreased from 7.49 µg/g and 15.19 µg/g to 1.65 µg/g and 2.09 µg/g under light and dark conditions. The decrease was attributed to exposure to light. In addition, it was reported by Oluwamukomi & Adeyemi (2015) that at 20°C and 30°C, the moisture content rose from roughly 9.36% to approximately 9.43% and 9.7%, respectively, whereas at 40°C, it decreased for soy-melon gari packaged in sack and high-density polyethylene material. Oluwamukomi & Adeyemi (2015) posited that the hygroscopic characteristics of soy-melon "gari" particles and the ambient relative humidity may have caused these variations in moisture content with variations in storage temperature. Moreover, the free fatty acid content rose when the temperature was 30°C. This was attributed to the influence of lipid oxidation in the presence of high moisture content. Further, Oluwamukomi & Adeyemi (2015) observed that after almost 20 weeks of storage at an elevated temperature of 40°C, browning rose significantly, moving from a monthly change in absorbance of 0.02 nm to 0.035 nm. This was attributed to Millard reaction at a storage temperature of 40°C. Similarly, the total viable count of bacteria up to 12 weeks of storage, increased initially before declining once more. As the air temperature approached 30°C, the amount of mould grew; yet, during the study period, no visible mould colonies were found at 40°C. This must have been due to the combined effect of prolonged heating at 40ºC and relative humidity of 45%, which must have made the environment unsuitable for growth and proliferation therefore leading to their reduction.

The cyanide content of biofortified gari was low (1 mg/L CN-1) upon storage but diminished after 6 months as described by Abiodun et al. (2020). The decrease in the amount of cyanide was attributed to the hydrogen cyanide's volatility after storage. However, colour difference saw an upsurge throughout storage, demonstrating how the gari's colour deviated from the normal colour. Because β-carotenoids are thought to be the main cause for the yellow pigments in meals, this could be because β-carotene is depleted during fermentation. Similarly, Abiodun et al. (2020) reported that the brightness and brownness of the biofortified gari increased for a protracted storage duration, thus whitening the gari at 6 months of storage. Moreover, scores for PH increased during storage. This may be due to the rancidity of the gari by hydroperoxide which invariably reduced the colour from two months of storage. Nevertheless, the low swelling capacity recorded was attributed to high temperature, level of gelatinisation, and moisture content.

The cyanide content of biofortified gari was low (1 mg/L CN-1) upon storage but diminished after 6 months as described by Abiodun et al. (2020).The decrease in the amount of cyanide was attributed to the hydrogen cyanide's volatility after storage. However, colour difference saw an upsurge over the course of storage, demonstrating how the gari's colour deviated from the normal colour. Because β-carotenoids are thought to be the main cause for the yellow pigments in meals, this could be because β-carotene is depleted during fermentation. Similarly, Abiodun et al. (2020) reported that the brightness and brownness of the biofortified gari increased for a protracted storage duration, thus whitening the gari at 6 months of storage. Moreover, scores for PH increased during storage. This may be due to rancidity of the gari by hydroperoxide which invariably reduced the colour from two months of storage. Nevertheless, the low swelling capacity recorded was attributed to high temperature, level of gelatinisation, and moisture content.

Economic Importance of Gari

Amongst all the by-products of cassava, Gari remains the product most people in West Africa cherish to prepare, eat, and sell (Esheya, 2021). Similarly, in Ghana, close to 70% of all marketable cassava products are gari. The demand for gari has grown in recent years among consumers particularly students, and the working population in the country and outside (Amoah et al., 2022). Opoku-Mensah et al. (2013) posited that gari manufacturers made GH45 per 50kg of gari, GH25 per 50kg of *agbelima*, and GH40 to 50 per 50kg of high-quality cassava flour. Given such marketing conditions, gari is the most cherished by-product to manufacture and market. Nimoh et al. (2020) posited that gari producers make a revenue of sixty-five thousand seven hundred fifty-six pesewas per year for every fifty-two thousand and fifty-two kilograms of cassava processed with a total production cost of fifty-one and forty pesewas and a mean net income of fourteen thousand seven hundred and sixteen cedis seven pesewas making gari production a profitable enterprise.

Transforming cassava into other products provides avenues for employment, value addition, and waste reduction, and enhances the business prowess of cottage folks (Amoah et al., 2022; Esheya, 2021). This thus provides an avenue for expansion and sustainability of the gari business (Esheya, 2021; Nimoh et al., 2020). Cassava processing guarantees a higher revenue for processors as high as 50% (Opoku-Mensah et al., 2013). Moreover, enhancing gari production in Ghana has addressed food security menace as well as generating income for an improved standard of living especially amongst women (Nimoh et al., 2020). The Gari manufacturing industry has shown to be an important small and medium enterprise in West Africa, creating jobs, and the GDP of most countries (Fuseini, 2022). The ability of the gari business to enhance the standard of living is remarkable given its high demand in the market. Coincidentally, the cost of production is comparatively cheap, an entirely artisanal-based agro-processing enterprise with maximum returns. The long storage life and the ready-to-eat nature of gari ensure convenience and boost the trade of the product in Ghana (Opoku-Mensah et al., 2013).

CHAPTER THREE

MATERIALS AND METHODS

Sample Acquisition and Preparation

Fresh cassava (*afisiafi*) was bought from Jukwa in the Cape Municipality and yam (*D. praehensilis*) was bought from Sefwi Debiso in the Western North Region was sent to Duakror in Cape Coast for gari processing. The cassava was peeled and any infested parts were removed. The cassava was then washed in clean water to remove sand and impurities and then packed into clean aluminium basins before weighing. Yam tubers (*D. praehensilis*) were peeled directly into a mixture of 1% citric acid and 0.5% ascorbic solutions and then allowed in the solution for 1 hour to reduce enzymatic browning. A 3kg of each sample (cassava and yam) was weighed and mixed based on the design requirements as shown in Table 1 and Figure 1 below**.** The samples were then ground into a smooth dough. The dough was put into polypropylene sacks, tied and pressed to remove water, and then allowed to ferment for days (1-3 days) in the open.

Roasting of Composite Yam-cassava dough into Composite Gari

Roasting of gari occurred at Duakror, a locality in the Cape Coast metropolis. The composite yam-cassava dough which has been packed into sacks was screw-pressed and allowed to ferment for days one, two, and three. Specimen were sampled for 24 hours representing day one, 48 hours representing day two, and 72-hours representing day three of the fermentation duration. Each sample of the composite yam-cassava dough was sieved using 1.2 mm screens and roasted to a moisture content of 5.6 ± 1.2% (in aluminium pans) based on the fermentation duration (FD) and roasting temperature (RT) as shown in Table 1**.** An IR thermometer (-4 to 950ºF/-20 to 510ºC) was used to measure the temperature that causes the cassava-yam composite gari to gelatinize, dry out, and become crisp. The gari was permitted to cool to a temperature of 35ºC in a clean bowl and packed in white airtight polythene. The Screening was not done for the cassava-yam composite gari sample but was done for the controls (whole cassava gari) using 0.6 mm screens to produce uniform gari texture and then packed back into the white polythene bags for analysis.

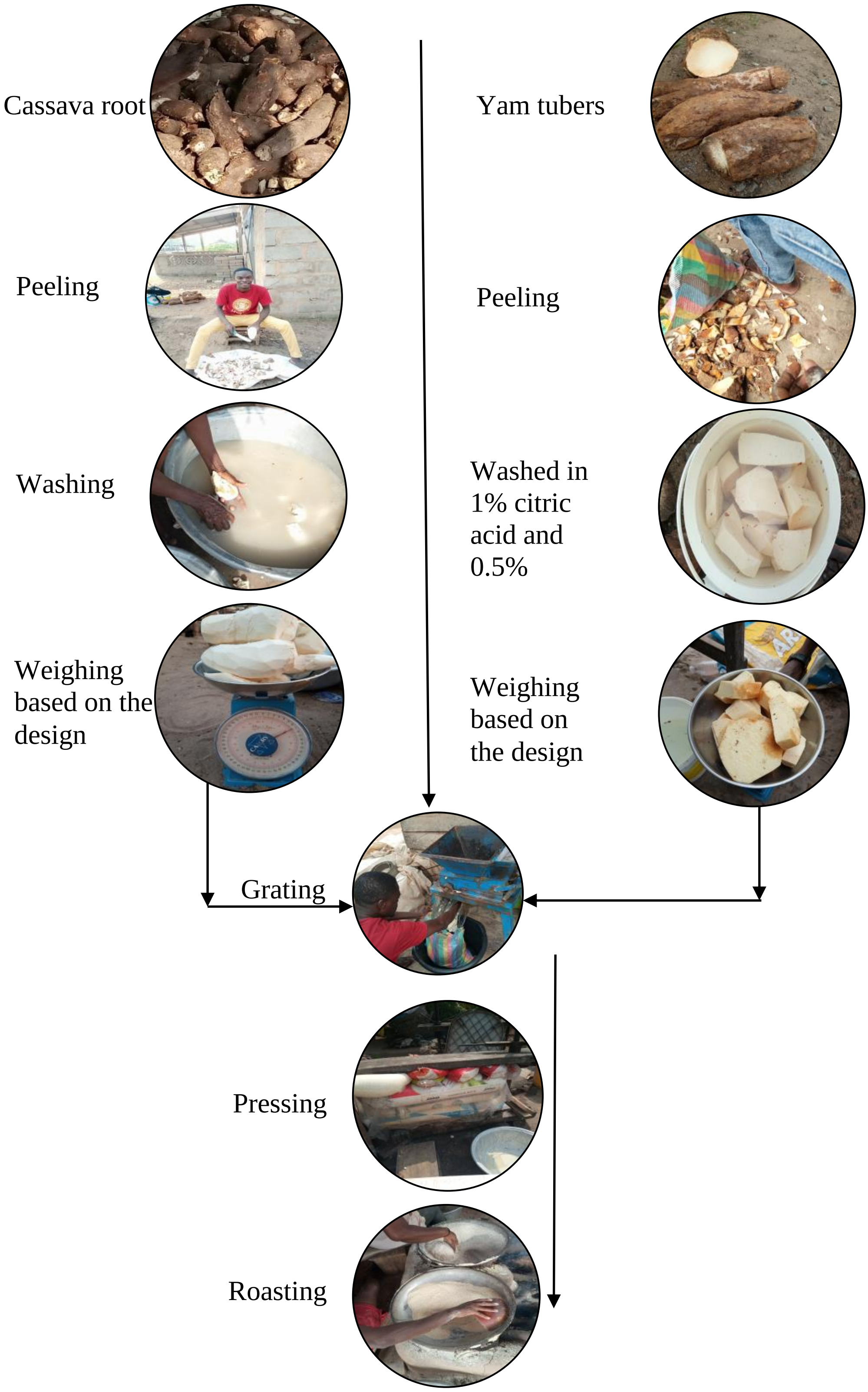


Figure 1: Flow diagram of cassava-yam gari

Analyses of Gari
Measurement of Colour

The colour properties of the were measured in Hunter's parameters using an automatic colour difference metre (6CR-410, Wavelength 60nm Japan). To calibrate the machine before use, the tip of the source of measuring light flux was placed against the surface of the white calibration plates provided by the producer. Colour measurement was then carried out on the samples depicting L*, a*, b*, and hue angles were calculated. The values of the L*, which range from zero (black) to one hundred (white), represent the brightness of gari. Whiteness (plus sixty) and redness (plus one hundred) are determined by the chromaticity, a*. The chromaticity coordinates, a* and b*, measure yellow if positive and blue if negative, respectively, and measure redness if positive (+60) and greenness if negative (60). The browning index and colour difference were also determined using the following equations;

Browning index, BI = $\frac{100(X-0.31)}{0.17}$ (1)

Where X = $\frac{a+1.75L}{5.645L+a-3.01b}$

Colour difference, ΔE = $\sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$ (2)

Colour difference = $\sqrt{(L*-Lo)^2 + (a*-ao)^2 + (b*-bo)^2}$ (3)

where L_o, a_o, and b_o are the original brightness, brownness, and yellowness of the cassava mash, respectively, whereas L, a, and b are the brightness, brownness, and yellowness of the composite gari, respectively.

Swelling Capacity Determination

Swelling capacity (SC) was calculated based on a procedure described by Abano et al. (2020) with slight modifications. A 3g of yam gari sample was put into fifty mils measuring cylinder which was initially cleaned and dried.

The gari was levelled by simply taping the cylinder and the volume, V_1 was determined. 30millimetres of distilled water were added followed by swirling of the measuring for about a second. The cylinder was then permitted to stand for one hour and volume, V_2 was determined. The procedure was repeated for all the samples and the S.C of the cassava-yam composite gari samples was calculated from the equation below;

$$\boldsymbol{S.C} = \frac{\boldsymbol{V2-V1}}{\boldsymbol{V1}} \quad (4)$$

Sensory Evaluation

Sensory analysis was done at the University of Cape Coast using students of the University. The selection of the sensory panels was based on their availability and willingness to take part in the exercise, they are students and so they eat gari regularly, they were healthy and without any history of reaction to gari, they could identify colour of any product and express their taste perception regarding sweet, bitter, and umami taste. A panellist of 50 students was chosen and semi-trained to identify and arrogate scores to quality characteristics of the yam gari samples such as appearance, texture, flavour, taste, and overall acceptability. Samples were offered to panellists in transparent containers during the early hours of the day at 9:00 am. Before sensory evaluation, it was ensured that no panellist had eaten prior to the sensory exercise. Panels were offered water to intermittently wash their mouth as they tested the samples. The panels established sensory properties of the yam gari product using a nine-point hedonic scale designated as 1-dislike extremely, 2-dislike very much, 3-dislike moderately, 4-dislike slightly, 5-neither like nor dislike, 6-like slightly, 7-like moderately, 8-like very much, and 9-like extremely.

Determination Of Beta-Carotene Content of The Cassava-Yam Composite Gari

The vitamin A precursor content of the composite dough and processed gari will be determined according to a technique outlined by Abano et al. (2020) with minor adjustments. 1g of dough and processed gari will be loaded into a volumetric flask containing ten millilitres of ethanol and allowed for 20 min while shaking intermittently. The quantification of the beta carotene with ethanol will be done three times to ensure that all the colour is removed from the samples. The resultant solution will be filtered using 0.45-µm filter paper. 15ml of petroleum ether (40 to 60ºC) will be mixed with the filtrate to mix well by shaking and the mixture left to stand for 20min forming a two-layered solution. The top layer which is the β-carotene will be pipetted for the absorbance measurement at 450 nm wavelength against a blank of petroleum ether. The amount of β-carotene will be calculated by the expression below;

$$\text{Total carotenoids} = \frac{ABS \times V(ml) \times 10000}{2592 \times W\,(g)} \qquad (5)$$

Determination of Iron and Zinc Content of the Composite Cassava-yam Gari

Micro nutritional content was quantified based on a procedure described by Faustina Dufie et al. (2013) with slight modifications. A 0.4g gari specimen was put into a 100mL Kjeldahl flask, 4.4mL of mixed digestive solution was added and the samples were digested at 360°C for two hours.

Blank digestions were performed similarly. Following digestion, digested substances were proportionally poured into 100mL volumetric flasks and diluted to the volume.

Standard solutions of 1, 2, and 5μg/mL solutions of Fe and Zn were prepared. The standard solutions were put into the atomic absorption spectrophotometer (AAS), and the resulting calibration curves were displayed on the instrument. As the sample solutions were aspirated, their amounts were recorded.

Iron (Fe) and zinc (Zn) content were calculated using the formula below.

$$\text{Fe } (\mu g/g) = \frac{C\left(\mu\frac{g}{ml}\right) \times solution\ volume\ (ml)}{sample\ weight\ (g)} \quad (6)$$

$$\text{Zn } (\mu g/g) = \frac{C\left(\mu\frac{g}{ml}\right) \times solution\ volume\ (ml)}{sample\ weight\ (g)} \quad (7)$$

Optimisation of the Composite Cassava-yam Gari

The optimisation of the gari was done using the response optimiser in Minitab Statistical Software 19. In this research, optimisation goals including maximise, minimise, and target were employed for the factors and responses. Moreover, the goal for the yam quantity, fermentation duration, and roasting temperature were within the design limit. Nevertheless, maximising SC, brightness, brownness, appearance, flavour, taste, texture, overall acceptability, and beta-carotene was recommended in this study. Equation 8 as reported by (Abano et al., 2020) was used for quantifying the composite desirability. From equation 8, n represents the number of responses, di represents desirability index for each variable, Yi represents the optimisation method for exhibiting the desirability of the several responses considered in this research, and CDI represents the composite desirability Index with a scale of zero to one.

$$CDI = \left[\prod_{i=1}^{n} di(Yi)\right]^{\frac{1}{n}} \quad (8)$$

Storage Study of the Optmised Gari

The packaging materials (polyethylene PE, polyethylene/polyethylene terephthalate PE/PET, polyethylene terephthalate/aluminium PE /PET/Al) were purchased from the local market. The packaging materials were chosen because of easy accessibility on the Ghanaian market and are used for packaging dried foods. The PE and PE/PET/Al were ready-made and with dimensions 11cm×13cm while the PE/PET was designed into a pouch with dimensions 11cm×13cm using the KRUPS Vacupack device.

The effects of packaging materials on the physico-nutritional qualities of the optimized gari were carried out as reported by Dufera et al. (2023) with few modifications. 40grams of optimized gari was packaged in pouches designed with PE, PE/PET, and PE/PET/AL packaging materials, sealed with the KRUPS Vacupack device and stored under three storage environments; supermarket (SM), room storage (RM), and open market (OM) while making sure the packages were completely sealed to prevent moisture and oxygen migration to the food samples. At the one-month interval, nine samples of the optimized gari were randomly selected (sampled) from the packaging materials, three from each for nutritional (iron and zinc), colour, and sensory analysis for a five-month storage period.

Techno-Economic Assessment of Producing One Tonne (1000kg) of The Optimized Cassava-Yam Composite Gari

The cost of producing a tone (1000kg) in a year was carried out as reported by Dimopoulou et al. (2021) with slight alterations. Specifically, fixed and variable costs (operating costs) involved in gari processing were considered to determine the economic viability of producing 1000kg of the optimized gari. The fixed cost included the cost of machines/tools, housing facilities, depreciation, taxes, and insurance. Operating costs included the cost of raw materials, fuel, repairs and maintenance, and the cost of unit operations at each stage of the Gari production process. The machine's total cost is the sum of its total fixed and variable costs. Depreciation of machines (grater, screw press) was computed using Hunt's (1983) straight-line method, using Equation 9, and interest on machine ownership was calculated using Equation 10.

$$\text{Depreciation} = \frac{Cost\ price - salvage\ price}{Economic\ life} \quad (9)$$

$$\text{Interest} = \text{Rate}\ \frac{Cost\ price + salvage\ price}{2} \quad (10)$$

Taxes, insurance, and shelter were determined at 1.0% of the cost price. Repairs and maintenance costs were 5% of the cost price whereas costs of labour depended on the number of workers to process 1000kg of gari. From the total cost of processing 1000kg of gari, revenue, profit, and break-even cost were determined.

Experimental Design

The design chosen for the optimisation study was Box Behnken's design with a three-factor, three-level response surface as shown in (Table 1**).** This design has a variety of responses, including three factors that aid in optimization. Various yam proportions ranging from 10 to 30% were selected because of a similar study for orange flesh sweet potato (OFSP) gari (Abano et al., 2020). The FD of 1 day (24 hours) to 3 days (72 hours) was chosen based on how long the cassava dough must ferment before being processed into gari. A roasting temperature of 100^{o}C to 140^{o}C was chosen based on a preliminary investigation into cassava-yam composite gari.

15 experimental runs were produced from the composite with three centre points using Minitab software 19. Yam was not added to the control samples (cassava gari). The outcome of the three factors on gari colour (L*, a*, and b*), SC, sensory characteristics (flavour, taste, texture, and overall acceptability), and nutritional contents (Zn and Fe) were examined. $3^2 \times 3$ factorial arrangement in a completely randomized design was used for the effects of storage conditions and packaging materials on the physico-nutritional qualities of the optimized gari.

Statistical Analysis

Data was analysed using analysis of variance technique using Minitab 19 to determine the effects of YQ, FD, and RT on colour, SC, and sensory attributes of the yam gari at a significance level of 5% ($p<0.05$). Surface plots for the independent variables (FD, YQ, and RT) and the residuals (SC, colour, and sensory attributes), and quadratic models were generated. $3^2 \times 3$ factorial was used for the effects of storage conditions and packaging materials on the sensory and nutritional qualities of the optimised gari.

CHAPTER FOUR

RESULTS AND DISCUSSION

Table 1: Results from the Response Surface Methodology (RSM) for the yam composite gari

X_1 (%)	X_2 (days)	X_3 (ºC)	SC	L*	a*	b*	Appearance.	Taste	Texture	Flavour.	Overall.	Fe (µg/g)	Zn (µg/g)	B. Carotene
30	3	120	2.66	33.72	-0.90	8.70	6.51	6.75	6.88	7.23	7.16	241.49	85.92	3.36
20	1	100	3.20	30.69	-0.16	9.36	6.15	5.91	6.51	5.30	6.09	286.45	54.14	7.05
10	3	120	3.40	36.63	-2.50	8.03	6.32	6.34	6.24	6.39	6.60	205.01	41.25	4.09
20	3	140	3.82	38.87	-3.62	7.17	7.21	6.42	6.60	6.89	7.18	241.99	53.34	9.10
10	1	120	3.40	33.95	-1.09	8.90	7.15	6.62	6.82	6.64	7.15	198.24	65.81	4.69
20	2	120	2.90	35.54	-1.72	6.36	6.84	6.21	7.10	6.52	6.82	261.58	51.66	8.89
20	3	100	3.18	36.34	-1.91	9.16	6.27	7.42	6.88	6.69	7.46	171.42	44.04	4.30
30	2	140	2.60	34.40	-1.29	7.68	7.16	6.79	7.31	6.98	7.15	213.74	69.91	5.00
20	1	140	3.00	32.63	-0.21	10.5	6.38	6.79	6.93	7.07	6.96	205.56	55.38	5.30
30	1	120	2.75	27.42	-0.15	6.42	6.89	6.00	6.39	6.28	7.04	219.36	56.32	8.00
10	2	140	3.10	37.63	-2.46	8.20	7.02	6.11	6.81	6.14	7.15	127.96	39.62	4.82
30	2	100	2.65	35.38	-1.57	8.96	7.30	6.82	6.98	6.69	6.97	200.42	53.86	4.36
10	2	100	3.20	37.11	-2.45	6.80	6.59	6.47	6.75	6.37	7.00	190.22	37.21	6.80
20	2	120	3.12	36.35	-2.11	7.60	6.80	6.19	7.00	6.50	6.85	195.01	41.21	8.01
20	2	120	2.99	35.94	-1.92	6.98	6.90	6.57	6.92	6.57	7.00	202.66	37.21	7.82
Cont.	1	120	4.00	39.93	-3.59	8.79	8.38	7.82	7.64	7.82	8.44	175.32	30.00	4.60
Cont.	2	120	3.82	40.62	-3.49	7.47	7.91	7.88	7.61	7.44	8.20	189.44	34.28	4.40
Cont.	3	120	4.10	40.50	-3.52	7.35	8.01	7.07	7.41	7.64	8.13	151.22	34.86	4.55

X_1 = yam quantity (YQ) in %, X_2 = fermentation duration (FD) in days, X_3 = roasting temperature (RT) in ºC, SC = swelling capacity, L* = brightness of the cassava-yam composite gari, a* = brownness of the cassava-yam composite gari, b* = yellowness of the cassava-yam composite gari, Fe = iron content measured in µg/g, Zn = zinc content measured in µg/g, and Cont.= control

Table 2: Results of browning index (BI) and colour difference from the Response Surface Methodology (RSM) for the yam composite gari

X_1 (%)	X_2 (days)	X_3 (°C)	BI	ΔE
30	3	120	207.52	9.65
20	1	100	215.52	12.74
10	3	120	199.36	6.43
20	3	140	193.22	4.30
10	1	120	207.67	9.36
20	2	120	196.07	8.10
20	3	100	204.73	6.84
30	2	140	202.26	8.97
20	1	140	217.82	11.02
30	1	120	206.10	16.06
10	2	140	199.43	5.50
30	2	100	205.55	7.86
10	2	100	195.22	6.32
20	2	120	198.92	6.90
20	2	120	197.50	7.49
Cont.	1	120	197.78	2.89
Cont.	2	120	193.75	2.76
Cont.	3	120	193.37	2.91

BI = browning index, ΔE = colour difference, and cont.=control

Table 3: Regression Coefficients of Yam Quantity (X_1), Fermentation Duration (X_2), and Roasting Temperature (X_3

Response	β_0	X_1	X_2	X_3	X_1^2	X_2^2	X_3^2	X_1X_2	X_1X_3	X_2X_3	R^2
SC	2.25	-.009	-.241	0.032	-.0006	0.126	-.0001	-0035	0.00006	-.0019	97.93%
p-value		0.000	0.378	*0.04	0.313	*0.03	0.313	0.298	0.809	0.477	
L*	59.3	0.125	7.46	- .532	- .007	1.973	.00241	0.106	-.00187	0.0073	95.35%
p-value		*0.003	*0.00	0.252	0.255	*0.00	0.146	*0.02	0.531	0.804	
a*	-9.8	0.005	0.11	0.132	.00137	0.506	-.0004	-.0229	0.00036	.00036	87.00%
P-value		*0.04	*0.00	0.448	0.700	0.151	0.618	0.297	0.833	0.245	
b*	31.5	0.335	- 0.39	-.445	-.0006	1.010	0.0024	0.0443	-.00335	- .0393	70.76%
p-value		0.949	0.595	0.793	0.909	0.062	0.089	0.177	0.202	0.143	
Appearance	6.17	-.002	-0.35	0.013	.00198	0.230	-.00003	0.0089	-0.0007	0.0088	84.71%
p-value		0.483	0.834	0.212	0.468	0.243	0.950	0.469	0.476	0.380	
Taste	10.96	-.097	2.408	-.091	.00004	0.014	.00053	.02763	.00042	.02348	90.74%
p-value		0.319	0.070	0.534	0.978	0.920	0.181	*0.01	0.553	*0.01	
Texture	6.67	-.019	1.968	-.019	.00093	-.291	.00014	0.0136	.000337	- .0088	91.77%
p-value		0.093	0.662	0.310	0.331	*0.00	0.310	*0.03	0.456	0.080	
Flavour	0.70	-.137	1.92	.0765	.00088	0.063	-.00016	.02166	0.00065	-.0196	89.28%
p-value		0.098	*0.03	*0.04	0.592	0.674	0.701	*0.05	0.415	*0.03	
Overall	6.09	-.080	1.59	-.001	.00123	- .007	.00014	0.0157	0.00004	-0.0143	89.67%
p-value		0.620	0.172	0.293	0.438	0.960	0.711	0.121	0.960	0.084	
Fe (µg/g)	-228	- 9.09	- 121	0.349	0.349	6.5	-.0513	0.315	- 0.0263	0.733	80.57%
p-value		*0.038	0.946	*0.05	*0.03	0.616	0.172	0.708	0.698	0.296	
Zn (µg/g)	537	-13.6	- 51.2	- 5.23	0.0938	6.86	0.013	0.018	0.0804	0.166	76.91%
p-value		*0.035	0.699	0.433	0.165	0.180	0.724	0.245	0.434	0.716	
B. carotene	-50.9	0.931	7.56	0.738	0.0076	-.711	-.00262	0.0329	-.00436	-.0395	94.28%
p-value		*0.00	*0.03	*0.00	0.071	0.068	*0.023	0.168	*0.039	0.055	
BI	469	-1.52	–47.6	–3.38	0.0103	5.04	0.01087	-0.207	0.0114	0.223	77.66%
p-value		0.445	*0.031	0.333	0.72	0.091	0.161	0.252	0.421	0.139	
ΔE	79.4	-0.26	–0.8	–1.08	–0.0022	1.36	0.00401	–.0669	0.00424	–.0334	66.95%
p-value		0.843	0.534	0.125	0.894	0.392	0.356	0.511	0.604	0.681	

*Significant $p < 0.05\%$, β_0 is the intercept of the model. X_1^2, X_2^2, and X_3^2) are the curvature effects of yam quantity, fermentation duration, and roasting temperature. X_1X_2, X_1X_3, and X_2X_3 are the interaction effects of yam quantity, fermentation duration, and roasting temperature

Effects of Yam Quantity, Fermentation Duration, and Roasting Temperature on the Colour of the Gari

Colour is one of the quality parameters of gari. It enhances the appearance of the gari thereby influencing consumer perception. Adebayo B. Abass et al. (2012) posited that colour of gari should be unique; white or cream. Consumers prefer gari that is uniform and bright in colour. White gari is mostly deemed pure by Ghanaians. From Figure 2 (a) adding yam to cassava dough decreases the brightness of the cassava-yam composite gari while FD increases the brightness. However, both YQ and FD had a significant ($p<0.05$) effect on the brightness of the cassava-yam composite gari as well as the curvature and interaction effects of fermentation duration. Interestingly, RT was not significant ($p>0.05$) in addition to its curvature and interaction effects. Additionally, the addition of yam to cassava dough and FD affected the brightness positively indicating an increase in brightness whereas the RT affected it negatively as shown by the regression model 11. Nevertheless, FD contributed to the brightness more (59.68 times) than YQ and (-14.02 times) than RT decreasing the brightness as depicted by the regression model 11. The decrease in brightness may partly be due to the colour of the yam used in the formulation as the yam undergoes high enzymatic browning and wholly due to a high roasting temperature which may promote caramelisation of sugars and Maillard reaction during the thermal processing. This finding agrees with Guo et al. (2022) and Tekgül Barut et al. (2023).

The brownness of the cassava-yam composite gari was positively affected by YQ, FD, and RT as shown by the regression model 12 and Figure

2 (b) indicating that an increase in each of the independent variables causes a corresponding increase in the brownness. Additionally, YQ and FD affected the brownness with a statistically significant effect ($p<0.05$) as shown in Table 4. However, the curvature and interaction effects for all processing variables were not significant ($p>0.05$). Moreover, RT contributed more to the brownness than FD (1.2 times) and YQ (26.4 times) as shown in regression model 12. This may be due to the non-enzymatic browning induced by the caramelisation of sugars as was reported in similar research works which involved orange-fleshed sweet potato gari (Abano et al., 2020) and bread (Soleimani Pour-Damanab et al., 2014). This suggests that reducing the FD to a day (24 hours), RT to around 100ºC, and yam quantity will significantly reduce the brownness. This is necessary because brown gari is not desirable in the Ghanaian market, therefore, reducing the brownness will boost its desirability. Further, the browning index (BI) was negatively affected by all three processing variables (regression model 15) indicating an increase in BI when the processing variables decrease and vice versa. However, YQ contributed more to the BI than FD and RT as shown in Table 3 **(**formulations with 20% and 30% have the highest BI) and regression model 15. Moreover, FD has a significant effect ($p<0.05$) on the BI while YQ and RT were not significant as well as the curvature and interaction effects of all processing variables. Similar trends were observed for colour difference (ΔE); however, the FD was not significant as observed in the latter. This finding is consistent with Younge et al. (2022) who reported an increase in ΔE of fufu when the OFSP amount was increased. The relevance of determining ΔE is for matching

colours accurately and measuring colour change over time (Younge et al., 2022).

The yellowness of the yam gari was negatively affected by FD and RT (as shown by the coefficients of the regression model 13) which implies that an increase in both FD and RT decreases the yellowness of the yam gari. However, YQ affected the yellowness positively. The yam quantity contributed more to the yellowness than FD and RT, though it was not significant as depicted by Table 4. This observation is highly expected because the yam used for the gari processing was not purely white. This observation is consistent with Abano et al. (2020) who reported an enhancement in yellowness of OFSP gari with an increment in OFSP amount. Moreover, all the processing variables were not significant as well as the curvature and interaction effects.

$$Y_{L*} = 59.3 + 0.125 X_1 + 7.46X_2 - 0.532 X_3 - 0.00733 X_1^2 - 1.973 X_2^2 + 0.00241 X_3^2 + 0.1062 X_1X_2 - 0.00187 X_1X_3 + 0.0073 X_2X_3 \quad (11)$$

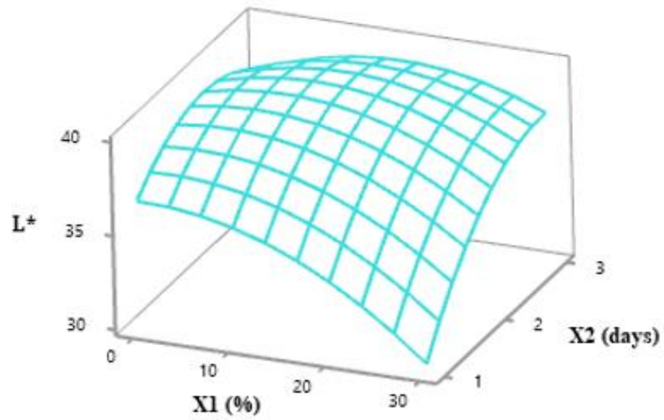
$$Y_{a*} = -9.8 + 0.005X_1 + 0.11X_2 + 0.132 X_3 + 0.00137X_1^2 + 0.506 X_2^2 - 0.000444X_3^2 - 0.0229X_1X_2 + 0.00036X_1X_3 - 0.0207X_2X_3 \quad (12)$$

$$Y_{b*} = 31.5 + 0.335X_1 - 0.39X_2 - 0.445X_3 - 0.00059X_1^2 + 1.010X_2^2 + 0.00244X_3^2 + 0.0443X_1X_2 - 0.00335X_1X_3 - 0.0393X_2X_3 \quad (13)$$

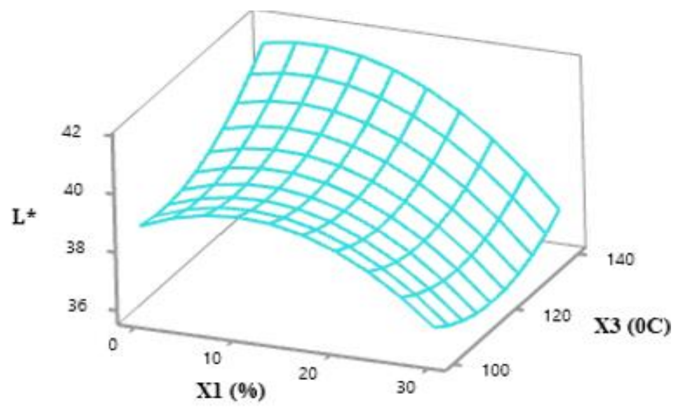
$$Y_{BI} = 469 – 1.52X_1 – 47.6X_2 – 3.38X_3 + 0.0103X_1^2 + 5.04X_2^2 + 0.01087X_3^2 - 0.207X_1X_2 + 0.0114X_1X_3 + 0.223X_2X_3 \quad (14)$$

$$Y_{\Delta E} = 79.4 - 0.26X_1 - 0.8X_2 - 1.08X_3 - 0.0022X_1^2 + 1.36X_2^2 + 0.00401X_3^2 - 0.0669X_1X_2 + 0.00424X_1X_3 - 0.0334X_2X_3 \quad (15)$$

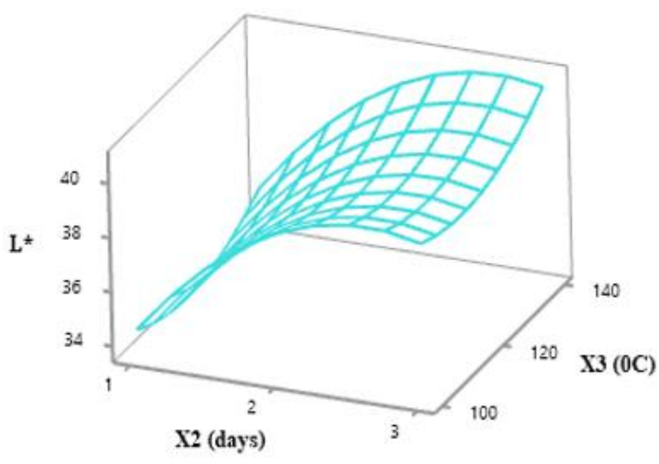
(a)



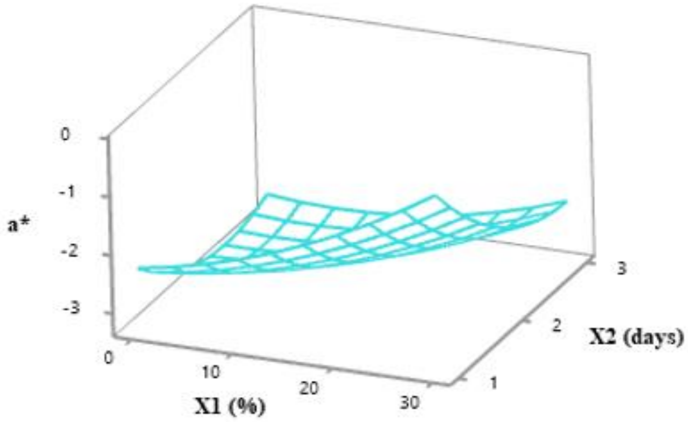
(a)



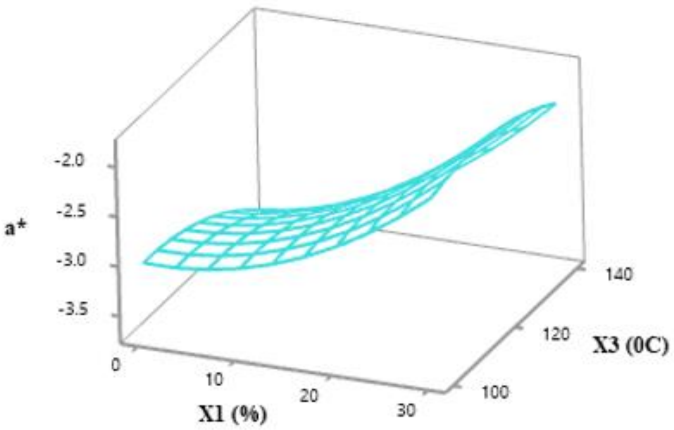
(a)



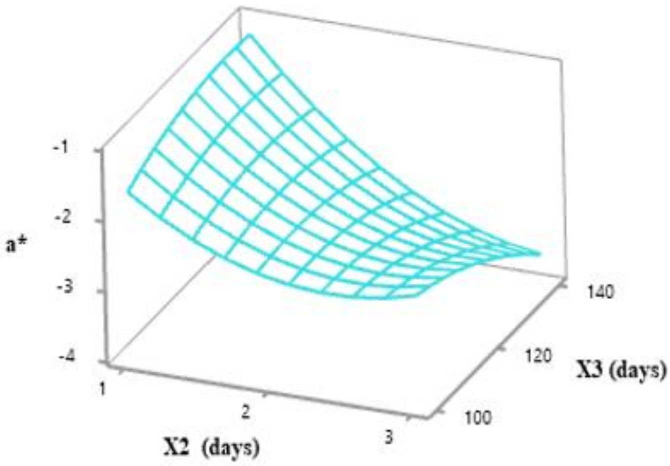
(b)


0
-1
-2
-3
a*
0
10
20
30
X1 (%)
1
2
3
X2 (days)

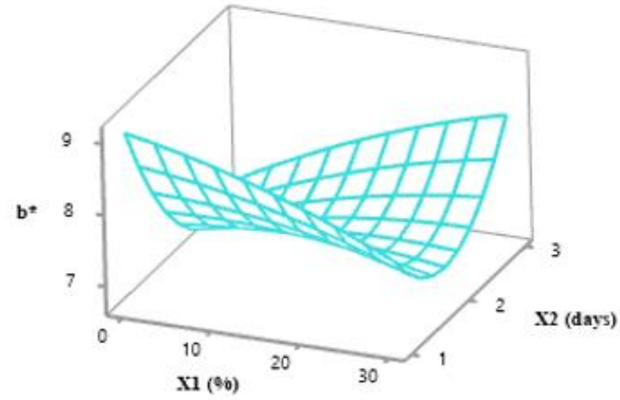
(b)


-2.0
-2.5
-3.0
-3.5
a*
0
10
20
30
X1 (%)
100
120
140
X3 (0C)

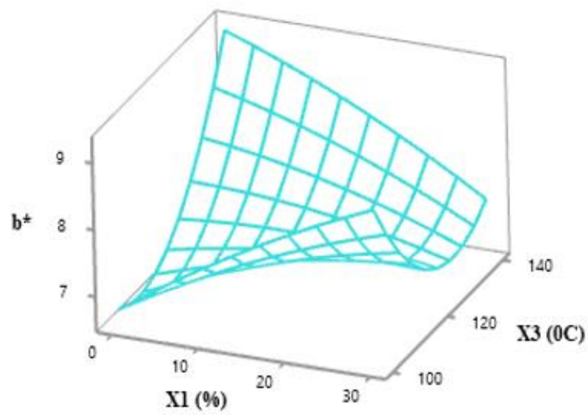
(b)


-1
-2
-3
-4
a*
1
2
3
X2 (days)
100
120
140
X3 (days)

(c)



(c)



(c)

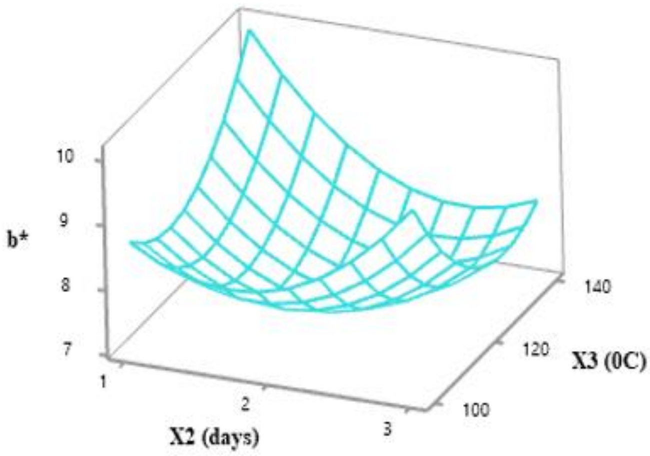


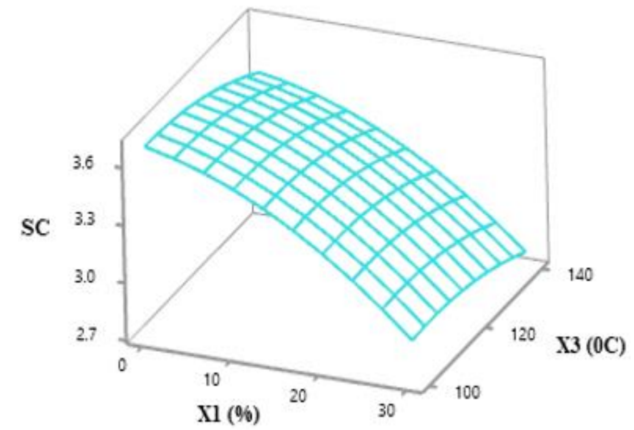
Figure 2: Effects of YQ, FD, and RT on (a) brightness, (b) brownness, and (c) yellowness of the cassava-yam composite gari. X_1 = yam quantity (YQ) in %, X_2 = fermentation duration (FD) in days, and X_3 = roasting temperature (RT) in ^{0}C

Effects of Yam Quantity, Fermentation Duration, and Roasting Temperature on the Swelling Capacity

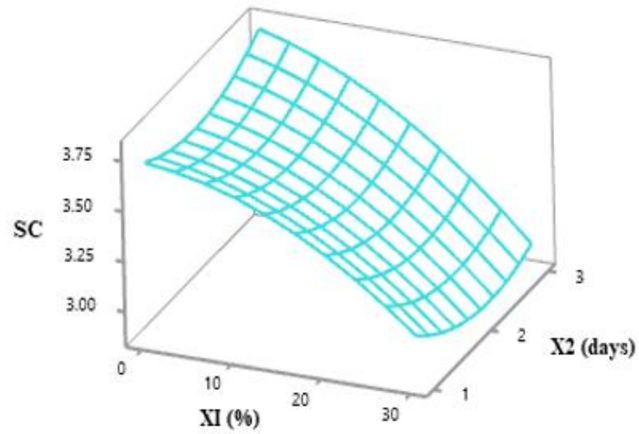
One quality characteristic that consumers desire from gari is swelling capacity because it gives a sense of satisfaction. Consumers consider good quality gari to be one whose swelling capacity is three times its initial volume (Atuna et al., 2021; Escobar et al., 2018). In the same vein, a swelling capacity ranging from 300% of the original volume is regarded as quality gari by customers (Abano et al., 2020; Akingbala et al., 2005; Atuna et al., 2021; S. O. Nwancho et al., 2014). The swelling capacity from this research ranges from 260% to 340% as shown in Table 1 which is dependent on the quantity of yam utilised for the composite dough. However, the SC for gari processed without yam recorded higher scores of 382% - 410% (Table 1). From Table 4, YQ of 10 to 30% had a significant effect ($p < 0.05$) on the SC (260% to 340%), however, its curvature effect and interaction effect were not significant ($p > 0.05$). Moreover, it is worth noting from model equation 16 in addition to Figure 3 (a**)** and (b) that the YQ negatively affected the SC indicating that as YQ decreases, SC increases. This may be due to the reduction in starch coupled with a reduction in amylose and amylopectin content in the composite by replacing cassava with yam mash thereby reducing the SC of the cassava-yam gari compared with the controls. In addition, FD affected the SC negatively depicting that as FD decreases SC increases as shown in the regression model 16. This is because starch/sugars may have been hydrolysed by fermentation. Fermentation breaks down starch into sugars, alcohol, and lactic acid thereby reducing starch content and SC of the gari. The alcohol however, escapes through roasting (Abano et al., 2020; Akinoso & Olatunde, 2014; Akintayo et al., 2019; Chinma et al., 2020; Godswill et al., 2019). Lactic acid-related fermentation has been observed to reduce the starch and fibre content of gari. Additionally, FD was not significant ($p>0.05$) as well as its interaction effects, however, its curvature effect was significant ($p<0.05$) as shown in Table 4. FD of the cassava composite dough contributed 28.3 times reducing the SC of the gari compared to the yam quantity. RT was significant on the SC ($p<0.05$). However, its curvature effect and interaction effects were not significant ($p>0.05$). Moreover, RT influenced the SC positively as shown in regression equation 16, indicating that as RT increases SC increases. This is attributed to the gelatinization of starch which enhances the SC of the cassava-yam composite gari. Further, RT made a contribution of -3.7 and -0.1 times increasing the SC of the composite gari compared to yam quantity and FD as depicted by regression equation 16 and Figure 3 (c). Nevertheless, it has been observed in this study that particle sizes for cassava-yam composite gari have been generally small. Generally, SC is affected by the gari's particle size, amount of moisture, and FD coupled with amylose and amylopectin content (Abano et al., 2020). Similar findings were reported for β-carotene fortified gari Abano et al. (2020) and Atuna et al. (2021), yam-flour composite bread (Amandikwa et al., 2015), and gari from fresh cassava roots and dry chips (Nwancho et al., n.d.).

$$Y_{SC} = 2.25 - 0.0085 X_1 - 0.241 X_2 + 0.0320 X_3 - 0.000565 X_1^2 + 0.1259 X_2^2 - 0.000141X3^2 - 0.00348 X_1X_2 + 0.000063X_1X_3 - 0.00187 X_2X_3 \quad (16)$$

(a)



(b)



(c)

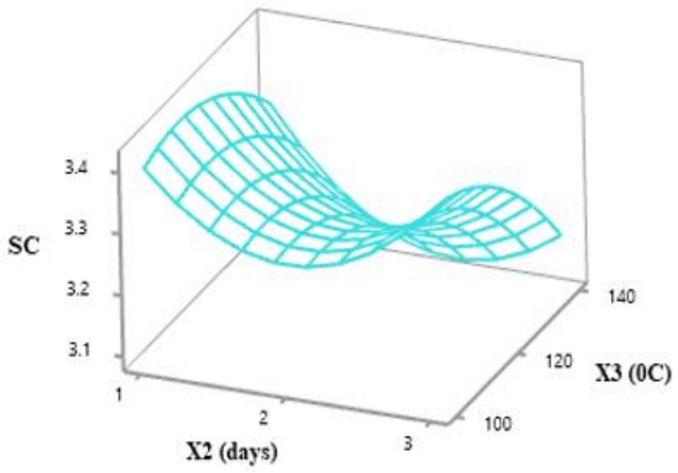


Figure 3: Effects of YQ, FD, and RT, on the (a)(b)(c) SC of the casava-yam composite gari. X_1 = % quantity of yam %, X_2 = fermentation duration in days, and X_3 = roasting temperature in ^{0}C

Effects of Yam Quantity, Fermentation Duration, and Roasting Temperature on the Sensory Attributes of the Gari

The influence of YQ, FD, and RT on the sensory attributes based on the response from sensory panellists is illustrated in Figure 4 and regression equations 17 - 21. The taste of the cassava-yam composite gari was affected negatively by the YQ as shown by the regression model 18. However, it was enhanced positively by FD indicating that increasing the former decreases the taste and increasing the latter increases the taste. This is because fermentation produces a variety of aroma-related compounds, including those associated with bitter, umami, sweet, sour, and salty tastes including alcohols, aldehydes, amines, and ketones (Xiang et al., 2019). Similarly, from Figure 4 (b, c, d, and e), an increase in FD increases flavour, taste, texture, and overall acceptability. However, it was observed that as FD increases beyond two days, sour taste is formed which can make the composite gari undesirable. This is because fermentation beyond two days results in a sour taste of gari due to the high acid produced from fermentation though it has other beneficial features such as reducing the amount of cyanide and improving the storage life of the gari.

Similar trends were observed for flavour, taste, texture, and overall acceptability where FD for all model terms had a positive influence on flavour, taste, texture, and overall acceptability while YQ had a negative effect as depicted by the regression models 17-21. Additionally, the contribution by FD to the sensory qualities in this study exceeded that of YQ and RT as shown by model coefficients in equation (17-21). This observation is consistent with a study by Abano et al. (2020) who worked on beta carotene-fortified gari. Moreover, YQ, FD, and RT were not significant on all sensory attributes

($p>0.05$) except for flavour where FD and RT were significant ($p<0.05$) as well as its curvature effects as shown in Table 4. The interaction effects of taste and curvature effect of texture as well as its interaction effects were also significant ($p<0.05$).

In contrast, the appearance of the cassava-yam composite gari was negatively affected by YQ and FD as shown by model equation 17. The negative coefficients observed for YQ and FD imply that increasing these variables decreases the appearance with none of the processing variables having a significant effect ($p>0.005$) on the appearances as well as their curvature and interaction effects as shown in Table 4. Similarly, from Figure 4 (a), increasing YQ and FD decreased the appearance. However, RT affected the appearance positively as shown in Figure (a), and was not statistically significant on the appearance ($p>0.05$).

Moreover, increasing the YQ in the yam gari sample reduces the particle size of the yam gari in that it makes the gari smooth and increases consumer acceptability of the texture Figure 4 (d). This observation may be attributed to less fibre in yam which was used to replace cassava thereby reducing the coarseness and improving the smoothness of the cassava-yam composite gari. This further suggests that the proportion of yam in yam-cassava composite gari should not exceed 30% as this may result in the production of smooth (fine particles) gari. In sum, the controls (whole cassava gari) had higher consumer acceptability than the cassava-yam composite gari as shown in Table 1. This suggests that a small quantity of yam should be incorporated into gari for fortification to reduce mineral deficiency and to meet consumer desirability. This observation agrees with Atuna et al. (2021)

who reported that substituting up to 25% cassava mash with sweet potato enhanced consumer acceptability of cassava-OFSP gari.

$$\mathbf{Y}_{Appearance} = 4.64 - 0.002 X_1 - 0.35 X_2 + 0.013 X_3 + 0.00198 X_1^2 - 0.230X_2^2 - 0.000032X_3^2 + 0.0089X_1X_2 - 0.000710X_1X3 + \mathbf{0.}00882X_2X_3 \quad (17)$$

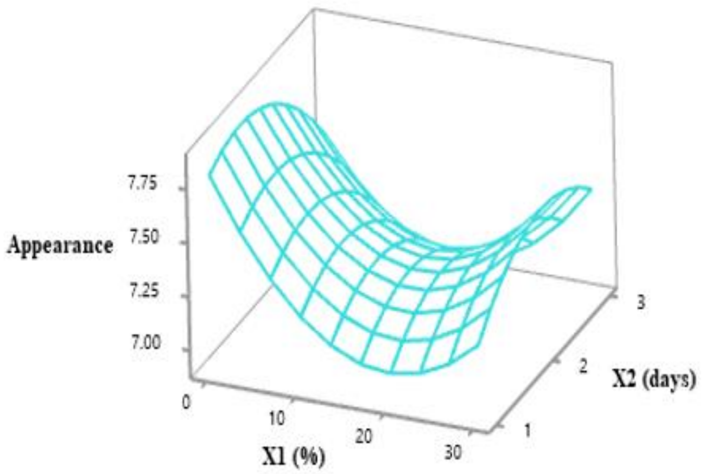
$$\mathbf{Y}_{\mathbf{Taste}} = 10.96 - 0.097X_1 + 2.408X_2 - 0.0905X_3 + 0.00004X_1^2 + 0.014X_2^2 + 0.000525X_3^2 + 0.02763X_1X_2 + 0.000422X_1X_3 - 0.02348X_2X_3 \quad (18)$$

$$\mathbf{Y}_{\mathbf{Texture}} = 6.67 - 0.0188X_1 + 1.968X_2 - 0.0187X_3 - 0.000930X_1^2 - 0.2911X_2^2 + 0.000136X_3^2 + 0.01363X_1X_2 + 0.000337X_1X_3 - 0.00875X_2X_3 \quad (19)$$

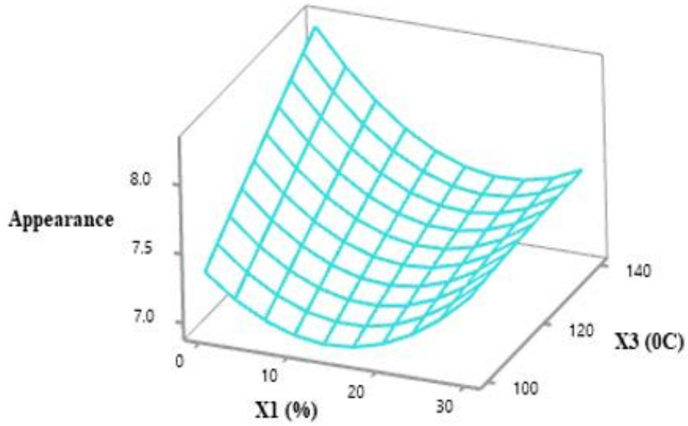
$$\mathbf{Y}_{\mathbf{Flavour}} = 0.70 - 0.137X_1 + 1.92X_2 + 0.0765X_3 + 0.00088X_1^2 + 0.063X_2^2 - 0.000157X_3^2 + 0.02166X_1X_2 + 0.000653X_1X_3 - 0.01960X_2X_3 \quad (20)$$

$$Y_{Overall} = 6.09 - 0.080X_1 + 1.59X_2 - 0.0008X_3 + 0.00123X_1^2 - 0.007X_2^2 + 0.000144X_3^2 + 0.01567X_1X_2 + 0.000038X_1X_3 - 0.01437X_2X_3 \quad (21)$$

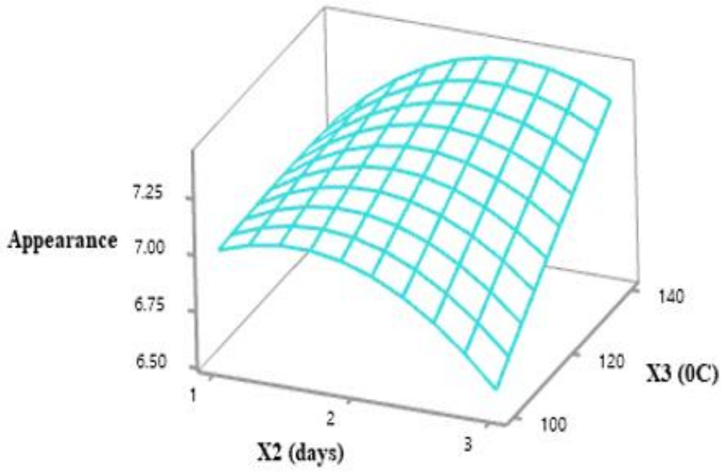
(a)



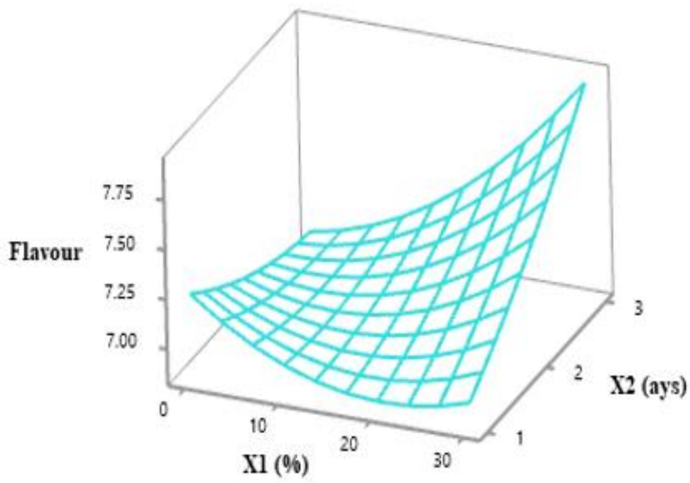
(a)


Appearance
8.0
7.5
7.0
0
10
20
30
X1 (%)
100
120
140
X3 (0C)

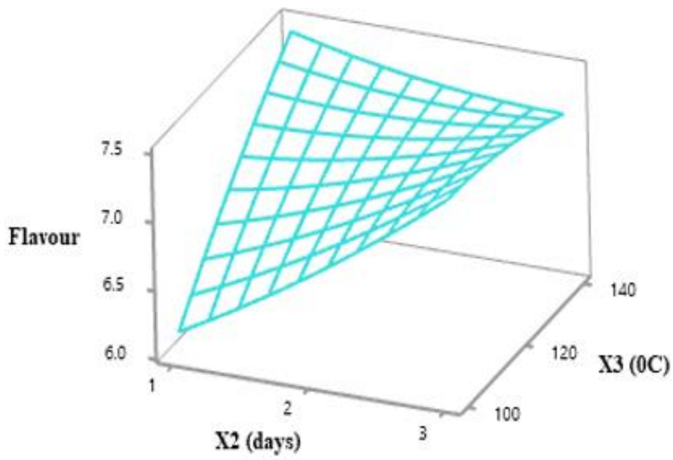
(a)


Appearance
7.25
7.00
6.75
6.50
1
2
3
X2 (days)
100
120
140
X3 (0C)

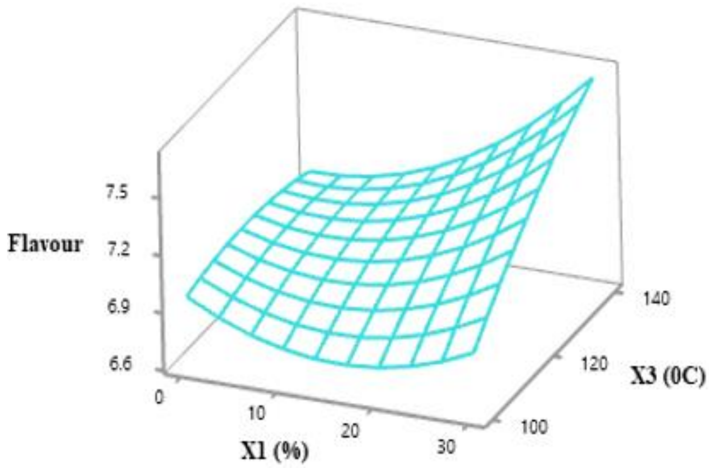
(b)


Flavour
7.75
7.50
7.25
7.00
0
10
20
30
X1 (%)
1
2
3
X2 (ays)

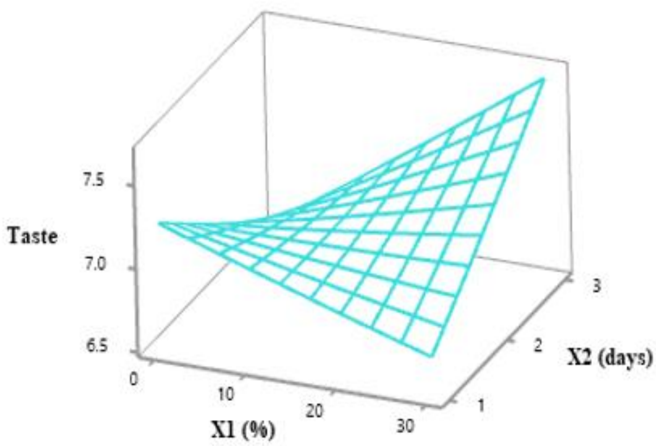
(b)


Flavour
7.5
7.0
6.5
6.0
1
2
3
X2 (days)
140
120
100
X3 (0C)

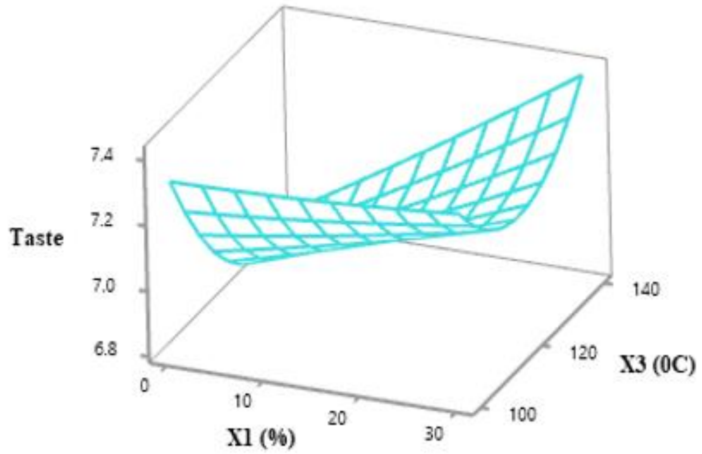
(b)


Flavour
7.5
7.2
6.9
6.6
0
10
20
30
X1 (%)
140
120
100
X3 (0C)

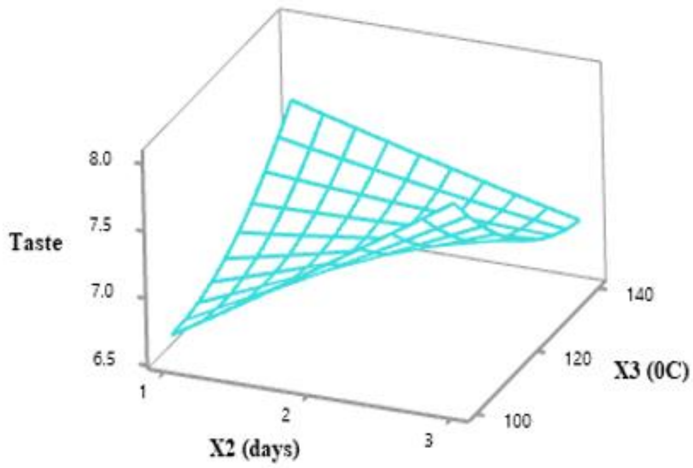
(c)


Taste
7.5
7.0
6.5
0
10
20
30
X1 (%)
3
2
1
X2 (days)

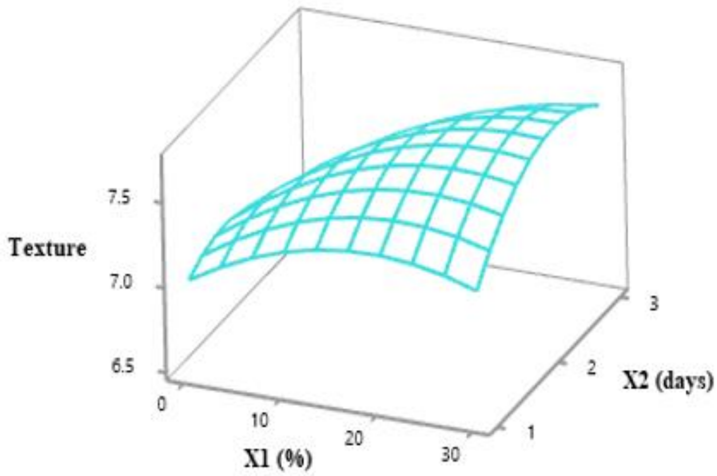
(c)


Taste
7.4
7.2
7.0
6.8
0
10
20
30
X1 (%)
100
120
140
X3 (0C)

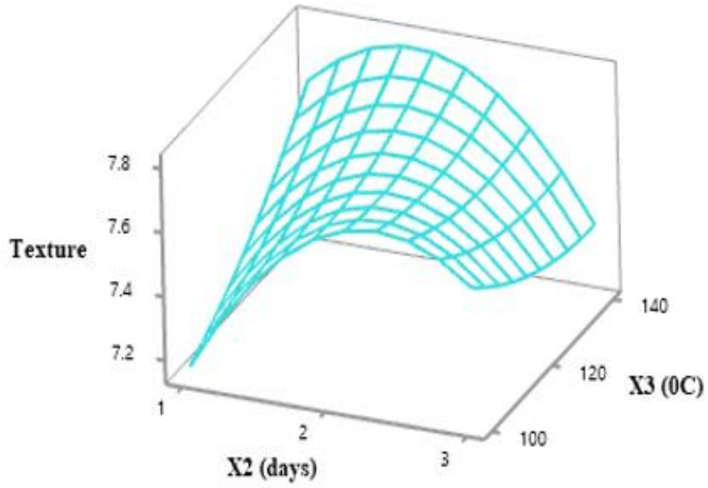
(c)


Taste
8.0
7.5
7.0
6.5
1
2
3
X2 (days)
100
120
140
X3 (0C)

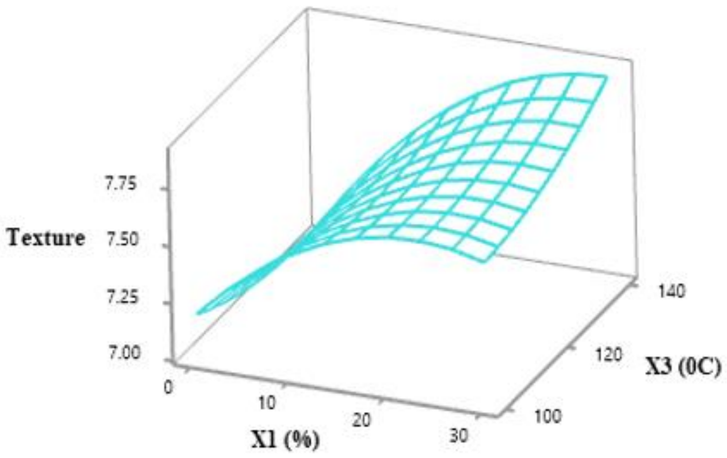
(d)


Texture
7.5
7.0
6.5
0
10
20
30
X1 (%)
1
2
3
X2 (days)

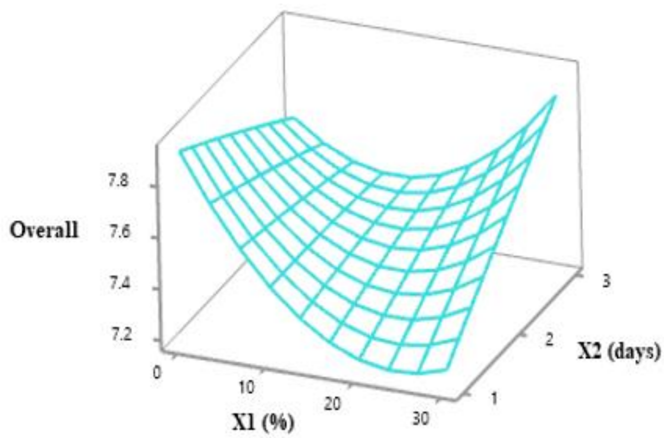
(d)


Texture
7.8
7.6
7.4
7.2
1
2
3
X2 (days)
100
120
140
X3 (0C)

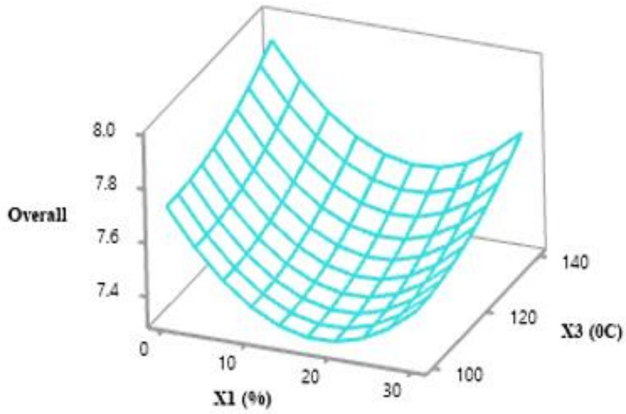
(d)


Texture
7.75
7.50
7.25
7.00
0
10
20
30
X1 (%)
100
120
140
X3 (0C)

(e)


Overall
7.8
7.6
7.4
7.2
0
10
20
30
X1 (%)
1
2
3
X2 (days)

(e)



(e)

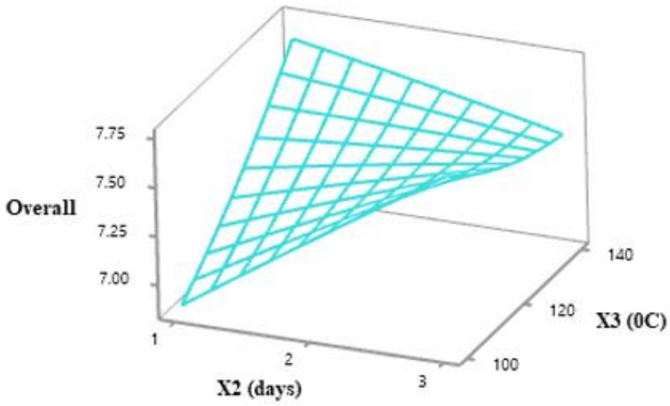


Figure 4: Effects of YQ, FD, and RT on the sensory attributes cassava-yam composite gari; (a) Appearance, (b) Flavour, (c) Taste, (d) Texture, and (e) Overall acceptability. X_1 = % quantity of yam %, X_2 = fermentation duration in days, and X_3 = roasting temperature in ^{0}C

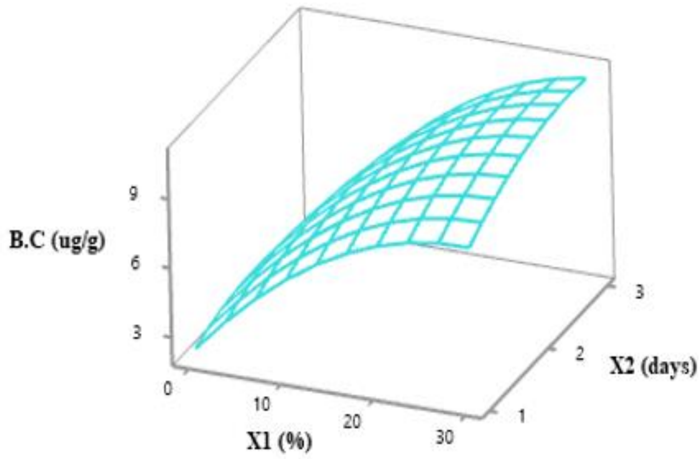
Effects Of Cassava-Yam Composite, Fermentation Duration, And Roasting Temperature on The Beta Carotene Content of Gari

Beta carotene is a carotenoid found in the diet of humans and can be converted to retinol in the body though, not all is converted to vitamin A. It is a secondary metabolic product manufactured in plants that is a member of the unoxidized carotenoids chemical group and has the potential to reduce malnutrition related to vitamin A deficiency (Bogacz-Radomska & Harasym, 2018). The effects of YQ, FD, and RT are illustrated in Figure 6. Interestingly, an increase in YQ, FD, and RT resulted in a significant ($p<0.05$) increase in the beta carotene content of the cassava-yam composite gari as well as the curvature (X_3^2) and interaction effects of RT as depicted in Table 4. Moreover, all the processing variables affected the beta carotene content positively indicating an increase in beta carotene content when the processing variables increased. Similarly, from Figure 6 (f), an increase in YQ and FD caused an increase in the beta carotene content, however, the beta carotene content of the cassava-yam composite was reduced when the RT was increased. The surge in beta carotene content of the cassava-yam composite gari could be a result of the addition of yam to cassava mash. From Figure 6 (e), the beta carotene content of the cassava-yam composite gari rose to about 10ug/g when the roasting temperature was 120ºC but reduced when the temperature exceeded 120ºC. This is because at elevated temperatures beta carotene is degraded. Abano et al. (2020) posited that applying heat causes all trans-β-carotene to isomerize with cis-trans-β-carotene, which has a lower retinol activity. As a result, all trans-β-carotene contributes more than cis-trans-β-carotene.

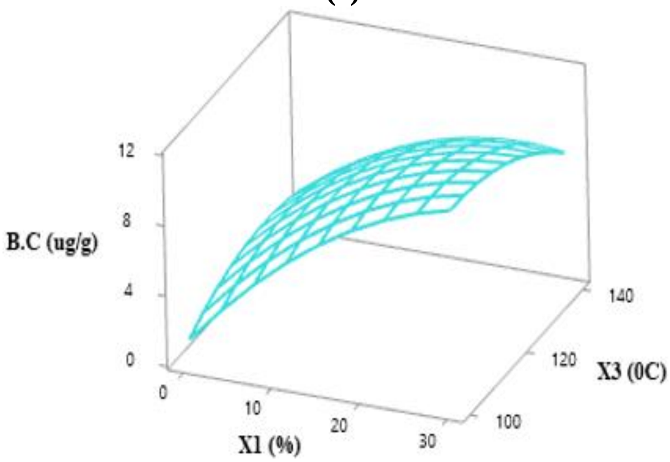
However, FD contributed more to the beta carotene amount (8.1 times YQ and 10.2 times RT) than YQ and RT as depicted by the model terms in regression equation 20. This may be due to the disruption of antinutritional factors bonded to the beta carotene present in the composite dough during fermentation (Nkhata et al., 2018) as well as the loss of dry matter and water as fermentation duration increases (Sharma et al., 2020).

$$Y_{B.C(ug/g)} = -50.9 + 0.931X_1 + 7.56X_2 + 0.738X_3 - 0.00761X_1^2 - 0.711X_2^2 - 0.002602X_3^2 + 0.0329X_1X_2 - 0.00436X_1X_3 - 0.0395X_2X_3 \quad (20)$$

(e)



(e)



(e)

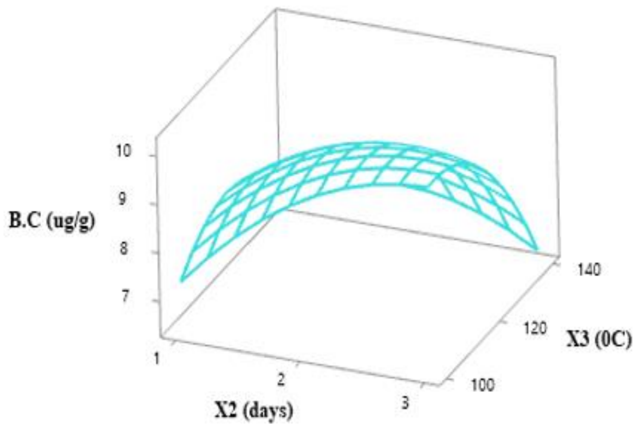


Figure 5: Effects of YQ, FD, and RT on the Beta carotene content (BC, ug/g) of the cassava-yam composite gari. X_1 = % quantity of yam %, X_2 = fermentation duration in days, and X_3 = roasting temperature in ⁰C

Effects of Yam Quantity, Fermentation Duration, and Roasting Temperature on the Iron Content of the Gari

Iron is one of the main components of oxygen transporters, including haemoglobin and myoglobin, hem-containing enzymes, and non-hem proteins, iron is essential for oxygen uptake. The effect of YQ, FD, and RT on the iron content of the cassava-yam composite gari is illustrated in Figure 7 and Table 2. From Figure (a and b) an increase in yam amount increases the iron content to around 210ug/g with a statistically significant effect as well as its curvature effect ($p < 0.05$) as shown in Table 4. The increase in iron content could be a result of replacing cassava with yam in the dough used to prepare the gari. Interestingly, from Figure 6 (c) an increase in FD appeared to have decreased the iron amount marginally from 160ug/g to 130ug/g. The decrease in iron amount may be due to the leaching of some soluble iron during the fermentation process. This finding agrees with Ajifolokun & Adeniran (2018). However, an increase in RT to 120ºC caused a corresponding increase in iron content but reduced slightly when the roasting temperature reached 140ºC with a statistically significant effect ($p<0.05$) as shown in Table 4. Moreover, it is worthy of notice that both YQ and FD affected the iron content negatively indicating a decrease in iron content when both YQ and FD increased. RT however affected the amount of iron positively with a higher effect (-0.085 times) than FD and (-1.13 times) YQ as shown in regression equation 23. This finding is consistent with Amoakoah Twum et al. (2021) who reported an increase in iron content of gari when iron was added before roasting compared to gari with iron added after roasting. In general, minerals including iron withstand heat processing and thus enhance the amount due to loss of moisture during the thermal process.

$$Y_{Fe(ug/g)} = -228 - 9.09X_1 - 121.0X_2 + 10.30X_3 + 0.349X_1^2 + 6.5X_2^2 - 0.0513X_3^2 + 0.315X_1X_2 - 0.0263X_1X_3 + 0.733X_2X_3 \quad (23)$$

(a)

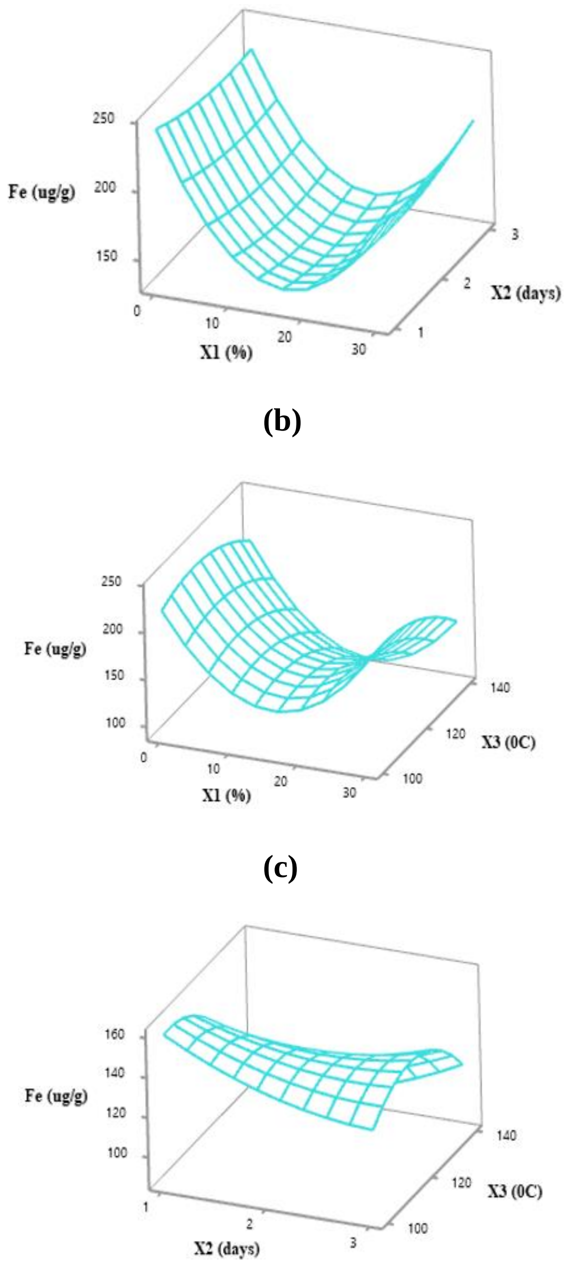


Figure 6: Effects of YQ, FD, and RT on the (a)(b)(c) Iron content (Fe, ug/g) of the cassava-yam composite gari. X_1 = % quantity of yam %, X_2 = fermentation duration in days, and X_3 = roasting temperature in ⁰C

Effects of Yam Quantity, Fermentation Duration, and Roasting Temperature on the Zinc Content of the Gari

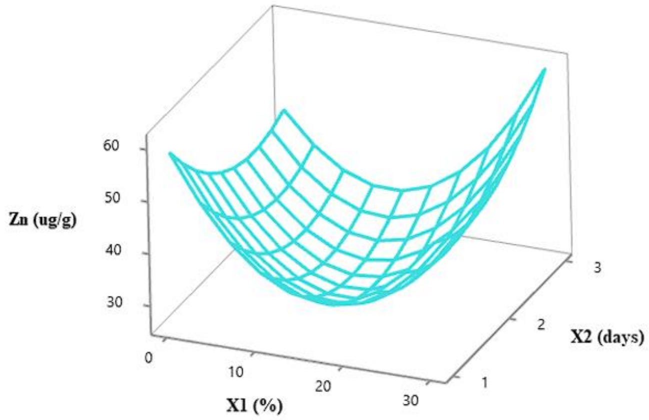
Zinc is an important mineral that aids in cell division, DNA and protein synthesis, and the metabolic function of enzymes in the body (Deshpande et al., 2013). The effect of YQ, FD, and RT on the zinc content of the cassava-yam composite gari is illustrated in Figure 7 and Table 1. From Figure 7 (a, b, c), the addition of yam and an increase in FD increased the zinc content of the cassava-yam composite gari. The increase in zinc amount when YQ increases may be due to replacing cassava with yam in the composite dough used for the gari.

Moreover, both YQ and FD affected the zinc content negatively (regression equation 22). However, YQ had a significant effect ($p>0.05$) on the zinc content of the cassava-yam composite gari. Its curvature and interaction effects were not significant as shown in Table 2. Both FD and RT were not significant as well as their curvature and interaction effects.

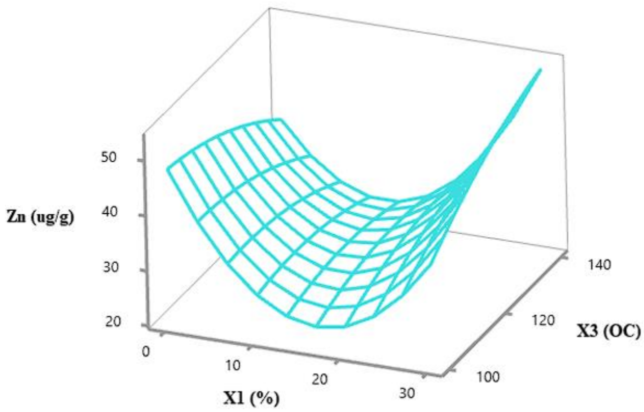
Additionally, FD contributed more to the reduction in zinc content (8.299 times) as depicted in equation 24. The reduction in zinc content, when fermentation increases, could be a result of the leaching of available zinc during dewatering (Ajifolokun & Adeniran, 2018). Interestingly, RT appeared to have boosted the zinc amount slightly as shown in Figure 7. The slight increment in zinc content could be attributed to the destruction of antinutritional factors bound to zinc during thermal treatment (Mohamed Ahmed et al., 2020).

$$Y_{Zn\ (ug/g)} = 74 - 5.94X_1 - 49.3X_2 + 0.73X_3 + 0.0857X_1^2 + 7.58X_2^2 - 0.0051X_3^2 + 0.418X_1X_2 + 0.0221X_1X_3 + 0.101X_2X_3 \quad (24)$$

(a)



(b)



(c)

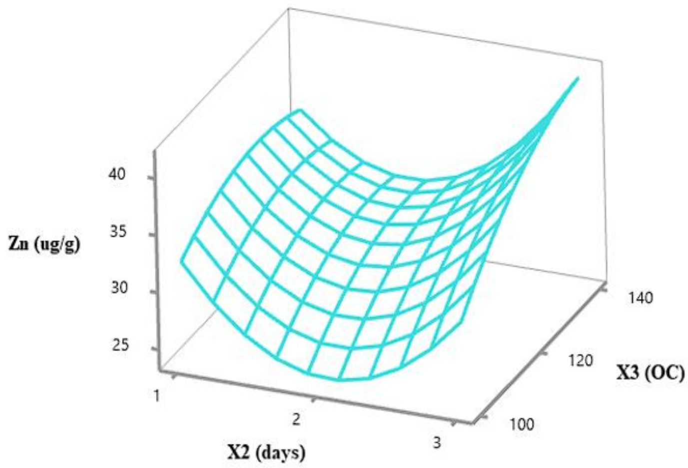


Figure 7: Effects of YQ, FD, and RT on the (a)(b)(c) Zinc content (Zn, ug/g) of the cassava-yam composite gari. X_1 = % quantity of yam %, X_2 = fermentation duration in days, and X_3 = roasting temperature in ^{0}C

Optimization of the Yam-Cassava Composite Gari

The results from the optimization analysis with ninety-five percent confidence indicated that YQ of 30%, RT of 100ºC, and FD of 3 days are the optimal processing variables for the yam gari. These optimal conditions produced 38.2036 brightness, 38.2036 greenness, 300.22% SC and an appearance of 7.12, a taste of 7.12, texture of 7.66, flavour of 7.85, overall acceptability of 8.07, beta carotene content of 12.29µg/g and composite desirability of 0.67 for the effect of the processing variables on the quality of the yam gari and sensory characteristics. Based on the desirability index from Figure 8**,** appearance, beta carotene, flavour, taste, and texture had the highest desirability of 1. This observation reflects consumer preference because those sensory attributes largely influence consumer behaviour and acceptability of gari in the market. Overall acceptability and brightness had desirability indices of 0.84 and 0.82 respectively. SC, however, had the lowest desirability from the optimization analysis.

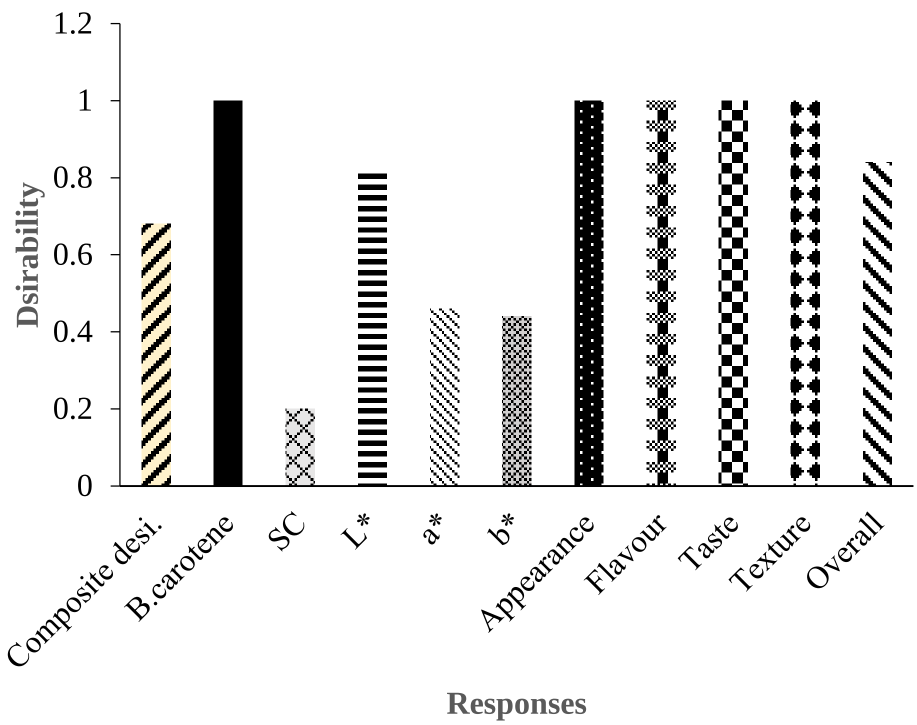


Figure 8: Desirability of the cassava-yam gari composite for the responses

Effects of Packaging Materials and Storage Conditions on the Physico-Nutritional Quality of the Optimised Gari

To investigate how storage and packaging affect the physico-nutritional characteristics of the created optimal yam composite gari. For 5 months, samples of the optimized gari were stored in airtight plastic pouches in room (RM), supermarket (SM), and open market (OM) settings. Every 28 days, some samples were collected for examination. Figures 9 through 18 and Table 4 illustrate the effects of storage on the nutritional makeup of the optimized cassava-yam composite gari, as mentioned in the subsection pages.

Polyethylene **(**PE)

Polyethylene/polyethylene/terephthalate (PE/PET)

Polyethylene/polyethylene/terephthalate/Aluminium (PE/PET/AL)

Figure 9: Optimised gari packaged in polyethylene (PE), polyethylene/ polyethylene terephthalate (PE/PET), and polyethylene/ polyethylene terephthalate/ aluminium (PE/PET/AL)

Table 4: Thickness, oxygen permeability (OP), and water vapour permeability (WVP) of packaging materials

Packaging material	Thickness (µm)	OP (cm3 / m2 d bar)	WVP (g/m2 d)
Polyethylene (PE)	**50**	**50 – 200**	**0.5-2** (Dufera et al., 2023)
Polyethylene terephthalate (PE/PET)	**50/12**	**1-5**	**0.5-2**(Lange&Wyser, 2003)
Polyethylene terephthalate/aluminium (PE/PET/AL)	**50/12/9**	**0**	**0** (Lange&Wyser, 2003)

Table 5: Temperature of each of the storage conditions

Storage Condition	Temperature (°C)
Room Storage (RS)	**27.45 ± 2.35**
Supermarket (SM)	**27.90 ± 3.09**
Open Market (OM)	**32.22 ± 3.34**

Effects of Packaging Materials and Storage Conditions on the Colour (L* and a*) of the Optimised Gari

Effects on the Brightness (L*)

From Figure 10 below, the brightness (L*) of the optimised gari in all packaging materials and storage conditions decreased from the predicted value of 38.20 for the first month of storage to the fifth month. However, for gari packaged in PE, PE/PET stored at an OM temperature of 32.22 ± 3.34°C and PE/PET and PE/PET/AL stored at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) respectively, the brightness increased to around 39 for the first month of storage before finally decreasing for the entire period. The decrease in brightness could be due to browning caused by storage temperature. However, the rate of decrease was significantly higher for all packaging materials under OM (32.22 ± 3.34°C). Moreover, all packaging materials and storage conditions were not statistically significant ($p>0.05$) for the first two months of the storage period, however, the rate of retention of brightness in PE/PET and PE/PET/AL stored in RM and SM was lower compared to PE, PE/PET, and PE/PET/AL stored in OM. Indicating that the brightness was largely reduced in polyethylene than in polyethylene terephthalate and polyethylene terephthalate/ aluminium. This observation corroborates with what was reported by Kamble et al. (2020) for the reduction of brightness in pasta stored at different storage temperatures and packaging materials (HDPE) and Jan et al. (2017) for the decrease in brightness in cookies.

Additionally, it is worth noting that from the third month of storage to the last period of storage the rate of degradation of brightness is low in PE/PET and PE/PET/AL stored at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C)), and OM (32.22 ± 3.34°C) with a significant effect ($p<0.05$). The higher scores of brightness for the optimised gari stored in PE/PET and PE/PET/AL stored in RM and SM could be a result of strong barrier properties against oxygen permeation and temperature.

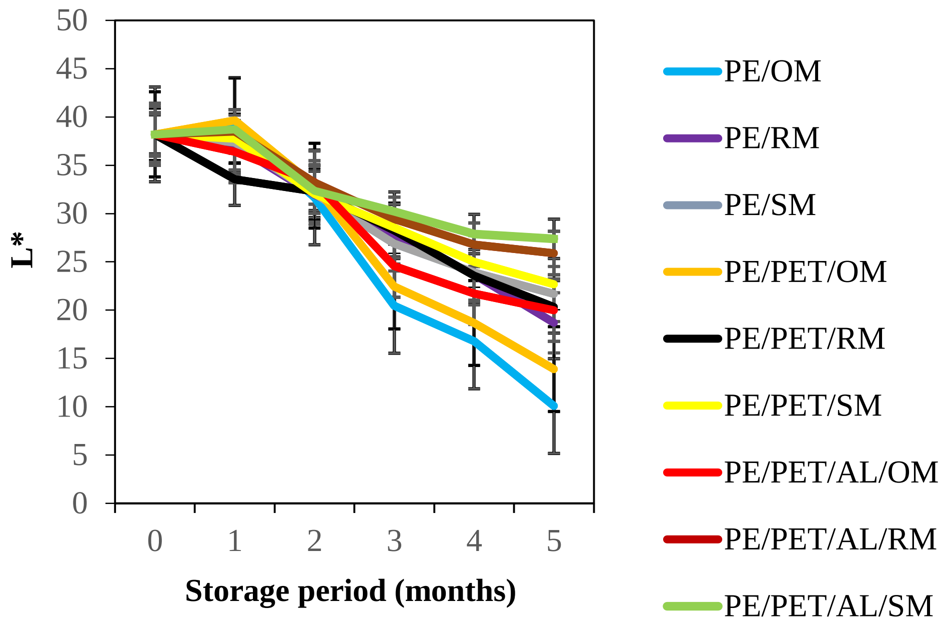


Figure 10: Effects of packaging materials and storage on the brightness (L*) of the optimised gari.

Effects on Brownness (a*)

The brownness of the optimised gari packaged in polyethylene (PE), polyethylene/polyethylene terephthalate (PE/PET), and polyethylene/ polyethylene terephthalate/aluminium (PE/PET/AL) and stored at RM (27.45 ± 2.35°C), SM (27.90 ± 3.09°C), and OM (32.22 ± 3.34°C) respectively for the first month increased from the predicted a* value of -2.04 to 8.55. However, the increase in brownness was significantly higher in all packaging material for the second month of storage at OM (32.22 ± 3.34°C), especially for gari packaged in PE, and finally hitting a peak a* score of 21.89 as shown in Figure 11. Moreover, the level of brownness was highest in PE and lowest in PE/PET/AL at the end of the storage period with a statistically significant effect. The increase in brownness may be due to loss of luminance caused by exposure to elevated temperatures that caused brownness (non-enzymatic).

This finding is consistent with Oluwamukomi & Adeyemi (2015) for increased brownness in protein-fortified gari during storage.

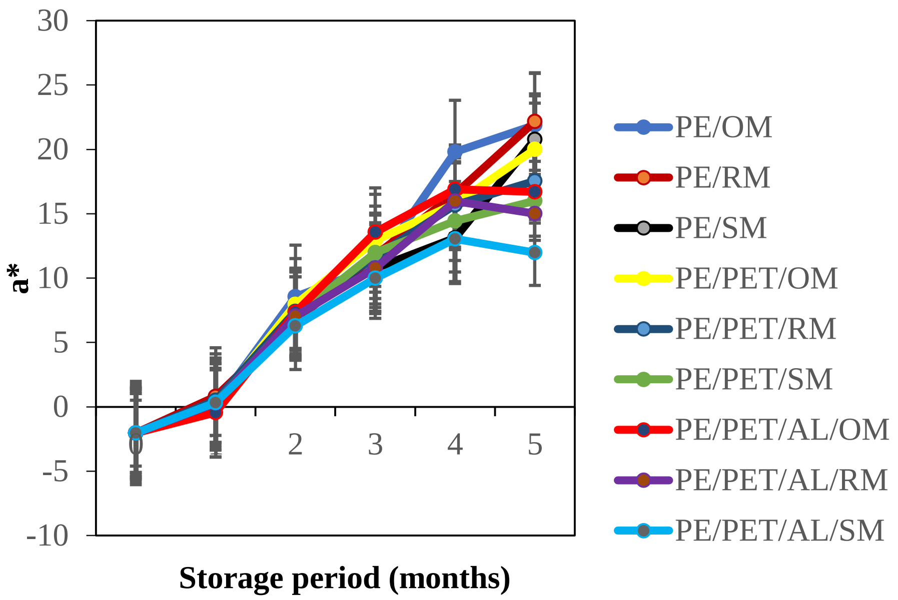


Figure 11: Effects of packaging materials and storage on the brownness (a*) of the optimised gari

Effects of Packaging Materials and Storage Conditions on Sensory Attributes

Sensory evaluation of the optimised gari was done based on appearance, flavour, taste, texture, and overall acceptability since these attributes present a better indication of the physicochemical changes that occur during the storage period.

Appearance

The predicted score for appearance is 7.12. This score of appearance increased for the optimised gari in PE/PET/AL to 7.45, evened out for PE/PET, but decreased for PE under all storage conditions, at RM (27.45 ± 2.35°C), SM (27.90 ± 3.09°C), and OM (32.22 ± 3.34°C) for the first month of storage. Moreover, after one month of storage, the appearance decreased in PE stored at OM (32.22 ± 3.34°C C) with a statistically significant effect at the end of the storage period. However, the decrease in the appearance of the optimise gari in PE/PET at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) was low and not significant at the end of the storage period. The decrease in appearance generally could be ascribed to the oxidation of colour. This observation agrees with (Abiodun et al., 2020) who reported a decrease in the appearance of biofortified cassava gari.

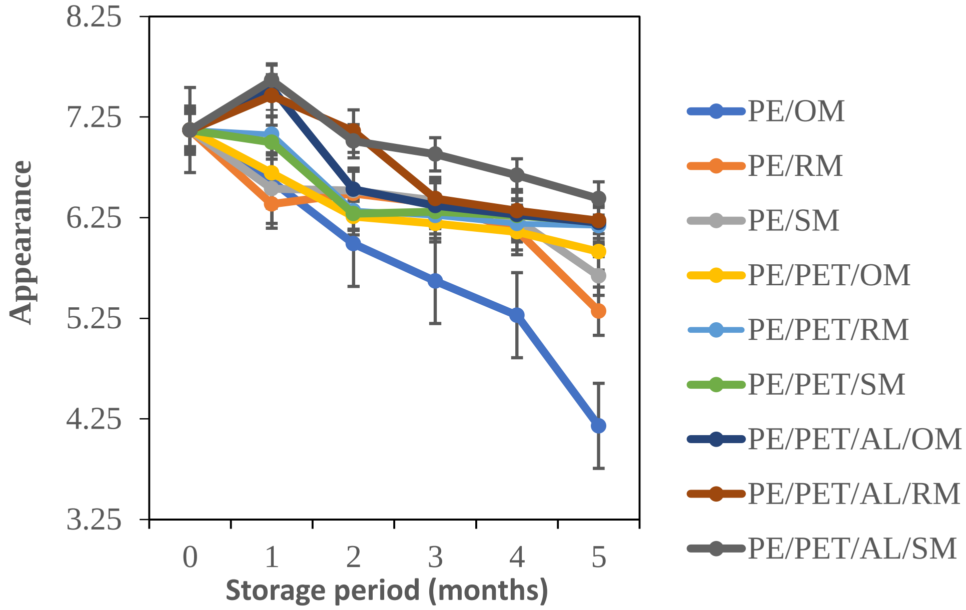


Figure 12: Effects of packaging materials and storage on the appearance of the optimised gari

Flavour

Overall, the flavour of the optimised gari packed in PE and stored under OM (32.22 ± 3.34°C) condition decreased (7.8 to 4.21) significantly ($p<0.05$) for the first two months of storage but the decrease in flavour under RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) condition was not significant. This indicates that the volatility of flavour through PE and the rate of carotenoid oxidation were highest in PE under high temperatures. Moreover, the flavour of the packed optimised gari in PE/PET/AL stored at OM **(**32.22 ± 3.34°C) at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) decreased slightly, especially under OM and evened off for the rest of the storage period though it was not significant. This indicates the ability of PE/PET/AL to provide a strong barrier against high temperature and oxygen permeation. PE/PET, however, saw a steady decline to around 6.21 in the flavour of the optimised gari. The decrease in flavour in all packaging materials is consistent with Abiodun et al. (2020) for biofortified cassava gari.

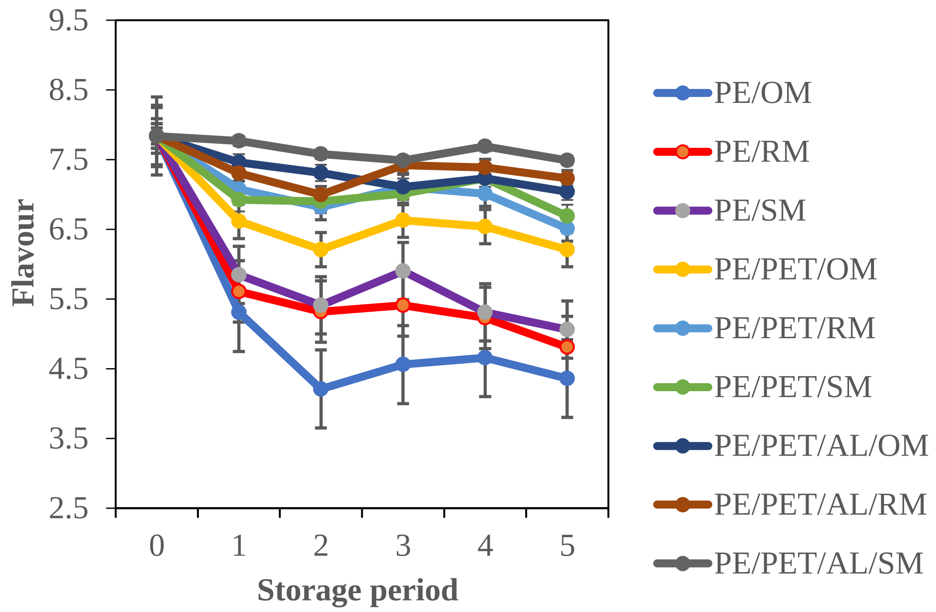


Figure 13: Effects of packaging materials and storage on the flavour of the optimised gari

Taste

The taste of the optimised gari followed a trend similar to flavour. The taste of the optimised gari packed in PE and stored at OM (32.22 ± 3.34°C) condition decreased significantly from the predicted score of 8.33 (with an actual score of 4.38) for the first two months and finally hit a low of 3.50

indicating the effects of temperature and PE on the taste whilst gari in PE/PET/AL under all storage conditions decreased slightly for the first two months and evened off for the entire period as depicted in Figure 14. However, gari in PE material and stored at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) in two months of storage decreased from 8.33 to 5.30 and 5.21 respectively and appreciated to 5.81 and 6.10 under RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) conditions. The decrease in a taste of gari packaged in PE/PET and PE/PET/AL under all conditions of temperature was generally low; however, PE/PET at OM (32.22 ± 3.34°C) conditions for the first two months of storage was significant on the taste. The decrease in taste could be attributed to oxidation of gari in the packaging material

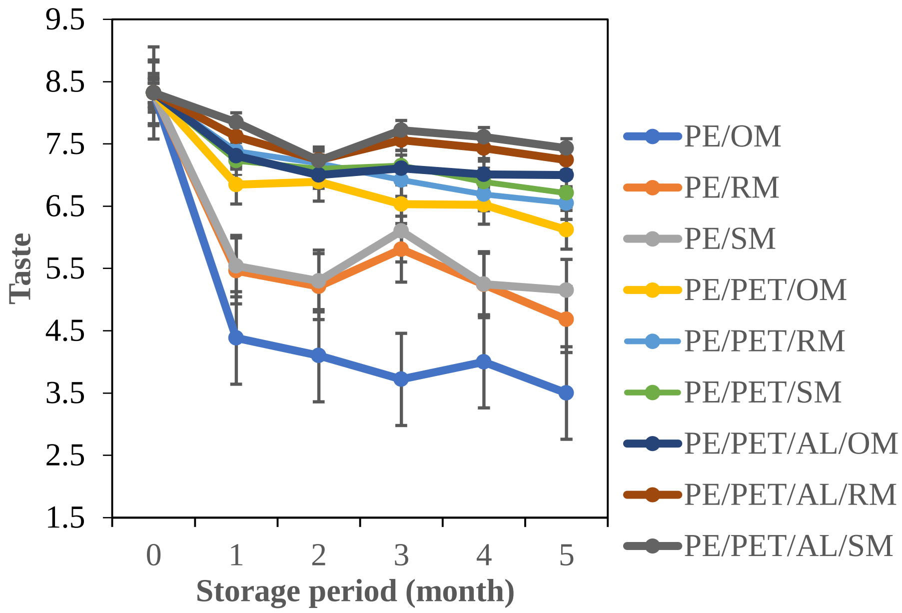


Figure 14: Effects of packaging materials and storage conditions on the taste of the optimised gari

Texture

Similarly, the texture of the optimised gari in PE packaging material for the first month of storage under all storage conditions decreased, however, the texture was reduced significantly by PE at OM (32.22 ± 3.34°C) at RM (27.45 ± 2.35°C) storage conditions. Expectedly, the texture of the gari packaged in PE/PET and PE/PET/AL and stored under OM (32.22 ± 3.34°C) at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) conditions for the first two months, decreased very slightly indicating the potency of PE/PET and PE/PET/AL in providing a strong barrier against temperature. However, there was no significant difference between PE/PET/AL and PE/PET under OM (32.22 ± 3.34°C), RM (27.45 ± 2.35°C), and SM (27.90 ± 3.09°C) from the first month up till the end of the storage period. The decrease in texture could be attributed to the accumulation of moisture in the packaging materials. This observation is consistent with Marangoni Júnior et al. (2018) who reported of loss of crispiness in potato chips under storage.

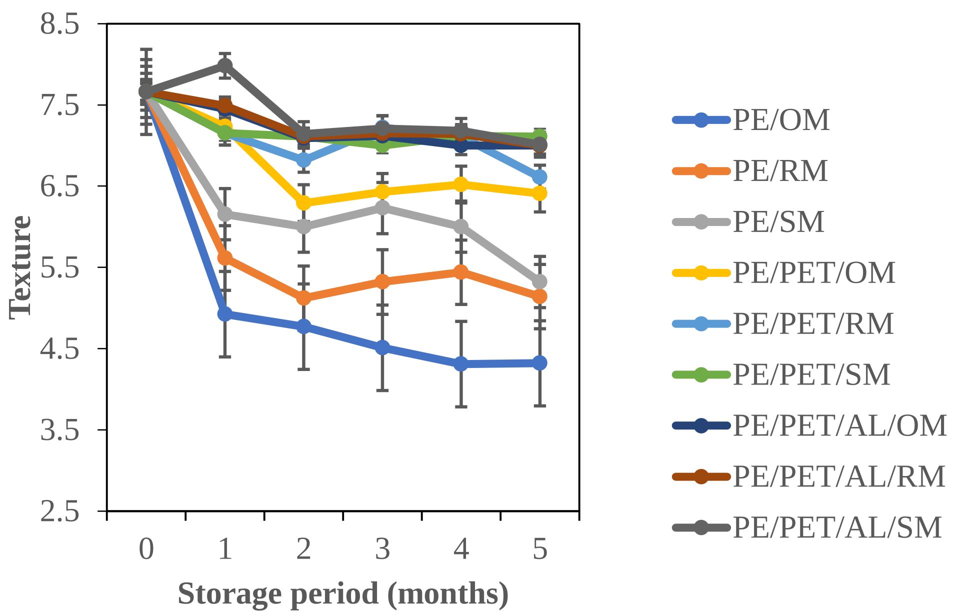


Figure 15: Effects of packaging materials and storage conditions on the texture of the optimised gari.

Overall Acceptability

The overall acceptability of the optimised gari indicates the consumer acceptability and possible commercialisation of the product. From Figure 16, the consumer acceptability of the optimised gari packaged in PE and stored under OM **(**32.22 ± 3.34°C) and RM (27.45 ± 2.35°C) was reduced significantly from the predicted score of 8.07 to 4.99 and 5.32 at the end of the storage period as shown in Figure 17. However, PE under SM (SM (27.90 ± 3.09°C) reduced significantly for the first two months from 8.07 to 6.13 and appreciated and finally to a score of 5.66 at the end of the 5 months. The consumer acceptability of the optimised gari packaged in PE/PET and PE/PET/AL under OM **(**32.22 ± 3.34°C), RM (27.45 ± 2.35°C), and SM (27.90 ± 3.09°C) conditions reduced slightly in PE/PET material from 8.07 to 6.62, 6.91, and 7.00 and PE/PET/AL material from 8.07 to 7.11, 7.10, and 7.21 but were not significant. The reduction in acceptability may be due to oxygen permeation and moisture. This observation agrees with Abiodun et al. (2020) who reported a decrease in the acceptability of yellow-fleshed cassava gari.

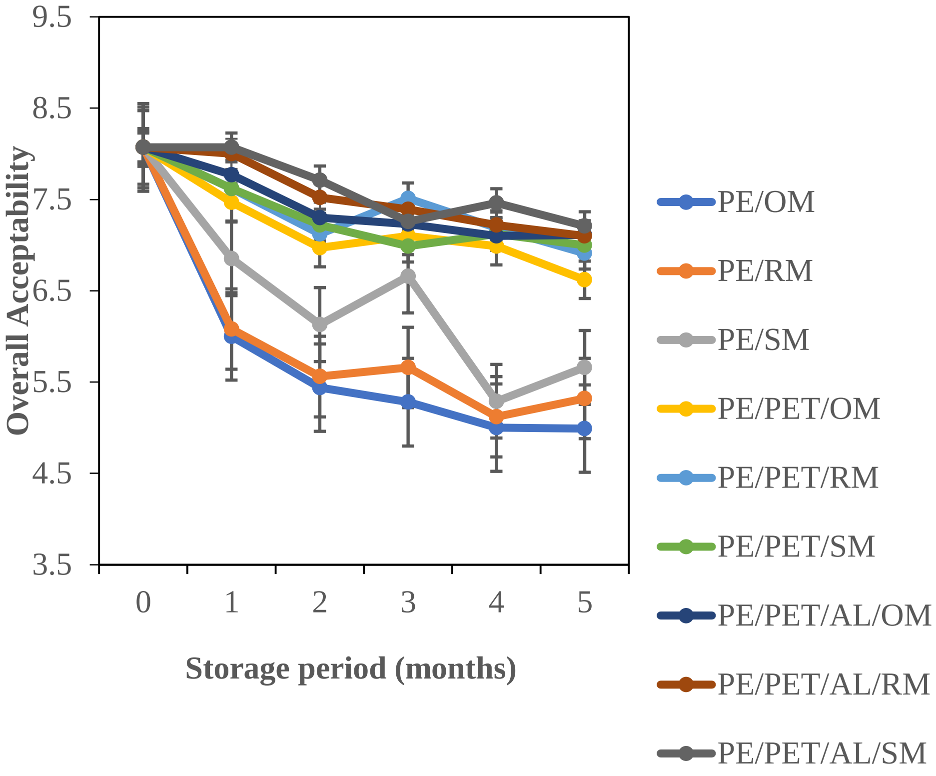


Figure 16: Effects of packaging materials and storage conditions on the overall acceptability of the optimised gari.

Beta Carotene

Beta carotene is mostly found in plants and consumed by humans in diets to meet their vitamin A requirements. From Figure 17, the beta carotene content in all packaging materials and under all storage conditions saw a downward trend. Specifically, the quantity of beta carotene degraded significantly in PE from 12.29µg/g to 4.34µg/g at OM **(**32.22 ± 3.34°C), 4.51µg/g at RM (27.45 ± 2.35°C), and 4.55µg/g at SM (27.90 ± 3.09°C) conditions. A similar trend was observed for PE/PET under all conditions for the first month of storage but was not significant. However, it is worth noting that beta carotene content decreased steadily in PE and PE/PET for the rest of the storage period and finally hit a significant low of 1.54 µg/g for PE at OM (32.22 ± 3.34°C). Optimised gari in PE/PET/AL saw a steady degradation pattern indicating a strong barrier against temperature. Interestingly, PE/PET/AL packaging material reduces the rate of beta carotene degradation significantly under all storage conditions. The loss of beta carotene in PE/PET/AL may be attributed to oxygen accumulation in the headspace of packaging. This observation is consistent with Udemba et al. (2023) for loss of beta carotene yellow fleshed cassava gari.

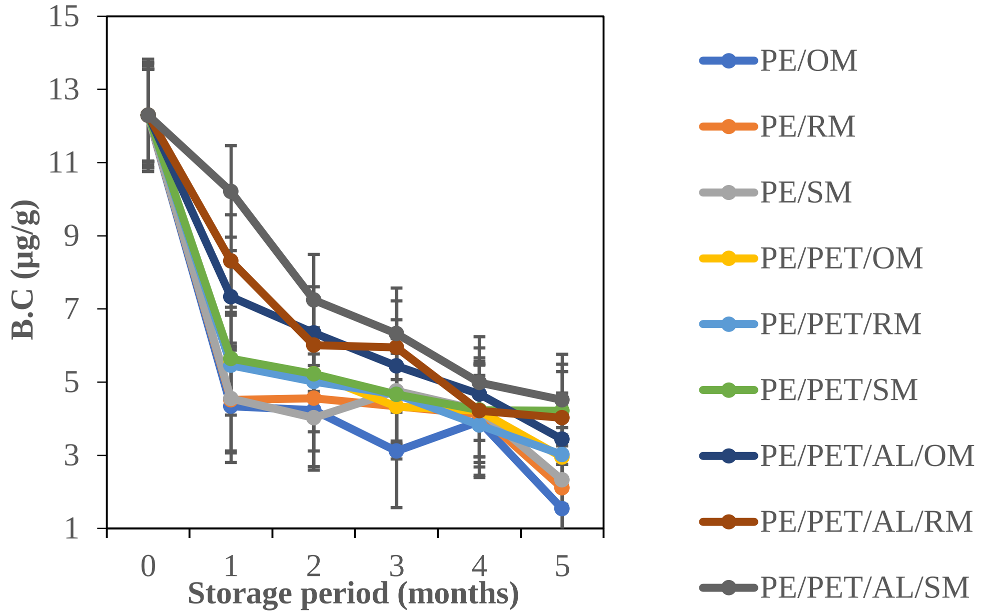


Figure 17: Effects of packaging materials and storage conditions on the beta carotene quantity of the optimised gari.

Swelling Capacity

The swelling capacity of the optimised gari in PE/PET/AL reduced very slightly from 3.00 of the first month of storage at OM **(**32.22 ± 3.34°C), RM (27.45 ± 2.35°C), and SM (27.90 ± 3.09°C) conditions to 2.9 of the last months but was not significantly different from PE/PET indicating the effectiveness of the packaging against temperature. Similarly, in PE/PET material, the swelling capacity decreased slightly from 2.9 in the third month at OM (32.22 ± 3.34°C) condition to 2.7 at the end of storage. Swelling capacity was however high (2.9) at RM (27.45 ± 2.35°C) and SM (27.90 ± 3.09°C) conditions at the end of the storage period. Swelling capacity in PE started decreasing from 2.8 in the second month at OM (32.22 ± 3.34°C) to 2.7 at the end of the period and was not significantly different. PE/PET/AL therefore provided a strong barrier as its swelling capacity values are within the recommended range (3.00 - 4.5). This observation is consistent with Abiodun et al. (2020) for decrease in swelling capacity of gari under storage and packaging.

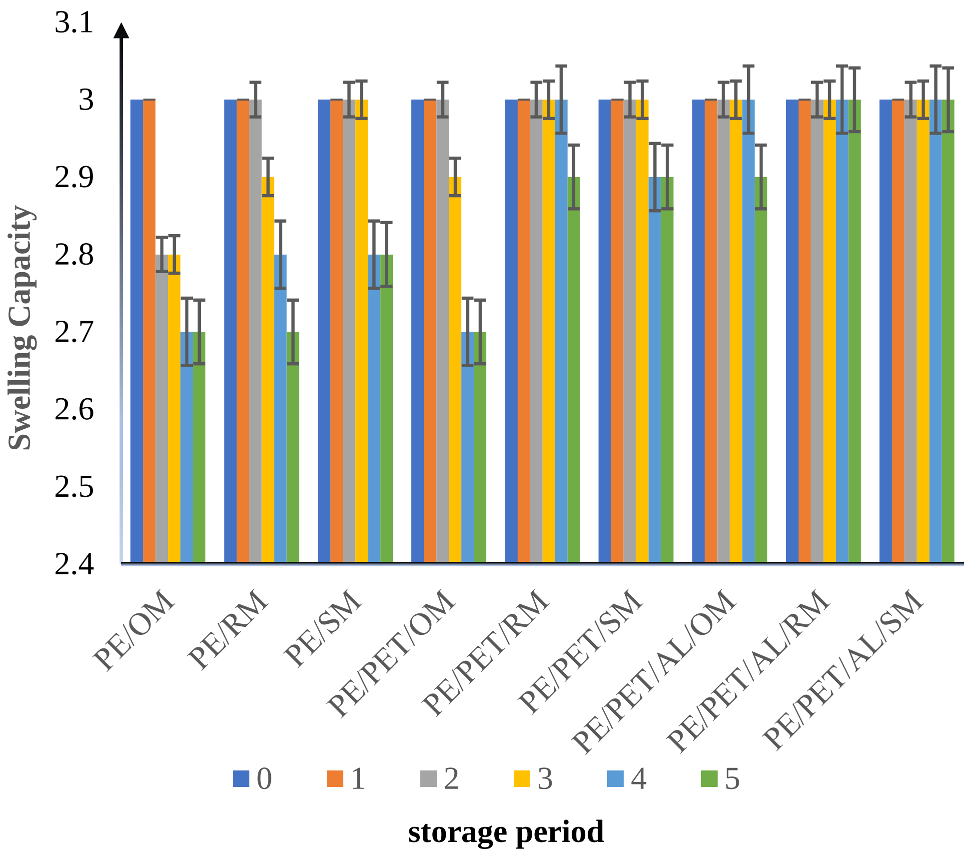


Figure 18: Effects of packaging materials and storage conditions on the swelling capacity of the optimised gari.

Techno-Economic Assessment

The cost of producing a tone (1000kg/year) of the optimised gari was determined by considering fixed and variable costs (operating costs). The fixed cost included the cost of machines/tools, housing facilities, depreciation, taxes, and insurance. Operating costs included the cost of raw materials, fuel, repairs and maintenance, and the cost of unit operations at each stage of the Gari production process. The grater's total cost is the sum of its total fixed and variable costs. Depreciation of the grater was computed using Hunt's (1983) straight-line method, using equation 8, and interest on machine ownership was calculated using equation 9.

Taxes, insurance, and shelter were calculated at 1.0% of the cost price. Repairs and maintenance costs were determined at 5% of the cost price whereas costs of labour depended on the number of workers that processed a tone of gari. From the total cost of processing a tone of gari, breakeven, revenue, and profit were determined.

Table 6: Fixed Cost (GHS)

Item	Cost (GHS)
Grating machine	2000.00
Salvage value	1000.00
Economic life	5years*
Depreciation	200.00
Repairs and Maintenance	100.00
Taxes	20.00
Insurance	20.00
Interest	30.00
Shed	20.00
Screw press	1500.00
Roasting pan	400.00
Oven	30.00
Silver basin	50.00
Rafia Sieve	30.00
Peeling knife	10.00
Kitchen stool	20.00
Roaster	10.00
Two wooden boards (2x8)	160.00
Total Fixed Cost	6,230.00

Table 7: Operating Cost (GHS/5kg)

Item	Cost
Yam	30.00
Cassava	50.00
Water	5.00
Polypropylene sack	4.00
Firewood	50/sack
Labour (cost of unit operations)	50/day
Number of labourers	1/day
Fuel (engine oil)	10.00
Fuel (diesel)	35.00
T & T	100.00
Total Variable Cost	334.00

Table 8: Operating Cost (GHS/1000kg)

ITEM	COST
Yam	3000.00
Cassava	7000.00
Water	40.00
Polypropylene sack	30.00
Firewood	750/15 sacks
Labour (cost of unit operations)	2,500/five days
Number of labourers	10/day
Fuel (engine oil)	10.00
Fuel (diesel)	500.00
T & T	1000.00
Total Variable Cost	14,830.00
Total Fixed Cost	6,230.00
Total Cost	21,060.00

Table 9: Profitability Analysis (GHS/1000kg)

Quantity (kg)	Fixed Costs (GHS)	Variable Costs (GHS)	Total Costs (GHS)	Total Revenue (GHS)	Profit/Loss (GHS)
0	6,320	0	6,320	0	-6,320
100	6,320	1,483	7,803	3,500	-4,303
200	6,320	2,966	9,286	7,000	-2,286
300	6,320	4,449	10,769	10,500	-269
313.32	6,320	4,646.28	10,966.28	10,966.20	-0.08
400	6,320	5,932	12,252	14,000	1,748
500	6,320	7,415	13,735	17,500	3,765
600	6,320	8,898	15,218	21,000	5,782
700	6,320	10,381	16,701	24,500	7,799
800	6,320	11,864	18,184	28,000	9,816
900	6,320	13,347	19,667	31,500	11,833
1,000	6,320	14,830	21,150	35,000	13,850

$$\text{Variable Cost/kg} = \frac{\textbf{Total variable cost}}{\textbf{Quantity}} \qquad (25)$$

$$\text{Variable Cost/kg} = \frac{\text{GHS14,830}}{\text{1000kg}} = \text{GHS14.83/kg}$$

Discussion

The techno-economic assessment was done to ascertain the economic viability of producing 1000kg (1 tonne) of the optimised gari in a year. Results showed that the fixed costs involving machines, tools, and equipment's ownership, taxes, insurance, depreciation, repairs, and maintenance amounted to GH6,230.00/5kg of optimised gari as shown in Table 5. The total variable costs and the total cost of producing 1000kg/year are GHS14,830 and 21,060 respectively as shown in Table 6. From equation 25, the variable cost of production per kg amounted to GH14.83/kg.

Moreover, from Table 8, and keeping the fixed cost constant throughout the year, no revenue was realised for the first year. Similarly, losses were made when the quantity of gari produced for the first three months started and increased by 100kg and sold at GHS35/kg. However, a breakeven quantity of approximately 313kg was realised by the fifth month indicating that the total cost was equal to the total revenue as shown in Table 8.

Interestingly, after the fifth month, profit started accruing when the quantity of production exceeded the breakeven point. A profit of GHS13,850 was realised at the end of the year when 1000kg of the gari was produced.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

Conclusion

From this study, YQ of 30%, FD of 3 days (72 hours), and RT of 100^{o}C are the optimal processing conditions for the optimised cassava-yam composite gari. These conditions yield a beta carotene content of 12.29µg/g and a swelling capacity of 3.0022. However, the swelling capacity was reduced by yam quantity and fermentation duration. Interestingly, the yam quantity, fermentation duration, and roasting temperature improved the quantity of iron in the gari improved. Additionally, the zinc amount of the cassava-yam composite gari was increased significantly by the addition of yam indicating the effects of yam in the composite gari.

The sensory attributes such as flavour, taste, texture, and overall acceptability were positively influenced by the fermentation duration but were not significant except for flavour. Whilst the appearance was affected positively by the roasting temperature but was not significant. From the study, a yam amount in composite cassava-yam composite gari should not exceed 30% as this will impair the sensory attributes and the overall consumer acceptability.

The brightness of the cassava-yam composite gari was reduced by yam quantity. The brownness was affected positively by the three processing variables. However, both yam quantity and roasting temperature affected the brownness more than fermentation duration with a statistically significant effect indicating the effects of Millard reaction. Yam quantity affected the yellowness positively and contributed more to the yellowness than fermentation duration and roasting temperature but was significant.

From the storage study, the beta carotene content of the optimised gari in packaging materials and under storage conditions decreased throughout the storage period, especially in polyethylene packaging material under open market condition (OM). Similar trends were observed for appearance, flavour, taste, texture, overall acceptability, and the brightness of the optimised gari. The brownness, however, increased in all packaging materials and under storage conditions throughout the storage period.

From the fixed cost of production, variable cost, and revenue, findings revealed that producing a tonne of the optimised cassava-yam composite gari yielded profit.

Recommendations

1. From the findings of this study, further studies involving yellow yams of the same variety should be used.
2. Further studies on the moisture content and microbial quality of the stored gari should be conducted in future research.

REFERENCES

Abano, E. E., Quayson, E. T., Bosompem, M., & Quarm, M. (2020). β-Carotene-fortified gari: Processing variables effect on nutritional and sensory qualities. *Journal of Food Process Engineering*, *43*(2). https://doi.org/10.1111/jfpe.13322

Abiodun, O. A., Ayano, B., & Amanyunose, A. A. (2020a). Effect of fermentation periods and storage on the chemical and physicochemical properties of biofortified cassava gari. *Journal of Food Processing and Preservation*, *44*(12). https://doi.org/10.1111/jfpp.14958

Abiodun, O. A., Ayano, B., & Amanyunose, A. A. (2020b). Effect of fermentation periods and storage on the chemical and physicochemical properties of biofortified cassava gari. *Journal of Food Processing and Preservation*, *44*(12). https://doi.org/10.1111/jfpp.14958

Abu, M., & Adzigiwe, K. F. (2021). Possible Causes of Health Disorders in Stored Yam at Farm Gate. *Agricultural Sciences*, *12*(09), 960–976. https://doi.org/10.4236/as.2021.129062

Adebayo B. Abass, Nanam T. Dziedzoave, Bamidele E. Alenkhe, and, & Braima D. James. (2012). *Quality management manual for the production of gari*. International Institute of Tropical Agriculture (IITA), 2012. Ibadan, Nigeria. http://www.iita.org/

Adebayo, W. G. (2023). Cassava production in africa: A panel analysis of the drivers and trends. *Heliyon*, *9*(9). https://doi.org/10.1016/j.heliyon.2023.e19939

Adebowale, A. R. A., Wahab, A. B., Sobukola, P. O., Obadina, A. O., Kajihausa, E. O., Adegunwa, O. M., Sanni, O. L., & Tomlins, K. (2018a). The antinutritional and vitamin composition of high-quality yam flour as affected by yam specie, pretreatment, and drying method. *Food Science and Nutrition*, *6*(8), 1985–1990. https://doi.org/10.1002/fsn3.619

Adebowale, A. R. A., Wahab, A. B., Sobukola, P. O., Obadina, A. O., Kajihausa, E. O., Adegunwa, O. M., Sanni, O. L., & Tomlins, K. (2018b). The antinutritional and vitamin composition of high-quality yam flour as affected by yam specie, pretreatment, and drying method. *Food Science and Nutrition*, *6*(8), 1985–1990. https://doi.org/10.1002/fsn3.619

Adebowale, A. R. A., Wahab, A. B., Sobukola, P. O., Obadina, A. O., Kajihausa, E. O., Adegunwa, O. M., Sanni, O. L., & Tomlins, K. (2018c). The antinutritional and vitamin composition of high-quality yam flour as affected by yam specie, pretreatment, and drying method. *Food Science and Nutrition*, *6*(8), 1985–1990. https://doi.org/10.1002/fsn3.619

Adebowale, A. R. A., Wahab, A. B., Sobukola, P. O., Obadina, A. O., Kajihausa, E. O., Adegunwa, O. M., Sanni, O. L., & Tomlins, K. (2018d). The antinutritional and vitamin composition of high-quality yam flour as affected by yam specie, pretreatment, and drying method. *Food Science and Nutrition*, *6*(8), 1985–1990. https://doi.org/10.1002/fsn3.619

Adewumi, A. S., Asare, P. A., Adu, M. O., Taah, K. J., Akaba, S., Mondo, J. M., & Agre, P. A. (2021a). Farmers' perceptions on varietal diversity, trait preferences and diversity management of bush yam (Dioscorea praehensilis Benth.) in Ghana. *Scientific African*, *12*. https://doi.org/10.1016/j.sciaf.2021.e00808

Adewumi, A. S., Asare, P. A., Adu, M. O., Taah, K. J., Akaba, S., Mondo, J. M., & Agre, P. A. (2021b). Farmers' perceptions on varietal diversity, trait preferences and diversity management of bush yam (Dioscorea praehensilis Benth.) in Ghana. *Scientific African*, *12*. https://doi.org/10.1016/j.sciaf.2021.e00808

Adinsi, L., Akissoé, N., Escobar, A., Prin, L., Kougblenou, N., Dufour, D., Hounhouigan, D. J., & Fliedel, G. (2019). Sensory and physicochemical profiling of traditional and enriched gari in Benin. *Food Science and Nutrition*, *7*(10), 3338–3348. https://doi.org/10.1002/fsn3.1201

Adomėnienė, A., & Venskutonis, P. R. (2022). Dioscorea spp.: Comprehensive Review of Antioxidant Properties and Their Relation to Phytochemicals and Health Benefits. In *Molecules* (Vol. 27, Issue 8). MDPI. https://doi.org/10.3390/molecules27082530

Agwu, N., Anyanwu, C., & Uchenna, H. (2015). *Factors influencing cassava value addition by rural agribusiness entrepreneurs in Abia State, Nigeria*. https://www.researchgate.net/publication/317157338

Ajifolokun, O. M., & Adeniran, H. A. (2018). Proximate and Mineral Composition of Co-Fermented Breadfruit and Cassava into Gari Analogue. *Journal of Nutrition & Food Sciences*, *08*(01). https://doi.org /10.4172/2155-9600.1000658

Akingbala, J. O., Oyewole, O. B., Uzo-Peters, P. I., Karim, R. O., & Baccus-Taylor, G. S. H. (2005). Evaluating stored cassava quality in gari production. In *Journal of Food, Agriculture & Environment* (Vol. 3, Issue 1). www.world-food.net

Akinoso, R., & Olatunde, S. J. (2014). Effect of mash quantity and roasting duration on some physical and pasting properties of gari. In *International Food Research Journal* (Vol. 21, Issue 1).

Akintayo, O. A., Obadu, J. M., Karim, O. R., Balogun, M. A., Kolawole, F. L., & Oyeyinka, S. A. (2019). Effect of replacement of cassava starch with sweet potato starch on the functional, pasting and sensory properties of tapioca grits. *LWT*, *111*, 513–519. https://doi.org/10.1016 /j.lwt.2019.05.022

Alene, A. D., Abdoulaye, T., Rusike, J., Labarta, R., Creamer, B., del Río, M., Ceballos, H., & Becerra, L. A. (2018). Identifying crop research priorities based on potential economic and poverty reduction impacts: The case of cassava in Africa, Asia, and Latin America. *PLoS ONE*, *13*(8). https://doi.org/10.1371/journal.pone.0201803

Alleluyanatha,` E. (2022). 10. factors influencing cassava processing among smallholder farmers in Imo State. *Int'l Journal of Agric. and Rural Dev.*, 01–08.

Amandikwa, C., Iwe, M. O., Uzomah, A., & Olawuni, A. I. (2015). Physico-chemical properties of wheat-yam flour composite bread. *Nigerian Food Journal*, *33*(1), 12–17. https://doi.org/10.1016/j.nifoj.2015.04.011

Amoah, F., Akowuah, J. O., & Bobobee, E. Y. H. (2022). The need for adoption of improved technologies to address challenges in small-scale cassava processing in Ghana. *African Journal of Food, Agriculture, Nutrition and Development*, *22*(6), 20609–20622. https://doi.org/10.18697/ajfand.111.22060

Amoakoah Twum, L., Ocloo, F. C. K., Duah-Bisiw, D., & Odai, B. T. (2021). Determining the effect of heat treatment on iron fortified soybean gari blend and its bioavailability. *Scientific African*, *12*. https://doi.org/10.1016/j.sciaf.2021.e00763

Amoo, A. R. N. (2014). Physicochemical and Pasting Properties of Starch Extracted from Four Yam Varieties. *Journal of Food and Nutrition Sciences*, *2*(6), 262. https://doi.org/10.11648/j.jfns.20140206.14

Andres, C., AdeOluwa, O. O., & Bhullar, G. S. (2016). Yam (Dioscorea spp.). In *Encyclopedia of Applied Plant Sciences* (Vol. 3, pp. 435–441). Elsevier Inc. https://doi.org/10.1016/B978-0-12-394807-6.00177-5

Annisa, D., Affan, I., Ahmad, A., Muliadi, T., Fitriyaningsih, E., Puteri, A., Azizah, N., & Arifin, S. R. (2023). The Effect of Adding Purple Yam Flour on the Organoleptic Properties of Biscuits. *JNS: Journal of Nutrition Science*, *4*(1), 7182. https://doi.org/10.35308/jns.v4i1.7182

Anokye, M., Tetteh, J., Tetteh, J. P., & Otoo, E. (2014). Morphological Characterization of Some Water Yam (Dioscorea alata L.) Germplasm in Ghana. In *Journal of Agricultural Science and Technology B* (Vol. 4). https://www.researchgate.net/publication/274070176

Arinola, S. O., & Olanrewaju, A. S. (2016). Effect of garification (roasting) duration on the quality characteristics of cassava gari. *Annals. Food Science and Technology*, *17*(2). www.afst.valahia.ro

Arinola, S. O., Oluwasola, E. I., Olanrewaju, A. S., & Idowu, O. E. (2017). Arinola Stephen Olanrewaju, Oluwasola Ebenezer Idowu. Quality Assessment of Cassava Gari Produced in Some Selected Local Governments of Ekiti State. *Nigeria. American Journal of Food Science and Nutrition*, *4*(4), 36–41. http://www.aascit.org/journal/ajfsn

Arnau, G., Bhattacharjee, R., Sheela, M. N., Chair, H., Malapa, R., Lebot, V., Abraham, K., Perrier, X., Petro, D., Penet, L., & Pavis, C. (2017). Understanding the genetic diversity and population structure of yam (Dioscorea alata L.) using microsatellite markers. *PLoS ONE*, *12*(3). https://doi.org/10.1371/journal.pone.0174150

Atuna, R. A., Achaglinkame, M. A., Accorley, T. A. S., & Amagloh, F. K. (2021a). Cassava Orange-Fleshed Sweetpotato Composite Gari: A Potential Source of Dietary Vitamin A. *Frontiers in Nutrition*, *8*. https://doi.org/10.3389/fnut.2021.646051

Atuna, R. A., Achaglinkame, M. A., Accorley, T. A. S., & Amagloh, F. K. (2021b). Cassava Orange-Fleshed Sweetpotato Composite Gari: A Potential Source of Dietary Vitamin A. *Frontiers in Nutrition*, *8*. https://doi.org/10.3389/fnut.2021.646051

Awoyale, W., Adebayo, B. A., Malu, N., Bussie, M.-D., & Sulyok, M. (2017). *Assessment of the potential industrial applications of commercial dried cassava products in Nigeria*. *11*. https://doi.org/10.1007/s11694-016-9428-7/Published

Ayantunde, A. A., Niayale Rober, & Addah Weseh. (2019). *Utilization of cassava peels as feed for ruminants in Ghana, A review of alternative methods of improving their nutritional value*. https://www.researchgate.net/publication/346212894

Ayele, E., Urga, K., & Chandravanshi, B. S. (2015). Effect of cooking temperature on mineral content and anti-nutritional factors of yam and taro grown in southern Ethiopia. *International Journal of Food Engineering*, *11*(3), 371–382. https://doi.org/10.1515/ijfe-2014-0264

Baffour-Ata, F., Awugyi, M., Ofori, N. S., Hayfron, E. N., Amekudzi, C. E., Ghansah, A., & Akorli, R. (2023). Determinants of yam farmers' adaptation practices to climate variability in the Ejura Sekyedumase municipality, Ghana. *Heliyon*, *9*(3). https://doi.org/10.1016/j.heliyon.2023.e14090

Baiyeri, S. O., & Samuel-Baiyeri, C. C. (2023). Nutrients, the Bioavailability of Micronutrients and Antinutrient Composition of African Yam Bean Tubers. *Tropical Journal of Natural Product Research*, *7*(4), 2823–2828. https://doi.org/10.26538/tjnpr/v7i4.26

Bani R, J., Kyereh E., & Obeng-Ofori D. (2013). Effect of Cassava Processing Equipment on Quality of Gari Produce in Selected Processing Site in Ghana. In *International Journal of Agriculture Innovations and Research* (Vol. 2, Issue 2).

Banson, K., & Danso, K. (2013). Improving the Size and Market Value of an Underutilised Yam (Dioscorea esculenta) in Ghana: Implications for Crop Breeding and Production Choices. *Journal of Life Sciences*, *7*(7), 732–741. https://doi.org/10.17265/1934-7391/2013.07.009

Bassey, E. E. (2017). Constraints and prospects of yam production in Nigeria. *European Journal of Physical and Agricultural Sciences*, *5*(1). www.idpublications.org

Bayata, A. (2019). Review on Nutritional Value of Cassava for Use as a Staple Food. *Science Journal of Analytical Chemistry*, *7*(4), 83. https://doi.org/10.11648/j.sjac.20190704.12

Bechoff, A., Chijioke, U., Tomlins, K. I., Govinden, P., Ilona, P., Westby, A., & Boy, E. (2015). Carotenoid stability during storage of yellow gari made from biofortified cassava or with palm oil. *Journal of Food Composition and Analysis*, *44*, 36–44. https://doi.org/10.1016/j.jfca.2015.06.002

Boadu, P., Aidoo, R., Ohene-Yankyera, K., Kleih, U., Abdoulaye, T., Maroya, N., Orchard, J., & Bekoe, S. (2018). *Farmers' Perception about Quality of Planted Seed Yam and their Preferences for Certified Seed Yam in Ghana*. *6*(3), 71–83.

Boateng, L., Quarpong, W., Ohemeng, A., Asante, M., & Steiner-Asiedu, M. (2019). Effect of complementary foods fortified with Moringa oleifera leaf powder on hemoglobin concentration and growth of infants in the Eastern Region of Ghana. *Food Science and Nutrition*, *7*(1), 302–311. https://doi.org/10.1002/fsn3.890

Bogacz-Radomska, L., & Harasym, J. (2018). β-Carotene-properties and production methods. In *Food Quality and Safety* (Vol. 2, Issue 2, pp. 69–74). Oxford University Press. https://doi.org/10.1093/fqsafe/fyy004

C. Onodu, B., J. Culas, R., & U. Nwose, E. (2018). Facts about dietary fibre in cassava: Implication for diabetes' medical nutrition therapy. *Integrative Food, Nutrition and Metabolism*, *5*(3). https://doi.org/10.15761/ifnm.1000216

Chandrasekara, A., & Josheph Kumar, T. (2016). Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. In *International Journal of Food Science* (Vol. 2016). Hindawi Publishing Corporation. https://doi.org/10.1155/2016/3631647

Chaweewan, Y., & Taylor, N. (2015). Anatomical Assessment of Root Formation and Tuberization in Cassava (Manihot esculenta Crantz). *Tropical Plant Biology*, *8*(1–2), 1–8. https://doi.org/10.1007/s12042-014-9145-5

Chen, X., Lu, J., Li, X., Wang, Y., Miao, J., Mao, X., Zhao, C., & Gao, W. (2017). Effect of blanching and drying temperatures on starch-related physicochemical properties, bioactive components and antioxidant activities of yam flours. *LWT*, *82*, 303–310. https://doi.org/10.1016/j.lwt.2017.04.058

Chinma, C. E., Azeez, S. O., Sulayman, H. T., Alhassan, K., Alozie, S. N., Gbadamosi, H. D., Danbaba, N., Oboh, H. A., Anuonye, J. C., & Adebo, O. A. (2020). Evaluation of fermented African yam bean flour composition and influence of substitution levels on properties of wheat bread. *Journal of Food Science*, *85*(12), 4281–4289. https://doi.org/10.1111/1750-3841.15527

Chipeta, M. M. (2013a). *Status of cassava (Manihot esculenta) production and utilization in Malawi*. https://www.researchgate.net/publication/301199984

Chipeta, M. M. (2013b). *Status of cassava (Manihot esculenta) production and utilization in Malawi*. https://www.researchgate.net/publication/301199984

Christiana, E., & Nkemakonam, C. (2018). Production and quality evaluation of enriched cookies from wheat, African yam bean and carrot composite flours. In *Available on-line at www.afst.valahia.ro* (Vol. 1, Issue 1). www.afst.valahia.ro

Demini, D., & Rajagopalan, U. (2023). *Significance of Iron as a micronutrient in human health and the importance of iron-rich food and iron supplementation Iron as a macronutrient and iron supplementation Malshani Jayasinghe LOLC Advanced Technologies 3 Publications of Citations See Profile*. 1–68. https://doi.org/10.22541/au.167595292.29077365/v1

Deshpande, J., Joshi, M., & Giri, P. (2013). Zinc: The trace element of major importance in human nutrition and health. *International Journal of Medical Science and Public Health*, *2*(1), 1. https://doi.org/10.5455/ijmsph.2013.2.1-6

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. In *Journal of Agriculture and Food Research* (Vol. 3). Elsevier B.V. https://doi.org/10.1016/j.jafr.2021.100117

Dias, M. G., Camões, M. F. G. F. C., & Oliveira, L. (2014). Carotenoid stability in fruits, vegetables and working standards - Effect of storage temperature and time. *Food Chemistry*, *156*, 37–41. https://doi.org/10.1016/j.foodchem.2014.01.050

Dilworth, L. L., Brown, K. J., & Asemota, H. N. (2013). Bioavailability of Essential Minerals from Staples Commonly Consumed in the Tropics. *Journal of Food Research*, *2*(2), 83. https://doi.org/10.5539/jfr.v2n2p83

Dimopoulou, M., Offiah, V., Falade, K., Smith, A. M., Kontogiorgos, V., & Angelis-Dimakis, A. (2021). Techno-economic assessment of polysaccharide extraction from baobab: A scale up analysis. *Sustainability (Switzerland)*, *13*(17). https://doi.org/10.3390/su13179915

Djeni, N. T., Bouatenin, K. M. J. P., Assohoun, N. M. C., Toka, D. M., Menan, E. H., Dousset, X., & Dje, K. M. (2015). Biochemical and microbial characterization of cassava inocula from the three main attieke production zones in Coˆte d'Ivoire. *Food Control*, *50*, 133–140. https://doi.org/10.1016/j.foodcont.2014.08.046

Dogoré Digbeu, Y., Gnanwa Makambou, J., & Ahipo Dué, E. (2018). The Impact of Cooking on the Proximate Composition and Antinutritional Factors of yam Dioscorea esculenta Tubers. In *International Journal of Trend in Research and Development* (Vol. 5, Issue 2). www.ijtrd.com

Dufera, L. T., Hofacker, W., Esper, A., & Hensel, O. (2023). Effect of packaging materials on lycopene vitamin C and water activity of dried tomato (Lycopersicon esculentum Mill.) powder during storage. *Food Science and Nutrition*. https://doi.org/10.1002/fsn3.3562

Dutta, B., & Barnali Dutta, C. (2015). Food and medicinal values of certain species of Dioscorea with special reference to Assam. ~ *15 ~ Journal of Pharmacognosy and Phytochemistry*, *3*(4), 15–18.

Edhirej, A., Sapuan, S. M., Jawaid, M., & Zahari, N. I. (2017). Cassava: Its polymer, fiber, composite, and application. *Polymer Composites*, *38*(3), 555–570. https://doi.org/10.1002/pc.23614

Escobar, A., Dahdouh, L., Rondet, E., Ricci, J., Dufour, D., Tran, T., Cuq, B., & Delalonde, M. (2018a). Development of a Novel Integrated Approach to Monitor Processing of Cassava Roots into Gari: Macroscopic and Microscopic Scales. *Food and Bioprocess Technology*, *11*(7), 1370–1380. https://doi.org/10.1007/s11947-018-2106-5

Escobar, A., Dahdouh, L., Rondet, E., Ricci, J., Dufour, D., Tran, T., Cuq, B., & Delalonde, M. (2018b). Development of a Novel Integrated Approach to Monitor Processing of Cassava Roots into Gari: Macroscopic and Microscopic Scales. *Food and Bioprocess Technology*, *11*(7), 1370–1380. https://doi.org/10.1007/s11947-018-2106-5

Esheya, S. E. (2021). *Economic Analysis of Gari Processing in Ebonyi State, Nigeria*. 1–5. http://www.ajol.info/index.php/najhttps://www.naj.asn.org

Faustina Dufie, W. M., Oduro, I., Ellis, W. O., Asiedu, R., & Maziya-Dixon, B. (2013). Potential health benefits of water yam (Dioscorea alata). *Food and Function*, *4*(10), 1496–1501. https://doi.org/10.1039/c3fo60064e

Felix, F., Danquah Eric, O., Kwesi, A. A., Ama, E. S., Henry, A., & Norbert, M. (2020a). Demonstrating the efficacy of existing yam technologies in the Forest-Savannah transition zone of Ghana. *Journal of Agricultural Science and Practice*, *5*(2), 2536–7072. https://doi.org/10.31248/JASP2020.193

Felix, F., Danquah Eric, O., Kwesi, A. A., Ama, E. S., Henry, A., & Norbert, M. (2020b). Demonstrating the efficacy of existing yam technologies in the Forest-Savannah transition zone of Ghana. *Journal of Agricultural Science and Practice*, *5*(2), 2536–7072. https://doi.org/10.31248/JASP2020.193

Ferguson, M. E., Shah, T., Kulakow, P., & Ceballos, H. (2019). A global overview of cassava genetic diversity. In *PLoS ONE* (Vol. 14, Issue 11). Public Library of Science. https://doi.org/10.1371/journal.pone.0224763

Ferraro, V., Piccirillo, C., Tomlins, K., & Pintado, M. E. (2016). Cassava (Manihot esculenta Crantz) and Yam (Dioscorea spp.) Crops and Their Derived Foodstuffs: Safety, Security and Nutritional Value. *Critical Reviews in Food Science and Nutrition*, *56*(16), 2714–2727. https://doi.org/10.1080/10408398.2014.922045

Fuseini, M. N. (2022). Exploring the Problems the Gari Processing Industry Encounter in the West Gonja Municipality, Ghana. In *Ghana Journal of Development Studies* (Vol. 19, Issue 1).

Gharibzahedi, S. M. T., & Jafari, S. M. (2017). The importance of minerals in human nutrition: Bioavailability, food fortification, processing effects and nanoencapsulation. In *Trends in Food Science and Technology* (Vol. 62, pp. 119–132). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2017.02.017

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).

Gong, L., Hu, L., Feng, D., Chi, J., Wang, B., & Wang, J. (2021). Effects of different household cooking methods on the biological properties of Chinese yam. *Food Chemistry*, *363*. https://doi.org/10.1016/j.foodchem.2021.130246

Greffeuille, V., Dass, M., Fanou-Fogny, N., Nyako, J., Berger, J., & Wieringa, F. T. (2023). Micronutrient intake of children in Ghana and Benin: Estimated contribution of diet and nutrition programs. *Maternal and Child Nutrition*, *19*(2). https://doi.org/10.1111/mcn.13453

Guo, Q., Xu, S., Liu, H. M., Liu, M. W., Wang, C. X., Qin, Z., & Wang, X. De. (2022). Effects of roasting temperature and duration on color and flavor of a sesame oligosaccharide-protein complex in a Maillard reaction model. *Food Chemistry: X*, *16*. https://doi.org/10.1016/j.fochx.2022.100483

Harrison, O. A., Hays, N. P., Ansong, R. S., Datoghe, D., Vuvor, F., & Steiner-Asiedu, M. (2022). Effect of iron-fortified infant cereal on nutritional status of infants in Ghana. *Food Science and Nutrition*, *10*(1), 286–294. https://doi.org/10.1002/fsn3.2669

Hsu, C. L., Hurang, S. L., Chen, W., Weng, Y. M., & Tseng, C. Y. (2004). Qualities and antioxidant properties of bread as affected by the incorporation of yam flour in the formulation. *International Journal of Food Science and Technology*, *39*(2), 231–238. https://doi.org/10.1046/j.0950-5423.2003.00770.x

Igbabul, B. D., Iorliam, B. M., & Umana, E. N. (2015). Physicochemical and Sensory Properties of Cookies Produced From Composite Flours of Wheat, Cocoyam and African Yam Beans. *Journal of Food Research*, *4*(2), 150. https://doi.org/10.5539/jfr.v4n2p150

Ikuemonisan, E. S., Mafimisebi, T. E., Ajibefun, I., & Adenegan, K. (2020). Cassava production in Nigeria: trends, instability and decomposition analysis (1970–2018). *Heliyon*, *6*(10). https://doi.org/10.1016/j.heliyon.2020.e05089

Jan, R., Saxena, D. C., & Singh, S. (2017). Effect of storage conditions and packaging materials on the quality attributes of gluten-free extrudates and cookies made from germinated chenopodium (Chenopodium album) flour. *Journal of Food Measurement and Characterization*, *11*(3), 1071–1080. https://doi.org/10.1007/s11694-017-9484-7

Kamble, D. B., Singh, R., Kaur, B. P., & Rani, S. (2020). Storage stability and shelf life prediction of multigrain pasta under different packaging material and storage conditions. *Journal of Food Processing and Preservation*, *44*(8). https://doi.org/10.1111/jfpp.14585

Karim, O. R., Balogun, A., Oyeyinka, S. A., & Abolade, R. M. (2015). *Comparative analysis of the physicochemical and acceptability of enriched gari (fermented cassava product)*. http://chimie-biologie.ubm.ro/carpathian_journal/index.html

Karya Kate Nanbol, & Otsanjugu Aku Timothy Namo. (2019). The Contribution of Root and Tuber Crops to Food Security: A Review. *Journal of Agricultural Science and Technology B*, *9*(4). https://doi.org/10.17265/2161-6264/2019.04.001

Kasaye T, Melese A, Amare G, & Hailaye G. (2018). *Effect of Fermentation and Boiling on Functional and Physico Chemical Properties of Yam and Cassava Flours*.

Kehinde AT, E. O. U. (2013). Studies on the Physicochemical, Functional and Sensory Properties of Gari Processed from Dried Cassava Chips. *Journal of Food Processing & Technology*, *05*(01). https://doi.org/10.4172/2157-7110.1000293

Kofi Chikpah, S., M, D. T., & K, C. S. (2013). Yam Germplasm in Ghana-A Survey on Varietal Identification and Characterisation of Dioscorea Rotundata-Alata in Northern Region of Ghana. *International Journal of Agronomy and Plant Production*, *4*(4), 719–726. http://www.ijappjournal.com

Kokoh, A.-M., Elleingand, E., & Koffi, E. (2019). Physico-Chemical and Sensory Properties of Breads Produced from Wheat and Fermented Yam Composite Flour Fortified with Moringa Leaves Powder. *Journal of Food and Nutrition Research*, *7*(11), 772–777. https://doi.org/10.12691/jfnr-7-11-3

Kotsiou, K., Sacharidis, D. D., Matsakidou, A., Biliaderis, C. G., & Lazaridou, A. (2021). Impact of roasted yellow split pea flour on dough rheology and quality of fortified wheat breads. *Foods*, *10*(8). https://doi.org/10.3390/foods10081832

Lange, J., & Wyser, Y. (2003). Recent Innovations in Barrier Technologies for Plastic Packaging - A Review. In *Packaging Technology and Science* (Vol. 16, Issue 4, pp. 149–158). https://doi.org/10.1002/pts.621

Legg, J. P., Lava Kumar, P., Makeshkumar, T., Tripathi, L., Ferguson, M., Kanju, E., Ntawuruhunga, P., & Cuellar, W. (2015). Cassava virus diseases: Biology, epidemiology, and management. In *Advances in Virus Research* (Vol. 91, Issue 1, pp. 85–142). Academic Press Inc. https://doi.org/10.1016/bs.aivir.2014.10.001

Leng, M. S., Tobit, P., Demasse, A. M., Wolf, K., Gouado, I., Ndjouenkeu, R., Rawel, H. M., & Schweigert, F. J. (2019a). Nutritional and anti-oxidant properties of yam (Dioscorea schimperiana) based complementary food formulation. *Scientific African*, *5*. https://doi.org/10.1016/j.sciaf.2019.e00132

Leng, M. S., Tobit, P., Demasse, A. M., Wolf, K., Gouado, I., Ndjouenkeu, R., Rawel, H. M., & Schweigert, F. J. (2019b). Nutritional and anti-oxidant properties of yam (Dioscorea schimperiana) based complementary food formulation. *Scientific African*, *5*. https://doi.org/10.1016/j.sciaf.2019.e00132

Li, L., Wang, Q., Liu, C., Hong, J., & Zheng, X. (2023). Effect of oven roasting on major chemical components in cereals and its modulation on flour-based products quality. In *Journal of Food Science* (Vol. 88, Issue 7, pp. 2740–2757). John Wiley and Sons Inc. https://doi.org/10.1111/1750-3841.16625

Li, Q. M., Li, Y., Zou, J. H., Guo, S. Y., Wang, F., Yu, P., & Su, X. J. (2020). Influence of Adding Chinese Yam (Dioscorea opposita Thunb.) Flour on Dough Rheology, Gluten Structure, Baking Performance, and Antioxidant Properties of Bread. *Foods*, *9*(3). https://doi.org/10.3390/foods9030256

Li, S., Cui, Y., Zhou, Y., Luo, Z., Liu, J., & Zhao, M. (2017). The industrial applications of cassava: current status, opportunities and prospects. In *Journal of the Science of Food and Agriculture* (Vol. 97, Issue 8, pp. 2282–2290). John Wiley and Sons Ltd. https://doi.org/10.1002/jsfa.8287

M. O., O., & O. O., A. (2015). Thermal and Physicochemical Properties of Some Starchy Foods: Yam (Dioscorea rotundata), Cocoyam (Xanthosoma sagittifolium) and Plantain (Musa paradisiaca). *Food Science and Technology*, *3*(1), 9–17. https://doi.org/10.13189/fst.2015.030102

Marangoni Júnior, L., Ito, D., Ribeiro, S. M. L., Silva, M. G. da, & Alves, R. M. V. (2018). Stability of β-carotene rich sweet potato chips packed in different packaging systems. *LWT*, *92*, 442–450. https://doi.org/10.1016/j.lwt.2018.02.066

Martins da Costa, J. C., Lima Miki, K. S., da Silva Ramos, A., & Teixeira-Costa, B. E. (2020). Development of biodegradable films based on purple yam starch/chitosan for food application. *Heliyon*, *6*(4). https://doi.org/10.1016/j.heliyon.2020.e03718

Maziya-Dixon, B., Alamu, E. O., Dufie Wireko-Manu, F., & Robert, A. (2017). Retention of iron and zinc in yam flour and boiled yam processed from white yam (D. rotundata) varieties. *Food Science and Nutrition*, *5*(3), 662–668. https://doi.org/10.1002/fsn3.445

Mezette, T. F., Blumer, C. G., & Veasey, E. A. (2013). Diversidade morfológica e molecular entre genótipos de mandioca. *Pesquisa Agropecuaria Brasileira*, *48*(5), 510–518. https://doi.org/10.1590/S0100-204X2013000500007

Mingle, E., Elsie Sanful, R., & Narku Engmann, F. (2017). Sensory and physicochemical properties of bread made from aerial yam (Dioscorea bulbifera) and wheat (Triticum aestivum) flour. *International Journal of Innovative Food Science and Technology*, *1*(1), 29–35. https://doi.org/10.25218/ijifst.2017.01.001.05

M.O. Iwe1, U. Onyeukwu1 and, & A.N. Agiriga. (2016). Proximate, functional and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Cogent, Food, and Agriculture*, 1–11.

Mohamed Ahmed, I. A., Al Juhaimi, F. Y., Osman, M. A., Al Maiman, S. A., Hassan, A. B., Alqah, H. A. S., Babiker, E. E., & Ghafoor, K. (2020). Effect of oven roasting treatment on the antioxidant activity, phenolic compounds, fatty acids, minerals, and protein profile of Samh (Mesembryanthemum forsskalei Hochst) seeds. *LWT*, *131*, 109825. https://doi.org/10.1016/j.lwt.2020.109825

Mohidin, S. R. N. S. P., Moshawih, S., Hermansyah, A., Asmuni, M. I., Shafqat, N., & Ming, L. C. (2023). Cassava (Manihot esculenta Crantz): A Systematic Review for the Pharmacological Activities, Traditional Uses, Nutritional Values, and Phytochemistry. In *Journal of Evidence-Based Integrative Medicine* (Vol. 28). SAGE Publications Ltd. https://doi.org/10.1177/2515690X231206227

Montagnac, J. A., Davis, C. R., & Tanumihardjo, S. A. (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. *Comprehensive Reviews in Food Science and Food Safety*, *8*(3), 181–194. https://doi.org/10.1111/j.1541-4337.2009.00077.x

Ndjouenkeu, R., Ngoualem Kegah, F., Teeken, B., Okoye, B., Madu, T., Olaosebikan, O. D., Chijioke, U., Bello, A., Oluwaseun Osunbade, A., Owoade, D., Takam-Tchuente, N. H., Biaton Njeufa, E., Nguiadem Chomdom, I. L., Forsythe, L., Maziya-Dixon, B., & Fliedel, G. (2021). From cassava to gari: mapping of quality characteristics and end-user preferences in Cameroon and Nigeria. *International Journal of Food Science and Technology*, *56*(3), 1223–1238. https://doi.org/10.1111/ijfs.14790

Ngoualem Kégah, F., & Ndjouenkeu, R. (2023). Gari, a Cassava (Manihot esculenta Crantz) Derived Product: Review on Its Quality and Their Determinants. In *Journal of Food Quality* (Vol. 2023). Hindawi Limited. https://doi.org/10.1155/2023/7238309

Ngwe, M. F. S. N., Omokolo, D. N., & Joly, S. (2015). Evolution and Phylogenetic Diversity of Yam Species (Dioscorea spp.): Implication for Conservation and Agricultural Practices. *PLoS ONE*, *10*(12). https://doi.org/10.1371/journal.pone.0145364

Nimoh, F., Richmond Anaman, R., Asiamah, M. T., Yeboah, B., Agyekum, I., Kpe, P. D. K., & Kouao, D. K. (2020). Financial performance and constraints in gari production in Kumasi, Ghana. *African Journal of Food, Agriculture, Nutrition and Development*, *20*(4), 16085–16098. https://doi.org/10.18697/ajfand.92.18410

Nkhata, S. G., Ayua, E., Kamau, E. H., & Shingiro, J. B. (2018). Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. In *Food Science and Nutrition* (Vol. 6, Issue 8, pp. 2446–2458). Wiley-Blackwell. https://doi.org/10.1002/fsn3.846

Nwancho, S. O. ;, Mgbebu, P. O., Njoku C. K;, & Okoro, C. (n.d.). Effect of Particle Size on the Functional, Pasting and Textural Properties of Gari Produced from Fresh Cassava Roots and Dry Chips. In *The International Journal Of Engineering And Science (IJES)* ||. www.theijes.com

Nwosu, J. N. (2014). *Evaluation of the proximate and sensory properties of biscuits produced from aerial yam flour (Dioscorea bulbifera)* (Vol. 2, Issue 3). www.usa-journals.com

Obidiegwu, J. E., & Akpabio, E. M. (2017). The geography of yam cultivation in southern Nigeria: Exploring its social meanings and cultural functions. *Journal of Ethnic Foods*, *4*(1), 28–35. https://doi.org/10.1016/j.jef.2017.02.004

Obidiegwu, J. E., Lyons, J. B., & Chilaka, C. A. (2020). The dioscorea genus (Yam)—An appraisal of nutritional and therapeutic potentials. In *Foods* (Vol. 9, Issue 9). MDPI AG. https://doi.org/10.3390/foods9091304

Ogbo Frank, C., & Kingsley, C. A. (2014). *Article no. JSRR.2014.003 SCIENCEDOMAIN international Original Research Article Frank and Kingsley*. JSRR.

Okache, T. A., Agomuo, J. K., & Taiwo, M. K. &. (2016). Evaluation of Antinutrients, Minerals and Mineral Bioavailability of Water Yam Based Ojojo Supplemented with Bambara Groundnut. In *International Journal of Agricultural Research and Food Production (IJARFP)* (Vol. 51, Issue 2). http://www.casirmediapublishing.com

Okeke, C., & Oluka, S. (2019). Effect of drying method on functional properties of Yam (Dioscorea sp.) flour. *Poljoprivredna Tehnika*, *44*(3), 59–68. https://doi.org/10.5937/poljteh1903059o

Ola, O., & Adedayo, O. (2020). Analysis of cassava production and processing by various groups in support of cassava value chain in the south west of Nigeria. *ISABB Journal of Food and Agricultural Sciences*, *9*(1), 11–19. https://doi.org/10.5897/isabb-jfas2020.0113

Oladebeye, A. O., Oladebeye, A. A., & Arawande, J. O. (2023). Physicochemical Properties of Wild Yam (Dioscorea villosa) Starch. *International Journal of Food Science, 2023*. https://doi.org/10.1155/2023/8868218

Olatunde, S. J., Owoola, G. O., Ajiboye, T. S., & Babarinde, G. O. (2021). quality evaluation of gari produced from provitamin a cassava (Manihot esculenta) enriched with African yam bean (Sphenostylis stenocarpa). *African Journal of Food, Agriculture, Nutrition and Development, 21*(3), 17682–17695. https://doi.org/10.18697/ajfand.98.19635

Oluba, O. M., Oredokun-Lache, A. B., & Odutuga, A. A. (2018). Effect of vitamin A biofortification on the nutritional composition of cassava flour (gari) and evaluation of its glycemic index in healthy adults. *Journal of Food Biochemistry, 42*(4). https://doi.org/10.1111/jfbc.12450

Oluwamukomi, M., & Adeyemi, I. (2015). Influence of Temperature and Packaging Materials on the Storage Qualities of Soy-Melon "Gari" - A Protein Enriched Cassava Product. *American Journal of Advanced Food Science and Technology*. https://doi.org/10.7726/ajafst.2015.1004

Oluwaniyi, O., & Oladipo, J. (2017). Comparative Studies on the Phytochemicals, Nutrients and Antinutrients Content of Cassava Varieties. *Journal of the Turkish Chemical Society, Section A: Chemistry*, 661–661. https://doi.org/10.18596/jotcsa.306496

Omolayo Fasuan, T., Judith Uchenna, C., & Temitope Omolayo, F. (2017). Development and quality evaluation of biscuits form ulated from flour blends of wheat, bambara nut and aerial yam development and quality evaluation of biscuits formulated from flour blends of wheat, bambara nut and aerial yam. In *Annals. Food Science and Technology* (Vol. 18, Issue 1). www.afst.valahia.ro

Opoku-Mensah, S., Agbekpornu, H., & Wongnaa C. A. (2013). Economic Returns of Gari Processing Enterprises in the Mampong Municipality of Ghana. *International Journal of Agriculture Innovations and Research*, 1–8.

Otegbayo, B. O., Oguniyan, D. J., Olunlade, B. A., Oroniran, O. O., & Atobatele, O. E. (2018a). Characterizing genotypic variation in biochemical composition, anti-nutritional and mineral bioavailability of some Nigerian yam (Dioscorea spp.) land races. *Journal of Food Science and Technology*, *55*(1), 205–216. https://doi.org/10.1007/s13197-017-2913-0

Otegbayo, B. O., Oguniyan, D. J., Olunlade, B. A., Oroniran, O. O., & Atobatele, O. E. (2018b). Characterizing genotypic variation in biochemical composition, anti-nutritional and mineral bioavailability of some Nigerian yam (Dioscorea spp.) land races. *Journal of Food Science and Technology*, *55*(1), 205–216. https://doi.org/10.1007/s13197-017-2913-0

Otekunrin, O. A., & Sawicka, B. (2019). *ACTA SCIENTIFIC AGRICULTURE (ISSN: 2581-365X) Cassava, A 21 st Century Staple Crop: How can Nigeria Harness its Enormous Trade Potentials?*

Otoo, E. (2017). Yam Breeding in Ghana. *Journal of Agricultural Science, 9*(10), 122. https://doi.org/10.5539/jas.v9n10p122

Oyeyinka, S. A., Ajayi, O. I., Gbadebo, C. T., Kayode, R. M. O., Karim, O. R., & Adeloye, A. A. (2019). Physicochemical properties of gari prepared from frozen cassava roots. *LWT*, *99*, 594–599. https://doi.org/10.1016/j.lwt.2018.10.004

Padhan, B., Biswas, M., & Panda, D. (2020). Nutritional, anti-nutritional and physico-functional properties of wild edible yam (Dioscorea spp.) tubers from Koraput, India. *Food Bioscience*, *34*. https://doi.org/10.1016/j.fbio.2020.100527

Padhan, B., Nayak, J. K., & Panda, D. (2020). Natural antioxidant potential of selected underutilized wild yams (Dioscorea spp.) for health benefit. *Journal of Food Science and Technology*, *57*(6), 2370–2376. https://doi.org/10.1007/s13197-020-04470-x

Padhan, B., & Panda, D. (2020). Potential of Neglected and Underutilized Yams (Dioscorea spp.) for Improving Nutritional Security and Health Benefits. In *Frontiers in Pharmacology* (Vol. 11). Frontiers Media S.A. https://doi.org/10.3389/fphar.2020.00496

Panghal, A., Munezero, C., Sharma, P., & Chhikara, N. (2021). Cassava toxicity, detoxification and its food applications: a review. In *Toxin Reviews* (Vol. 40, Issue 1, pp. 1–16). Taylor and Francis Ltd. https://doi.org/10.1080/15569543.2018.1560334

Parmar, A., Sturm, B., & Hensel, O. (2017). Crops that feed the world: Production and improvement of cassava for food, feed, and industrial uses. In *Food Security* (Vol. 9, Issue 5, pp. 907–927). Springer Netherlands. https://doi.org/10.1007/s12571-017-0717-8

Perera, P. I. P., Ordoñez, C. A., Lopez-Lavalle, L. A. B., & Dedicova, B. (2014). A milestone in the doubled haploid pathway of cassava: A milestone in the doubled haploid pathway of cassava (Manihot esculenta Crantz): Cellular and molecular assessment of anther-derived structures. *Protoplasma*, *251*(1), 233–246. https://doi.org/10.1007/s00709-013-0543-6

Polycarp, D., Afoakwa, Budu, & Otoo, E. (2012). Characterization of chemical composition and anti-nutritional factors in seven species within the Ghanaian yam (Dioscorea) germplasm. In *International Food Research Journal* (Vol. 19, Issue 3).

SHAN, N., WANG, P. tao, ZHU, Q. long, SUN, J. yu, ZHANG, H. yu, LIU, X. yue, CAO, T. xu, CHEN, X., HUANG, Y. jin, & ZHOU, Q. hong. (2020). Comprehensive characterization of yam tuber nutrition and medicinal quality of Dioscorea opposita and D. alata from different geographic groups in China. *Journal of Integrative Agriculture*, *19*(11), 2839–2848. https://doi.org/10.1016/S2095-3119(20)63270-1

Sharma, R., Garg, P., Kumar, P., Bhatia, S. K., & Kulshrestha, S. (2020). Microbial fermentation and its role in quality improvement of fermented foods. In *Fermentation* (Vol. 6, Issue 4). MDPI AG. https://doi.org/10.3390/fermentation6040106

Siddiqui, S., Ahmed, N., Devi, A., Singh, R., & Lalramhlimi, B. (2022). *Root Vegetables Having Medicinal Properties: Their Possible Use in Pharmaceutical and Food Industries*. www.intechopen.com

S.L. Tan. (2015). *Cassava-silently, the tuber fills 1*.

Soleimani Pour-Damanab, A., Jafary, A., & Rafiee, S. (2014). Kinetics of the crust thickness development of bread during baking. *Journal of Food Science and Technology*, *51*(11), 3439–3445. https://doi.org/10.1007/s13197-012-0872-z

Sonar, C. R., Paccola, C. S., Al-Ghamdi, S., Rasco, B., Tang, J., & Sablani, S. S. (2019). Stability of color, β-carotene, and ascorbic acid in thermally pasteurized carrot puree to the storage temperature and gas barrier properties of selected packaging films. *Journal of Food Process Engineering*, *42*(4). https://doi.org/10.1111/jfpe.13074

Song, J., Wei, Q., Wang, X., Li, D., Liu, C., Zhang, M., & Meng, L. (2018). Degradation of carotenoids in dehydrated pumpkins as affected by different storage conditions. *Food Research International*, *107*, 130–136. https://doi.org/10.1016/j.foodres.2018.02.024

Sruthi, N. U., Premjit, Y., Pandiselvam, R., Kothakota, A., & Ramesh, S. V. (2021). An overview of conventional and emerging techniques of roasting: Effect on food bioactive signatures. In *Food Chemistry* (Vol. 348). Elsevier Ltd. https://doi.org/10.1016/j.foodchem.2021.129088

Syamila, M., Gedi, M. A., Briars, R., Ayed, C., & Gray, D. A. (2019). Effect of temperature, oxygen and light on the degradation of β-carotene, lutein and α-tocopherol in spray-dried spinach juice powder during storage. *Food Chemistry*, *284*, 188–197. https://doi.org/10.1016/j.foodchem.2019.01.055

Tamaroh, S., & Sudrajat, A. (2021). Antioxidative Characteristics and Sensory Acceptability of Bread Substituted with Purple Yam (Dioscorea alata L.). *International Journal of Food Science, 2021*. https://doi.org/10.1155/2021/5586316

Tanko, M., & Alidu, A.-F. (2017). PROFIT EFFICIENCY OF SMALL SCALE YAM PRODUCTION IN NORTHERN GHANA. In *Article in International Journal of Development Research*. www.eajournals.org

Tekgül Barut, Y., Çalışkan Koç, G., Rayman Ergün, A., Bozkır, H., & Pandiselvam, R. (2023). Effect of different roasting methods on the proximate by composition, flow properties, amino acid compositions, colour, texture, and sensory profile of the chickpeas. *International Journal of Food Science and Technology*, *58*(1), 482–492. https://doi.org/10.1111/ijfs.16072

Teye, E., Amoah, R. S., Adu, M. O., & Darko, D. (2017). Evaluation and Developing Simple Techniques for Assessing Gari Adulteration "Evaluation and Developing Simple Techniques for Assessing Gari Adulteration. *Journal of Food Security*, *5*(5), 162–168. https://doi.org/10.12691/jfs-5-5-2

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. In *International Journal of Food Science* (Vol. 2020). Hindawi Limited. https://doi.org/10.1155/2020/8826693

Timoneda, J., Rodríguez-Fernández, L., Zaragozá, R., Marín, M. P., Cabezuelo, M. T., Torres, L., Viña, J. R., & Barber, T. (2018). Vitamin A deficiency and the lung. In *Nutrients* (Vol. 10, Issue 9). MDPI AG. https://doi.org/10.3390/nu10091132

Tonukari, N. J., Tonukari, N. J., Ezedom, T., Enuma, C. C., Sakpa, S. O., Avwioroko, O. J., Eraga, L., & Odiyoma, E. (2015). White Gold: Cassava as an Industrial Base. *American Journal of Plant Sciences*, *06*(07), 972–979. https://doi.org/10.4236/ajps.2015.67103

Tortoe, C., Dowuona, S., Akonor, P. T., & Dziedzoave, N. T. (2017). Examining the physicochemical, functional and rheological properties in flours of farmers' 7 key yam (Dioscorea spp.) varieties in Ghana to enhance yam production. *Cogent Food and Agriculture*, *3*(1). https://doi.org/10.1080/23311932.2017.1371564

Tortoe, C., Dowuona, S., Akonor, P. T., & Dziedzoave, N. T. (2020). Enhancing the food security status of yam (Dioscorea spp.) for smallholder farmers through an improved farm-gate storage structure in Ghana. *African Journal of Science, Technology, Innovation and Development*, *12*(4), 499–504. https://doi.org/10.1080/20421338.2019.1636488

Udemba, I. O., Olasanmi, B., & Iluebbey, P. (2023). Variation in Total Carotenoid Content of Gari from Yellow Root Cassava (Manihot Esculenta Crantz) Varieties During Prolonged Storage. *European Journal of Agriculture and Forestry Research*, *11*(1), 56–68. https://doi.org/10.37745/ejafr.2013/vol11n15668

Umoh, E. O. (2013). *Ant nutritional factors of false yam (Icacina tricachantha) folur*. https://www.researchgate.net/publi cation/2959121 73

Verter, N., & Becvarova, V. (2014). Yam production as pillar of food security in logo local government area of Benue State, Nigeria. In *European Scientific Journal* (Vol. 10, Issue 31).

Verter, N., & Bečvářová, V. (2015). An analysis of yam production in Nigeria. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *63*(2), 659–665. https://doi.org/10.11118/actaun20156302 0659

Visses, F. de A., Sentelhas, P. C., & Pereira, A. B. (2018). Yield gap of cassava crop as a measure of food security - an example for the main Brazilian producing regions. *Food Security*, *10*(5), 1191–1202. https://doi.org/10.1007/s12571-018-0831-2

Wegmüller, R., Bentil, H., Wirth, J. P., Petry, N., Tanumihardjo, S. A., Allen, L., Williams, T. N., Selenje, L., Mahama, A., Amoaful, E., Steiner-Asiedu, M., Adu-Afarwuah, S., & Rohner, F. (2020). Anemia, micronutrient deficiencies, malaria, hemoglobinopathies and malnutrition in young children and non-pregnant women in Ghana: Findings from a national survey. *PLoS ONE*, *15*(1). https://doi.org/10.1371/journal.pone.0228258

Wirth, J. P., Petry, N., Tanumihardjo, S. A., Rogers, L. M., McLean, E., Greig, A., Garrett, G. S., Klemm, R. D. W., & Rohner, F. (2017). Vitamin a supplementation programs and country-level evidence of vitamin A deficiency. *Nutrients*, *9*(3). https://doi.org/10.3390/nu9030190

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. https://doi.org/10.1080/10408398.2016.1160362

Wumbei, A., Kengni Nerlus Gautier, S., Kwowura Kwodaga, J., Fovo Joseph, D., & Joseph Hubert Galani, Y. (2023). State of the Art of Yam Production. In *Advances in Root Vegetables Research*. IntechOpen. https://doi.org/10.5772/intechopen.106504

Xiang, H., Sun-Waterhouse, D., Waterhouse, G. I. N., Cui, C., & Ruan, Z. (2019). Fermentation-enabled wellness foods: A fresh perspective. *Food Science and Human Wellness*, *8*(3), 203–243. https://doi.org/10.1016/j.fshw.2019.08.003

Younge, S., Amoah, R. S., Abano, E. E., Kumi, F., & Anyebuno, G. (2022). Physico-nutritional characterization of composite cassava and orange-fleshed sweet potato flours and sensory evaluation of “fufu” prepared from the flour blends. *Journal of Food Processing and Preservation*, *46*(12). https://doi.org/10.1111/jfpp.17254

Zekarias Tsige, T. (2019). Medicinal, Nutritional and Anti-Nutritional Properties of Cassava (Manihot esculenta): A Review. *01*, 01–14. https://doi.org/10.5829/idosi.ajn.2019.34.46

Zhang, H., Patel, J., Bhunia, K., Al-Ghamdi, S., Sonar, C. R., Ross, C. F., Tang, J., & Sablani, S. S. (2019). Color, vitamin C, β-carotene and sensory quality retention in microwave-assisted thermally sterilized sweet potato puree: Effects of polymeric package gas barrier during storage. *Food Packaging and Shelf Life*, *21*. https://doi.org/10.1016/j.fpsl.2019.100324

Zhang, Z., Gao, W., Wang, R., & Huang, L. (2014). Changes in main nutrients and medicinal composition of Chinese yam (Dioscorea opposita) tubers during storage. *Journal of Food Science and Technology*, *51*(10), 2535–2543. https://doi.org/10.1007/s13197-012-0776-y

Zhu, F. (2015). Isolation, Composition, Structure, Properties, Modifications, and Uses of Yam Starch. *Comprehensive Reviews in Food Science and Food Safety*, *14*(4), 357–386. https://doi.org/10.1111/1541-4337.12134

APENDICES

APENDIX A

SENSORY EVALUATION FORM FOR THE COMPOSITE

	<20	20-35	>35	**How often do you eat gari? Please tick**	1-4 times/ month	5-9 times /month	Over 10 times/ month

Instruction: Taste the samples in front of you from left to right.

On a scale of 1 to 9, how do you like the following attributes of the **CODED** gari?

1- dislike extremely **2**- dislike very much **3**- dislike moderately **4**- dislike slightly

5- neither like nor dislike

6- like slightly **7**- like moderately **8-** like very much **9**- like extremely

Appearance: How attractive is the gari?

Texture: How the product looks in terms particle size

Taste: sensation felt in your mouth while you chew/eat the gari

Flavour: the taste of gari after swallowing. Do you feel the normal gari flavour?

Overall Acceptance: Combined effect of appearance, texture, taste, flavour

	CODE	**Appearance**	**Taste**	**Texture**	**Flavour**	**Overall acceptance**
DAY 1	**1D,30,120**					
	1D,20,140					
	1D,20,100					
	1D,10,120					
	1D, CONT					

DAY 2	**2D,20,120**					
	2D,10,140					
	2D,10,100					
	2D,30,100					
	2D,20,120					
	2D,30,140					
	2D, CONT					
DAY 3	**3D,30,120**					
	3D,10,120					
	3D,20,100					
	3D, 20,140					
	3D, CONT					

APENDIX B

SENSORY EVALUATION FORM FOR THE OPTIMISED GARI

	<20	20-35	>35	**How often do you eat gari? Please tick**	1-4 times/ month	5-9 times /month	Over 10 times/ month

Instruction: Taste the samples in front of you from left to right.

On a scale of 1 to 9, how do you like the following attributes of the CODED gari?

1- dislike extremely **2-** dislike very much **3-** dislike moderately **4-** dislike slightly

5- neither like nor dislike

6- like slightly **7-** like moderately **8-** like very much **9-** like extremely

Appearance: How attractive is the gari?

Texture: How the product looks in terms particle size

Taste: sensation felt in your mouth while you chew/eat the gari

Flavour: the taste of gari after swallowing. Do you feel the normal gari flavour?

Overall Acceptance: Combined effect of appearance, texture, taste, flavour

	CODE	**Appearance**	**Taste**	**Texture**	**Flavour**	**Overall acceptance**
	PE/SM					
	PE/ OM					
	PE/ RM					
	PE/ PET/ SM					
	PE/ PET/OM					
	PE/ PET/RM					

	PE/PET/AL/SM					
	PE/PET/AL/OM					
	PE/PET/ AL/RM					

APENDIX C

ANOVA FOR THE THREE-FACTOR THREE LEVELS RESPONSES

BETA CAROTENE

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	54.7181	5.4718	11.54	0.002
Blocks	1	3.8160	3.8160	8.05	0.025
Linear	3	35.3746	11.7915	24.86	0.000
YQ	1	23.1267	23.1267	48.76	0.000
FD	1	3.4273	3.4273	7.23	0.031
RT	1	8.8207	8.8207	18.60	0.004
Square	3	7.3269	2.4423	5.15	0.034
YQ*YQ	1	2.1396	2.1396	4.51	0.071
FD*FD	1	2.2055	2.2055	4.65	0.068
RT*RT	1	4.0043	4.0043	8.44	0.023
2-Way Interaction	3	6.6620	2.2207	4.68	0.043
YQ*FD	1	1.1245	1.1245	2.37	0.168
YQ*RT	1	3.0365	3.0365	6.40	0.039
FD*RT	1	2.5011	2.5011	5.27	0.055
Error	7	3.3202	0.4743		
Lack-of-Fit	5	2.4741	0.4948	1.17	0.521
Pure Error	2	0.8461	0.4230		
Total	17	58.0383			

IRON CONTENT (µg/g)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	19560.3	1956.03	2.90	0.085
Blocks	1	3723.5	3723.53	5.53	0.051
Linear	3	8065.9	2688.64	3.99	0.060
YQ	1	4399.2	4399.19	6.53	0.038
FD	1	3.3	3.33	0.00	0.946
RT	1	3663.4	3663.41	5.44	0.052
Square	3	6635.7	2211.91	3.28	0.088
YQ*YQ	1	4499.0	4499.01	6.68	0.036
FD*FD	1	185.5	185.50	0.28	0.616
RT*RT	1	1555.9	1555.94	2.31	0.172
2-Way Interaction	3	1073.2	357.72	0.53	0.675
YQ*FD	1	102.9	102.88	0.15	0.708
YQ*RT	1	110.4	110.40	0.16	0.698
FD*RT	1	859.9	859.88	1.28	0.296
Error	7	4716.4	673.78		
Lack-of-Fit	5	4637.7	927.54	23.56	0.041
Pure Error	2	78.7	39.37		
Total	17	24276.8			

ZINC CONTENT (μg/g)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	1880.66	188.07	0.89	0.581
Blocks	1	292.31	292.31	1.38	0.278
Linear	3	222.25	74.08	0.35	0.790
YQ	1	37.39	37.39	0.18	0.687
FD	1	105.45	105.45	0.50	0.503
RT	1	79.41	79.41	0.38	0.559
Square	3	557.73	185.91	0.88	0.496
YQ*YQ	1	325.50	325.50	1.54	0.255
FD*FD	1	204.88	204.88	0.97	0.358
RT*RT	1	100.59	100.59	0.48	0.512
2-Way Interaction	3	1079.45	359.82	1.70	0.253
YQ*FD	1	0.32	0.32	0.00	0.970
YQ*RT	1	1034.84	1034.84	4.90	0.063
FD*RT	1	44.28	44.28	0.21	0.661
Error	7	1479.20	211.31		
Lack-of-Fit	5	1467.86	293.57	51.77	0.019
Pure Error	2	11.34	5.67		
Total	17	3359.86			

SWELLING CAPACITY

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	3.30189	0.330189	33.17	0.000
Blocks	1	0.06323	0.063231	6.35	0.040
Linear	3	0.81428	0.271427	27.27	0.000
YQ	1	0.74420	0.744200	74.76	0.000
FD	1	0.00883	0.008832	0.89	0.378
RT	1	0.06125	0.061250	6.15	0.042
Square	3	0.09942	0.033139	3.33	0.086
YQ*YQ	1	0.01179	0.011785	1.18	0.313
FD*FD	1	0.06907	0.069074	6.94	0.034
RT*RT	1	0.01179	0.011785	1.18	0.313
2-Way Interaction	3	0.01885	0.006283	0.63	0.618
YQ*FD	1	0.01260	0.012600	1.27	0.298
YQ*RT	1	0.00063	0.000625	0.06	0.809
FD*RT	1	0.00562	0.005625	0.57	0.477
Error	7	0.06968	0.009955		
Lack-of-Fit	5	0.04522	0.009043	0.74	0.661
Pure Error	2	0.02447	0.012233		
Total	17	3.37158			

BRIGHTNNESS (L*)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	185.413	18.5413	14.36	0.001
Blocks	1	6.560	6.5600	5.08	0.059
Linear	3	85.154	28.3847	21.98	0.001
YQ	1	25.896	25.8960	20.05	0.003
FD	1	57.248	57.2482	44.33	0.000
RT	1	2.010	2.0100	1.56	0.252
Square	3	23.237	7.7457	6.00	0.024
YQ*YQ	1	1.987	1.9869	1.54	0.255
FD*FD	1	16.964	16.9643	13.13	0.008
RT*RT	1	3.448	3.4482	2.67	0.146
2-Way Interaction	3	12.375	4.1251	3.19	0.093
YQ*FD	1	11.729	11.7293	9.08	0.020
YQ*RT	1	0.560	0.5600	0.43	0.531
FD*RT	1	0.086	0.0860	0.07	0.804
Error	7	9.041	1.2915		
Lack-of-Fit	5	8.710	1.7420	10.53	0.089
Pure Error	2	0.331	0.1654		
Total	17	194.453			

BROWNNESS (a*)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	20.0565	2.00565	4.68	0.026
Blocks	1	0.4827	0.48273	1.13	0.324
Linear	3	8.6841	2.89471	6.76	0.018
YQ	1	2.6259	2.62587	6.13	0.042
FD	1	5.7820	5.78200	13.50	0.008
RT	1	0.2763	0.27627	0.65	0.448
Square	3	1.3375	0.44583	1.04	0.432
YQ*YQ	1	0.0690	0.06897	0.16	0.700
FD*FD	1	1.1156	1.11562	2.61	0.151
RT*RT	1	0.1165	0.11651	0.27	0.618
2-Way Interaction	3	1.2532	0.41773	0.98	0.457
YQ*FD	1	0.5437	0.54374	1.27	0.297
YQ*RT	1	0.0205	0.02054	0.05	0.833
FD*RT	1	0.6889	0.68890	1.61	0.245
Error	7	2.9971	0.42816		
Lack-of-Fit	5	2.9237	0.58473	15.92	0.060
Pure Error	2	0.0735	0.03674		
Total	17	23.0536			

YELLOWNESS (b*)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	15.3302	1.53302	1.69	0.249
Blocks	1	0.0317	0.03175	0.04	0.857
Linear	3	0.3523	0.11744	0.13	0.939
YQ	1	0.0039	0.00390	0.00	0.949
FD	1	0.2812	0.28120	0.31	0.595
RT	1	0.0672	0.06722	0.07	0.793
Square	3	7.5980	2.53266	2.80	0.118
YQ*YQ	1	0.0127	0.01270	0.01	0.909
FD*FD	1	4.4423	4.44227	4.91	0.062
RT*RT	1	3.5291	3.52909	3.90	0.089
2-Way Interaction	3	6.3016	2.10054	2.32	0.162
YQ*FD	1	2.0411	2.04111	2.26	0.177
YQ*RT	1	1.7956	1.79560	1.98	0.202
FD*RT	1	2.4649	2.46490	2.72	0.143
Error	7	6.3334	0.90477		
Lack-of-Fit	5	5.5728	1.11457	2.93	0.274
Pure Error	2	0.7606	0.38028		
Total	17	21.6636			

APPEARANCE

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	5.51072	0.551072	3.88	0.043
Blocks	1	0.17987	0.179873	1.27	0.298
Linear	3	0.35272	0.117573	0.83	0.519
YQ	1	0.07782	0.077823	0.55	0.483
FD	1	0.00671	0.006709	0.05	0.834
RT	1	0.26819	0.268188	1.89	0.212
Square	3	0.40411	0.134704	0.95	0.468
YQ*YQ	1	0.14488	0.144879	1.02	0.346
FD*FD	1	0.23088	0.230885	1.62	0.243
RT*RT	1	0.00061	0.000608	0.00	0.950
2-Way Interaction	3	0.28851	0.096171	0.68	0.593
YQ*FD	1	0.08327	0.083272	0.59	0.469
YQ*RT	1	0.08064	0.080640	0.57	0.476
FD*RT	1	0.12460	0.124601	0.88	0.380
Error	7	0.99474	0.142105		
Lack-of-Fit	5	0.99039	0.198078	91.19	0.011
Pure Error	2	0.00434	0.002172		
Total	17	6.50545			

FLAVOUR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	5.05257	0.505257	6.86	0.009
Blocks	1	0.46758	0.467583	6.35	0.040
Linear	3	0.45367	0.151223	2.05	0.195
YQ	1	0.08476	0.084761	1.15	0.319
FD	1	0.33745	0.337450	4.58	0.070
RT	1	0.03146	0.031457	0.43	0.534
Square	3	0.16330	0.054432	0.74	0.561
YQ*YQ	1	0.00006	0.000058	0.00	0.978
FD*FD	1	0.00080	0.000805	0.01	0.920
RT*RT	1	0.16276	0.162758	2.21	0.181
2-Way Interaction	3	1.70426	0.568088	7.71	0.013
YQ*FD	1	0.79386	0.793855	10.78	0.013
YQ*RT	1	0.02856	0.028557	0.39	0.553
FD*RT	1	0.88185	0.881851	11.97	0.011
Error	7	0.51554	0.073649		
Lack-of-Fit	5	0.42545	0.085090	1.89	0.381
Pure Error	2	0.09009	0.045046		
Total	17	5.56811			

TASTE

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	5.05257	0.505257	6.86	0.009
Blocks	1	0.46758	0.467583	6.35	0.040
Linear	3	0.45367	0.151223	2.05	0.195
YQ	1	0.08476	0.084761	1.15	0.319
FD	1	0.33745	0.337450	4.58	0.070
RT	1	0.03146	0.031457	0.43	0.534
Square	3	0.16330	0.054432	0.74	0.561
YQ*YQ	1	0.00006	0.000058	0.00	0.978
FD*FD	1	0.00080	0.000805	0.01	0.920
RT*RT	1	0.16276	0.162758	2.21	0.181
2-Way Interaction	3	1.70426	0.568088	7.71	0.013
YQ*FD	1	0.79386	0.793855	10.78	0.013
YQ*RT	1	0.02856	0.028557	0.39	0.553
FD*RT	1	0.88185	0.881851	11.97	0.011
Error	7	0.51554	0.073649		
Lack-of-Fit	5	0.42545	0.085090	1.89	0.381
Pure Error	2	0.09009	0.045046		
Total	17	5.56811			

TEXTURE

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	2.28927	0.228927	7.81	0.006
Blocks	1	0.45038	0.450380	15.36	0.006
Linear	3	0.15167	0.050555	1.72	0.249
YQ	1	0.11045	0.110450	3.77	0.093
FD	1	0.00610	0.006104	0.21	0.662
RT	1	0.03511	0.035112	1.20	0.310
Square	3	0.41300	0.137668	4.70	0.042
YQ*YQ	1	0.03194	0.031943	1.09	0.331
FD*FD	1	0.36942	0.369421	12.60	0.009
RT*RT	1	0.01099	0.010989	0.37	0.560
2-Way Interaction	3	0.33406	0.111355	3.80	0.066
YQ*FD	1	0.19334	0.193339	6.59	0.037
YQ*RT	1	0.01822	0.018225	0.62	0.456
FD*RT	1	0.12250	0.122500	4.18	0.080
Error	7	0.20524	0.029320		
Lack-of-Fit	5	0.18897	0.037794	4.65	0.187
Pure Error	2	0.01627	0.008133		
Total	17	2.49451			

OVERALL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	4.97790	0.497790	6.08	0.013
Blocks	1	0.23811	0.238113	2.91	0.132
Linear	3	0.31690	0.105632	1.29	0.350
YQ	1	0.02205	0.022050	0.27	0.620
FD	1	0.18905	0.189046	2.31	0.172
RT	1	0.10580	0.105800	1.29	0.293
Square	3	0.06555	0.021851	0.27	0.847
YQ*YQ	1	0.05548	0.055485	0.68	0.438
FD*FD	1	0.00022	0.000221	0.00	0.960
RT*RT	1	0.01223	0.012231	0.15	0.711
2-Way Interaction	3	0.58632	0.195440	2.39	0.155
YQ*FD	1	0.25547	0.255471	3.12	0.121
YQ*RT	1	0.00023	0.000225	0.00	0.960
FD*RT	1	0.33063	0.330625	4.04	0.084
Error	7	0.57333	0.081905		
Lack-of-Fit	5	0.55473	0.110946	11.93	0.079
Pure Error	2	0.01860	0.009300		
Total	17	5.55123			

APPENDIX D

RESPONSE OPTIMISATION PREDICTION

Variable	Setting
YQ	30
FD	3
RT	100

Response	Fit	SE Fit	95% CI	95% PI
B. Carotene (ug/g)	12.299	0.994	(9.948, 14.650)	(9.439, 15.158)
Overall	8.073	0.413	(7.096, 9.050)	(6.884, 9.261)
Flavour	7.848	0.435	(6.819, 8.878)	(6.596, 9.100)
Texture	7.661	0.247	(7.077, 8.246)	(6.950, 8.372)
Taste	8.322	0.392	(7.395, 9.248)	(7.195, 9.449)
Appearance	7.121	0.544	(5.834, 8.408)	(5.556, 8.687)
a	-2.039	0.945	(-4.273, 0.195)	(-4.756, 0.678)
L	38.20	1.64	(34.32, 42.08)	(33.48, 42.92)
SC	3.002	0.144	(2.662, 3.343)	(2.588, 3.417)

APPENDIX E

ETHICAL CLEARANCE

UNIVERSITY OF CAPE COAST

INSTITUTIONAL REVIEW BOARD SECRETARIAT

TEL:
E-MAIL:
OUR REF: IRB/C3/Vol.2/0279
YOUR REF:
OMB NO: 0990-0271
IORG #: IORG0011497

28TH JANUARY, 2025

Mr. Amos Manyo
Department of Agricultural Engineering
University of Cape Coast

Dear Mr. Manyo,

ETHICAL CLEARANCE – ID (UCCIRB/CANS/2023/35)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted Provisional Approval for the implementation of your study titled **Effects of Packaging Materials and Storage Conditions on the Quality Attributes and Shelf Stability of Optimized Cassava-Yam Composite Gari.** This approval is valid from **28th January, 2025 to 27th January, 2026.** You may apply for a renewal of ethical approval if the study lasts for more than 12 months.

Please note that any modification to the project must first receive renewal clearance from the UCCIRB before its implementation. You are required to submit a periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

Always quote the protocol identification number in all future correspondence with us about this protocol.

Yours faithfully,

Kofi F. Amuquandoh
Ag. Administrator

Prof Fiifi Amoako Johnson
Chairperson

CHAIRPERSON
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST