UNIVERSITY OF CAPE COAST

DEVELOPMENT OF GLUTEN-FREE NOODLES FROM CASSAVA-BAMBARA GROUNDNUT COMPOSITE FLOUR

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BY

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DECLARATION

Candidate's Declaration

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

Candidate's Signature: .... Date: ....

Name: Akwetey, Ebenezer Bassey

Supervisors' Declaration

I 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.

Principal Supervisor's Signature: .... Date: ....

Name: Dr. (Mrs.) Rosemond Godbless Dadzie

ABSTRACT

Noodles are now a common food in the World, eaten by many from different cultural backgrounds and races. However, noodles made from wheat are often seen as less healthy. As people become more health-conscious, researchers are experimenting with different ingredients to make noodles that are healthier, gluten-free, and meet changing food preferences. The study was centered on the development of gluten-free noodles from Casava-Bambara groundnut composite flour and the determination of the functional, textural, colour, sensory and nutritional composition of the resulting noodles. A simplex centroid mixture design in Minitab software was used for the formulations with the two mixture variables: Cassava flour [X_1 (% w/w)] and Bambara groundnut flour [X_2 (% w/w)] equaling 100 %. The ash, protein and fibre contents significantly increased (from 0.84 % to 1.52 %, 4.16 % to 7.27 % and 3.01 % to 4.48 % respectively) whereas the moisture and carbohydrate contents decreased (from 8.35 % to 7.35 and 87.23 % to 82.84 % respectively) as the percentage of Bambara Groundnut Flour increased. In addition, zinc, calcium, magnesium, iron, and potassium for Bambara Groundnut Flour incorporated noodles increased. Cooking losses were also minimal for formulations containing Bambara groundnut flour compared to the noodles prepared from 100 % Cassava Flour. Noodles with 30 % Bambara Groundnut Flour was the most preferred after the sensory evaluation. The results are relevant for utilizing Bambara groundnut as an ingredient in gluten-free noodle production as its addition improved the functional properties, nutritional composition and sensory attributes.

KEYWORDS

Noodles

Bambara groundnut

Cassava flour

Gluten-free noodles

Nutritional composition

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Thank you all.

DEDICATION

To the Akwetey family, who have always been my steadfast support and inspiration. Your endless love and encouragement have made this journey achievable. I dedicate this work to you, with sincere appreciation.

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LIST OF ABBREVIATION

BGF	Bambara Groundnut Flour
CF	Cassava Flour
SDGs	Sustainable Development Goals

CHAPTER ONE

INTRODUCTION

Background to the study

There is an urgent need for nutritious and gluten-free food options due to the increased awareness of celiac disease and gluten intolerance in recent years. Millions of people worldwide, including a growing number in developing nations, suffer from celiac disease, an autoimmune disorder caused by consuming gluten (Cataldo *et al*., 2017). For individuals with this condition, traditional wheat-based noodles can cause serious health problems and do not meet their dietary needs. Moreover, conventional noodles have often been criticized for their poor nutritional profile, high in fats/oil and carbohydrates yet lacking dietary fiber, essential minerals, vitamins and protein (Wahjuningsih *et al*., 2023). These concerns highlight the need for healthier, gluten-free noodle alternatives that addresses specific dietary requirements while improving overall nutritional value.

In Ghana, noodles have become a staple food, consumed by many due to their simplicity, affordability, and versatility. However, their widespread popularity also raises nutritional concerns, especially for children attracted to the artificial colours, flavours, and taste enhancers often found in these products. The main ingredient in noodle production, Wheat flour, has a high glycemic index, low protein content, and lacks essential micronutrients (Dankwa *et al*., 2017). Additionally, wheat flour is costly in Ghana, with an annual per capita consumption of approximately 20 kg, primarily for bakery products (Owusu *et al*., 2017). This dependence on imported wheat puts pressure on Ghana's food security, making it essential to find affordable, locally sourced alternatives.

To address these issues, researchers have explored incorporating local crops and legumes into noodle production. Cassava, a widely grown root crop in Ghana, has emerged as a promising alternative to wheat flour, which has high carbohydrate content, is affordable, and is readily available. Products from cassava are considered to have a glycemic index that is lower than that of wheat-based products, making them a healthier option, and are rich in minerals such as calcium, zinc, iron, and magnesium (Hussin *et al.*, 2020). Furthermore, utilizing cassava reduces post-harvest losses, promotes industrial processing, and supports the livelihoods of farmers and processors. However, the low protein content and insufficient amounts of essential amino acids in cassava flour are its primary limitations (Chijioke *et al.*, 2017), necessitating supplementation with protein-rich ingredients to create a nutritionally balanced product.

Bambara groundnut, a locally available legume, is a great option for improving the nutritional quality of cassava-based noodles. It is well-known for having high protein content, a balanced amino acid profile and being rich in lysine and methionine, which are essential amino acids often lacking in cereal and root-based foods (Elegbede, 1998). Incorporating Bambara groundnut flour into cassava noodles not only increases their protein content but also boosts their mineral levels, addressing key nutritional deficiencies (Nwadi *et al.*, 2020). Reports from other studies have demonstrated that replacing wheat flour with Bambara groundnut flour enhances both functional properties and nutritional value of noodles, while also providing a sustainable, cost-effective solution for local communities (Mepba *et al*., 2021).

This study aimed to optimise the formulation of gluten-free noodles using composite flour made from cassava and Bambara groundnut. A mixture design approach was employed to analyse the effects of varying flour ratios on the nutritional composition, cooking characteristics, textural properties, physicochemical attributes, and sensory acceptability of the noodles. This research aims to solve the problems of gluten intolerance and poor nutrition by creating a healthier, gluten-free noodle that meets consumer preferences. It also uses local ingredients to improve food security and support economic growth in Ghana.

Statement of the problem

Traditionally, noodles are made with gluten-containing wheat flour, which makes noodle consumption unsafe for people with celiac disease. Albuja-Vaca *et al*. (2019) described Celiac disease as a chronic digestive condition that causes nutrient malabsorption and may lead to serious health complications when gluten is consumed. With rising health consciousness among consumers, there is growing interest in developing healthier and gluten-free noodle alternatives. This has driven researchers to explore new ingredients to produce noodles that are both nutritious and safe for individuals with gluten intolerance.

Cassava and Bambara groundnuts are two gluten-free crops with significant potential for use in food production. Despite their availability, they remain underutilised, especially in their use for innovative food products like gluten-free noodles. While cassava flour has been studied to partially replace wheat flour in baked goods, limited research has focused on its application in noodle production. Research has shown that cassava flour can be used as a suitable substitute for wheat flour in noodles (Abidin *et al*., 2014; Omeire & Kabuo, 2023). However, these studies predominantly relied on cassava-wheat composite flours rather than entirely gluten-free formulations.

To address this, combining cassava flour with protein-rich Bambara groundnut flour offers a promising solution. Bambara groundnuts also enhance the essential amino acid content, making the final product more balanced and nutritious. Therefore, it is essential to investigate and optimise the formulation of Cassava-Bambara groundnut noodles to achieve acceptable nutritional, functional, cooking and sensory qualities.

Main Objective

The main aim of this study was to determine the quality characteristics of gluten-free noodles made from Cassava and Bambara groundnut flours using a mixture design.

Research Objectives

1. To determine the physicochemical properties of the noodles made from Cassava and Bambara groundnut flour.
2. To evaluate the functional, textural, and cooking characteristics of the noodles made from Cassava and Bambara groundnut flour.
3. To determine the sensory properties and overall acceptability of the Cassava-Bambara groundnut flour noodles.

Research Questions

1. How do the varying proportions of cassava flour and Bambara groundnut flour affect the physicochemical properties of the noodles produced?
2. How do different ratios of cassava and Bambara groundnut flour influence the functional, textural and cooking characteristics of the noodles?
3. How do the varying proportions of cassava flour and Bambara groundnut flour affect the overall acceptability and other sensory properties of noodles?

Significance of the study

The enrichment of noodles with Bambara Groundnut Flour would be relevant for improving the cooking properties, nutritional, and consumer acceptability of noodles, which could help in the utilisation of cassava and Bambara groundnut for food. Exploring more utilisation of Cassava for food would be relevant for reducing post-harvest losses in the cassava production industries. Also, utilising cassava flour instead of wheat flour in noodle production would be relevant for reducing the importation cost of wheat and the material cost in noodle production. The acceptance of Cassava-Bambara groundnut noodles would be relevant for providing a variety of nutrient-rich diets in the global market and thus hinder hunger and eliminate poverty, leading to the achievement of the SDGS (1 and 2). Moreover, gluten-free noodles are a safe option for individuals who have gluten intolerance or celiac disease, as they do not contain gluten, a protein that can trigger adverse reactions in these individuals.

Organisation of the study

This research is organised into five chapters: The first chapter contains the background to the study, statement of the problem, research questions, objectives (general and specific), and significance of the study. Chapter two documents the literature on noodle products and the nutritional and health benefits of cassava and Bambara groundnuts. Chapter three presents the materials and methods. The section highlights the procedure for noodles development, flour processing, and the procedure used for analysing the samples and the data. Chapter four contains the results and discussion. Chapter five contains the summary, conclusions, and recommendations.

CHAPTER TWO

LITERATURE REVIEW

Overview and Production of Cassava

Cassava, *Manihot esculenta*, is a tropical root crop and a reliable source of carbohydrate. It is considered a ‘‘low risk’’ crop that adapts readily to a wide variety of agroecological conditions. This makes its production and availability all year round (Afoakwa *et al*., 2012). Growing to a height of three meters or more, the cassava plant is a short-lived, woody, shrubby perennial with an erect, glabrous stem with visible knobby leaf scars that branch to varying degrees (Okafor, 2019). A vibrant root system and a shoot system are other features of cassava plants. The shoot system is made up of stems, leaves, and flowers, whereas the roots and tubers make up the root system (Okeke, 2011). According to Tan *et al*. (2020), it is considered a crucial crop that helps with food security issues in the tropics, where it is primarily grown. Cassava, a drought-tolerant crop, can be grown successfully on low-nutrient soils but can give yields that many other crops cannot contain.

The plant adapts well to latitudes between 30° north and south of the equator, elevations between sea level and 2,000 meters (7,000 feet) above sea level, equatorial temperatures, and poor soils with ph values ranging from acidic to alkaline. This condition is preferably experienced in. According to Oladunmoye et al. (2017), these conditions are more prevalent in South America and Africa. Through government policies and initiatives, root and tuber production has shown a positive growth trend over time. The Ghana Statistical

Service (2020) reported that cassava production spiked from 10.5 million metric tons in 2014 to 14.7 MT in 2019. This significant increase is attributable to the introduction of improved varieties. For instance, the adoption of high-yielding cassava varieties, such as the "*Ampong*", "*Bankye Hemaa*" and "*Cape vas bankye*" has shown promising results in improving yields and income for farmers (Gulia *et al*., 2014).

Economic Importance of Cassava

Globally, cassava production is projected at 242 million tons of cassava, with Africa accounting for 54 % (130 million tons) of this total. On the other hand, Ghana ranks third among African producers, behind Nigeria and the Democratic Republic of the Congo, with an annual production of about 10 million tons, representing 8 % of the continent's total cassava production (Yahaya *et al*., 2022). In addition to the significant production advantages, fresh cassava generates income for farmers, agricultural labourers, and those involved in its sales, such as itinerant traders who transport the crop from village to village and urban marketers who sell the product in retail locations. (Okeke, 2011). With relatively low input costs, it is an accessible crop that can generate income and contribute to local economies. Cassava plays a significant role in Ghana's agricultural economy and is thought to account for 15 % of the country's total agricultural GDP (Dankwa *et al*., 2017). In many countries, cassava is also essential to food security, especially in tropical regions where it is extensively grown because of its exceptional drought resistance. It also acts as a vital buffer during periods of food scarcity or when the price of other staple crops, like grains, fluctuates (Amelework *et al.*, 2021). The crop can flourish in poor soil conditions and withstand periods of limited rainfall, making it a dependable option in regions affected by climate variability (Yahaya *et al.*, 2022). Moreover, the crop's versatility enhances its pivotal role in food security as it can be transformed into various food products, including flour, tapioca, and fermented items. This adaptability allows it to be incorporated into diverse diets and culinary traditions, catering to different cultural preferences (Immanuel *et al.*, 2024). On the other hand, the potential for processing cassava into various products creates job opportunities and enhances food systems. Processing can also help reduce post-harvest losses, ensuring that more of the harvest contributes to food security (Ministry of Food and Agriculture, 2021).

Nutritional and Anti-nutritional properties of cassava

Cassava roots are a rich source of carbohydrates and also contain significant amounts of various minerals, vitamins and dietary fibre (Zekarias *et al.*, 2019). However, they are relatively low in protein, with only approximately 1-2 % protein, making them primarily starchy foods (Aydin and Gocmen, 2011). About half of the crude protein in the cassava comprises entirely of free amino acids, notably glutamic and aspartic acids, and non-protein compounds such as nitrites, nitrates, and cyanogenic compounds, while whole protein makes up the remaining half (Ogbadoyi *et al*., 2006). Zvinavashe *et al*. (2011) also noted that the roots have relatively high levels of arginine, glutamic acid, and aspartic acid, but relatively low levels of some essential amino acids, including methionine, cysteine, and tryptophan. Cassava roots contain significant amounts of minerals, including calcium, iron, potassium, magnesium, copper, zinc, and manganese, in addition to proteins and carbohydrates (Adugna, 2022). Roots from cassava, despite their numerous benefits, have some anti-nutritional factors. Anti-nutrients, also widely recognised as nutritional stress factors, can be synthetic or natural substances that inhibit nutrients from being absorbed. Among these antinutrients are phenolic compounds, cyanogenic glycosides (cyanide), phytates, nitrates and nitrites, and oxalates (Tan *et al.,* 2020). The type of cassava also determines the amount of cyanide in the crop, though most variety has varying amounts of this toxic substance (Anbuselvi and Balamurugan, 2014). Chronic exposure to cyanide can lead to cyanide poisoning, which manifests as goitres, neurological disorders, and in extreme cases, even death. This consequence is a result of the synthesis of thiocyanate, a byproduct of cyanide metabolism that inhibits the thyroid gland from absorbing iodide (Wahjuningsih *et al.*, 2023). On the other hand, the actions of tannins are evident in cassava roots as they tend to bind to proteins and other nutrients, reducing their bioavailability and impairing the functionality of digestive enzymes, thus causing protein precipitation and slowing digestion (Beecher, 2013). Traditional techniques of processing such as cutting, soaking, fermentation and drying or cooking can effectively detoxify cassava, removing the cyanogenic glycosides and reducing the levels of other anti-nutritional factors (Bahekar and Kale, 2013).

Overview of Bambara Groundnut Production

Bambara groundnut, an easy-to-cultivate and drought-tolerant legume, has gained international recognition because it is widely used in the food industry and its ability to survive in hot temperatures and is also tolerant to rainfall (Aremu *et al.*, 2021). It is extensively grown in Malaysia, Indonesia, Sri Lanka, India, and Africa (Mateva *et al.*, 2023). It is an intermediate annual herbaceous plant with ground-level creeping stems. Depending on the number of seeds they contain, the pods can grow up to 3.7 cm and typically develop underground. Mature pods range in color from yellow to reddish dark brown, are indehiscent, and frequently wrinkle. According to Oyeyinka *et al.* (2021), seeds can be cream, white, yellow, purple, red, brown, or black. It is regarded as a snack or dietary supplement rather than a profitable cash crop and considered to be the third most important legume after cowpeas and groundnuts (Hillocks *et al.*, 2012).

Traditional Uses of Bambara Groundnuts

Bambara groundnut seeds are eaten in a variety of ways. Fresh and dried seeds, either mature or immature, can be eaten raw, grilled or boiled and may also be grounded into a powder that can be used to make cakes and treats (Tan *et al.*, 2020). Its use extends from eating to diversified usage in the food production and processing industry as flour from the nuts has gained popularity worldwide. Flours from the seeds are considered to be highly nutritious. Given this, food manufacturers pursuing fortifying their products and making them more wholesome rely on the flour from Bambara groundnuts. This is more evident in the noodles, pastry, and other food production industries.

Nutritional Composition of Bambara Groundnuts

Bambara groundnut is a highly nutritious crop, boasting a well-balanced composition of macronutrients and essential micronutrients. It is regarded as a highly nutritious crop rich in protein (ranging from 15 % to 25 % of its total dry weight) and other nutrients (such as magnesium, potassium, calcium, zinc, iron, and fiber) as well as thiamin, niacin and riboflavin (Hillocks *et al.*, 2012). The seeds are unusually high in methionine, an essential Sulphur-containing amino acid (Aremu *et al.*, 2021). Furthermore, the seed contains about 17 - 24.6 % crude proteins, 5.3 - 7.8 % crude fat, 54.5 - 69.3 % carbohydrate content and about 367 - 414 Kcal calories per 100 g serving (Bamishaiye and Bamishaiye, 2011). The unique nutritional profile of this crop makes it a valuable food alternative, particularly for populations facing food insecurity and malnutrition. Its protein-rich composition can help address protein deficiencies, while its mineral and vitamin content can contribute to the prevention and alleviation of micronutrient deficiencies, such as anemia and stunting (Tan, *et al.*, 2016). Additionally, Bambara groundnut have antioxidants and other bioactive compounds that provides even more therapeutic benefits, like a lower chance of developing chronic illnesses (Yao et al., 2020). However, the presence of anti-nutritional elements in Bambara groundnut, like oligosaccharides, phytic acid, and tannins, may make it difficult for the food industry to use and adopt it widely. Concerns regarding the nutrients' suitability for human and animal consumption may spring up from these anti-nutritional factors' effects on their digestibility and bioavailability (Yao et al., 2020). However, research has shown that appropriate processing methods, such as soaking, germination, and fermentation, can effectively reduce the levels of these anti-nutritional factors, improving crop's nutritional profile (Wahjuningsih *et al.*, 2023).

Composite Flour and Its Importance

Sobowale *et al.*, (2021) defined composite flour as a mixture of flour, starches, and other ingredients intended to replace wheat flour totally or partially in bakery and pastry products. Dankwa *et al.* (2017) also agreed with that as the composite flours used in sample preparation were either binary or ternary mixtures of flours from some other crops with or without wheat flour. The use of composite flours has few advantages in terms of: the saving of hard currency; promotion of high-yielding, native plant species; a better supply of protein for human nutrition; and better overall use of domestic agriculture production (Mohd *et al.*, 2014). Composite flour is considered to be important to in developing nations so it promotes the use of locally produced crops for flour and greatly reduces the need to import wheat flour (Noorfarahzilah, *et al.*, 2014).

The expanding market for baked goods is influencing an upsurge in the use of local raw materials as a substitute to wheat flour (Yahaya et al., 2022). Consequently, a number of developing countries have encouraged the reliability of initiatives to using local available flour in place of wheat flour (Abdelghafor *et al.*, 2011). Correspondingly, the Food and Agriculture Organization (FAO) introduced the idea of composite technology with the goal of cutting the cost the of support for temperate countries by promoting the use of indigenous crops like cassava, yam, maize, and others in partial replacement of wheat flour (Abidin *et al.*, 2014). Mohd et al. (2014) reported that using domestically grown products instead of wheat could meet demand for bread and pastry products and that using the composite flour in a variety of food products would be economically advantageous if wheat imports could be significantly reduced or even eliminated.

According to Liu *et al.* (2015), tubers and roots have comparatively higher levels of resistant starch, a significant type of starch that is indigestible and functions as fiber than cereals. In decreasing to the risks of diabetes, heart disease, and adiposity, these traditional starchy plants may be essential to a person's diet. Besides that, these roots and tubers are gluten-free. In order to bring down the prevalence of Celiac Disease (CD) and other gluten-related allergic reactions, composite flours made from these could potentially replace wheat in specific food applications (Sabença *et al*., 2021).

Traditional Noodles from Wheat flour

Traditional noodles have a long-standing history and cultural significance in various cuisines worldwide. Conventional noodles have their roots particularly in Asia. ancient civilizations, the existence of noodles made from wheat flour and water is stated in Chinese ancient records from the Han Dynasty (206 BCE–220 CE) (Goldin, 2018). Noodles were introduced to Japan, Korea, and Southeast Asia, where they underwent local adaptations and became integral to their respective culinary traditions (Lee, 2016; Kim, 1996). The production methods of traditional noodles vary depending on the culture and ingredients used. Wheat-based noodles, such as Chinese hand-pulled noodles and Italian pasta, often involve a process of kneading, rolling, and cutting (Chen *et al*., 2018; Moretti *et al*., 2020). Noodles made from Rice, a staple in Southeast Asian cuisines, are typically made by grinding rice into flour and adding water to form a batter, which is steamed, rolled, and cut into various shapes (Nguyen, 2017). Japanese soba noodles, on the other hand, are made from buckwheat flour or a combination of buckwheat and wheat flour, requiring specialized techniques like milling, kneading, and rolling (Mikami *et al*., 2018). Traditional noodles hold significant cultural value in many societies. In China, the consumption of long noodles during celebratory occasions, such as birthdays and the Lunar New Year, symbolizes longevity and good fortune (Li *et al*., 2022). In Japan, soba noodles are associated with traditions like *Toshikoshi Soba*, which are consumed on New Year's Eve to bid farewell to the old year (Mikami *et al*., 2018). Noodles also play a role in religious rituals, such as the Korean custom of making and sharing noodles during ancestral memorial ceremonies (Kim, 1996). Furthermore, traditional noodle dishes are often regarded as cultural icons, reflecting the culinary heritage and identity of a particular region or country. Traditional noodles offer varying nutritional profiles depending on the ingredients used. Wheat-based noodles, for example, provide a source of dietary fiber, some essential vitamins and minerals and carbohydrates (Sissons, 2022). Rice noodles, commonly found in Southeast Asian cuisines, are gluten-free and contain a higher proportion of carbohydrates compared to wheat-based noodles (Yalcin, 2021). Additionally, the health implications of traditional noodles can be influenced by factors such as cooking methods, portion sizes, and accompanying ingredients. Noodles can be included in a balanced diet, but it's important to take into consideration respectively personal health needs and general dietary patterns.

Production of Noodles from Roots and Tubers

Noodles, derived from the roots and tubers, have garnered attention for their gluten-free nature and versatile culinary applications. Moreover, a shift from the use of traditional ingredients such as wheat has been on the rise. This has triggered more studies that have explored the incorporation of different root and tuber flours into noodle production, demonstrating improvements in health-related properties such as antioxidant capacity and glycemic index. Studies by Aydin *et al.* (2023) have explored the sensory attributes and nutritional composition of cassava noodles, highlighting their potential as a wholesome alternative for individuals with gluten sensitivities. A report on research by Ang *et al.*, (2020) where they produced Instant noodles made with purple sweet potato, beet, and carrot flours showed higher antioxidant levels compared to traditional wheat noodles and further concluded that, the inclusion of these flours resulted in a lower glycemic index, making them a healthier option for consumers. Subroto *et al.*, (2023) further reported that, the use of acetylated taro starch in noodle production improved physical and chemical characteristics, contributing to better texture and cooking properties. Another research by Alam, (2021) also delved into the health benefits of sweet potatoes and their derivatives, making clear the positive impact of incorporating sweet potato noodles into a balanced diet and further reported that, resultant noodles were rich in vitamins, fiber, and antioxidants and offered a burst of nutritional goodness in every bite. Other studies by Kang *et al.*, (2017) where noodles' cooking quality was assessed through parameters such as cooking loss, water absorption and volume increase, wheat flour noodles showed higher water absorption and cooking loss compared to potato-based noodles, which varied depending on the potato variety used.

Production of Noodles from Cereals and other Legumes

The increased awareness in the world pertaining to noodles has increased the research capabilities of noodle producers. Research by Kadam and Salunkhe, (2020), on incorporating noodles with legumes showed that the use of legumes in noodles production led to very high-quality noodles after cooking and cooling in cold water at 20^oC. The resulting product looked dry, white and transparent and had low water absorption capacity and high tensile strength. Arogundade and Oyewole, (2021) did follow-up research on incorporating legumes such as cowpea into noodles and found that cowpea flour could be successfully incorporated into noodle formulations up to a level of 20 %, without adversely affecting the sensory quality of the noodles. They noted that the incorporation of cowpea flour increased the protein and fiber content of the noodles, and had a positive impact on their nutritional value. However, the incorporation of legumes can be expensive and may lead to changes in the texture, colour, and flavour of the noodles, which may be undesirable for some consumers (Gharibzahedi and Mousavi, 2021; Ojokoh and Olaleye, 2020).

Oppong (2015) conducted research focused on developing instant noodles from maize and cowpea and found that *asomdwee* cowpea flour had exceptional potential with a protein content of 24.53 % and could be selected for use in complementary food products as a protein-rich food to alleviate malnutrition. Additionally, Oppong (2015) found that wheat and cowpea flour had higher final viscosities (116.67 and 69.66), high peak viscosities (150.00 and 58.33), and low gelatinization temperatures (79.23 and 80.030C, respectively), which improved their pasting qualities. The proximate composition of the cowpea flour was low in carbohydrates (57.35 %) but rich in crude protein (24.53 %), crude fiber (3.21 %), moisture (10.90 %), and ash (3.00 %). Nonetheless, the wheat flour had a high carbohydrate content (83.60 %) but a low moisture content (3.33 %), crude protein (10.23 %), crude fiber (0.51 %), ash (1.00 %), and fat (1.33 %). In terms of bulk density (0.82g/cm3), water absorption capacity (2.27 %), swelling power (12.11 %), solubility (27.26 %), and foam capacity (19.00 %), the cowpea flour exhibited superior values. The results of the study support and demonstrate the use of cereals and legumes for noodle production with taste, colour, and texture being determinant of overall consumer acceptability.

Research in the noodles industry has been centered on fortifying the products with emphasis on the achievement of Sustainable Development Goal (SDG) number two which aims to end hunger, improve nutrition, achieve food security and promote sustainable agriculture by 2030. By fortifying noodle, there is potential to improve dietary diversity and overall nutrient intake, contributing to better health outcomes and also encouraging sustainable agricultural practices by integrating locally sourced micronutrients, thus supporting local economies and reducing dependence on imported supplements.

Trends in Nutritional Improvement

Noodles can be fortified by adding fortifiers, such as soy, gluten, buckwheat, barley, oats and leguminous flour, or by fortifying the seasoning that is boiled and consumed with the noodles (Van Hung et al., 2007). It is important to consider the recommended daily values and the stability of micronutrients such as vitamin A, vitamin B1, vitamin B2, folic acid, niacin and iron during processing and preparation of noodles (Mendoza et al., 2014). It is also possible to enhance the nutritional qualities of instant noodles by adding gluten and calcium carbonate. While instant noodles with various micronutrients have been initiated in some countries, government regulations may not require it. However, around 80 % of noodles produced in Asian countries like the Philippines are voluntarily fortified. On the other hand, fortifying the seasoning instead of the flour has the advantage of protecting fortificants from moisture and heat during processing, as well as being better protected in a sachet (Capanzana and Barba, 2017). Sissons *et al.* (2022) examined the effects of fortifying wheat noodles with iron and folic acid. The research demonstrated significant increase in the iron and folate levels of the instant noodles, which helped in addressing iron deficiency anemia, particularly in vulnerable populations. Studies by Akajiaku *et al.* (2017) have also explored the incorporation of legume flours (such as lentil or chickpea flour) into noodle formulations. These legumes are high in protein, fiber, and various micronutrients. Fortified noodles with legume flours exhibited improved nutritional profiles, including higher protein content and better amino acid balance, along with acceptable cooking and sensory properties. Hau *et al.* (2009) also investigated the stability of folic acid in fortified instant noodles and reported that it was stable during mixing, sheeting, steaming, and frying.

Sensory Characteristics of noodles

The quality of noodles is heavily influenced by their flavour texture, colour, mouthfeel among others. Flavour, which is determined by a range of chemical and sensory factors including carbohydrates, lipids, and proteins in the noodle dough, as well as the addition of seasonings, is key in the food industry. Processing techniques such as frying or baking, as well as the quality of the oil used, can also generate new flavour compounds that affect the overall flavour of noodles. Sensory evaluation methods, such as descriptive analysis and consumer testing, are commonly employed to assess noodle flavour (Shi *et al*., 2020). Colour of any food product also has a significant influence on its consumer appeal. Color is commonly measured with a Spectro colorimetric, like a Hunter Lab colorimeter, using the L* (brightness or lightness), a* (redness), and b* (yellowness) scales (Chen and Zhao, 2021). The L* value of noodles correlates positively with sedimentation volume and adversely with the quantity of alcohol and salt-soluble proteins in the flour. Furthermore, the b* value of instant noodles is connected to protein quality criteria. According to Meenu *et al*. (2022), the type and amount of food additives used in noodle production can have a considerable impact on the colour of the finished product.

According to Wang *et al*. (2020), noodle texture can be described as rubbery, smooth and firm and can be assessed using sensory or instrumental methods (Lin and Zhao, 2021). Various textural parameters such as softness, smoothness, stickiness, hardness/firmness, cohesiveness, gumminess, chewiness, and elasticity are commonly employed to evaluate noodles (Wang and Adhikari, 2019). Flour quality, additions like salt or alkaline reagents, water absorption and processing parameters such as sheeting, steaming, and dehydration method all affect noodle texture, making it a complex characteristic (Ross, 2006). Instrumental measurement of cooked noodle texture provides a reliable and convenient alternative to sensory evaluation (Hasnul *et al.*, 2021). Compression techniques, such as simple compression, texture profile analysis, and tensile tests, are the basic methods exploited. These tests include several textural qualities in one test, including chewiness, hardness or stiffness, gumminess, and cohesion, which is analogous to chewing in the mouth (Guo *et al.*, 2021).

Noodles made from non-traditional flours, such as rice, chickpea, quinoa, and buckwheat, have gained popularity due to their nutritional benefits and gluten-free properties. However, these noodles often present various sensory challenges that can affect consumer acceptance. Rath *et al.* (2004) reported that non-traditional flours may have larger particle sizes, leading to a gritty mouthfeel (requiring more chewing) that can be unappealing to consumers. On the other hand, noodles made from alternative flours may exhibit a less vibrant color compared to traditional wheat noodles and also possess distinct flavors, which can affect visual appeal and the overall flavor profile of the noodles respectively (Rawiwan *et al.*, 2018). These sensory problems according to Rath *et al.* (2004) are attributable to gluten (which provides elasticity and chewiness), processing methods and starch present in different flours used. Research by Rawiwan *et al.* (2018) suggested that the variation in starch composition for different flours, tends to influence hydration and cooking properties, which may lead to textural differences. Kumar *et al*. (2018) further reported that processing methods, like fine milling, can create a smoother flour that yields a more desirable texture in noodles while other methods like toasting or roasting the flour, can enhance the flavor. Techniques such as fermentation can also increase the bioavailability of nutrients and improve digestibility in the final product (Pérez-Jiménez and Negrón, 2012).

Cooking characteristics of noodles

Noodle quality and consumer acceptance are significantly influenced by cooking quality parameters (Rani *et al*., 2018). Significant factors that impact the quality of noodles includes cooking time, cooking loss and cooked weight. The number of solids that dissolve in water while cooking, known as "cooking loss," clearly demonstrates how well the noodles maintain its structure while cooking. High cooking loss is undesirable as it can cause starch and other solid components to leach out and cause the noodle structure to be lost whereas cooking yield describe the noodles' capacity to absorb water during cooking, or the rise in noodle weight following cooking (Sim *et al*., 2020). Rani *et al*. (2018) discovered that addition of chickpea protein isolate prolonged the cooking time of gluten-free noodle samples. This may be due to the protein in chickpea as it interacts with starch granules to absorb water. However, the inclusion of chickpea protein lowered cooking loss, presumably because the proteins in the chickpeas replaced the starch and a rigorous protein-starch matrix was formed.

Instant noodles on cooking must have a smooth, firm surface and a pleasing mouthfeel (Hou, 2001). More so, a number of variables, including the thickness of the noodle strands, the frying conditions, the protein and ash contents and the starch quality may affect the cooking quality. Cooking quality and ease of preparation are also measured by rehydration rate, cooking loss and cooking time. The optimum cooking time for Noodles is positively linked with the protein content and negatively correlated with the amylose content (Chen *et al*., 2019). However, a positive correlation was observed between the amount of ash in flour and the rates of weight and volume gain during cooking (Czaja, 2020). Noodle rehydration rate and cooking time are also influenced by the frying time (Ding and Ainsworth, 2020). During Cooking, proteins play an important role in the structural integrity of noodles, allowing noodle strands to integrate and maintain their original form (Alam, 2021). Important factors that affect how well instant noodles cook include the heating method, heat transfer rate, and cooking duration (Gulia *et al*., 2014).

Nutritional properties of noodles

A wholesome diet with an ideal amount of nutrients such as carbohydrates, protein, fats, vitamins and minerals are needed for normal body growth, development, maintaining a healthy body weight, delayed aging and lowering the risk of chronic diseases in humans (Meenu et al., 2022). Shi *et al*. (2020) reported that carbohydrates make up the bulk of the macronutrient content in noodles. A recent study showed that rice-based noodles made with germinated chickpea protein isolate flour had high protein content. (Sofi *et al*., 2020). In a similar vein, it has been discovered that multigrain wheat-based noodles enhanced with soy and sorghum contain higher amounts of ash, protein, fat and fiber than control samples. This is due to the high iron content in sorghum-soy-based. The addition of multigrain (soybean and sorghum) to wheat flour for noodle formulation has been proven to positively affect noodles with higher levels of crude fiber, protein, ash, and iron than refined wheat noodles (Rani *et al*. 2018).

Functional Properties of Noodles

Reports by Xiong *et al*. (2021) who worked on the effect of characteristics of different wheat flours on the quality of fermented hollow noodles, attest that non-traditional flours, including those from legumes, whole grains, and pseudo-cereals, typically contain higher levels of protein, fiber, vitamins, and minerals than regular wheat flour. Therefore, using these flours can enhance the nutritional value of noodles, which can attract health-conscious consumers. It was further reported that noodles made from legume flours tend to have a firmer texture and may exhibit different cooking qualities, such as increased cooking time and altered water absorption rates which may affect the overall mouthfeel and consumer acceptance of the product. Wang *et al*. (2020) also reported that the addition of certain non-traditional flours specifically those from legumes, may lead to higher cooking losses and changes in the swelling behavior of starch, which can affect the final texture and appearance of the noodles

The carbohydrate content of noodles, mainly starch, is a crucial component of their flavour and texture. Proteins on the other hand are also essential for noodle structure, providing elasticity and firmness. The protein content of noodles can be boosted by using high-protein flours or by adding protein isolates like soy protein and nuts. Proteins also contribute to noodle flavour by providing amino acids such as glutamic acid and aspartic acid that enhance their taste. During noodle processing, the Maillard reaction between proteins and carbohydrates can create flavour compounds. According to Gao *et al.* (2017), the water absorption index is a good measure for evaluating the functional qualities of noodles as it evaluates the product's capacity to bind to water in a dry environment, which can enhance its capacity to form dough. They further reported that adding hydrocolloids such as xanthan gum to the dough improves its consistency while maintaining a steady moisture content for making gluten-free noodles. This action is normally triggered by the hydrocolloids' tendency to hold onto water, which increases their capacity to absorb water. While cooking, this increases in the noodles ability to absorb water may also affect the weight of the wheat-based noodles to ascend. (Liu *et al.*, 2015).

Oil absorption can be explained by capillary action or oil replacing displaced water (Ding and Ainsworth, 2020). During the process of noodle frying, oil rapidly replaces water, causing the noodles' surface to become covered in numerous tiny holes (Hou, 2001). Wheat protein content and quality are thought to be crucial in determining oil absorption. For example, Oluwole and Akinoso (2013) found out that, noodles made with high-protein wheat flour absorbed less oil than those made with low-protein flour. They further reported that the reason for this formation of coarse globules during steaming is that it facilitates oil penetration through the noodles. Also, the formation of a smooth and compact surface structure during steaming may be the reason why wheat flours with a high protein content and low levels of salt-soluble protein typically produce noodles with low levels of free lipids. Gluten, as shown by Gazmuri and Bouchon (2009), is essential to the structure of noodles since it makes the dough more elastic and less prone to absorbing oil. Starch-amylose content is may also contribute to the development of tiny bubbles on the surface of the strands. High oil absorption during frying shortens shelf life and raises production costs. The main variables that were found to be negatively linked with the oil content of noodles were protein content and quality (Ding and Ainsworth, 2020).

Market Potential and Scope of Noodles

In recent time, the noodle industry has gained prevalent popularity in both developed and developing countries because of its easy preparation and nutritious makeup. Due to the rising standard of living in urban areas and the fast urbanization occurring in rural areas, it is anticipated that the consumption of noodles will rise steadily. The product has a high sensory appeal and costs less as compared to other products (Adomako and Danso, 2019). Bello and Akingbala (2018) also reported that the excellent storage stability and nutrition content also increases consumers' demand in the noodle and hence the upward spike in the consumption of noodles. There have been concentrated attempts to examine the viability of using instant noodles as a vehicle for micronutrient fortification due to the rising consumption of noodles. Although there are still a number of implementation and technological impediments to overcome, this product seems to have the potential to be a successful food vehicle for micronutrient fortification. (Appiah and Kumah, 2018).

CHAPTER THREE

RESEARCH METHODOLOGY

Materials and Methods

Fresh cassava tubers were obtained from Twifo Hemang Lower Denkyira District farm in the Central Region while the Bambara groundnuts were sourced from the Hemang local market, all in Ghana. All chemicals and reagents used for the analysis were of analytical grade.

Preparation of Cassava Flour

Cassava flour was produced according to the process described by Sanni *et al.* (2006) with some modifications. Briefly, fresh root tubers were thoroughly washed to remove adhering soil and other undesirable materials and peeled. The peeled roots were washed and then sliced into sizes of about 2 cm in thickness, 2kg slices were weighed with an electronic balance and immediately dried using a convective hot air dehydrator at 70 °C for 8 hours. The dried chips were milled into flour using a Hammer mill, screened through a mesh sieve of 250-µm aperture and stored in airtight containers for further analysis.

Preparation of Bambara Groundnut Flour

The preparation of Bambara Groundnut Flour was done following the method as described by Abdul-Rahman *et al.* (2012) with slight modifications. Cleaned Bambara groundnut seeds were soaked for 18 h, boiled for 30 min, dehulled after cooling, and dried. Dried Bambara groundnut was milled into fine flour and passed through a 250-µm mesh sieve to obtain a fine powder. The flour was kept in an airtight container at room temperature until further use.

Experimental Design for Cassava-Bambara Groundnut Composite Flour

A simplex centroid mixture design for two components in Minitab Software (Version 18) was used for composite flour formulation as depicted in Table 1. This design was chosen based on its robustness for optimisation studies involving food prepared from many ingredients. The effects of different proportions of cassava flour (CF) from 70 % to 100 % and Bambara Groundnut Flour from 0 % to 30 % were selected for the study. The mixture design consisted of 5 runs, with each run adding up to 100 %.

Table 1: Simplex Centroid Design for Cassava-Bambara Groundnut Noodles Preparation

Run	Cassava flour (%)	BGF (%)
1	100	00
2	92.5	7.5
3	85	15
4	77.5	22.5
5	70	30

Production of Noodles

Noodles were prepared following the method described by Oppong (2015) with modifications. To each mixture of 100 g, approximately 50 ml filtered water was added and mixed thoroughly to form a dough. The dough was steamed for 2 min at 100°C. The steamed dough was kneaded, rolled, and then extruded in the form of 2 mm diameter strand noodles using a manual noodle press machine. The extruded noodles were set on a rack to dry in a dehydrator for 3 hours at 60°C.

Finally, the noodles were cooled at room temperature and packed in polyethene bags before analysis.

Analytical Methods

Proximate Composition Analysis

Determination of Moisture Content

The moisture content was determined by the hot air oven method as reported by Ezeocha and Onwuneme (2016). An empty crucible was weighed, and 2g of the sample was transferred into the crucible. This was taken into the hot air oven and dried for 24 hours at 100°C. The crucible and its contents were cooled in the desiccator, and their weights were taken. The loss in weight was regarded as moisture content and expressed as;

$$\% \text{ moisture} = \frac{Weight\ loss}{Weight\ of\ sample} * 100 \qquad (4)$$

Determination of Ash Content

Ash content was determined using the method reported by Laurie *et al.* (2018). About 5 g of each sample was weighed into crucibles in duplicate, and then the sample was incinerated in a muffle furnace at 550°C until light grey ash was observed and a constant weight obtained. The sample was cooled in the desiccator to avoid absorption of moisture and weighed to obtain ash content.

$$\text{Ash } (\%) = \frac{Weight\ loss}{Weight\ of\ sample} * 100 \qquad (5)$$

Determination of Crude Fibre

The crude fibre was determined using a method reported by Laurie *et al.* (2018). About 5 g of each sample was weighed into a 500 ml Erlenmeyer flask, and 100 ml of TCA digestion reagent was added. It was then brought to a boil and refluxed for exactly 40 min, counting from the start of boiling. The flask was removed from the heater, cooled a little, then filtered through a 15.0 cm number 4 Whatman paper. The residue was washed with hot water, stirred once with a spatula, and transferred to a porcelain dish. The sample was dried overnight at 105°C. After drying, it was transferred to a desiccator and weighed as W_1. It was then burnt in a muffle furnace at 500°C for 6 hours, allowed to cool, and reweighed as W_2.

$$\% \text{ Crude fiber } = \frac{W_1 - W_2}{W_0} * 100 \qquad (6)$$

where; W_1=weight of crucible+fiber+ash,

W_2=weight of crucible+ash,

W0 = Dry weight of food sample

Determination of Fat Content

The Soxhlet extraction method reported by Laurie *et al.* (2018) was used to determine the fat content of the samples. About 2g of the sample was weighed, and the weight of the flat-bottom flask was taken with the extractor mounted on it. The thimble was held halfway into the extractor and the weighted sample. Extraction was carried out using (boiling point 40-60°C). The thimble was plugged with cotton wool. At completion of extraction for 8 hours, the solvent was removed by evaporation on a water bath, and the remaining part in the flask was dried at 80°C for 30 minutes in the air oven to dry the fat and cooled in a desiccator. The flask was reweighed and the percentage of fat was calculated as;

$$(\%) \text{ Fat} = \frac{Weight\ loss}{Weight\ of\ sample} * 100 \qquad (7)$$

Determination of Protein Content

The micro Kjedal method, as reported by Malavi *et al.* (2022), was used to determine crude protein. About 2 g of the sample was put into the digestion flask. Ten grams of copper sulphate and sodium sulphate (catalyst) in the ratio of 5:1, respectively, and 25 ml of concentrated sulphuric acid were also added to the digestion flask. The flask was placed into the digestion block in the fume cupboard and heated until frothing ceased, giving a clear and light blue-green colouration. The mixture was then allowed to cool and diluted with distilled water until it reached a 250 ml volumetric flask. The distillation apparatus was connected, and 10 ml of the mixture was poured into the receiver of the distillation apparatus, and 10 ml of 40 % sodium hydroxide was added. The released ammonia by boric acid was then treated with 0.02 M of hydrochloric acid until the green colour changed to purple. The percentage of nitrogen in the sample was calculated using the formula below:

$$\text{Nitrogen (\%)} = \frac{(Titre - Blank) x 14.008\ x\ Normality}{Weight\ of\ sample} * 100\ \% \tag{8}$$

% Crude protein = % Nitrogen x 6.25

Determination of Carbohydrate Content

The carbohydrate content was calculated by difference according to Kidane *et al.* 2013).

Determination of Minerals

Iron (Fe), Zinc (Zn), Calcium (Ca), Potassium (K), and Magnesium (Mg) contents were determined by using the atomic absorption spectrometry method (PerkinElmer Model 3300) as reported by Maigari *et al* (2022) with a few modifications. 2g of each flour blend was weighed and labelled appropriately, and was later placed in a digestion vessel. 20 ml of concentrated nitric acid was added to the flour mixtures and was heated for 30 minutes. After digestion, the mixture was allowed to cool and filtered to remove any undigested particles, ensuring a clear liquid for analysis. The filtered solution was diluted with deionised water to 50 ml. A series of iron standard solutions with known concentrations (0, 5 and 10 mg/l) was prepared to be used to create a calibration curve. The Atomic Absorption Spectrophotometer was calibrated using the prepared standard solutions to create a calibration curve, plotting absorbance against concentration. The prepared sample solution was introduced into the Atomic Absorption Spectrophotometer via a nebuliser, which transformed the liquid into an aerosol. The aerosol was transported into the furnace, where the atoms were atomised, allowing them to absorb light at the specified wavelength. The absorbance of the sample solution, which correlates directly to the concentration of iron, zinc, calcium, potassium and magnesium present (with adjustment in the wavelength and standard solutions accordingly), was measured and recorded accordingly.

Cooking Characteristics of Noodles

Cooking time, cooking loss, and weight gain after cooking were done according to the methods described by Suhendro *et al.* (2000). Optimal cooking time was evaluated by observing the time of disappearance of the core of the noodle strand during cooking (every 20 sec) by squeezing the noodles between two transparent glass slides.

The cooking loss was determined by measuring the amount of solid substance lost to cooking water. Exactly, 10 g of noodles was placed into 100 ml of boiling water in a 500 ml beaker. Cooking water was collected in a pre-weighed glass dish placed in a hot air oven at 105°C and evaporated to dryness. The dry residue was weighed and reported as a percentage. Weight gain after cooking was calculated using the formula:

% WA (Weight of cooked noodles- Initial weight of dry noodles) x 100

Sensory Properties

To determine the acceptability of cassava flour (CF) noodles enriched with BGF (BGF), a method according to Kizzie-Hayford *et al.* (2023) was used. Consumer preference for noodles enriched with BGF was determined using a 9-point hedonic scale by rating noodles attributes (appearance, texture, aroma, taste, aftertaste and overall preferences) from like 9 (like extremely) to 1 (dislike extremely). A 50-member panel was randomly recruited for the study. About 20 g of noodle samples were randomly labelled and served. A bottle of water was given to participants to rinse their mouths between samples. The sensory experiment was done once.

Determination of Functional Properties of Noodles

Bulk density

As reported by Idowu *et al.* (2021), the bulk density of each sample was determined when 10 g of noodle flour was weighed into a 50-calibrated measuring cylinder. The sample was packed gently by tapping on the benchtop ten times from a height of 5cm. The volume of the sample occupied in the measuring cylinder was recorded, and the bulk density was calculated as follows:

$$P_b = \frac{W_t}{V_t} \quad (1)$$

Where P_b is bulk density (g/ml), Wt is the weight of the tapped sample (g), and Vt is the volume of the tapped sample (ml).

Swelling capacity

As reported by Idowu *et al.* (2021), 80 ml of distilled water was added to 20 g of weighed samples into a calibrated, cleaned measuring cylinder, and air bubbles were eliminated by mixing carefully and quickly. The final volume was recorded after the sample was allowed to settle for 3 hr. The swelling ability was then computed using the equation below:

$$S_c = \frac{V_f}{V_i} \quad (2)$$

Where S_c is the swelling capacity, V_f is the final volume (ml), and V_i is the initial volume (ml).

Water Absorption Capacity (WAC)

A method reported by Idowu *et al.* (2021) was adopted to estimate the water absorption capacity with slight modification. In this method, 10g of each sample was added to about 10 ml of distilled water in a glass beaker and stirred. The soaked samples were drained through a filter paper for half an hour. The water and oil absorption capacity were then computed using the expression as the weight of soaked flour per weight of the dried flour:

$$\% \text{ WAC} = \frac{W_s}{W_d} \quad (3)$$

Where WAC is the water absorption capacity, Ws is the weight of the soaked flour sample, and W_d is the weight of the dried flour sample.

Texture Profile Analysis (TPA)

About 5g of dried noodles were boiled in 200 ml of water for 25 minutes. The cooked noodles were then left to sit in the water, which was boiled for two minutes and then strained. The noodles were cooked by putting them in water for 5 minutes. It was strained again and placed in a beaker. The Brookfield CT3 texture analyser was used to analyse the texture profile of the cooked noodles. The speed used was 5.0mm/s with a trigger of 5g and a deformation of 0.9. The probe used was a TA 4/1000 cylinder with a diameter of 38.1mm and a volume of 200 ml. The bulk method was used, where the cooked sample was divided into three parts to represent a replicate, and the probe was allowed to compress each section from the range of parameters that are automatically calculated from TPA tests. The hardness, springiness, cohesiveness, and chewiness are reported. This process was done for all the samples, and the values were recorded.

Colour Determination

Colour properties of the noodles were determined by adopting the method according to Jarosław (2015). A Colourimeter (CR- 410, Japan) was used based on the (CIE) L*a*b* scale. The instrument was calibrated using a zero-calibration mask followed by a white calibration plate (Oke *et al.*, 2019; Omale *et al.*, 2018). Samples were measured by placing them on sample holders and capturing them. The colour attributes related to lightness (L*) (0 = black and 100 = white) and chromaticity coordinates a*(red to green) and b* (blue-yellow) were recorded

(Oke *et al.*, 2019; Omale *et al.*, 2018). The instrument was calibrated using a white tile (L*=94.52,* = -0.36, and b* = 1.04) as standard.

Statistical Analyses

To determine the effects of BGF substitution on the response parameters, Minitab software was used to analyse the data, calculating the mean and standard deviation. Statistical significance was assessed at a 95 % confidence level. Graphs were plotted using Excel software.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This study explored the use of Cassava and Bambara Groundnut Flour in noodle production and evaluated their effects on the physicochemical, cooking characteristics, functional, textural and sensory properties of the resulting noodles. The cost-effectiveness of noodles derived from the composite blends was determined.

Proximate Composition of Cassava-Bambara Groundnut Noodles

The Proximate composition of the Cassava-Bambara groundnut composite flour noodles is depicted in Table 2. The substitution of cassava with Bambara groundnut had a significant ($p<0.05$) effect on the moisture content of noodles. Comparably, 100 % cassava noodles had the highest moisture content (8.35 %), whereas increasing the addition of BGF led to a general decrease in the moisture content, ranging from 7.41 to 7.15 %. It was observed that noodles with 30% BGF recorded the lowest moisture content, while 100 % cassava flour noodles had the highest moisture content. However, the moisture content of all the samples fell within the acceptable range of not more than 10 % to cause microbial growth, leading to noodles' spoilage. These results agree with the findings reported by Ocheme *et al.* (2018). Oke *et al.* (2022) also reported similar findings after enriching noodles with sorghum-groundnut flour.

The ash content, which indicates the amount of essential mineral levels in the noodles, was significantly ($p<0.05$) affected by the substitution of BGF.

Whereas 100 % cassava noodles recorded 0.84 % ash content, the inclusion of BGF increased ash content, ranging from 0.94 % to 2.29 % at increasing levels of 7.5 % to 30 %. At 7.5 % addition of BGF, a low ash content of 0.94 % was recorded (whereas noodles containing 30 % BGF recorded the highest ash content of 2.29 %. The results obtained in this study are similar to the findings by Omeire and Kabuo (2023) that the enrichment of noodles with protein-rich concentrate from Bambara groundnut elevates the mineral content, hence increasing the ash content. Additionally, Mepba *et al*. (2021) reported a progressive increase in the ash content of noodles after fortifying with BGF.

Enrichment of noodles with BGF significantly increased ($p<0.05$) the protein content. It was noticed that 100 % cassava flour had a protein content of 2.51 %, being the lowest among the samples. This indicates that the protein content in cassava flour is low. Similarly, Oladunmoye *et al*. (2017) reported that the cassava flour has low protein compared to legume crops, hence less protein enhancement in the noodles derived thereafter. Increasing the inclusion of BGF substitution led to a general increase in protein content ranging from 4.16 % to 7.27 %. The highest protein content was noticed at 30 % substitution of BGF, while 7.5 % was recorded as the lowest 4.16 % protein content. The increase in protein content may be due to the increase in the inclusion levels of BGF. Some studies reported that Bambara groundnut contains considerable protein content comparable to other legume crops (Abidin *et al*., 2014; Mensah, 2011). The results obtained in this study corroborate the findings reported by Mepba *et al*. (2021) that high protein content was noticed when BGF was added to the produced Wheat: acha: Bambara: cocoyam flour noodles. Additionally, Abidin *et al*. (2014) reported that instant noodles produced from Bambara groundnut and cassava composite flour attained the highest protein content compared to 100 % CF instant noodles. Protein is crucial to consumer health, contributing to the development of cells and repair of tissues and other metabolic activities. Therefore, these results may be relevant in enhancing the nutritional qualities of baked products.

Fat/oil performs several critical functions as it generates hormones and is an energy source. Also, without lipids, maximum digestion and absorption would not be possible. Also, vulnerable people make maximum utilization of fat as a critical tool to increase energy density. The inclusion of BGF led to a significant ($p<0.05$) increase in the fat content of the noodles. Comparably, fat content of cassava flour noodles was 0.18 % while the addition of BGF led to a general increase of fat/oil in noodles ranging between 0.54 % to 3.06 %. The lowest value was noticed at 7.5 % while the highest value was recorded at 30 % addition of BGF. These results agree with the results reported by Abidin *et al*. (2014) that increasing the inclusion of Bambara groundnut in instant noodles leads to a progressive increase in fat content. Additionally, Gulia *et al*. (2014) established that the fat content in Bambara groundnut is much higher than cassava flour hence increasing Bambara groundnut concentrate in instant noodles increases the fat/oil content. Therefore, these noodles may be relevant for providing an additional energy source for food in the market.

Dietary fibre is crucial to consumer health contributing to the prevention of celiac disease including cancer, obesity, and cardiovascular disorders (Akubor, *et al,* 2023). The fibre content significantly ($p<0.05$) increased after the inclusion of the BGF during noodles production. The fibre content was low (3.01 %) in 100 % cassava flour while after partial with BGF, the dietary fibre increased ranging between 3.22 % to 5.22 % at an increased level of 7.5 % to 30 % respectively. The increase in fiber content of noodles may be due to the addition of BGF. Similarly, Mensah (2011) reported an increase in noodles' fiber content at an increasing level of Bambara groundnut substitution. Additionally, Abidin *et al*. (2014) confirmed that increasing the inclusion of BGF increases the fiber content of instant noodles. Consuming dietary fiber is strongly advised for people with type 2 diabetes, cardiovascular disease, colorectal cancer, and gastrointestinal disorders (Dankwa *et al*., 2017). Therefore, a 30 % addition of BGF would be beneficial for improving the dietary fiber of other complementary foods. The beneficial effects of dietary fiber intake on disease-associated risk factors have demonstrated a decreased risk of chronic diseases in populations that consume adequate amounts of it (Omeire and Kabuo, 2023).

Partial substitutions of cassava flour with BGF resulted in significant ($p<0.05$) changes in the carbohydrate content of the developed noodles. The carbohydrate content of the unenriched noodles was 87.23 %. However, the enrichment of noodles with BGF led to a general decrease in the carbohydrate content, with ranges between 85.96 % to 79.97 % at increasing levels of 7.5 % to 30 % Bambara groundnut flour. The decrease in the carbohydrate content may be due to the low carbohydrate content in Bambara groundnut, comparable to cassava flour. Abidin *et al.* (2014) reported that the carbohydrate content in Bambara groundnut is less than that of cassava flour, and therefore, increasing the inclusion of Bambara groundnut led to a decrease in the carbohydrate content of instant noodles. Although carbohydrate content is crucial in contributing to the health function of the body, high-carbohydrate foods impose health issues as they increase blood cholesterol, high blood pressure, glucose levels, and lipids (Riccardi and Rivellese, 1991). Therefore, noodles with less carbohydrate content are important for people with high blood sugar or high blood pressure. Finally, the nutritional composition plays a significant role in reducing malnutrition, a serious issue in most mild-income countries. Bambara groundnut is locally cultivated yet considered underutilized, has several health benefits, and would be feasible for reducing most of the nutrient deficiency-related problems.

Table 2: Effects of BGF Enrichment on the Proximate Composition of Noodles

CF: BGF	Moisture	Ash	Protein	Oil/fat	Fibre	Carbohydrate
100: 00	8.35 ± 0.06[a]	0.84 ± 0.01[a]	2.51 ±0.08[a]	0.18 ± 0.00[a]	3.01 ± 0.01[a]	87.23 ± 0.09[a]
92.5: 7.5	7.46 ± 0.02[b]	0.94 ± 0.02[b]	4.16 ±0.03[b]	0.54 ± 0.01[b]	3.22 ± 0.07[ab]	85.96 ± 0.06[b]
85: 15	7.41 ± 0.05[b]	1.05 ± 0.03[c]	5.86 ±0.02[c]	0.80 ± 0.00[c]	3.39 ± 0.03[b]	82.97 ± 0.04[c]
77.5:22.5	7.35 ± 0.05[b]	1.52 ± 0.08[d]	6.99 ±0.08[d]	1.00 ± 0.00[d]	4.48 ± 0.07[c]	82.84 ± 0.07[c]
70: 30	7.15 ± 0.06[c]	2.29 ± 0.14[e]	7.27 ±0.08[e]	3.06 ±0.01[e]	5.22 ± 0.09[d]	79.97 ± 0.15[d]

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different.

Minerals Content of Cassava-Bambara Groundnut Noodles

The effects of Bambara groundnut enrichment on the mineral properties of noodles are presented in Table 3. Noodles were analyzed for zinc, calcium, magnesium, iron, and potassium. Zinc content increased at increasing levels of Bambara Groundnut flour. Noodles made from 100% cassava flour recorded the lowest zinc content of 76.17 µg/g. On the other hand, inclusion of BGF led to a significant ($p<0.05$) increase in the zinc content of noodles ranging between 84.71 to 124.90 µg/g at an inclusion range of 7.5 % to 30 % respectively. These results collaborate with the findings of Gulia *et al*. (2014) that instant noodles fortified with BGF attained the highest zinc content compared to wheat flour noodles. The results show that enrichment of noodles with Bambara groundnut could boost zinc properties, an essential mineral contributing to the health functioning of the human body.

Calcium content in food is crucial to consumer health, contributing to the prevention of rickets in children and osteomalacia in adults. The inclusion of BGF had a significant ($p<0.05$) effect on the calcium content of the noodles. The lowest calcium content (7793.40 µg/g) was observed in the 100 % cassava flour noodles while noodles containing Bambara groundnut flour increased in calcium content ranging from 8201.13 µg/g to 8550.47 µg/g. The increase in calcium content may be attributed to the incorporation of BGF. Dankwa *et al.* (2017) similarly reported that incorporating BGF in cookies improves the calcium content. These results may be relevant for improving the utility of BGF in complementary food for children with rickets bones and osteomalacia in adults. Moreover, plant-based calcium is cheaper compared to animal-based calcium (Geller *et al.*, 2022). This study provides a basis for utilizing locally available crops to provide varied calcium-rich noodles for the growing population.

The inclusion of BGF significantly ($p<0.05$) influenced the iron content of the noodles as depicted in Table 3. The results revealed that 100 % cassava flour noodles recorded the least 4.41 µg/g whereas increasing the inclusion of BGF from 7.5 % to 30 % increased the iron content ranging from 8.88 µg/g to12.30 µg/g respectively. The increase in iron content may be attributed to the inclusion of BGF. The results reported in this study are in line with results from previous studies by Adegbanke *et al.*, 2020 and Mepba *et al.*, 2021, where it was reported that, an increase in the quantity of BGF led to an increase in iron content. Iron deficiency, anemia, is common in most developing countries due to low intake and poor absorption of iron in the body system. Hence, the addition of BGF in noodle production would be essential for providing iron-rich food for the vulnerable population.

As depicted in Table 3, the inclusion of BGF had a significant ($p<0.05$) influence on the potassium content of the noodles. Results show that the enrichment of noodles with BGF led to a general increase in potassium content ranging between 5377.48 µg/g/g to 6137.08 µg/g. The increase in potassium content in the noodles may be caused by the addition of BGF, which has been reported to have high potassium content. A similar increase in potassium content was reported by Mensah (2011) for instant noodles. Additionally, Yahaya *et al*. (2022) reported that increasing De-hulled BGF increases the potassium content of the cookies produced. Moreover, Alimi et al., (2024) confirmed that increasing the substitution of BGF in cake progressively increased the potassium content of the cake due to the high potassium content in BGF. Potassium content in diet is relevant for the prevention of blood pressure, and cardiovascular risks including stroke and coronary heart disease (Hussin *et al*., 2020).

Table 3: Effects of BGF Enrichment on the Minerals Content of Noodles

CF: BGF	Zn (μg/g)	Ca (μg/g)	Mg (μg/g)	Fe (μg/g)	K (μg/g)
100: 00	76.17 ± 1.09[a]	7793.40 ± 153.04[a]	1127.13 ± 36.17[a]	4.41 ± 0.06[a]	5068.01 ± 10.23[a]
92.5: 7.5	84.71 ± 1.95[b]	8201.13 ± 133.12[b]	1317.67 ± 25.98[b]	8.88 ± 0.20[b]	5377.48 ± 16.10[b]
85: 15	98.48 ± 1.30[c]	8295.57 ± 170.03[b]	1328.53 ± 57.53[b]	9.50 ± 0.37[c]	5541.51 ± 28.42[c]
77.5:22.5	104.78 ± 2.01[d]	8442.23 ± 166.78[b]	1346.87 ± 16.33[b]	11.34 ± 0.14[d]	5972.39 ± 29.26[d]
70: 30	124.90 ± 1.22[e]	8550.47 ± 125.23[b]	1391.03 ± 71.55[b]	12.30 ± 0.16[e]	6137.08 ± 22.64[e]

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different

Colour Properties of Cassava-Bambara Groundnut composite flour Noodles

The consumer acceptability of noodles depends on the physical qualities which are attributed to the colour, aroma, and taste. Colour significantly affects consumer judgment as colour influences oral and olfactory sensations (Zhou *et al.*, 2014). Cooked noodles prepared using the 100 % Cassava flour recorded a lightness value of 84.87 whereas the addition of Bambara groundnut flour led to a lighter noodle colour specifically from 84.68 to 77.71. The addition of Bambara groundnut flour to the noodles led to a general decrease in the lightness values of the noodles as depicted in Table 4. The inclusion of 7.5 % of BGF resulted in a higher lightness value of 84.68 whereas, at 30 % inclusion, the lightness values decreased to 77.71. The lightness of the noodles may have been influenced by the physicochemical characteristics such as water content, pH, reducing sugars, and amino acid content. Also, increasing the inclusion of BGF may cause the amino acids to increase, therefore increasing the browning of the noodles as a result of brown pigment development or Millard product. In addition, BGF contains brown pigment, and increasing the addition means the light colour of the cassava flour would be replaced with the brown colour of BGF, affecting the noodles' lightness. The results in this study are similar to the results reported by Nwadi *et al.* (2020) for Bambara groundnut flour bread. Also, Mepba *et al.* (2021) reported a similar decrease in the lightness of noodles when increasing the addition of BGF, which was attributed to the natural pigments, such as carotenoids and polyphenols, present in the Bambara groundnut, which heavily contribute to its yellowish-brown colour.

The inclusion of BGF led to a significant increase in the redness of noodles. The redness of the unenriched noodles was 1.62, whereas BGF-enriched noodles increased from 1.97 to 3.45 at an increased level from 7.5 % to 30 %, respectively. These results agreed with results reported by Mepba *et al.* (2021) that an increase of 10 % in BGF-enriched noodles resulted in the elevation of redness and yellowness. Notwithstanding, Alhassan *et al.* (2019) reported that enriching noodles with BGF decreases the lightness while increasing redness or yellowness. Omeire and Kabuo (2023) also reported that the addition of Bambara protein-rich concentrate in cassava increases the redness while decreasing the lightness of the noodles made thereafter. Partial inclusion of BGF in cassava composite blend led to a significant ($p<0.05$) increase in the yellowness of noodles as depicted in Table 4. After cooking, the yellowness of the unenriched noodles was 11.09 which increased at the range of 12.21 to 13.69 at an increase in the inclusion level of BGF from 7.5 % to 30 %. The increase in yellowness may be caused by the addition of BGF since BGF is more yellow in colour. The lowest value was noticed at 7.5 % while the highest was recorded in noodles with 30% Bambara groundnut flour. The results of this study agree with the findings reported by Omeire and Kabuo (2023) that the enrichment of noodles with BGF led to a significant ($p<0.05$) increase in the yellowness of noodles. Also, Hussin *et al.* (2020) reported that the inclusion of BGF led to a general increase in redness and yellowness while decreasing lightness. They further emphasized that BGF contains considerable protein and carbohydrates in the form of sugar which may be caramelized during cooking and hence increase yellowness. Despite the increase in yellowness, the noodle's physical qualities were not affected beyond acceptable ranges.

Table 4: Effects of BGF Enrichment on the Colour Properties of Noodles

CF: BGF	L*	**a***	**b***
100: 00	84.87 ± 0.20^{a}	1.62 ± 0.19^{a}	11.09 ± 0.16^{a}
92.5: 7.5	84.68 ± 0.13^{a}	1.97 ± 0.11^{b}	12.21 ± 0.12^{b}
85: 15	80.96 ± 0.08^{b}	2.70 ± 0.06^{c}	13.47 ± 0.88^{c}
77.5: 22.5	80.24 ± 0.90^{b}	2.81 ± 0.73^{c}	13.51 ± 0.62^{d}
70: 30	77.71 ± 0.34^{c}	3.45 ± 0.21^{d}	13.69 ± 0.30^{d}

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different

Functional Properties of Cassava-Bambara Groundnut Noodles

The functional properties of food material impact its interaction with other components and end applications. The hydration capacity of noodles ranged from 2.56 % to 2.94 %, with noodles containing 70 % BGF recording the highest, as shown in Table 5. After cooking, the noodles' hydration capacity was significantly ($p<0.05$) affected by increasing the substitution level of BGF from 7.5 % to 30 %. It was observed that 100 % cassava flour noodles recorded 2.56 %, which increased at an increasing addition of Bambara groundnut flours from 7.5 % to 30 % respectively. Water absorption relates to the protein network, which was higher at 30 % BGF inclusion. The increase in water absorption may be due to the addition of BGF (Nwadi *et al.*, 2020). These results confirm the findings reported by Nwadi *et al.* (2020) that legume crops including Bambara groundnut protein concentrate addition in wheat flour resulted in the elevation of water absorption capacity. Noodles with high hydration capacity would be relevant for improving the rheological properties and eating qualities as they increase softness.

The bulk density of the noodles was significantly ($p<0.05$) increased with an increase in BGF, as shown in Table 5. It was observed that 100 % CF noodles recorded the least bulk design, 0.86 g/cm³, while 30 % substitution of BGF recorded the highest, 0.96 g/cm³. It was noticed that at 7.5 % addition of BGF, the bulk density was 0.89 g/cm³, whereas at 30 %, the bulk density increased to 0.96 g/cm³. The increase in the bulk design may be caused by the addition of BGF during noodle production. Since it has considerable protein content, which increases the retention and absorption rate of water. These results are consistent with recent findings reported by Ocheme *et al.* (2018) that the addition of groundnut or Bambara groundnut protein concentrate increases the bulk density of the composite blends. The bulk density of flour is important as it influences mixing, packaging, and transportation. From the nutritional standpoint, it encourages the ingestion of more quantity of light food products which will be converted to more nutrients for the consumer.

Partial substitution of cassava with BGF significantly ($p<0.05$) increased the swelling capacity of the noodles. It was noticed that the swelling capacity of the 100 % cassava noodles was higher 1.35 ml compared to the Bambara groundnut enriched noodles. The lowest swelling capacity (1.02 ml) was noticed at 30 % substitution of BGF. The decrease in the swelling capacity of the noodles may be caused by the increasing levels of BGF thus decreasing the water-binding properties of the flour resulting in less swelling capacity. As the Bambara groundnut flour increases, the number of hydrophilic constituent's decreases decreasing the water absorption capacity proportional to the swelling capacity (Oke *et al.*, 2022). These results confirm the results reported by Binou *et al.* (2022), that the inclusion of BGF decreases the starch composition, affecting the swelling properties of the noodles.

Table 5: Effects of BGF on the Functional Properties of Noodles

CF: BGF	Hydration Capacity	Bulk Density	Swelling Capacity
100: 00	2.56 ± 0.01[a]	0.86 ± 0.00[a]	1.35 ± 0.00[a]
92.5: 7.5	2.69 ± 0.10[b]	0.89 ± 0.00[b]	1.21 ± 0.00[b]
85: 15	2.74 ± 0.03[b]	0.90 ± 0.01[b]	1.13 ± 0.00[c]
77.5: 22.5	2.88 ± 0.01[c]	0.93 ± 0.00[b]	1.08 ± 0.00[d]
70: 30	2.94 ± 0.01[c]	0.96 ± 0.01[d]	1.02 ± 0.00[e]

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different.

Textural Profile of Cassava-Bambara Groundnut Noodles

The influence of BGF enrichment on the textural characteristics of noodles is shown in Table 6. The textural profile was significantly ($p<0.05$) affected by the partial substitution with BGF after cooking. Briefly, the mean value of hardness, cohesiveness, springiness, adhesiveness, gumminess, and chewiness decreased by increasing the addition of BGF from 7.5 % to 30 %. After cooking, it was observed that the hardness, which is the maximum peak force during the first compression cycle on the noodles, decreased significantly with the increase in the inclusion level of BGF, and the lowest hardness was noticed at 100 % cassava flour noodles. The hardness results indicated that the noodles with high BGF were softer compared to 100% CF noodles. The hardness values were reported to be positively correlated to the protein network between the starch granules in the noodle dough, which may cause excess absorption of water and hence reduce the hardness of the noodles (Cao *et al.*, 2017). The reduction in the hardness may be caused by the addition of protein-rich sources of BGF, decreasing the starch structure of cassava flour, hence, high penetration of water in the noodles during cooking. The results obtained in this study coincide with the findings reported by Cao *et al*. (2017). Several studies reported that most protein-rich concentrates impact on the textural profile of noodles (Yao *et al*., 2020). The hardness affects the chewing properties of noodles, and therefore, the lower hardness of the Cassava-Bambara groundnut composite flour noodles would be relevant for improving the chewability of the noodles.

As depicted in Table 6, increasing the substitution of BGF in the noodles had a significant ($p<0.05$) effect on the cohesiveness and springiness properties of the noodles. It was noticed that 100 % cassava flour noodles recorded the highest cohesiveness of 0.90 and springiness of 0.70. On the other hand, increasing the inclusion of BGF from 7.5 % to 30 % resulted in a decrease in the cohesiveness from 0.87 to 0.75 and the springiness from 0.67 to 0.57, respectively. The decrease in cohesiveness and springiness of the noodles may be attributed to the increasing addition of BGF, increasing protein concentration, and water absorption capacity, which are imperative to strong network formation (Cao *et al*., 2017). Additionally, the decrease in cohesiveness and springiness means values could be attributed to the disruptive impact of the protein concentrate on the cassava starch network during the noodle production. The results obtained from this study confirmed the findings reported by Cao *et al*. (2017), who ascribed the reduction of cohesiveness and springiness to the coarse and protein concentrate, which absorbed water from the starch, resulting in the disruption of the dough matrix and insufficient formation of the starch converging surface. The cohesiveness and springiness properties contribute to the eating qualities.

Noodle adhesiveness is an undesirable metric for noodle quality. It is the amount of effort required to separate the probe from the noodle surface and is shown by the negative area between the first and second peak (Gulia *et al.*, 2014). It was observed that with the increase of BGF substitution, the noodles recorded an upward trend for adhesiveness, indicating that the Bambara groundnut-enriched noodles had a higher sticky surface than the 100 % cassava noodles. The increase in adhesiveness with an increase in the inclusion of BGF may be caused by the high protein content. The results of the study are consistent with those of Abidin *et al.* (2014), who observed that Bambara groundnut noodles had a higher adhesiveness than 100 % wheat flour. The adhesiveness indicates the elastic nature of the noodles, which may be relevant for improving the eating qualities.

Partial substitution of cassava with Bambara groundnut composite flour led to a general increase in the gumminess of noodles. Increasing the inclusion of BGF led to a significant ($p<0.05$) increase in the noodles' gumminess. After cooking, it was noticed that the unenriched noodles recorded a gumminess value of 8.70, whereas the Bambara groundnut enriched noodles increased between 10.21 to 10.74. The increase in gumminess may be caused by the addition of BGF, which increases the stickiness of the noodles. The findings in this study coincided with the results reported by Abidin *et al.* (2014) that the gumminess of noodles showed an increasing trend after Bambara groundnut concentrate was added. Additionally, Gulia *et al.* (2014) reported that protein impacts the gumminess of noodles, hence, higher protein would result in higher gumminess. These results may be beneficial for the improvement of the gumminess of noodles.

Chewiness, which is the combination of hardness, cohesiveness, and gumminess, was significantly ($p<0.05$) affected the noodles when the BGF was added. As depicted in Table 6, the chewiness was 8.31 in the 100 % cassava noodles while values for noodles containing Bambara groundnut flour ranged from 7.64 to 5.55. The decrease in chewiness may be caused by the addition of BGF, increasing the protein concentration and water absorption, and hence lower hardness. There was a general decrease in chewiness, at 7.5% the chewiness was 7.64, while a further increase in BGF resulted in a corresponding reduction in the noodles' chewiness to 5.55. These results agree with the findings reported by Abidin *et al.* (2014) that the inclusion of BGF makes noodles soft. Noodles with less chewing force may be relevant for improving the eating quality since children with weaker teeth can also chew them with less stress.

Table 6: CF:BGF on the func

CF: BGF	Hardness	Cohesiveness	Springiness	Adhesiveness	Gumminess	Chewiness
100: 00	13.00 ±2.65^{a}	0.90 ± 0.09^{a}	0.70 ± 0.10^{a}	0.13 ± 0.06^{a}	8.70 ± 2.78^{a}	8.31 ± 2.99^{a}
92.5: 7.5	13.00 ± 0.87^{a}	0.87 ± 0.04^{b}	0.67 ± 0.10^{b}	0.16 ± 0.01^{b}	10.21± 0.92^{b}	7.64 ± 1.12^{b}
85: 15	12.00 ± 1.80^{b}	0.79 ± 0.06^{b}	0.65 ± 0.15^{c}	0.16 ± 0.01^{b}	10.36 ± 2.07^{c}	7.58 ± 2.85^{c}
77.5: 22.5	11.50 ± 0.50^{b}	0.77 ± 0.14^{b}	0.62 ± 0.26^{d}	0.16 ± 0.03^{b}	10.44 ± 1.76^{v}	7.06 ± 3.81^{d}
70: 30	10.00 ± 1.50^{c}	0.75 ± 0.07^{b}	0.57 ± 0.15^{e}	0.22 ± 0.15^{c}	10.74± 1.48^{d}	5.55 ± 1.77^{b}

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different

Cooking Characteristics of Cassava-Bambara Groundnut Noodles

Results for cooking time, weight, and cooking loss of the Cassava-Bambara groundnut composite noodles are shown in Table 7. The noodles cooking time, weight gain, and cooking loss all showed significant ($p<0.05$) effects. Short cooking times and minimal solids loss in the cooking water are characteristics of high-quality noodles. Enrichment of noodles with BGF negatively affected the cooking time. While 100 % cassava flour noodles recorded the lowest cooking time of 5.13 min, noodle samples with BGF recorded high cooking times ranging from 5.55 to 6.14. indicating that cooking time increases as the inclusion of BGF increases. However, higher cooking time was noticed at 30 % inclusion of BGF. The results agree with the findings reported by

Aydin and Gocmen (2011) that the addition of BGF caused an increase in the cooking time of instant noodles.

The weight gains of the noodles varied from 15.23 g to 19.64 g among the Bambara groundnut enriched noodles. It was observed that increasing the inclusion of Bambara flour from 7.5 % to 15 % had no significant effect on the weight gain of the noodles. However, higher weight gain 19.64 g was noticed at 30 % inclusion of BGF noodles. The results agree with the findings reported by Aydin and Gocmen (2011) that increasing the inclusion of BGF increases the weight gain of instant noodles.

Cooking loss is an indicator of noodles' resistance to cooking (Aydin and Gocmen, 2011), so low levels are preferable. The inclusion of BGF had a significant ($p<0.05$) effect on the cooking loss of the noodles. After the assessment, the results revealed that the enriched Bambara groundnut noodles recorded the highest cooking loss (9.05 %). On the other hand, the inclusion of BGF in noodles led to a general decrease in cooking loss in the noodles ranging from 8.44 % to 5.96 %. The highest value was recorded at 7.5 % while the 30 % addition of BGF in the lowest cooking loss. These results collaborate with findings reported by Aydin and Gocmen (2011) that increasing the inclusion of Bambara groundnut in instant noodles decreases the cooking losses. Studies reported that cooking losses relate to the weakening/disruption of the protein-starch matrix (Aydin and Gocmen, 2011). Therefore, adding BGF increases the protein content and the starch-protein network, consequently decreasing the cooking loss. These results may be relevant for reducing the solid loss in noodles and also enhancing the utility of Bambara groundnut for food.

Table 7: Effects of BGF Enrichment on the Cooking Characteristics of Noodles

CF: BGF	Cooking time (min)	Weight gain (%)	Cooking loss (%)
100: 00	5.13 ± 0.13^{a}	15.01 ± 0.10^{a}	9.05 ± 0.01^{a}
92.5: 7.5	5.55 ± 0.10^{b}	15.23 ± 0.10^{b}	8.44 ± 0.02^{b}
85: 15	5.57 ± 0.03^{b}	15.31 ± 0.11^{b}	6.33 ± 0.02^{c}
77.5:22.5	6.09 ± 0.08^{c}	16.43 ± 0.01^{c}	6.28 ± 0.13^{d}
70: 30	6.14 ± 0.01^{c}	19.64 ± 0.12^{d}	5.96 ± 0.01^{e}

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different

Sensory Attributes of Cassava-Bambara Groundnut Noodles

The sensory evaluation of the noodles was carried out using a 9-hedonic scale (1 -dislike extremely to 9 -liked extremely), where 50 panellists were used. Results are presented in Table 8. In terms of noodles colour, 100 % cassava noodles had the lowest average score of (4.65 ± 2.17). On the other hand, increasing the inclusion of BGF from (7.5 % - 30 %) increased the colour acceptance rating from (5.75 to 5.99). It was observed that noodles with 7.5 % BGF recorded the lowest, while 30 % BGF recorded the highest consumer acceptance of the colour. In general, the Cassava-Bambara groundnut composite noodles' colour acceptance was higher than that of 100% cassava noodles. The combination of the light brown colour from the BGF and the Cassava-Bambara groundnut composite may be the reason for the increase in colour acceptance. The results obtained in this study corroborate the findings reported by Hussin *et al*. (2020) that the colour acceptance attribute of noodles was enhanced after the BGF addition. Similarly, Mensah (2011) established that instant noodles fortified with defatted BGF attained the highest ratings of colour acceptance by 50 panellists. Therefore, these results may be relevant for providing noodles with the best appearance.

For texture acceptance, the inclusion of BGF had a significant ($p<0.05$) impact on the texture acceptance of the noodles. The average mean score of the 100% cassava noodles was 5.23, Bambara groundnut enriched noodles attained the highest rating with an average score ranging from 5.50 to 6.33 at an increase in the inclusion range from 7.5 % - 30 %. It was observed that a further increase of BGF from 22.5 % to 30 % had no significant impact on the texture properties of the noodles. Hussin *et al*. (2020) also reported that the texture profile of noodles enriched with Bambara groundnut attained maximum acceptance with a mean score of 7.86, comparable to 100 % wheat flour noodles. Textural properties of noodles play an important role in their acceptance Hence, BGF would serve as an ingredient for improving the textural properties of noodles. These results would be relevant for improving the utility of Bambara groundnut in the food industry.

The aroma of noodles plays a key role in its acceptance by consumers (Paraskevopoulou *et al*., 2012). Aroma is one of the first characteristics perceived by consumers' olfactory senses when noodles are bought. After sensory evaluation, the results revealed that Bambara groundnut inclusion had a significant ($p<0.05$) effect on the aroma acceptance of the noodles. Cassava flour(100 %) noodles recorded 6.25, being the lowest score, while the inclusion of BGF in noodles increased the aroma acceptance, ranging from 6.27 to 7.26 at increasing levels of 7.5 % - 30 %, respectively. However, there was no significant impact on the noodle's aroma acceptance after 7.5 % inclusion of BGF. Further addition of Bambara groundnut flour levels of 15 % and 22.5 % led to a general increase in aroma acceptance, while 30 % BGF inclusion impacted significantly, resulting in a high rating of consumer preference, 7.26. The increase in aroma acceptance may be due to the beany flavour of BGF. These results are consistent with the findings reported by Hussin *et al*. (2020) that the inclusion of Bambara groundnut concentrate, on average, increases the aroma acceptance of 50 panellists. The high rating was attributed to the aroma properties of BGF. Additionally, the aroma profile of instant noodles enriched with defatted BGF attained a higher rating compared to 100 % cassava noodles (Gulia *et al*., 2014).

The persistent taste, such as saltiness, sourness, bitterness, and sweetness attributes of noodles after swallowing or while the noodles are in the mouth, plays a key role in their acceptance by consumers (Paraskevopoulou *et al*., 2012). As depicted in Table 8, the inclusion of BGF in noodle production significantly ($p<0.05$) impacted the consumer preference of the noodle taste. The unenriched Bambara groundnut noodles recorded an average score of 4.68. However, noodles with BGF led to a general increase in taste acceptance, ranging from 5.00 to 5.64. It was observed that at a 7.5 % inclusion level, the average score for taste acceptance was 5.00, while 30 % recorded the highest rating (5.64). However, increasing the inclusion level of BGF from 22.5 % to 30 % had no significant effect on the taste acceptance ratings. The increase in taste of the noodles may be attributed to the sweet taste of BGF. Similar findings were reported by Mepba *et al.* (2021). Alimi *et al.* (2024) also reported an increase in the acceptable taste of Bambara groundnut-fortified bread. Hence, the intrinsic palatable taste of Bambara groundnut resulted in high ratings. These results may be imperative for improving the taste of BGF products.

The aftertaste is the persistent taste, such as saltiness, sourness, bitterness, and sweetness attributes of noodles after swallowing and plays a key role in its acceptance by consumers (Paraskevopoulou *et al.*, 2012). As shown in Table 8, the partial substitution of cassava flour with BGF had a significant ($p<0.05$) effect on the noodles' aftertaste. The noodles prepared from 100% cassava flour recorded the lowest score aftertaste (5.20). On the other hand, noodles enriched with BGF recorded the higher values rating, ranging from 6.10 to 6.21, at 7.5%-30 % ranges of inclusion levels. Increasing the inclusion of BGF from 7.5 % to 15 % resulted in no significant increase in the aftertaste of noodles. Meanwhile, a further increase from 15 % to 30 % increased the aftertaste of the noodles. The increase in the aftertaste of Cassava-Bambara groundnut composite noodles may be attributed to the addition of the BGF. Similar studies by Alimi *et al.* (2024) reported that the aftertaste rating of noodles enriched with Bambara groundnut flour was higher compared to 100 % cassava noodles. Abidin *et al.* (2014) reported that optimising the proportion of BGF impacts positively on the aftertaste of instant noodles. Moreover, Mensah (2011) reported that instant noodle fortified with defatted BGF was highly rated with maximum acceptance by panellists. Therefore, these results may be relevant to using BGF as a suitable ingredient in complementary food development.

The overall acceptability (combined effect of appearance, texture, taste, and flavour) of noodles plays an imperative role in their acceptance by noodle consumers (Paraskevopoulou *et al.*, 2012). The results revealed that 100 % Bambara groundnut noodles recorded the lowest consumer acceptance (5.37). On the other hand, the inclusion of BGF had a significant ($p<0.05$) effect on the consumer likeness of the noodles. Increasing the inclusion of BGF from 7.5 % to 30 % led to a general increase in noodles' overall acceptance from 5.71 to 6.46, respectively. However, increasing the inclusion of Bambara groundnut from (7.5 % - 22.5 %) had no significant effect on consumer acceptance of noodles. Meanwhile, a further increase in BGF to 30 % increased the overall acceptance of the noodles. These results correlate with the findings reported by Alimi *et al.* (2024), that consumer acceptability of Bambara groundnut cake was higher than 100 % wheat flour cake. The combined intrinsic effects of taste, aroma, flavour, sweetness, and textural profile of BGF influence its acceptance in noodles. Consumer acceptability is paramount to product development. Hence, these results may contribute to improving the utility of Bambara groundnut in the food industry.

Table 8: Effects of BGF Enrichment on the Consumer Acceptability of Noodle

CF: BGF	Colour	Texture	Aroma	Taste	Aftertaste	Overall Accept.
100: 00	4.65 ± 2.17[a]	5.23 ± 2.01[a]	6.25 ± 2.12[a]	4.68 ± 2.08[a]	5.20 ± 2.07[a]	5.37 ± 2.29[a]
92.5: 7.5	5.75 ± 2.22[b]	5.50 ± 2.39[b]	6.27 ± 2.00[a]	5.00 ± 1.93[b]	6.10 ± 2.19[b]	5.74 ± 2.16[b]
85: 15	5.81 ± 1.69[c]	5.71 ± 2.07[c]	6.49± 1.81[b]	5.13 ± 1.98[c]	6.12 ± 2.02[b]	5.71 ± 1.90[b]
77.5:22.5	5.84 ± 1.65[c]	5.89 ± 1.61[d]	6.55 ± 1.51[b]	5.61 ± 1.80[d]	6.16 ± 1.77[b]	5.80 ± 1.72[b]
70: 30	5.99 ± 1.90[d]	6.33 ± 2.02[d]	7.26 ± 1.95[e]	5.64 ± 1.81[d]	6.21 ± 1.97[b]	6.46 ± 1.80[c]

Note: Means followed by the same letter in columns are not significantly ($p<0.05$) different.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Noodles, a wheat-based product, are high in carbohydrates and fat but deficient in dietary fibre, protein, vitamins, minerals and has high levels of gluten. In recent times, the use of locally inexpensive root tubers and legumes in the production of noodles has gained popularity, since it has considerably higher nutrient and gluten free as compared to the traditional wheat used in noodles production. Local crops such as Cassava is reported to be low in dietary fibre, protein, and essential amino acids (Chijioke *et al*., 2017), hence less exploited in the noodle industry. This has led to the search for nutrients like protein and essential amino acid sources. For instance, several authors have reported that legumes like Bambara groundnuts contain important essential amino acids and proteins. The substitution of wheat flour with cassava flour and enriched with Bambara groundnut would be relevant for improving the Nutri-functional qualities of the noodles. Thus, this study aimed at developing gluten-free noodles from Cassava-Bambara groundnut composite flour. To obtain the various formulations of Cassava-Bambara groundnut composite flour, a mixture design was used to generate a ratio of CF: BGF: 92.5:7.5 %, 85:15 %, 77.5:22,5 %, 70:30 %, and 100:00s.

Summary of key findings

1. The moisture content of the 100 % cassava flour noodles was 8.35 % while the Bambara groundnut enriched noodles recorded a moisture

content ranging from 7.46 % to 7.15 % at 7.5 % to 30 % inclusion level. This signaled a significant decrease in moisture content as BGF proportion increased.

2. On the other hand, the enrichment of noodles with Bambara groundnut led to a significant increase in the ash content, fiber as well as fat/oil content of all noodles and was attributable to the inclusion of BGF.
3. Noodles prepared using the 100 % cassava flour recorded a protein content of 2.51 % whiles 7.5 %, 15 %, 22.5 % and 30 % of Bambara groundnut flour inclusion recorded 4.16 %, 5.86 %, 6.99, and 7.27 respectively. This suggested that, the protein content increased as the proportion of Bambara groundnut flour increased.
4. Increasing the percentage incorporation of BGF led to a significant decrease in the carbohydrate content of all the noodle types. Thus, the 100 % Bambara groundnut noodles recorded 87.23 % while noodles enriched with BGF recorded carbohydrate content ranging from 85.96 % to 79.97 %.
5. The enrichment of noodles with BGF has led to a general increase in the mineral content of all the noodle types. The study further proved that an increase in the proportion of BGF significantly increased the zinc, calcium, magnesium, iron, and potassium of resulting noodles.
6. Noodles made from 100 % cassava flour recorded lightness value of 84.87 while the inclusion of Bambara groundnut from 7.5 % to 30 % decreased the lightness of noodles from 84.68 to 77.71 respectively.

7. The enrichment of noodles with BGF also led to a significant increase in the redness or brownness as well as the yellowness of all the noodle types.
8. There was a significant increase in hydration capacity, bulk density at an increase in the inclusion of BGF in noodles production.
9. The swelling capacity of the whole cassava flour noodles was high (1.35) which decreased with an increase in the inclusion levels from 7.5 % (1.21) to 1.02 at 30 %.
10. The hardness, cohesiveness, springiness, and chewiness of BGF-enriched noodles significantly decreased with an increase in the inclusion of BGF, while the adhesiveness and gumminess of the noodles increased with an increase in the proportion of BGF.
11. The enrichment of noodles with BGF had a significant impact on the cooking characteristics of all the noodle types. It was observed that as the proportion of BGF increased, more time was required to cook, resulting in noodles coupled with an increased weight gain. Less cooking time (5.13 min), weight gain (15.01 %) and high cooking losses (9.05 %) were recorded for the 100 % cassava flour noodle.
12. The enrichment of noodles with BGF has led to a significant increase in consumer rating of all the noodle types as panelists neither liked nor disliked noodles prepared from 100 % noodles (rating noodles approximately 5) while BGF-enriched noodles were liked by panelists (with a rating of approximately 6).

Conclusion

Based on the results obtained, the following conclusions were drawn:

Firstly, varying the amount of Bambara groundnut flour (BGF) significantly improved the proximate composition of the noodles. For instance, increasing BGF incorporation from 7.5% to 30% led to a progressive increase in protein content (from 4.16% to 7.27%), ash (from 0.94% to 2.29%), fiber (from 3.22% to 5.22%), and fat (from 0.54% to 3.06%), while reducing carbohydrate content (from 85.96% to 79.97%). These findings confirm that BGF enhances the nutritional profile of cassava-based noodles, making them a viable gluten-free alternative. The functional properties of the noodles were positively influenced by BGF inclusion. Hydration capacity increased from 2.56% (100% cassava flour) to 2.94% (30% BGF), while bulk density rose from 0.86 g/cm³ to 0.96 g/cm³. However, swelling capacity decreased from 1.35 mL to 1.02 mL, suggesting that higher BGF levels improve water absorption but reduce starch-based expansion. The textural analysis revealed that BGF incorporation reduced hardness (from 13.00 N to 10.00 N), cohesiveness (from 0.90 to 0.75), and chewiness (from 8.31 to 5.55), while increasing adhesiveness (from 0.13 to 0.22) and gumminess (from 8.70 to 10.74). These changes indicate a softer, more cohesive noodle texture, which aligns with sensory preferences. Additionally, BGF enrichment improved cooking characteristics, with weight gain increasing from 15.01% to 19.64% (30% BGF) and cooking loss decreasing from 9.05% to 5.96%. Although cooking time extended slightly (from 5.13 min to 6.14 min), the trade-off in reduced solid loss and enhanced water retention justifies the formulation. Finally, sensory evaluation demonstrated that noodles with 30% BGF received the highest overall acceptability score (6.46/9), outperforming the 100% cassava flour noodles (5.37/9) in color, texture, aroma, and taste. This confirms that a 30% BGF incorporation optimizes both nutritional and sensory quality, making it the ideal proportion for gluten-free noodle production.

Recommendation

Based on the results obtained, the following recommendations were drawn;

1. Further studies should be done on the cost-benefit analysis of noodles produced from Cassava-Bambara groundnut composite flour in comparison to traditional wheat-based noodles.
2. Also, optimization on the various noodles must be looked at by other researchers.
3. The Ministry of Food and Agriculture in Ghana, and the Ministry of Health in collaboration with the noodles industries should encourage the incorporation of 30 % BGF as a source of dietary fiber enrichment for bakery products. However, further studies should be conducted on the microstructure of partially substituted wheat flour with BGF for baked products.

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