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COLLEGE OF BASIC AND APPLIED SCIENCES

"FORMULATION AND OPTIMIZATION OF AN INSTANT BREAKFAST MEAL FROM ORANGE FLESHED SWEET POTATO, COWPEA, SESAME SEEDS AND RICE"

BY

MICHEALLA ELIKEM GOHOHO

11008496

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DECLARATION

This is to certify that this thesis is the result of the research undertaken by Michealla Elikem Gohoho towards the award of the Master of Philosophy degree in Food Science, in the Department of Nutrition and Food Science, University of Ghana.

Michealla Elikem Gohoho (Student: 11008496)	..... Signature	14/05/26 ..... Date
Dr. Bennett Dzandu (Supervisor)	..... Signature	14/05/26 ..... Date
Prof. Frederick Vuvor (Co-Supervisor)	..... Signature	14/05/26 ..... Date

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ABSTRACT

This study aimed to formulate and optimize an instant breakfast meal of low-cost from local ingredients that meets 30% of the Recommended Daily Allowance (RDA) for adolescents and adults. Linear Programming (LP) was employed to determine the optimal ingredient formulation(blend) from Orange-Fleshed Sweet Potato (OFSP), cowpea, sesame seeds and rice. The flour blend was analysed for nutritional composition, physicochemical and functional properties. Response Surface Methodology (RSM) was used to optimize the drum drying parameters (steam pressure and drum rotation speed), examining effect on the physicochemical, functional and sensory properties of the final product. The results showed that the final flour blend had 24.49g proteins, 58.66g carbohydrates, 12.9g fats, which met 30% of the RDA, 0.37mg beta-carotene and antioxidant activity of 52.33% with an ingredient cost of GH₵ 1.98/100g. The results also showed that both steam pressure and drum rotation speed influenced the overall quality and acceptability of the final product. Moisture content decreased with increased steam pressure and drum rotation speed. The sensory evaluation scores also increased when drum rotation speed and steam pressure increased. The optimal drum drying process conditions were 500kPa steam pressure and 15rpm drum rotation speed. This formulation represents a viable substitute for imported cereals, promoting the use of local crops and supporting Ghana's economic and public health objectives.

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DEDICATION

This work is dedicated to God Almighty, for seeing me through. And also, to my Parents and Supervisors for their support, patience, and guidance throughout this study.



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ABBREVIATIONS

OFSP- Orange Fleshed Sweet Potato

PUFAs- Polyunsaturated Fatty Acids

MUFAs- Monounsaturated Fatty Acids

RSM- Response Surface Methodology

LP- Linear Programming

WAC- Water Absorption Capacity

OAC- Oil Absorption Capacity

LGC- Least Gelation Capacity

PCA- Principal Component Analysis

ANFs – Anti Nutritional Factors

PDCASS- Protein Digestibility- Corrected Amino Acid Score

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CHAPTER ONE

1.0 INTRODUCTION

Rapid urbanization, changing lifestyles, and increasing occupational demands have significantly altered dietary patterns across sub-Saharan Africa, driving a growing reliance on convenient, minimally prepared breakfast products (Owusu et al., 2022). In Ghana, this shift has intensified demand for instant breakfast products; however, most commercially available options are formulated from imported cereals, primarily wheat and oats, which are not grown locally. This dependance on imported raw materials increases production costs, reduces the accessibility of nutritious foods for lower-income consumers, and places a recurring burden on foreign exchange reserves (Ghana Statistical Service, 2022). Moreover, many existing instant breakfast products are nutritionally inadequate, characterized by high refined carbohydrate content, elevated added sugars and low protein and micronutrient density.

Micronutrient deficiencies remain a persistent public health concern in Ghana. Vitamin A deficiency continues to affect children, adolescents and women of reproductive age, contributing to impaired immune function, increased susceptibility to infection and preventable vision loss (Ghana Health Service, 2022). Orange Fleshed Sweet Potato (OFSP) has been widely recognized as an effective biofortified crop for addressing vitamin A deficiency, given its high beta-carotene content alongside meaningful contributions of dietary fibre, vitamin C and potassium (van Jaarsveld et al., 2020). Intervention studies in Ghana have confirmed that regular consumption of OFSP-based products can measurably improve vitamin A status in target population (Asare et al., 2021).

Despite this documented potential, utilization of OFSP in industrial food processing in Ghana remains limited. Contributing barriers including the high perishability of fresh OFSP roots, with post-harvest losses of up to 40% under typical smallholder storage conditions, inadequate processing infrastructure, limited consumer awareness of OFSP flour as functional

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ingredient and the absence of standardized formulation protocols for OFSP-based processed foods (Adu-Kwarteng et al., 2022).Many published studies on OFSP in Ghana have focused on complementary foods and baked goods; instant breakfast meals, which represents one of the fastest-growing segments of Ghana's processed food market, have received little attention (Osei-Kwarteng et al., 2023). A specific gap therefore exists: no published study has reported an optimized breakfast meal combining OFSP with other indigenous Ghanaian crops using integrated formulation and process optimization tools benchmarked against defined national dietary targets.

The development of a composite flour-based instant meal incorporating OFSP, cowpea, sesame seeds and local rice offers a promising strategy for closing this gap. These four ingredients are nutritionally complementary: OFSP provides provitamin A carotenoids and energy; cowpea contributes plant protein, iron and lysine, compensating for the amino acids limitations in cereal grains; sesame seeds supply essential fatty acids, calcium and bioactive lignans; and rice provides a digestible starchy base with functional pasting properties suited to drum drying (Boukar et al., 2019; Gonçalves et al.,2020, Dossa et al., 2021). Owusu Osei et al. (2024) demonstrated that drum drying significantly influenced the nutritional composition and sensory attributes of root and tuber-based breakfast products, while Byamuka et al. (2025) confirmed that Response Surface Methodology (RSM) effectively improved the nutritional and functional properties of the composite flour formulations. However, limited research has integrated formulation optimization via Linear Programming (LP), process optimization via RSM and drum drying technology in a single study targeting locally grown crops. This study therefore seeks to develop and optimize an instant breakfast meal from OFSP, cowpea, sesame seeds and rice using an integrated LP-RSM framework.

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1.1 Rationale for study

The increasing demand for convenient and nutritious breakfast foods in Ghana, combined with persistent micronutrient deficiencies and the economic burden of cereal import dependency, underscores the urgent need for food product innovation using locally available ingredients. Ghana's expenditure on imported wheat and processed cereal products represents one of the largest food import categories, while domestically produced crops such as OFSP, cowpea, sesame and rice remain underutilized in the formal food processing sector (Ghana Statistical Service, 2022). Developing shelf-stable, nutritionally standardized products from these crops offers a dual benefit: reducing post -harvest losses and strengthening local agricultural value chains, while simultaneously improving dietary quality for Ghanaian consumers.

The full potential of OFSP as an ingredient in instant breakfast meal development has not yet been realized in Ghana. While existing research demonstrates the nutritional and functional suitability of OFSP flour in composite food systems, the specific combination with cowpea, sesame seeds, and rice and the application of LP to simultaneously optimize nutrient adequacy and production cost, followed by RSM-guided drum drying optimization has not been investigated. The 30% Recommend Dietary Allowance (RDA) for Ghanaian adolescents and adults was adopted as the primary nutritional standard for this study, reflecting the widely accepted principle that breakfast should contribute approximately one-third of daily nutrient requirements (Lartey et al., 2021). This study is therefore validated by its integration of formulation optimization, process optimization and nutritional and safety characterization within a single, applied product development framework targeted specifically to the Ghanaian food context and addressing an identified gap in both the scientific literature and the local food industry.

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1.2 Objective of study

To develop an instant meal from Orange fleshed sweet potato (OFSP), cowpea, local rice, and sesame seed.

1.2.1 Specific objectives

1. To formulate an instant meal from Orange Fleshed Sweet Potato, cowpea, local rice, and sesame seed using linear programming.
2. To evaluate the physicochemical and functional properties of the flour blend.
3. To optimize the production process for the instant meal.
4. To evaluate the sensory acceptability of the optimized product.
5. To evaluate the microbial quality of the drum dried product.

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CHAPTER TWO

2.0 Literature Review

2.1 Instant breakfast meals

The market for instant breakfast meals has grown significantly in recent decades, driven by urbanization, demographic shifts and changing dietary preferences. These products, which include cereal based powders, porridges, flakes and ready-to-drink formulations, are designed to require minimal preparation while providing adequate nutrition. In sub–Saharan Africa, the demand for convenient breakfast alternatives is particularly evident among urban populations, including students, working adults and low-income households that may lack the time or infrastructure to prepare traditional meals (Owusu et al., 2022). Despite this growing demand, many commercially available instant breakfast products in Ghana and across the region are wheat-based, heavily processed and imported which creates significant economic and nutritional vulnerabilities (Aryee et al., 2021).

The case for developing locally sourced, indigenous- ingredient based instant meals is therefore both nutritional and economic. Ghana currently spends a large portion of its food import budget in wheat and wheat-derived products (Ghana Statistical Service, 2022). The underutilization of nutritionally dense local crops such as Orange-Fleshed Sweet Potato (OFSP), cowpea, sesame seeds and rice, despite their wide availability, represents a missed opportunity for food system transformation. Several barriers have been identified as contributing to this underutilization, including inadequate processing infrastructure, limited consumer awareness of the nutritional value of these crops, post-harvest losses due to poor storage facilities and the nutritional value of the crops, post-harvest losses due poor storage facilities, and the absence of standardized formulations targeting specific nutritional benchmarks (Afoakwa et al., 2020; Adu-Kwarteng et al., 2022). These barriers emphasize the

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need for applied research into composite flour formulations from indigenous ingredients, which is the focus of this thesis.

2.1.1 Nutritional importance of breakfast

Breakfast is widely recognized as a critical meal in supporting daily nutritional adequacy, cognitive function, and metabolic health. Consuming a nutritionally balanced breakfast has been positively associated with improved dietary quality across the lifespan, including better nutrient intake and healthier body weight status (Gibney et al., 2018). Among adolescent and young adults in particular, regular breakfast consumption has been linked to improved academic performance, reduced risk of obesity and lower incidence of type 2 diabetes and cardiovascular disease (Rampersaud & Pereira, 2018). On the other, breakfast skipping has been discovered with overconsumption later in the day, poorer glycemic control, and increased risk of micronutrient deficiencies, which are already prevalent in many Ghanaian communities (Lartey et al., 2021).

In the Ghanaian context, deficiencies in iron, Vitamin A, and zinc remain significant public health concerns, particularly among women of reproductive age, children and adolescent (Ghana Health Service, 2022). An instant breakfast meal that meets approximately 30% of the recommended daily allowance (RDA) for key nutrients could make a meaningful contribution to addressing the deficiencies, especially for individuals who may not consume nutritionally diverse diets throughout the day. This reason informed the design of this study, including the selection of OFSP, cowpea, sesame seeds and rice.

2.1.2 Choice of ingredients for instant breakfast meal

The selection of OFSP, cowpea, sesame seeds, and rice as the primary ingredients for this instant breakfast meal formulation reflects both their nutritional complementarity and their

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economic and agricultural relevance to Ghana. These four ingredients represent distinct food groups: orange-fleshed sweet potato, a root crop rich in provitamin A carotenoids and dietary fibre; cowpea, a protein and iron rich legume with favourable amino acid diversity; Sesame seeds, an oil seed with a unique lignan and unsaturated fatty acid profile; and rice, a starchy cereal providing the bulk energy fraction. Their combination follows the principle of dietary complementarity in which the nutritional weakness of one ingredient are compensated by the strengths of another (Osei-Kwarteng et al., 2023). Notably, while each ingredient has been studied individually in Ghanaian and West African food systems, their combined use in an optimized composite flour for instant meal production has received limited systematic investigation, representing a clear gap this study aims to address.

2.2 Composition of Ingredients for instant breakfast meal

2.2.1 Orange-Fleshed Sweet Potato

Orange-fleshed sweet potato (*Ipomoea batatas)* is a nutrient-dense root crop with a macronutrient profile dominated by carbohydrates (approximately 20g/100g fresh weight), supplemented by dietary fibre (approximately 3g/100g), and moderate levels of protein (1.6g/100g). Its most significant nutritional attribute is its high beta carotene content, which serves as the primary vitamin A compound in many African diets. Concentrations of beta-carotene in OFSP has been reported to range widely from 3mg/100g to over 15mg/100g dry weight depending on the cultivar, growing conditions, post-harvest handling practices (van Jaarsveld et al.2020). In Ghana and across sub-Saharan Africa, OFSP-based biofortification programs have demonstrated significant potential to reduce vitamin deficiency (VAD) in children and women of reproductive age, with intervention studies reporting measurable improvements in the serum retinol concentrations (Asare al., 2021).

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Beyond provitamin A, OFSP provides meaningful quantities of vitamin C, potassium and manganese. Its relatively low glycemic index compared to refined cereal products makes it a suitable ingredient in formations targeting metabolic health, including the management of type 2 diabetes, which is increasingly prevalent in Ghanaian urban populations (Adu-Kwarteng et al., 2022). However, several studies have noted the beta-carotene bioavailability from OFSP is significantly affected by processing methods, food matrix fat content and individual absorptive capacity, which limits straightforward extrapolation of raw nutrient data to functional nutritional outcomes (Bechoff & Dhuique-Mayer, 2020).

2.2.1.1 Health benefits and functional properties of OFSP

The health benefits of OFSP extend beyond vitamin A precursor activity. Beta-carotene and other carotenoids in OFSP exhibit antioxidant activity by quenching singlet oxygen and scavenging reactive oxygen species, thereby potentially reducing the risk of oxidative stress-related chronic diseases (van Jaarsveld et al., 2020). The dietary fibre in OFSP includes both soluble fractions that improve bowel motility (Aryee et al., 2021). These functional properties make OFSP a compelling ingredient beyond simple energy provision.

Several studies in Ghana and Nigeria have demonstrated that OFSP flour can be incorporated into composite food products including weaning foods, baked goods and porridges with acceptable sensory outcomes (Asare et al., 2021; Osei-Kwarteng et al., 2023). However, a recurring limitation in this body of ork is the focus on two or three ingredient blends and the lack of systematic optimization of ingredient proportions using formal mathematical modelling tools. Additionally, relatively few studies have characterized the functional and physicochemical properties of drum dried OFSP-based composites, despite drum drying being highly relevant to instant meal production in the West African context.

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2.2.1.2 Bioavailability of nutrients in OFSP

The bioavailability of beta-carotene from OFSP is a well-studied but complex issue. Key determinants include the form of carotenoids present, disruption of the food matrix through processing, and co-consumption of dietary fat. Thermal processing generally increases carotenoids bio accessibility by disrupting cell wall structures and releasing carotenoids from chromoplast, though excessive heat can lead to isomerization of all-trans to less cis forms (Bechoff & Dhuique-Mayer, 2020). Boiling and steaming have been reported to result in higher bio accessibility that roasting, while drum drying, which involves intense but brief heat exposure, has been associated with moderate carotenoid retention relative to oven drying (Abano & Sam-Amoah, 2021). The inclusion of oilseeds such as sesame seeds in the blend, which contribute unsaturated fats may therefore have a synergistic effect on the beta-carotene bioavailability, though this interaction warrants explicit discussion and ideally and analytical confirmation in future studies.

2.2.2 Cowpea

Cowpea (*Vigna unguiculata*) is one of the most important grain legumes in sub-Saharan Africa, valued for its protein content (approximately 22-25g/100g dry weight), affordability and agronomic resilience under low-input rain-fed conditions (Boukar et al., 2019). In Ghana, cowpea is widely cultivated and consumed, particularly in the northern savanna zones, and plays an important role in household food security and dietary protein supply for low-income populations. Its macronutrient profile includes significant carbohydrate (approximately 60g/100g), dietary fibre (approximately 7g/100g) and micronutrients including iron (approximately 8mg/100g), magnesium, potassium, folate and B-vitamins (Gonçalves et al.,2020).

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A critical limitation frequently noted in the cowpea literature is the presence of antinutritional factors (ANFs), including phytates, tannins and trypsin inhibitors, which can reduce the digestibility and bioavailability of protein and minerals. Phytate, in particular, has a strong binding affinity for iron, zinc and calcium, which may substantially reduce the effective iron contribution of cowpea to the diet despite its apparently high raw iron content (Gonçalves et al., 2020). Soaking, dehulling and heat treatment, all of which applied during flour processing significantly reduces ANF levels, but residual phytate activity remains a concern in composite flour products that are not fermented. Future iterations of this formulation may benefit form incorporating a fermentation step to further reduce ANFs and improve mineral bioavailability.

2.2.2.1 Cowpea protein content and quality

The protein content of cowpea is notable not only for its quantity but also for its amino acid profile, while is rich in lysine, an amino acid that is limited in most cereal grains. This makes cowpea a highly complementary ingredient when combined with rice in a composite blend, as the lysine from cowpea compensates for rice's relative lysine deficiency, while rice provides the Sulphur-containing amino acids methionine and cysteine that are less abundant in cowpea (Boukar et al., 2019). This complementarity is a key nutritional rationale for the four-ingredient combination used in this study. Protein digestibility- corrected amino acid score (PDCAAS) values for cowpea flour have been reported in a range of 0.49-0.73, depending on processing conditions; when blended with cereals, the composite PDCAAS typically improves, though explicit calculation and reporting of PDCAAS for the final blend would strengthen the nutritional claims (Nwose & Aniebo, 2021).

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2.2.2.2 Nutritional and health benefits of cowpeas

Beyond protein, the dietary fibre and resistant starch in cowpea provide prebiotic effects, supporting the growth of beneficial gut and contributing to reduced post prandial blood glucose responses, an attribute particularly relevant in the context of Ghana's rising prevalence of type 2 diabetes (Lartey et al., 2021). The iron content of cowpea, while affected by phytate, remains among the highest of commonly consumed legumes in the region and can contribute meaningfully to daily iron requirements when the product matrix supports adequate bioavailability. The folate content is also noteworthy, supporting neural tube development and red blood cell formation which are nutritional benefits directly relevant to adolescent and young adult target consumers (Gonçalves et al, 2020).

Research comparing cowpea varieties cultivated in Ghana has reported variability in protein, iron and phytate content depending on genotype and growing environment (Afoakwa et al., 2020). Such Variability should be acknowledged as a potential source of batch-to-batch variability in the nutritional composition of the final composite product, and the selection of variety for production-scale formulation warrants consideration.

2.2.3 Sesame Seeds

Sesame (*Sesamum indicum*) is an ancient oilseed crop cultivated across tropical and subtropical regions, including Ghana's northern and upper regions. It is distinguished by its high fat content (approximately 49-55g/100g), predominantly unsaturated fatty acids including oleic acid (omega-9) and linoleic acid (omega-6), which are associated with cardioprotective effects (Dossa et al., 2021). Its protein content (approximately 17-20g/100g) and notable mineral content composition, including calcium (approximately 975mg/100g), magnesium and zinc, makes sesame seeds an important complementary ingredient in composite formulations targeting mineral adequacy (Adiamo et al., 2022).

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The unique health-promoting of sesame are largely attributed to its lignan content, particularly sesamin, sesamolin and sesamol. These lignans function as potent antioxidant and have been reported to regulate lipid metabolism, exhibit anti-inflammatory activity, and potentially contribute to blood pressure regulation human and animal studies (Hasan & Bhatt, 2021). Importantly, the antioxidant activity of sesame lignans may partially offset the pro-oxidative effects of elevated lipid content during processing and storage, contributing to the shelf stability of the composite flour blend.

2.2.3.1 Health and nutritional benefits of sesame seeds

Several review studies have consolidated evidence on the functional properties od sesame seeds as a food ingredient. Dossa et al. (2021) systematically reviewed the health benefits of sesame seed consumption, noting consistent associations between sesame lignan intake and improved cardiovascular risk markers, including reductions in total cholesterol and LDL cholesterol. However, the authors cautioned that the evidence base is largely derived from short term clinical trials with small sample sizes, that the bioavailability of sesame lignans is significantly influenced by gut microbiota composition, processing methods and the food matrix, factors that are rarely controlled for in a food product development study

From a food processing perspective, milling sesame seeds to produce flour presents challenges related to oil release, which can cause rancidity and clumping. Impact milling at controlled temperatures has been shown to produce sesame flour with adequate particle size distribution and acceptable oxidative stability for incorporation into composite blends (Adiamo at al., 2022). However, the thermal stability of sesame lignans during drum drying specifically has received limited attention in the published literature, representing a gap that future work on this formulation address.

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2.2.4 Rice

Rice (*Oryza sativa*) is a dominant cereal crop and energy staple for a large proportion of Ghanaian households, particularly in urban areas. It provides primarily carbohydrates (approximately 70-80% dry weight, primarily starch), which relatively modest protein (6-8g/100g) and fat (0.6g/100g) contributions. The starch composition of rice, particularly the amylose to amylopectin ratio, significantly influences its digestibility, glycemic index (GI), and functional behaviour in composite flour systems (Tian et al., 2021). High-amylose rice varieties have lower GI values compared to waxy varieties, a difference that becomes nutritionally relevant when targeting metabolic health outcomes in the product.

While white rice is the most commonly consumed form in Ghana, it lacks the bran and germ layers present in brown rice, resulting in significantly lower fiber, B vitamin and mineral content. The inclusion 0f rice as a flour component in this formulation primarily serves to contribute energy through digestible starch, improve the textural properties of the reconstituted product (particularly viscosity and mouthfeel), and reduce the beany flavour of cowpea. Research on rice flour functionality in the composite systems has shown that particle size and gelatinization temperature and water absorption capacity vary considerably across varieties and milling conditions, with implication for the drum dying behaviour and rehydration quality of the final product (Tian et al., 2021; Mahajan et al., 2021).

2.2.4.1 Functional properties of rice

The functional behaviour of rice in composite flour formulations is governed largely by its starch gelatinization properties. Gelatinization temperature for most white rice flours falls between 60-80°C, which aligns well with the drum drying temperatures typically used in instant meal production (Mahajan et al., 2021). Drum drying promotes full gelatinization and partial dextrinization of the starch, contributing to the improvement of reconstruction

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properties characteristic of drum dried instant products, a fact documented in drum dried rice-based foods such as instant congee and rice porridge (Abano & Sam-Amoah, 2021).

2.3 Processing of ingredients and optimization

2.3.1 Drying

Drying is the foundational unit operation in the production of instant meal products, serving to reduce water activity below the threshold for microbial growth and enzymatic activity, hence extending shelf life. The principal drying method applicable to composite flour production include solar drying, oven drying and drum drying, each of which has distinct implication for process efficiency, product quality and nutrient retention (Abano & Sam-Amoah, 2021). The choice of drying method is not merely technical but directly determines the functional and sensory properties of the final product, understanding the mechanisms and tradeoffs of each method is critical to the formulation strategy.

2.3.1.1 Convection oven drying

Oven drying uses forced hot air to facilitate moisture removal through evaporation. It offers greater process control than solar drying, including the ability to set and maintain precise temperature and airflow conditions. In the context of OFSP and cowpea processing, oven drying has been widely applied at temperatures ranging from 55°C to 70°, with drying times typically between 6 and 24 hours depending on the thickness, initial moisture content and the target final moisture content specification (Abano & Sam-Amoah, 2021), It is important that drying parameters including temperature, time and slice thickness can be documented precisely and consistently as variations in any of the parameters can produce substantially different outcomes in terms of moisture content, colour, texture and beta-carotene retention, all of which

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affect both the quality of the intermediate flour and the performance of the final composite blend.

The literature shows that beta-carotene retention in OFSP dried in an oven dryer is generally moderate to good (60-85%) when temperature are maintained below 70°C but degrades more rapidly at higher temperatures or prolonged drying times (van Jaarsveld et al., 2020). For sesame seeds, oven drying is typically not required as seeds arrive with low moisture content from harvesting; however light roasting is sometimes applied to enhance flavour. Each ingredient in the composite flour must therefore be dried under conditions optimized for that ingredient's specific physicochemical properties and those conditions must be consistent across batches to ensure reproducibility of the final product.

2.3.1.2 Drum drying

Drum drying is a primary processing technology for producing instant meal products with good rehydration properties. The process involves spreading a thin layer of food slurry onto the surface of internally steam-heated rotating stainless-steel drums; their brief contact time (typically 10-30 seconds) at high surface temperatures (120-160°C) rapidly evaporates moisture and the dried product is scraped off as flakes or powder. The short exposure time, despite the high temperature, limits heat damage to nutrients and sensory attributes compared to prolonged oven drying (Muzaffer et al., 2019). Key processing parameters, steam pressure which determines drum surface temperature, drum speed which determines contact time and thus drying intensity and fees slurry consistency, interact to determine product quality outcomes including moisture content, bulk density, water absorption capacity and sensory attributes.

A notable body of current literature has characterized drum drying parameters for various composite flour slurries, including cereal-legume and vegetable-based formulations.

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Muzaffar et al., (2019) demonstrated that increasing steam pressure improved the degree of starch gelatinization and product reconstitution, while excessive drum speed produced a product with inadequate moisture removal. In the context of OFSP-legume blends, the Millard reaction between the reducing sugars from OFSP and the amino groups form cowpea protein can produce a desired browning and flavour during drum drying but may also reduce available lysine if temperature are too high (Abano & Sam-Amoah,2021). The optimization of drum drying parameters for this specific four-ingredient composite blend is therefore a technical novel contribution as most published drum drying studies focus on single ingredient slurries or two simpler component flours.

A limitation of drum drying relevant to this study is the high cost of drum drying equipment, which restricts its use to medium and large-scale processors and may limit the immediate commercial scalability of the formulated products for smaller processors. Additionally, batch to batch consistency of the input slurry, particularly the slurry concentration, temperature at feeding and particle size distribution of the flour blend, must be tightly controlled to achieve reproducible drying outcomes.

2.3.2 Milling

Milling transforms dried ingredients into flours of specified particle size, which directly affect the functional, sensory and nutritional properties of composite blends. Smaller particle sizes generally improve solubility, dispersibility, and texture in reconstituted products but can also increase surface area available for lipid oxidation, particularly in oilseed-containing blends such as sesame-containing formulation in this study (Adiamo et al., 2022). For cereal and legume ingredients, hammer milling is widely used at the pilot and commercial scales due to its simplicity and throughput capacity, with screen size determining final particle size distribution. For sesame seeds, the high oil content requires careful management of milling

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temperature to prevent oil extraction, particle aggregation and rancidity development during storage of the flour.

Mahajan et al., (2021) compared the milling efficiency and flour functionality of rice flours produced by wet milling, dry hammer milling and pin milling, and found significant differences in particle size distribution, damaged starch content and pasting properties. Damaged starch produced in greater quantities by aggressive dry milling, absorbs more water and leads to higher peak viscosity during gelatinization, a property that may be advantageous for drum drying slurry preparation but can negatively affect the texture of the reconstituted product if overcorrected. These interactions between milling and downstream processing behaviour underscore the importance of characterizing and standardizing milling conditions for each ingredient before formulation.

2.3.3 Blending and formulation techniques

Composite flour blending requires careful control of mixing uniformly to ensure that each serving of the final product delivers a consistent nutritional and sensory profile. Dry blending, which is the most common approach for composite flour production, involves mechanical mixing of individual milled flours to achieve macroscopic homogeneity. Achieving uniformity when mixing requires the selection of an appropriate mixer type, mixing speed and time (Osei-Kwarteng et al., 2023). Non-uniform blending can result in serving-to-serving variability in both nutritional composition and sensory attributes, which undermines both the scientific validity of analytical results and the commercial consistency of the product.

Beyond mixing mechanics, the compatibility of ingredients in terms of water activity and moisture migration during storage is critical to product stability. Ingredients with different moisture contents will exchange moisture over time, potentially elevating water activity in the blend and creating conditions permissive for mould growth or beta-carotene degradation.

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Packaging in moisture-barrier materials and the potential use of silica gel desiccants are practical mitigation strategies, though these are rarely discussed explicitly in composite studies targeting the Ghanaian market.

2.3.4 Optimization methods

Mathematical optimization is an essential component of modern food product development, enabling the systematic identification of ingredient combinations and processing conditions that simultaneously satisfy multiple nutritional, sensory and economic objectives. Two complementary optimization tools were applied in this study: Linear Programming (LP) for ingredient proportion optimization and Response Surface Methodology (RSM) for drum drying process optimization.

Linear Programming is a quantitative technique that identifies the optimal values of a linear objective function subject to a set of linear inequality constraints. In food formulation, LP is most commonly applied to least-cost diet formulation, identifying the combination of ingredients that meet all specified nutritional constraints at minimum cost (Mubaiwa et al., 2021). Its power lies in its ability to simultaneously handle multiple nutritional constraints and ingredients inclusion bounds, generating formulations that are nutritionally adequate and economically efficient. In the context of this study, LP was used to identify the proportions of OFSP flour, cowpea flour, sesame flour and rice flour that met the target nutrient profile; including minimum protein, carbohydrates and fats aligned with 30% of Ghanaian RDA for adolescents and adults at a minimum ingredient cost.

Response Surface Methodology is a collection of statistical and mathematical tools used to model and optimize a response influence by multiple independent variables, particularly useful for investigating interactions effects and non-linear relationships that are common in food processing (Bezerra et al., 2019)., RSM using a central composite design or

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box-Behnken design is well suited to drum drying optimization, where the response variables of interest are influenced by interacting process parameters. Unlike LP, which are linear and produces a unique optimum, RSM produces continuous response surfaces that allow visualization of differences between competing objectives.

The combined application of LP for ingredient-level optimization followed by RSM for process-level optimization, as employed in this study, represents a meaningful methodological integration that has been rarely applied to OFSP-based composite flour formulations. Mubaiwa et al., (2021) applied LP to optimize a complementary food blend for OFSP and cowpea in Zimbabwe but did not extend the approach to process optimization. Conversely, several RSM studies om drum dried composite slurries have focused on single-ingredient products without LP-based nutritional optimization of the input blend. The sequential LP-RSM framework applied here, targeting a specific national RDA benchmark for the Ghanaian market, therefore constitutes an original methodological contribution to literature.

2.3.5 Sensory properties

Sensory acceptability is critical determinant of whether a nutritionally optimized product will achieve commercial success and dietary adoption. Among the sensory attributes relevant to instant breakfast meals, colour, aroma, taste, texture and overall acceptability are routinely evaluated using trained or consumer panels (Mahajan et al., 2021). In composite blends containing OFSP, the characteristic orange colour from carotenoids is generally regarded as a positive visual attribute, associated by Ghanaian consumers with natural, nutritious foods (Asare et al., 2021). However, drum drying-induced Millard browning can shift the colour toward yellow-brown tones, which may affect visual appeal depending on the degree of browning.

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The flavour profile the composite blend-creates a complex sensory matrix that requires empirical evaluation rather than the theoretical prediction. Published consumer acceptance for similar OFSP-legume blends in Ghana and Nigeria have generally reported hedonic scores in the range of 6.0-7.5 on a nine -point hedonic scale, indicating acceptable to good overall liking, though specific flavour and texture attributes frequently receive lower acceptance (Afoakwa et al., 2020; Osei- Kwarteng et al., 2023). A mean overall acceptance score in this range should be interpreted as indicating commercial potential with further development, particularly with respect to texture optimization and flavour modulation through seasoning or natural additives.

2.3.5.1 Sensory evaluation techniques

The principal sensory evaluation methods applicable to instant breakfast development include hedonic testing, descriptive analysis and preference testing. Hedonic testing using a nine-point hedonic scale is the most widely applied method for consumer acceptance studies in food product development, providing and overall liking score as well as attribute-level ratings that can identify specific areas for reformulation (Mahajan et al., 2021).

A key methodological consideration in consumer panel studies is panelist selection: panels should be representative of the target consumer demographic in terms of age, gender and familiarity with the ingredient types, as familiarity with OFSP and cowpea-based foods varies across Ghanaian regions and socioeconomic groups (Lartey et al., 2021).

Descriptive analysis using a trained panel, while more resource-intensive, provides quantitative characterization of specific sensory attributes and it particularly valuable for understanding the drivers of overall liking and guiding reformulation discussions. The inclusion of Principal Component Analysis (PCA) to explore relationships between sensory and physicochemical variables, as employed in this study, is a valuable methodological approach that can identify which physical product characteristics most strongly predict

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consumer acceptance, thereby providing actionable insights for future formulation optimization.

2.3.6 Microbial safety of flour blends

Microbial safety is non-negotiable requirement for any food product and composite flour blends are not exempt from contamination risks, particularly given the diverse raw material I input, and the multiple processing steps involved. The primary microbial hazards associated with composite flour products include bacterial pathogens such as Salmonella spp. and Bacillus cereus, moulds including Aspergillus ssp. that produce aflatoxins and spoilage organisms such as coliforms that indicate hygiene inadequacy during processing (Nwose & Aniebo, 2021). Among these, aflatoxin contamination in grains and legumes grown and stored under tropical conditions is of particular concern in Ghana, where surveys have reported aflatoxin levels in maize, groundnut and cowpea exceeding Codex Alimentarius and Ghana Food and Drugs Authority (FDA) permissible limits (Afoakwa et al., 2020).

In Ghana, composite flours products for products for human consumption are subject to Ghana FDA regulations, which specify maximum permitted levels for total plate count, coliform count, yeast and moulds, and mycotoxins include aflatoxins B1. Products that meet 30% RDA nutritional claim also fall under the may provisions that may trigger additional labelling and compositional requirements under Ghana's food labelling regulations. The heat treatment inherent in drum drying provides effective inactivation of vegetative bacterial pathogens but does not eliminate heat-stable mycotoxins or spore-forming bacterial endospores such as B. cereus. Post-drying contamination control through good manufacturing practices and appropriate packaging are therefore critical to ensuring the microbiological safety of the finished product (Muzaffar et al., 2019). The microbiological quality of the flour blends

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produced in this study should be assessed against Ghana FDA standards as required quality and safety parameter, in addition to the nutritional and sensory characterization.

2.4 Economic and Commercial Context for Locally-Sources Instant Breakfast Meals

The commercial viability of an instant breakfast meal formulated from indigenous Ghanaian ingredients is underpinned by several converging economic and policy trends. Ghana's continued dependence on wheat imports for processed food production represents a significant and growing burden on foreign exchange reserves; the Ghana Statistical Service reported that imported wheat and wheat flour constituted one of the largest categories of food imports by value (Ghana Statistical Service, 2022). At the same time, domestic production of OFSP, cowpea, sesame seeds and rice has been growing, supported by government programs including Planting for Food and Jobs, yet post-harvest losses and inadequate value addition remain significant barriers to economic returns for farmers (Adu-Kwarteng et al., 2022). The development of processed, shelf stable, nutritionally standardized products from these crops offer a mechanism for reducing post-harvest losses, adding value in the domestic food processing sector and substituting imported ingredients.

Consumer demand for convenient foods in Ghanaian urban centres has grown substantially, driven by demographic changes including increasing female labour force participation, longer urban commutes and the growing influence of younger consumer segments with different food preparation norms from previous generations (Owusu et al., 2022). While the market for premium health foods remain relatively small and concentrated among higher-income urban consumers, a growing body of body of evidence suggest that middle-income Ghanaian consumers are willing to pay a modest premium for processed foods that are perceived as natural, locally sourced and health promoting (Lartey et al., 2021). The cost optimization achieved through LP formulation is an important attribute that should be explicitly

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compared against the retail price of comparable imported instant breakfast products in the Ghanaian market to situate the commercial proposition.

2.5. Challenges and future direction for instant breakfast meals

2.5.1 Formulation challenges

The development of flour-based instant meals presents a complex set of formulation challenges that go beyond simple ingredient mixing. Chief among these is ensuring chemical and physical stability of the flour blend over the intended shelf life. The presence of ingredients with different hygroscopic characteristics creates conditions for moisture migration within the blend, elevation of water activity and consequent acceleration of millard browning, carotenoid degradation and lipid oxidation from sesame oil component (Dossa et al., 2021). Water activity monitoring and the use of appropriate moisture-barrier packaging are critical processes controls yet often underreported in the composite flour development studies.

A further challenge concerns the sensory impact of antinutritional factors in cowpea, particularly tannins and saponins that contribute to bitter and astringent notes in the constitutes product. Processing interventions including soaking, boiling and autoclaving are effective in reducing these compounds, but each with time and energy implications for scale up. The interaction between cowpea-derived off flavours and the naturally sweet earthy tones of OFSP in the reconstituted product requires empirical sensory profiling rather than the assumption of compatibility based on individual ingredient properties alone (Boukar et al., 2019).

2.5.2 Future research opportunities

Several directions for future research emerge directly from limitations of the current study and from gaps in the broader composite flour literature. First, nutritional characterization of the final drum-dried product is essential for accurate nutritional claims, as drum drying conditions

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may alter nutrient content, particularly the heat sensitive beta-carotene and lysin. Future studies should include full proximate and micronutrient analysis of the drum dried product under optimal processing conditions. Second, the application of formal bio-availability assessment methods to quantify the actual bioavailable fraction of key nutrients including iron and beta-carotene would substantially strengthen the nutritional contribution of this line of research (Bechoff & Dhuique-Mayer, 2020).

Third, a benchmarking study comparing the formulated product against commercially available instant breakfast products on the Ghanaian market would provide a clearer picture of the product's competitive positioning and incremental nutritional value. Fourth, scale-up studies assessing the feasibility of transitioning from pilot-scale drum drying to commercial-scale production, with particular attention to process consistency and cost-per-unit economics, are needed before commercialization recommendations can be made with confidence. Finally, research exploring the integration of germination or mild fermentation as a pre-processing step to reduce antinutrient content and improve mineral bioavailability, without compromising sensory quality, represents a promising avenue for enhancing the nutritional impact of OFSP-legume composite products in the West-African context (Nwose & Aniebo, 2021; Gonçalves et al., 2020).

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2.6 Research Gap and Justification for the Present Study

The review of the literature reveals specific knowledge gaps that collectively justify the research question addressed in this work. First, while OFSP and cowpea have been individually well-studies in Ghanaian and West African food systems, and while two and three component OFSP-legume blends have been investigated in a limited number of studies, they systematic formulation and optimization of a four component composite blend incorporating OFSP, cowpea, sesame seeds and local rice, with explicit nutritional targets aligned to Ghanaian RDAs,

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has not been reported. Secondly, the application of Linear Programming as a formal nutritional cost-optimization tool to this specific ingredient combination is a novel within the published literature on Ghanaian composite flour development. Thirdly, the use of Response Surface Methodology to optimize the drum drying parameters specifically for the composite slurry of this composition and the correlation of drum dying conditions with both physicochemical properties and consumer acceptance through Principal Component Analysis has not been reported.

Fourth, the exploration of production cost as an explicit optimization variable alongside nutritional adequacy, using LP modelling, addresses a practical commercialization consideration that is frequently absent from academic food product development studies in the region.

Taken together, these gaps define a research space in which this thesis makes an original and applied contribution: The development, optimization and characterization of a nutritionally adequate, cost effective, drum dried instant breakfast meal from four indigenous Ghanaian crops, using an integrated LP-RSM optimization framework. The findings of this study are expected to provide both a scientific basis for future product development work in this area and practical formulation guidance for food processors operating in the Ghanaian context.

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CHAPTER THREE

3.0 MATERIAL AND METHODS

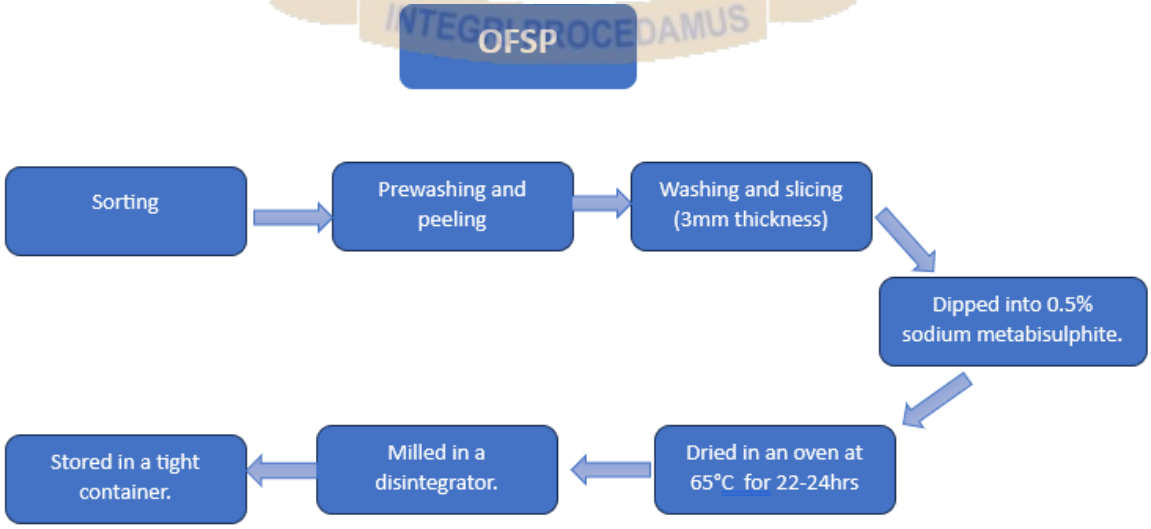
3.1 Raw materials

Mature Orange Fleshed Sweet Potato (OFSP), cowpea, local rice and sesame seed used for the study. OFSP was obtained from a farm in Tamale, and the other ingredients were obtained from the Madina market. The raw materials were transported to the Department of Nutrition and Food Science.

3.2 Preparation of raw materials

3.2.1 Sweet potato flour

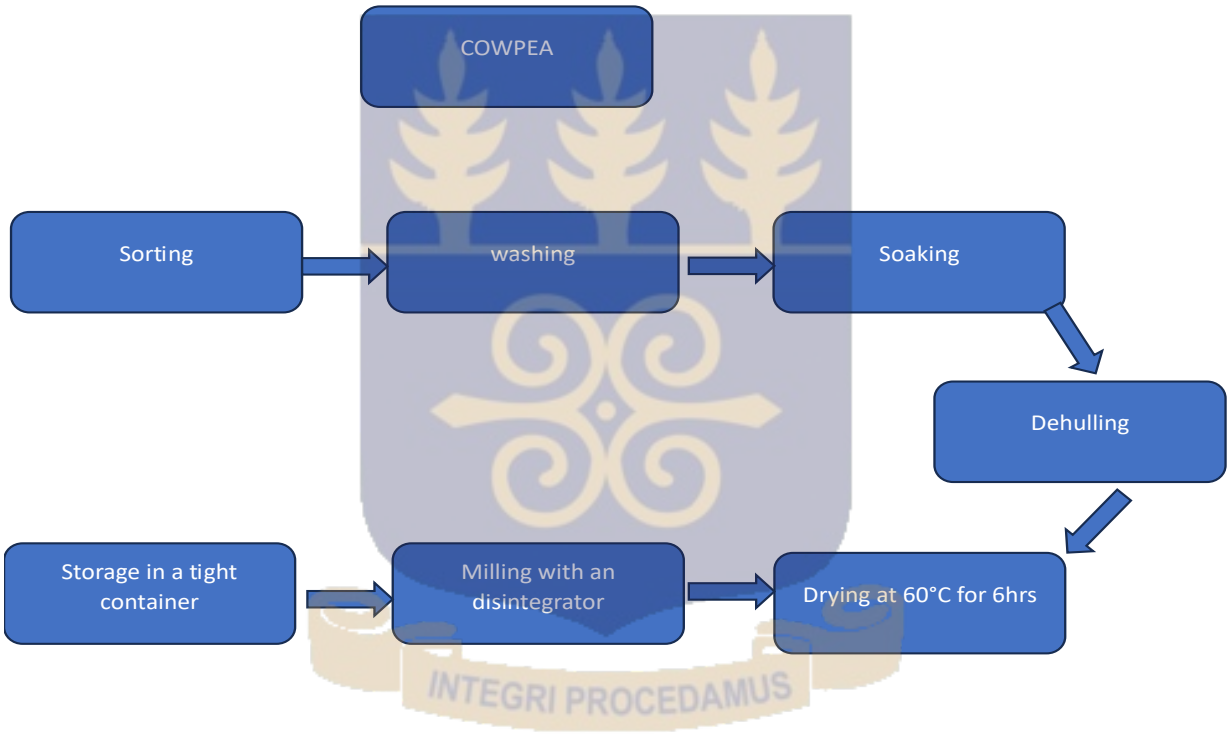
Sweet potato flour was prepared following the method described by Olapade & Ogunade (2014). The Orange fleshed sweet potatoes were sorted, pre-washed, peeled and washed twice with clean water. The washed tubers were sliced to a thickness of 5mm using a slicer. They were then submerged into a solution of 0.5% sodium metabisulphite for 5 minutes (to prevent enzymatic browning) and dried at 65 °C in an air oven for 24 hours. The dried slices was ground into flour using a hammer mill. The samples were collected into airtight containers for later use.



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3.2.2 Cowpea flour

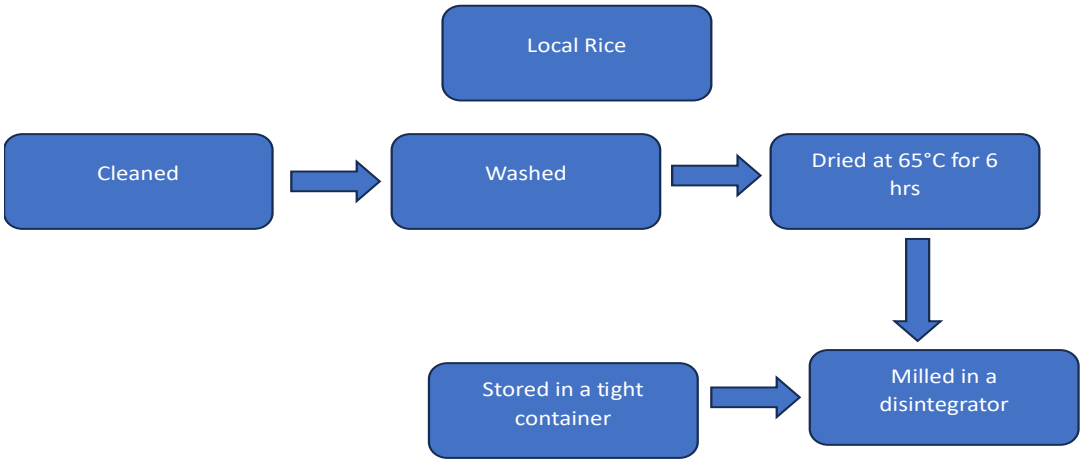
Cowpea flour was prepared using the method described by Phebean et al., (2017). The beans were cleaned and sorted to remove stones and shafts. The cleaned seeds were soaked in water for 3 hours to soften the hull to ease its removal. The hulls were removed by repeated working between the palms leaving behind dehulled seeds. The seeds were dried in an air oven at 60°C for 6 hours. The dried seeds were milled to obtain a fine powder. This was packaged in airtight containers for later use.



3.2.3 Rice flour

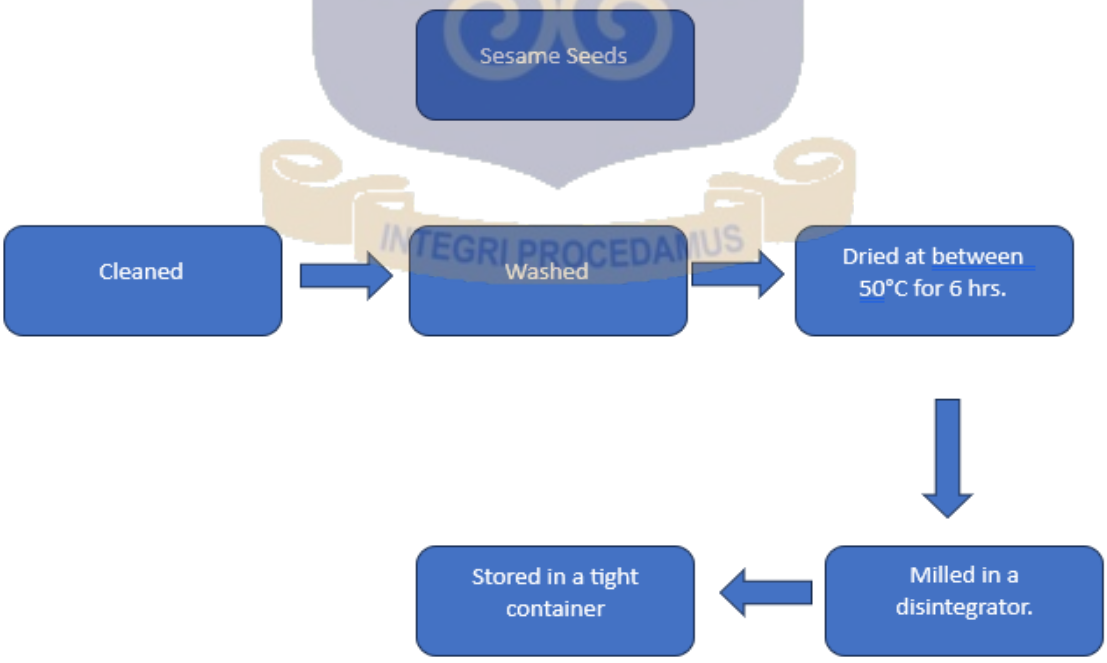
The rice flour was obtained using the method described by Okpala and Egwu (2015). The rice grains were cleaned by manually removing unwanted materials. The rice grains were washed with clean water, soaked in clean water for 1 hour, oven dried at 65°C for 6hrs and milled into powder. Flour was stored in an airtight container for later use.

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3.2.4 Sesame seed flour

The sesame seed flour was obtained using the method described by Ahmed et al. (2020). Sesame seeds were cleaned by handpicking and winnowing to remove foreign matter and then washed with clean water. They were dried in an oven at 50°C for 6 hrs., before being milled to obtain fine powder and then stored in an airtight container for later use.



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3.3 Linear programming

Linear programming (LP) was used to minimize the cost of the final product, subject to defined constraints on the nutrients (carbohydrate, protein, and fat) and the contribution of the ingredients to the total formulation. Constraints were defined on the lower and upper requirements, and on the contribution of each ingredient in terms of percentage. Codes were written using the Python programming language to solve the mathematical problem so as to obtain an optimized formulation. The equation used is as follows:

$$z = \sum_{j}^{n} =_{1} c_j x_j \quad , \qquad \text{Eq.1}$$

Subject to

$$\sum_{j}^{n} =_{1} a_{ij}\, x_j \geq l_i \qquad \text{i=1,2,3……,m} \qquad \text{Eq.2}$$

$$\sum_{j}^{n} =_{1} a_{ij}\, x_j \geq u_i \qquad \text{i=1,2,3……,m} \qquad \text{Eq.3}$$

$$x_j \geq 0 (x\ is\ a\ continous\ variable) \qquad \text{Eq. 4}$$

Z- total cost to be minimized (objective function)

N- total number of food items in the LP analysis

$x_j - portions\ of\ the\ food\ item\ j\ in\ g$

c_j - the cost of food item j per 100g

a_{ij} - amount of nutrient i in food item j

Table 1Hypothesized nutrient content of the flour blend generated through Linear Programing

Nutrients	**Amount (g/100g)**
Carbohydrate	40.36
Protein	13.8
Fats	10.96

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3.4 Process optimization

Response Surface Methodology (RSM) was used to optimize the process, using Minitab 17 Software. The RSM was used to study the effect of the drum drying parameters, namely steam pressure and rotation speed of the drum on the moisture, color, and water absorption capacity, bulk density and welling capacity of the drum dried samples. The ranges for the parameters were steam pressure: 300kPa-500kPa and drum rotation speed: 5rpm-15rpm. The generated RSM combinations for the optimization are as follows:

Table 2 Steam pressure and drum rotation speed combinations

Sample	Steam (Kpa)	Speed (rpm)
CSR 1	300	5
CSR 2	400	15
CSR 3	300	10
CSR 4	400	10
CSR 5	500	5
CSR 6	400	5
CSR 7	500	10
CSR 8	500	15
CSR 9	300	15

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3.5 Proximate analysis

3.5.1 Moisture

Moisture was determined using the oven method (AOAC, 2005). Two grams (2g) of the sample was weighed into a moisture can have known weight and dried in a hot air oven at 105°C for 4hrs. Sample was cooled in desiccators after drying and re-weighed. The moisture content was then calculated as: Moisture content (%) = $\frac{weight\ of\ moisture\ removed}{weight\ of\ sample}$ x 100

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3.5.2 Crude fat

Fat content analysis was carried out as stated by the Association of Official Agricultural Chemists(A0AC) method 960.39 (2000). The Soxhlet method was used for the analysis. Two (2) grams of the sample was weighed and placed into thimbles. The thimbles were placed into a Soxhlet extractor. About 90ml of petroleum ether was poured into a 150ml round bottom flask and the extractor was fixed onto the flasks and the setup was placed on a heating mantle for 3 hours. Excess solvent was evaporated using a vacuum condenser. The flask containing the extracted sample was kept at 80-90℃ until solvent was completely evaporated, and the flask completely dry. The flask containing the extracted fat after drying was allowed to cool in a desiccator and weighed. The percentage of fat was calculated using the formula:

$$\text{Fat } (\%) = \frac{weight\ of\ fat}{weight\ of\ sample} \times 100$$

3.5.3 Crude protein

About 2 g of the sample was weighed into a digestion flask. The sample was digested with 15 ml of concentrated H_2SO_4 and 8g of digestion mixture (K_2SO_4:$CuSO_4$ (8:1)). The digestion flask was swirled in order to mix the contents thoroughly then placed on a heater for 2 hours to start digestion till the mixture becomes clear. The digest was cooled and transferred to a 100ml volumetric flask, and a volume was made up by adding distilled water. About 10 ml of the digest was introduced into a distillation tube with 10ml of 0.5N NaOH gradually added through the same way. Distillation continued for at least 10 minutes and NH_3 produced was collected as NH_4OH 5in a conical flask containing 20ml of 4% boric acid solution with a few drops of modified methylene red indicator. During distillation a yellowish colour appears due to NH_4OH. The distillate was then titrated against standard 0.1N HCL solution till the appearance pink color. A blank was also run through all the steps above. Percent crude protein content of the sample was calculated by using the following formula:

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% Crude protein= 6.25 X %N (correction factor)

$$\%N = \frac{Sample\ titer - blank\ titre \times 100}{1000 \times weight\ of\ sample} \times 100$$

3.5.4 Total ash

About 2 g of the sample was weighed into a conditioned and weighed crucible. The crucible was transferred into a furnace at 600°C and burned until white, grey ash was obtained. The crucible was cooled in a desiccator and reweighed. The percentage ash content was calculated:

$$Ash\ \% = \frac{weight\ of\ ash}{weight\ of\ sample} \times 100$$

3.5.5 Carbohydrate

The carbohydrate content was determined using the difference method. The carbohydrate content was calculated by subtracting the sum of moisture, protein, fat, and ash from 100%.

Carbohydrate (%) =100% - (Moisture (%) + Protein (%) + Fat (%) + Ash (%))

3.5.6 Mineral content

Mineral content was determined using the method of AOAC (2003). Exactly 1g of the sample was transferred into a 75 ml digestion tube, 12 ml of HNO_3 was added, swirled, and placed in a fume cupboard. Digestion was for 2 hours at 150°C. These were samples removed from the digester, cooled for 10 min., and then 4 ml of $HClO_4$ was added to each tube. The mixture was digested for another 90 min. It was removed from the digester, cooled and 100 ml of distilled water was added to each tube. Each tube was stirred vigorously using the vortex mixer and the mineral element of each sample determined using Atomic Absorption Spectrophotometer (Hitachi model 170-10). The concentrations of the minerals were calculated as follows:

MW= $\frac{absorbancy \times dry\ weight \times D}{weight\ of\ sample \times 1000}$, where D = dilution factor of the mineral

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3.5.7 β-carotene content

Beta-carotene content was determined according to the method of Barros, Ferreira, Queiros, Ferreira, and Baptista (2007). One gram of the sample was mixed with 10 ml of acetone: hexane mixture (4:6) and vortexed for 5 min. Then, the mixture was filtered through Whatman no. 1 filter paper and absorbance was measured at 453, 505, and 663 nm. B-carotene content was calculated according to the following equation:

Beta carotene (mg/100 ml) = 0.216 (A663) – 0. 304 (A505) + 0.452 (A453); where A663 = absorbance at 663nm; A505 = absorbance at 505nm and A453 = absorbance at 453nm.

3.6 Physicochemical properties

3.6.1 Total antioxidant activity

The free radical scavenging ability of the extracts against DPPH free radical was evaluated as described as Donkor et. al. (2015). 20ml of extracts were each added to 40ml of 0.004% DPPH methanolic solution and incubated for 60 minutes. After 60 minutes of incubation at room temperature in the dark, the absorbance was measured at 517 nm. A blank sample containing only methanol was used to zero the spectrophotometer. Ascorbic acid was used as standard. Antioxidant activity (I %) was calculated as follows: $I\% = \frac{Abs0 - Abs\ 1}{Abs\ 0} \times 100$; where Abs0 = absorbance of 0.004% DPPH without analyte and Abs1 = absorbance of 0.004% DPPH plus the test compound.

3.6.2 Total Sugars

The total sugars were determined according to AOAC (2005). About 0.5 grams of each sample was weighed into a beaker and 50ml of distilled water was added. Concentrated HCl (0.5 ml) was added to the mixture and placed in a water bath at 70℃ for 10-15 minutes. The sample was cooled and neutralized to pH of 7 using NaOH. The resulting solution was poured into a

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200ml volumetric flask, and the volume was increased with distilled water to the graduated mark. The burette was filled with the resulting solution and titrated with equal volumes of Fehling's solution A and B. A 10ml of Fehling's solution was measured into a 250ml of conical flask and 15ml of sample from burette was added and placed on a heating mantle. 1ml was added per each titration while being heated. A brick-red colour is the expected end point upon the addition of methylene blue indicator. Total sugars (%) = $\frac{converted\ titre \times dilution\ factor}{weight\ of\ sample} \times 100$

3.6.3 pH

The pH of the drum dried product was measured using an electronic pH meter (HANNA, HI 11310) by following the procedure outlined in AOAC 29, 181 (AOAC 15th Edition, 2020).

3.6.4 Color

The color of the flour blend was determined. The color parameters L^*, a^* and b^* of the were measured with a colorimeter (CHORA METER CR-410, Minolta camera Co. Ltd, Osaka, Japan) in triplicates. The L^* values represented lightness (100 = lightness/brightness to 0 = darkness/blackness), a^* represented the extent of green color (in the range from negative=green to positive = redness), b^* quantifies blue color (in the range from negative=blue to positive=yellow). The total color change was estimated as $\Delta E = \sqrt{(\triangle L^2 + \triangle a^2 + \triangle b^2)}$

3.7 Functional properties

3.7.1 Water absorption capacity

Water absorption capacity was determined using methods described by AOAC (2005). About 1.7 g of the sample was transferred into a clean 15 mL centrifuge tube with 10 mL of distilled water and allowed to stand for 30 minutes. The sample was centrifuged at 3000xg for 15 min.

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After centrifugation, the supernatant was decanted, and the weight of the sediment taken to determine the water holding capacity.

$$\text{Water Absorption Capacity (\%)} = \frac{weight\ of\ sample - weight\ of\ water\ retained\ in\ the\ sample}{weight\ of\ sample} \times 100$$

3.7.2 Oil absorption capacity

The procedure described by Niba et al., (2001) was followed. Two (2) grams of each sample was suspended in 10ml of vegetable oil in a centrifugal tube, after which the slurry was shaken on a platform tube rocker for a minute at room temperature and centrifuged at 300rpm for 15 minutes. The supernatant was decanted and discarded.

$$\text{Oil Absorption Capacity (\%)} = \frac{weight\ of\ sample - weight\ of\ oil\ absorbed}{weight\ of\ sample} \times 100$$

3.7.3 Dispersibility

Dispersibility was determined using the method of Adesokan et al. (2023). Three (3) g of the sample was weighed into a 25-mL measuring cylinder and distilled water added to reach a volume of 15 ml. The mixture was stirred vigorously, and particles were allowed to stand for 3 hours, and the percentage volume of settled particles was calculated to determine the percentage dispersibility.

3.7.4 Swelling capacity

The method for the determination of the swelling capacity of the sample was done following the method described by Awuchi et al., (2019). Ten grams (10g) of the sample was weighed into a 100ml graduated cylinder. A 100ml of water was added, mixed thoroughly and allowed to stand. The volume of the sample was read after 1, 5, 10, 15, 30, 45 and 60 minutes. The experiment was repeated using water at 70℃ for each sample.

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3.7.5 Bulk Density

The procedure for the determination of bulk density was according to the method described by Ashraf et al., (2012). Twenty grams (20g) of sample was measured into a 50ml graduated cylinder and lightly tapped on the working bench several times until a constant height was attained. Bulk density = $\frac{weight\ of\ the\ sample\ (g)}{volume\ of\ the\ sample\ (ml)}$

3.7.6 Emulsion capacity and stability

The method used for emulsion capacity and stability followed was as described by Yasumatsu et al., (1972). About 0.5 grams of the sample, 5ml of distilled water and 5 ml of vegetable oil was mixed in a calibrated centrifuge tube. The emulsion was subjected to centrifugation at 3000×g for 15 minutes. The emulsion capacity was calculated as the ratio of emulsion layer's height to that of the mixture and multiplied by 100.

To determine the emulsion stability, the emulsion was heated at 80℃ for 30 minutes in a water bath, cooled for 15 minutes under running tap water. It was then centrifuged at 3000×g for 15 minutes. The emulsion stability was estimated as the ratio of the height of emulsion layer to the total height of the mixture.

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3.7.7 Foaming capacity and stability

The foam capacity (FC) and foam stability (FS) were determined as described by Chandra et. al (2014). About 1.0 g sample was added to 50 mL distilled water at 30±2 °C in a graduated cylinder. The suspension was mixed and shaken for 5 min to foam. The volume of foam at 30s after whipping was expressed as foam capacity. The volume of foam was recorded 1 hour after whipping to determine foam stability as per percent of initial foam volume. Foaming capacity (%) = $\frac{Volume\ of\ foam\ AW}{volume\ of\ foam\ BW} \times 100$; where, AW=after whipping, and BW=before whipping

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3.7.8 Least gelation concentration

The least gelation concentration (LGC) was evaluated using the method of Chandra et. al., (2014). The flour dispersions of 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 30 % (w/v) were prepared in 5 mL distilled water and heated at 90 °C for 1 h in a water bath. The contents were cooled under tap water and kept for 4 h at 25°C. The least gelation concentration was determined as that concentration when the sample from inverted tube did not slip.

3.7.9 Pasting properties

The pasting properties of samples were measured using Brabender Viscograph-E Measurement & Control Systems (Barbender GmbH & Co. KG, Germany). About 40g moisture-free sample (db) was suspended in 420ml distilled water to prepare slurry in a large beaker. The suspension of the starch/flour was mixed thoroughly and poured into the bowl of the Barbender Viscograph-E. The test was then run at a speed of seventy-five (75) revolution per minute with a measuring range of 700 cmg. The temperature of 50°c with heating analysis was programed to commence the measurement at a temperature of 50°c with heating at the rate of 3°c/min up to a temperature of 90°c. The temperatures of the samples were held constant for fifteen (15) minutes and then cooled at the rate of 3°C/min to a temperature of 55°C. This temperature was also held constant for fifteen minutes. The parameters to be recorded from the curve included: the time, temperature and viscosity at the beginning of gelatinization, maximum viscosity, start of the holding period, start of the cooling period, end of the cooling period, and at the end of the final holding period as well as breakdown and set back viscosities.

3.8 Preparation of the instant meal using drum drying technology

The OFSP flour, cowpea flour, sesame flour and rice flour were mixed to form a flour blend. The four blend was to be drum dried at different steam pressures and drum rotation speeds

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combination (Table 2). This led to having 9 different samples. Each sample was made into a slurry with water (1:2; flour: water) to obtain a slurry of the solids concentration before drum drying. Drying of the slurry was done by manually dispersing onto a drum dryer (ANDRITZ Gouda drum dryer, E5/5). For each sample, before placing the slurry on the drum surface, the temperature was raised by controlling the steam pressure and the drum rotation speed controlled. The steam pressure and drum rotation speed combination (Table 2) were used for each sample. Each drum has a scraper/knife to extract the dry product. The dried product was collected in a receiver after scraping. The dried flakes were allowed to cool then crushed into a powder and packaged into ziplock bags for further analysis (Annan et al. 2023).

3.9 Microbial analysis

Microbial analysis was conducted on the "instant meal" samples as reported by Quansah et al. (2018). Instant meal samples weighing 10 grams each was homogenized in 90 ml of sterile distilled water to give a 10^{-1} dilution. The population of the coliforms, yeast and mould were estimated by transferring 1ml of the diluent to a sterile petri dish and approximately 20ml of media that is Plate count agar, MacConkey agar, and Potato dextrose agar, for bacteria and yeast and mold were poured into the plates. The plates were rotated for uniform distribution of the inoculums. After solidification of the media, plates were inverted and incubated at 35°C for 24 hours for total bacteria and 48 hours for total coliforms, and 25°C for yeast and mold.

3.10 Consumer acceptance test

A survey of potential consumers was conducted to determine their interest in the instant meal from orange fleshed sweet potato, cowpea, sesame seeds and rice. For this test 108 participants both males and females were recruited from the University of Ghana. Participants were screened for allergies to sesame, legumes, and sweet potato prior to inclusion. Informed consent

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was obtained from all participants before the study. Each sample was reconstituted with boiling water at a flour-to-water ratio of 1:4 (w/v), allowed to stand for 2 minutes, cooled to approximately 55°C, and served in standardized plastic cups coded with three-digit random numbers. The panelists were given the sample to taste, and they were asked to rate the qualities of each sample on a nine-point hedonic scale: 9= like extremely, 8= like very much, 7= like moderately, 6= like slightly, 5= neither like nor dislike, 4= dislike slightly, 3= dislike moderately, 2= dislike very much, and 1= dislike extremely. The sensory qualities of the product which were assessed were appearance, aroma, flavour, mouthfeel, aftertaste and overall liking. The panelists expressed their dislikes and likes for each sample. The frequencies and percentages of similar remarks made for each sample (likes and dislikes) were counted and collated for the descriptive data. The relationship between the sensory attributes, physicochemical and functional properties of the instant meal was conducted using principal component analysis in XLSTAT 2024.

3.11 Data and statistical analysis

Analysis of variance ANOVA (one-way) was used to assess the significance of differences between the functional properties and proximate properties for the various drumdried samples of the instant meal. A post-hoc test was done to determine if there are any significant differences between the means. All statistical analyses was done using Minitab 2019, Microsoft Excel 365, R v.4.2.1 and XLSTAT.

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CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Formulation of flour blend

From Table 3, the flour blend formulated from OFSP, cowpea, sesame seed, and rice showed the deliberate effort to balance the macronutrients while enhancing the overall nutritional profile of the instant meal. The contribution of specific nutrients from the different ingredients made the formulation suitable for addressing various dietary needs. The OFSP is rich in carbohydrate and beta-carotene which is a precursor for vitamin A. The inclusion of 20% OFSP enhanced the formulation's carbohydrate content and micronutrient profile. Osei-Kwarteng et al., (2023) stated that OFSP has great potential for reducing vitamin A deficiency especially in low- and middle-income countries. The inclusion of cowpea (45%) in the formulation contributed to meeting the protein needs of an individual which is essential for muscle repair and building, immune support and overall body maintenance (Boukar et al., 2019). Sesame seeds (20.29%) are included in the formulation supplied lipid and minerals. Sesame seeds are high in polyunsaturated fatty acids, especially omega 9 and omega 6 fatty acids which supports cardiovascular health (Boukar et. al, 2019). They are also high in minerals such as calcium which is responsible for bone and teeth maintenance. The inclusion of rice (14.71%) provides an easily digestible source of carbohydrate and helps in enhancing the texture and sensory appeal of the formulation, making the final product more palatable.

Table 3 Formulation of flour blend

Ingredient	Percent (%)
OFSP	20
Cowpea	45
Sesame Seed	20.29
Rice	14.71

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4.2. Nutritional composition of flour blend

4.2.1 Protein content

From Table 4, the protein content of 25.49g per 100g is significantly high. According to the Dietary Reference Intakes (DRIs), adults aged 15-50 require 46-56g of protein day, and one third of the daily requirement is approximately 15.33g for women and 18.67 for men. Thus, the flour blend can provide more than one third of the daily requirement of an individual, making it an excellent protein source especially for those who rely on plant proteins. Cowpea is also known to be an excellent protein-rich source with a satisfactory amino acids profile, that complements cereals like rice (Boukar et.al, 2019).

4.2.2 Fat content

The flour blend had a fat content of 12.9g per 100g (Table 4). The fat content of the flour blend was mainly contributed by the sesame seeds. The recommended daily intake of fat is averagely 44g, and one third of this is approximately 14.67g. Thus, the flour blend value almost met the requirement, providing a significant amount of fat including polyunsaturated fatty acids such omega 6 and omega 9 fatty acids which are beneficial for heart health (Dossa et al., 2021). The fat content also contributes to the enhancement of the bio accessibility of beta-carotene from OFSP during digestion (Bechoff &Dhuique-Mayer, 2020).

4.2.3 Ash content

The high ash content of 2.14g per 100g indicates that the flour blend has moderate mineral content (Table 4). Ash content refers to the total mineral content of the flour blend after combustion. Sesame seeds is reported to be high in minerals such as calcium and phosphorous and cowpea which has iron and magnesium, and this can be associated with the high ash content of the flour blend (Adiamo et al., 2022; Gonçalves et al., 2020). The ash content is consistent

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with published values for similar OFSP-legume composite flour in the paper by Osei-Kwarteng et al., (2023).

4.2.4 Total carbohydrates (by difference)

The carbohydrate content of the flour blend constitutes more than half of its composition (58.66g per 100g). The recommended minimum carbohydrate intake is 130g per day, with one-third being approximately 43.33g. Thus, the flour blend exceeded the daily requirement of providing sufficient energy. Osei-Kwarteng et al. (2023), highlighted OFSP's role as an excellent source of carbohydrate with additional benefits like beta-carotene.

Table 4 Nutritional composition of flour blend

Nutrient	Amount (per 100g)
Protein	25.49±0.89g
Fat	12.9±0.03g
Carbohydrate	58.66±0.57g
Ash	2.41±0.14g
Calcium	0.94±0.02g
Phosphorous	1.23±0.06g
Potassium	0.24±0.00g
Magnesium	0.4±0.00g
Iron	0.11±0.00g
β-carotene	373.33±6.5µg

4.2.5 Mineral content of flour blend

From Table 4, the calcium content of the flour blend was 0.94g per 100g which is equivalent to 940 mg. The recommended daily intake (RDI) of calcium is 1000 mg per day and one third of this is approximately 333 mg (Oria et al., 2019) and the flour blend meets more than one

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third of the required intake. Calcium is responsible for bone and teeth formation and function (Mani et al., 2020). The inclusion of sesame seeds contributed a substantial amount of calcium to the flour blend (Adiamo et al., 2022).

The phosphorous content of the flour blend was 1.23g per 100g (Table 4) which is approximately 1,230 mg. Phosphorous is essential for bone formation and energy metabolism. The RDI for phosphorous is approximately 700 mg/day and one-third of the requirement is approximately 233 mg (Oria et al., 2019). The phosphorous content of the flour blend exceeds one-third of the requirement and also the average daily recommended intake. High phosphorous content of some foods is attributable to the presence of organic phosphates, esters and compounds such as phytic acid. Phytic acid is the major form of phosphorus in plants comprising 1-5% weight in cereals, legumes, oil seeds and nuts (Lampen et al., 2026).

Potassium is vital for regulating blood pressure and maintaining cardiovascular health. The recommended daily intake of potassium is approximately 4700 mg per day, with one-third being 1,567mg (Oria et al., 2019). The flour blend contained 240 mg of potassium per 100g (Table 4) which is relatively lower than the recommended daily intake.

Magnesium plays an important role in nerve function, muscle maintenance and the regulation of blood sugar (Mani et al., 2020). The RDI for magnesium is approximately 400 mg per day for males and 310 mg per day for females with one-third being approximately 113 mg for men and 103mg for women (Oria et al., 2019). The flour blend contained 0.4g of magnesium (Table 4) which is approximately 400 mg per 100g. This meets more than one-third of the daily requirement. Magnesium is beneficial for maintaining cardiovascular health and bone health (Mani et al., 2020).

The recommended daily allowance (RDA) for iron is approximately 18 mg per day for females and 8 mg per day for males. One-third of the requirement is 6 mg for females and 2.67 mg for males (Mani et al., 2020). The flour blend provided 0.11g (Table 4) which is

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approximately 110mg and this far exceeds the one third requirement. Iron is crucial for preventing anaemia, particularly in women of reproductive age. The high levels of iron reported may be due to the presence of substantial amount of non-heme mostly found in legumes, whole grains and oil seeds (López-Moreno et al., 2025).

4.2.6 Beta-carotene content

Beta-carotene is a precursor for vitamin A, which is essential for vision and immune function deficiency. The recommended daily intake for beta-carotene is 900 µg per day for men and 700µg per day for females. One third of the daily requirement is approximately 300 µg and 233 µg, respectively. From Table 4, the beta-carotene content of the flour blend was 373.33µg which covers more than one-third of the requirement. Beta-carotene is particularly important in the prevention of vitamin A deficiency since it is a precursor (Osei-Kwarteng et al., 2023).

4.3 Physicochemical properties of flour blend

4.3.1 Moisture content

The moisture content of the flour blend was 4.36% (Table 5) which suggest low water activity, and this is critical for preventing microbial growth and extending the shelf-life of the product (Mugo et al., 2021). Low moisture content improves product stability during storage and reduces spoilage thereby ensuring long-term storage at room temperature. For flours, moisture content below 10% is recommended for shelf stable products. Low moisture content is important for products in high humid environments where susceptibility to mould proliferation is high.

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4.3.2 pH

From Table 5, a pH value of 6.13 signifies that the flour blend is slightly acidic. A neutral or slightly acidic pH is favourable for sensory quality and product stability. It helps to maintain the color, flavor and nutritional integrity of the product. According to Ocheme et al. (2018), flour with pH between 5.5 and 6.5 shows favourable properties and good compatibility with food additives and preservatives.

Table 5 Physico-chemical properties of flour blend

Properties	Results
Moisture (%)	4.36±0.38
pH	6.13±0.01
Colour	
L	85.3±0.42
**a*	-2.17±0.25
**b*	33.48±0.38
Δ*E*	32.03±0.48
Total Sugars (%)	65.41±2.29
Antioxidant activity (%)	52.33±0.26

***L** denotes lightness, ***a** denotes the range between red and green, while ***b** signifies the span between yellow and blue and **ΔE** (total color difference)*

4.3.3 Colour

The colour parameters provides an understanding into the sensory and visual appeal of the flour blend. From Table 5, the high *L** value of 85.3 indicated that the flour was light in colour, which is visually appealing, and this is critical for consumer acceptance. The *b** value indicates a yellow hue obtained from the beta-carotene in the OFSP, and the negative *a** shows hints of green hue. Osei-Kwarteng et al. (2023) found that beta-carotene from OFSP contributed significantly to the yellow color of the flour, which consumers may associate with the

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abundance of nutrients in the product. A higher b^* value is associated with the presence of carotenoids.

4.3.4 Total sugar content

From Table 5, the high total sugar content (65.41%) of the flour blend is suggested to be primarily contributed by the OFSP and rice. The sugars contribute to the sweetness and energy content of the product. Mwasaru et al. (2020) reported that high sugar content in composite flours can enhance the flavor profile and consumer acceptance of the product. According to Osei-Kwarteng et al., (2023), the sugars found in sweet potatoes have been reported to have anti-diabetic properties and this is in relation to the high total sugar content.

4.3.5 Antioxidant activity

From Table 5, the high antioxidant activity (52.33%) of the flour blend is an important benefit. By neutralizing free radicals in the body, antioxidants lower the risk of chronic diseases such as cancer and cardiovascular disease (Liang et al., 2022). The antioxidant activity is associated with beta-carotene in the OFSP and the phenolic compounds in cowpea and sesame seeds. Liang et al. (2022) stated that the antioxidant content of plant-based foods can reduce oxidative stress hence improve the health of individuals.

4.4 Functional properties of flour blend

4.4.1 Dispersibility

The dispersibility describes how easily the flour diffuses in water. A value of 9.60 (Table 6) indicates high dispersibility, which is important for instant meals that require easy rehydration. Higher dispersibility ensures that the flour mixes well with liquids to form a homogeneous mixture. According to Adeoti et al. (2020), the dispersibility of a flour blend is an important

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property for instant meal formulations, as higher dispersibility eases preparation. Flours with good dispersibility have low clumping, making them perfect for instant meals.

4.4.2 Bulk density

Bulk density is the weight of the flour per unit volume. The value of 0.59g/ml (Table 6) indicates that the flour blend had a moderate bulk density. Bulk density affects packaging, transportation and storage. A high bulk density is desirable for reducing packaging space and storage cost, while a lower bulk density may result in a lighter product that is easier to consume. Bulk density affects the mouthfeel of the products and is important in the packaging process. High bulk density is often associated with high nutritional content, which is advantageous for instant meals (Ogunniyi et al., 2019).

4.4.3 Water absorption capacity

Water absorption capacity (WAC) is a measure of the flour's ability to absorb and retain water, which is important for rehydration of instant products. The high-water absorption capacity of 96.22% (Table 6) shows that the flour can absorb almost its entire weight of water, which is important for improving the texture and volume of the rehydrated product. Adeola and Ohizua (2018) stated that a higher WAC is important in flour blends used for instant meals as it helps to improve the palatability and consistency of the rehydrated product.

4.4.4 Oil absorption capacity

Oil absorption capacity (OAC) measures the flour's ability to bind with oil which affects mouthfeel and flavour retention. The moderately high OAC (79.39%) (Table 6) suggests that the flour can retain flavours and contribute to a rich texture. High OAC is associated with better flavour retention and improved palatability in the food product (Adeleke et al., 2019). Sesame

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seeds contributed significantly to the OAC due to their fat content which helps create a smooth rich texture of the flour blend.

4.4.5 Foaming capacity and stability

Foaming capacity and stability are important in flour blends used for instant products such as shakes and smoothies (Adeoti et al., 2020). The foaming capacity of 40% and stability of 20% (Table 6) suggest that the flour blend can form and maintain the foam produced to an extent. The proteins of cowpea contribute significantly to the foaming capacity, while the high fat content of sesame seeds may reduce the stability (Adeoti et al., (2020).

Table 6 Functional properties of flour blend

Functional Properties	Results
Dispersibility (ml/cm³)	9.60±0.17
Bulk Density (g/cm³)	0.59±0.00
Water absorption (%)	96.22±2.57
Oil absorption (%)	79.39±4.52
Foaming capacity (%)	40.00±0.00
Foaming Stability (%)	20.00±0.00
Emulsion capacity (%)	18.16±4.54
Emulsion stability (%)	4.54±0.00
Least Gelation Conc. (%)	2.00

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4.4.6 Emulsion capacity and stability

Emulsion capacity is the ability to stabilize oil-water mixtures whilst emulsion stability is the capacity of the emulsion to remain intact over time. The emulsion capacity of 18.16% (Table 6) indicates a moderate ability to form emulsion but the low emulsion stability of 4.54% (Table 6) shows the flour blend may not maintain emulsions for a long period of time. A study by Karuna et al., (2019) found that emulsion stability and capacity are important for instant food formulation that requires smooth texture and good flavour dispersion. The relatively low stability may be attributed to the composition of fat and protein in the flour blend. To enhance the emulsion stability of the product, the addition of natural emulsifiers such as lecithin may improve the stability of the flour blend.

4.4.7 Least gelation concentration

Least gelation concentration (LGC) refers to the minimum concentration of flour needed to form a gel when mixed with water. The LGC was 2.00% (Table 6) suggesting that the flour has good gelation property. This is advantageous for instant breakfast products that need to thicken when rehydrated or cooked. According to Ocheme et al., (2018), a low LGC is important for products such as instant breakfast meals as it ensures that the product thickens quickly with little flour use. The high protein content of the cowpea and rice starch are likely contributors to the flour's gelation properties.

4.4.8 Swelling capacity

At room temperature (25°C), the flour blend's swelling capacity peaked around 32 ml before declining and stabilizing around 29 ml after 20 minutes (Figure 1). The rapid hydration at the beginning can be attributed to starch from the OFSP and rice, which absorb water quickly at low temperature. Starch in these ingredients, particularly amylose component, hydrate and

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contribute to the initial volume increase, which is an important property for instant breakfast meal formulations aimed at fast rehydration and consumption (Kumar et. al., 2020). The decline in swelling capacity over time may be due to saturation as the starch granules reach their maximum water holding capacity without further expansion. This behaviour of the flour blend at 25°C supports the formulation's potential for cold preparation, offering flexibility for consumers who prefer instant meals without heating.

The initial swelling capacity of 43 ml at 70°C (Figure 1) is noticeably higher, showing the thermal gelatinization of starches especially those from rice and sweet potatoes. Ogundele et al., (2019), stated that gelatinization is an irreversible swelling process where the starch granules absorb water and rapture under heat which results in an increase in volume. This method works well for hot water preparations because it gives the product a more cohesive texture which appeals to consumers who want a filling breakfast. However, the swelling capacity decreases and stabilizes at 38ml when there was a continuous high temperature. This could be attributed to the rapturing of the swollen starch granules which releases the amylose and amylopectin into the water, and thus, results in a reduction in volume (Asare et al., 2021).

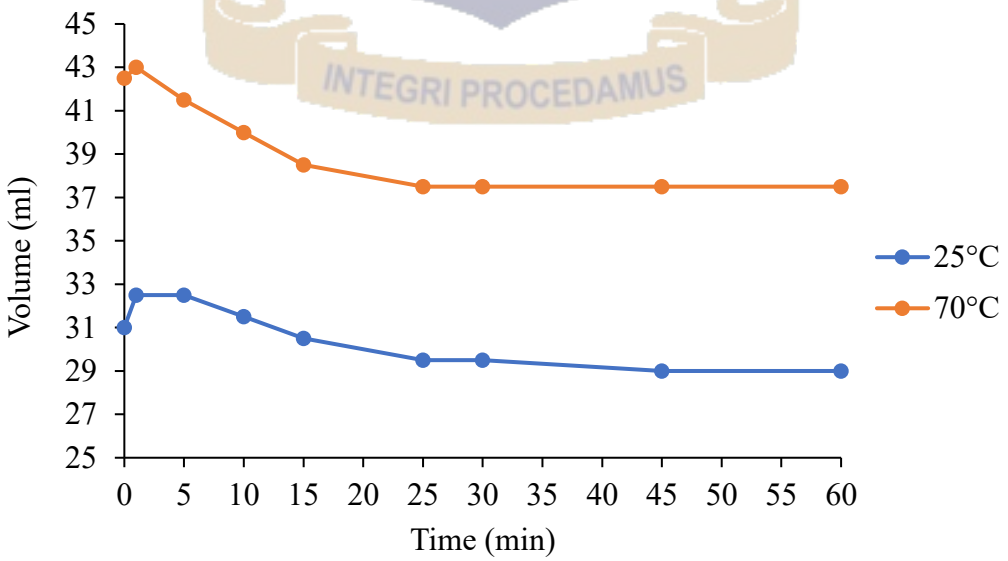


Figure 1. The swelling capacity of flour blend at 25°C and 70°C

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4.4.9 Pasting properties of flour blend

Table 7 shows the flour blend's pasting properties, which provides important information on the behaviour of the flour blend during heating and cooling. In evaluating the functional quality of a flour blend, evaluating the pasting properties is important particularly for instant breakfast meals. These properties have an effect on the texture, mouthfeel and consistency of the final product, which is important for effective rehydration and consumer acceptance.

The peak viscosity of the flour blend was recorded to be 165±1.41 BU (Table 7). The peak viscosity shows the water holding capacity of starch granules during heating, showing the maximum swelling capacity before they rapture. This property is important in instant breakfast meals, as high peak viscosity can contribute to thicker and satisfying consistency when the product is rehydrated. The main ingredients of the flour blend (OFSP, cowpea, and rice) are high in starch with different levels of amylose and amylopectin, which influences swelling and peak viscosity (Toa et al., 2020). Oil and protein content of the sesame seeds can indirectly 9affect the viscosity of the flour blend which can also interfere with starch gelatinization.

The peak time indicates the time for the flour blend to reach peak viscosity. For instant meals, a relatively short peak time is preferred as it translates to faster preparation time. However, the peak time of 14 minutes (Table 7) is a moderate peak time, which shows that while the blend requires some time for proper gelatinization, it is still within an acceptable range for an instant meal product. This behavior of the flour blend might appeal to consumers looking for convenient, nutritious meals that can be prepared with a little waiting time (Wu et al., 2018).

The viscosity at 95°C (160.5±0.70 BU) and the decrease to 140±2.12 BU after 30 minutes (Table 7) at this temperature reflects the stability of the starch granules when held at high temperatures. This decline in viscosity indicates shear-thinning behaviour of the starch paste under continuous heating. The moderate breakdown seen suggests a product that would

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not thin out excessively upon reconstitution, hence maintaining a desirable consistency during consumption. This stability is beneficial as it ensures the product does not thin out after preparation (Niba et al., 2019).

The viscosity of 179.5±5.35 BU, when cooled to 50°C showed a slight decrease to 178.5±2.12 BU after 30 minutes at the same temperature (Table 7). This reflects the re-association of starch molecules especially amylose during cooling, resulting in gel formation. This is desirable for products that are expected to thicken upon cooling, improving the texture and mouthfeel of the product. This suggests that the blend will maintain a thick consistency even when not consumed immediately, which is advantageous for instant meals that may be prepared in advance (Adebowale et al., 2021).

Maximum setback viscosity of 38±1.41 BU (Table 7) is suggestive of the retrogradation tendency of the flour blend. Retrogradation is the re-association of gelatinized starch molecules upon cooling. Retrogradation can influence the texture and shelf stability of the product. While high setback viscosity can lead to a firmer gel, it may also lead to syneresis upon storage. The moderate setback viscosity indicates that the product will achieve desirable thickness (Gani et al., 2020).

Table 7 Pasting properties of flour blend

Parameter	Results
Peak Viscosity (BU)	165±1.41
Peak Time (min)	14 ±0.00
Viscosity at 95°C (BU)	160.5±0.70
Viscosity after 30 min at 95°C (BU)	140±2.12
Viscosity at 50°C (BU)	179.5±3.53
Viscosity after 30 min at 50°C (BU)	178.5±2.12
Maximum setback viscosity (BU)	38±1.41

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4.5 Moisture content of drum dried product

Table 8 shows that higher steam pressures (400 - 500 Kpa) combined with higher drum rotation speeds (10 - 15 rpm) is likely to reduce the moisture content more effectively than lower pressures and speeds. For instance, CSR 5 dried at 500 Kpa and 5rpm, had the lowest moisture content of 1.31%, while CSR 9, dried at 300Kpa and 5 rpm had the highest moisture content of 2.65% (Table 8). The variations in the moisture can be linked to the higher heat input at increased steam pressures, which causes a more rapid evaporation of water from the products. Moreover, faster drum speeds can lead to thinner film formation, quicker drying and reduction of the moisture content further (Abioye et al., 2019). Low moisture content of instant food products is crucial for extended shelf life and reduced microbial growth risk. Oyeyinka et al., (2020), stated that moisture content below 3% is important for maintaining the stability of instant breakfast meals as they reduce the activity of water-dependent enzymatic and microbial degradation. All the samples had moisture content below 3%, indicating adequate drying. Moisture content also affects the rehydration rate of the drum dried product, which is critical for consumer appeal (Asaolu et al., 2021). Lower moisture content seen in product CSR 5 (1.31%) and CSR 6 (1.41%) (Table 8), will likely result in faster rehydration due to a more porous and brittle structure formed during the drying process. Slightly higher moisture content of the products such as CSR 1 and CSR 3 may require slightly longer rehydration times and provide a softer texture upon rehydration, which appeals to some consumers.

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Table 8 Moisture content of drum dried product

Sample	Steam (Kpa)	Speed (rpm)	Moisture (%)
CSR 1	300	5	2.39 ± 0.01^{ab}
CSR 2	400	15	2.03 ± 0.01^{bc}
CSR 3	300	10	2.38 ± 0.01^{ab}
CSR 4	400	10	1.99 ± 0.27^{bcd}
CSR 5	500	5	1.31 ± 0.08^{e}
CSR 6	400	5	1.41 ± 0.04^{de}
CSR 7	500	10	1.48 ± 0.17^{cde}
CSR 8	500	15	1.96 ± 0.29^{bcd}
CSR 9	300	15	2.65 ± 0.07^{a}

** Values are means ± standard deviations of triplicate determinations. Values in the same column with different superscript letters are significantly different ($p \leq 0.05$)*

4.7 Colour of drum dried products

Colour is essential in food product development as they influence consumer perception. The *L** value represent the lightness which varied significantly ranging from 67.29 to 80.89 (Table 9). Product CSR 9 (300Kpa, 15rpm) had the highest lightness value of 80.86, while CSR 5 (500Kpa, 5 rpm) recorded the lowest (67.29) (Table 9). Higher lightness (*L**) value indicates that the products may retain more of the appealing colour which is typical of OFSP. Lower lightness (*L**) values for the samples processed at higher steam pressures may be due to increased Maillard reactions or caramelization at elevated temperatures, causing darker colouration (Nde et al., 2020). Maintaining high lightness value could be desirable for consumer acceptance as it gives the impression of freshness.

The *a** values range from -0.86 to 7.30 (Table 9), with positive values indicating a red hue and the negative values indicating a green hue. Higher positive values in CSR 5 suggests

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a stronger red hue, due to higher steam pressure during processing (Kolawale et al., 2020). Products with negative (a^*) values show a slight shift towards green indicating minimal processing impact on natural colours of the samples. The b^* values range from 25.22 to 28.89 (Table 9), with most of the products showing a positive yellow hue. The higher b^* values reflect a strong yellow colour which is good for products containing OFSP as it is associated with the natural colour of the OFSP. The low b^* values indicate that higher processing conditions can cause a loss in the yellow colour. The ΔE value measures the overall colour difference among the products. From Table 9, a more distinct colour difference between the products (ranging from 37.84 to 26.81) was observed. According to Sanusi & Jimoh, (2019), this change reflects shifts in the redness, yellowness and other colour components of the flour, which could influence consumer perception and product quality. These changes may be due to variations in processing methods and parameters.

Table 9 Colour of drum dried products

Sample	Steam (Kpa)	Speed (rpm)	*L*	*a**	*b**	Δ*E*
CSR 1	300	5	74.66±0.27^{d}	3.70±0.03^{c}	28.89±0.36^{a}	33.03±0.16^{b}
CSR 2	400	15	79.85±0.06^{b}	1.74±0.02^{e}	27.99±0.33^{bc}	29.19±0.31^{c}
CSR 3	300	10	80.36±0.06^{ab}	0.58±0.04^{f}	27.47±0.48^{c}	27.51±1.07^{d}
CSR 4	400	10	75.25±0.07^{d}	3.14±0.06^{d}	28.37±0.06^{ab}	32.21±0.11^{b}
CSR 5	500	5	67.29±0.08^{f}	7.30±0.06^{a}	28.14±0.21^{abc}	37.84±0.63^{a}
CSR 6	400	5	69.17±0.26^{e}	6.39±0.09^{b}	28.21±0.16^{abc}	36.53±0.06^{a}
CSR 7	500	10	76.66±0.21^{c}	3.13±0.07^{d}	28.59±0.11^{ab}	31.55±0.21^{b}
CSR 8	500	15	79.82±0.15^{b}	-0.65±0.27^{g}	25.22±0.09^{e}	26.81±0.16^{d}
CSR 9	300	15	80.86±0.06^{a}	-0.86±0.04^{h}	26.43±0.18^{d}	27.29±0.18^{d}

*The value **L** signifies brightness, ***a** denotes the range between red and green, while ***b** signifies the span between yellow and blue and **ΔE** (total color difference). * Values are means ± standard deviations of triplicate determinations. Values in the same column with different superscript letters are significantly different ($p \leq 0.05$).*

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4.8 Functional properties of drum dried products

4.8.1 Water Absorption capacity

Water absorption capacity (WAC) is essential in food formulations especially for instant meals, as it affects texture, viscosity and the ability to rehydrate quickly (Adeola & Ohizua, 2018). High WAC values are often desirable in instant products, as they improve the mouthfeel upon rehydration. From Table 10, there was no significant difference in the WAC of the products. The high WAC suggested an improved ability to absorb water and possibly yielding a desirable texture in the final product. Higher WAC may be due to the breakdown of the starch granules, as high steam pressures change the starch structures making them more water-accessible (Elhaw et al., 2021).

4.8.2 Bulk density

From Table 10, there was no significant difference among the bulk densities of the drum dried products. Bulk density is important for packaging and storage. A lower bulk density results in a lighter product with increased rehydration properties, which is beneficial for instant breakfast meals. From Table 10, the products showed moderate bulk densities. The consistency in the bulk density values suggests that the drum drying conditions such as steam pressure and speed may have a limited effect on this property (Zhou et al., 2018). Moderate bulk density can be observed in drum dried products, particularly when higher drying temperatures are involved. High temperature treatment reduces particle compaction, leading to a more porous structure (Zhou et al., 2018).

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Table 10 Functional properties of drum dried products

Sample	Steam (Kpa)	Speed (rpm)	Water Absorption capacity (%)	Bulk Density (g/cm^3)
CSR 1	300	5	381.80±4.12^a	0.61±0.04^a
CSR 2	400	15	373.30±23.2^a	0.63±0.01^a
CSR 3	300	10	353.70±32.9^a	0.63±0.01^a
CSR 4	400	10	339.00±19.9^a	0.63±0.01^a
CSR 5	500	5	303.60±52.3^a	0.61±0.03^a
CSR 6	400	5	330.70±50.2^a	0.63±0.01^a
CSR 7	500	10	382.49±12.7^a	0.63±0.01^a
CSR 8	500	15	366.10±21.2^a	0.57±0.02^a
CSR 9	300	15	317.30±39.7^a	0.57±0.02^a

** Values are means ± standard deviations of triplicate determinations. Values in the same column with different superscript letters are significantly different ($p \leq 0.05$)*

4.8.3 Swelling capacity

The swelling capacity of the drum dried products at 25°C (Figure 2) showed significant variation. CSR 1 and CSR 2 demonstrated higher swelling capacities, stabilizing around 35 to 45ml, which suggests higher water uptake (Figure 2a). CSR 3, CSR 4, CSR 5 (Figure 2a) and CSR 8 (Figure 2b) exhibited moderate swelling capacity stabilizing between 30 to 40 ml. CSR 6, CSR 7 and CSR 9 demonstrated low swelling capacities (Figure 2b). This suggests that higher processing conditions (e.g., steam pressure and drum speed) may reduce the swelling capacity due to potential structural breakdown in the starches, reducing their water retention capacity (Adebowale et al., 2014).

At 70°C (Figure 3), all the samples demonstrated an increase in swelling capacity which stabilized over time. The trend was similar to the observations at 25°C, with CSR 1, CSR 2, CSR 7, showing the highest swelling capacity at around 55 to 60ml. The increased temperature enhanced starch gelatinization among the products, leading to a higher water absorption (Hoover & Ratnayake, 2020). CSR 3, CSR 8 and CSR 9 displayed moderate swelling, steadying between 45 to 55ml. CSR 6, CSR 8 and CSR 9 (Figure 3b) showed lower swelling

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capacities, as a result of the impact of their processing conditions which may have degraded the structural components necessary for water binding.

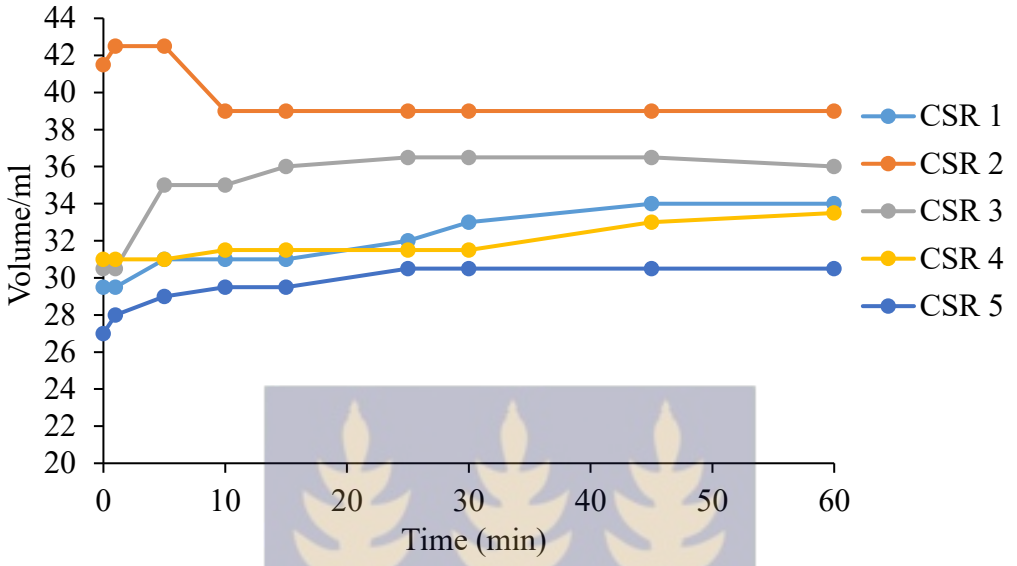


Figure 2a: Swelling capacities of drum dried samples at 25°C

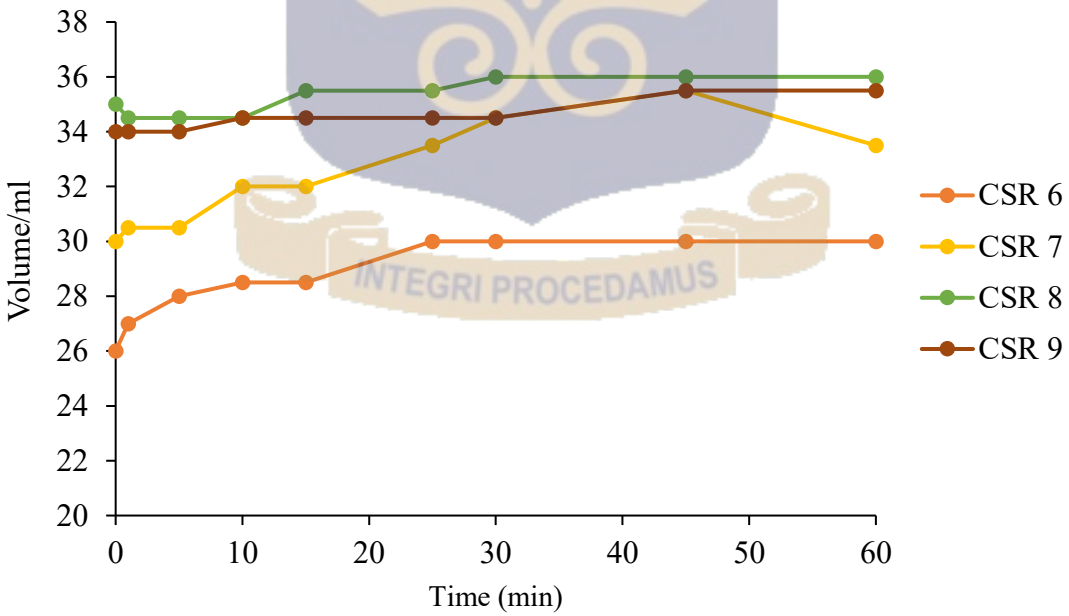


Figure 2b: Swelling capacities of drum dried samples at 25°C

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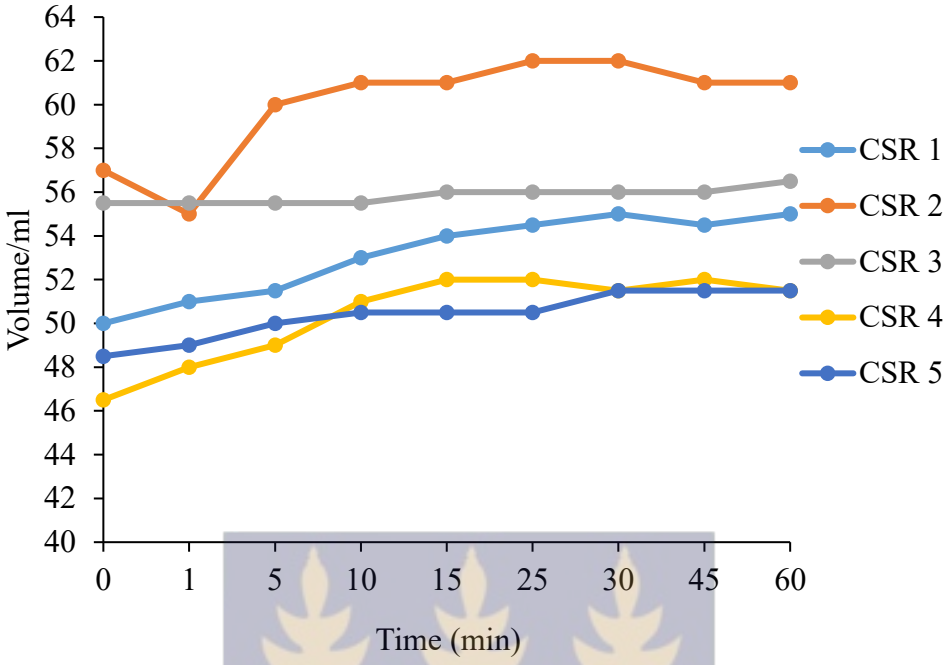


Figure 3a Swelling capacities of drum dried samples at 70°C

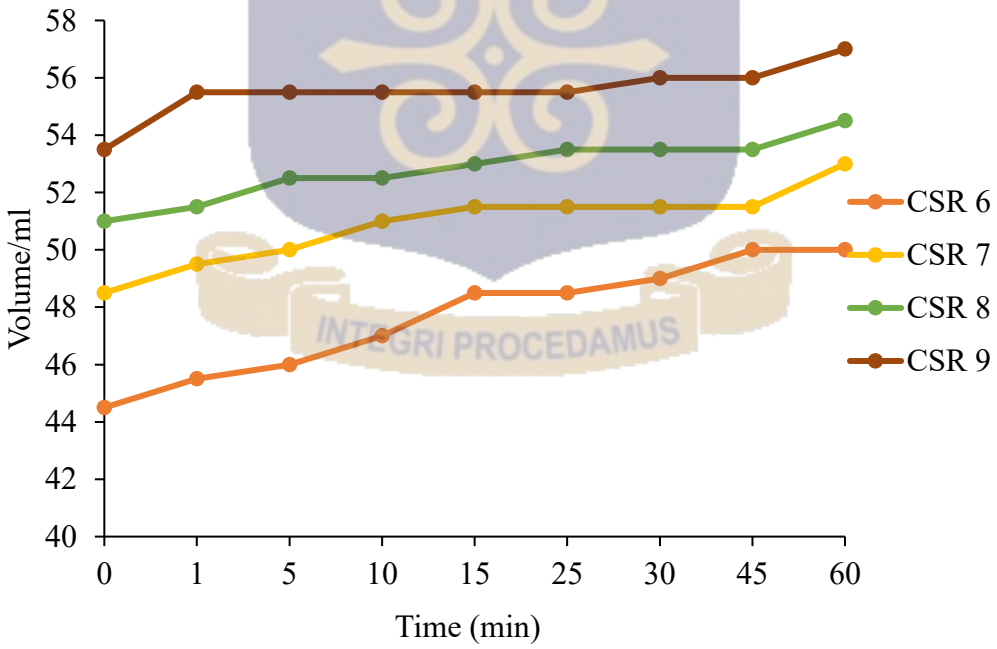


Figure 3b Swelling capacities of drum dried samples at 70°C

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4.9 Microbial analysis of the drum dried products

The microbial load analysis of the drum dried products (Table 11) provides insights into the safety and stability of the instant breakfast products. The microorganisms tested were yeast and mould, coliform, and total bacteria, which are essential for food safety, as higher microbial counts can lead to spoilage, loss in quality and also pose health risk. These counts also reflect the effectiveness of the drying process in reducing the microorganisms.

Yeast and mould count ranged from 0.00 log CFU/g to 2.79 log CFU/g (Table 11). CSR 3 and CSR 7 showed the lowest yeast and mould count. This is as a result of the lower moisture content of the products. It has been reported that drum drying at the right temperature can lower yeast and mould count by creating an unfavorable environment for their growth (Mukisa et al., 2019). Although CSR 2 and CSR 4 had a higher yeast and mold count, they are still within the acceptable limits for dry food products. These higher counts may be due to variations in the processing and storage conditions which can affect the microbial load (Oduro-Yeboah et al., 2022).

Coliform count suggest that the products have been potentially contaminated or handled in an unsanitary environment (Nzamwita et al.,2020). It ranged from 0.00 log CFU/g to 1.74 log CFU/g (Table 11). CSR 3, CSR 5 and CSR 7 showed no coliform counts, which highlights efficient processing and handling practices. The absence of coliforms suggests a low risk of contamination, which is important in instant meal production. CSR 2 exhibited the highest coliform count indicating that improvements in post-processing handling could reduce the microbial load.

The total plate count shows a measure of the samples' total microbial load. The values ranged from 1.00 to 3.10 log CFU/g (Table 11). The lowest total aerobic plate count (CSR 8) recorded can be said to be due to the processing conditions which limited the growth of the sensory quality of the product. CSR 4 had the highest total plate count, but this was still within

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the acceptable limits, suggesting that certain adjustments in the processing conditions might improve microbial reduction (Oduro-Yeboah et al., 2022).

Table 11 Microbial load of drum dried products

Sample	Yeast/Mold (log CFU/g)	Coliform (log CFU/g)	Total Plate count (log CFU/g)
CSR 1	2.57	1.48	2.92
CSR 2	2.79	1.74	2.97
CSR 3	1.00	0.00	1.48
CSR 4	2.62	1.40	3.10
CSR 5	2.49	0.00	2.62
CSR 6	2.61	1.18	1.70
CSR 7	0.00	0.00	2.79
CSR 8	1.30	1.30	1.00
CSR 9	2.46	1.48	2.52

4.10 Sensory evaluation of drum dried products

The sensory evaluation of the drum dried products (Table 12) provides insights into the consumer's acceptability of product attributes, including appearance, aroma, mouthfeel, aftertaste, and overall liking. Understanding sensory qualities is essential in formulating a breakfast meal that meets consumer expectation, and these sensory attributes directly impact product acceptance.

4.10.1 Appearance

Appearance is a visual characteristic of the product. It can include elements such as colour, shape, size and overall presentation. Differences in appearance can affect consumer preference and expectations. The scores for appearance varied from 5.25 to 7.14 (Table 12), with CSR 2 and CSR 8 receiving the highest score. A high appearance score is beneficial as it indicates that

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consumers are likely to find the product visually appealing. Studies have shown that colour and visual appeal can significantly influence a consumer's choice of food products, especially instant meals (Anuouye et al., 2021). CSR 5 had the lowest appearance rating and may be due to the processing conditions, which likely affected visual appeal.

4.10.2 Aroma

Aroma assesses the smell of the sample. The scores ranged from 5.98 to 7.25 (Table 12), with CSR 2 and CSR 8 scoring the highest. Aroma is an important sensory attribute as it influences the flavor perception and overall acceptability. The aroma of the product is said to be from the ingredients used. The higher aroma score for CSR 2 and CSR 8 is consistent with studies indicating that appealing aroma of food products enhances consumer satisfaction (Oduro-Yeboah et al., 2022).

4.10.3 Flavour

Flavour scores were high, with CSR 8 having the highest of 6.67 and CSR 5 with the lowest score of 5.52 (Table 12). The success of an instant meal is mostly dependent on the flavour, as it directly affects consumer choice. CSR 8's high flavour score may be attributed to the optimal proportions of the ingredients and processing parameters, which enhanced the products' palatability. Studies have suggested that the interaction between sweet potatoes and legumes can yield desirable flavours when well-balanced (Okafor et al., 2020).

4.10.4 Mouthfeel

Mouthfeel scores were greatest for CSR 8 (6.98) and lowest for (5.43) (Table 12). A satisfying mouthfeel contributes to a positive eating experience, especially in instant meals where texture is an important property. Drum drying has an effect on the mouthfeel as it can affect texture

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and consistency. CSR 8's high mouthfeel score suggests a smoother and more palatable texture. Studies have shown that a smooth texture for instant meal products is generally preferred (Anuouye et al., 2021).

4.10.5 Aftertaste

Aftertaste scores showed CSR 8 having the highest score (6.68) and CSR 5 having the lowest score (5.15) (Table 12). According to Mukisa et al (2019), aftertaste is important because it affects the consumers' tendency to rebuy. CSR 8's favorable aftertaste is indicative of a balanced blend without overpowering or bitter flavours, which is preferred in breakfast meals. CSR 5 had a low aftertaste score which may be caused by a bitter or burnt flavour, that might have resulted from the processing conditions.

4.10.6 Overall liking

The overall liking scores reflect the combined influence of all the sensory attributes, with CSR 8 scoring the highest (6.72) and CSR 5 the lowest (5.50) (Table 12). CSR 8's high score for overall liking indicated that this product aligns well with consumer expectation across the sensory attributes. Adjustments can be made to enhance CSR 5's sensory qualities, such as optimizing the processing conditions, which could potentially increase its overall acceptance. Generally, product CSR 8 appeared to offer the most balanced sensory profile among the different products.

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Table 12 Sensory evaluation scores of drum dried products

Sample	Appearance	Aroma	Flavour	Mouthfeel	Aftertaste	Overall liking
CSR 1	5.90±1.93^{cd}	6.78±1.55^{ab}	6.09±1.76^{ab}	6.05±1.80^{ab}	6.00±2.01^{ab}	6.34±1.77^{ab}
CSR 2	7.14±1.50^{a}	7.25±1.36^{a}	6.31±1.99^{ab}	6.58±1.82^{a}	5.98±1.78^{ab}	6.63±1.66^{a}
CSR 3	6.73±1.73^{abc}	6.83±1.66^{ab}	5.98±1.88^{ab}	6.39±1.72^{ab}	6.03±1.78^{ab}	6.53±1.77^{ab}
CSR 4	6.70±1.73^{abc}	6.97±1.44^{a}	6.32±1.94^{ab}	6.49±1.69^{a}	6.09±2.07^{ab}	6.53±1.81^{ab}
CSR 5	5.25±2.02^{d}	5.98±2.14^{b}	5.25±2.08^{b}	5.43±2.30^{b}	5.15±2.15^{b}	5.50±1.90^{b}
CSR 6	5.95±2.16^{bcd}	6.62±1.63^{ab}	5.95±2.01^{ab}	6.32±1.82^{ab}	6.20±1.24^{ab}	6.17±1.88^{ab}
CSR 7	6.95±1.57^{ab}	7.18±1.47^{a}	6.05±1.87^{ab}	6.45±1.89^{ab}	5.72±2.12^{ab}	6.22±1.72^{ab}
CSR 8	7.05±1.56^{a}	7.22±1.19^{a}	6.57±1.63^{a}	6.98±1.53^{a}	6.68±1.63^{a}	6.72±1.64^{a}
CSR 9	6.51±1.87^{abc}	6.73±1.57^{ab}	6.14±1.99^{ab}	6.64±1.56^{a}	5.73±2.07^{ab}	6.10±2.11^{ab}

** Values are means ± standard deviations of triplicate determinations. Values in the same column with different superscript letters are significantly different ($p \leq 0.05$)*

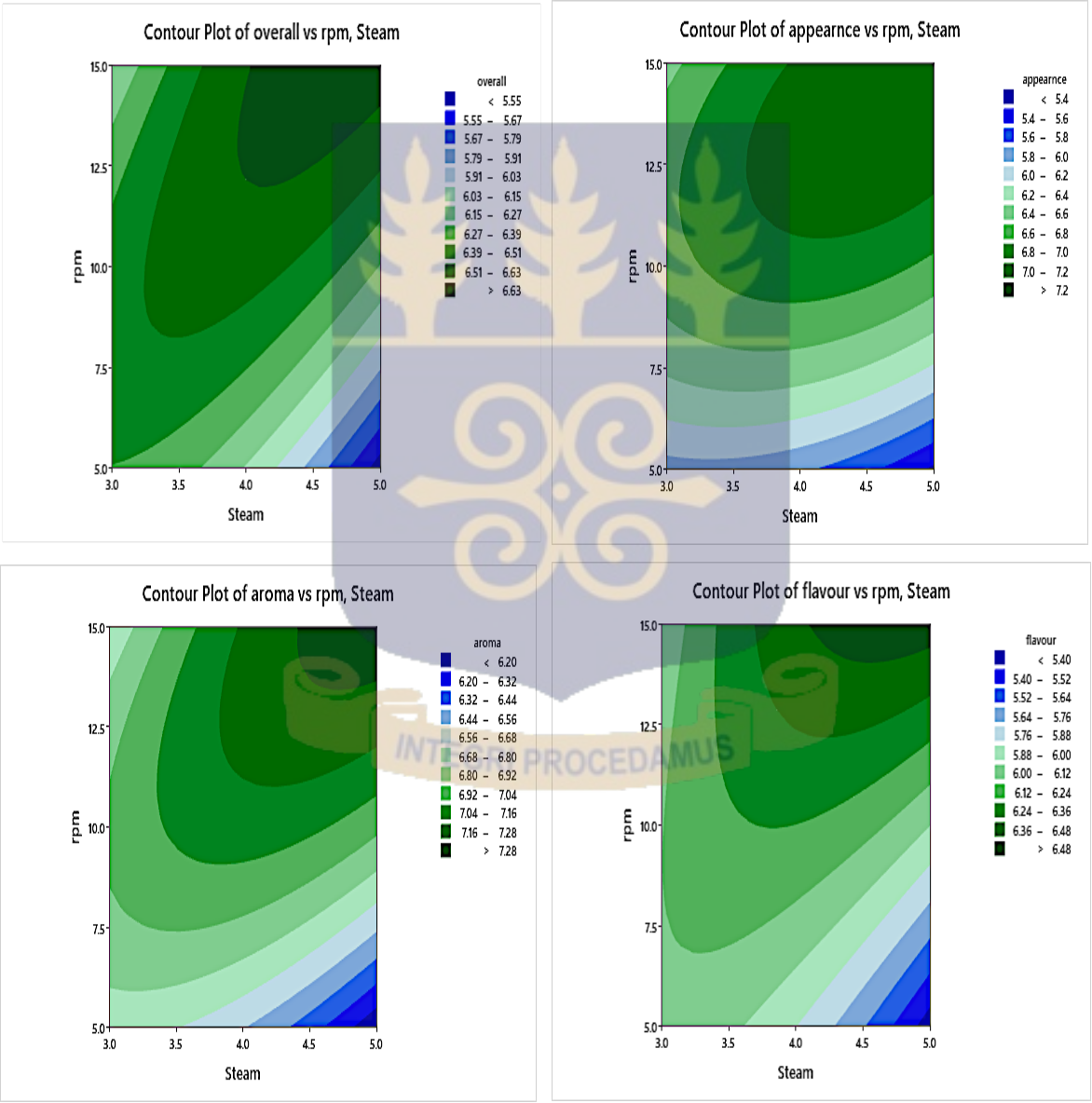
4.11 Optimization of drum drying parameters

The contour plots in Figure 4 shows the influence of steam pressure and drum speed on the individual sensory attributes (Wang et al., 2022). The contour plots for the sensory attributes showed that high steam pressures combined with moderate to high drum speed enhanced all the attributes. The findings highlight the need to carefully balance steam pressure and drum speed during the drum drying process to optimize the sensory attributes of the product. From the contour plot for overall acceptability (Figure 4), the intersection of the high steam pressure and drum speed, aligned with CSR 8's processing parameters which scored the highest overall liking.

The overlaid contour plot in Figure 5 provides a combined view of the impact of steam pressure and drum speed on the sensory attributes of drum dried products. The overlaid contour plots demonstrate how the processing parameters affect the sensory attributes simultaneously,

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which is essential for determining optimal conditions for consumer preference. According to the plot (Figure 4.5), moderate to high steam pressures (around 400 KPa to 500 Kpa) and moderate to high drum speeds (10rpm to 15rpm) were where the sensory attributes showed the maximum scores. This means that processing conditions from moderate to high are ideal for maximizing the sensory appeal of the final product (Dong et al. 2019).



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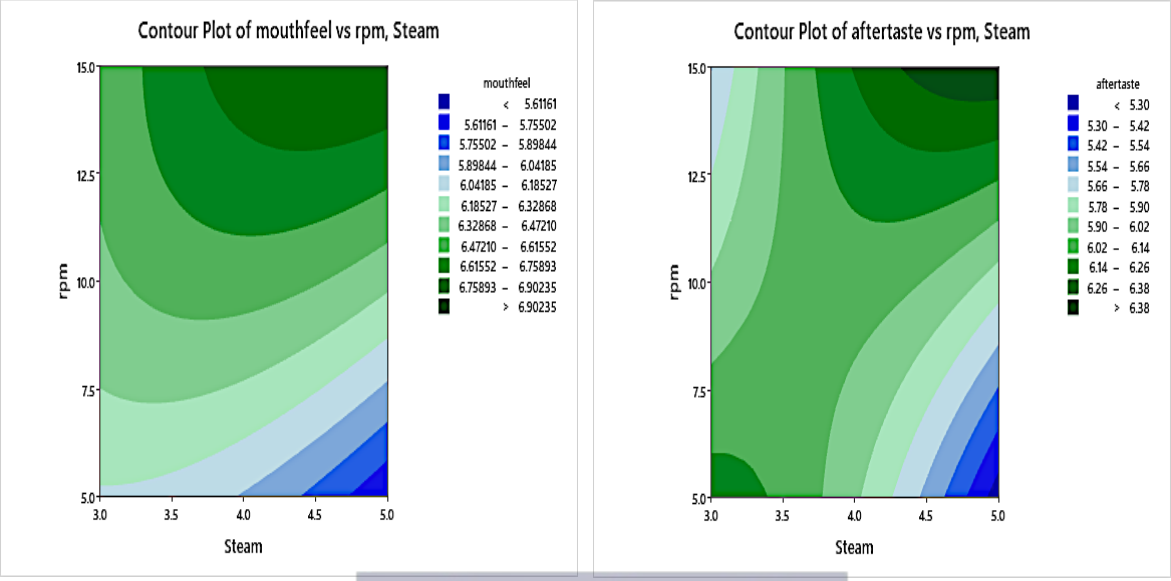


Figure 4 Contour plots of the sensory attributes of the instant meal as significantly affected (<0.05) by the process parameters.

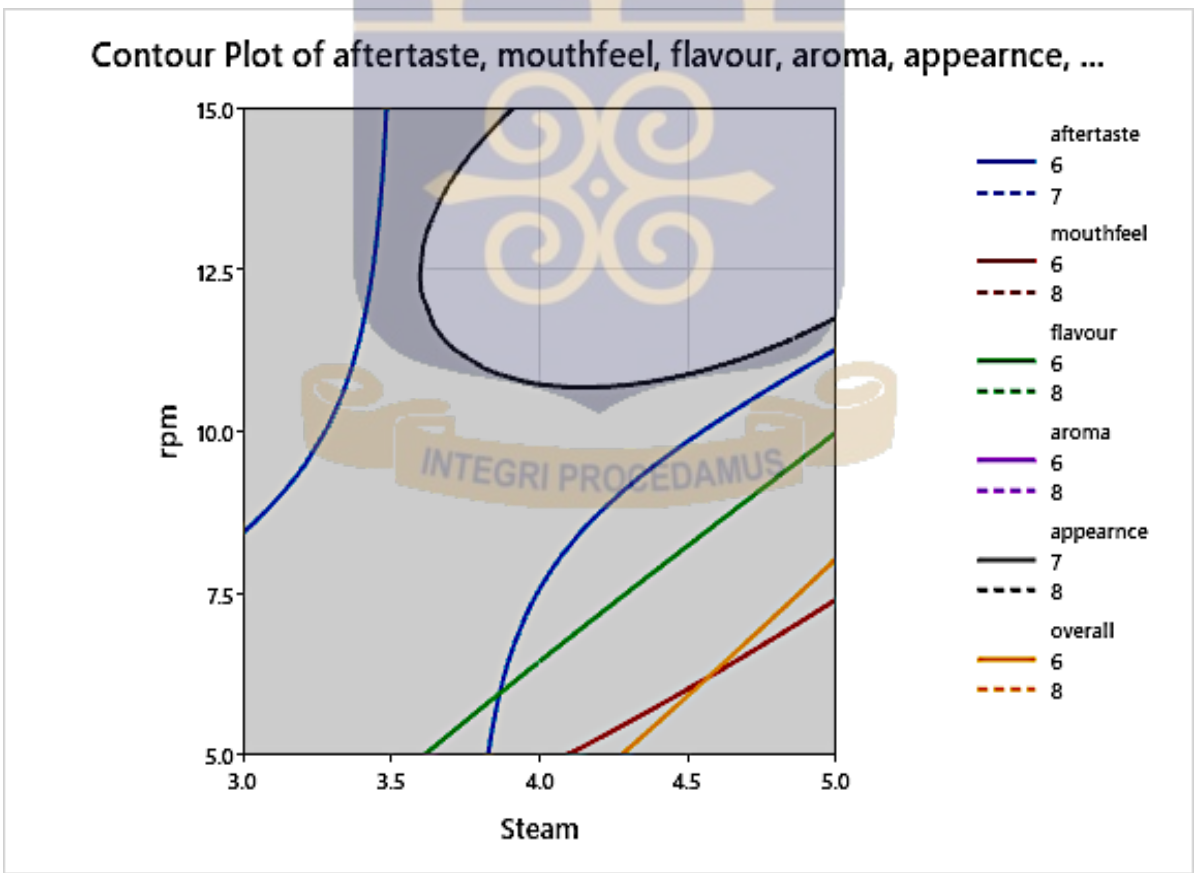


Figure 5 Overlaid plot of the contour plots of the sensory attributes to the steam pressure and drum speed

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4.12 Principal component analysis

The principal component analysis (PCA) biplot in Figure 6 visualizes the relationships between the physicochemical, functional and sensory properties of the drum dried products. PCA explained 81.05% of the total variances of the data. This dimensional reduction allows for an exploration of how the samples' properties relate to their sensory attributes, helping to identify optimal formulations.

Products with the highest score in aroma are likely to have high scores in the other sensory attributes as shown in the PCA biplot (Figure 6) which suggests a positive correlation between the sensory attributes that are clustered to the right on the F1 axis (Figure 6). This finding is consistent with studies by Martinez et al., (2020), which found that aroma and flavour are major factors that influence consumer preference in choosing breakfast cereals.

The functional properties, WAC and bulk density, are positioned on the top right quadrant, opposite moisture content, which is positioned at the lower right quadrant. This spacial distribution indicates that products with high moisture content tend to have low bulk density and water absorption capacity. A study by Ali et al. (2021), showed a similar trend between moisture content and bulk density in drum dried products as higher moisture generally reduces the density and the ability to absorb water. The results indicate that balancing moisture content, bulk density and water absorption capacity is essential for achieving optimal sensory qualities in the instant breakfast meal. This analysis provides a foundation for fine-tuning processing parameters to enhance product quality and consumer acceptance.

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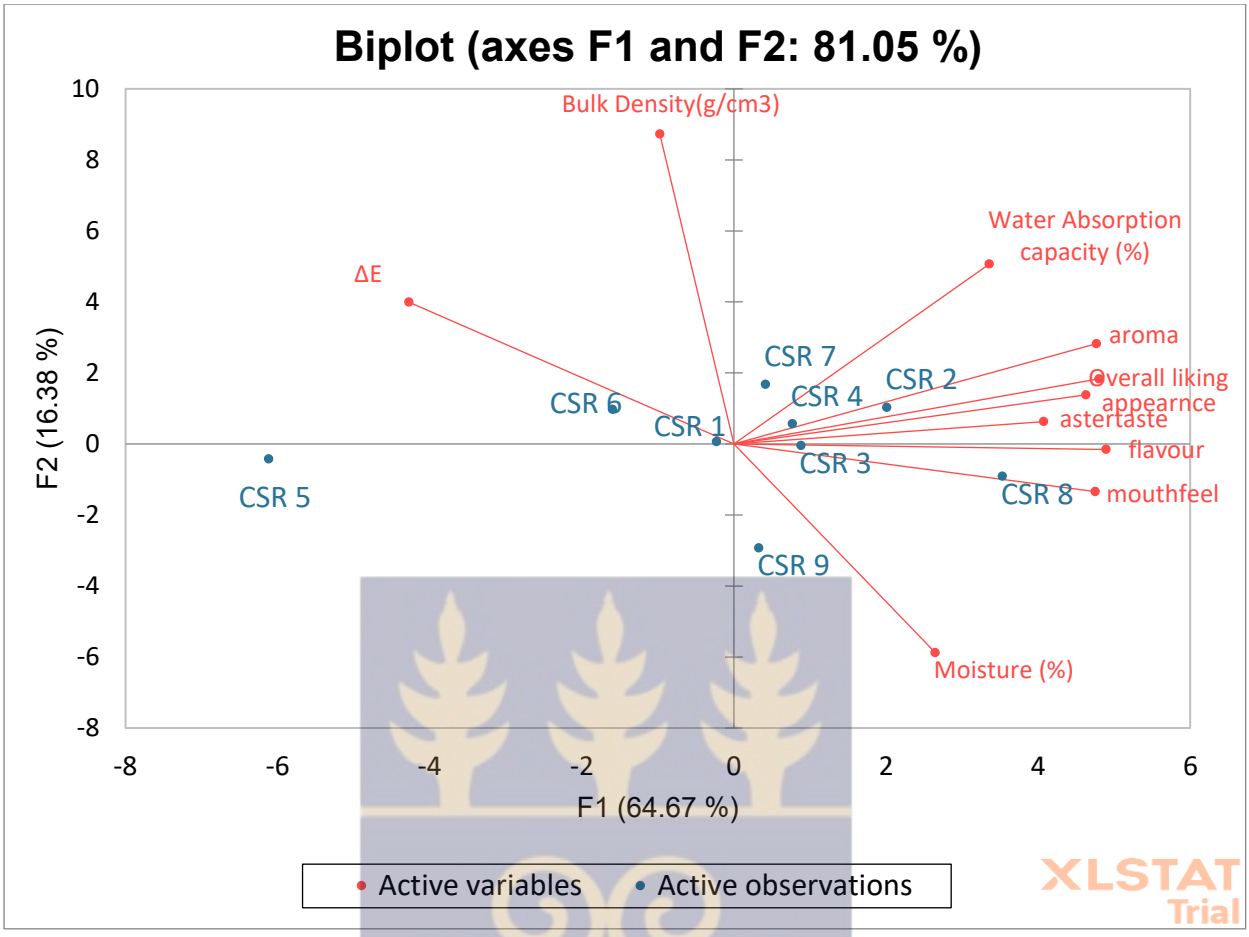


Figure 6 PCA biplot with the physicochemical and functional properties of the drum dried together with the sensory scores of the attributes of the products.

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CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The formulation and optimization of an instant breakfast meal from Orange Fleshed Sweet Potato (OFSP), cowpea, sesame seeds and rice presents a substitute to imported cereals, addressing the issues of food security, nutritional adequacy and economic sustainability in Ghana. The combination of these local ingredients resulted in a blend that met all defined macronutrient constraints while minimizing cost, demonstrating that intentional formulation using LP can simultaneously achieve nutritional adequacy and economic efficiency — a combination directly relevant to Ghana's food security and cereal import substitution objectives. This study demonstrated that the optimized flour blend enriched with beta carotene and antioxidant, had a favorable nutrient profile which can contribute to overall health benefits such as vitamin A deficiency prevention, immune support and cardiovascular health.

The functional properties, including water and oil absorption, bulk density, dispersibility and gelation capacity, showed that the blend is well suited for instant products, particularly those that need rehydration. The drum drying process with optimized parameters of steam pressure and drum rotation speed resulted in a product with low moisture content, extended shelf life and high consumer acceptability. The sensory evaluation scores suggested that the formulation was appealing in terms of flavour, aroma, mouthfeel and appearance, with high consumer preference, particularly for products dried at moderate to high steam pressure and drum speed. The use of linear programing and response surface methodology showed a balance in ingredient proportions and processing conditions, achieving a product that is nutritious, affordable and meets consumer expectations. This formulation serves as a practical alternative for imported cereals, promoting the use of locally grown crops like OFSP, rice,

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sesame seeds and cowpeas and thus not only supporting the Ghanaian economy but also improving food and nutrition security.

5.2 Recommendation

- Nutritional analysis could be done on the drum dried flour blend and be compared to other commercially sold instant products on the market.
- Future studies could explore alternative processing methods, such as freeze-drying and eco-friendly packaging, to enhance the products' shelf life and environmental sustainability.
- Additionally, investigating the inclusion of natural emulsifiers could improve the product's emulsion stability.
- Further modifications could be made to the formulation to cater to specific dietary needs, such as low glycemic index options for diabetic consumers or increased fiber content for weight management. This would widen the product's appeal across various consumer segments.
- Other nutrient dense local ingredients could be explored to further enhance the nutritional profile and market value of the product.

INTEGRI PROCEDAMUS

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