PROXIMATE COMPOSITION AND FORMULATION OF COMPLEMENTARY FOOD FROM SOYBEAN GROUNDNUT AND CRAYFISH BLENDS

BY

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BENIN CITY.

JUNE, 2026

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A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF MICROBIOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF PSOTGRADUATE DIPLOMA (PGD) DEGREE IN MICROBIOLOGY, UNIVERSITY OF BENIN, BENIN CITY.

JUNE, 2026

CERTIFICATION

This is to certify that this project work was carried out by IFASOGIE OSASOGIE in the Department of Microbiology, Faculty of Life Sciences, University of Benin, Benin City under my supervision.

______________________ ____________________

PROF .S.E. OMONIGHO DATE

(Project Supervisor)

______________________ ____________________

PROF .E.O. IGBINOSA DATE

(Head of Department)

DEDICATION

This project work is dedicated to God Almighty, for His grace, mercy, and strength throughout this academic journey. I am truly grateful.

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First and foremost, all glory and honour be to Almighty God for His boundless grace, mercy, and strength throughout this academic journey. His guidance has been my anchor, and I am grateful for seeing me through every step of this endeavour.

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ABSTRACT

Malnutrition among infants and young children remains a major public health challenge in Nigeria and many developing countries due to dependence on traditional cereal-based complementary foods with low protein, energy and micronutrient contents. This study developed and evaluated nutrient-dense complementary food formulations from locally available soybean, groundnut, and crayfish as affordable alternatives to traditional weaning foods. Three formulations were prepared: Sample A (70:20:10), Sample B (60:30:10), and Sample C (50:40:10), alongside a commercial complementary food as control. The formulations were evaluated for microbiological quality, proximate composition, functional properties, and sensory attributes. Microbiological analysis of raw ingredients showed total heterotrophic bacterial counts ranging from 11.00 ± 2.83 $\times 10^5$ cfu/g in crayfish to 23.50 ± 7.78 $\times 10^5$ cfu/g in groundnut, while no Enterobacteriaceae were detected before processing. Following processing, heterotrophic bacterial counts decreased to 0.90 ± 0.28 $\times 10^5$–1.35 ± 0.35 $\times 10^5$ cfu/g. Bacterial isolates identified included Staphylococcus aureus (26.67%), Escherichia coli (20.00%), Salmonella spp. (16.67%), Enterobacter sp. (16.67%), Bacillus subtilis (13.33%), and Shigella sp. (6.67%). Proximate analysis revealed low moisture content (2.48–4.46%), crude fat ranging from 29.90–32.97%, and protein values of 15.30–22.53%, with Sample A recording the highest protein content. Functional properties showed acceptable bulk density (1.14–1.29 g/ml), dispersibility (58–70%), and water absorption capacity (0.63–0.92). Sensory evaluation indicated that Sample B had the highest acceptability among the formulated blends, although the control sample recorded superior scores across sensory parameters. This findings indicate that soybean–groundnut–crayfish blends are nutritionally improved, affordable, and culturally acceptable complementary foods with potential to reduce protein-energy malnutrition in Nigeria. Further studies on micronutrient composition, shelf-life stability, and growth performance are recommended.

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Complementary feeding is essential for the optimal growth and development of infants and young children, particularly from six months of age when exclusive breastfeeding alone no longer meets their increasing nutritional needs (Lutter et al., 2021). The World Health Organization (WHO) defines complementary foods as any nutrient-containing foods or liquids other than breast milk offered to infants to satisfy their evolving energy and nutrient requirements (WHO, 2003). In many low- and middle-income countries, including Nigeria, traditional complementary foods are primarily cereal-based porridges such as maize pap (ogi), sorghum, or millet gruels (Akinsola et al., 2017). These staples are often characterized by low nutrient density, poor protein quality, high bulk viscosity, and limited micronutrient bioavailability, which contribute substantially to the high burden of protein-energy malnutrition (PEM), stunting, wasting, micronutrient deficiencies, and impaired cognitive development (Onofiok and Nnanyelugo, 1998; Abeshu et al., 2016; Ekong et al., 2022).

Protein-energy malnutrition remains a major public health issue in sub-Saharan Africa, where suboptimal complementary feeding practices exacerbate undernutrition among children aged 6–23 months. Cereal-dominated diets frequently lack adequate levels of essential amino acids (particularly lysine and sulphur-containing amino acids), iron, zinc, calcium, and vitamin A. This nutritional inadequacy leads to growth faltering, weakened immune responses, and increased susceptibility to infections (Issaka et al., 2015; Ekong et al., 2022). To overcome these limitations, researchers have focused on the development of improved complementary food formulations using locally available, nutrient-dense ingredients that provide nutritional complementarity.

Soybean (*Glycine max*), groundnut (*Arachis hypogaea*), and crayfish (*Procambarus clarkii* or *Macrobrachium* spp.) have emerged as promising components for such blends. Soybean is valued for its high protein content (approximately 35–40%), balanced essential amino acid profile, dietary fibre, isoflavones, and minerals. Groundnut contributes high-quality lipids, protein (25–30%), and energy density, while crayfish, an affordable animal-source food abundant in Nigeria, supplies high-quality complete protein rich in methionine and lysine, along with bioavailable minerals such as calcium, zinc, iron, and the antioxidant astaxanthin (Ibironke et al., 2014; Adegbusi et al., 2022; Adegbusi et al., 2023).

Empirical studies have demonstrated the nutritional advantages of these blends. Omueti et al. (2009) evaluated the functional properties of complementary diets (Propalm and Prowena) formulated from blends of soybean, groundnut, and crayfish, reporting improvements in water absorption capacity, swelling index, and sensory attributes suitable for infant feeding. Adegbusi et al. (2022) formulated complementary foods from Nigerian yellow maize, soybean, and crayfish (e.g., maize-soybean-crayfish at 80:10:10% w/w) and found that the inclusion of 10% crayfish significantly enhanced protein content (up to higher protein energy percent), ash, sulphur amino acids, iron, zinc, and calcium levels while reducing antinutritional factors compared to maize-only or maize-soybean blends.

Further research by Adegbusi et al. (2023) assessed the effects of these formulated blends on growth performance and physiological status in Sprague Dawley rats. The maize-soybean-crayfish diet resulted in significantly higher body weight gain, improved protein efficiency ratio, better haematological parameters (e.g., haemoglobin and red blood cell counts), and no adverse effects on organ health, confirming the safety and nutritional efficacy of crayfish incorporation. Similar findings were reported in studies evaluating blends with millet, soybean, groundnut, and crayfish, where protein levels exceeded those of some commercial products, with enhanced mineral contents and acceptable sensory properties (Okereke, 2025; Okpo, various).

Improved processing methods are critical for maximizing the benefits of these formulations. Techniques such as soaking, roasting, germination, fermentation, and milling effectively reduce antinutritional factors (phytates, tannins, trypsin inhibitors), improve digestibility, lower viscosity, and enhance nutrient bioavailability and shelf stability (Omueti et al., 2009; various processing studies). Fermentation, in particular, has been shown to decrease pH, increase titratable acidity, and improve overall nutritional profiles in cereal-legume blends (Ijarotimi and Keshinro, 2012, as referenced in related works). Fortification with vitamin C or strategic blending further augments iron absorption and hematopoietic potential (Adegbusi et al., 2024).

These locally sourced formulations address key challenges of affordability, cultural acceptability, and accessibility in Nigeria, where commercial fortified foods like Cerelac remain expensive for many households. They align with Codex Alimentarius guidelines on formulated complementary foods for older infants and young children, promoting sustainable solutions to malnutrition (Codex Alimentarius Commission, 2013, cited in Adegbusi et al., 2023).

Despite these advancements, gaps remain in the systematic optimization of blend ratios, large-scale processing technologies, microbial safety, long-term shelf-life, and human efficacy trials. Variability in raw material quality and consumer acceptance also requires continued investigation. This study seeks to build upon existing evidence by developing and optimizing improved methods for the formulation of high-quality complementary foods from soybean, groundnut, and crayfish blends, contributing to efforts to combat child malnutrition in Nigeria and similar contexts.

1.2 Statement of the Problem

Traditional complementary foods in Nigeria and many parts of sub-Saharan Africa predominantly consist of cereal-based porridges, such as maize ogi, sorghum, or millet gruels. These foods frequently fail to satisfy the nutritional requirements of rapidly growing infants and young children aged 6–23 months. They are typically characterized by low protein quantity and poor protein quality, insufficient energy density, high viscosity and bulkiness, and limited micronutrient bioavailability. Such deficiencies contribute significantly to the persistent high prevalence of protein-energy malnutrition (PEM), stunting, wasting, micronutrient deficiencies (particularly iron, zinc, vitamin A, and calcium), impaired cognitive development, and increased susceptibility to infectious diseases (Onofiok and Nnanyelugo, 1998; Abeshu et al., 2016; Issaka et al., 2015; Akinsola et al., 2017).

In Nigeria, suboptimal complementary feeding practices exacerbate the national burden of child undernutrition. Many caregivers rely heavily on low-nutrient-density staples that become even more diluted to reduce viscosity, further lowering nutrient intake per feeding session. This dietary pattern often results in inadequate dietary diversity and minimum acceptable diet scores, with adverse long-term consequences on child growth and development (Ekong et al., 2022; Adegbusi et al., 2022). Despite the nutritional potential of locally available ingredients, many households cannot afford commercial fortified complementary foods, leaving a critical gap that locally formulated blends must address.

Soybean, groundnut, and crayfish offer promising nutritional complementarity due to their high protein content, essential amino acid profiles, lipids, and bioavailable minerals. However, several challenges limit their effective utilization. Suboptimal processing methods often result in elevated levels of antinutritional factors, such as phytates, tannins, and trypsin inhibitors, which reduce nutrient digestibility and mineral bioavailability. Inconsistent blend ratios, inadequate processing optimization (e.g., roasting, fermentation, germination, or soaking), and limited fortification strategies frequently lead to products with poor functional properties, including high viscosity, undesirable sensory attributes, and variable shelf stability (Omueti et al., 2009; Adegbusi et al., 2022; Gemede, 2020).

Although studies have demonstrated improvements through blends incorporating maize, soybean, groundnut, and crayfish, systematic optimization of formulation ratios, processing protocols, and comprehensive quality evaluation remains insufficient. Many existing formulations lack robust data on microbial safety, long-term storage stability, consumer acceptability among target populations, and in vivo efficacy in promoting growth and health outcomes. Variability in raw material quality, seasonal availability, and processing scalability further hinder widespread production and adoption at household or small-enterprise levels (Adegbusi et al., 2023; Okereke, 2025).

Consequently, a significant research gap persists in the development of enhanced, standardized methods for producing safe, nutrient-dense, palatable, affordable, and culturally acceptable complementary foods from soybean, groundnut, and crayfish blends. Addressing these challenges is essential to combat child malnutrition effectively and support sustainable, locally driven solutions in Nigeria. This study seeks to contribute to filling these gaps through targeted formulation development and optimization.

.3 Aim and Objectives of the Study

Aim: The aim of this study was to develop improved methods for the formulation of locally processed complementary food from soybean, groundnut, and crayfish blends.

The specific objectives were to;

1. determine the total heterotrophic bacterial count and total Enterobacteriaceae count of the raw ingredients (soybean, groundnut, and crayfish) before processing.
2. formulate complementary food blends in different ratios (Soybean:Groundnut:Crayfish = 70:20:10; 68:20:10; and 50:40:10).
3. determine the total heterotrophic bacterial count and Enterobacteriaceae count of the formulated blends and a market sample (control).
4. determine the pH, moisture content, and proximate composition (fat, ash, crude fibre, protein, and carbohydrate content) of all samples.
5. determine the functional properties (bulk density, dispersibility, and water absorption capacity) of the formulated blends.
6. Carryout a sensory evaluation of the prepared porridge (mixed with water as pap) from the formulated blends.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Complementary Feeding

Complementary feeding refers to the process of providing foods and liquids in addition to breast milk or infant formula when these alone are no longer sufficient to meet the nutritional requirements of infants and young children (D'Auria et al., 2020; Lutter et al., 2021). This phase generally commences at approximately 6 months of age and extends until 23 months, although breastfeeding or appropriate milk feeding may continue beyond this period (WHO, 2023; Capra et al., 2024).

The term "complementary" underscores that these foods and liquids complement not replace the primary milk source, which remains a critical component of the diet (Capra et al., 2024). Complementary items encompass any nutrient-containing solid, semi-solid, or soft foods, whether prepared at home or commercially manufactured, while excluding non-nutritious beverages such as tea, coffee, or sugar-sweetened drinks (WHO, 2003).

This developmental window is pivotal. Infants acquire the ability to accept a diverse range of healthy foods and beverages, thereby establishing foundational dietary patterns that may influence lifelong eating habits. Concurrently, it represents a period of heightened vulnerability to growth faltering, micronutrient deficiencies, and infectious diseases if feeding practices prove inadequate (WHO, 2023; Abeshu et al., 2016).

2.1.1. Transition from Exclusive Breastfeeding to Complementary Feeding

Global health authorities, including the World Health Organization and UNICEF, advocate exclusive breastfeeding for the first 6 months of life, followed by the introduction of nutritionally adequate, safe, and appropriate complementary foods while sustaining breastfeeding up to 2 years of age or beyond (WHO, 2003; PAHO/WHO, 2003).

Exclusive breastfeeding satisfies all nutritional and immunological needs of healthy term infants during the initial 6 months, owing to the optimal composition of breast milk in terms of energy, macronutrients, micronutrients, and bioactive factors (Dewey, 2001). After this age, however, breast milk alone fails to fully address the escalating demands driven by rapid somatic growth, neurological development, and increasing physical activity. An energy and nutrient gap emerges that complementary foods must bridge (Michaelsen et al., 1998; Butte et al., 2004).

Developmental readiness constitutes a key consideration for the timing of introduction. Indicators include the infant's capacity to sit with minimal support, disappearance of the tongue-thrust reflex, demonstration of interest in surrounding foods, and enhanced oral motor skills suitable for handling semi-solid textures (Naylor and Morrow, 2001, as cited in Capra et al., 2024; WHO, 2023).

Premature introduction before 4–6 months poses risks, including gastrointestinal immaturity, heightened susceptibility to infections, potential displacement of breast milk intake, and increased likelihood of overweight or obesity in later life (Chiang et al., 2023; Pérez-Escamilla et al., 2019). Conversely, substantial delay beyond 6 months elevates the probability of iron and zinc deficiencies, impaired growth, and challenges in food acceptance (Romero-Velarde et al., 2016).

Feeding progression follows a structured pattern. For breastfed infants aged 6–8 months, complementary foods are typically provided 2–3 times daily, increasing to 3–4 times per day (plus 1–2 nutritious snacks) for those aged 9–23 months. Gradual augmentation of food consistency from smooth purees to mashed, chopped, and family foods aligns with advancing oral motor capabilities (WHO, 2023 Lutter et al., 2021). Responsive feeding practices remain essential throughout the transition. Caregivers should attentively recognize hunger and satiety signals, feed in a calm and encouraging environment, and avoid force-feeding or distractions. Such approaches foster healthy self-regulation of intake and positive parent-child interactions (WHO, 2023; UNICEF, 2020).

2.1.2. Importance of Complementary Feeding in Infant Nutrition

Appropriate complementary feeding assumes central importance in safeguarding optimal growth, preventing undernutrition, and promoting long-term health trajectories. Suboptimal practices—characterized by untimely introduction, inadequate nutrient density, insufficient dietary diversity, or poor hygiene—contribute substantially to the high burden of stunting, wasting, micronutrient deficiencies, and morbidity observed globally during the 6–24-month window (Michaelsen et al., 1998; Dewey, 2013; Stewart et al., 2013).

Breast milk continues to furnish a substantial proportion of nutritional needs roughly one-half or more of energy requirements between 6 and 12 months, and approximately one-third between 12 and 24 months while delivering immunological protection and bioactive compounds. Complementary foods address the residual "nutrient gap," particularly for iron, zinc, vitamin A, and other limiting micronutrients (Beal et al., 2021; Meek et al., 2022).

Beyond immediate nutritional adequacy, this phase shapes taste preferences, food acceptance, and eating behaviours. Early exposure to a variety of flavours and textures may reduce neophobia and support healthier dietary patterns later in childhood, potentially mitigating risks of obesity and diet-related non-communicable diseases (Capra et al., 2024; Caroli et al., 2022). Adequate nutrition during this critical period also underpins cognitive and motor development through provision of energy and specific nutrients essential for brain maturation (WHO, 2023).

In low- and middle-income countries, where dietary diversity is often limited, inappropriate complementary feeding ranks among the foremost contributors to the double burden of malnutrition. Evidence from intervention studies demonstrates that enhancements in complementary feeding practices yield measurable improvements in linear growth, micronutrient status, and developmental outcomes (Dewey and Adu-Afarwuah, 2008; Abeshu et al., 2016).

Public health interventions focusing on education, dietary diversity, and responsive feeding have proven effective in diverse contexts, underscoring the potential for scalable impact on child survival and thriving (Michaelsen et al., 2017).

2.1.3. Nutritional Requirements of Infants (6–24 Months)

Infants aged 6–24 months exhibit exceptionally high nutrient demands relative to body size, driven by rapid growth velocity, brain development (which consumes a disproportionate share of energy), and rising physical activity levels. Energy needs from complementary foods are estimated at approximately 200 kcal/day for ages 6–8 months, 300 kcal/day for 9–11 months, and 550 kcal/day for 12–23 months, assuming average breast milk intake (PAHO/WHO, 2003; WHO, 2009; Dewey and Brown, 2002). Protein requirements approximate 1.2 g/kg body weight/day in the 7–12-month period, declining modestly thereafter, with priority placed on high-quality, bioavailable sources to support tissue accretion. Dietary fat should contribute 30–40% of energy intake initially to facilitate brain development and absorption of fat-soluble vitamins, while carbohydrates from varied sources supply energy and introduce gradual fibre intake (Krebs, 2007; Capra et al., 2024).

Critical Micronutrients:

- Iron: Stores deplete rapidly after 6 months; daily requirements reach 8–11 mg, necessitating highly bioavailable heme sources (e.g., meat, liver) or fortified foods, as non-heme iron absorption is limited (Dewey, 2001; Miniello et al., 2021).
- Zinc: Vital for growth, immunity, and cellular function; often deficient in predominantly plant-based diets due to phytate inhibition (Krebs, 2007).
- Vitamin A, Calcium, Riboflavin, and Others: Complementary foods must supply these to complement breast milk contributions, emphasizing vitamin A-rich produce, dairy or fortified alternatives, and diverse sources (WHO, 2023).

Dietary diversity constitutes a cornerstone strategy: daily inclusion of animal-source foods (meat, fish, eggs, dairy), fruits and vegetables (particularly vitamin A-rich varieties), and legumes or nuts where appropriate. In settings where local diets cannot fully meet needs, strategically fortified complementary foods or multiple micronutrient powders may serve as valuable adjuncts (WHO, 2023; Csölle et al., 2022). Additional guiding principles encompass maintenance of responsive feeding, sustained breastfeeding, rigorous hygiene to prevent infections, and restriction of ultra-processed foods, added sugars, salt, and non-nutritive beverages (UNICEF, 2020; WHO, 2023). Complementary feeding represents a foundational phase demanding meticulous attention to timing, nutrient quality and density, feeding frequency, consistency progression, and caregiver practices. Evidence-based adherence to guidelines from WHO, UNICEF, and allied bodies optimizes immediate nutritional status, growth, development, and long-term health potential across varied socioeconomic and cultural contexts.

2.2 Nutritional Challenges of Traditional Complementary Foods

Traditional complementary foods in Nigeria, while culturally appropriate, affordable, and widely accessible, frequently present significant nutritional limitations. These foods predominantly consist of cereal-based porridges that fail to adequately address the elevated energy and nutrient demands of infants aged 6–24 months. Consequently, reliance on such diets contributes to widespread undernutrition during a critical developmental window (Akinsola et al., 2017; Onofiok and Nnanyelugo, 1998).

2.2.1 Common Traditional Weaning Foods in Nigeria

Traditional complementary foods in Nigeria are deeply rooted in local agricultural staples, cultural practices, affordability, and seasonal availability. These foods are typically introduced between 3 and 6 months of age, although global recommendations emphasise waiting until around 6 months for optimal health outcomes (Onofiok and Nnanyelugo, 1998; Akinsola et al., 2017). The primary category consists of cereal-based porridges, supplemented by tuber-based preparations and occasional legume items. While these foods are culturally acceptable and accessible, most require fortification or diversification to adequately meet the nutritional needs of infants aged 6–24 months.

2.2.1.1. Pap (Ogi, Akamu, or Koko)

Pap, regionally known as ogi (Yoruba), akamu (Igbo), or koko (Hausa), is by far the most common first traditional weaning food in Nigeria. It is a fermented cereal gruel prepared primarily from maize (Zea mays), although millet (Pennisetum glaucum) or sorghum/ guinea corn (Sorghum bicolor) are also widely used, either singly or in combinations (Onofiok and Nnanyelugo, 1998; Akinsola et al., 2017).

The production process involves steeping cleaned grains in water for 24–72 hours to initiate lactic acid fermentation, followed by wet milling, sieving to remove bran and fibre, sedimentation, and decantation of the starchy slurry. The resulting sediment is cooked with water into a smooth, semi-liquid porridge. Fermentation imparts a characteristic sour taste, enhances digestibility, reduces certain antinutritional factors such as phytates, and improves microbial safety through acidification (Akinsola et al., 2017; Akinsola et al., 2021).

Nutritionally, plain ogi is predominantly carbohydrate-based with high starch content, but it has low protein levels (typically 7–15% on a dry matter basis, often much lower in the diluted gruel), minimal fat, and limited micronutrients. Extensive sieving and processing result in significant losses of protein, fibre, vitamins, and minerals. Energy density is frequently low (often below 0.5 kcal/g) due to the addition of large amounts of water to achieve a thin consistency suitable for infants (Onofiok and Nnanyelugo, 1998; Akinsola et al., 2017; Gyaami, 1974).

Caregivers sometimes enrich pap with additives such as soybean flour, groundnut paste, crayfish powder, palm oil, or milk, particularly in higher-income households. However, such enhancements are often inconsistent or insufficient. Pap’s smooth texture, cultural familiarity, probiotic potential from fermentation, and low cost make it a staple introductory food, yet sole or predominant reliance contributes substantially to nutrient gaps (Ukegbu and Anyika, 2012; Akinsola et al., 2021).

2.2.1.2. Yam (Dioscorea spp.) Preparations

Pounded yam (iyan) or yam porridge (asaro) ranks among the next most common traditional foods introduced after initial cereal gruels. Yam, a major staple tuber in southern and central Nigeria, is boiled, pounded into a sticky swallow, or mashed into soft porridges, often mixed with light soups, palm oil, or vegetables. For infants, it is typically prepared as a smooth puree or thin porridge (Onofiok and Nnanyelugo, 1998; Akinsola et al., 2017).

Yam is rich in complex carbohydrates (primarily starch) and provides moderate energy, along with some potassium, vitamin C, and dietary fibre. However, its protein content is notably low (approximately 1.5–2% on a fresh weight basis), with limited essential amino acids. When prepared for infants, it is often diluted or served plain, further reducing nutrient density. It offers good digestibility when well-cooked and mashed, making it suitable for transitioning textures, although it remains primarily an energy source rather than a nutrient-dense option (Onofiok and Nnanyelugo, 1998).

2.2.1.3. Gari (Fermented Cassava Grits)

Gari (also called garri), a granular fermented cassava product, is a ubiquitous staple across Nigeria, particularly in the south and southwest. For infant feeding, it is typically soaked in hot or cold water to form soft eba, mixed into thin porridges, or incorporated into light soups. Fermentation of cassava roots reduces cyanogenic glycosides, thereby improving safety (Onofiok and Nnanyelugo, 1998; Akinsola et al., 2017).

Nutritionally, gari is high in carbohydrates but very low in protein (typically 1–2%), fat, and most micronutrients unless fortified or enriched. It provides calories and some resistant starch beneficial for gut health, but its overall nutrient profile is inadequate as a primary weaning food. Processing losses and dilution for infant-appropriate consistency further exacerbate these limitations. It is valued for its availability, shelf-stability, and cultural acceptance but requires significant supplementation with proteins and vegetables (Onofiok and Nnanyelugo, 1998).

2.2.1.4. Cocoyam (Taro/Colocasia esculenta or Xanthosoma spp.)

Cocoyam, known locally as ede or tannia, serves as another traditional tuber used in weaning, especially in southeastern Nigeria. It is boiled and mashed into soft porridges or puddings (mpotompoto), sometimes combined with crayfish, fish, or palm oil. Its small starch granules and mucilaginous texture contribute to high digestibility and a smooth mouthfeel suitable for infants (Onofiok and Nnanyelugo, 1998; Okeke et al., 2009).

Cocoyam offers carbohydrates for energy, some dietary fibre, vitamins (including vitamin C and B-group), and minerals such as calcium and potassium. It generally has slightly higher protein and mineral content than cassava and is less prone to certain processing losses. However, it contains oxalates that require proper cooking to reduce, and overall nutrient density remains insufficient without additional protein sources. It is culturally regarded as gentle on the digestive system and suitable for weaning and special diets (Okeke et al., 2009).

2.2.1.5. Rice-Based Porridges and Legume Preparations

Soft rice porridges (often overcooked white rice that is mashed or blended) are common, particularly in urban and rice-producing areas. They provide easily digestible carbohydrates but are low in protein, iron, and other micronutrients (Akinsola et al., 2017). Legume-based items such as moin moin (steamed bean pudding from cowpeas) and akara (fried bean cakes) appear less frequently as primary weaning staples but are introduced as protein sources. These offer higher protein quality (rich in lysine) and iron compared to cereals. They are typically mashed or pureed for safety and digestibility, though seasonings may require adjustment for very young infants (Ekong et al., 2022).

2.2.1.6. Other Regional Variations

Additional foods include plantain porridges, sweet potato mashes, and occasional millet-based preparations such as hauza koko in northern regions. Overall, these traditional foods reflect Nigeria's agricultural diversity but share common challenges of suboptimal nutrient density when used without enrichment or diversification (Onofiok and Nnanyelugo, 1998; Akinsola et al., 2017). A comprehensive understanding of these foods highlights their strengths in cultural integration and accessibility, alongside the critical need for improvement through education, fortification strategies, and dietary diversification to support optimal infant growth and development in Nigeria.

2.2.2 Limitations of Traditional Complementary Foods

Traditional Nigerian complementary foods, predominantly cereal-based porridges such as pap or ogi, exhibit several inherent nutritional limitations that compromise their ability to meet the elevated requirements of infants aged 6–24 months. These constraints arise primarily from the nature of the raw materials, traditional processing methods, and preparation practices for infant feeding.

One major limitation concerns the low protein quantity and quality. Cereal proteins are incomplete, notably deficient in essential amino acids such as lysine and tryptophan. Traditional processing of maize into ogi exacerbates these deficiencies through significant nutrient losses during steeping, wet milling, sieving, and decantation. For instance, up to 98% of tryptophan may be lost during ogi production from maize, while overall protein content in the final gruel is often too low to support optimal growth (Makinde and Lachance, 1976, as cited in Akinsola et al., 2017; Gyaami, 1974).

Another critical drawback is the low energy density of these foods. High starch gelatinization during cooking produces highly viscous gruels. Caregivers commonly dilute them with substantial amounts of water to achieve a consistency suitable for infants, which drastically reduces energy and nutrient density. Consequently, infants may consume large volumes yet fail to meet their energy requirements. This issue is compounded by the small gastric capacity of young children (Amagloh et al., 2013, as cited in Oladiran and Emmambux, 2020; Onofiok and Nnanyelugo, 1998).

Traditional complementary foods are also typically low in bioavailable micronutrients, including iron, zinc, vitamin A, calcium, and several B vitamins. High levels of phytates and other antinutrients present in cereals further inhibit mineral absorption. These deficiencies become particularly pronounced when animal-source foods or fortified items are not regularly included in the diet (Gibson et al., 2010, as cited in Oladiran and Emmambux, 2020; Akinsola et al., 2017).

Additional concerns include the potential for microbial contamination when hygiene practices during preparation and storage are suboptimal, as well as limited dietary diversity that restricts exposure to a broad range of nutrients. These factors collectively undermine the nutritional adequacy of traditional weaning foods when they form the primary component of an infant's diet.

2.2.3 Malnutrition Issues Associated with Suboptimal Complementary Feeding

Inadequate traditional complementary feeding practices significantly contribute to various forms of malnutrition among Nigerian infants and young children. Protein-energy malnutrition (PEM) manifests in clinical forms such as marasmus, kwashiorkor, or marasmic-kwashiorkor. These conditions arise when energy and protein intakes fail to meet the high demands of rapid growth, particularly in the presence of infections or inadequate overall dietary intake (Ubesie, 2012).

Nigeria continues to bear a substantial burden of undernutrition. Stunting, a marker of chronic malnutrition, affects approximately 32% of children under five years nationally, with markedly higher rates in northern regions. Wasting, indicative of acute malnutrition, impacts millions of children. Only a small proportion of children aged 6–23 months receive a minimum acceptable diet. Suboptimal complementary feeding underlies a significant portion of this burden, elevating risks of morbidity, impaired cognitive development, increased susceptibility to infections, and long-term health and economic consequences (UNICEF, 2019; Udoh et al., 2016).

2.2.4 Need for Nutrient-Dense Complementary Foods

The documented limitations of traditional complementary foods highlight the urgent need for nutrient-dense alternatives or improved strategies to support optimal infant growth and development in Nigeria. Effective approaches include the fortification or enrichment of staples such as ogi with legumes (soybean, cowpea, or groundnut), animal-source foods (fish, crayfish, or eggs), or multiple micronutrient powders. These enhancements can substantially improve protein quality, energy density, and micronutrient content while preserving cultural acceptability.

Promotion of dietary diversity through regular incorporation of fruits, vegetables, and varied protein sources represents another essential strategy. Improved processing techniques that enhance nutrient retention and bioavailability—such as optimised fermentation, germination, or reduced sieving should be encouraged alongside maintenance of traditional sensory qualities. Furthermore, sustained education of caregivers on responsive feeding practices, food hygiene, appropriate food consistency, and overall infant and young child feeding guidelines is critical for translating nutritional improvements into better health outcomes (Dewey and Adu-Afarwuah, 2008; Ekong et al., 2022; Akinsola et al., 2017). Collectively, these interventions can help bridge nutrient gaps, reduce the prevalence of malnutrition, and support the long-term developmental potential of Nigerian children.

2.3 Soybean as a Functional Ingredient in Complementary Foods

Soybean (Glycine max) has gained considerable recognition globally as one of the most important plant-based protein sources used in complementary food formulation due to its rich nutritional profile, affordability, and functional versatility. In many developing countries, including Nigeria, soybean has become increasingly valuable in addressing protein-energy malnutrition among infants and young children, especially during the transition from exclusive breastfeeding to complementary feeding. Traditional cereal-based complementary foods such as pap, ogi, or akamu are often deficient in protein, essential amino acids, fats, and micronutrients required for optimal growth and development. Consequently, supplementation or fortification with soybean significantly improves the nutritional quality of these traditional weaning foods (Anigo et al., 2010). The use of soybean in complementary food production is particularly important because it offers a sustainable and locally available alternative to expensive animal protein sources. According to Akinsola et al. (2017), soybean cultivation has increased substantially in Nigeria due to its nutritional and economic importance. Its incorporation into infant diets helps combat undernutrition, stunting, and micronutrient deficiencies prevalent among children in low-income communities. In addition to its nutritional benefits, soybean contributes functional properties such as emulsification, water absorption, and improved texture in food formulations, thereby enhancing product quality and acceptability (Rosiana et al., 2023).

Soybean is also considered a functional food ingredient because it contains several bioactive compounds including isoflavones, phytosterols, lecithin, and antioxidant peptides which provide additional physiological benefits beyond basic nutrition. These compounds have been associated with improved immune response, reduced oxidative stress, and enhanced metabolic health (Messina, 2016). In complementary foods, soybean not only improves nutrient density but also contributes to better growth performance and cognitive development in infants when consumed in adequate amounts.

The incorporation of soybean into cereal-legume blends has been extensively studied and has consistently demonstrated improvements in protein quality and overall nutrient balance. Omueti et al. (2009) reported that soybean-enriched complementary foods showed significantly higher protein and mineral contents compared to traditional cereal-only formulations. Similarly, Noah Abimbola Aduke (2017) observed that soybean-fortified weaning foods improved the nutritional adequacy of infant diets and could potentially reduce the incidence of kwashiorkor and marasmus among vulnerable populations.

2.3.1 Nutritional Composition of Soybean

Soybean possesses a unique nutritional composition that distinguishes it from many other legumes and plant-based food sources. It contains substantial amounts of high-quality protein, lipids, carbohydrates, vitamins, minerals, and phytochemicals essential for infant growth and development. The nutrient density of soybean makes it particularly suitable for fortifying low-protein cereal-based complementary foods commonly consumed in Nigeria and other parts of sub-Saharan Africa (Anigo et al., 2010).

2.3.1.1 Protein Content

Among legumes, soybean contains one of the highest protein concentrations, ranging from approximately 35–43% depending on variety, environmental conditions, and processing methods (Marcel et al., 2021). This exceptionally high protein content makes soybean highly suitable for improving the protein quality of infant complementary foods. Protein is essential during infancy because it supports tissue synthesis, muscle formation, enzyme production, hormonal regulation, and immune function.

Protein deficiency during the weaning period is one of the major causes of protein-energy malnutrition in developing countries. Traditional complementary foods based solely on cereals such as maize or millet are generally low in protein and deficient in lysine, an essential amino acid required for growth. Soybean effectively corrects this deficiency because it contains substantial quantities of lysine and other indispensable amino acids (Mathai et al., 2017).

Studies have shown that incorporating soybean into cereal-based formulations significantly increases crude protein content. Anigo et al. (2010) demonstrated that supplementation of maize-based complementary foods with soybean increased protein content from less than 10% to over 18%. Similar findings were reported by Omueti et al. (2009), who observed improved nitrogen retention and protein efficiency ratios in soybean-fortified formulations.

Furthermore, soybean proteins possess excellent functional properties including water-binding, emulsification, foaming, and gel formation. These properties improve the texture and consistency of porridges prepared for infants, making them more palatable and easier to consume (Rosiana et al., 2023). Soy protein also contributes to satiety and sustained energy release, which is important for growing infants requiring frequent nutrient intake.

The digestibility of soybean protein improves significantly after appropriate processing methods such as roasting, fermentation, boiling, and germination. Raw soybean contains trypsin inhibitors that interfere with protein digestion; however, heat treatment effectively inactivates these compounds and enhances protein bioavailability (Akinsola et al., 2017).

2.3.1.2 Fat Content

Soybean contains approximately 18–20% lipid, making it an excellent source of dietary fat and energy in complementary foods. The lipid fraction consists predominantly of unsaturated fatty acids, especially linoleic acid and alpha-linolenic acid, which are essential fatty acids required for normal neurological development and visual acuity in infants (Soy Connection, 2025).

Dietary fats are particularly important during infancy because they provide concentrated energy necessary to support rapid growth and development. Infants have relatively small stomach capacities; therefore, complementary foods must possess high nutrient and energy density. The incorporation of soybean into cereal blends substantially increases caloric value, thereby reducing the risk of energy deficiency among children (Rosiana et al., 2023).

The presence of essential fatty acids in soybean contributes significantly to brain development, myelination, and hormone synthesis. According to Innis (2007), omega-3 and omega-6 fatty acids are critical for cognitive development and retinal function during early childhood. Soybean oil therefore enhances the nutritional adequacy of complementary foods beyond simple energy provision.

Additionally, soybean lipids improve the organoleptic qualities of complementary foods by enhancing smoothness, flavour, and mouthfeel. This increased palatability may improve infant acceptance and feeding frequency. However, high fat levels can predispose products to oxidative rancidity during storage if proper packaging and preservation methods are not employed (Noah Abimbola Aduke, 2017).

2.3.1.3 Vitamins

Soybean contains appreciable quantities of vitamins, particularly members of the B-complex group, which play essential roles in cellular metabolism and growth. These include thiamine (vitamin B1), riboflavin (vitamin B2), niacin, pyridoxine (vitamin B6), pantothenic acid, and folate (Soy Connection, 2025).

Thiamine is involved in carbohydrate metabolism and nerve function, while riboflavin supports energy production and tissue repair. Niacin contributes to enzymatic activities involved in metabolism, whereas vitamin B6 plays an important role in amino acid metabolism and neurotransmitter synthesis. Folate is particularly critical during infancy because it supports DNA synthesis, cell division, and red blood cell formation (Marcel et al., 2021).

Although soybean is not a major source of vitamins A and C, its nutritional limitations can be addressed through composite food formulation involving fruits, vegetables, or fortified ingredients. The combination of soybean with vitamin-rich food materials can therefore produce balanced complementary diets suitable for infants and young children (Anigo et al., 2010).

The vitamin content of soybean may also be influenced by processing methods. Excessive heating can reduce heat-sensitive vitamins such as thiamine; however, moderate thermal processing enhances digestibility and safety while preserving most micronutrients (Akinsola et al., 2017).

2.3.1.4 Minerals

Soybean is a rich source of essential minerals including calcium, iron, zinc, magnesium, phosphorus, potassium, and manganese. These minerals perform critical physiological functions necessary for growth, immunity, bone development, and metabolic regulation (Ezeokeke et al. 2016). Iron deficiency is among the most common nutritional disorders affecting infants worldwide. Since endogenous iron stores become depleted after approximately six months of age, complementary foods must provide adequate iron to prevent anaemia. Soybean contributes substantially to dietary iron intake and therefore helps improve haemoglobin synthesis and oxygen transport (WHO, 2020).

Zinc present in soybean supports immune competence, wound healing, and cellular growth. Zinc deficiency during infancy has been associated with impaired growth, increased susceptibility to infections, and delayed cognitive development (Brown et al., 2010). Calcium and phosphorus are essential for skeletal development and bone mineralisation, while magnesium supports enzymatic reactions and neuromuscular function. Despite its mineral richness, the bioavailability of some soybean minerals may be limited by antinutritional factors such as phytates and oxalates. These compounds can chelate minerals and reduce absorption in the gastrointestinal tract. However, processing techniques such as soaking, fermentation, germination, and roasting significantly reduce phytate levels and improve mineral bioavailability (Hotz and Gibson, 2007). Anigo et al. (2010) reported that fermentation and roasting enhanced the nutritional quality and mineral accessibility of soybean-based complementary foods. Similarly, Rosiana et al. (2023) noted that appropriate processing techniques improve both nutrient retention and digestibility in soybean formulations.

2.3.2 Amino Acid Profile and Protein Quality

Soybean protein is often regarded as one of the highest-quality plant proteins because it contains all nine essential amino acids required for human growth and development. Unlike many cereal proteins that are deficient in lysine, soybean possesses abundant lysine content, making it highly effective for amino acid complementation when blended with maize, sorghum, millet, or rice (van den Berg et al., 2022). The amino acid profile of soybean closely approximates that of animal proteins, particularly in terms of leucine, isoleucine, valine, phenylalanine, and lysine concentrations. This balanced amino acid composition makes soybean highly suitable for infant nutrition, where rapid tissue growth and protein synthesis occur continuously (Mathai et al., 2017).

Protein quality is commonly evaluated using indices such as the Protein Digestibility-Corrected Amino Acid Score (PDCAAS) and the Digestible Indispensable Amino Acid Score (DIAAS). Properly processed soy protein products frequently achieve PDCAAS values between 0.95 and 1.00, indicating excellent protein quality comparable to milk and egg proteins (Hughes et al., 2011).

The DIAAS method, currently recommended by the FAO, further confirms soybean's superior digestibility and amino acid availability. Herreman et al. (2020) reported DIAAS values ranging from 75–100 depending on the soy product and processing technique employed. Such high scores demonstrate soybean's ability to support efficient nitrogen utilization, tissue repair, and growth in children.

Soybean also contains significant levels of glutamic acid and arginine, amino acids important for metabolic regulation and immune support. Furthermore, blending soybean with cereals creates synergistic nutritional effects because cereals provide methionine, which soybean contains in relatively lower quantities, while soybean supplies lysine absent in cereals. This mutual supplementation produces a more balanced and biologically valuable protein mixture suitable for complementary feeding (Marcel et al., 2021).

The digestibility and utilization of soybean protein depend heavily on processing conditions. Heat treatment improves digestibility by denaturing storage proteins and destroying protease inhibitors. Fermentation additionally enhances amino acid availability by partial hydrolysis of proteins into more digestible peptides and amino acids (Akinsola et al., 2017). Overall, the superior amino acid composition and high protein quality of soybean make it one of the most suitable ingredients for developing nutrient-dense complementary foods aimed at reducing childhood malnutrition and promoting healthy growth among infants in resource-limited settings.

2.3.3 Health Benefits of Soybean in Complementary Foods

The incorporation of soybean into complementary food formulations provides numerous physiological and nutritional advantages that extend beyond the provision of basic nutrients. Soybean is widely regarded as a functional food ingredient because, in addition to supplying proteins, fats, vitamins, and minerals, it contains biologically active compounds capable of promoting health and reducing disease risk. These bioactive substances include isoflavones, phytosterols, saponins, lecithin, peptides, and antioxidants, all of which contribute to improved nutritional outcomes among infants and young children (Messina, 2016).

In developing countries such as Nigeria, where protein-energy malnutrition and micronutrient deficiencies remain major public health concerns, soybean serves as a cost-effective and locally available strategy for improving the nutritional quality of traditional complementary foods. Soybean-enriched formulations have been shown to improve growth performance, immune function, nutrient utilization, and overall health status in children during the vulnerable weaning period (Anigo et al., 2010).

Beyond its nutritional contribution, soybean may also exert long-term protective effects against chronic diseases when introduced early in life through healthy dietary patterns. According to Rosiana et al. (2023), regular consumption of soybean-containing foods may contribute to improved metabolic health, reduced oxidative stress, and better cardiovascular outcomes later in life.

2.3.3.1 Anti-Malnutrition Effects

One of the most important benefits of soybean in complementary feeding is its significant role in combating protein-energy malnutrition among infants and young children. Malnutrition remains a leading cause of morbidity and mortality among children under five years in many low-income countries, particularly in sub-Saharan Africa. Inadequate intake of protein and essential nutrients during the weaning period frequently results in growth retardation, weakened immunity, underweight conditions, stunting, and wasting (UNICEF, 2021).

Traditional complementary foods commonly consumed in Nigeria, such as maize pap or ogi, are often bulky and deficient in protein and micronutrients. Consequently, infants fed predominantly on such diets may fail to meet their nutritional requirements during periods of rapid growth and development. The inclusion of soybean in these formulations significantly improves nutrient density, particularly protein quality and caloric value, thereby helping to reduce the incidence of malnutrition (Anigo et al., 2010).

Soybean contributes high-quality protein containing essential amino acids required for tissue synthesis, muscle growth, enzyme production, and immune development. Studies have shown that soybean-fortified complementary foods support better weight gain and linear growth in infants compared to plain cereal-based porridges. Abiodun (1991) reported that children consuming soybean-enriched weaning foods exhibited improved anthropometric indices and recovery from protein-energy malnutrition.

Similarly, Muhammad et al. (2025) observed that regular consumption of soybean-fortified complementary foods significantly reduced the prevalence of stunting and underweight conditions among children in rural communities. The study further demonstrated improvements in haemoglobin concentration and overall nutritional status following dietary intervention with soybean-based blends. The high energy density of soybean also contributes to improved nutritional outcomes. Since infants possess relatively small gastric capacities, nutrient-dense foods are essential to ensure adequate energy intake without excessive food volume. Soybean's lipid content increases caloric concentration while its protein fraction enhances satiety and growth support (Rosiana et al., 2023).

Furthermore, soybean provides essential micronutrients such as iron and zinc that are often deficient in cereal-only diets. Iron supports haemoglobin formation and oxygen transport, while zinc is critical for immune competence and cellular growth. Deficiencies of these minerals are strongly associated with impaired cognitive development, susceptibility to infections, and poor growth among infants (Brown et al., 2010). Soybean-fortified complementary foods have therefore been recommended as practical nutritional interventions in resource-limited settings because they are affordable, culturally acceptable, and nutritionally superior to many traditional weaning foods (Akinsola et al., 2017).

2.3.3.2 Cholesterol Reduction

Soybean and soy-derived products have been widely studied for their cholesterol-lowering properties, particularly due to the presence of soy protein, isoflavones, phytosterols, and unsaturated fatty acids. These bioactive compounds contribute to reductions in low-density lipoprotein (LDL) cholesterol and improvement in lipid metabolism, thereby supporting cardiovascular health (Gaddi et al., 1987).

Although most studies on cholesterol reduction have focused on adults, increasing evidence suggests that introducing healthy plant-based proteins early in life may establish beneficial metabolic patterns that persist into adulthood. Soy protein has been shown to modulate cholesterol synthesis and enhance hepatic LDL receptor activity, resulting in improved clearance of cholesterol from circulation (Messina, 2016).

The unsaturated fatty acids present in soybean, especially linoleic and alpha-linolenic acids, further contribute to cardiovascular protection by improving lipid profiles and reducing inflammatory processes. According to Soy Connection (2025), regular consumption of soybean products may help lower total cholesterol levels while promoting healthier ratios of HDL to LDL cholesterol.

Introducing soybean-based complementary foods during infancy may therefore provide long-term health advantages by encouraging healthier dietary patterns from an early age. In addition, soybean lacks cholesterol entirely, unlike many animal-derived protein sources, making it a healthier alternative for improving protein intake in complementary feeding formulations.

Additional Health Benefits of Soybean

Apart from its anti-malnutrition and cholesterol-lowering effects, soybean offers several additional physiological benefits relevant to infant nutrition and development.

Soybean contributes significantly to improved micronutrient status due to its content of iron, zinc, magnesium, calcium, and phosphorus. These minerals support bone development, enzymatic activities, immune response, and neurological function. Iron-rich soybean formulations may help reduce the prevalence of iron-deficiency anaemia among infants and young children (WHO, 2020).

Fermented soybean products may also improve gut health due to the presence of beneficial microorganisms and bioactive metabolites produced during fermentation. These probiotics support intestinal microbial balance, improve digestion, enhance nutrient absorption, and reduce the risk of gastrointestinal infections (Elhalis et al., 2024). Additionally, soybean contains antioxidant compounds such as isoflavones and phenolic acids that help neutralize free radicals and reduce oxidative stress. These antioxidant effects may contribute to reduced inflammation and protection against chronic diseases later in life (Messina, 2016). The regular inclusion of soybean in complementary foods may therefore provide both immediate nutritional benefits and long-term protective health effects.

2.3.4 Anti-Nutritional Factors

Despite its numerous nutritional advantages, soybean also contains several anti-nutritional compounds capable of interfering with nutrient utilization and digestion if not adequately processed. These compounds are naturally occurring defense substances synthesized by the plant and may reduce protein digestibility, mineral absorption, and overall nutritional efficiency (Nwabueze, 2007). The presence of anti-nutritional factors is particularly important in infant feeding because infants possess immature digestive systems and high nutritional requirements. Consequently, proper processing methods are essential before soybean can be safely incorporated into complementary foods (Omosebi et al., 2018).

2.3.4.1 Phytates

Phytates, also known as phytic acid or myo-inositol hexaphosphate, represent one of the major anti-nutritional factors present in soybean. Phytates have a strong capacity to chelate minerals such as iron, zinc, calcium, and magnesium, forming insoluble complexes that reduce their bioavailability in the gastrointestinal tract (Alabi et al., 2022). The inhibitory effect of phytates is particularly concerning in developing countries where complementary diets are already heavily dependent on cereals and legumes containing high phytate concentrations. Such diets may contribute to persistent micronutrient deficiencies despite apparently adequate mineral content (Hotz and Gibson, 2007). High phytate intake among infants can impair iron and zinc absorption, thereby increasing the risk of anaemia, weakened immunity, poor growth, and cognitive impairment. According to Nwabueze (2007), phytate reduction is essential for improving the nutritional quality of soybean-based infant foods.

Fortunately, several traditional processing methods effectively reduce phytate content. Techniques such as soaking, fermentation, germination, roasting, and enzymatic treatment activate endogenous phytase enzymes that hydrolyse phytates into lower inositol phosphates with reduced mineral-binding capacity (Chauhan et al., 2022). Fermentation has been identified as particularly effective because microbial phytases produced during fermentation substantially degrade phytates and improve mineral bioavailability (Elhalis et al., 2024).

2.3.4.2 Trypsin Inhibitors

Trypsin inhibitors are another important anti-nutritional component found in soybean. These compounds interfere with protein digestion by inhibiting proteolytic enzymes such as trypsin and chymotrypsin in the small intestine. As a result, protein digestibility and amino acid absorption may be significantly reduced when raw or inadequately processed soybean is consumed (Vagadia et al., 2017). Excessive intake of trypsin inhibitors may also stimulate pancreatic enlargement and increased enzyme secretion, thereby placing physiological stress on the digestive system. In infants, whose digestive systems are still developing, high levels of trypsin inhibitors may negatively affect nutrient utilization and growth performance (Omosebi et al., 2018).

However, trypsin inhibitors are heat-labile compounds and can be effectively inactivated through proper thermal processing methods such as boiling, roasting, autoclaving, extrusion, and toasting. Roasting soybean at moderate temperatures significantly reduces trypsin inhibitor activity while simultaneously improving flavour and digestibility (Akinsola et al., 2017). The destruction of trypsin inhibitors through processing is therefore critical for maximizing the nutritional benefits of soybean in complementary foods.

2.3.5 Processing Methods

Proper processing of soybean is essential to improve digestibility, enhance nutrient bioavailability, reduce anti-nutritional factors, and improve sensory acceptability. Processing also contributes to longer shelf life and microbial safety of soybean-based complementary foods (Agume et al., 2017). Traditional and modern processing methods have been widely employed to optimize the nutritional potential of soybean for infant feeding applications.

2.3.5.1 Soaking

Soaking is one of the simplest and most commonly used preliminary processing methods for soybean preparation. During soaking, soybean seeds absorb water, soften, and undergo biochemical changes that facilitate further processing operations such as dehulling, milling, and cooking. One major nutritional advantage of soaking is the activation of endogenous phytase enzymes, which hydrolyse phytates and improve mineral bioavailability (Chauhan et al., 2022). Soaking also reduces oligosaccharides such as raffinose and stachyose that are associated with flatulence and gastrointestinal discomfort. Agume et al. (2017) reported that soaking soybean for 12–24 hours significantly reduced anti-nutritional factors and improved digestibility in complementary food formulations. Additionally, soaking enhances heat transfer during cooking and contributes to softer texture and improved palatability.

2.3.5.2 Roasting

Roasting is a widely practiced thermal processing technique used to improve the nutritional and sensory qualities of soybean. The process involves dry heating at temperatures ranging from approximately 130–180°C for specific durations depending on the intended product (Akinsola et al., 2017). Roasting effectively inactivates heat-sensitive anti-nutritional compounds such as trypsin inhibitors while improving protein digestibility and flavour development. The process also reduces the characteristic “beany” flavour often associated with soybean, thereby increasing acceptability among infants and caregivers.

Furthermore, roasting lowers moisture content, thereby improving shelf stability and reducing microbial spoilage. In many Nigerian households and small-scale food processing settings, roasting remains a practical and low-cost technique for soybean utilization in complementary food production.

2.3.5.3 Fermentation

Fermentation is considered one of the most effective processing methods for enhancing the nutritional quality of soybean. During fermentation, microorganisms such as lactic acid bacteria, yeasts, and moulds metabolize complex compounds within soybean, resulting in improved digestibility and nutrient availability (Elhalis et al., 2024). Fermentation substantially reduces phytates and trypsin inhibitors through microbial enzymatic activity. It also enhances amino acid availability, increases certain B vitamins, and produces beneficial bioactive compounds with probiotic effects (Akinsola et al., 2018).

Fermented soybean products have been shown to possess improved sensory characteristics including flavour, aroma, and texture, which contribute to higher consumer acceptance. Additionally, fermentation may improve gut microbial balance and reduce gastrointestinal infections among infants through probiotic activity (Elhalis et al., 2024). Overall, fermentation represents a highly valuable strategy for maximizing the nutritional and functional potential of soybean in complementary food systems.

2.4 Groundnut as a Complementary Food Ingredient

Groundnut (*Arachis hypogaea*), commonly known as peanut, is one of the most widely cultivated and consumed legumes in Nigeria and many developing countries. It serves as an important component of household diets due to its high nutritional value, affordability, availability, and versatility in food preparation. In complementary food formulation, groundnut has gained considerable importance because of its rich energy, protein, and lipid content, making it highly suitable for improving the nutritional quality of traditional cereal-based weaning foods such as ogi, pap, and millet gruels (Ekong et al., 2022).

In many parts of sub-Saharan Africa, complementary foods fed to infants are predominantly cereal-based and are often deficient in essential nutrients required for proper growth and development. Such foods are generally characterized by low energy density, inadequate protein quality, and poor micronutrient composition. The incorporation of groundnut into these formulations significantly improves caloric density, protein content, and sensory acceptability, thereby contributing to the prevention of childhood malnutrition and growth faltering (Adepeju et al., 2016). Groundnut is particularly valuable in low-resource settings because it represents an inexpensive source of concentrated nutrients compared to animal-derived foods. Its use in complementary feeding formulations supports sustainable nutrition interventions aimed at combating protein-energy malnutrition among infants and young children. According to Alamu et al. (2018), groundnut-based complementary foods are culturally acceptable in many Nigerian communities and can be produced using locally available technologies and processing methods. In addition to its nutritional value, groundnut contains several biologically active compounds including phenolic acids, flavonoids, phytosterols, and resveratrol, which possess antioxidant and anti-inflammatory properties. These compounds may contribute to improved health outcomes and long-term disease prevention when included as part of balanced infant diets (Arya et al., 2015).

Groundnut also contributes desirable sensory characteristics to complementary foods, including improved flavour, aroma, creaminess, and mouthfeel. These sensory attributes may enhance food acceptance among infants and caregivers, thereby increasing feeding frequency and nutrient intake during the critical weaning period (Shokunbi et al., 2012).

2.4.1 Nutritional Composition of Groundnut

Groundnut possesses an exceptionally rich nutrient composition that makes it highly beneficial for complementary food formulation. It contains substantial amounts of lipids, proteins, carbohydrates, vitamins, minerals, and bioactive compounds necessary for infant growth and physiological development. Its nutrient density allows relatively small quantities to provide significant nutritional benefits, which is particularly important during infancy when gastric capacity is limited (Shewa et al., 2025). The nutritional composition of groundnut varies depending on factors such as cultivar, environmental conditions, agricultural practices, and processing methods. Nevertheless, its overall nutrient profile consistently demonstrates its value as a fortifying ingredient in complementary feeding programs (Ekong et al., 2022).

2.4.1.1 Lipids Content

One of the most notable nutritional characteristics of groundnut is its exceptionally high lipid content, which typically ranges from 45–55% on a dry weight basis. Nigerian varieties commonly contain approximately 45.4% fat, making groundnut one of the richest plant-based energy sources available for infant feeding applications (Shokunbi et al., 2012). The lipid fraction of groundnut consists predominantly of unsaturated fatty acids, especially oleic acid and linoleic acid. These essential fatty acids perform critical physiological functions in growing infants, including brain development, maintenance of cell membrane integrity, hormone synthesis, and absorption of fat-soluble vitamins such as vitamins A, D, E, and K (Arya et al., 2015).

Essential fatty acids are particularly important during infancy because the brain undergoes rapid growth and development during the first two years of life. Adequate dietary fat intake supports cognitive function, visual development, and neurological maturation. According to Innis (2007), insufficient intake of essential fatty acids during early childhood may impair neural development and learning capacity.

The high fat content of groundnut also contributes significantly to the energy density of complementary foods. Since infants possess relatively small stomach capacities, nutrient-dense foods are required to provide adequate calories in manageable portions. The addition of groundnut to cereal-based porridges therefore helps increase caloric concentration without greatly increasing food bulk (Shewa et al., 2025).

Furthermore, groundnut lipids improve the organoleptic properties of complementary foods by enhancing smoothness, creaminess, flavour, and mouthfeel. Improved sensory qualities may encourage greater food acceptance and intake among infants and caregivers. Shokunbi et al. (2012) reported that groundnut-fortified porridges demonstrated superior sensory ratings compared to plain cereal formulations.

However, the high lipid content of groundnut may predispose products to oxidative rancidity if not properly processed and stored. Exposure to oxygen, light, and moisture can lead to lipid oxidation, resulting in off-flavours and nutrient deterioration. Consequently, appropriate packaging and storage conditions are essential to maintain product quality and shelf stability (Alamu et al., 2018).

2.4.1.2 Protein Content

Groundnut is also an important source of plant protein, containing approximately 24–28% protein depending on variety and processing conditions. This relatively high protein concentration makes it highly valuable in improving the protein quality of cereal-based complementary foods, which are often protein-deficient (Ndubuisi et al., 2025). Protein plays a fundamental role in infant growth and development by supporting tissue synthesis, muscle development, enzyme production, hormone formation, and immune function. During the complementary feeding period, infants experience rapid growth rates and therefore require sufficient quantities of high-quality dietary protein to meet physiological demands (WHO, 2020).

Groundnut protein contains appreciable amounts of essential amino acids such as lysine and tryptophan, although it is somewhat deficient in sulfur-containing amino acids including methionine and cysteine. This amino acid profile makes groundnut highly complementary to cereal proteins, which are generally low in lysine but relatively richer in methionine. Combining groundnut with cereals therefore produces improved amino acid balance and enhanced biological protein value (Shokunbi et al., 2012). Several studies have demonstrated that the incorporation of groundnut into maize, millet, or sorghum-based complementary foods significantly increases protein content and improves nutritional adequacy. Adepeju et al. (2016) observed that groundnut supplementation enhanced the crude protein content and overall nutrient profile of maize-based weaning foods.

Groundnut proteins also contribute functional properties such as emulsification, water absorption, and texture improvement in complementary food formulations. These properties help produce smoother porridges with improved consistency suitable for infant feeding (Ekong et al., 2022). Nevertheless, proper processing is essential to improve digestibility and reduce anti-nutritional compounds associated with legumes.

Groundnut plays a crucial role in enhancing the caloric value of traditional complementary foods. Most cereal-based porridges commonly consumed in Nigeria are bulky but nutritionally dilute due to their low fat content and excessive water dilution during preparation. Such porridges often fail to provide sufficient calories required for optimal infant growth and development (Ekong et al., 2022). The incorporation of relatively small amounts of groundnut flour or paste into cereal blends substantially increases total energy content because of its concentrated lipid composition. Studies have shown that adding approximately 5–15% groundnut to maize or millet-based formulations significantly improves caloric density without negatively affecting texture or acceptability (Adepeju et al., 2016).

Improved caloric density is critical because infants between 6–24 months experience rapid growth and increased physical activity, both of which elevate energy requirements. Inadequate calorie intake during this period may result in underweight conditions, poor growth, delayed development, and increased vulnerability to infections (WHO, 2020). Groundnut supplementation also improves satiety and sustained energy release due to its fat and protein composition. This may contribute to improved feeding intervals and reduced hunger among infants.

Additionally, increased caloric density reduces the need for large meal volumes, thereby improving feeding efficiency. This is particularly beneficial for infants recovering from illness or experiencing poor appetite, as smaller food portions can still provide substantial nutritional benefits (Ekong et al., 2022).

2.4.3 Health Benefits and Limitations

2.4.3.1 Health Benefits

The inclusion of groundnut in complementary foods provides several nutritional and physiological benefits essential for infant growth and development. Groundnut supplies high-quality lipids, proteins, vitamins, and minerals that collectively support neurological development, immune function, tissue growth, and metabolic regulation (Arya et al., 2015).

Groundnut is particularly rich in vitamin E, a fat-soluble antioxidant that protects cellular membranes against oxidative damage. Vitamin E also supports immune function and may contribute to healthy skin and tissue maintenance. In addition, groundnut provides niacin, folate, magnesium, phosphorus, and potassium, all of which play important roles in energy metabolism and cellular function (Shokunbi et al., 2012). The presence of bioactive compounds such as resveratrol, flavonoids, and phenolic acids contributes antioxidant and anti-inflammatory effects that may help reduce oxidative stress and support long-term health (Arya et al., 2015).

Emerging evidence also suggests that early introduction of groundnut-containing foods under safe conditions may reduce the likelihood of peanut allergy development later in life. Early dietary exposure may promote immune tolerance and reduce hypersensitivity reactions in susceptible individuals (Du Toit et al., 2015). Groundnut consumption has additionally been associated with improved weight gain and growth outcomes among children in nutrition intervention studies conducted in developing countries (Ekong et al., 2022).

2.4.3.2 Limitations (Aflatoxin Contamination Risk)

Despite its nutritional advantages, one major limitation associated with groundnut utilization is the high risk of aflatoxin contamination. Aflatoxins are toxic secondary metabolites produced primarily by *Aspergillus flavus* and *Aspergillus parasiticus*, fungi that thrive under warm and humid storage conditions commonly found in tropical countries such as Nigeria (Ojuri et al., 2018).

Groundnut is particularly susceptible to fungal invasion both before and after harvest. Poor drying, improper storage, insect damage, and high moisture conditions significantly increase the likelihood of aflatoxin contamination (Alamu et al., 2018). Aflatoxins pose serious public health concerns because they are highly carcinogenic, hepatotoxic, immunosuppressive, and growth-inhibiting. Chronic exposure among infants and children has been associated with stunting, impaired immune function, liver damage, and increased susceptibility to infectious diseases (Vabi et al., 2018).

Several studies conducted in Nigerian markets have reported aflatoxin levels exceeding internationally permissible limits in groundnut and groundnut-based products. Such contamination presents significant risks for infants consuming complementary foods prepared with contaminated ingredients (Ojuri et al., 2018). Therefore, strict quality control measures and proper processing techniques are essential to ensure the safety of groundnut-based complementary foods.

2.4.4 Processing Techniques to Enhance Safety and Quality

Appropriate processing methods are essential for improving the nutritional quality, safety, digestibility, and sensory acceptability of groundnut used in complementary food formulations.

2.4.4.1 Roasting

Roasting is one of the most widely used processing techniques for groundnut in Nigeria. The process involves heating groundnut at controlled temperatures to reduce moisture content, improve flavour, and enhance shelf stability (Alamu et al., 2018). Roasting also improves protein digestibility by denaturing storage proteins and reducing anti-nutritional compounds. Furthermore, it helps minimize the characteristic raw or beany flavour associated with legumes, thereby improving sensory acceptability in infant foods. Importantly, roasting may contribute to partial reduction of aflatoxin levels, although it does not completely eliminate contamination. Proper temperature control is therefore necessary to optimize nutritional quality while minimizing toxin persistence.

2.4.4.2 Sorting, Cleaning, and Dehulling

Sorting and cleaning are critical pre-processing operations aimed at removing mouldy, damaged, shrivelled, or discoloured kernels that are more likely to contain high aflatoxin levels. Manual sorting remains widely practiced in household and small-scale processing settings in Nigeria (Vabi et al., 2018). Dehulling, which involves removal of the outer seed coat, further improves product quality by reducing microbial load, fibre content, and certain anti-nutritional substances. Thorough cleaning and dehulling therefore contribute significantly to safer and more digestible complementary foods.

2.4.4.3 Fermentation, Soaking, and Proper Storage

Fermentation and soaking are additional processing methods that improve the nutritional quality of groundnut. These processes reduce anti-nutritional factors, improve digestibility, and may contribute to partial detoxification of certain contaminants (Ojuri et al., 2018). Proper drying to moisture levels below 8–10% is essential to prevent fungal growth and aflatoxin production during storage. Hermetic storage technologies, airtight containers, and improved warehouse conditions further help preserve quality and minimize contamination risks (Alamu et al., 2018). Good post-harvest handling practices therefore play a critical role in ensuring the safety and effectiveness of groundnut-based complementary foods.

2.5 Crayfish as an Animal Protein Source

Crayfish, commonly referred to in Nigeria as ede, is one of the most widely utilized animal-source food ingredients in household meal preparation and complementary feeding. It occupies a significant place in traditional Nigerian diets because of its rich nutritional value, affordability, availability, and cultural acceptability across different ethnic groups. In complementary food formulation, crayfish serves as a highly valuable fortifying ingredient capable of improving the nutritional quality of cereal-based weaning foods that are often deficient in protein and essential micronutrients (Adegbusi et al., 2022).

In many developing countries, including Nigeria, complementary foods fed to infants are predominantly plant-based and consist mainly of cereals such as maize, millet, sorghum, and rice. Although these staples provide carbohydrates and some energy, they are generally inadequate in high-quality protein, essential amino acids, and critical micronutrients required for proper infant growth and development. Consequently, the inclusion of animal-source foods such as crayfish helps bridge nutritional gaps and contributes significantly to improved dietary quality during the complementary feeding period (Ibironke et al., 2014). Animal-source foods are particularly important in infant nutrition because they contain highly bioavailable proteins and micronutrients necessary for tissue synthesis, immune function, brain development, and skeletal growth. Crayfish is especially beneficial because it provides concentrated nutrients in relatively small quantities, making it suitable for incorporation into infant diets where meal volume is often limited by gastric capacity (Adegbusi et al., 2024).

In addition to its nutritional benefits, crayfish contributes desirable flavour and aroma to complementary foods, thereby enhancing palatability and acceptability among infants and caregivers. Its distinct umami taste improves sensory appeal and may encourage better feeding practices in households. According to Adegbusi et al. (2023), crayfish-fortified complementary foods generally demonstrate higher consumer acceptability compared to unfortified cereal porridges. Crayfish also represents a practical nutritional intervention in low-resource settings because it is relatively inexpensive compared to other animal protein sources such as meat, fish, eggs, and dairy products. Its widespread availability in local markets further supports its use in community-based complementary feeding programs aimed at reducing childhood malnutrition and micronutrient deficiencies (Adegbusi et al., 2022).

2.5.1 Nutritional Composition of Crayfish

Crayfish possesses an exceptionally rich nutritional composition characterized by high-quality protein, essential amino acids, minerals, vitamins, and beneficial fatty acids. Its nutrient density makes it highly suitable for fortifying traditional complementary foods consumed by infants and young children.

Compared with many plant-based ingredients, crayfish contains concentrated levels of highly digestible nutrients with superior bioavailability. This characteristic is particularly important during infancy because nutrient requirements are high while food intake capacity remains relatively limited (Ibironke et al., 2018).

2.5.1.1 High-Quality Protein

One of the most important nutritional attributes of crayfish is its exceptionally high protein content. Studies have shown that crayfish contains approximately 60–64% protein on a dry matter basis, with some Nigerian analyses reporting crude protein values as high as 64.14% (Adegbusi et al., 2024). Protein is one of the most essential nutrients required during infancy and early childhood because it supports rapid tissue growth, muscle development, enzyme synthesis, hormone production, and immune function. Protein deficiency during the complementary feeding period may result in severe nutritional disorders such as kwashiorkor, growth retardation, weakened immunity, and delayed cognitive development (WHO, 2020). Crayfish protein is regarded as high biological value protein because it contains all essential amino acids required for human growth and maintenance. Of particular importance is its rich content of sulfur-containing amino acids such as methionine and cysteine, which are commonly deficient in cereal-legume based complementary foods (Ibironke et al., 2014).

Most plant proteins used in complementary feeding, including soybean and cereals, possess limitations in one or more essential amino acids. Cereals are typically deficient in lysine, while legumes may contain lower amounts of methionine and cysteine. Crayfish effectively complements these deficiencies by supplying balanced amino acids that improve overall protein quality when incorporated into cereal-legume blends (Adegbusi et al., 2023). Methionine plays important roles in methylation reactions, detoxification processes, and synthesis of biologically important compounds such as creatine and glutathione. Cysteine contributes to antioxidant defence systems and protein structure formation. Adequate intake of these amino acids is particularly important during periods of rapid growth and cellular development in infancy (Wu, 2016).

Furthermore, crayfish protein demonstrates high digestibility due to its relatively low connective tissue content and absence of many anti-nutritional compounds associated with plant proteins. This enhances amino acid absorption and nutrient utilization in infants whose digestive systems are still developing (Ibironke et al., 2018). Studies evaluating complementary food formulations containing crayfish have consistently reported significant improvements in protein content and amino acid quality. Adegbusi et al. (2023) observed that maize-soybean-crayfish blends demonstrated superior protein quality and improved growth performance compared to cereal-only formulations.

2.5.1.2 Minerals (Calcium, Iodine and Others)

Crayfish is an exceptionally rich source of essential minerals required for healthy infant growth and physiological development. It contains substantial quantities of calcium, iron, zinc, phosphorus, magnesium, selenium, copper, potassium, and iodine, all of which contribute significantly to metabolic and developmental processes (Adegbusi et al., 2024). One of the most abundant minerals present in crayfish is calcium, with reported values ranging between 500–1,149 mg per 100 g dry matter. Calcium is critical for bone formation, teeth development, muscle contraction, nerve transmission, and blood clotting. Adequate calcium intake during infancy supports optimal skeletal development and reduces the risk of rickets and poor bone mineralization (Ibironke et al., 2018).

Iron present in crayfish contributes to haemoglobin synthesis and oxygen transport within the body. Iron deficiency remains one of the most widespread nutritional deficiencies among infants and young children in developing countries and is strongly associated with anaemia, poor cognitive development, weakened immunity, and reduced physical growth (WHO, 2020). Crayfish also supplies zinc, an essential trace mineral involved in immune competence, enzyme function, wound healing, and cellular growth. Zinc deficiency among infants has been associated with growth retardation, increased susceptibility to infections, and impaired neurological development (Brown et al., 2010).

Another nutritionally important component of crayfish is iodine. Iodine is required for thyroid hormone synthesis, which regulates metabolism, growth, and brain development. Inadequate iodine intake during infancy can lead to impaired mental development and developmental abnormalities. The inclusion of crayfish in complementary foods may therefore contribute significantly to preventing iodine deficiency disorders in vulnerable populations (Adegbusi et al., 2022).

Additionally, selenium present in crayfish functions as an antioxidant micronutrient that supports immune function and protects cellular components against oxidative damage. Magnesium and phosphorus further contribute to bone health and enzymatic activities necessary for energy metabolism (Ibironke et al., 2018). Because many cereal-based complementary foods are naturally low in these minerals, fortification with crayfish substantially improves micronutrient density and nutritional adequacy.

2.5.2 Role in Enhancing Protein Quality and Micronutrient Content

Crayfish plays a highly significant role in improving both the quantity and quality of nutrients in traditional complementary food formulations. When incorporated into cereal-based porridges such as maize, millet, or sorghum ogi, crayfish significantly increases protein concentration while improving amino acid balance and micronutrient composition (Adegbusi et al., 2023). Protein complementation is one of the major nutritional benefits associated with crayfish fortification. Most cereal proteins are deficient in lysine, while legumes may lack sufficient sulfur-containing amino acids. Crayfish provides these limiting amino acids and thereby improves overall protein utilization and biological value in composite complementary foods (Ibironke et al., 2014). Studies have shown that adding approximately 5–15% crayfish powder to cereal-based formulations markedly improves crude protein content and amino acid quality. Adegbusi et al. (2023) reported that maize-soybean-crayfish blends demonstrated superior protein digestibility and improved nutritional quality compared with unfortified cereal formulations.

Crayfish fortification also enhances micronutrient density by increasing calcium, iron, zinc, phosphorus, selenium, and iodine concentrations in complementary foods. These nutrients are frequently deficient in monotonous plant-based diets consumed by infants in low-resource settings (Adegbusi et al., 2022). The improved nutrient density resulting from crayfish supplementation contributes to better growth performance, stronger immunity, and reduced risk of nutrient deficiency disorders. This is particularly important during the complementary feeding period, when rapid physical and cognitive development occurs simultaneously. Furthermore, the umami flavour imparted by crayfish improves sensory acceptability and may increase food intake among infants. Better acceptability often translates into improved feeding frequency and enhanced nutrient consumption.

2.5.3 Digestibility and Bioavailability

Digestibility and nutrient bioavailability are critical considerations in infant nutrition because the immature digestive systems of infants may limit nutrient utilization from poorly digestible foods. Crayfish possesses excellent digestibility and high nutrient bioavailability, making it highly suitable for complementary feeding applications (Ibironke et al., 2014). Animal-source proteins generally exhibit superior digestibility compared to many plant proteins because they contain fewer anti-nutritional compounds such as phytates, tannins, and enzyme inhibitors. Crayfish proteins are therefore more efficiently broken down into absorbable amino acids within the gastrointestinal tract (Adegbusi et al., 2022).

High protein digestibility is especially important during infancy because rapid tissue synthesis requires continuous availability of amino acids. Easily digestible proteins support efficient growth, muscle development, enzyme synthesis, and immune responses. The minerals present in crayfish also demonstrate relatively high bioavailability. Calcium, iron, and zinc from animal-source foods are generally absorbed more efficiently than minerals derived from plant sources because they are less affected by phytates and fibre interference (Gibson et al., 2010).

Additionally, combining crayfish with vitamin C-rich foods such as fruits and vegetables may further enhance iron absorption and improve overall mineral utilization. Appropriate processing techniques such as drying, grinding, and controlled heating also contribute to improved digestibility and nutrient accessibility (Adegbusi et al., 2024). The high digestibility and bioavailability of crayfish therefore make it particularly valuable for infants recovering from illness, undernutrition, or poor appetite.

2.5.4 Use in Infant Food Formulations

In Nigeria, crayfish is extensively utilized in infant food preparation because of its nutritional richness, flavour-enhancing properties, affordability, and local availability. It is commonly processed into sun-dried powder and incorporated into complementary foods such as ogi, yam porridge, bean porridge, and cereal-legume blends (Adegbusi et al., 2022). The powdered form of crayfish is especially suitable for infant feeding because it disperses easily into foods, produces smooth-textured porridges, and minimizes chewing difficulties. Caregivers traditionally add small amounts of crayfish powder to infant meals to improve flavour and nutrient density without greatly altering consistency.

Several studies have evaluated the nutritional effects of crayfish-fortified complementary foods. Ibironke et al. (2014) reported that maize-soybean-crayfish blends exhibited significantly improved protein content, mineral composition, and sensory acceptability compared to maize-only formulations. Similarly, Adegbusi et al. (2023) found that formulations containing approximately 10% crayfish flour demonstrated superior protein quality, improved amino acid balance, enhanced calcium and iron concentrations, and better growth-supporting potential.

Crayfish supplementation also contributes to improved dietary diversity in infant feeding practices. Dietary diversity is considered an important indicator of nutrient adequacy and is strongly associated with improved nutritional status among children (WHO, 2021). Furthermore, the incorporation of crayfish into locally prepared complementary foods aligns well with culturally familiar feeding practices, thereby increasing the likelihood of sustained household adoption.

However, proper handling and hygienic processing are essential to ensure product safety. Poor drying and storage conditions may predispose crayfish to microbial contamination and spoilage. Therefore, adequate drying, airtight packaging, and hygienic preparation practices are necessary to maintain quality and safety in infant food applications (Adegbusi et al., 2024).

2.6. Processing Methods for Complementary Food Production

Complementary foods are nutrient-dense preparations, other than breast milk or infant formula, introduced to infants from around six months of age to meet their increasing nutritional needs alongside continued breastfeeding. Processing methods play a pivotal role in converting locally available staples, such as cereals (maize, millet, sorghum) and legumes (soybean, groundnut), into safe, digestible, palatable, and shelf-stable products suitable for young children. These methods significantly influence nutrient bioavailability, the reduction of anti-nutritional factors, microbial safety, and sensory acceptance (Hotz and Gibson, 2007; Oke, 2022).

2.6.1. Traditional Processing Methods

Traditional processing methods are low-cost, accessible techniques widely practiced at household or small-scale levels, particularly in resource-limited settings. These approaches enhance digestibility, reduce dietary bulk, and improve product safety using basic equipment and indigenous knowledge (Nout and Ngoddy, 1997).

2.6.1.1. Fermentation

Fermentation represents one of the oldest and most prevalent traditional methods for complementary food production. It involves the controlled activity of microorganisms, primarily lactic acid bacteria and yeasts, on cereal-legume slurries or doughs. This leads to acidification, partial hydrolysis of starches and proteins, and the generation of organic acids (Oke, 2022; Adeoye et al., 2018).

In typical practice, grains are soaked, wet-milled into slurry, and fermented naturally or with back-slopping for 24–72 hours at ambient temperatures. The process reduces pH, imparts a characteristic sour taste, decreases viscosity, and allows for higher nutrient density in porridges. Fermentation improves protein digestibility, elevates certain B-vitamins, and enhances mineral bioavailability through phytate degradation (Hotz and Gibson, 2007; Atuna et al., 2022). Research on maize-soybean or sorghum-soybean blends confirms that fermentation increases crude protein, fat, and fibre contents while improving sensory acceptability (Adeoye et al., 2018; Okoronkwo, 2023).

2.6.1.2. Roasting

Roasting, also known as toasting, entails dry-heat treatment of whole or milled grains and legumes at temperatures ranging from 150–200°C for short durations. This method develops desirable flavours via Maillard reactions, inactivates enzymes and certain anti-nutritional factors, and reduces moisture content for improved storability (Adeoye et al., 2018; Oke, 2022).

Roasted products exhibit high nutrient density owing to minimal water absorption and demonstrate extended shelf life when adequately protected. However, excessive heat may lead to losses in heat-labile vitamins. In complementary food applications, roasting of pearl millet, soybean, or cereal-legume blends enhances palatability and functional properties, including reduced bulk density (Atuna et al., 2022).

2.6.1.3. Drying

Drying, commonly achieved through sun-drying or air-drying, removes moisture to inhibit microbial proliferation and enzymatic activity, thereby preserving the food matrix. It is frequently combined with other unit operations such as fermentation or germination (Nout and Ngoddy, 1997).

In complementary food production, fermented or germinated slurries are dried into flours for convenient reconstitution into porridges. While drying substantially prolongs shelf life and supports year-round availability in seasonal climates, it requires careful management to minimise contamination and losses of sensitive nutrients, such as vitamins, from prolonged exposure (Hotz and Gibson, 2007).

2.6.2. Improved/Modern Processing Techniques

Improved and modern processing techniques integrate scientific control, mechanisation, and fortification to achieve greater consistency, safety, nutritional enhancement, and scalability. Prominent methods include germination (malting), extrusion cooking, drum drying, spray drying, and micronutrient fortification (Nout and Ngoddy, 1997; Oke, 2022). Germination activates endogenous enzymes that degrade starches and anti-nutrients, yielding low-viscosity, energy-dense porridges suitable for infants. Extrusion cooking, a high-temperature short-time process combining heat, pressure, and shear, produces gelatinised starches, inactivated anti-nutrients, and ready-to-eat or instant products with superior digestibility and hygiene (Duguma et al., 2021). Drum and spray drying generate instant flours with excellent rehydration characteristics. Modern processes frequently incorporate fortification with iron, zinc, and vitamins to combat prevalent micronutrient deficiencies (Hotz and Gibson, 2007).

These techniques generally provide superior nutrient retention, reduced processing variability, and enhanced safety relative to purely traditional approaches, although they often demand higher capital investment.

2.6.3. Effects of Processing on Key Attributes

2.6.3.1. Nutritional Quality

Processing methods generally enhance the nutritional quality of complementary foods by improving digestibility and bioavailability, although effects vary according to the technique and specific nutrient. Fermentation and germination increase protein digestibility, mineral absorption (through phytate reduction), and select vitamin levels, while simultaneously lowering dietary bulk to permit greater energy intake per feeding volume (Hotz and Gibson, 2007; Atuna et al., 2022).

Thermal processes such as roasting and extrusion promote starch gelatinisation and improve protein quality but can result in modest losses of heat-sensitive vitamins (e.g., vitamin C and some B-group vitamins). Optimally balanced processing maximises macronutrient retention and amino acid availability in cereal-legume composites (Oke, 2022; Gemede, 2020).

2.6.3.2. Anti-nutritional Factors

Anti-nutritional factors (ANFs), including phytates, tannins, trypsin inhibitors, and lectins, prevalent in cereals and legumes, impair nutrient bioavailability. Both traditional and improved processing methods effectively mitigate these compounds. Fermentation, soaking, germination, and roasting substantially reduce phytate and tannin levels via enzymatic degradation and leaching (Atuna et al., 2022; Hotz and Gibson, 2007). Extrusion and other thermal treatments inactivate heat-labile inhibitors such as trypsin inhibitors. These reductions markedly improve iron, zinc, and protein utilisation, rendering the foods more appropriate for infant nutrition (Duguma et al., 2021; Gemede, 2020).

2.6.3.3. Shelf Life

Processing extends shelf life primarily by decreasing water activity and microbial load.

Drying, roasting, and fermentation lower moisture content and pH, thereby suppressing spoilage organisms. Modern techniques such as extrusion, combined with appropriate packaging, further improve stability by eliminating vegetative pathogens and producing low-moisture, dense matrices (Nout and Ngoddy, 1997). Nevertheless, post-processing hygiene remains critical; well-optimised drying and roasting, supported by proper storage, can yield products stable for several months.

2.6.3.4. Sensory Properties

Sensory attributes including taste, aroma, texture, colour, and overall acceptability — are essential for consumption and sustained use. Roasting generates pleasant toasted flavours and improves texture, while fermentation produces characteristic sour notes that enhance palatability in many cultural contexts and reduce astringency from tannins (Adeoye et al., 2018). Extrusion and malting yield smoother, less viscous porridges favoured by infants. Optimised fermented or roasted cereal-legume blends frequently receive high sensory scores comparable to or exceeding commercial controls (Oke, 2022). Excessive processing, however, may occasionally introduce off-flavours.

2.7. Functional and Physicochemical Properties of Complementary Foods

Functional and physicochemical properties of complementary food flours and porridges determine their handling, reconstitution, cooking behaviour, nutrient delivery, and acceptability for infant feeding. These properties include water absorption capacity, bulk density, swelling capacity, and viscosity/pasting characteristics. They directly influence energy density, ease of preparation, digestibility, and the overall suitability of the food for young children with immature digestive systems (Oke, 2022; Hotz and Gibson, 2007).

2.7.1. Water Absorption Capacity (WAC)

Water absorption capacity refers to the ability of flour to absorb and retain water, expressed as grams of water absorbed per gram of sample. It is influenced by protein content, starch damage, fibre, and processing methods. Higher WAC often results from protein hydration and starch gelatinisation during processing such as fermentation, germination, or extrusion (Adeoye et al., 2018; Alomatu et al., 2025). In complementary foods, moderate to high WAC supports good reconstitution into smooth porridges but must be balanced to avoid excessive thickening that reduces energy density. Studies on cereal-legume blends report WAC values ranging from 1.6–2.5 g/g, with fermentation and malting sometimes lowering it due to enzymatic breakdown of macromolecules. Optimal WAC enhances mouthfeel and nutrient dispersion without requiring excessive dilution (Birungi et al., 2023; Omah et al., 2022).

2.7.2. Bulk Density

Bulk density (loose or packed) measures the mass per unit volume of flour and is a key indicator of packaging requirements and energy density in prepared porridges. It is expressed in g/ml or g/cm^3. Lower bulk density is preferred for complementary foods as it allows higher nutrient and energy intake per unit volume of porridge fed to infants (Anosike et al., 2020; Ayele, 2021). Typical values for complementary food flours range from 0.4–0.8 g/ml. Processing methods such as fermentation, germination, and extrusion generally reduce bulk density by altering particle structure and increasing porosity. High bulk density leads to thick, energy-dilute porridges that limit intake in infants with small stomach capacity. Optimised blends from millet, sorghum, soybean, or orange-fleshed sweet potato often achieve desirably low bulk density (Omah et al., 2022; Alomatu et al., 2025).

2.7.3. Swelling Capacity (Swelling Power/Index)

Swelling capacity indicates the extent to which flour particles or starch granules absorb water and expand upon hydration and heating. It is closely linked to starch gelatinisation and is expressed as grams of swollen sample per gram of dry matter or as a swelling index. Higher swelling capacity reflects good water-binding ability of starch and proteins (Fatima et al., 2025; Alomatu et al., 2025). In complementary food formulations, swelling capacity typically ranges from 3.0–9.5 g/g depending on the blend and processing. Fermentation and malting moderately increase swelling due to partial starch hydrolysis, while excessive thermal processing (e.g., high-temperature extrusion) may reduce it. Balanced swelling contributes to desirable porridge texture without excessive viscosity (Oke, 2022; Birungi et al., 2023).

2.7.4. Viscosity and Pasting Properties

Viscosity refers to the resistance to flow of the porridge, while pasting properties describe the behaviour of starch during heating and cooling, measured using instruments such as the Rapid Visco Analyser (RVA). Key parameters include peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, and pasting temperature (Anosike et al., 2020; Sobowale et al., 2025). High peak viscosity indicates thick porridges that require dilution, reducing energy and nutrient density. Complementary foods ideally exhibit low to moderate viscosity for easy swallowing. Traditional processing (fermentation, malting) and modern methods (extrusion) significantly lower viscosity by degrading starches and anti-nutrients, enabling energy-dense yet thin porridges. Pasting temperature reflects the point of starch gelatinisation, typically 70–85°C in cereal-legume blends. Lower setback viscosity indicates reduced retrogradation and better stability upon cooling (Amagloh et al., 2013; Duguma et al., 2021).

2.7.5. Importance in Infant Feeding (Ease of Swallowing, Digestibility)

These functional properties are critical for infant feeding because young children have limited gastric capacity, immature dentition, and developing digestive enzymes. Low bulk density and reduced viscosity permit higher energy and nutrient intake per feeding without causing satiety too quickly or requiring excessive liquid dilution, which would lower nutrient density (Hotz and Gibson, 2007; Oke, 2022).

Adequate water absorption and controlled swelling promote smooth, lump-free textures that facilitate swallowing and reduce choking risk. Lower viscosity and improved pasting stability enhance digestibility by increasing starch gelatinisation and reducing anti-nutritional interference with enzyme action. Processing methods that optimise these properties improve bioavailability of macronutrients and micronutrients while enhancing palatability and acceptance by infants and caregivers (Anosike et al., 2020; Ayele, 2021). Poor functional properties, such as excessively high bulk density or viscosity, contribute to inadequate intake, energy dilution, and suboptimal growth in infants. Therefore, formulation and processing are designed to achieve low bulk density (<0.7 g/ml), moderate WAC, controlled swelling, and low-viscosity pastes suitable for spoon-feeding or cup-feeding from 6 months of age.

Understanding and optimising the functional and physicochemical properties of complementary foods through appropriate raw material selection and processing is essential for developing safe, nutritious, and acceptable products that support optimal infant growth and development. Further studies on context-specific blends and processing interactions are recommended to refine these attributes.

2.8 Microbial Quality and Safety of Complementary Foods

Microbial quality and safety are among the most critical determinants of the nutritional effectiveness and health impact of complementary foods. Complementary foods are introduced to infants during a highly vulnerable stage of development when the immune system, gastrointestinal tract, and detoxification mechanisms are still immature. Consequently, infants and young children are particularly susceptible to foodborne infections and microbial toxins that may arise from contaminated weaning foods (Motarjemi et al., 1993).

In many developing countries, including Nigeria, complementary foods are commonly prepared under suboptimal hygienic conditions using locally available cereals, legumes, nuts, and animal-source foods. Although these foods may provide essential nutrients, contamination during cultivation, processing, storage, preparation, or feeding can compromise their safety and nutritional value. Contaminated complementary foods have been identified as major contributors to diarrhoeal diseases, gastrointestinal infections, malnutrition, and increased under-five mortality in low- and middle-income countries (Ogunniran, 2024).

The World Health Organization (WHO) and UNICEF have consistently emphasized that safe complementary feeding practices are essential for reducing childhood morbidity and mortality. According to WHO (2021), unsafe food and water contribute significantly to recurrent infections among infants, thereby impairing nutrient absorption and growth. Repeated exposure to microbial pathogens during early childhood may also lead to environmental enteric dysfunction, a chronic inflammatory condition of the intestine associated with poor growth and cognitive impairment (Müller-Hauser et al., 2022). Microbial contamination not only affects the safety of complementary foods but also influences sensory quality, shelf stability, and nutrient retention. Spoilage microorganisms may produce undesirable odours, flavours, and textures that reduce food acceptability, while pathogenic organisms and microbial toxins may cause acute or chronic health effects (Mekuria et al., 2021).

In Nigeria and many parts of sub-Saharan Africa, complementary foods are often prepared in households where refrigeration facilities, clean water supply, and food safety knowledge may be inadequate. As a result, microbial contamination remains a persistent public health concern. Locally prepared weaning foods frequently exhibit higher microbial loads compared to commercially processed alternatives due to prolonged holding at ambient temperatures and poor handling practices (Oluwafemi and Ibeh, 2011).

Ensuring microbial safety therefore requires a comprehensive approach involving proper agricultural practices, hygienic processing, effective preservation techniques, safe storage, and caregiver education on food hygiene.

2.8.1 Sources of Contamination

Contamination of complementary foods may occur at various stages along the food production and preparation chain, beginning from the farm level and continuing through processing, storage, distribution, preparation, and feeding. The multiple routes through which microorganisms gain access to complementary foods contribute significantly to the high prevalence of foodborne illnesses among infants in developing countries

(Achaglinkame et al., 2017).

Raw agricultural materials such as cereals, legumes, groundnuts, and animal-source ingredients may become contaminated during cultivation through contact with contaminated soil, irrigation water, animal waste, and untreated manure. Soil naturally contains various microorganisms including bacteria, fungal spores, and parasites that may adhere to harvested crops (Ogunniran, 2024).

Poor agricultural practices further increase contamination risks. The use of polluted irrigation water, exposure to animal faeces, and inadequate sanitation around farms contribute to microbial contamination of food ingredients even before harvest. According to Achaglinkame et al. (2017), cereals and legumes commonly used in complementary food production may harbour pathogenic microorganisms if proper agricultural hygiene is not maintained.

Post-harvest handling practices represent another major source of contamination. During drying, transportation, storage, and milling, food materials are frequently exposed to environmental contaminants including dust, insects, rodents, birds, and contaminated surfaces. In tropical regions such as Nigeria, high temperature and humidity conditions also favour microbial growth and spoilage during storage (Ojuri et al., 2018).

Household preparation practices significantly contribute to contamination of complementary foods. In many homes, porridges are prepared in large quantities and stored at ambient temperature for several hours before consumption. Such conditions create ideal environments for microbial proliferation, particularly for organisms such as Bacillus cereus and Staphylococcus aureus (Malik et al., 2021).

Water used for food preparation also serves as an important contamination source. Inadequately treated or contaminated water may introduce pathogenic bacteria, viruses, and protozoa into complementary foods. Motarjemi et al. (1993) noted that contaminated water used for reconstituting weaning foods significantly increases the risk of diarrhoeal infections among infants.

Unclean utensils, feeding bottles, spoons, plates, and storage containers further contribute to microbial contamination. Inadequate washing practices and use of contaminated cloths or sponges may facilitate the transfer of microorganisms onto prepared foods (Oluwafemi and Ibeh, 2011).

Caregivers themselves may act as sources of contamination through poor hand hygiene during food preparation and feeding. Pathogens may be transferred from hands to food following contact with contaminated surfaces, diapers, waste materials, or infected individuals. Flies and other insects additionally contribute to mechanical transmission of pathogens onto exposed foods (Malik et al., 2021).

Commercially manufactured complementary foods may also become contaminated if Good Manufacturing Practices (GMP), Hazard Analysis and Critical Control Point (HACCP) systems, and sanitation procedures are inadequate. However, industrially processed products generally exhibit lower microbial loads than home-prepared foods when produced under properly controlled conditions (Mekuria et al., 2021).

Overall, contamination sources are multifactorial and interconnected, necessitating integrated interventions across the entire food production and feeding chain.

2.8.2 Common Microorganisms Associated with Weaning Foods

Complementary foods are commonly contaminated with a wide range of microorganisms including bacteria, fungi, yeasts, viruses, and parasites. Among these, bacterial and fungal contaminants are most frequently reported in studies conducted across Nigeria and other developing countries (Ogunniran, 2024).

2.8.2.1 Bacterial Pathogens

Bacterial contamination represents one of the most significant microbiological hazards associated with complementary foods, particularly in developing countries where sanitation infrastructure, potable water supply, and food hygiene practices may be inadequate. Infants and young children are highly susceptible to bacterial infections because their immune systems and gastrointestinal defence mechanisms are still immature. The low gastric acidity of infants reduces the destruction of ingested pathogens, thereby increasing vulnerability to gastrointestinal colonization and infection (Motarjemi et al., 1993).

Complementary foods prepared under household conditions are especially prone to contamination due to improper handling, prolonged storage at ambient temperatures, contaminated water, poor personal hygiene, and exposure to environmental contaminants. Several studies conducted in Nigeria and other low-income countries have reported high bacterial loads in cereal-based porridges and locally prepared weaning foods, often exceeding internationally recommended microbiological limits (Oluwafemi and Ibeh, 2011; Islam et al., 2012).

The bacterial pathogens most frequently associated with complementary foods include Escherichia coli, Salmonella species, Staphylococcus aureus, Bacillus cereus, and Shigella species. These organisms are capable of causing diarrhoea, vomiting, fever, dehydration, malnutrition, and severe systemic infections in young children (Black et al., 1982).

2.8.2.1.1. Escherichia coli

Escherichia coli (E. coli) is one of the most important bacterial indicators of faecal contamination in foods and water. It is among the most commonly isolated bacterial pathogens from complementary foods prepared in households and informal food-processing settings. The organism originates primarily from human or animal faeces and enters food through contaminated water, poor sanitation, unwashed hands, contaminated utensils, and environmental exposure (Oluwafemi and Ibeh, 2011).
Although many strains of E. coli exist harmlessly in the intestinal tract of humans and animals, pathogenic strains possess virulence factors that enable them to cause disease. Important pathogenic strains associated with infant diarrhoeal diseases include enterotoxigenic E. coli (ETEC), enteropathogenic E. coli (EPEC), enterohaemorrhagic E. coli (EHEC), and enteroinvasive E. coli (EIEC) (Nataro and Kaper, 1998).

Enterotoxigenic E. coli is one of the leading causes of diarrhoea among infants in developing countries. It produces heat-labile and heat-stable enterotoxins that stimulate excessive secretion of water and electrolytes into the intestinal lumen, resulting in profuse watery diarrhoea and dehydration (Qadri et al., 2005). Persistent diarrhoea caused by ETEC contributes significantly to malnutrition and growth retardation among children. Enteropathogenic E. coli damages intestinal epithelial cells by attaching to and effacing the intestinal microvilli, thereby impairing nutrient absorption and intestinal barrier integrity. This may result in prolonged diarrhoea, poor nutrient utilization, and weight loss in infants (Nataro and Kaper, 1998).

Several studies conducted in Nigeria have reported frequent isolation of *E. coli* from homemade complementary foods and cereal porridges. Oluwafemi and Ibeh (2011) found significant levels of *E. coli* contamination in weaning foods prepared under poor hygienic conditions in southwestern Nigeria. Similarly, Islam et al. (2012) observed widespread contamination of complementary foods with faecal coliforms and pathogenic *E. coli* strains in household-prepared infant foods. The presence of *E. coli* in complementary foods is particularly concerning because it indicates possible contamination with other enteric pathogens. Infants infected with pathogenic *E. coli* may experience severe dehydration, weakness, electrolyte imbalance, and in severe cases, death if treatment is delayed (WHO, 2021). Repeated exposure to contaminated foods may also contribute to environmental enteric dysfunction, a chronic inflammatory disorder of the intestine associated with stunting and impaired cognitive development in children (Müller-Hauser et al., 2022).

2.8.2.1.2. Salmonella Species

Salmonella species are among the most important foodborne bacterial pathogens associated with contaminated complementary foods. These Gram-negative bacteria are widely distributed in the environment and may contaminate cereals, legumes, animal-derived foods, water, and food-processing surfaces (Black et al., 1982). Non-typhoidal *Salmonella* species are particularly implicated in foodborne gastroenteritis among infants and young children. Contamination of complementary foods may occur through contaminated raw ingredients, animal faeces, rodents, insects, poultry products, or cross-contamination during food preparation (Motarjemi et al., 1993).

One important characteristic of *Salmonella* is its ability to survive in dry food materials such as cereal flours and powdered complementary foods for prolonged periods. When these foods are reconstituted with water and stored at room temperature, the organisms can multiply rapidly to infectious levels (Forsythe, 2010). Salmonella infection, known as salmonellosis, is characterized by symptoms such as fever, nausea, vomiting, abdominal cramps, headache, and diarrhoea, which may be watery or bloody. In infants, severe fluid loss resulting from diarrhoea may rapidly lead to dehydration and electrolyte imbalance (Ryan et al., 2014). Young children are particularly vulnerable to invasive salmonellosis because of their immature immune systems. In severe cases, the bacteria may penetrate the intestinal mucosa and enter the bloodstream, causing septicemia, meningitis, and systemic infections that may become life-threatening (Crump et al., 2015).

Studies in developing countries have repeatedly isolated Salmonella species from cereal-based weaning foods and infant feeding utensils. Black et al. (1982) demonstrated that contaminated complementary foods play a major role in the transmission of enteric infections among children in low-resource settings. The risk of Salmonella contamination increases significantly when cooked porridges are stored at ambient temperatures for prolonged periods without refrigeration. Warm tropical climates such as those in Nigeria provide ideal conditions for bacterial proliferation (WHO, 2021). Furthermore, recurrent salmonellosis may contribute to poor nutrient absorption, reduced appetite, and impaired growth among infants and young children.

2.8.2.1.3. Staphylococcus aureus

Staphylococcus aureus is a Gram-positive bacterium commonly associated with human skin, nasal passages, hair, and hands. It is one of the most important bacterial contaminants introduced into complementary foods during handling and preparation (Horwitz, 1977). Food handlers are the major sources of S. aureus contamination. Poor handwashing practices, coughing, sneezing, and direct contact with prepared foods facilitate transfer of the organism onto complementary foods and feeding utensils (Jay et al., 2005).

One particularly dangerous characteristic of S. aureus is its ability to produce heat-stable enterotoxins in foods. These toxins remain active even after the bacterial cells have been destroyed by reheating or cooking. Consequently, foods that appear microbiologically safe may still cause illness if toxins were produced prior to heating (Forsythe, 2010). Complementary porridges stored at room temperature for several hours provide favourable conditions for the growth of S. aureus and subsequent toxin production. This is especially common in many Nigerian households where prepared weaning foods may be held for repeated feeding throughout the day (Motarjemi et al., 1993). Staphylococcal food poisoning is characterized by rapid-onset nausea, vomiting, abdominal pain, weakness, and diarrhoea. Symptoms may develop within a few hours after ingestion of contaminated food due to the action of pre-formed enterotoxins (Jay et al., 2005).

Although the illness is often self-limiting in adults, infants and young children may develop severe dehydration due to persistent vomiting and diarrhoea. In malnourished children, complications may become more severe because of weakened immunity and poor physiological reserves. Studies on household-prepared weaning foods in developing countries have frequently reported significant contamination with Staphylococcus aureus, indicating poor hygienic handling practices during food preparation and feeding (Oluwafemi and Ibeh, 2011). The organism therefore serves as an important indicator of poor personal hygiene and inadequate food handling practices in complementary feeding environments.

2.8.2.1.4. Bacillus cereus

Bacillus cereus is a spore-forming Gram-positive bacterium widely distributed in soil, dust, cereals, and raw agricultural products. It is commonly isolated from rice, maize, millet, sorghum, and cereal-based complementary foods because its spores naturally contaminate grains during cultivation and harvesting (Yeak et al., 2024). The spores of B. cereus are highly resistant to environmental stress and can survive drying, cooking, roasting, and mild heat treatments commonly used in food preparation. When cooked foods are improperly stored at ambient temperatures, the spores germinate into actively growing cells capable of producing toxins (Granum and Lund, 1997). Bacillus cereus produces two major types of toxins. The emetic toxin causes nausea and vomiting, while enterotoxins produced in the intestine cause abdominal cramps and watery diarrhoea (Ehling-Schulz et al., 2019). Cereal-based complementary foods are particularly susceptible to B. cereus contamination because the organism thrives well in starchy foods. Prepared porridges stored at room temperature for prolonged periods provide ideal conditions for bacterial multiplication and toxin production (Mekuria et al., 2021).

Several studies have reported high counts of B. cereus in complementary food flours and prepared infant porridges in developing countries. Yeak et al. (2024) documented significant contamination of cereal-based infant foods with Bacillus cereus spores capable of surviving processing conditions. Infants infected with B. cereus may develop diarrhoea, vomiting, dehydration, abdominal discomfort, and reduced nutrient absorption. Persistent gastrointestinal disturbances may worsen malnutrition and increase susceptibility to other infections. The risk associated with B. cereus highlights the importance of proper temperature control, immediate consumption of prepared foods, and hygienic storage practices.

2.8.2.1.5. Shigella Species

Shigella species are highly infectious Gram-negative bacteria responsible for shigellosis or bacillary dysentery. They are important enteric pathogens transmitted primarily through the faecal-oral route via contaminated food, water, and poor hygiene practices (Black et al., 1982). One notable characteristic of Shigella is its extremely low infectious dose. Ingestion of only a few bacterial cells may be sufficient to cause disease, making the organism highly transmissible in overcrowded environments with inadequate sanitation (Kotloff et al., 2018). Contamination of complementary foods typically occurs through the use of contaminated water, poor hand hygiene by caregivers, exposure to flies, and improper food handling practices. Prepared porridges held under unhygienic conditions may become important vehicles for transmission.

Shigellosis is characterized by fever, severe abdominal cramps, tenesmus, and diarrhoea that often contains blood and mucus. The disease causes inflammation and ulceration of the intestinal mucosa, resulting in painful dysentery (Kotloff et al., 2018). Infants and young children are particularly susceptible to severe complications including dehydration, malnutrition, seizures, and systemic infection. Repeated shigellosis episodes contribute significantly to undernutrition and growth impairment in low-income countries (Black et al., 1982).

Studies conducted in developing regions have consistently implicated contaminated weaning foods as important sources of *Shigella* transmission among children. Motarjemi et al. (1993) emphasized that poor food hygiene practices during complementary feeding significantly increase exposure to enteric pathogens including *Shigella* species. The high infectivity and severe clinical manifestations associated with shigellosis make it one of the most dangerous bacterial pathogens associated with complementary foods.

2.8.2.2 Fungi and Mycotoxins

Fungal contamination is one of the major microbiological challenges associated with complementary foods, especially in tropical and subtropical regions where warm temperatures and high humidity favour fungal growth and mycotoxin production. Cereals, legumes, groundnuts, and other ingredients commonly used in complementary food formulation provide suitable substrates for fungal colonization during cultivation, harvesting, processing, transportation, and storage (Pitt and Hocking, 2009). Unlike many bacterial contaminants that primarily cause acute infections, fungi associated with complementary foods often produce toxic secondary metabolites known as mycotoxins. These mycotoxins can persist in foods even after the fungal cells have been destroyed, making them particularly dangerous to infants and young children (WHO, 2023).

Infants are highly susceptible to the adverse effects of mycotoxins because their detoxification systems, liver function, immune responses, and gastrointestinal barriers are not fully developed. Chronic exposure to mycotoxins through contaminated complementary foods has been associated with stunting, immune suppression, impaired cognitive development, liver damage, nephrotoxicity, and increased susceptibility to infectious diseases (Ojuri et al., 2018). The major fungal genera commonly associated with complementary foods include Aspergillus, Penicillium, and Fusarium. These fungi contaminate staple crops such as maize, millet, sorghum, rice, and groundnuts, which form the basis of many complementary foods consumed in Nigeria and other developing countries (Pandey et al., 2023). Mycotoxin contamination is particularly problematic because many toxins are heat-stable and cannot be completely eliminated through ordinary cooking, roasting, boiling, or traditional processing methods. Consequently, prevention through proper agricultural practices, drying, storage, and handling remains the most effective control strategy (Xue et al., 2025).

2.8.2.1 Aspergillus Species

Aspergillus species are among the most important fungal contaminants associated with complementary foods worldwide. The species most frequently implicated in mycotoxin contamination are Aspergillus flavus and Aspergillus parasiticus, both of which produce highly toxic aflatoxins (Ojuri et al., 2018). These fungi thrive under warm and humid environmental conditions commonly found in tropical countries such as Nigeria. Poor drying practices, insect damage, high moisture content, and inadequate storage conditions greatly enhance fungal growth and aflatoxin production in cereals and groundnuts used for infant food preparation (WHO, 2023).

Aflatoxins produced by Aspergillus species include aflatoxin B1, B2, G1, and G2, with aflatoxin B1 regarded as the most toxic and carcinogenic. The International Agency for Research on Cancer (IARC) classifies aflatoxin B1 as a Group 1 human carcinogen because of its strong association with hepatocellular carcinoma (WHO, 2023). Chronic exposure to aflatoxins in infants and young children has been strongly linked to growth retardation, stunting, immune suppression, and impaired nutrient utilization. Aflatoxins interfere with protein synthesis, liver function, and intestinal integrity, thereby worsening malnutrition and susceptibility to infections (Gong et al., 2004).

Several studies conducted in sub-Saharan Africa have demonstrated significant associations between aflatoxin exposure and childhood stunting. Gong et al. (2004) reported that children with high aflatoxin exposure exhibited significantly lower height-for-age scores compared to less exposed children. Acute aflatoxin poisoning, known as aflatoxicosis, may also occur when heavily contaminated foods are consumed. Symptoms include vomiting, abdominal pain, jaundice, liver enlargement, haemorrhage, and potentially death due to acute liver failure (Williams et al., 2004).

In Nigeria, aflatoxin contamination is particularly prevalent in maize and groundnut-based complementary foods because these commodities are often stored under humid conditions favourable for fungal proliferation (Ojuri et al., 2018). Studies have reported aflatoxin levels exceeding internationally permissible limits in many locally prepared weaning foods. Apart from aflatoxins, Aspergillus species may also produce other toxic metabolites capable of suppressing immune responses and impairing growth in children. The persistence of aflatoxins despite cooking or roasting underscores the importance of preventive measures such as proper drying, sorting of mouldy grains, hermetic storage, and improved agricultural practices.

2.8.2.2.2. Penicillium Species

Penicillium species are important storage fungi commonly associated with cereals, legumes, fruits, and processed complementary foods. These fungi grow particularly well under cool to moderate temperatures combined with high moisture conditions during storage (Pitt and Hocking, 2009). Several Penicillium species produce dangerous mycotoxins, notably ochratoxin A and patulin. Ochratoxin A is one of the most significant mycotoxins associated with complementary foods and has been implicated in nephrotoxicity, immunotoxicity, teratogenicity, and carcinogenicity (Bennett and Klich, 2003).

Ochratoxin A primarily affects the kidneys and may impair renal function following prolonged exposure. In infants and young children, chronic ingestion of ochratoxin-contaminated foods may contribute to growth impairment, weakened immunity, and increased susceptibility to infections (Pfohl-Leszkowicz and Manderville, 2007). The toxin also interferes with protein synthesis and cellular metabolism, potentially affecting tissue growth and neurological development during infancy. Because young children consume more food relative to body weight compared to adults, they are particularly vulnerable to the toxic effects of ochratoxin exposure. Patulin, another toxin associated with some Penicillium species, is commonly found in mouldy fruits and processed foods. Patulin has been linked to gastrointestinal disturbances, nausea, vomiting, intestinal inflammation, and immune dysfunction (Bennett and Klich, 2003).

Storage conditions characterized by poor ventilation, elevated humidity, and inadequate drying significantly increase the risk of Penicillium growth and toxin production in complementary food ingredients. Studies conducted in developing countries have reported contamination of cereal-based infant foods with ochratoxin A, highlighting the need for improved post-harvest handling and storage practices (Pandey et al., 2023).

The prevention of *Penicillium* contamination requires proper moisture control, hygienic storage facilities, adequate aeration, and routine inspection of stored food materials for mould growth.

2.8.2.2.3. Fusarium Species

Fusarium species are field fungi commonly associated with cereals such as maize, sorghum, millet, rice, and wheat. These fungi infect crops during cultivation and may continue to proliferate during storage if environmental conditions remain favourable (Xue et al., 2025). *Fusarium* species produce several important mycotoxins including fumonisins, zearalenone, and trichothecenes such as deoxynivalenol (DON). These toxins represent significant public health concerns because of their multiple toxicological effects on humans and animals (Pandey et al., 2023).

Fumonisins are among the most extensively studied *Fusarium* toxins. They disrupt sphingolipid metabolism and interfere with cellular signalling pathways, membrane integrity, and tissue development (Marasas, 2001). Chronic exposure to fumonisins has been associated with oesophageal cancer, neural tube defects, liver toxicity, and growth impairment. In infants and young children, fumonisins may impair intestinal health and nutrient absorption, thereby contributing to undernutrition and developmental problems (Wild and Gong, 2010).

Zearalenone possesses estrogenic activity because of its structural similarity to natural estrogens. Exposure may interfere with hormonal regulation, reproductive development, and endocrine function. Although infants may be less exposed than adults, chronic low-level exposure through contaminated complementary foods remains a concern (Pandey et al., 2023). Trichothecenes such as deoxynivalenol inhibit protein synthesis and damage rapidly dividing cells within the gastrointestinal tract. Symptoms associated with trichothecene exposure include nausea, vomiting, diarrhoea, abdominal pain, immune suppression, and reduced appetite (Pestka, 2010).

One important challenge associated with Fusarium contamination is the frequent co-occurrence of multiple mycotoxins within the same food product. Cereal-legume blends used for complementary feeding may simultaneously contain fumonisins, zearalenone, and trichothecenes, thereby amplifying toxic effects through additive or synergistic interactions (Xue et al., 2025). Several studies conducted in Africa have reported significant contamination of maize-based complementary foods with Fusarium toxins, particularly fumonisins. Wild and Gong (2010) emphasized that chronic exposure to these toxins may contribute substantially to childhood growth impairment and poor health outcomes. Because Fusarium toxins are relatively stable during cooking and food processing, prevention relies mainly on pre-harvest and post-harvest interventions including resistant crop varieties, proper drying, insect control, and improved storage systems.

2.8.2.3. Pathogenic Protozoa

Pathogenic protozoa are transmitted primarily via faecally contaminated water or ingredients and are less frequently quantified in dry complementary food flours than bacteria or fungi. However, they pose significant risks in prepared porridges or when reconstitution uses unsafe water. Common protozoa include Giardia lamblia (causing giardiasis with persistent diarrhoea, malabsorption, and failure to thrive), Entamoeba histolytica (amebiasis leading to dysentery and potential liver abscesses), and

Cryptosporidium spp. (cryptosporidiosis, which causes severe watery diarrhoea, especially in malnourished or immunodeficient children). These organisms are resilient in the environment and can contaminate foods through poor hygiene or irrigation water. Studies in weaning contexts highlight their role in prolonged gastrointestinal infections during the complementary feeding period (Palmieri et al., 2018; Tsai et al., 2019). The microbial profile of complementary foods reflects prevailing environmental and hygiene conditions. Integrated control strategies targeting raw material quality, processing, and caregiver practices are essential to minimise exposure of vulnerable infants to these diverse pathogens.

2.8.3 Health Implications of Contaminated Foods

Consumption of microbiologically contaminated complementary foods has serious short-term and long-term health consequences for infants and young children. Foodborne infections contribute significantly to childhood morbidity, mortality, malnutrition, and impaired development worldwide (Motarjemi et al., 1993). One of the most immediate consequences of contaminated complementary foods is diarrhoeal disease. Pathogenic bacteria such as enterotoxigenic E. coli, Salmonella, and Shigella cause acute gastroenteritis characterized by diarrhoea, vomiting, abdominal pain, dehydration, and fever. Diarrhoeal illnesses are particularly dangerous in infants because they rapidly lead to fluid and electrolyte loss (Sheth, 2006). Repeated episodes of diarrhoea interfere with nutrient absorption, suppress appetite, and increase metabolic demands, thereby creating a vicious cycle between infection and malnutrition. Malnourished children are more susceptible to infections, while recurrent infections further worsen nutritional status (Müller-Hauser et al., 2022). Chronic exposure to contaminated foods may also contribute to environmental enteric dysfunction, a subclinical intestinal disorder characterized by inflammation, impaired intestinal barrier function, and reduced nutrient absorption. This condition has been strongly associated with stunting, poor growth, and cognitive impairment among children in low-income settings (WHO, 2021).

Mycotoxins present in contaminated complementary foods pose additional chronic health risks. Aflatoxins have been linked to hepatotoxicity, immunosuppression, growth retardation, and increased susceptibility to infectious diseases. Long-term exposure may also increase the risk of liver cancer later in life (Ojuri et al., 2018). Young children are particularly vulnerable because of their lower gastric acidity, immature detoxification systems, and developing gut microbiota, which reduce their ability to resist pathogen colonization and toxin exposure (Müller-Hauser et al., 2022). Furthermore, foodborne infections during infancy may negatively affect cognitive development, school performance, and productivity later in life. The cumulative impact of repeated exposure to unsafe foods therefore extends beyond immediate illness to broader developmental and socioeconomic consequences.

2.8.4 Preservation and Storage Techniques

Proper preservation and storage practices are essential for maintaining microbial safety, extending shelf life, and preserving the nutritional quality of complementary foods. Effective preservation methods reduce microbial growth, prevent toxin production, and minimize spoilage during storage and distribution (Tropea, 2022). Traditional preservation methods commonly used in Nigeria include sun-drying, roasting, smoking, fermentation, and toasting. Drying reduces moisture content and water activity, thereby limiting microbial growth and enzymatic reactions. Sun-drying remains widely practiced due to its low cost and accessibility, although improper drying conditions may expose foods to dust, insects, and environmental contaminants (Ogunniran, 2024).

Fermentation is another important traditional preservation technique that improves both safety and nutritional quality. During fermentation, beneficial microorganisms produce organic acids that lower pH and inhibit the growth of pathogenic bacteria. Fermentation also improves digestibility and reduces anti-nutritional factors in cereals and legumes (Mekuria et al., 2021). Roasting and toasting further contribute to microbial reduction by applying heat capable of destroying vegetative microbial cells and reducing moisture levels. These methods additionally improve flavour and shelf stability (Tropea, 2022).

Modern food preservation technologies such as extrusion cooking, spray-drying, pasteurization, vacuum packaging, and aseptic processing provide more effective microbial control. Extrusion cooking combines high temperature, pressure, and mechanical shear to destroy pathogens while producing low-moisture shelf-stable products suitable for complementary feeding (Mekuria et al., 2021).

Proper packaging is equally important in preventing recontamination and moisture absorption during storage. Airtight, moisture-proof packaging materials help maintain product stability and reduce microbial proliferation (Tropea, 2022).

For prepared complementary porridges, immediate consumption is generally recommended. If storage becomes necessary, refrigeration below 5°C or reheating above 60°C is essential to avoid microbial growth within the danger temperature zone of 5–60°C (Malik et al., 2021). Household hygiene interventions also play critical roles in food safety. These include proper handwashing before food preparation and feeding, use of clean utensils, boiling of water used in food preparation, and proper waste disposal. Caregiver education on hygienic preparation and safe storage practices significantly reduces microbial contamination risks (Motarjemi et al., 1993).

2.9. Previous Studies on Complementary Food Formulation

Over the past decade, several studies have formulated nutrient-dense complementary foods by blending locally available cereals with legumes (especially soybean), oilseeds (groundnut), and small animal proteins (notably crayfish). These efforts consistently show that adding soybean or groundnut to cereal porridges significantly boosts protein, fat, and micronutrient levels. For example, Anigo et al. (2010) found that 60:20:20 cereal:soybean:groundnut blends doubled protein content relative to plain maize porridge, with amino acid profiles meeting infant requirements and acceptable sensory scores. Similarly, Shiriki et al. (2015) reported that a maize:soy:peanut (60:30:10) blend attained 16–18% protein and ~470 kcal/100g, with protein quality (PER/NPR) improved by modest fortification (Figure 1). More recent work by Adegbusi et al. (2022) demonstrated that adding 10% crayfish (animal protein) to a maize–soy formula further raised nutritional scores, yielding the highest composite score among tested blends. Ogbonnaya et al. (2024) similarly reported that incorporating soybean, groundnut and crayfish into a maize/sorghum porridge significantly enhanced protein quality (higher serum protein and growth in rats) and improved taste compared to cereal-only diets. Across studies, formulated blends systematically outperformed traditional porridges in key nutrients (protein, energy, iron, zinc) and met or exceeded WHO/FAO requirements for infant foods, while generally obtaining good to very good acceptability in taste tests. Despite these successes, common gaps remain. Many studies used small sample sizes

or animal models rather than human feeding trials, limiting generalizability. Long-term efficacy and safety (e.g. mycotoxin contamination) are seldom assessed.
Methodological weaknesses include inconsistent processing protocols and lack of standardized acceptability testing. Few trials examine gender/age subgroup responses or storage stability. In summary, blends of soybean, groundnut and crayfish show clear nutritional benefits for complementary feeding, but larger-scale and longer-term studies are needed to confirm their impact under real-world conditions.
The table below summarizes major peer-reviewed studies on Complementary Food Formulation containing soybean, groundnut. All studies report higher protein, fat, and micronutrients in the blends vs. traditional porridges.

Table 2.1. Studies on Complementary Food Formulation

Study	Country	Ingredients / Formulation (w/w)	Processing Methods	Nutritional Outcomes (Protein, Energy, Micronutrients)	Sensory Acceptability	Microbial/ Safety
Anigo et al., 2010	Nigeria (Northwest)	Cereal mash (malted maize or sorghum/ millet) 60% + soybean 20% + groundnut 20%	Local processing: malting, boiling, roasting, milling	Crude protein 6.4–7.9 g/ 100g (dry basis) in gruels; lysine, methionine above FAO req.; Zn 74–108 ppm; Fe 177–477 ppm	Formulated gruels rated “good” acceptability; no significant sensory differences vs. plain cereal porridge	Total coliforms and aerobes low; no Salmonella or Shigella; occasional E. coli/Staph found
Shiriki et al., 2015	Nigeria (Makurdi)	Maize 60% + soybean 30% + peanut 10% (control), with 5–15% Moringa fortification	Standard home methods; flours blended, fed to rats	Protein ~16–17.6% with fortification; fat ~20–23%; energy ~448–473 kcal/100g; P/E improved (PER 1.77! 1.90); feed efficiency best at 10% Moringa	Sensory not the main focus (animal trial); composite "diet acceptability" not explicitly reported	Not assessed (animal trial)
Adegbusi et al., 2022	Nigeria (Kano)	MF: maize 100%; MSF: maize 72% + soy 28%; MSCF: maize 80% + soy 10% + crayfish 10%	Standard lab prep; flours mixed; analyses	Composite nutrient score used. MSCF had best profile by scoring (15 vs 20–31 for others); expected protein, fat, Ca, Fe, Zn vs maize.	Not reported (focus on composition)	Not reported (focus on composition)
Ogbonnaya et al., 2024	Nigeria (Port Harcourt)	Maize + sorghum base diets; soybean, groundnut, crayfish added (details unpublished)	Traditional processing; diets fed to rats	Inclusion of soybean, groundnut, crayfish ! higher serum proteins, RBC, Hb, PCV vs control; improved weight gain; protein	Sensory panel: only the sample with crayfish (no other additions) scored significantly better taste/ acceptability	Not reported

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was conducted in New Benin Market, Benin City, Edo State, Nigeria. Benin City is the capital of Edo State, located at approximately latitude 6°20'N and longitude 5°37'E, in the south-southern zone of Nigeria. The city is characterized by a tropical rainforest climate with high humidity and relatively high temperatures throughout the year, conditions that are particularly conducive to microbial activity. New Benin Market is one of the largest and most active markets in Benin City, serving as a major commercial hub for food commodities, agricultural produce, and processed goods. The market is densely populated with traders, consumers, and food vendors, making it a representative site for sourcing commercially available food ingredients used in the formulation of complementary foods. The high traffic volume and informal nature of food trading activities within this market environment provided an appropriate context for evaluating the quality of raw ingredients used in complementary food production for infant and young child feeding.

3.2 Sample Collection

Samples of three raw ingredients soyabean, groundnut, and crayfish were collected from New Benin Market, Benin City, Edo State. The samples were obtained from three different vendor stalls to account for inter-vendor variability and ensure representative sampling. Each ingredient was purchased in sufficient quantity and immediately transferred into properly labeled sterile polythene bags to maintain integrity and minimize microbial changes during transit. All samples were transported to the laboratory and processed within two hours of collection. The purchased raw ingredients were subsequently subjected to processing into powder form following established protocols, prior to analysis and formulation of the complementary food blends.

3.3 Sample Processing

3.3.1 Processing of Soyabean into Flour

Soyabean seeds were first washed thoroughly with distilled water to remove surface debris and extraneous matter. The cleaned seeds were then steeped in distilled water for 18 hours to facilitate adequate hydration prior to germination. Following steeping, the seeds were spread on perforated trays lined with moist muslin cloth and allowed to germinate for 72 hours under controlled conditions. After germination, the seeds were oven-dried at 50°C for 24 hours to reduce moisture content and halt further germination activity. Dehulling was subsequently carried out manually under aseptic conditions, ensuring clean surfaces and sterile hands and bowls were used throughout the process to prevent contamination. The dehulled seeds were then milled (ground) using a sterilized blender to produce a fine flour, which was further sieved using a 60 mm mesh sieve to obtain a uniform particle size. Separate sieves were used for individual samples to prevent cross-contamination. The resulting soyabean flour was collected and stored aseptically pending formulation (Agume et al., 2017).

3.3.2 Processing of Groundnut into Powder

Groundnut seeds were sorted to remove damaged, mouldy, and shrivelled kernels as well as any foreign materials. The sorted seeds were cleaned and manually dehulled to remove the outer shells. The dehulled groundnuts were then oven-dried at 40°C for 12 hours to reduce moisture content sufficiently. Following drying, the seeds were milled using a sterilized blender and the resulting material was processed into a fine powder form. The groundnut powder was stored under aseptic conditions until required for blending (Okaka, 2005).

3.3.3 Processing of Crayfish into Powder

Crayfish samples were sorted to remove all debris, broken shells, foreign materials, and damaged particles. The cleaned crayfish were oven-dried using very low heat to reduce moisture content while preserving nutritional quality and minimizing heat-induced deterioration. The dried crayfish were then milled using a sterilized blender to produce a coarse material, which was subsequently sieved (steveed) to obtain a fine, uniform crayfish powder. The powder was stored aseptically pending use in the formulation of complementary food blends (Ihekoronye & Ngoddy, 1985).

3.4 Formulation of Complementary Food Blends

Complementary food blends were formulated by combining the processed soyabean flour, groundnut powder, and crayfish powder in three different ratios, designated as Samples A, B, and C, with a commercially available complementary food product serving as the Control. The blending ratios were as follows:

Sample A: Soyabean (S) 70% : Groundnut (G) 20% : Crayfish (C) 10%

Sample B: Soyabean (S) 60% : Groundnut (G) 30% : Crayfish (C) 10%

Sample C: Soyabean (S) 50% : Groundnut (G) 40% : Crayfish (C) 10%

Each blend was prepared under aseptic conditions and mixed thoroughly to ensure homogeneity. The formulated blends were then packaged and stored appropriately pending microbiological, physicochemical, proximate, functional, and sensory analyses

(Okaka et al., 2002).

3.5 Preparation of Culture Media

All culture media were prepared in strict accordance with the manufacturers' instructions. The media employed in this study were Nutrient Agar (NA) for total heterotrophic bacterial enumeration and MacConkey Agar (MCA) for selective enumeration of Enterobacteriaceae.

3.5.1 Preparation of Nutrient Agar

Twenty-eight (28) grams of Nutrient Agar powder was dissolved in 1 litre of distilled water in a conical flask sealed with cotton wool and aluminium foil. The suspension was thoroughly mixed and sterilized by autoclaving at 121°C for 15 minutes. The medium was cooled to 45–50°C and dispensed aseptically into sterile petri dishes inside a laminar flow cabinet.

3.5.2 Preparation of MacConkey Agar

Fifty-five (55) grams of MacConkey Agar powder was dissolved in 1 litre of distilled water in a conical flask sealed with cotton wool and aluminium foil. The suspension was thoroughly mixed and sterilized by autoclaving at 121°C for 15 minutes. The medium was cooled to 45–50°C and dispensed aseptically into sterile petri dishes inside a laminar flow cabinet.

3.6 Microbiological Analysis

3.6.1 Bacterial Enumeration of Raw Ingredients and Formulated Blends

Microbiological analysis was carried out on both the raw ingredients before processing and on the formulated blends after processing. Ten gram (10 g) of each sample was weighed aseptically and placed in 90 ml of sterile peptone water, allowed to stand for 30 minutes to ensure proper homogenization. The resulting suspension was used as the primary inoculum. Appropriate volumes of the suspension were transferred aseptically to sterile petri plates. The prepared Nutrient Agar was poured aseptically for total heterotrophic bacterial enumeration, while MacConkey Agar was poured for selective enumeration of Enterobacteriaceae. All plates were incubated at 37°C for 24 hours. After incubation, colonies were counted using a colony counter, and results were recorded per dilution. The number of colony forming units per gram (cfu/g) was calculated using the formula:

$$cfu/g = \text{Number of colonies} / (\text{Volume plated} \times \text{Dilution factor})$$

3.7 Physicochemical Analysis

3.7.1 pH Determination

The pH of each sample was determined using a calibrated pH meter (Singh et al., 2012). The pH probe was submerged in each water-dissolved sample and held for a few minutes to achieve a stabilized reading before the value was recorded.

3.8 Functional Properties

3.8.1 Water Absorption Capacity

Water absorption capacity (WAC) was determined according to the method of AOAC (2010). Two grams (2 g) of each sample powder was weighed into a centrifuge tube and 20 ml of distilled water was added. The tube was shaken and allowed to stand at room temperature (25°C) for 30 minutes, after which it was centrifuged for 30 minutes at 2000 rpm. The excess water was decanted by inverting the tube, and the weight of water bound was determined by difference. Water absorption capacity was calculated using the formula:

$$WAC = (W2 - W1) / W0$$

Where W0 = weight of sample; W1 = weight of tube; W2 = weight of tube and sample after centrifugation.

3.8.2 Bulk Density

Bulk density was determined using the method of AOAC (2010). Twenty grams (20 g) of each sample was weighed into a 100 ml graduated cylinder. The cylinder was tapped ten times against the palm to consolidate the sample. The final volume was then read and bulk density (g/ml) was calculated using the formula:

$$\text{Bulk Density} = W1 / W2$$

Where W1 = mass of material; W2 = volume of material after tapping.

3.8.3 Dispersibility

Dispersibility was determined by the method described by Kulkarni et al. (1991). Ten grams (10 g) of each flour sample was weighed into a 100 ml graduated cylinder, and water was added to the 100 ml mark. The mixture was shaken vigorously and allowed to stand for 3 hours. The volume of settled particles was recorded and dispersibility was calculated as:

$$\text{Dispersibility (\%)} = 100 - \text{Volume of settled particles (ml)}$$

3.9 Proximate Composition Analysis

Proximate composition of all formulated blends was determined in duplicate using the methods of AOAC (2010), including moisture content, ash content, crude fibre, crude fat (lipids), crude protein, and nitrogen-free extract (carbohydrate) as described below.

3.9.1 Moisture Content Determination

Crucibles were oven-dried at 105°C for one hour to ensure complete dryness, then transferred into a desiccator to cool for approximately 30 minutes and weighed (W1). One gram (1 g) of sample was weighed into the pre-weighed crucible (W2). The crucible and content were oven-dried at 105°C for 3 hours, transferred to a desiccator to cool for about 10 minutes, and weighed (W3). The process was repeated until a constant weight was obtained. Moisture content was calculated as:

$$\% \text{ Moisture Content} = [(W2 - W3) / (W2 - W1)] \times 100$$

3.9.2 Ash Content Determination

Crucibles were pre-dried and weighed (W1). One gram (1 g) of sample was added to each crucible (W2). The crucibles containing samples were placed in a muffle furnace for 3 hours, then removed, reweighed, and returned to the furnace until a constant weight was achieved (W3). Ash content was calculated as:

$$\% \text{ Ash} = [(W3 - W1) / (W2 - W1)] \times 100$$

3.9.3 Crude Fat Determination

The dried sample was crushed to powder form to facilitate entry of the organic solvent. A filter paper was weighed (W1), and 1 g of sample was weighed onto the filter paper (W2). The conical flask of the Soxhlet extractor was half-filled with petroleum ether, and the sample-bearing filter paper was placed in the sample holder. The extractor was fitted with a reflux condenser and the heat source was adjusted. Extraction was carried out for over 5 hours at a condensation rate of 5–6 drops per second. The filter paper and residual sample were removed and oven-dried at 105°C for 1–2 hours until a constant weight was obtained (W3). Crude fat was calculated as:

$$\% \text{ Crude Fat} = [(W2 - W3) / W1] \times 100$$

3.9.4 Crude Protein Determination

Between 0.5 g and 1 g of each sample was weighed into a conical or volumetric flask. Ten millilitres (10 ml) of concentrated H_2SO_4 and 1 g of mixed catalyst (copper sulphate and sodium sulphate) were added. The flask was swirled to mix contents thoroughly and placed on a heat source for digestion for approximately 2 hours until the mixture turned whitish or clear light green. The digest was cooled and transferred to a 100 ml volumetric flask, made up to the mark with distilled water. Twenty-five millilitres (25 ml) of the diluted digest was introduced into the distillation tube along with 25 ml of 40% NaOH. Distillation was continued for at least 10 minutes, and the produced NH_3 was collected as NH_4OH in a conical flask containing 25 ml of 4% boric acid and methyl red indicator. Twenty millilitres (20 ml) of distillate was titrated against standard 0.1N HCl solution until a pink colour appeared. Crude protein was calculated as:

$$\% \text{ Crude Protein} = [(S \times N \times 0.014 \times D \times 100 \times 6.25) / (\text{Weight of sample} \times V)]$$

Where S = sample titration reading; N = normality of HCl; D = dilution after digestion; V = volume taken for distillation; 0.014 = milliequivalent weight of nitrogen.

3.9.5 Crude Fibre Determination

Two grams (2 g) of sample was weighed into a 250 ml volumetric flask (W0). One hundred millilitres (100 ml) of 1.25% sulphuric acid was added and boiled gently for 30 minutes. The mixture was filtered through muslin cloth and rinsed thoroughly with hot distilled water to remove all acid residues. The residue was returned to the flask, 100 ml of 1.25% NaOH added, and boiling continued for a further 30 minutes. The residue was filtered again, rinsed with hot distilled water, and transferred into a crucible with the addition of drops of acetone to neutralize remaining acid and base. The residue was oven-dried at 105°C for 2–3 hours, cooled in a desiccator, and weighed (W1). The crucible was then transferred to a muffle furnace at 300°C for 1 hour, cooled in a desiccator, and reweighed (W2). Crude fibre was calculated as:

$$\% \text{ Crude Fibre} = [(W1 - W2) / W0] \times 100$$

3.9.6 Nitrogen-Free Extract (Carbohydrate)

Carbohydrate content was determined by difference, using the following formula:

$$\text{NFE} (\%) = 100 - (\% \text{ Moisture} + \% \text{ Ash} + \% \text{ Fat} + \% \text{ Crude Protein} + \% \text{ Crude Fibre})$$

3.10 Sensory Evaluation

Sensory evaluation of the prepared porridges was carried out by mixing each formulated blend with water and pap (ogi). Panellists were selected from among trained assessors who evaluated the samples based on colour, aroma, taste, mouthfeel, and overall acceptability. A nine-point hedonic scale was employed, where 9 represented 'like extremely' and 1 represented 'dislike extremely'. The commercial complementary food product served as the control. Results were recorded and analysed accordingly.

3.11 Statistical Analysis

All analyses were conducted in duplicate, and results were expressed as mean ± standard deviation (SD). Data obtained were subjected to appropriate statistical analysis using descriptive statistics to compute means and standard deviations for all measured parameters.

CHAPTER FOUR

4.1. RESULTS

The total heterotrophic bacteria count of raw ingredients before processing is presented in Table 4.1. Counts ranged from 11.00 ± 2.83 $\times 10^5$ cfu/g in crayfish to 23.50 ± 7.78 $\times 10^5$ cfu/g in groundnut, while soybean recorded 16.00 ± 4.24 $\times 10^5$ cfu/g.

Table 4.2 presents the mean Enterobacteriaceae count of the raw ingredients before processing. No Enterobacteriaceae growth was observed in soybean, crayfish, and groundnut samples, as all samples recorded 0.00 ± 0.00 $\times 10^5$ cfu/g.

The total heterotrophic bacterial count of the formulated complementary food blends after processing is presented in Table 4.3. Counts ranged from 0.90 ± 0.28 $\times 10^5$ cfu/g (50% soybean : 40% groundnut : 10% crayfish) to 1.35 ± 0.35 $\times 10^5$ cfu/g (70% soybean : 20% groundnut : 10% crayfish), while the control recorded 1.05 ± 0.35 $\times 10^5$ cfu/g.

Table 4.4 shows the Enterobacteriaceae counts of the formulated blends after processing, which ranged from 1.50 ± 0.12 $\times 10^5$ cfu/g (60% soybean : 30% groundnut : 10% crayfish) to 9.50 ± 2.12 $\times 10^5$ cfu/g (70% soybean : 20% groundnut : 10% crayfish). The blend containing 50% soybean : 40% groundnut : 10% crayfish and the control recorded 8.50 ± 4.95 $\times 10^5$ cfu/g and 3.50 ± 2.12 $\times 10^5$ cfu/g, respectively.

Figure 4.1 shows the mean heterotrophic bacteria count and Enterobacteriaceae count of the formulated complementary food blends after processing. The heterotrophic bacterial counts ranged from 9.00 ± 2.83 $\times 10^5$ cfu/g (50% soybean : 40% groundnut : 10% crayfish) to 13.50 ± 3.54 $\times 10^5$ cfu/g (70% soybean : 20% groundnut : 10% crayfish), while Enterobacteriaceae counts ranged from 1.50 ± 2.12 $\times 10^5$ cfu/g (60% soybean : 30% groundnut : 10% crayfish) to 9.50 ± 2.12 $\times 10^5$ cfu/g (70% soybean : 20% groundnut : 10% crayfish). The figure further illustrates that the blend containing 70% soybean : 20% groundnut : 10% crayfish recorded the highest heterotrophic bacterial count and Enterobacteriaceae count among the formulated blends.

Table 4.5 presents the cultural, morphological, and biochemical characteristics of bacterial isolates from the formulated complementary food samples. The isolates identified included Staphylococcus aureus, Escherichia coli, Salmonella spp., Shigella sp., Enterobacter sp., and Bacillus subtilis.

Table 4.6 shows the frequency of occurrence of bacterial isolates. Staphylococcus aureus had the highest occurrence (26.67%), followed by Escherichia coli (20.00%). Salmonella spp. and Enterobacter sp. each recorded 16.67%, while Bacillus subtilis accounted for 13.33%. Shigella sp. had the lowest occurrence (6.67%).

The proximate composition of the formulated complementary food blends and the control sample is presented in Table 4.7. Moisture content ranged from 2.48 ± 0.69% (60% soybean : 30% groundnut : 10% crayfish) to 4.46 ± 0.65% in the control. Ash content ranged from 2.94 ± 1.38% in the control to 5.91 ± 0.04% (60% soybean : 30% groundnut : 10% crayfish). Crude fibre ranged from 1.75 ± 1.06% (50% soybean : 40% groundnut : 10% crayfish) to 3.75 ± 1.77% in the control. Crude fat values ranged from 29.90 ± 0.15% (50% soybean : 40% groundnut : 10% crayfish) to 32.97 ± 0.52% (60% soybean : 30% groundnut : 10% crayfish). Crude protein ranged from 15.30 ± 0.11% (50% soybean : 40% groundnut : 10% crayfish) to 22.53 ± 1.45% (70% soybean : 20% groundnut : 10% crayfish). Nitrogen-free extract ranged from 37.60 ± 2.50% (70% soybean : 20% groundnut : 10% crayfish) to 45.07 ± 0.41% (50% soybean : 40% groundnut : 10% crayfish).

Figure 4.2 presents the proximate composition of the formulated blends and control sample, showing variations in moisture, ash, crude fibre, crude fat, crude protein, and carbohydrate contents across all samples.

The functional properties and pH of the formulated complementary food blends are presented in Table 4.8. Bulk density ranged from 1.14 ± 0.02 g/ml (50% soybean : 40% groundnut : 10% crayfish) to 1.29 ± 0.00 g/ml (70% soybean : 20% groundnut : 10% crayfish). Dispersibility ranged from 58.00 ± 1.41% in the control to 70.00 ± 0.00% (70%

soybean : 20% groundnut : 10% crayfish) and (60% soybean : 30% groundnut : 10% crayfish). Water absorption capacity ranged from 0.63 ± 0.01 (70% soybean : 20% groundnut : 10% crayfish) to 0.92 ± 0.01 in the control. The pH values ranged from 5.85 ± 0.07 in the control to 6.05 ± 0.07 (70% soybean : 20% groundnut : 10% crayfish).

Table 4.9 presents the sensory evaluation scores of pap prepared from the formulated soyabean-groundnut-crayfish blends and the commercial complementary food (control). Colour scores ranged from 6.33 ± 0.82 (70% soybean : 20% groundnut : 10% crayfish) to 7.67 ± 0.66 in the control. Aroma scores ranged from 6.89 ± 0.57 (70% soybean : 20% groundnut : 10% crayfish) to 7.89 ± 0.57 in the control. Taste scores ranged from 6.33 ± 1.15 (70% soybean : 20% groundnut : 10% crayfish) to 7.67 ± 1.00 in the control. Mouthfeel scores ranged from 5.89 ± 0.99 (70% soybean : 20% groundnut : 10% crayfish) to 8.06 ± 0.83 in the control. Overall, the control sample consistently recorded higher sensory scores across all evaluated parameters.

Table 4.1: Total Heterotrophic Bacteria Count of Raw Ingredients before Processing

Raw Ingredients	Heterotrophic Bacteria Count ($\times 10^5$ cfu/g)
Soybean	16.00 ± 4.24
Crayfish	11.00 ± 2.83
Groundnut	23.50 ± 7.78

Values represented in mean± standard deviation

Table 4.2: Total Enterobacteriaceae Count of Raw Ingredients on Macconkay Agar Before Processing

Raw Ingredients	Enterobacteriaceae Count ($\times10^5$ cfu/g)
Soybean	0.00 ± 0.00
Crayfish	0.00 ± 0.00
Groundnut	0.00 ± 0.00

Values represented in mean± standard deviation

Table 4.3: Total Heterotrophic Bacteria Count of Formulated Blends After Processing (Mean ± Standard Deviation)

Formulated Blends	Heterotrophic Bacteria Count ($\times 10^5$ cfu/g)
A	1.350 ± 0.35
B	1.15 ± 0.35
C	0.90 ± 0.28
Control	1.05 ± 0.35

Values represented in mean± standard deviation

Keys:

A = Soyabean (70%) : Groundnut (20%) : Crayfish (10%)

B = Soyabean (60%) : Groundnut (30%) : Crayfish (10%)

C = Soyabean (50%) : Groundnut (40%) : Crayfish (10%)

Table 4.4: Mean Enterobacteriaceae Count of Formulated Blends on Macconkay Agar After Processing

Formulated Blends	Enterobacteriaceae Count ($\times 10^5$ cfu/g)
A	9.50 ± 2.12
B	1.50 ± 0.12
C	8.50 ± 4.95
Control	3.50 ± 2.12

Values represented in mean± standard deviation

Keys:

A = Soyabean (70%) : Groundnut (20%) : Crayfish (10%)

B = Soyabean (60%) : Groundnut (30%) : Crayfish (10%)

C = Soyabean (50%) : Groundnut (40%) : Crayfish (10%)

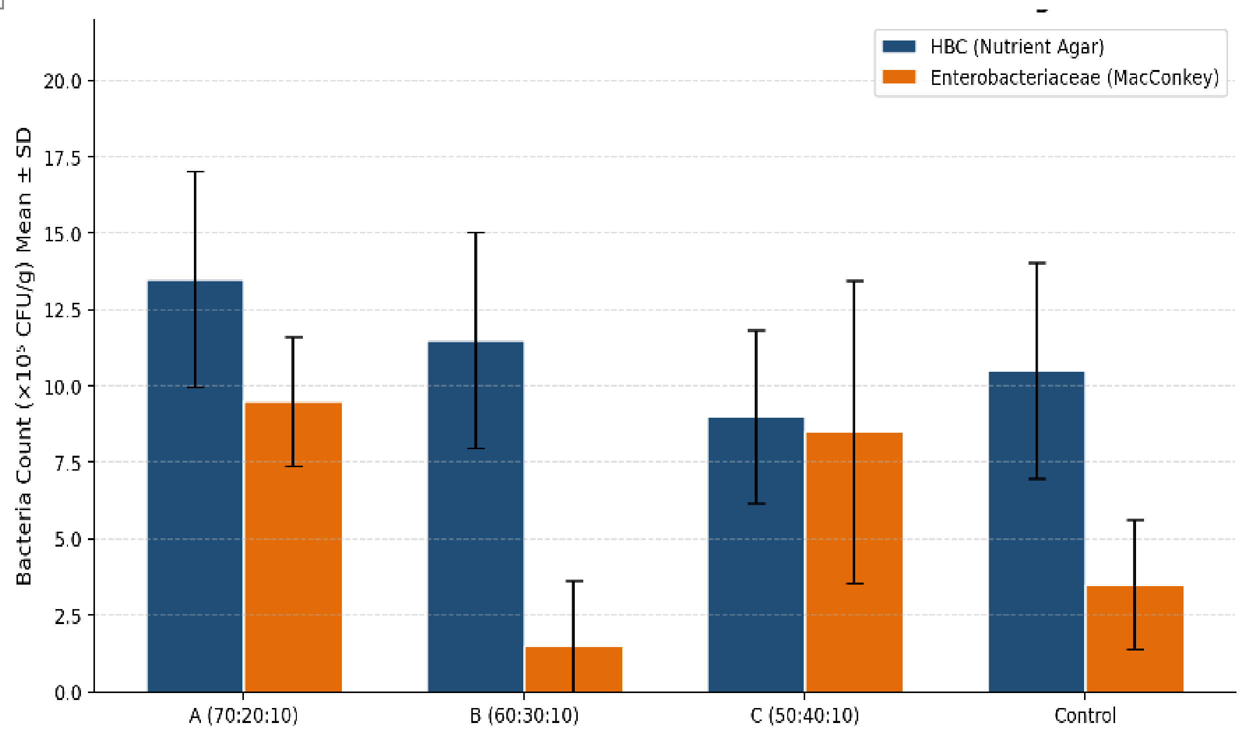

Figure 4.1. Mean Heterotrophic bacteria count and Enterobacteriaceae count of formulated blends after processing

Table 4.5: Cultural, Morphological and Biochemical Characteristics of Bacterial Isolates

Characteristics	IS1	IS2	IS3	IS4	IS5	IS6

Color	Creamy	Pinkish	Colourless	Colourless	Mucoid	Dry white
Size	Small	Medium	Medium	Small	Large	Large
Shape	Circular	Circular	Irregular	Circular	Mucoid	Irregular
Elevation	Raised	Flat	Raised	Flat	Raised	Flat
Margin	Entire	Entire	Undulate	Entire	Entire	Irregular
Opacity	Opaque	Translucent	Opaque	Transparent	Opaque	Opaque
Gram reaction	+	−	−	−	−	+
Morphology	Cocci	Rod	Rod	Rod	Rod	Rod
Cell arrangement	Clusters	Single	Single	Single	Single	Chains
Catalase	+	+	+	+	+	+
Indole	−	+	−	−	−	−
Oxidase	−	−	−	−	−	−
Citrate	−	−	+	−	+	+
Urease	+	−	−	−	+	−
Glucose (TSI)	+	+	+	+	+	+
Sucrose (TSI)	−	−	+	−	−	−
Lactose (TSI)	−	+	−	−	+	−
H_2S	−	−	+	−	−	−
Gas	−	+	−	−	−	−
Probable Bacterial Identity	Staphylococcus aureus	Escherichia coli	Salmonella spp.	Shigella sp.	Enterobacter sp.	Bacillus subtilis

Key: + = Positive reaction, − = Negative reaction, TSI (Triple Sugar Iron Agar)

Table 4.6: Frequency of Occurrence of Bacterial Isolates

Bacterial Isolate	Frequency	Percentage Occurrence (%)
Staphylococcus aureus	8	26.67
Escherichia coli	6	20.00
Salmonella spp.	5	16.67
Enterobacter sp.	5	16.67
Bacillus subtilis	4	13.33
Shigella sp.	2	6.67

Table 4.7: Proximate Composition of Formulated Blends

Sample	Moisture (%)	Ash (%)	Crude Fibre (%)	Crude Fat (%)	Crude Protein (%)	NFE (%)
A	2.50 ± 0.71	4.42 ± 3.45	2.50 ± 0.00	30.46 ± 3.11	22.53 ± 1.45	37.60 ± 2.50
B	2.48 ± 0.69	5.91 ± 0.04	2.75 ± 0.35	32.97 ± 0.52	18.28 ± 0.25	37.62 ± 0.57
C	3.50 ± 0.71	4.49 ± 2.14	1.75 ± 1.06	29.90 ± 0.15	15.30 ± 0.11	45.07 ± 0.41
Control	4.46 ± 0.65	2.94 ± 1.38	3.75 ± 1.77	30.21 ± 1.47	17.62 ± 0.03	41.02 ± 0.30

Values represented in mean± standard deviation

Keys:

A = Soyabean (70%) : Groundnut (20%) : Crayfish (10%)

B = Soyabean (60%) : Groundnut (30%) : Crayfish (10%)

C = Soyabean (50%) : Groundnut (40%) : Crayfish (10%)

NFE = Nitrogen-Free Extract (Carbohydrate); SD = Standard Deviation

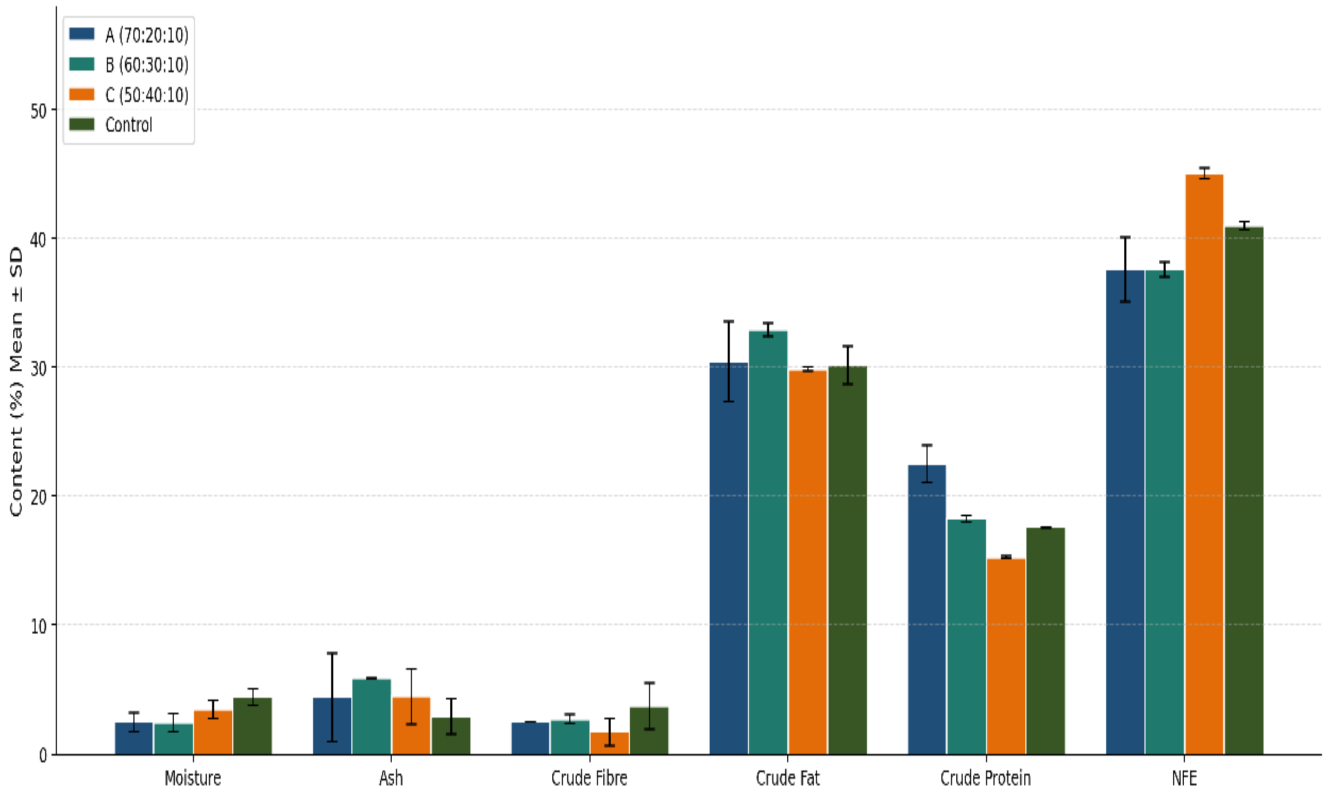

Figure 4.2. Proximate composition of formulated blends and control

Table 4.8: Functional Properties and pH of Formulated Blends

Sample	Bulk Density (g/ ml)	Dispersibility (%)	Water Absorption Capacity	pH Mean ±
A	1.29 ± 0.00	70.00 ± 0.00	0.63 ± 0.01	6.05 ± 0.07
B	1.21 ± 0.01	70.00 ± 0.00	0.70 ± 0.00	6.00 ± 0.00
C	1.14 ± 0.02	62.00 ± 0.00	0.64 ± 0.00	6.00 ± 0.00
Control	1.22 ± 0.02	58.00 ± 1.41	0.92 ± 0.01	5.85 ± 0.07

Values represented in mean± standard deviation

Keys:

A = Soyabean (70%) : Groundnut (20%) : Crayfish (10%)

B = Soyabean (60%) : Groundnut (30%) : Crayfish (10%)

C = Soyabean (50%) : Groundnut (40%) : Crayfish (10%)

Control = Commercial complementary food product

Table 4.9: Mean Sensory Scores of Pap Mixed with Soyabean, Groundnut and Crayfish Flour Blends and Control

Sample	Colour	Aroma	Taste	Mouthfeel

A	6.33 ± 0.82	6.89 ± 0.57	6.33 ± 1.15	5.89 ± 0.99
B	7.00 ± 1.05	7.67 ± 0.82	7.44 ± 1.06	7.00 ± 1.05
C	7.00 ± 1.63	7.33 ± 1.47	7.11 ± 1.20	6.44 ± 1.57
Control	7.67 ± 0.66	7.89 ± 0.57	7.67 ± 1.00	8.06 ± 0.83

Values represented in mean± standard deviation

Keys:

A = Soyabean (70%) : Groundnut (20%) : Crayfish (10%)

B = Soyabean (60%) : Groundnut (30%) : Crayfish (10%)

C = Soyabean (50%) : Groundnut (40%) : Crayfish (10%)

Scores are on a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely)

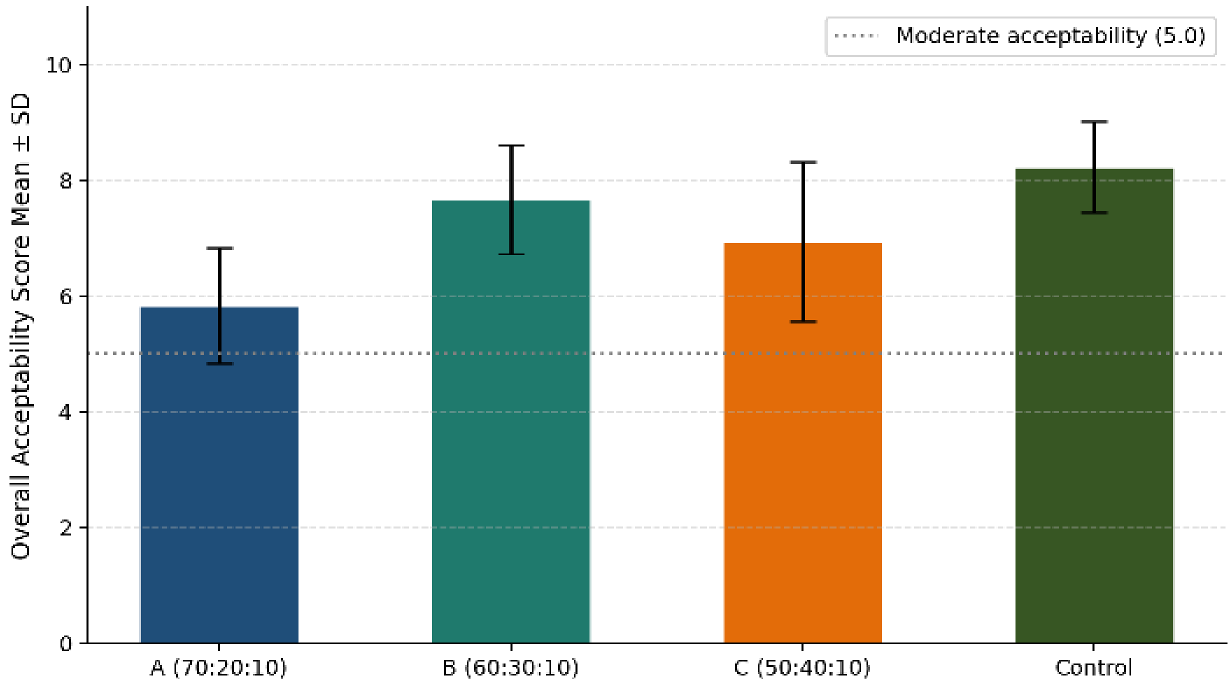

Figure 4.3. Overall acceptability score of blends (9-point hedonic scale)

Keys:

A = Soyabean (70%) : Groundnut (20%) : Crayfish (10%)

B = Soyabean (60%) : Groundnut (30%) : Crayfish (10%)

C = Soyabean (50%) : Groundnut (40%) : Crayfish (10%)

CHAPTER FIVE

DISCUSSION

The development and evaluation of complementary food blends from soybean, groundnut, and crayfish in this study yielded products with desirable nutritional, functional, sensory, and microbial characteristics that position them as viable alternatives to commercial options. The total heterotrophic bacteria count of raw ingredients before processing ranged from 11.00 ± 2.83 $\times 10^5$ cfu/g (Crayfish) to 23.50 ± 7.78 $\times 10^5$ cfu/g (Groundnut), while Soybean recorded 16.00 ± 4.24 $\times 10^5$ cfu/g. No Enterobacteriaceae growth was observed in soybean, crayfish, and groundnut samples, as all samples recorded 0.00 ± 0.00 $\times 10^5$ cfu/g. Following processing, the total heterotrophic bacterial count of the formulated blends ranged from 0.90 ± 0.28 $\times 10^5$ cfu/g (Sample C) to 1.35 ± 0.35 $\times 10^5$ cfu/g (Sample A), while the control recorded 1.05 ± 0.35 $\times 10^5$ cfu/g. Enterobacteriaceae counts of the formulated blends ranged from 1.50 ± 0.12 $\times 10^5$ cfu/g (Sample B) to 9.50 ± 2.12 $\times 10^5$ cfu/g (Sample A). Sample C and the control recorded 8.50 ± 4.95 $\times 10^5$ cfu/g and 3.50 ± 2.12 $\times 10^5$ cfu/g respectively. Sample A recorded the highest heterotrophic bacterial count and Enterobacteriaceae count, whereas Sample B recorded the lowest Enterobacteriaceae count among the formulated blends.

These reductions demonstrate the effectiveness of thermal processing methods in lowering microbial burdens, consistent with findings in related studies. For instance, Omosuli et al. (2019) reported total bacterial counts ranging from 28 to 50 $\times 10^4$ cfu/g, coliform counts of 18–37 $\times 10^4$ cfu/g, and yeast/mould counts of 40–62 $\times 10^4$ cfu/g in sweet potato-based complementary foods fortified with soybean and crayfish, all within recommended safe limits. Similarly, processing steps such as roasting and drying have been shown to significantly reduce microbial loads in cereal-legume-crayfish blends while maintaining product safety (Eze, 2017; Okoronkwo, 2023). In a study involving maize-soybean-crayfish formulations, Adegbusi et al. (2023) observed no adverse health effects or signs of infection in feeding trials, underscoring the microbial safety of properly processed blends incorporating crayfish (Adegbusi et al., 2022; Felix et al., 2022).

The observed post-processing counts in this study remain within tolerable limits for dry complementary food flours according to established guidelines (Codex Alimentarius Commission, 2013), yet they highlight the necessity for stringent process controls and good manufacturing practices. Higher Enterobacteriaceae in Sample A emphasizes potential recontamination risks or ingredient-specific factors that require optimization. Broader literature on complementary foods in sub-Saharan Africa consistently stresses that unhygienic handling, contaminated raw materials, or inadequate processing can elevate pathogenic risks, including Escherichia coli, Staphylococcus aureus, and Bacillus cereus (Mekuria, 2021). The current findings align with these observations and affirm that the applied processing methods effectively mitigated initial loads, supporting the safety of the formulations when prepared and stored appropriately. Nevertheless, routine monitoring and adherence to HACCP principles are essential to prevent post-processing contamination, particularly under tropical storage conditions prevalent in regions like Nigeria (Ilemobayo et al., 2024).

The bacterial isolates identified from the formulated complementary food samples included Staphylococcus aureus, Escherichia coli, Salmonella spp., Shigella sp., Enterobacter sp., and Bacillus subtilis. Staphylococcus aureus exhibited the highest frequency of occurrence (26.67%), followed by Escherichia coli (20.00%). Salmonella spp. and Enterobacter sp. both recorded 16.67%, while Bacillus subtilis and Shigella sp. recorded 13.33% and 6.67%, respectively. The predominance of Staphylococcus aureus and Escherichia coli is consistent with their common association with food handling environments and raw agricultural materials in tropical regions (Moges et al., 2024; Viana et al., 2025). These organisms, along with the detected enteric pathogens (Salmonella spp. and Shigella sp.), underscore the need for rigorous hygiene practices throughout the production chain to minimise potential health risks in complementary foods intended for infants. Similar microbial profiles have been reported in other locally formulated complementary foods in Nigeria, where S. aureus, E. coli, and Bacillus species were frequently isolated due to post-processing contamination or inadequate heat treatment (Ekong et al., 2022; Fasanmi et al., 2023).

The proximate composition results revealed moisture contents ranging from 2.48% to 4.46%, with the control sample exhibiting the highest value. These low moisture levels across all samples are advantageous for extended shelf stability, as they minimize the risk of microbial growth and enzymatic activities that could lead to spoilage (Iombor and Olumese, 2009). The moisture values obtained in this study are lower than those reported by Omosuli et al. (2019) for sweet potato-based complementary foods fortified with soybean and crayfish, which ranged between 6.50% and 8.50%. Ash content was notably higher in the formulated blends, peaking in Sample B at 5.91%. This elevation reflects the rich mineral profile contributed by crayfish and compares favourably with the ash content range of 5.50–9.50% documented by Omosuli et al. (2019). Such findings corroborate earlier reports that incorporation of crayfish or fish powder significantly boosts ash content and overall mineral density in weaning foods (Omueti et al., 2009; Adegbusi et al., 2022; Felix et al., 2022). Crude fibre values remained moderate, with the control recording the highest. This range supports gastrointestinal health in infants. The crude fibre levels in the present study are higher than the 0.13–0.27% reported by Omosuli et al. (2019), likely due to differences in ingredient proportions and processing techniques such as dehulling or roasting (Eze, 2017).

The crude fat content (29.90% to 32.97%) was relatively high, primarily due to the oil-rich nature of groundnut and soybean. This is substantially higher than the 4.20–6.20% reported by Omosuli et al. (2019), reflecting the lipid-dense composition of the current formulations. Crude protein levels ranged from 15.30% to 22.53%, with Sample A demonstrating the highest. These values, while slightly lower than the 25.10–28.50% range in Omosuli et al. (2019), highlight the success of the blends in achieving protein complementarity between legumes and crayfish. The protein contents compare favourably with or surpass those reported in several commercial samples and other local formulations (Iombor and Olumese, 2009; Okoronkwo, 2023; Felix et al., 2022; Ilemobayo et al., 2024). Nitrogen-free extract (carbohydrate) was highest in Sample C at 45.07%. This is lower than the 47.73–56.27% carbohydrate range documented by Omosuli et al. (2019), as expected given the higher fat and protein contributions in the soybean-groundnut-crayfish blends. Collectively, the proximate profiles indicate that the developed blends meet or exceed recommended nutritional benchmarks for complementary feeding, offering improved macronutrient balance suited to resource-limited environments (Adegbusi et al., 2023; Mbame et al., 2023).

Functional properties further affirmed the practical utility of the formulations. Bulk density values (1.14 to 1.29 g/ml), high dispersibility (up to 70%), and the pH range of 5.85 to 6.05 indicate mild acidity that promotes stability and palatability. These attributes align with those reported for thermally processed soybean-groundnut-crayfish diets (Omueti et al., 2009).

Sensory evaluation revealed generally acceptable scores across attributes on the 9-point hedonic scale, although the commercial control consistently received the highest ratings. Among the experimental blends, Sample B excelled in most sensory parameters. These outcomes are consistent with studies showing that moderate crayfish inclusion enhances sensory profiles in legume-based weaning foods (Iombor and Olumese, 2009; Omueti et al., 2009; Achidi et al., 2016; Ilemobayo et al., 2024; Abiamuwe et al., 2021).

The findings of this study demonstrate that soybean, groundnut, and crayfish blends, particularly Sample B, constitute nutritionally enhanced, affordable, and culturally relevant complementary foods capable of addressing protein-energy malnutrition in settings such as Nigeria. Nevertheless, certain limitations warrant acknowledgment. Future research should focus on advanced processing techniques, micronutrient fortification, comprehensive safety validation, and clinical feeding trials.

5.2 Conclusion

The present study successfully developed and evaluated improved complementary food formulations from blends of soybean, groundnut, and crayfish using locally available and affordable ingredients. The proximate analysis showed that the formulated blends had low moisture content, high ash, elevated crude protein levels (up to 22.53%), substantial crude fat, and adequate carbohydrates, making them nutrient-dense and suitable for complementary feeding. Functional properties confirmed their practicality for easy household preparation into smooth gruels. Sensory evaluation revealed that Sample B achieved the highest overall acceptability among the experimental blends, while microbial assessments indicated effective reduction in bacterial loads after processing, with counts within acceptable limits for dry flours.

Overall, the incorporation of crayfish significantly enhanced the nutritional profile through better protein quality and mineral content. The study demonstrates that optimized soybean, groundnut, and crayfish blends offer high-quality, culturally acceptable, and cost-effective alternatives to commercial complementary foods, with strong potential to help combat protein-energy malnutrition in resource-limited settings.

5.2 Contribution to Knowledge

This study contributes to knowledge in the following ways:

1. It provides empirical evidence that processing soybean, groundnut, and crayfish

into complementary foods significantly improved microbial quality, reducing total heterotrophic bacterial counts from 11.00–23.50 $\times 10^5$ cfu/g in raw ingredients to 0.90–1.35 $\times 10^5$ cfu/g in the finished products. The study also identified six bacterial species associated with the formulations, with Staphylococcus aureus showing the highest prevalence (26.67%).

2. It demonstrates the effect of ingredient proportions on nutritional quality, showing that Sample A (70% soybean, 20% groundnut, and 10% crayfish) recorded the highest crude protein content (22.53 ± 1.45%), while Sample B (60% soybean, 30% groundnut, and 10% crayfish) had the highest crude fat (32.97 ± 0.52%) and ash (5.91 ± 0.04%) contents.

3. It establishes that the formulated complementary foods possessed desirable functional properties, including bulk density (1.14–1.29 g/ml), dispersibility (62–70%), and pH (5.85–6.05), indicating their suitability for preparation and consumption as infant complementary foods.

4. It identifies Sample B (60% soybean, 30% groundnut, and 10% crayfish) as the optimum formulation, combining the best microbial quality, favourable nutritional composition, acceptable functional properties, and the highest sensory scores for aroma (7.67 ± 0.82), taste (7.44 ± 1.06), and mouthfeel (7.00 ± 1.05), thereby providing a cost-effective alternative to commercial complementary foods.

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