

**DEVELOPMENT OF SORGHUM-WHEAT BUNS
ENRICHED WITH GIANT AFRICAN LAND SNAIL
MEAT POWDER FOR IMPROVED PROTEIN AMONG
CHILDREN AGED 3-10 YEARS**

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**Development of Sorghum-Wheat Buns Enriched with Giant African
Land Snail Meat Powder for Improved Protein among Children
Aged 3-10 Years**

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**A Thesis Submitted in Partial Fulfilment of the Requirements for
the Degree of Doctor of Philosophy in Food Science and Nutrition of
the Jomo Kenyatta University of Agriculture and Technology**

2026

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

This thesis is dedicated to: Children aged 3 to 10 years, whose nutritional needs motivated the efforts to develop practical and sustainable solutions for improving protein intake.

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ACRONYMS AND ABBREVIATIONS

AACC	American Association of Cereal Chemists
AAS	Atomic Absorption Spectrophotometry
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
APD	Apparent Protein Digestibility
CFU	Colony Forming Units
CRD	Complete Random Design
DIAAS	Digestible Indispensable Amino Acid Score
EAR	Estimated Average Requirement
FAO	Food and Agriculture Organization
FER	Food Efficiency Ratio
IAA	Indispensable Amino Acid
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Funds for Agricultural Development
LSD	Least Significant Difference
NPRR	Net Protein Retention Ratio
NRC	National Research Council
PCA	Plate Count Agar

PDA	Potato Dextrose Agar
PDCAAS	Protein Digestibility Corrected Amino Acid Score
PEM	Protein Energy Malnutrition
PER	Protein Efficiency Ratio
SDG	Sustainable Development Goals
SMP	Snail Meat Powder
S-WB	Sorghum – Wheat Bun
TAC	Total Aerobic Bacterial Count
TCC	Total Coliform Count
TMC	Total Mould Count
TPD	Total Protein Digestibility
UNICEF	United Nations International Children's Emergency Fund
UNU	United Nations University
USDA	National Nutrient Database for Standard Reference
WFP	World Food Program
WHO	World Health Organization

DEFINITION OF OPERATIONAL TERMS

- Apparent Protein Digestibility** Protein digestibility from the faecal index
- Complementation** Compensation for a relative deficiency of amino acids of one protein by surplus from the amino acids of the other protein consumed together
- Controlled Trial** Direct comparison between two or more treatment groups, one of which serves as a control.
- Dietary Diversity** Variety of foods or food groups consumed as an indicator of diet quality and nutritional adequacy.
- Digestible Indispensable Amino Acid Score** Protein quality in food based on amino acid content and digestibility.
- In vitro Digestibility** A single or multi-enzyme assay to make available information on the efficacy of protein digestion or induced changes in protein quality.
- In vivo Digestibility** Protein digestibility index using an animal assay.
- Net Protein Retention Ratio** A growth assay taking into account proteins intended for both growth and maintenance of experimental animals fed on a protein-free diet.
- Protein Digestibility Corrected Amino Acid Score** Ability of proteins in the diet to provide the required amino acids and nitrogen to the human body.
- Protein Efficiency Ratio** Routine evaluation of protein quality in the human diet using growing animals.
- Sensory Evaluation** Characterization of food as perceived through sight, smell, taste, touch, and hearing.

Supplementation Provision of considerably large doses of micronutrients in the form of capsules, pills, or syrups.

True Protein Digestibility The principal in vivo protein digestibility index used to compute measures of PDCAAS

LIST OF PUBLICATIONS

1. **Agengo, B. F.**, Onyango, A. N., Serrem, C. A., & Okoth, J. (2020). Effect of Fortification with Snail Meat Powder on Physicochemical Properties and Shelf-life of Sorghum-Wheat Buns. *Current Nutrition & Food Science*. Vol. 16(5), pp. 749-756.
2. **Agengo, B. F.**, Onyango, A. N., Serrem, C. A., & Okoth, J. (2020). Efficacy of compositing with snail meat powder on protein nutritional quality of sorghum-wheat buns using a rat bioassay. *Journal of the Science of Food and Agriculture*. Vol. 100(7), pp. 2963-2970.
3. **Agengo, B. F.**, Onyango, A. N., Serrem, C. A., & Okoth, J. (2022). Effect of incorporation of snail meat powder on sensory attributes and consumer acceptability of sorghum-wheat buns. *Journal of Food Science & Nutrition*. Vol. 10, pp. 1820-1829.

ABSTRACT

Protein nutrition is important for human health because its deficiency results in public health problems such as Protein Energy Malnutrition (PEM). The situation is worse among children aged 3 to 10 years, a critical stage of physical development, where undernutrition results in irreversible effects, including delayed physical and cognitive development, as well as increased risk of infections and even mortality. Formulating cereal-based diets enriched with animal protein has been proposed as the most practical strategy to improve the nutritional quality of the diet. Buns are appropriate food vehicles because of their popularity among all age groups in rural and urban settlements due to their attractive features, including good eating quality, low cost, varied taste, and relatively long shelf-life. The main objective of this study was to formulate and develop sorghum-wheat buns enriched with snail meat powder for improved protein intake. Buns were prepared by replacing part of the sorghum-wheat flour with 5, 10, 15, 20, and 25% of SMP. Physical properties of volume, density, baking loss, yield, weight, hardness, and colour, proximate analyses including moisture, crude protein, crude fat, crude fibre, and ash, and mineral composition of iron, zinc, calcium, copper, and magnesium were determined for the buns. In vitro protein digestibility was tested using a single-enzyme assay with pepsin, whereas plate count agar and potato dextrose agar were used to enumerate the fungal and bacterial flora contaminating the buns during storage. Shelf-life determination for the buns was based on the number of days before the production of off-flavours and the presence of a fungal infestation. The protein nutritional quality of buns was evaluated on a Complete Randomized Design (CRD) with diets as treatments. Rats were randomly assigned to groups based on weight, forming the blocks, and each treatment was replicated three times within each block. Male weanling albino rats (*Sprague Dawley*) were used to determine the indices of PER, FER, NPRR, APD, and TPD. Bun amino acid efficiency was calculated using PDCAAS and DIAAS. Descriptive sensory and consumer acceptability with children followed RCBD that evaluated six variations of buns as treatments, which were randomized and replicated thrice with panelists as units and sessions as blocks. The adult consumer studies were based on the CRD approach. Randomized three-digit codes were assigned to the bun for blinding purposes, with sample arrangement on trays randomized for each panelist. The evaluation process was also randomized, with evaluators coming to the evaluation room at random to evaluate samples for acceptability. A descriptive panel was used to characterize the buns, and a consumer panel for acceptability using a 7-point facial scale with school children of 8-9 years old. Compositing with SMP progressively improved the buns' density, baking loss, yield, weight, and texture. Protein, fat, ash, energy, iron, zinc, calcium, magnesium, and copper were also increased. Enriching buns with between 5% and 25% SMP improved in-vitro protein digestibility. The maximum bacterial count in buns was below the International Microbiological Standard recommended units for dry and ready-to-eat foods of 10^3 cfu/g. Enriching with SMP also significantly ($P < 0.05$) enhanced protein efficiency ratio from 0.21% to 2.70%, food efficiency ratio from 0.02% to 0.27%, apparent protein digestibility from 81.17% to 88.28%, and true protein digestibility from 87.48% to 95.38%. Protein digestibility corrected amino acid score, and the digestible indispensable amino acid score increased from 45% to 78% and 44% to 69%, respectively, in unenriched buns to buns enriched with 25% SMP. Principal Component Analysis (PCA) revealed 99% total variation of 23 attributes for

buns scored by a descriptive sensory panel, of which 98% was due to the proportion of SMP that replaced sorghum-wheat composite flour in buns, and the remainder 1% was due to the buns' physical appearance. Compositing sorghum-wheat buns with SMP imparts positive consumer attributes of fine crumb, sponginess, and crumbly texture. Positive sensory score by school children of 8 to 9 years old for enriched buns was sustained throughout the three consumption sessions. The data obtained in this study indicate that incorporation with SMP imparted positive sensory characteristics associated with buns to the sorghum-wheat buns, and acceptance of such buns may be sustained over an extended period. Compositing sorghum-wheat flour with SMP is beneficial in formulating buns with superior protein and mineral quality in proportion to the amount of SMP added. Enriching with SMP also imparts positive physical characteristics of higher density, yield, and weight, reduces bun hardness and baking loss, and promotes better-keeping quality. In addition, enriching only at 5% with SMP significantly improved *in vitro* protein digestibility by 29% compared to the control. Enriching with SMP significantly promotes growth in rats, improves net protein retention, protein retention ratio, true protein digestibility, and protein digestibility corrected amino acid score of the sorghum-wheat buns to levels considered potential for use as supplementary or rehabilitation diets. Buns enriched at 25% with SMP have protein quality that promotes catch-up growth in emaciated rats, as assessed by the PER. Therefore, has the potential to alleviate PEM among children in developing countries.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Recent estimates indicate that nearly 820 million people are chronically undernourished (FAO/IFAD/UNICEF/WFP/WHO, 2023). A majority of them live in sub-Saharan Africa, where one in every four children is facing chronic hunger (UNICEF, 2024; WHO, 2024). Moreover, millions of resource-underprivileged households largely survive on cereals and other starchy staples with little or no animal protein (Adesogan, Havelaar, McKune, Eilitta, & Dahl, 2020). Cereal proteins are deficient in the indispensable amino acid lysine (Tomicic, et al., 2022). Thus, protein and energy malnutrition (PEM) is a significant burden in most developing countries, where nearly 12 million children are severely undernourished (UNICEF/WHO/WB, 2025). The situation is further aggravated by deficiencies in vital minerals such as calcium and iron (WHO, 2024; Titi-Lartey & Daley, 2025), resulting in stunted physical growth, intellectual impairment, and increased risk of morbidity and mortality (Alaaraj, Soliman, & Rogol, 2021). Hence, innovative, cost-effective approaches are required to improve the situation.

Snails are an excellent source of high-quality protein that averages 60-70% on a dry matter basis (Celik, et al., 2020) and rich in indispensable amino acid lysine (Ghosh, Jung, & Meyer-Rochow, 2017), which is the first limiting amino acid in plant-based diets widely consumed by economically deprived populations (Tomicic, et al., 2022). The amino acid profile in snail meat satisfies the demands for proper growth and development of infants and children (Ugwuowo, Ezeano, Osita, & Chukwuemeka, 2019). In addition, it is a good source of minerals such as calcium, iron, and zinc that are usually deficient in plant food-based diets (Nkansah, Agyei, & Opoku, 2021), as well as the two essential polyunsaturated fatty acids, linoleic and α -linolenic fatty acids (Nyoagbe, Appiah, Nketsia-Tabiri, Larbi, & Adjei, 2016), various vitamins, and energy (Nkansah et al., 2021). Thus, blending cereals with snail meat is an appropriate approach to promote protein and essential minerals intake in complementary diets to

manage PEM and alleviate hidden hunger in young children (Adeyeye, Bolaji, Abegunde, & Adesina, 2020).

Wheat is a unique cereal whose flour has distinct rheological properties and positive attributes for baking, and is therefore the most widely used in the development of baked products, including buns (Hughes, Vaiciurgis, & Grafenauer, 2020). Unfortunately, wheat production currently cannot meet industrial demands, partly due to challenges associated with global warming, leading to an increase in wheat prices (Enghiad, Ufer, Countryman, & Thilmany, 2017). One strategy a section of the baking industry has employed to cope with increasing wheat prices is to blend with other cereals such as sorghum (Saeed, Hong, Zheng, & Khashaba, 2023). Sorghum is a drought-resistant crop that thrives well in regions where other cereals have failed (Njinju, Gweyi, & Mayoli, 2022) and is a principal source of protein and energy for millions of resource-underprivileged households in Africa and Asia (Hariprasanna & Rakshit, 2017). However, it has a relatively lower protein quality and digestibility in wet cooking compared to other cereal proteins, such as maize (Tasie & Gebreyes, 2020).

Enrichment has been proposed as the most practical approach to improve the nutritional quality of supplementary diets in developing countries (Teye, Deha, Dadzie, & MacArthur, 2020). Combining lysine-rich foods with cereals that are good sources of sulphur-containing amino acids results in protein nutrition compensation (Burger & Zhang, 2019). Efforts to develop low-cost supplementary diets by blending cereals with animal proteins have been made in Kenya. Although snails have high nutritional value, they are not traditionally consumed by Kenyan communities, and their adoption might be easier as enrichment agents for commonly consumed foods such as buns. In a related study, it was demonstrated that substituting just 5% wheat flour with edible termite powder significantly enhanced protein, retinol, riboflavin, iron, and zinc content of buns between 16% and 53% and improved consumer acceptability of the products (Kinyuru, Kenji, & Njoroge, 2009). This study, therefore, was designed to evaluate the nutritional and sensory attributes of sorghum-wheat buns enriched with giant African land snail (*Achatina fulica*) meat powder for improved protein intake in children aged 3-10 years.

1.2 Problem Statement

Most developing countries continue to experience intense protein deficiency resulting from over-reliance on cereals or starchy staples as primary dietary sources (De Vries-Ten Have, Owolabi, Steijns, Kudla, & Melse-Boonstra, 2020). In these regions, many households are unable to afford protein-rich food sources due to a decline in per capita income (Erokhin et al., 2021) and reduced food production resulting from recurrent droughts and animal diseases (Dzavo, Zindove, Dhliwayo, & Chimonyo, 2019). These, coupled with the ever-increasing human population and rise in cost of living (FAO/IFAD/UNICEF/WFP/WHO, 2022), have negatively impacted the conventional animal protein sources, such as beef, goat, poultry, and pork (Emelue & Dododawa, 2017), making them too expensive for resource-underprivileged households, especially in sub-Saharan Africa (De Bruyn, et al., 2016). This has spurred greater demands for supplementary non-conventional animal protein sources, such as the giant African land snail (GALS), which is considered a nutritious and inexpensive source of high-quality protein widely appreciated by its consumers (Adeyeye et al., 2020). Notwithstanding, snail meat remains underutilized in the diets of most Kenyans and across the African continent due to cultural aversion, lack of familiarity, and a negative attitude towards its consumption.

1.3 Justification

GALS meat is a valuable source of high-quality protein (Celik, et al., 2020), whose amino acid profile meets the requirements for normal growth and development in children (Ugwuowo et al., 2019). It is also an excellent source of minerals like calcium, iron, and zinc, which are commonly low in cereal-based diets (Nkansah et al., 2021). Thus, it has the potential to supplement carbohydrate-rich diets, thereby contributing to the prevention and management of PEM in children (Nkansah et al., 2021). Wheat flour is the main ingredient in baking because of its unique properties of holding and retaining water vapour and carbon dioxide, resulting in the spongy feel of baked goods (Odedeji, Ojo, Arogundade, & Oyeleke, 2014). However, rising wheat prices, driven by increased consumption of wheat-based products such as buns, are currently posing a challenge to the bakery industry (Sibanda, Ncube, & Ngoromani, 2015). This has

spurred interest in the development of composite flours with other cereals, such as sorghum, to enhance baking flour functionality (Salim, Ahmed, Mohamed, ALSiddig, & Hamed, 2017).

Efforts to improve the nutritional quality of baked products through animal-based protein enrichment have been demonstrated in earlier studies. For example, bread enriched with chicken meat powder showed improved nutritional quality (Cakmak, Altinel, Kumcuoglu, & Tavman, 2013), whereas buns developed using wheat flour blended with ground termite powder recorded higher protein and mineral content as well as sustained consumer preference (Kinyuru et al., 2009). Equally, the acceptability of snail meat powder blended in the diet of breastmilk-weaned toddlers by young mothers as an alternative food formula further suggests its potential when incorporated into modern diets (Engmann et al., 2013). However, snail meat remains underutilized in the diets of many communities in Kenya and the African continent due to limited familiarity and cultural perceptions. This study addresses this gap by proposing the incorporation of snail meat into baked products such as buns, offering a practical and acceptable way to improve protein intake. The study focuses on the utilization of locally available ingredients to develop nutrient-dense supplementary foods. Therefore, contributing to strategies geared towards reducing protein deficiency, particularly among children in the complementary feeding stage, and enhancing the overall protein quality of plant-based diets in communities.

1.4 Objectives of the Study

1.4.1 Main Objective

To formulate and develop sorghum-wheat buns enriched with snail meat powder for improved protein intake among children aged 3-10 years

1.4.2 Specific Objectives

1. To develop sorghum-wheat buns enriched with snail meat powder
2. To determine the physical properties of sorghum-wheat buns enriched with snail meat powder

3. To evaluate the sensory acceptability of sorghum-wheat buns enriched with snail meat powder
4. To determine the nutrient composition of sorghum-wheat buns enriched with snail meat powder
5. To evaluate the protein nutritional quality of sorghum-wheat buns enriched with snail meat powder using a rat bioassay
6. To determine the keeping quality of sorghum-wheat buns enriched with snail meat powder

1.5 Hypotheses

- H₀₁:** There is no significant difference in the physical properties of sorghum-wheat buns enriched with snail meat powder
- H₀₂:** There is no significant difference in sensory acceptability of sorghum-wheat buns enriched with snail meat powder
- H₀₃:** There is no significant difference in the nutrient composition of sorghum-wheat buns enriched with snail meat powder
- H₀₄:** There is no significant difference in protein nutritional quality of sorghum-wheat buns enriched with snail meat powder using a rat bioassay
- H₀₅:** There is no significant difference in keeping quality of sorghum-wheat buns enriched with snail meat powder

CHAPTER TWO

LITERATURE REVIEW

2.1 Snails

Snails are bilateral invertebrate animals that are members of the phylum *Mollusca* and class *Gastropoda* (Jain, 2016). *Mollusca*, endowed with over 100,000 species, is the second largest phylum in the Kingdom Animalia (Haszprunar, 2020). This phylum includes slugs, oysters, squids, and cuttlefish that are characterized by a soft body, slippery skin, and a segmented exoskeleton in the form of calcareous shells (Jain, 2016). Snails are widely spread across the land, sea, and freshwater, with land species having a preference for moist environments, as seen in wet seasons (Ibrahim, Hamed, & Ghareeb, 2021). The land snail species are physiologically adapted to deal with cold (hibernation) and heat (aestivation), and this allows them to survive extended periods without any form of nourishment (Etukudo & Bassey, 2025). Snails are herbivorous, feeding on many vegetables, fruits, and plants, and calcium-rich sources such as carcass bones, sand, and small stones to maintain their shell durability (Snail-World, 2016).

Snails are natives of the East African coastal regions of Mozambique, Kenya, Tanzania, and Somalia (Gadekar, 2025), from where their spread to other parts of the world was due to their food and medicinal values (Ugwuowo et al., 2019). Snails have formed part of the human diet since prehistoric times (Pathak, Luitel, Utaaker, & Khanal, 2024), with significant evidence indicating that people in high forest zones consumed snail meat many thousands of years ago (Ohimain, Alikwe, Emasealu, & Orutugu, 2024). Snail meat (escargot) is a delicacy esteemed by some communities in the African continent, Europe, America, and Australia (Ohimain, Oku, & Charles, 2025). The snail family "*Achatinidea*" is the most edible species, with the giant African land snail being the most common in the human diet (Adeyeye et al., 2020). In contrast, snails are important vectors of human parasitic infections due to their feeding behaviour (Pathak et al., 2024). Hence, their meat should be adequately processed to ensure safety from a public health point of view.

In recent times, persistent droughts, increased animal diseases, and the high cost of animal feeds have resulted from the effects of global warming (Dzavo et al., 2019), causing a decrease in per capita income and numbers of conventional animal protein sources such as beef, goat, pork, and poultry (Emelue & Dododawa, 2017). All these, together with the ever-increasing human population and rise in costs of living (FAO/IFAD/UNICEF/WFP/WHO, 2022), make food too expensive for the resource-underprivileged households, leading to inadequate intake of high-quality animal proteins in the diet (Al Mamun, Yudhastuti, Mahmudiono, & Yaakob, 2025). Thus, consumption of mini-livestock such as snail meat should be promoted in human diets to help improve people's living conditions (Adeyeye et al., 2020). Indeed, snails have gained more attention as highly appreciated food sources occasioned by inadequate protein intake by most households in the tropics (Ohimain et al., 2024).

2.1.1 Snails Description

Mature adult snails comprise between 7 and 9 body whorls, which are somewhat swollen, and a sharp conical spire that is reddish-brown with pale yellow vertical markings (Etukudo & Basse, 2025). Adult snails can attain a maximum mature body size of above 20 cm in length and 10 cm in diameter (Etukudo & Basse, 2025). Snails are hermaphrodite animals that are known to practice sexual reproduction (Gadekar, 2025), unless in circumstances where their populations are too low, then self-fertilization will take place. They have prolific fecundity compared to conventional domesticated animals, such as livestock, and can continue laying eggs over an extended period after a single mating session (Al Mamun et al., 2025).



Figure 2.1: Giant African Land Snail (*Achatina fulica*)

Source: (Nkansah et al., 2021)

The egg-laying ability of snails begins immediately after they attain a sexual maturity age of about 8 to 12 months or when their body weight is approximately 110 g to 125 g, with an average production of 4 to 18 eggs between 1 to 2 minutes (Ohimain et al., 2024). Earlier, Gadekar (2025) reported that an average snail could lay between 5 and 11 eggs in a similar period and may continue to lay eggs on nests excavated in soil, leaves, or stone surfaces for another 8 to 20 days after a single copulation. A single snail may lay up to 100 eggs in the first year of life and another 500 eggs in the second year, with fecundity declining in the second year of life (Snail-World, 2016). Thus, in their average five-year lifespan, snails could continue to lay up to 1,000 egg clutches (Roda, Nachman, Weihman, Yong Cong, & Zimmerman, 2016). Snail eggs could hatch in about 11 days in humid tropical conditions and attain adult size in almost 6 months (Ohimain et al., 2024). On average, snails live for about 5 to 7 years, but may live close to 9 or 10 years under favourable environmental conditions, without predation leading to their mortality (Snail-World, 2016).

2.1.2 Nutrient Composition of the Snail Meat

Snails are good sources of high-quality protein, which averages about 60 to 70 g/100 g on a dry matter basis (Celik, et al., 2020), and excellent sources of indispensable amino acids lysine (Ghosh et al., 2017). Snail meat protein compares in quality and digestibility favourably to conventional animal sources such as poultry eggs and flesh (Pathak, et al., 2025). Earlier, Nyoagbe, et al. (2016) noted that snail meat presents an

important source of essential fatty acids, linoleic and α -linolenic acids, and is low in cholesterol and sodium (Ohimain et al., 2024). In addition, it is a good source of vitamins and Energy (Nkansah et al., 2021). Ohimain et al. (2024) established that snail meat is a significant source of vital minerals such as calcium, phosphorus, potassium, zinc, iron, and copper.

Table 2.1: Nutrient Composition of Snail, Chicken, Beef, and Pork per 100 g

Nutrient	Unit	Values per 100 g			
Proximate		Snail	Chicken	Beef	Pork
Water	G	79.20	79.33	69.50	60.60
Energy	kJ	377	-	770	-
Energy	Kcal	90	94	184	247
Protein	G	16.10	17.66	13.40	15.30
Total lipid (fat)	G	1.40	2.06	14.60	19.87
Ash	G	1.30	-	1.40	-
Carbohydrate, by difference	G	2.00	0.00	1.10	0.73
Fibre, total dietary	G	0.0	0.0	0.2	0.0

Adapted from the USDA National Nutrient Database for Standard Reference Release 28 (2018).

Table 2.2: Proximate Composition of Three Achatina Species Meat Powder

Nutrient	Unit	Value per 100 g (mean \pm SD)		
Proximate		A. marginata	A. achatina	A. fulica
Moisture	G	5.2 \pm 0.05	6.1 \pm 0.01	4.88 \pm 0.01
Fat	Kcal	4.37 \pm 0.06	5.06 \pm 0.14	2.27 \pm 0.16
Protein	G	85.12 \pm 2.14	71.66 \pm 1.24	62.56 \pm 1.23
Fibre	G	1.32 \pm 0.15	1.21 \pm 0.03	0.03 \pm 0.01
Ash	G	3.06 \pm 0.02	3.49 \pm 0.01	3 \pm 0.01
Carbohydrate	G	2.25 \pm 0.11	13.69 \pm 0.15	27.29 \pm 1.21
Energy	kJ	1646.98 \pm 8.68	1638.17 \pm 6.53	1611.44 \pm 8.6

Adapted from Nkansah et al. (2021).

Table 2.3: Nutrient Composition of Snail Meat per 100 g

Nutrient	Unit	Value per 100 g
Proximate		
Water	G	79.20
Energy	kJ	377
Protein	G	16.10
Total lipid (fat)	G	1.40
Ash	G	1.30
Carbohydrate, by difference	G	2.00
Fibre, total dietary	G	0.0
Minerals		
Calcium, Ca	Mg	10
Iron, Fe	Mg	3.50
Magnesium, Mg	Mg	250
Phosphorus, P	Mg	272
Potassium, K	Mg	382
Sodium, Na	Mg	70
Zinc, Zn	Mg	1.00
Vitamins		
Vitamin C, total ascorbic acid	Mg	0.0
Thiamine	Mg	0.010
Riboflavin	Mg	0.120
Niacin	Mg	1.400
Vitamin B-6	Mg	0.130
Folate, DFE	µg	6
Vitamin B-12	µg	0.50
Vitamin A, RAE	µg	30
Vitamin A,	IU	100
Vitamin E (α -tocopherol)	Mg	5.00
Vitamin D (D2 + D3)	µg	0.0
Vitamin	IU	0
Vitamin K (Phylloquinone)	µg	0.1
Lipids		
Fatty acids, total saturated	G	0.361
Fatty acids, total monounsaturated	G	0.259
Fatty acids, total polyunsaturated	G	0.252
Cholesterol	Mg	50

Adapted from the USDA National Nutrient Database for Standard Reference Release 28 (2018).

Table 2.4: Mineral Composition of Three Achatina Species Meat Powder

Nutrient	Unit	Values in mg/100 g (mean \pm SD)		
		<i>A. marginata</i>	<i>A. achatina</i>	<i>A. fulica</i>
Proximate				
Na	Mg	67.64 \pm 0.19	58.09 \pm 0.12	73.38 \pm 0.27
K	Mg	111.43 \pm 0.46	114.65 \pm 0.44	111.02 \pm 0.3
Ca	Mg	701.79 \pm 4.32	656.9 \pm 5.46	402.29 \pm 5.18
Mg	Mg	308.7 \pm 0.42	304.62 \pm 0.19	301.2 \pm 0.33
P	Mg	268.53 \pm 5.34	241.9 \pm 11.3	61.29 \pm 11.34
Zn	Mg	8.41 \pm 0.12	6.28 \pm 0.1	5.81 \pm 0.1
Fe	Mg	6.33 \pm 0.05	5.75 \pm 0.05	26.64 \pm 0.26
Mn	Mg	0.73 \pm 0.04	0.17 \pm 0.03	1.29
Cu	Mg	0.98 \pm 0.03	0.73 \pm 0.02	3.83 \pm 0.08

Adapted from Nkansah et al. (2021).

2.1.3 Influence of Snails on Human Health

There is a link between good nutrition and better health that has led most people to seek advice on diets and how they help manage diseases. Snail meat is an excellent source of protein (Celik, et al., 2020), rich in the indispensable amino acid lysine (Ghosh et al., 2017), responsible for repairing worn-out cells and body tissues (Tanyitiku, 2022). Thus, the amino acid profile of snail meat makes it suitable to complement carbohydrate diets (Nkansah et al., 2021), which is vital in preventing and managing PEM. Similarly, the two principal polyunsaturated fatty acids, linoleic and α -linolenic, present in snail meat are suitable for slowing the occurrence of arteriosclerosis and other heart-related diseases (Ghosh et al., 2017). Also helps to regulate prostaglandin metabolism, platelet aggregation, and other vascular activities vital for health (Ohimain et al., 2025).

Snail meat is an important source of essential minerals, calcium, iron, phosphorus, zinc, potassium, and copper (Ohimain et al., 2024) required to promote optimal cognitive development and health as children transition to solid foods (Hamner, Perrine, & Scanlon, 2016). Iron is essential for managing anaemia, a major public health problem linked to impaired cognition, psychomotor, and intellectual development (Yu, et al., 2023). Calcium contributes to the development of stronger bone mass (Thandrayen & Pettifor, 2018), while zinc is involved in protein and DNA synthesis (Yu, et al., 2023). Snail meat is also a good source of glandular substances

with the potential to cause agglutination of bacteria, thereby preventing ailments related to bacterial invasion (Al Mamun et al., 2025). Correspondingly, snails secrete antimicrobial peptides on their surface mucus, which inhibit both Gram-positive and Gram-negative bacteria (Ohimain et al., 2025).

2.1.4 Acceptability of Snail Meat in the Human Diet

Consumer acceptability of snail meat in the diet varies across religious and cultural contexts. For instance, helix species are delicacies in many European cuisines, while GALS are traditionally eaten in parts of Sub-Saharan Africa due to their pleasant taste, chewy texture, and mushroom-like flavour (Tanyitiku, 2022). Snail meat is a savoury delicacy prepared using traditional methods or seasoned with ingredients such as olive oil, salt, vinegar, and rosemary, depending on cuisine and consumer preference (Pissia, Matsakidou, & Kiosseoglou, 2021). Likewise, preference is influenced by familiarity with the product and sensory attributes. Kougiagka, Apostologamvrou, Giannouli, and Hatzioannou (2022) reported that physical characteristics of size and colour affected the acceptability of snail meat among its consumers, while unfamiliarity influenced acceptance of snail meat in the diet (Adeola, et al., 2022).

Acceptance of novel foods, such as snail meat, may be enhanced if they are presented as an ingredient in a product. Engmann, Afoakwah, Darko, and Sefah (2013) showed that young mothers valued snail meat incorporated in powder form as an alternative food formula for breastmilk-weaned toddlers, suggesting its potential to be blended in modern products. Snail meat is prepared by removing the shell, thoroughly washing the flesh in saline water, and boiling (Ghosh et al., 2017). Whereas, consumption of raw or undercooked snail meat is discouraged as it is associated with the transmission of infectious diseases, including angiostrongyliasis (Pathak et al., 2024). Therefore, dehydrating snail meat into powder and incorporating it into modern products, such as buns, has the potential to improve its acceptability, shelf-life, and palatability (Pissia, Matsakidou, Paraskevopoulou, & Kiosseoglou, 2022).

2.2 Sorghum

Sorghum (*Sorghum bicolor* (L) Moench) is, by acreage, the fifth leading crop in the world after other cereals such as wheat, rice, maize, and barley (Bakari, et al., 2023). Sorghum is genetically suited to hot and dry agroecological conditions of the semi-arid and arid tropics in Africa, where its grain serves as an important source of protein and energy to over 500 million resource-underprivileged households (Tasie & Gebreyes, 2020). Sorghum is consumed as a whole grain or ground into flour (Awadelkareem, Hassan, Fageer, Sulieman, & Mustafa, 2015) and utilized in assorted traditional foods as well as in the formulation of baked products (Saeed et al., 2023). Sorghum originated from North-Eastern Africa, with anthropological studies indicating that hunter-gatherer communities could have consumed its grains as early as 8000 BC (Winchell, et al., 2018). Similarly, activities for its domestication began in the African continent about 3000 years ago (Barron, et al., 2020) with a focus on improving the genetic quality of small, shattered wild grain species into large, non-shattered seeds. This was followed by procedures to develop high-yielding and stable varieties through plant breeding that involved the selection of positive traits such as resistance to drought, disease, pests, and insensitivity to photoperiods (Dorter & Marakli, 2024). Currently, interest has been increased to promote the production of sorghum on the realization that it has the potential to alleviate hunger in developing countries (Barron, et al., 2020).

2.2.1 Sorghum Grain Morphology

A review by Abah, Ishiwu, Obiegbuna, and Oladejo (2020) described sorghum grain as a blunt, pointed, round-shaped structure with varied sizes and colours depending on the cultivar. The grain is covered in glumes, which are maternal plant tissues in the panicle involved in holding the developing caryopses after pollination, and is composed of three main parts, which are the seed coat (testa or pericarp), germ (embryo), and endosperm (storage tissue). It has a thicker seed coat whose pigmentation is influenced by the concentration of polyphenols as modulated by complementary B₁ and B₂ genes (Boatwright, et al., 2021). Endosperm comprises aleurone, peripheral, corneous, and floury portions (Figure 2.2). Aleurone is a single

layer of rectangular cells with a thicker cell wall adjacent to the testa. The cells have large amounts of proteins, oil, minerals, and water-soluble vitamins (Abah et al., 2020).

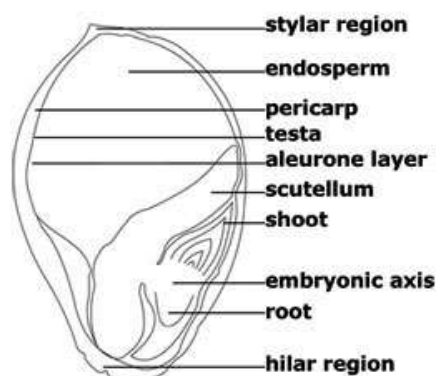


Figure 2.2: Sorghum Grain

Source : Abah, et al. (2020)

Taylor and Duodu (2019) documented that the peripheral endosperm layer comprises blocky cells with starch granules embedded in a dense proteinaceous matrix of glutelin proteins and prolamin protein bodies just beneath the aleurone layer. The corneous and floury endosperm cells contain starch granules, protein matrix, protein bodies, and cell walls rich in cellulose, arabinoxylans, and hemicelluloses. The grain germ comprises two main parts: the embryonic axis and the scutellum, which is a bridge between the endosperm and germ (Taylor & Duodu, 2019).

2.2.2 Chemical Composition of Sorghum Grain

Sorghum grain has an average 70 g/100 g carbohydrate content (Abah et al., 2020) stored as starch in two polymer forms of amylose, accounting for 20 to 30 percent, and amylopectin, 70 to 80 percent of carbohydrate (Varghese, et al., 2022). Protein is the second most abundant nutrient in the grain at about 8 g/100 g to 12 g/100 g (Abah et al., 2020). However, its quality may vary among cultivars due to variations composition of the amino acids (Tasie & Gebreyes, 2020). Similarly, the fat content in grains may vary with cultivars. For example, Abah et al. (2020), evaluating the

nutritional composition of the sorghum grains, reported a crude fat content of between 2.1 g/100 g and 7.6 g/100 g among the evaluated varieties and opine that oleic and linoleic acids are the principal fatty acids present in grains. Sorghum grains are also good sources of vitamins, minerals, including calcium, potassium, iron, phosphorus, and sodium (Tasie & Gebreyes, 2020), antioxidants, phenols, and cholesterol-lowering waxes (Varghese, et al., 2022).

Table 2.5: Nutrient Composition in Sorghum Flour and Whole Grain per 100 g

Nutrient	Unit	Value per 100 g
Proximate		
Water	G	10.26
Energy	KJ	1503
Protein	G	8.43
Total lipid (fat)	G	3.34
Ash	G	1.32
Carbohydrate, by difference	G	76.64
Fiber, total dietary	G	6.6
Minerals		
Calcium, Ca	Mg	12
Iron, Fe	Mg	3.14
Magnesium, Mg	Mg	123
Phosphorus, P	Mg	278
Potassium, K	Mg	324
Sodium, Na	Mg	3
Zinc, Zn	Mg	1.63
Copper, Cu	Mg	0.258
Manganese, Mn	Mg	1.258
Selenium, Se	µg	12.2
Vitamins		
Vitamin C, total ascorbic acid	Mg	0.8
Thiamine	Mg	0.329
Riboflavin	Mg	0.061
Niacin	Mg	4.496
Vitamin B-6	Mg	0.325
Folate, DFE	µg	25
Vitamin A, RAE	µg	0
Vitamin A,	IU	0
Vitamin E (α -tocopherol)	Mg	0.50
Vitamin K (Phylloquinone)	µg	6.4
Lipids		
Fatty acids, total saturated	G	0.528
Fatty acids, total monounsaturated	G	0.943
Fatty acids, total polyunsaturated	G	1.403

Adapted from the USDA National Nutrient Database for Standard Reference Release 28 (2018).

2.2.3 Influence of Sorghum Grains on Human Health

Sorghum grains are a significant source of soluble dietary fibre, which lowers blood cholesterol and controls plasma glucose levels in diabetics through insulin modulation to maintain normal blood glucose levels (de Moraes, Pinheiro, Martino, & Pinheiro-Sant'Ana, 2017). Furthermore, some of the naturally occurring phenolic compounds in sorghum grains limit pancreatic lipase activity, which regulates calorie intake and fat digestion, which is critical in managing obesity (Xu, Wang, & Zhao, 2021). Other compounds, including flavonoids, are said to have anti-inflammatory and antioxidant properties that are important for decreasing tumour progression (Vanamala, Massey, Pinnamaneni, Reddivari, & Reardon, 2018). The primary staple cereals for people with celiac disease are gluten-free sorghum grains, which also regulate the immunological reactions brought on by gluten exposure (Khalid, et al., 2022). However, tannins present in sorghum grains reduce the ability of the body to absorb proteins and other essential nutrients necessary for health (Tasie & Gebreyes, 2020).

2.3 Wheat

Wheat (*Triticum aestivum*), an ancient cereal thought to have originated in South-Eastern Turkey (Onur & Ceylan, 2023), is considered to have been spread through the cultivation of bread wheat approximately 9,000 years ago (Levy & Feldman, 2022). It can be posited that the Neolithic Revolution significantly influenced the domestication and cultivation of wheat as humans shifted from hunting and gathering to settled agriculture (Scanes, 2018). Wheat grains have been exploited for their food value since the beginning of human civilization (Li, Xuan, & Cai, 2020) and were first introduced to the Egyptian shore in Africa around 3,000 BC (Scott, et al., 2019). The grains are utilized as flour in producing baked foods, including buns (Cappelli & Cini, 2021).

Currently, hexaploid bread wheat occupies 95 percent of the world's wheat cultivated area, while tetraploid durum accounts for the remainder 5 percent (Mastrangelo & Cattivelli, 2021). Wheat contributes approximately 21 percent of the global food supply and serves as a staple for more than 80 percent of the world's population (Msundi, et al., 2021). For example, global wheat harvests in 2023-2024 were

estimated at 791.21 million tonnes, up from 789.89 million tonnes in the previous season (Kumar, Singh, Kumar, Sinha, & Panwar, 2025). Despite this increase, demand is projected to rise by 33 percent by 2025, driven by annual human population growth of about 1.6 percent (Msundi, et al., 2021). This notwithstanding, land acreage for the production of wheat grains is progressively becoming limited due to heightened urbanization (Polat, Cifci, & Yagdi, 2016).

2.3.1 Wheat Kernel Morphology

The wheat kernel is typically round and has a crease along the side where it was attached to the flower (Attwal & Dhiman, 2024).

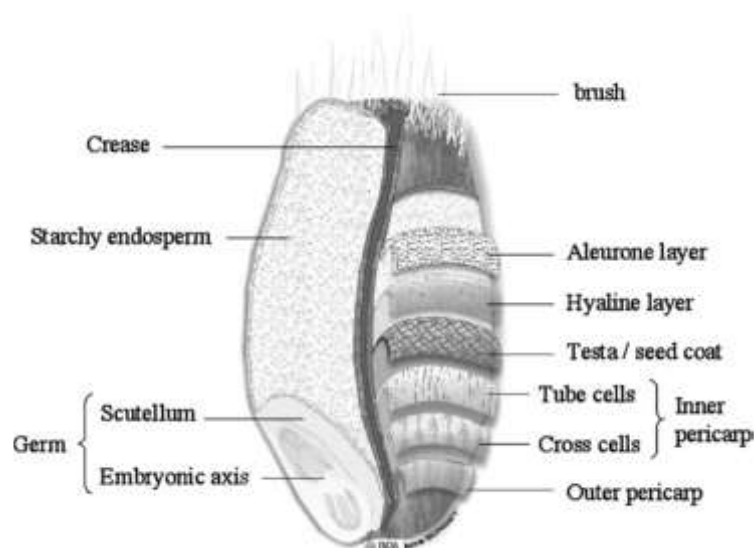


Figure 2.3: Wheat Kernel

Source: Khalid et al. (2023)

The kernels are nearly spherical, elongated or thin, or flat in shape, with a length of about 5 to 9 mm and a weight of 35 to 50 mg, depending on the type of wheat (Khalid, Hameed, & Tahir, 2023). The main factors influencing kernel weight are filling level and grain size; larger grains and quicker, earlier, and longer grain filling are linked to higher kernel weight (Wang, Shi, Zheng, & He, 2023). The wheat kernel is composed of around 2-3% germ, 13-17% bran, and 80-85% endosperm on a dry matter basis (Khalid et al., 2023).

2.3.2 Chemical Composition of Wheat Kernel

About 80% of the wheat kernel is made up of carbohydrates, which are found as starch in two polymers: 20-30% amylose and 70-80% amylopectin (Iqbal, Shams, & Fatima, 2022). The kernel protein contains around 15% albumin, 5% globulin, 33% gliadin, 14% soluble gluten, and 33% insoluble gluten (Wieser, Koehler, & Scherf, 2023). It also lacks the essential amino acid lysine, which is necessary for young children to release growth hormones (Siddiqi, Singh, Rani, Sogi, & Bhat, 2020). Insoluble dietary fibre, minerals, B complex vitamins, and bioactive substances such as phenolic acids, carotenoids, lignans, phytosterols, flavonoids, and phytic acid (Wieser et al., 2023).

Table 2.6: Nutrient Composition in Wheat Flour and Whole Grain per 100 g

Nutrient	Unit	Value per 100 g
Proximate		
Water	G	10.74
Energy	KJ	1424
Protein	G	13.21
Total lipid (fat)	G	2.50
Ash	G	1.58
Carbohydrate, by difference	G	71.97
Fibre, total dietary	G	10.7
Minerals		
Calcium, Ca	Mg	34
Iron, Fe	Mg	3.60
Magnesium, Mg	Mg	137
Phosphorus, P	Mg	357
Potassium, K	Mg	363
Sodium, Na	Mg	2
Zinc, Zn	Mg	2.60
Copper, Cu	Mg	0.410
Manganese, Mn	Mg	4.067
Selenium, Se	µg	61.8
Vitamins		
Vitamin C, total ascorbic acid	Mg	0.0
Thiamine	Mg	0.502
Riboflavin	Mg	0.165
Niacin	Mg	4.957
Vitamin B-6	Mg	0.407
Folate, DFE	µg	44
Vitamin A, RAE	µg	0
Vitamin A,	IU	0

Nutrient	Unit	Value per 100 g
Vitamin E (α -tocopherol)	Mg	0.71
Vitamin K (Phylloquinone)	μ g	1.9
Lipids		
Fatty acids, total saturated	G	0.430
Fatty acids, total monounsaturated	G	0.283
Fatty acids, total polyunsaturated	G	1.167
Cholesterol	Mg	0

Adapted from the USDA National Nutrient Database for Standard Reference Release 28 (2018).

2.4 Buns

Buns, like bread, are bakery products made from flour, salt, and yeast in a series of steps that include mixing dried ingredients, kneading, proving, and shaping the dough into nearly spherical shapes with a bun moulder (Vijayendra & Sreedhar, 2023). The dough is then baked in a preheated oven at a temperature of approximately $200^{\circ}\text{C} \pm 5^{\circ}\text{C}$. Flour obtained from milling wheat grains is the most popular in baking because of its unique properties of holding and retaining water vapour and carbon dioxide, resulting in a spongy texture of baked products such as buns (Akintayo, et al., 2020). Other cereal flours, such as sorghum, could also be incorporated in wheat flour to improve dough qualities of retaining carbon dioxide gas, viscoelasticity, volume, and crumb uniformity (Jafari, Koocheki, & Milani, 2017). Also, milk, eggs, sugar, spices, fruits, vegetables, and grains or nuts can be added in baking to improve the nutritional quality of the final product (Gil, de Victoria, & Olza, 2015). However, differences in physical characteristics of colour and sensory attributes of flavour and aroma in buns may be ascribed to the heat period and temperature used during baking, since they influence the physicochemical properties of baking (Peluola-Adeyemi, Obi, & Ugbogu, 2016).

2.5 Roles of Dietary Protein on the Health of Children

The link between diet and the occurrence of diseases in childhood is well-documented (Fabek, Salamat, & Anderson, 2025). The early years of life have been identified as a critical window that may influence health later in life (Zheng, et al., 2018). Therefore, good nutrition is essential for the effective functioning of the body, the prevention of

ailments, and the development of children (Fabek et al., 2025). A protein-rich diet supports cell growth, repair, and maintenance, as well as maintaining electrolyte and acid-base balance, and enhancing enzyme and hormone function (Hudson, Baum, Diaz, & Børsheim, 2021). Adequate dietary protein intake in children enhances the immune system's ability to produce antibodies that fight infections (Lakra & Gahlawat, 2016), as well as gains in body mass index (Braun, et al., 2016). Animal proteins are considered excellent sources of the indispensable amino acid lysine, which helps in the release of growth hormones in children, leading to an increase in weight and height (Ugwuowo et al., 2019). However, protein nutrition remains a major challenge for children in most developing countries, particularly in Sub-Saharan Africa (UNICEF, 2024), where diets are predominantly cereal or starchy staples with minimal diversity (Tololu, Teshome, Fessaha, & Kaso, 2025).

2.6 Nutrition Intervention Strategies to Improve Protein Quality in Diet

Sustainable approaches for preventing PEM and meeting the nutritional requirements of infants and young children include dietary diversification, food fortification and enrichment, supplementation, and complementation.

2.6.1 Dietary Diversification

According to de Oliveira Otto et al. (2018), dietary diversification is a technique for improving the number and variety of foods consumed at the household level, including animal proteins. Sustainable approaches in this area include domestic crop production, innovations in food preparation, processing, preservation, storage, and marketing, as well as consumption trends (Ayenew, Biadgilign, Schickramm, Abate-Kassa, & Sauer, 2018). Such strategies are meant to ensure availability, accessibility, and utilization of different types of foods such as fruits, vegetables, and animal products, to control both macro and micronutrient deficiencies (de Oliveira Otto, et al., 2018). Diversification of diet is also important to reduce the risk of mortality that may result from cardiovascular disease and diabetes (Bruins, Dael, & Eggersdorfer, 2019). Adesogan et al. (2020) posited that excessive dependence on cereals or starchy foods, with little or no animal proteins, increases the incidence of PEM and hidden hunger. Therefore, initiatives that support the attainment of Sustainable Development Goal (SDG) 2 on

agricultural production are considered appropriate to improve the livelihoods of resource-underprivileged households in developing countries like Kenya (Ayenew et al., 2018). The techniques should employ the use of affordable and locally available resources (Dwivedi, et al., 2017).

2.6.2 Food Fortification

According to Olson, Gavin-Smith, Ferraboschi, and Kraemer (2021), fortification is the addition of micronutrients to foods that are already processed. It is a food-based approach used in times of scarcity or limited access by supplementing with appropriate nutrients. It is mainly used to control micronutrient deficiencies where the deficient element is added to food during processing. Food fortification may be used to improve micronutrient status in a population at an affordable cost because it uses the already existing infrastructure and technology (Chadare, et al., 2019). It involves the use of a centrally processed food vehicle, and the fortifying agents should not interfere with the sensory attributes of the food vehicle. In addition, fortification levels must be within the limits of 2,000 kcal daily intake set by the Codex Alimentarius Commission for foods intended for children (Endevelt, et al., 2023).

Food fortification is an effective public health strategy to reach a large number of at-risk groups using existing food systems without significant changes in consumption habits (Osendarp, et al., 2018). It is applied to restore nutrients lost during processing, increase nutrient levels above normal, or add nutrients that are normally not present in a food item, using readily available, commonly consumed foods as vehicles (Endevelt, et al., 2023). Food fortification has effectively been used in the Western world to combat nutritional deficiencies such as goitre, rickets, beriberi, and pellagra (Osendarp, et al., 2018). In recent years, many ingredients have been used to fortify cereal products. For example, to accommodate trends in lifestyle and customer interest in health. Tolve and Simonato (2024) revealed that bread products have been fortified with a variety of protein sources, both animal and plant-based. Cereals are deficient in lysine but are good sources of sulphur-containing amino acids (Burger & Zhang, 2019). As a result, combining cereals with animal products could produce an appropriate amino acid profile to support growth.

2.6.3 Food Enrichment

Enrichment refers to the addition of nutrients to foods. According to the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO), enrichment is "synonymous with fortification" and refers to the addition of micronutrients in food that are eliminated during processing (Kumar, et al., 2022). Foods like fruits and vegetables may be incorporated in powder form to develop more health-promoting products (Kowalska, Czajkowska, Cichowska, & Lenart, 2017). Furthermore, popular bakery products like biscuits and bread have the potential for enrichment with minerals, vitamins, fibres, and secondary metabolites like polyphenols because of their beneficial characteristics. Enrichment has been used for centuries at the household level to enhance cereal products with macronutrients, but Food-to-Food enrichment is a new method for managing micronutrient deficits (Kruger, Taylor, Ferruzzi, & Debelo, 2020).

2.6.4 Supplementation

Ronis, Pedersen, and Watt (2018) described supplementation as a process in which considerably large doses of micronutrients are provided as capsules, pills, or syrups to promote the intake of optimal amounts of target nutrients in the most absorbable form. Banerjee et al (2024) reported that supplementation with iron tablets to prevent and control iron-deficiency anaemia or anaemia in pregnancy, and periodic distribution of high doses of vitamin A to preschool children or targeted high-risk groups are the most appropriately employed strategies. In a region with a high prevalence of iodine deficiency disorders and no supply of iodized salt, iodized oil capsules could be prescribed to fulfill the daily iodine requirements (Hatch-McChesney & Lieberman, 2022). Supplementation is a short-term intervention to provide direct, controlled, and concentrated doses of the intended micronutrient to a population at the highest risk. In addition, this method is cost-effective in achieving the intended health and nutritional goals (Abeshu & Geleta, 2016). Nonetheless, supplementation should be followed with long-term and sustainable food-based strategies such as food enrichment and dietary modification owing to the inability to sustain high coverage over a long period of time, changes in health priorities, and poor compliance of the target group.

2.6.5 Complementation

The term complementation is used with respect to proteins when a relative deficiency in amino acids of one protein is compensated for by the surplus from the amino acids of the other protein consumed together (Dimina, Remond, Huneau, & Mariotti, 2022). Thus, to improve the protein value of infant and young children's diets in sub-Saharan Africa, researchers have formulated foods using the principle of complementation to enhance the quality of diets by utilizing some of the locally available and widely acceptable foods as vehicles. For instance, in a blend of cereal and legume, amino acids from one of the foods supplement the other food to improve the quality of deficient amino acids and create a balance in protein quality, resulting in nutritional complementation (Dimina et al., 2022). Codex Alimentarius Commission of the United Nations recommended the complementation principle as an effective technique to enhance the nutritive quality of diets formulated and developed for infants and young children (Endevelt, et al., 2023). Many protein food sources could also be employed as fortificants in supplementary foods, depending on their availability, accessibility, and acceptability. Thus, food-enriching agents may vary depending on ecological zones, culture, and people's beliefs. As such, it is important to identify an appropriately sustainable food-enriching agent that is readily accepted by most of the population. Snail meat is one such food-enriching agent (Adeyeye et al., 2020).

2.7 Supplementary Foods

2.7.1 Development of Low-Cost Supplementary Foods

Protein Energy Malnutrition (PEM) is a serious problem in most developing countries where diets are predominantly cereal or starch-based (WHO, 2024). However, cereals can be enriched with protein-rich foods to formulate a supplementary diet to manage PEM among vulnerable communities. Thus, efforts to develop low-cost supplementary foods from locally available and widely consumed cereals blended with animal proteins are a work in progress. For example, Cakmak, et al. (2013) enriched white and whole wheat bread with chicken meat and chicken meat powder at five levels of 10, 15, 20, 25, and 30% and observed that substituting with chicken meat and chicken meat powder respectively increased protein value from 7.60 g/100 g to 18.44 g/100 g

and 18.70 g/100 g for white bread and 8.85 g/100 g to 14.23 g/100 g and 16.49 g/100 g for whole wheat bread. In a related study, Kinyuru, et al. (2009) blended wheat flour with ground termite powder at 0, 5, 10 and 20% levels by weight for the development of buns and demonstrated that replacing at just 5% significantly increased protein, retinol, riboflavin, iron and zinc contents at between 16% and 53% and was the most preferred by consumers.

A study by Serrem, de Kock, and Taylor (2011a) evaluated the nutritional quality, sensory quality, and consumer acceptability of sorghum and bread wheat biscuits fortified with defatted soy flour and recommended that developing a compact, ready-to-eat, high nutrient-dense product is acceptable for the economically underprivileged communities living in deplorable conditions with lack of infrastructure for distribution of foods, clean water and facilities to prepare foods from fortified blends. Thus, incorporating snail meat into a modern diet, such as buns, could significantly enhance protein intake, thereby preventing protein deficiency in young children brought about by food shortages, especially in sub-Saharan Africa. Snail meat is a cheap source of animal protein with a balance of indispensable amino acids (Ghosh et al., 2017). Thus, consumption of snails as animal protein sources for humans should be highly promoted to enhance the intake of protein and essential minerals for managing PEM and hidden hunger in young children (Adeyeye et al., 2020).

2.7.2 Sorghum Use in Formulation of Supplementary Foods

Sorghum grain is very similar to corn (maize) in terms of its nutritional content (Ape, Nwongu, Uwakwe, & Ikedinobi, 2016), even though it has inferior protein quality due to the presence of its primary storage protein, kafirin, which is poorer in indispensable amino acid lysine (Hurst, et al., 2023). Weerasooriya, Bean, Nugusu, Ioerger, and Tesso (2018) opine that sorghum nutritional constraint is aggravated by the low digestibility of kafirin protein in the wet cooking of foods. Digestibility is an indicator of protein quality. A highly digestible protein is considered to have better nutritional value than one with low digestibility, as it provides more amino acids for absorption on proteolysis (Kaur, et al., 2022). Enrichment is recommended as the most practical method to improve the protein quality of starchy or cereal foods such as sorghum

(Delimont, et al., 2017). This is because blending lysine-rich foods with cereals that are good sources of sulphur-containing amino acids will result in protein nutritional compensation (Dimina et al., 2022).

Sorghum has been used in the production of enriched foods with animal products. For example, Awobusuyi, Siwela, and Pillay (2020a) blended sorghum-termite flour at 20%, 40%, and 60% into wheat cookies and found that the enriched samples had a significantly higher protein content, ranging from 36.4 g/100 g to 41.0 g/100 g, compared to the control at 10.5 g/100 g. Furthermore, the sensory evaluation of sorghum-insect meal-supplemented biscuits (Awobusuyi, Pillay, & Siwela, 2020b) revealed that wheat biscuits supplemented with sorghum-insect meal at 15% and 5% (B20) were more acceptable than control biscuits and palatable than those blended at 30% and 10% (B40), as well as 45% and 15% (B60) with sorghum-insect meal. Similarly, Serrem et al. (2011a) demonstrated that compositing sorghum with defatted soy flour considerably increased the in vitro protein digestibility of the biscuits when compared to the 100% sorghum biscuit. In this study, replacing sorghum flour with 28.6, 50, and 71.4% defatted soy flour improved in vitro protein digestibility by 148, 170, and 191%, respectively.

2.7.3 Challenges Linked with Supplementary Feeding

Previous research has established that supplementary diets in developing countries are often low in both the quality and quantity of proteins and essential minerals. For example, Salim et al. (2023) noted that a major setback of supplementary feeding is a reduction in mineral bioavailability in plant-based diets, which is attributed to the presence of antinutritional factors such as glucosinolates, trypsin inhibitors, oxalates, phytates, and lectins. Phytic acid is abundant in cereal grains, where it forms complexes with iron and zinc, related to mineral deficiencies in humans that negatively affect protein absorption (Brouns, 2021). However, resource-underprivileged households are unable to afford the recommended supplementary foods. This is a great concern, as animals are the principal source of highly digestible proteins (Kaur, et al., 2022).

2.8 Management of Protein Energy Malnutrition in Children

Protein Energy Malnutrition (PEM), which results from undernutrition and was first recognized in the 21st century, is today the most severe form of nutrition deficiency, with infants and children being the most vulnerable to its associated growth impairment due to their high energy and protein requirements (Zhang, et al., 2022). According to Bhatti, Nawaz, and Ali (2021), PEM is a range of pathological conditions caused by protein and energy deficiencies. It is characterized by measurements that are below minus two standard deviations of normal weight for age (underweight), height for age (stunting), or weight for height (wasting). The condition is synonymous with the transitional period when children are weaned from liquid to semi-solid or full adult diets (Pandey & Singh, 2019). This is because at this point, in addition to their mothers' breast milk, they require nutritionally balanced, calorie-dense supplementary diets that will support their rapid growth (Moideen, et al., 2024).

Sub-Saharan Africa remains the most troubled region, with the highest child mortality rates attributable to undernutrition, which accounts for about 45% of all deaths reported for children under the age of five (Akombi, Agho, Merom, Renzaho, & Hall, 2017). For example, in 2017 alone, the number of stunted children increased from 50.6 million to 58.7 million, while wasting was at 7.1% or 13.8 million children, with 4 million severely wasted (WHO, 2019). In this region, PEM increases the susceptibility of children to life-threatening diseases, such as tuberculosis, diarrhea, and pneumonia (Majumdar, Saraf, Sahu, Verma, & Vishwakarma, 2025). It also decreases productivity, impairs cognitive development, and increases the burden of healthcare costs across the lifespan (Zubair, Mishra, Kumar, & Mishra, 2024). In addition, PEM is linked to micronutrient deficiencies since proteins have a role in the transportation of fat-soluble vitamins and minerals such as iron, calcium, and potassium (Titi-Lartey & Daley, 2025).

The burden of PEM is particularly severe in regions with exponential population growth but with inadequate agricultural development or productivity, resulting in a lack of high-quality protein at the household level (Wells, et al., 2021). According to research, enhanced production of mini-livestock such as snails can increase protein

intake in diets and improve children's nutritional status (Adeyeye et al., 2020). It is worth noting that snail meat is a significant source of protein and indispensable amino acids lysine (Ghosh et al., 2017), which compares favourably in quality and digestion to poultry egg and flesh (Pathak, et al., 2025). Its amino acid profile meets the recommended requirements for adequate growth and development of children (Ugwuowo et al., 2019). As a result, snail meat has the potential to improve the nutritional well-being of disadvantaged populations by supplementing the amino acid profile of cereal proteins (Adeyeye et al., 2020). Children who fail to meet their recommended daily protein intake are at risk of kwashiorkor, marasmus, or stunting (Patel & Rouster, 2020).

2.9 Evaluation of Protein Quality of Supplementary Foods

As documented by the Food and Agriculture Organization (FAO, 2018), protein nutritive quality depends on its capacity to provide nitrogen and amino acids in sufficient quantities to meet the requirements of an organism. Both amino acid composition and protein digestibility measurements are necessary to accurately predict protein quality in human diets.

2.9.1 Controlled Trials

New supplementary products formulated to manage PEM should be evaluated for physicochemical and functional properties, as well as their effect on customer acceptability (Edima-Nyah, Amande, & Ekanem, 2024; Chemutai, Mburu, Njoroge, & Zettel, 2024). Similarly, there are specific standards and regulations that food-grade items should attain before being released to the market. In this regard, Manservisi et al. (2016) suggested that an animal model, such as the rat bioassay, be exploited in evaluating food product quality, as metabolic and digestive processes in monogastric animals like rats are similar to those of humans. However, rat bioassays have the drawback of being based on the amino acid requirements of rats and not human beings (Kamau, Serrem, & Wamunga, 2017). Thus, such assays could be misleading as rats have considerably higher requirements, especially for sulphur-containing amino acids, than humans (Marinangeli & House, 2017). Hence, to overcome this problem, young rats whose nutritional requirements and metabolic utilization of essential nutrients

closely resemble those of growing children should be utilized (Gilani, Xiao, & Cockell, 2012). Also, (FAO, 2018) has recommended using direct comparison methods of food proteins to human amino acid patterns, such as Protein Digestibility Corrected Amino Acid Score and Digestible Indispensable Amino Acid Score.

2.9.2 In Vivo Protein Digestibility

A study by Tavano, Neves, & da Silva Junio (2016) determined that in vivo digestibility methods are most suitable for assessing the levels of protein digestibility and in assessments related to the quality of diets for physiological activities. These authors further established that this method might be too slow, expensive, and time-consuming because digestion speed varies depending on the animal species employed, the type and quantity of food evaluated, and prevailing environmental conditions such as temperature. Thus, such studies require smaller animals, such as rats, that are known to digest their food in a shorter period than large ones (Gilani et al., 2012). Growth assays using rats are meant to predict protein quality in foods (Kamau et al., 2017). Tavano et al. (2016) further added that the digestibility of foods could be determined in two ways: one is the direct method of weighing the amount of food ingredients to be transported through the digestive system and what is extracted from faeces, and the second involves measuring food ratios and other indicator material in diets and faeces of animals.

2.9.3 In Vitro Protein Digestibility

In vitro protein digestibility is carried out using either a single- or multi-enzyme assay to provide information on the efficacy of protein digestion and the detection of induced changes in protein quality (Dervan & Classen, 2020). A single enzyme assay has been extensively employed to determine the protein digestibility of cereal-based diets. For example, Serrem et al. (2011a) utilized pepsin to assess the digestibility of sorghum and wheat bread biscuits composed of defatted soy flour, and they determined that compositing with defatted soy flour considerably enhanced the in-vitro digestibility of the fortified biscuits compared to 100% cereal biscuits. Equally, Weerasooriya et al. (2018) evaluated the in vitro digestibility of sorghum cooked products using pepsin digestion and found that wet cooking reduces sorghum digestibility depending on the

genotypes tested. According to Bryan and Classen (2020), a multi-enzyme technique involving two or more enzymes is more comparable to *in vivo* digestibility, because multiple enzymes are involved in the digestion process.

2.9.4 Protein Efficiency Ratio (PER)

The Protein Efficiency Ratio is a 28-day growth assay intended to maximize the value of proteins consumed, while overcoming age-related differences in amino acid (AA) requirements (Mansilla, et al., 2020). It was developed for routine evaluation of protein quality in human diets using rapidly growing animals, such as weanling rats, based on weight on a test protein and a control diet containing 10% protein (FAO, 2011). In this method, the efficacy of dietary proteins is computed by dividing weight gain in experimental animals by the sum of protein consumed (Sarwar, 2012). Despite this, PER is inefficient in predicting the quality of proteins used for maintenance purposes (Malomo & Alamu, 2015). As such, a protein may score a lower PER value or fail to support growth but may be adequate for maintenance purposes.

2.9.5 Net Protein Retention Ratio (NPRR)

According to Sarwar (2012), the Net Protein Retention Ratio is a 10 to 14-day growth assay recommended by the Protein Advisory Group of the United Nations to address shortcomings in the PER technique by taking into account weight losses in animals fed a protein-free diet and weight gain in animals fed test protein. This method accounts for both growth and maintenance proteins in experimental animals fed a protein-free diet (Oibiokpa, Akanya, Jigam, Saidu, & Egwim, 2018). Diets are evaluated at 10% protein in NPRR and PER tests, although diets can be evaluated at 8% protein for high-quality proteins like egg and casein (Sarwar, 2012).

2.9.6 Apparent and True Protein Digestibility

Apparent Protein Digestibility (APD) is a method for determining protein digestibility from the faecal index. As a result, the nitrogen excreted in faeces is subtracted from the amount ingested, and the result is expressed as a percentage of intake (Boye, Wijesinha-Bettoni, & Burlingame, 2012). This approach assumes that AA is digested

and absorbed throughout the digestive tract, which influences the accuracy of the digestibility coefficient generated (Mansilla, et al., 2020). Conversely, True Protein Digestibility (TPD) is the principal *in vivo* protein digestibility index used to calculate PDCAAS (Boye et al., 2012). It is calculated by obtaining the difference between nitrogen in the diet and nitrogen excreted in faeces using an animal bioassay (Zem, Helm, Henriques, Cabrini, & Zuffellato-Ribas, 2017).

2.9.7 Protein Digestibility Corrected Amino Acid Score (PDCAAS)

During a consultative meeting in 1985, the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) adopted PDCASS as a method to assess dietary protein quality (FAO, 2018). This technique evaluates the ability of a protein to provide the required amino acids and nitrogen to the human body (Kamau et al., 2017). In computing PDCAAS, the digestibility of a food must be determined either *in vivo* or *in vitro* (Tavano et al., 2016). Nonetheless, a challenge identified with this procedure is that it is difficult to experimentally carry out digestibility studies using young children due to ethical issues involved and cost implications (Gan, Bornhorst, Henrick, & German, 2018). As a result, rat assays are used in assessing protein quality in foods, as they are more sensitive when rats are fed entirely on an experimental diet. The shortcoming of such trials is that rats have a higher amino acid requirement than infants and young children. Therefore, to qualify and add reliability to the use of PDCAAS in evaluating the protein quality of supplementary foods, WHO/FAO/UNU (Boye et al., 2012) established that the PDCAAS score of foods should be associated with amino acid requirement patterns for subjects in a particular age group. Codex Alimentarius Commission set PDCAAS in infant and young children's diets at 0.70 or 70 percent (Lewis, 2012).

Food and Agriculture Organization (FAO, 2018) indicated that the PDCAAS method compares the concentration of the first limiting indispensable amino acid in the test protein and the amino acid in a reference (scoring) pattern. When using PDCAAS, the protein quality rankings are determined by comparing the amino acid profile of a specific food protein against the standard amino acid profile, with the highest possible score of 1.0. This score means that after digestion of the protein, it provides per unit

of 100 percent protein or more of the indispensable amino acids required (FAO, 2018). Protein quality measurement should evaluate proteins relative to human requirements. Since the protein value is principally related to amino acid content relative to human amino acid needs, the primary criterion for judging any food protein should be its indispensable amino acid content relative to human amino acid requirements (FAO, 2013). PDCAAS considers the amino acid profile, digestibility, and ability to supply indispensable amino acids in amounts required for human requirements (FAO, 2018).

2.9.8 Digestible Indispensable Amino Acid Score (DIAAS)

The food protein quality is determined according to amino acid content and digestibility (Tas, Umit, Alkan, Boynak, & Yeral, 2019). Digestibility is an empirical measurement in humans or animals with an ileostomy, a surgical diversion that circumvents the colon (Manservigi, et al., 2016). The Food and Agriculture Organization of the United Nations (FAO, 2013) has recommended the use of DIAAS. This method utilizes individual amino acid digestibility determined at the ileum to replace PDCAAS in evaluating food protein quality. This method eliminates the confounding effect of catabolism and synthesis of amino acids by hindgut microflora on faecal measurements (Wolfe, Rutherford, Kim, & Moughan, 2016). The DIAAS method does not require truncation of the scores, recognizes the excess value of amino acids, such as in dairy proteins, and takes into account the variations in amino acid reference patterns among different age groups (FAO, 2013).

DIAAS indicates a percentage of the total daily requirement of the most limiting indispensable Amino Acid (IAA) contained in an amount of protein equivalent to the estimated average requirement (EAR) for the total daily protein intake of the test protein (Wolfe, et al., 2016). Nosworthy et al. (2017) indicated that the dietary content of each digestible IAA in the test protein should be calculated as the content of each amino acid of the protein multiplied by its respective digestibility coefficient. Digestibility coefficient is based on the disappearance of amino acids from the gastrointestinal tract as measured at the end of the ileum (true ileal digestibility). In the case of lysine and processed foods, the digestibility depends on lysine reactivity (Wolfe, et al., 2016). A reference ratio of the digestible amino acid content of each

IAA in the test protein to the content of the corresponding amino acid in 1 g of reference protein is calculated, and the lowest value or most limiting IAA is the DIAAS, expressed as a percentage (FAO, 2013). The amount and pattern of each IAA in reference protein reflect the amount that will meet the daily requirement for each IAA by ingesting an amount of that protein equal to the EAR (Wolfe, et al., 2016).

2.10 Sensory Evaluation

Sensory evaluation is a scientific discipline used to evoke measures, analyze, and interpret reactions to characterize food materials as perceived by the senses of sight, smell, taste, touch, and hearing (Civille, Carr, & Osdoba, 2024). These include the food's appearance, odour, taste, feel in the mouth, and sound (Pop, 2023). Therefore, food companies regularly use sensory tests, such as descriptive analyses and consumer affective tests, to study the effects of ingredients, processing variables, and food storage changes (Civille et al., 2024). Sensory attributes provide vendors with an understanding of product quality and requirements for product reformulation, if need be, from the consumers' perspective (Pop, 2023).

The primary goal of sensory assessment is to conduct a valid and reliable test that might provide essential data that could be utilized to produce a sound decision about a particular food product (Swiader & Marczewska, 2021). In this case, a well-trained descriptive sensory panel can be involved to evaluate and detect quality problems at the same time, using a preference test to gain insight into what might influence consumer preference (Civille et al., 2024). In descriptive sensory tests, human subjects have been used as instruments, where they are screened, selected (approximately 8-12 people), and trained (Singh-Ackbarali & Maharaj, 2016). After extensive training, the panel evaluates the overall flavour quality and intensity of individual off-flavours (Civille et al., 2024).

Food product quality, especially those related to flavour, could affect decisions made by consumers about purchasing and consuming foods (Imtiyaz, Soni, & Yukongdi, 2021). Thus, the real or perceived quality shortfalls may shape consumers' desires to eat certain foods and products developed from them, and the food sensory attributes could be the immediate and future drive of consumers' food consumption patterns

(Pop, 2023). As such, the process of adopting a healthy diet might be affected by concern about food quality, as consumers emphasize their sensory experience that includes the food's physical appearance, texture, aroma, and taste and pleasure derived from consuming certain foods being the most important motivators of eating (Imtiyaz, et al., 2021).

Certain foods are specifically consumed because they are an important source of nutrients required for the human body, rather than because eating them is enjoyable due to cultural, social, aesthetic, and moral value (Almerico, 2014). Though choices must be made based on individual preferences (Adejo, Mohammed, & Aliu, 2016). Research on the sensory attributes of snail meat and snail meat products is ongoing, and preliminary results indicate that cultural variables, such as social and economic as well as nutritional considerations, mostly dictate their consumption (Garkov & Nikovska, 2024). For instance, Engmann et al. (2013) showed that young mothers valued snail meat incorporated in powder form as an alternative food formula for breastmilk-weaned toddlers, suggesting its potential to be blended in modern products. This could have been due to snail meat's tender texture and good taste (Tanyitiku, 2022).

2.10.1 Sensory Evaluation of Products with Children

Patterson and Beeren (2011) conducted a study with children on sensory qualities of foods and established that food products exclusively developed for children must be evaluated by children themselves using simple and reliable but more dynamic methods to measure preference. Studies have been conducted to assess the acceptability of foods using children as consumers. For example, Santana et al. (2023) found that the verbal or Peryam and Kroll (P&K) scale was more effective than the 9-point hedonic or facial scale in assessing food acceptability with children. However, food preferences in children are age-specific, with a 3-point facial scale used for 36-47-month-olds, a 5-point facial scale for children 48-59 months, and a 7-point scale for children older than five years. Sigh et al. (2018) previously showed that a 5-point hedonic scale is used as a standard tool to assess food quality in children aged 4 to 10 years. Simons et al. (2019) concluded that children aged 7-12 years were more adept at utilizing a 7-

point hedonic scale to assess their preferences for Navel oranges, preferring fruit with higher levels of sweetness and sourness. The sensory evaluation room must be designed so that panellists do not affect one another's preferences (Civille et al., 2024).

2.10.2 Evaluating Long-Term Food Acceptability

Food neophobia can prevent children from eating a diverse diet, increasing the risk of nutritional deficiencies (Kozioł-Kozakowska, Piorecka, & Schlegel-Zawadzka, 2018). Consequently, repeated exposure may improve consumer acceptance of novel products (Karaagac & Bellikci-Koyu, 2023). Earlier, Karagiannaki et al. (2021) demonstrated that repeated exposure was an effective strategy to enhance liking and intake of novel foods among children. Besides, the flavour developed from the blending of composite flours also improves the overall acceptability of novel foods (Adedola, Adefunke, Oluwafemi, Damaris, & Tajudeen, 2019). In addition, long-term acceptance may result from exposure to novel foods over several days or weeks (Karaagac & Bellikci-Koyu, 2023).

2.11 Microbiological and Shelf-Life Qualities of Bakery Products

According to Muhammad, Dileep, and Saghir (2012), the bakery industry has, in more significant ways, contributed to the development of humanity long before recorded history existed. This industry recorded tremendous advancements in the late 20th Century with the growth and development of small urban settlements into large towns and cities, improving the demand for baked foods. Bakery foods are significant sources of vital nutrients such as carbohydrates, proteins, lipids, vitamins, and minerals among many cultures and nations (Sarwar, 2012). It is also considered safe from microbial contamination because of its low water activity (Khanom, Shammi, & Kabir, 2016). Food safety is a main concern regarding product quality as it describes the occurrence of microorganisms in food within acceptable limits or the absence of chemicals, microbial contaminants, and other entities that may cause harm to human health (Osimani, Aquilanti, & Clementi, 2015). Under unsuitable storage conditions, bakery products are subjected to microbial spoilage (Sarwar, 2012). Most common microorganisms implicated in the spoilage of bakery products are moulds, which grow on baked foods following post-processing contamination by spores present in the

atmosphere when the products are undergoing cooling, slicing, packaging, and storage (Nirmala, Pathmanathan, & Selvaratnam, 2016). Bread moulds such as *Rhizopus* and *Mucor* are always the first colonizers during spoilage, followed by other fungal species such as *Aspergillus*, *Penicillium*, and *Fusarium*, of which the *Penicillium species* are the most common, even though *Aspergillus species* are of great microbial significance among countries in tropics countries (Ravimannan, Sevel, & Saarutharshan, 2016).

2.12 Summary of Literature and Gaps in Knowledge

This literature review highlights the significant issue of low dietary protein quality in children's diets in developing countries like Kenya. Despite various efforts to improve nutrition, challenges persist, particularly among resource-underprivileged households where access to protein-rich foods from animal sources and commercial supplements is limited. As a result, these children predominantly consume starchy or cereal staple foods, which are often bulky and lacking in essential nutrients. To manage the situation, enriching cereal flours with alternative protein sources, such as snail meat, offers a promising solution for creating supplementary diets, such as buns, to combat PEM. Snails are an excellent source of high-quality protein and provide a balanced profile of indispensable amino acids along with nutritional compensation of cereals. However, the integration of snail meat into the family diet in Kenya and other African countries is not widely embraced. This study fills the gap in the literature by exploring strategies to incorporate snail meat in addressing nutritional challenges like PEM in sub-Saharan Africa.

CHAPTER THREE

EFFECT OF FORTIFICATION WITH SNAIL MEAT POWDER ON PHYSICOCHEMICAL PROPERTIES AND SHELF LIFE OF SORGHUM- WHEAT BUNS

3.1 Introduction

Today, the world faces a more serious problem in providing adequate and nutritious food to the ever-increasing human population (Obande et al., 2013). This situation is further aggravated by nutrient imbalances in developing countries where diets are deficient in protein and essential minerals (FAO/IFAD/WFP, 2014). A more recent estimate indicates that about 820 million people are chronically undernourished, a vast majority of them in developing countries (FAO/IFAD/UNICEF/WFP/WHO, 2023). In these regions, resource-underprivileged households predominantly survive on cereals or starchy foods with little or no animal protein (Schonfeldt & Hall, 2012). Cereal proteins are nutritionally deficient in the indispensable amino acid lysine (Serrem et al., 2011a).

Cereals are important sources of food with wider consumption due to their versatile storage stability when dry (Pekmez, 2016). In developing countries, a single cereal serves as a principal source of energy, protein, vitamins, and minerals to millions of the populace (Kiran, et al., 2022). Food formulation from a cereal-based diet enriched with animal protein has been proposed as the most practical approach to improving nutritional quality in diets (Cakmak et al., 2013). Baked foods such as buns have been designed with improved nutritional quality to reduce the risk of undernutrition in developing countries (Kinyuru et al., 2009). Buns are popular among all age groups in rural and urban areas due to their attractive features that include good eating quality, low cost, varied taste, and relatively longer shelf-life (Vijayendra & Sreedhar, 2023).

Wheat is a cereal with unique rheological properties and positive baking quality used to formulate products such as buns (Hughes et al., 2020). However, the bakery industry is currently faced with the challenge of rising wheat prices brought about by reduced agricultural land due to urbanization (Polat et al., 2016) and unfavourable climatic

conditions caused by global warming, particularly in the tropics, which has led to a decrease in wheat production (Opara, Edem, & Anierobi, 2013). This has prompted the need to complement wheat flour with other cereal flours such as sorghum. Sorghum is a drought-resistant cereal crop that thrives well in regions where other cereals fail to grow (Njinju et al., 2022) and is a principal source of protein and energy for millions of resource-underprivileged households in Africa and Asia (Hariprasanna & Rakshit, 2017). However, sorghum has a lower protein quality of 10.62 g/100 g (USDA, 2015), and its protein digestibility is significantly reduced on wet cooking compared to other cereal proteins such as maize (Tasie & Gebreyes, 2020).

Protein nutritional quality of sorghum-wheat buns may be enhanced to meet human physiological requirements by the principle of complementation (Adeyeye et al., 2020). Snail meat is a source of high-quality protein (Celik, et al., 2020) that compares favourably with poultry egg and flesh in indispensable amino acids and digestibility (Pathak, et al., 2025). Snail meat is also a good source of minerals such as calcium, phosphorus, potassium, zinc, iron, and copper (Nkansah et al., 2021), essential fatty acids (Nyoagbe et al., 2016), vitamins, and energy (Nkansah et al., 2021). Consumption of snail meat can be greatly improved by integration into modern human diets through enrichment. This study aimed to investigate the effect of enriching with varying ratios of SMP on the physicochemical properties and shelf-life of sorghum-wheat buns for feeding young children.

3.2 Materials and Methods

3.2.1 Materials for Buns

Giant African Land Snails were purchased from Prime-Cuts Ltd, Nairobi, Kenya, and white-non-tannin sorghum (*Sorghum bicolor*) from the University of Eldoret farm, Eldoret, Kenya. Other ingredients including all-purpose wheat flour “Exe” (Unga Millers (U) Limited, Nairobi, Kenya), pure white sugar (Mumias Sugar Company Ltd, Mumias, Kenya), salt (Kensalt Limited, Nairobi, Kenya), shortening (Blue band - Unilever Kenya Limited, Nairobi, Kenya), non-fat dry milk “Miksi” (Promasidor Kenya Ltd, Nairobi, Kenya) and yeast “sifa fresh-wet yeast” (Agro-Chemicals and

Food Company LTD, Muhoroni, Kenya), which were purchased from the local supermarkets in Eldoret, Kenya

3.2.2 Processing of Snail Meat

Snails were rinsed in distilled water and boiled for 20 minutes to aid in evisceration, elimination of intestinal tract contaminants harmful to consumers, and reduction of microbial load. Snails were then allowed to cool to room temperature, and the viscera were removed from the shell using a clean knife. The meat was then separated from intestinal materials, cut into smaller pieces, and dried in an oven at 105°C for 2 hours to minimize oxidative reactions of proteins and lipids, which are exacerbated at high temperatures and prolonged drying times (Xia, et al., 2021). The meat was later cooled to room temperature before milling into a fine powder using a kitchen blender with a grinder (Wahl ZX805, 450w 3 Pint 2 Speed Silver). The SMP was then stored in an airtight plastic container at room temperature until required for use.

3.2.3 Flour Formulation for Buns

The procedures of Ayo and Nkama (2003), in line with an acceptable cereal blend of sorghum and wheat flour at the ratio of 7:3, were used. Flour for bun formulation was prepared by replacing a part of sorghum-wheat flour with 5, 10, 15, 20, and 25% of SMP. To formulate five (5) groups of buns, each sample of flour was weighed into a bowl, and the required amount of SMP was added and mixed using an electric kitchen mixer (Kenwood Chef KMC200, Kenwood Co. Ltd, United Kingdom) at medium speed for 2 minutes. The flours were transferred into plastic airtight containers, thoroughly mixed by physical shaking of the containers, and stored at room temperature until required for use.

3.2.4 Preparation of Buns

Buns were prepared according to the procedure developed by Arora and Saini (2016), and those with 0% SMP served as the control. All other ingredients for buns included 2 g yeast, 2 g salt, 5 g shortening, 2 g skimmed milk powder, 10 g sugar, and 65-85 ml water added to 100 g flour. Sugar, skimmed milk powder, and shortening were mixed

using an electric kitchen mixer at medium speed for about 10 minutes. Thereafter, composite flour, yeast powder, and salt were slowly added to the mixture and thoroughly mixed for another 10 minutes using a kitchen mixer. Water was added, and the dough was kneaded by hand until it formed a smooth, elastic ball. The dough was then divided into four equal parts, rolled into round balls, weighed, and placed in bowls covered with cling film. Dough balls were then kept in the proofing chamber at 35°C for 1 hour. Baking of buns was carried out in an oven heated at 200±5°C for between 25-30 minutes. Buns were allowed to cool to room temperature, after which they were weighed and packed in separate zip-lock plastic bags.

3.3 Proximate Analyses of Buns

3.3.1 Moisture Content

The moisture contents were determined using the oven-drying procedures of the AOAC International (2000), Method 925.09. Exactly 2.0 g of samples were accurately weighed into previously cleaned, dried, and weighed glass crucibles. The crucibles with their contents were put into a drying oven at 105°C for 3.5 hours. Thereafter, the samples were cooled in desiccators and weighed. The process was repeated until a constant weight was obtained. The loss in weight expressed as a percentage of the initial weight of the samples gave the percent moisture content.

% Moisture Cont.

$$= \frac{(\text{Weight of wet sample} - \text{Weight of dry sample})}{\text{Weight of wet sample}} \times 100 \quad \text{Equation 1}$$

3.3.2 Crude Protein

Crude protein contents were determined through procedures of the AOAC International (2000), Method 992.23. Approximately 2.0 g of sample was weighed into a digestion flask, and 0.5 g of selenium catalyst was added. About 25 ml of conc. H₂SO₄ was added, and the flask was shaken to mix the contents. The flask was then placed on a digestion burner for 8 hours and heated until the solution turned green, and then clear. The sample solution was then transferred into a 100 ml volumetric flask and made up to the mark with distilled water. Roughly 25 ml of 2% boric acid was

pipetted into a 250 ml conical flask, and 2 drops of mixed indicator (20 ml of bromocresol green and 4 ml of methyl red) solution were added. Then, into the decomposition chamber of the distillation apparatus was added about 15 ml of 40% NaOH solution. Approximately 10 ml of the digested sample solution was then introduced into a Kjeldahl flask. The condenser tip of the distillation apparatus was then dipped into the boric acid contained in the conical flask. Ammonia in the sample solution was then distilled in boric acid until it completely changed to bluish-green. The distillate was titrated with 0.1N HCl solutions until it became colourless.

$$\begin{aligned} & \text{\% Total Nitrogen} \\ & = \frac{100 \times (V_A - V_B) \times N_A \times 0.01401 \times 100 \times 6.25}{10W} \end{aligned} \quad \text{Equation 2}$$

Where,

V_A = Volume of standard acid (ml)

V_B = Volume of standard acid in the blank (ml)

N_A = Normality of HCl

W = Weight of sample (grams)

$F (6.25)$ = Nitrogen factor

3.3.3 Crude Fat

The crude fat content was determined based on the Soxhlet extraction procedure of AOAC International (2000), method 922.06. A 250 ml round-bottom flask was washed and dried in an oven at 105°C for roughly 25 minutes and then allowed to cool to room temperature before weighing. About 2.0 g of the sample was weighed into a muslin thimble. This was inserted into the extraction column with the condenser connected. Approximately 200 ml of extracting solvent (petroleum ether, boiling point 40-60°C) was poured into the round-bottom flask and fitted into the extraction unit. The flask was then heated with the aid of an electrothermal heater at 60°C for 2 hours. Losses of solvent due to heating were checked with the aid of the condenser, so that it cools and refluxes the evaporated solvent. After extraction, the thimble was removed, and the solvent was salvaged by distillation. The flask containing the fat and residual solvent

was placed in a water bath to evaporate the solvent, followed by further drying in an oven at 105°C for 30 minutes to completely evaporate the solvent. It was then cooled in a desiccator and weighed. The fat obtained was expressed as a percentage of the initial weight of the sample.

$$\begin{aligned} & \text{\% Crude fat} \\ = & \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100 \end{aligned} \quad \text{Equation 3}$$

3.3.4 Crude Fiber

Crude fibre was determined by the procedures developed by AOAC International (2000), Method 920.86. The defatted sample (from crude fat determination) was transferred into a 750 ml Erlenmeyer flask, and about 0.5 g of asbestos was added. Almost 200 ml of boiling 1.25% H₂SO₄ was added, and the flask was immediately set on a hot plate and a condenser connected to it. The content was brought to a boil within 1 minute, and the sample was digested for 30 minutes. At the end of the 30 minutes, the flask was removed, and the content was filtered through a linen cloth in a funnel and subsequently washed with boiling water. The sample was washed back into the flask with 200 ml boiling 1.25% NaOH solution. The condenser was again connected to the flask, and the contents of the flask boiled for roughly 30 minutes. It was then filtered through a linen cloth and thoroughly washed with boiling water. The residue was transferred to a clean crucible with a spatula, and the remaining particles were washed off with nearly 15 ml of ethanol into the crucible. The crucible with its content was dried in an oven at 105°C overnight, cooled in a desiccator, and weighed. The crucible with its content was then ignited in a furnace at 600°C for 30 minutes, cooled, and reweighed. The loss in weight was given as the crude fibre content and was expressed as a percentage of the initial weight of the sample.

$$\begin{aligned} & \text{\%CF} \\ = & \frac{\{(Wt \text{ of cc} + \text{Smp before ignition}) - (Wt \text{ of cc} + \text{ash})\}}{\text{Weight of fresh sample}} \times 100 \end{aligned} \quad \text{Equation 4}$$

3.3.5 Ash Content

The ash contents were determined by the procedures of the AOAC International (2000) Method 923.03. Exactly 2.0 g of the sample was weighed into a previously dried and weighed porcelain crucible. The crucible with its content was placed in a Muffle furnace (Carbolite 530 2 AU, Bamford, Sheffield, England) preheated to 600°C for 2 hours. After this period, the crucible with its content was removed, cooled in a desiccator, and later weighed. The weight of ash was expressed as a percentage of the initial weight of the sample.

$$\% \text{ Ash} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100 \quad \text{Equation 5}$$

3.3.6 Carbohydrate Determination

Carbohydrate content was determined by subtracting the sum of weights of moisture, protein, fat, ash, and fibre from 100% dry matter (FAO, 2003).

$$100\% - \{\text{Moisture (\%)} + \text{Protein (\%)} + \text{Lipid (\%)} + \text{Ash (\%)} + \text{Fibre (\%)}\} \quad \text{Equation 6}$$

3.3.7 Energy Determination

The energy content of buns was determined by multiplying the mean values of crude protein, fat, and total carbohydrate by Atwater factors of 16.736 kJ, 37.656 kJ, and 16.736 kJ, respectively, taking the sum and results expressed in kJ/100 g (FAO, 2003).

3.4 Physical Properties of Buns

3.4.1 Bun Volume

The bun volume was determined after cooling for 15 min using the rapeseed displacement method of the AACC (2000), and results were expressed as the mean of triplicate values with standard deviation in cm³.

3.4.2 Specific Volume

The specific volume of buns was determined after about 30 minutes of baking as per the procedures of the AACCC (2000), method 10-05.

$$\text{Specific volume (cm}^3\text{/g)} = \frac{\text{volume of bun}}{\text{Weight of bun}} \quad \text{Equation 7}$$

3.4.3 Density

Bun density was determined according to the procedures of Shogren, Mohamed, & Carriere (2003) as a ratio of mass to volume of buns expressed in g/cm³.

3.4.4 Baking Loss

Baking loss is the amount of water and organic materials (sugars fermented and released as CO²) lost during baking and was calculated as per the procedures of Laura, Mark, Arend, & Gallagher (2010).

$$\text{Baking loss (\%)} = \frac{\text{Wgt before baking} - \text{Wgt after baking and cooling}}{\text{Wgt before baking}} \times 100 \quad \text{Equation 8}$$

3.4.5 Yield

The yield of the bun was calculated as the weight of the baked bun divided by the weight before baking (AACCC, 2000).

$$\text{Yield (\%)} = \frac{\text{Weight of baked bun}}{\text{Weight of loaf before baking}} \times 100 \quad \text{Equation 9}$$

3.4.6 Colour

Crust and crumb colours were determined using a colour Spectrophotometer (CM-2600d/2500d, Konica Minolta, Japan). The colour parameters of L* (Lightness), a* (redness), and b* (yellowness) were recorded in triplicate. The total colour difference (ΔE) was calculated using a tile that was white as a reference.

$$\Delta E = [(L_s - L^*)^2 + (a_s - L^*)^2 + (b_s - L^*)^2]^{1/2} \quad \text{Equation 10}$$

3.4.7 Texture

Bun hardness was measured one day after baking at room temperature using a Texture Analyzer (CT3, Brookfield Ametek, USA) in accordance with AACC (2000), method 74-09. The pre-test, test, and post-test speeds were all 5 mm/s, with a test time of 5 seconds. The sample analyses were done in triplicate, and the results were expressed in Newtons.

3.5 Mineral Analyses of Buns

Minerals essential for growth and development in children were analyzed using Atomic Absorption Spectrophotometry (AAS) (Shimadzu AA-6200, Tokyo, Japan), AOAC (2000), method 985.35. According to Mosha and Vicent (2004), these include Zinc (Zn), Iron (Fe), Calcium (Ca), Magnesium (Mg), and Copper (Cu).

3.6 In vitro Protein Digestibility of Buns

In vitro protein digestibility was determined by pepsin digestion as per the procedure of Boisen (2000). About 200 mg of the sample was weighed and digested with P7000-100G porcine pepsin, activity 863 units/mg protein (Sigma-Aldrich, St. Louis, MO) for 2h at 37°C. The supernatant was pipetted off using a Pasteur pipette, the residue was washed, and the clear supernatant was pipetted off again. The residues were dried overnight in an oven at 100°C. Protein content in the dried residue was determined by the micro Kjeldahl method (section 3.3.2). Digestibility was calculated based on the difference between total protein and residual protein and expressed as a percentage of the total protein.

3.7 Microbiological Quality of Buns

Plate count agar (PCA) and potato dextrose agar (PDA) media were used to enumerate bacterial and fungal flora contaminating the buns. An accurately weighed 1g of the buns sample was homogenated with 10 ml of sterile saline solution (9‰), and serial dilutions (10^{-1} , 10^{-2} , 10^{-3} , and 10^{-4}) were prepared. One hundred (100) μ l of each

dilution was plated on PCA and PDA plates and incubated for 24h at 37°C and 48h at 30°C, respectively. Plates with 30-300 colonies were selected, and the average number of colonies was used to calculate the viable cell concentrations expressed in Colony Forming Units/gram (cfu/g) of buns.

3.8 Keeping Quality of Buns

The buns were stored in a temperature-controlled microbiology laboratory (22°C - 25°C) in transparent plastic containers with lids and evaluated on alternate days for off-flavours and fungal infestation, as described by Shahnawaz, Lohano, and Sheikh (2012).

3.9 Statistical Analysis

All measurements were performed in triplicate, and the mean values are presented. Data was analyzed using One-Way Analysis of Variance (ANOVA) and means separated by the Least Significant Difference (LSD) with a probability of $P < 0.05$. Results obtained from microbial analyses were analyzed using a completely randomized design test.

3.10 Results and Discussion

3.10.1 Proximate Composition of Buns

Results on the proximate composition of buns are presented in Table 3.1. Enriching sorghum-wheat buns with SMP at between 5% and 25% led to a significant difference ($P < 0.04$) in protein content of unenriched buns. Protein content of unenriched bun was 9.93 g/100 g compared to 20.51 g/100g in buns enriched at 25% with SMP, which is equivalent to a 52% increase in protein content. The observed increase was likely due to the high-quality protein of snail meat powder that averages 60 to 70 g/100 g, which improved the protein profile of the enriched buns (Celik, et al., 2020). Earlier, Cercel, Burluc, and Alexe (2016) documented an increase in protein content from 9.73 g/100 g in unenriched bread to 10.45 g/100 g and 19.26 g/100 g in wheat bread enriched with fish protein concentrate lyophilized and fish protein concentrate, respectively. Similarly, Kinyuru et al. (2009) determined that supplementing wheat buns with edible

termite flour enhanced protein content by 47.5% compared to the control. Blending sorghum-wheat buns at 10% with SMP has the potential to provide the recommended 13 g of protein per day in the diet for children of 1 to 3 years, which is adequate in the management of PEM (WHO, 2013).

Ash content of the sorghum-wheat buns ranged between 8% and 38% on enrichment at 5% and 25% with SMP, respectively, compared to the unenriched buns. Ash is the inorganic residue that remains after water and other organic matter have been removed by heat in the presence of an oxidizing agent (Harris & Marshall, 2017). The increase in ash percentage was likely due to the improved quality of mineral content in sorghum-wheat buns after enrichment with SMP (Nkansah et al., 2021). A study by Olorunfemi et al. (2014) found that snacks made from snail meat had a slightly higher ash content when compared to fish snacks. Correspondingly, Cakmak et al. (2013) documented an increase in ash content in wheat and whole wheat breads from 2.22 g/100 g to 2.36 g/100 g and from 3.83 g/100 g and 3.23 g/100 g to 6.79 g/100 g and 8.79 g/100 g, respectively, when supplemented with chicken meat and meat powder at 10% and 30%. It is worth noting that minerals are crucial in the diet for bodybuilding, mental and physical health, as well as the metabolism of carbohydrates, fats, and proteins (Ikuomola, Otutu, & Oluniran, 2017).

There was a minimal, but significant increase in fat from 10.46 g/100 g in unenriched buns to 11.89 g/100 g in buns incorporated at 25% with SMP. The increase in fat content may be partially due to the inclusion of snail meat powder in the bun samples (Nyoagbe et al., 2016). In addition, the inclusion of the shortening agents used in the bun formulations (Serrem et al., 2011a). Earlier, El-Beltagi, El-Senousi, Ali, and Omran (2017) established that the utilization of dried carp fish powder improves the content of fatty acids. Fats supply essential fatty acids to the body and improve energy density and good mouth feel of foods (Serrem et al., 2011a). The fat content in sorghum-wheat buns was within the recommended 10-25 g/100 g for supplementary diets formulated for young children (Ayoob, et al., 2024).

Substituting sorghum-wheat bun at 5% and 25% with SMP led to a 0.3% and 28% decrease in crude fibre, respectively. Fibre was high at 3.00 g/100 g in the unenriched

bun and low at 2.35 g/100 g in the bun enriched at 25% with SMP. The reduction could be due to blending with snail meat powder, which is a poor source of fibre (USDA, 2018). Niaba et al. (2013) evaluated the qualitative characteristics of sorghum biscuits on substituting between 5% and 25% with defatted termite flour, and reported a considerable increase in crude fibre from 2.63 g/100 g to 2.95 g/100 g and 4.44 g/100 g. These researchers attributed their results to the high fibre value in defatted termite flour. Dietary fibre plays a crucial role in managing obesity and diabetes, while also helping to lower cholesterol levels, reduce constipation, and the risk of coronary heart disease (Gibson, 2014). The FAO/WHO recommends that fibre and non-absorbable carbohydrate levels in supplementary foods should remain below 5 g/100 g on a dry matter basis. Thus, a diet excessively high in fibre can lead to increased bulk, which may impair digestibility and protein absorption (Grundy, et al., 2016).

Moisture content in buns decreased from 7.82 g/100 g in the control to 6.55 g/100 g in buns blended at 25% with SMP. This reduction in moisture is ascribed to improvements in mineral quality from the blending process (Ndife, Obiegbunna, & Ajayi, 2013). In a related study, Arshad, Imran, Afzaal, and Shah (2023) determined a reduction in moisture content from 8.30 g/100 g to 4.50 g/100 g upon incorporation with soy flour at 5% and 25%, respectively. Similarly, Raihan and Saini (2016) evaluated multigrain buns and observed a gradual decrease in moisture when wheat buns were substituted with a mixture of oat, sorghum, and amaranth from 0 to 25%. Higher moisture content in baked foods encourages microbial growth that causes spoilage (Khanom et al., 2016).

The carbohydrate value in sorghum-wheat buns decreased by 2% and 13% when enriched with SMP at 5% and 25%, respectively. This reduction is perhaps due to the incorporation of buns with SMP. Previously, Niaba et al. (2013) found a decrease of 2% to 27% in the carbohydrate value of biscuits made with 5% and 25% defatted termite flour compared to unenriched sorghum biscuits. Likewise, Serrem et al. (2011a) reported a significant decrease of 22% to 73% in carbohydrate content for sorghum and bread wheat biscuits when substituted with defatted soy flour at 28.6% and 71.4%, respectively, compared to cereal biscuits. Carbohydrates provide

approximately 95 g of recommended daily energy in children of 1 to 3-year-old (WHO, 2013).

The energy content of sorghum-wheat buns supplemented with SMP met the minimum recommended energy value of 1674 kJ/100 g required in foods formulated for young children (Serrem et al., 2011a). The energy density of these buns increased between 1.2% and 6.2% upon enriching at 5% and 25% respectively, with SMP. This increase in energy content can be attributed to the inclusion of snail meat proteins and corn oil in the formulation. Previous studies have reported similar findings; for instance, Glover-Amengor, Quansah, and Peget (2013) noted a 0.37% increase in energy for soy-fortified yam flour. Equally, Sadaat et al. (2023) concluded that incorporating high-quality protein and oil sources into baked goods significantly enhanced the energy content in the diet. Enriching buns with SMP provides the required calories in the diet that spares protein to build and repair the worn-out body tissues.

Table 3.1: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on Proximate Composition (g/ 100 g Dry Matter)

Buns	Proximate						
	Protein	Ash	Fat	Crude Fibre	Moisture	¹ Carbohydrate	² Energy (kJ)
S-WB 0% SMP	9.93 ^f ±0.12	3.08 ^f ±0.21	10.46 ^e ±0.08	3.00 ^a ±0.09	7.82 ^a ±0.23	65.68 ^a ±0.06	1659.29 ^f ±0.06
S-WB 5% SMP	11.97 ^e ±0.08	3.34 ^e ±0.10	10.47 ^e ±0.26	2.99 ^a ±0.56	7.43 ^b ±0.11	64.84 ^b ±0.27	1679.75 ^e ±0.05
S-WB 10 SMP	13.63 ^d ±1.12	3.42 ^d ±0.51	11.10 ^d ±0.51	2.97 ^b ±0.11	7.12 ^c ±0.17	63.48 ^c ±0.47	1708.49 ^d ±0.11
S-WB 15% SMP	15.58 ^c ±0.22	3.52 ^c ±0.32	11.38 ^c ±0.09	2.88 ^c ±0.21	6.73 ^d ±0.17	62.19 ^d ±0.12	1730.08 ^c ±0.09
S-WB 20% SMP	17.75 ^b ±0.09	4.01 ^b ±0.28	11.43 ^b ±0.56	2.67 ^d ±0.21	6.66 ^e ±0.22	60.44 ^e ±0.09	1739.00 ^b ±0.03
S-WB 25% SMP	20.51 ^a ±0.12	4.12 ^a ±0.10	11.89 ^a ±0.08	2.35 ^e ±0.11	6.55 ^f ±1.02	58.01 ^f ±0.34	1761.84 ^a ±0.10

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at ($p < 0.05$) as assessed by the Least Significant Difference.

¹Calculated by difference [Organic matter (%) - (Moisture (%) + Protein (%) + Lipid (%) + Ash (%) + Fibre (%)) in 100 g of food

²Calculated by multiplying with Atwater factors the mean values of Protein (16.736kJ), Lipid (37.656kJ), and Carbohydrate (16.736kJ)

S-WB - sorghum wheat bun; SMP - snail meat powder

3.10.2 Mineral Composition of Buns

The iron content in sorghum-wheat bun increased from 3.15 mg/100 g to 17.78 mg/100 g (Table 3.2) as blending increased from 0 to 25% with SMP. These results correspond to an increase in ash value (Table 3.1). Previously, Niaba et al. (2013) reported an increase in iron value from 13.52 g/100 g to 43.33 g/100 g in sorghum biscuits fortified between 0 and 25% with termite flour. Similarly, Kinyuru et al. (2009) substituted wheat buns at 5% with edible termite flour and recorded a 50% increase in iron value. Iron deficiency critically occurs during weaning when children's requirements for iron in relation to energy intake are very high (Joo, Kim, Kim, Lee, & Kim, 2016). This situation is worse in developing countries, where cereals and other starchy foods are consumed as dietary staples for adults and weaning foods for children (De Vries-Ten Have et al., 2020). Iron intake of 13-15 mg/day in diets of 2 to 11-year-old children is adequate to help in the formation of haemoglobin, development of the brain and other body tissues, and prevent the development of anaemia (Cohen & Powers, 2024).

Blending sorghum-wheat bun from 0 to 25% with SMP-enhanced zinc contents from 0.64 mg/100 g to 3.18 mg/100 g (Table 3.2). The increase in zinc could be attributed to the good quality of mineral elements in SMP (Ohimain et al., 2024). These findings are in agreement with the findings of other researchers on supplementing cereals with animal flesh. For example, Niaba et al. (2013) revealed that blending sorghum biscuits at 0% and 25% with termite powder improved zinc values from 3.62 mg/100 g to 12.85 mg/100 g. Kinyuru et al. (2009) concluded that supplementing wheat buns at 5% with edible termite powder contributed 21.5% of the recommended daily zinc intake for adult males. A daily dietary intake of 3 mg of zinc in children aged 7 months to 3 years, and 5 mg in those aged 4 to 8 years, is sufficient to maintain the metabolism of nucleic acid and protein, protect the body from cadmium and lead toxicity, and promote prostate gland health (Ahmadu & Ojogho, 2012).

Calcium content in the present study ranged between 31.40 mg/100 g in an unenriched bun and 153.42 mg/100 g in buns enriched at 25% with SMP (Table 3.2). Snail meat is an excellent source of calcium that is recommended to be incorporated in weaning foods in powder form (Tanyitiku, 2022). Drying snail meat reduces moisture content

and improves mineral concentration (Olorunfemi, et al., 2014). Earlier, Kinyuru et al. (2009) determined an increase of 8.3% in calcium content on fortification of wheat at 5% with edible termite powder. Similarly, an increase in calcium from 24.40 mg/100 g to 74.68 mg/100 g on blending sorghum biscuits at 0% and 25% with defatted termite powder has been reported (Niaba et al., 2013). Calcium is responsible for active skeletal muscle growth in young children and the management of convulsions and irritable nerve tissues (Tanyitiku, 2022). Buns evaluated in the present investigation did not meet the 700 mg/day of calcium required for 1-3-year-olds. Hence, it should be consumed in combination with other valuable, cheap sources of calcium, such as green leafy vegetables (Kumar, Kumar, & Shekhar, 2020).

The magnesium content of the sorghum-wheat bun substituted at 25% with SMP increased by 197% compared to the unenriched bun. The lowest mean value of 45.01 mg/100 g was recorded in the unenriched bun, and the highest value of 134 mg/100 g was in the bun incorporated at 25% with SMP (Table 3.2). Snail meat is a significant source of both macro and micro elements required for health (Marcel, et al., 2020). These findings are in agreement with those reported by Niaba et al. (2013), who found an increase of 76% in the magnesium content of sorghum biscuits supplemented at 25% with defatted termite powder. The deficiency of magnesium in young children from developing countries is associated with PEM, which decreases the ability of magnesium to be absorbed from the intestinal tract (Batool, Butt, Sultan, Saeed, & Naz, 2015). A daily recommended intake of 130 mg/100 g of magnesium is appropriate for effective neuromuscular transmission and skeletal tissue metabolism in young children (Liguori, Moretti, Paoletta, Gimigliano, & Iolascon, 2024).

According to Wang et al. (2023), copper promotes the appropriate absorption, use, and conversion of iron into haemoglobin and cytochrome molecules. It is also a cofactor for antioxidant enzymes, which protect the body from free oxygen radicals produced during oxidative stress. Copper content varied from 0.40 mg/100 g in an unenriched bun to 4.06 mg/100 g in buns enriched at 25% with SMP (Table 3.2). Substituting with SMP improved mineral elements in buns to provide sufficient copper (Tanyitiku, 2022) that met the recommended average daily allowance of 3.4 mg/100 g for children 1 to 3 years old and 4.4 mg/100 g for 4 to 8 years old. A study by Niaba et al. (2013)

attributed the increase in the value of copper in biscuits to blending with defatted termite powder. In their study, substituting sorghum biscuits at 0% and 25% with defatted termite powder led to an increase in the concentration of copper between 1.18 mg/100 g and 8.66 mg/100 g, respectively. Cereals are poor sources of copper as they form complexes with phytates in the intestinal mucosa, making them unavailable for absorption (Espinosa & Stein, 2021).

Table 3.2: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on Mineral Composition (mg/100 g Dry Weight)

Buns	Minerals				
	Iron	Zinc	Calcium	Magnesium	Copper
S-WB 0% SMP	3.15 ^f ±0.02	0.64 ^f ±0.02	31.40 ^f ±0.03	45.01 ^f ±0.3	0.40 ^f ±0.01
S-WB 5% SMP	5.97 ^e ±0.01	1.19 ^e ±0.03	54.19 ^e ±0.01	59.34 ^e ±0.04	1.17 ^e ±0.03
S-WB 10 SMP	7.31 ^d ±0.02	1.62 ^d ±0.01	67.80 ^d ±0.01	74.08 ^d ±0.05	1.77 ^d ±0.03
S-WB 15% SMP	10.39 ^c ±0.04	2.29 ^c ±0.02	96.41 ^c ±0.02	94.07 ^c ±0.01	2.33 ^c ±0.01
S-WB 20% SMP	13.04 ^b ±0.03	2.77 ^b ±0.03	117.71 ^b ±0.02	108.08 ^b ±0.02	3.76 ^b ±0.03
S-WB 25% SMP	17.78 ^a ±0.02	3.18 ^a ±0.02	153.42 ^a ±0.03	134.88 ^a ±0.02	4.06 ^a ±0.01

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at ($p < 0.05$) as assessed by the Least Significant Difference.

S-WB - sorghum – wheat bun; SMP – snail meat powder

3.10.3 In Vitro Protein Digestibility

In vitro, protein digestibility is an important procedure to determine protein quality in foods (Dervan & Classen, 2020). Highly digestible proteins offer a better nutritional value than those of lower digestibility, as they provide more amino acids for absorption on proteolysis (Kaur, et al., 2022). Substituting sorghum-wheat buns with SMP between 5% and 25% resulted in improvement of in vitro protein digestibility by 41% and 77%, respectively (Table 3.3). This is an indication that snail meat powder has the potential to improve the digestibility of the less digestible cereal proteins. These findings align with other studies that have demonstrated in vitro protein digestibility using a single enzyme assay. Serrem et al. (2011a) obtained digestion rates of 81% and 94% for sorghum and wheat bread flours substituted with defatted soy flour at a 50:50 ratio compared to 100% cereal biscuit. Similar conclusions were drawn by Mosha and Bennink (2004) in supplementary diets developed with beans and sardines. Processing snail meat into powder improves its protein quality (Nkansah et al., 2021).

Table 3.3: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on In Vitro Protein Digestibility of Buns

	Buns					
	0%	5%	10%	15%	20%	25%
Digestibility level	48.94 ^f ±0.06	68.83 ^c ±0.04	73.36 ^d ±0.05	79.82 ^e ±0.06	82.41 ^b ±0.09	86.50 ^a ±0.07

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p < 0.05$) as assessed by the Least Significant Difference.

3.10.4 Physical Characteristics of Buns

The physical characteristics of weight, volume, specific volume, density, baking loss, yield, and hardness of the buns are presented in Table 3.4. The weights of sorghum-wheat buns enriched with SMP were significantly higher than those of the control group ($P < 0.05$). Enrichment at 25% with SMP resulted in an increase in weight to 58.16 g, compared to 54.13 g for the unenriched buns. This increase may be ascribed to the decline in the water and carbon dioxide retention properties of the dough (Julianti, Rusmarilin, Ridwansyah, & Yusraini, 2017). Previously, Ikuomola et al. (2017) found that cookies prepared by substituting part of the wheat flour with malted

barley bran also exhibited higher weights than the control. Similarly, bread made from a composite flour of sweet potato, maize, soybean, and xanthan gum had higher weights compared to the control (Julianti et al., 2017).

Volume is an important factor in determining the quality of baking (Agiriga, 2014). Control bun had the highest volume at 244.50 cm³ and specific volume at 4.15 cm³, while the buns developed with 25% SMP showed the lowest values, with a volume of 177.50 cm³ and a specific volume of 3.05 cm³. The decrease could be attributed to a reduction in the gluten network responsible for holding gas during dough fermentation. Similar results have been reported by other researchers. For instance, Arora and Saini (2016) described that the progressive incorporation of gluten-free de-oiled maize germ into wheat flour for buns formulation significantly decreased the volume and specific volume of buns. In addition, Raihan and Saini (2016) observed a decrease in both volume and specific volume in baked buns from 260 cm³ to 245 cm³ and 2.39 cm³/g to 2.21 cm³/g when wheat was substituted with a mix of oat, sorghum, and amaranth flours in the dough formulation.

The density of sorghum-wheat buns increased from 0.24 g/cm³ to 0.33 g/cm³ when blended at 25% with SMP. This increase in density was due to increased weight and decreased volume and specific volume, resulting from a reduction in gluten content due to enriching with SMP. Studies have shown that substituting wheat flour with other flours of low gluten quality leads to products of higher density. For example, Arora and Saini (2016) found that blending wheat flour with 25% de-oiled maize germ resulted in a maximum bun density of 0.42 g/cm³, while the control bun had the least density of 0.38 g/cm³. Equally, Sandeep, Singh, Nandi, and Singh (2014) reported that the inclusion of 25% makhana flour in wheat flour resulted in a bun density of 0.32 g/cm³, compared to the lowest density of 0.24 g/cm³ in buns blended at 5% with makhana flour. In contrast, Raihan and Saini (2016) showed that a 15% blend of wheat flour with oat-sorghum-amaranth composite flour produced buns with a peak density of 0.39 g/cm³, which decreased to 0.33 g/cm³ on substitution 25%.

Baking loss refers to the loss of water and sugar during the baking as carbohydrates ferment to release carbon dioxide (Alvarez-Jubete, Auty, Arendt, & Gallagher, 2010).

Enriching the sorghum-wheat buns with SMP significantly reduced the baking loss, likely due to a decrease in the water-holding capacity of the buns. Blending with 25% SMP resulted in a baking loss of 3.07%, which was three times lower than the 9.78% in unenriched buns. Similar findings have been reported by Raihan and Saini (2016), who showed that replacing a part of wheat flour with oats-sorghum-amaranth flour led to a decrease in baking loss in buns. Also, Sandeep et al. (2014) observed a progressive baking loss from 15% in the control buns to 9% on blending from 0 to 25% with makhana flour. A similar trend was reported on inclusion with extruded maize flour at different levels in the formulation of gluten-free bread (Ozola, Straumite, Galoburda, & Klava, 2012).

The yield of sorghum-wheat buns showed a significant increase of 7.44% when composited at 25% with SMP compared to unenriched sorghum-wheat buns. Yield is the percentage of a product obtained after baking (Raihan & Saini, 2016) and is inversely related to baking loss. Previously, Sandeep et al. (2014) determined a 7.72% increase in yield for buns enriched at 25% with makhana flour compared to unenriched wheat buns. Furthermore, Arora and Saini (2016) have reported similar results when the quantity of de-oiled maize germ was increased to substitute wheat in the preparation of composite buns. The researchers associated their observed linear increase in yield to the high moisture content of the unenriched sample.

Bun hardness significantly ($P < 0.05$) decreased from 8.52 N in unenriched buns to 5.97 N when sorghum-wheat buns were substituted with 25% SMP. This was perhaps due to a reduction in bun crude fibre with increased concentration of SMP (Table 3.1), since hard crumb texture in baked products results from increased fibre content (Eimam, Amir, & Mustafa, 2008). A previous study by Zaker, Genitha, and Hashmi (2012) assessed the effects of incorporating defatted soy flour on the physical, sensorial, and nutritional properties of biscuits and determined that blending wheat flour from 0 to 30% with defatted soy flour resulted in a linear decrease in biscuit hardness. These authors attributed their results to a higher water-binding capacity of defatted soy flour. Conversely, Arora & Saini (2016) revealed that substituting wheat buns with de-oiled maize germ increases the value of hardness due to higher fibre content.

Table 3.4: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on Volume, Specific Volume, Density, Baking Loss, Yield, Weight, and Hardness of the Buns

Parameters	Buns					
	0%	5%	10%	15%	20%	25%
Volume (cm³)	224.50 ^a ±0.13	211.60 ^b ±0.15	204.60 ^c ±0.12	196.40 ^d ±0.23	181.60 ^e ±0.14	177.50 ^f ±0.10
Specific volume (cm³/g)	4.15 ^a ±0.14	3.74 ^b ±0.12	3.61 ^c ±0.14	3.45 ^d ±0.15	3.14 ^e ±0.14	3.05 ^f ±0.13
Density (g/cm³)	0.24 ^f ±0.11	0.27 ^e ±0.11	0.28 ^d ±0.13	0.29 ^c ±0.22	0.32 ^b ±0.13	0.33 ^a ±0.14
Baking loss (%)	9.78 ^a ±0.13	5.80 ^b ±0.18	5.43 ^c ±0.17	5.07 ^d ±0.17	3.63 ^e ±0.15	3.07 ^f ±0.09
Yield (%)	90.22 ^f ±0.12	94.20 ^e ±0.14	94.57 ^d ±0.15	94.93 ^c ±0.21	96.37 ^b ±0.14	96.93 ^a ±0.14
Bun weight (g)	54.13 ^f ±0.11	56.52 ^e ±0.09	56.74 ^d ±0.12	56.96 ^c ±0.14	57.82 ^b ±0.14	58.16 ^a ±0.15
Hardness (N)	8.52 ^a ±1.09	7.74 ^b ±1.04	7.70 ^b ±0.27	6.90 ^c ±1.01	6.00 ^d ±1.24	5.97 ^d ±0.99

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p < 0.05$) as assessed by the Least Significant Difference.

3.10.5 Colour Characteristics of Buns

Crust and crumb colours determined by L^* (Lightness), a^* (Redness), b^* (Yellowness), and ΔE (Whiteness index) are shown in Table 3.5. Control buns exhibited a higher L^* value of 55.90 for the crust and 50.69 in the crumb, while buns composed of 25% with SMP yielded a lower L^* value for the crust and crumb at 50.92 and 45.78, respectively. The differences exhibited in crust and crumb colours may be due to maillard reactions between amino acids and reducing sugars (Fennema, 2017). Earlier, Arora and Saini (2016) reported a higher L^* value for the crust in control buns. Raihan and Saini (2016) also observed that wheat buns fortified at 25% with oat-sorghum-amaranth mix flour were darker in colour compared to other buns. Liu, Duan, Mao, and Yu (2020) concluded that substituting wheat flour with flaxseeds decreases the L^* value in bread crumbs.

The values of a^* and b^* for crust and crumb were lower in an unenriched sorghum-wheat bun, but increased on gradual inclusion of SMP from 0 to 25%. Higher a^* and b^* values in enriched buns might have resulted from the inclusion of SMP in sorghum-wheat buns. These findings are in line with those previously reported by Sandeep et al. (2014), who observed that the value of a^* decreased in control buns. Arora and Saini (2016) have also established that fortifying between 5% and 25% with de-oiled maize germ increased the yellow tint in buns. Equally, Liu et al. (2020) reported an increase in the value of a^* and a decrease in the value of b^* on blending wheat bread with flaxseed. Likewise, the changes in whiteness index (ΔE) of buns composited with SMP between 5 % and 25 % were significantly different ($P < 0.05$) from unenriched buns. This difference could be attributed to variations in basic colour characteristics for crust and crumb (Sandeep et al., 2014).

Table 3.5: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on the Crust and Crumb Colour of the Buns

Buns	Crust				Crumb			
	L*	a*	b*	ΔE	L*	a*	b*	ΔE
0%	55.90 ^a ±1.10	15.63 ^f ±0.09	20.83 ^f ±1.12		50.69 ^a ±0.22	14.44 ^f ±0.13	18.28 ^f ±0.20	
5%	54.24 ^b ±0.67	16.01 ^e ±1.18	32.43 ^a ±1.15	46.31 ^e ±0.20	48.27 ^b ±1.09	15.56 ^e ±0.21	18.68 ^e ±0.47	47.59 ^a ±0.10
10%	53.90 ^b ±1.12	16.30 ^d ±0.21	24.33 ^e ±0.19	50.68 ^a ±0.17	48.55 ^b ±0.21	15.69 ^d ±0.28	19.46 ^d ±0.28	46.96 ^b ±0.31
15%	52.73 ^c ±0.11	17.30 ^c ±0.12	25.73 ^d ±1.21	49.10 ^b ±0.45	47.83 ^b ±0.27	16.65 ^c ±0.19	19.93 ^c ±0.26	45.97 ^c ±0.28
20%	51.25 ^c ±1.14	17.59 ^b ±0.27	26.47 ^c ±0.33	48.54 ^c ±0.17	46.51 ^c ±1.01	17.35 ^b ±0.31	20.34 ^b ±0.42	45.28 ^d ±0.24
25%	50.92 ^d ±0.41	18.06 ^a ±1.15	28.93 ^b ±0.16	46.74 ^d ±0.34	45.78 ^d ±0.12	17.61 ^a ±1.16	20.88 ^a ±0.54	44.80 ^e ±0.20

Values are means ± standard deviation. Values followed by the same letter superscripts in the same column are not significantly different at ($p < 0.05$) as assessed by the Least Significant Difference.

L* (Lightness), a* (Redness), b* (Yellowness), and ΔE (Whiteness index)

3.10.6 Microbiological Quality of Buns

After storage for 10 days, the Total Aerobic Bacterial Count (TAC) ranged between 1.3×10^2 cfu/g and 1.8×10^2 cfu/g, with the highest count of 1.8×10^2 cfu/g reported in the control and 1.3×10^2 cfu/g in buns enriched at 25% with SMP (Table 3.6). The lowest TAC that limited the range of microbial growth may be attributed to an improvement in the mineral content of the buns due to enrichment with SMP. Minerals have hygroscopic properties that make moisture unavailable for microbial cell growth (Ndife et al., 2013). In addition, SMP contains some antimicrobial substances, since snails secrete glycoprotein achacin on their surface mucus that has a bactericidal effect against gram-positive and negative bacteria (Santana, et al., 2012). The maximum TAC in the present study was below the International Microbiological Standards recommended units for dry and ready-to-eat foods of 10^3 cfu/g (Khanom et al., 2016). Previously, a higher TAC of 3.1×10^2 cfu/g in white bread compared to whole wheat bread at 1.2×10^2 cfu/g and 1.5×10^2 cfu/g was reported (Ndife et al., 2013).

Coliform growth (TCC - Total Coliform Count) was not detected in all the bun samples in the present study (Table 3.6). According to International Microbiological Standards, recommended units of coliform on dry and ready-to-eat foods should be below 10^3 cfu/g (Khanom et al., 2016). Coliforms are the indicator microorganisms that provide evidence of hygiene standards maintained in food production processes. Thus, a higher coliform load in food is considered the result of unsanitary handling and possibly faecal contamination during manufacture (Ndife et al., 2013). Glycoprotein achacin is also known to deter the growth and multiplication of *Escherichia coli* and *Staphylococcus aureus*, and yeast *Saccharomyces cerevisiae* (Chotimah, et al., 2024).

Average Mould Count (TMC) after 10 days of storage at ambient temperature was $<2.0 \times 10^1$ in buns enriched with 25% SMP and 2.5×10^1 cfu/g in control (Table 3.6). Mould counts in the present study were below the World Food Program (WFP, 2018) recommended limit of 10^5 cfu/g for both control and bun samples enriched with SMP. This may have been facilitated by the effective packaging and favourable storage conditions of the buns. Ravimannan et al. (2016) reported a range of between 7×10^4 and 10×10^4 cfu/g for TMC in bread after 5 5-day incubation period. Mould growth is

a major factor that limits the shelf life of baked products, especially during warm weather abetted by humid storage conditions, including moisture condensation on the product surface during packaging before complete cooling (Saranraj & Geetha, 2012).

Table 3.6: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on Microbial Quality of Buns (cfu/g) after 10 10-Day Storage Period

Parameter	Buns					
	0%	5%	10%	15%	20%	25%
TAC	$1.8 \pm 0.15^a \times 10^2$	$1.6 \pm 0.11^b \times 10^2$	$1.6 \pm 0.19^b \times 10^2$	$1.4 \pm 0.13^c \times 10^2$	$1.3 \pm 0.18^d \times 10^2$	$1.3 \pm 0.10^d \times 10^2$
TCC	Nil	Nil	Nil	Nil	Nil	Nil
TMC	$2.5 \pm 0.12^a \times 10^1$	$2.3 \pm 0.09^b \times 10^1$	$2.2 \pm 0.05^c \times 10^1$	$2.1 \pm 0.15^d \times 10^1$	$< 2.0 \pm 0.28^e \times 10^1$	$< 2.0 \pm 0.20^e \times 10^1$

Values are means \pm standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p < 0.05$) as assessed by the Least Significant Difference.

3.10.7 Keeping Quality of Buns

Buns were examined for production of off-flavours and fungal infestation in 10 days of storage at ambient temperature on alternate days. As shown in Table 3.7, control buns have a shelf life of 4 days. The 5% and 10% SMP-enriched buns lasted for 6 days, while at 15%, 20%, and 25% levels of SMP enrichment, the buns lasted for 8 days. Moisture content in baked products such as buns may adversely affect shelf life (Madukwe, Obizoba, & Chukwuka, 2013). In the present study, control samples had the highest moisture content of 7.82 g/100 g (Table 3.1) and the shortest shelf life of 4 days (Table 3.7). Other studies have evaluated the shelf-life characteristics of baked products. For example, Ijah, Auta, Aduloju, and Aransiola (2014) observed that substituting wheat flour at 10% with hydrated potato flour in bread prolonged shelf life for 6 to 8 days and considerably reduced staling. Also, Mohsen, Aly, Attia, and Osman (2016) observed that using sourdough in bread production had a significant role in extending the shelf-life of bread to 8 days from 3 days in control bread.

Table 3.7: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on Keeping the Quality of the Buns

Spoilage	Buns					
	0%	5%	10%	15%	20%	25%
Day 2	χ	χ	χ	χ	χ	χ
Day 4	χ	χ	χ	χ	χ	χ
Day 6	P	χ	χ	χ	χ	χ
Day 8		P	P	χ	χ	χ
Day 10				P	P	P

χ - Mould absence, P - Mould present

3.11 Conclusion

Compositing sorghum-wheat flour with SMP is beneficial in formulating buns of superior protein and mineral qualities, in proportion to the amount of SMP added. Substituting sorghum-wheat buns at 10% with SMP has the potential to provide the recommended 13 g of protein per day in the diet of 1 to 3-year-old children to manage PEM. Enriching with SMP imparts positive physical characteristics of higher density, yield, and weight, reduces bun hardness and baking loss, and promotes better-keeping

quality. Furthermore, enriching with only 5% of SMP significantly improved in-vitro protein digestibility by 29% compared to the control. Enriching buns with SMP between 5% and 25% improves shelf life compared to an unenriched bun and maintains the total aerobic bacterial count below 10^3 cfu/g, recommended for dry and ready-to-eat foods. Hence, buns enriched with SMP have the potential to help alleviate PEM among young children in developing countries.

CHAPTER FOUR

EFFICACY OF COMPOSITING WITH SNAIL MEAT POWDER ON PROTEIN NUTRITIONAL QUALITY OF SORGHUM-WHEAT BUNS USING A RAT BIOASSAY

4.1 Introduction

Protein Energy Malnutrition (PEM) is a significant health burden in most developing countries (WHO, 2024), increasing children's susceptibility to more life-threatening illnesses such as malaria and tuberculosis (Majumdar et al., 2025), as well as prolonged illness, delayed motor skills, and poor cognitive development (Zhang, et al., 2022). Recent estimates indicate that nearly 45% of all deaths in children less than 5 years old are due to PEM, a vast majority of them living in sub-Saharan Africa (WHO, 2018). The World Health Organization and the Food and Agriculture Organization of the United Nations (WHO/FAO, 2006) have recommended complementary diets as one of the most effective interventions for preventing nutritional deficiencies by utilizing locally available, commonly consumed, low-cost foods as vehicles. Sorghum, a gluten-free cereal, is an important staple food to millions of resource-underprivileged households in the tropics (Hariprasanna & Rakshit, 2017) that has the potential to be processed into several products, including baked foods such as buns (Ratnavathi & Patil, 2013), and is therefore an appropriate food enrichment vehicle. Even though it has poor rheological qualities related to rolling, extension, and flexibility (Dube, Xu, & Zhao, 2020), it may be incorporated in wheat flour for developing protein-rich diets, such as the SMP enriched sorghum-wheat buns, to help alleviate PEM in children.

Buns prepared from sorghum-wheat composite flours enriched with snail meat powder are considered complementary in alleviating PEM as SMP has the potential to improve the protein content of such buns (Adeyeye et al., 2020). However, the interactions with other ingredients in the buns might influence the protein bioavailability of SMP. In this regard, although proximate analyses may give useful information relating to the protein content in foodstuffs, they will not show to what extent that protein is useful for growth, especially in young children (Lewis, 2012). A protein-rich food may not necessarily have high contents of bioavailable indispensable amino acids (Shaheen,

Islam, Munmun, Mohiduzzaman, & Longvah, 2016). Therefore, clinical or animal assays, such as rat bioassay, to determine growth or digestibility, have been proposed as the most accurate method in assessing protein quality in foodstuffs (Lewis, 2012). Procedures to evaluate nitrogen balance using animals are considered important in computing PDCAAS and calculating the true digestibility of proteins in humans (Boye et al., 2012). The FAO (2013) also recommends DIAAS, a method based on digestible individual indispensable amino acids in dietary protein relative to the human reference amino acid requirement pattern, suitable for evaluating protein quality in human diets.

Rat bioassays are widely used to predict the protein quality of foods, but the only problem with such assays is the high requirement of sulfur-containing amino acids for rats compared with human requirements (Sikalidis & Stipanuk, 2010). The Food and Agriculture Organization of the United Nations (FAO, 2011) has proposed a reference pattern based on the requirements of weanling rats to be used in assessing protein quality for human diets. For this reason, young rats whose nutritional requirements and metabolism of essential nutrients closely resemble those of growing children should be utilized (Onabanjo, Maziya-Dixon, Oguntona, & Dixon, 2009). Consequently, protein nutritional quality is subject to its ability to make available sufficient quantities of nitrogen and amino acids to meet the dietary needs of an organism (FAO, 2011). Digestibility determines protein availability; therefore, a highly digestible protein is significantly of greater nutritional quality than a low-digestible protein since it will deliver more of the amino acids for absorption on proteolysis (Kaur, et al., 2022). Thus, supplementary foods with high sorghum percentages and enhanced protein digestibility will offer the much-needed improvement in protein availability to ensure the nutrition security of young children in developing countries such as Kenya. This study was therefore designed to fill this gap by evaluating the efficacy of compositing with SMP on the protein nutritional quality of sorghum-wheat buns using a rat bioassay.

4.2 Materials and Methods

4.2.1 Experimental Design

The protein nutritional quality study was carried out using a Complete Randomized Design (CRD). Diet-formed treatments and rats were randomly assigned to groups that formed blocks. Each treatment was replicated three times in a block, and rats were randomly assigned to the treatments based on their weights.

4.2.2 Formulation and Preparation of Buns

The procedures of Ayo and Nkama (2003), in line with an acceptable cereal blend of sorghum and wheat flour at the ratio of 7:3, were used. Flour for bun formulation was prepared by replacing a part of sorghum-wheat flour with 5, 10, 15, 20, and 25% of SMP. Six varieties of sorghum-wheat buns were formulated according to the procedure developed by Arora and Saini (2016) as described in Chapter Three, Section 3.2, subsection 3.2.4, and those with 0% SMP served as the control. Buns were allowed to cool to room temperature, after which they were weighed and packed in separate zip-lock plastic bags.

4.2.3 Diet Formulation

The diets used in this study (Table 4.1) were formulated in accordance with AOAC International (2000) procedures, method 960.48 with modifications. The final diets were made to provide 8% crude protein on a dry weight basis. This was because the protein content of buns with 0% SMP was 9.93 g/100 g. Buns used to formulate the diets were ground using a high-powered blender (Vitamix Professional, 750 Series, Olmsted Falls, OH, USA), set at moderate speed for 2 min. The percentages of ingredients in the diets were computed in relation to the proximate composition of the buns (Table 4.2). Seven isonitrogenous diets were prepared, six from the variations of sorghum-wheat buns, and the seventh was a reference diet made using skimmed milk powder formulated as described by Kamau et al (2017). Buns and skimmed milk powder were incorporated into the basal diet at the expense of a cornstarch and sucrose mixture at a ratio of 1:1 to bring the diet composition to 100%. The eighth, basal diet

(protein-free), used to estimate endogenous nitrogen excretion by rats, was prepared by replacing the test food with a cornstarch-sucrose mixture. All the diets were made to supply adequate nutrients by incorporating (1%) vitamins, (1%) cellulose, (5%) minerals, and fat content adjusted to 9% using corn oil. A ninth rehabilitation diet was formulated to promote catch-up growth by providing 16% protein using the diet with the highest PER. To prepare each diet, all the dry ingredients were precisely mixed for 10 min using a Kenwood food mixer (Kenwood Chef KMC 200, Havant, UK) operated at moderate speed to ensure even distribution. Later, oil was added, and the diet was mixed again for another 10 min. Each diet was packaged in a separate plastic container with a lid and stored in a refrigerator at 4°C until required. A calculated amount of dry feed from each diet was mixed with 5 g of distilled water per day for each rat before feeding to wet the feed and make it easier for the rats to consume.

Table 4.1: Formulation of the Experimental Diets (g/Kg)

Ingredients	Diet composition (g)								
	0%	5%	10%	15%	20%	25%	Reference diet	Basal diet	Rehabilitation diet
S-WB 0% SMP	805.64	0	0	0	0	0	0	0	0
S-WB 5% SMP	0	668.34	0	0	0	0	0	0	0
S-WB 10% SMP	0	0	586.94	0	0	0	0	0	0
S-WB 15% SMP	0	0	0	513.48	0	0	0	0	0
S-WB 20% SMP	0	0	0	0	450.70	0	0	0	0
S-WB 25% SMP	0	0	0	0	0	390.05	0	0	780
Skimmed milk powder	0	0	0	0	0	0	266.67	0	0
Corn oil	90	90	90	90	90	90	90	90	90
Mineral mix	50	50	50	50	50	50	50	50	50
Vitamin mix	10	10	10	10	10	10	10	10	10
Cellulose	10	10	10	10	10	10	10	10	10
Sucrose	17.18	85.83	126.53	163.26	194.65	224.98	286.67	420	30
Corn flour	17.18	85.83	126.53	163.26	194.65	224.98	286.67	420	30
	1000	1000	1000	1000	1000	1000	1000	1000	1000

Skimmed milk powder (Miksi, by Promasidor (Kenya) Ltd, Nairobi), mineral and vitamin mixtures (Amilyte, manufactured by Ultravetis East Africa Ltd, Nairobi, Kenya), wheat bran (locally milled), sucrose (Mumias Sugar Company Ltd, Mumias, Kenya), corn flour (Zesta, manufactured by Trufoods (K) Ltd, Nairobi, Kenya), and corn oil (Elianto, manufactured by Bidco Oil Refineries, Thika, Kenya).

S-WB - sorghum - wheat bun; SMP - snail meat powder

Table 4.2: Effect of Compositing Sorghum-Wheat with Snail Meat Powder on Proximate Analyses of Buns (g/100 g Dry Matter)

Proximate	Buns					
	0%	5%	10%	15%	20%	25%
Protein	9.93	11.97	13.63	15.58	17.75	20.51
Ash	3.08	3.34	3.42	3.52	4.01	4.12
Fat	10.46	10.47	11.10	11.38	11.43	11.89
Crude fibre	3.00	2.99	2.97	2.88	2.67	2.35
Moisture	7.82	7.43	7.12	6.73	6.66	6.55
Carbohydrate	65.68	64.84	63.48	62.19	60.44	58.01

4.2.4 Animals and Housing

Thirty-two (32) male weanling albino rats (Sprague Dawley) aged between 25 and 28 days with initial weights of between 37 g and 41 g were involved in the study. The rat bioassay was carried out in the Animal Research Laboratory, University of Eldoret, Kenya, following the procedures of the AOAC International (2003), method 960-48, with modifications. Each rat was individually housed in a wire-bottomed cage to allow the faecal materials to drop to the base of the collecting tray. The cages were placed in a well-ventilated room with a 12-hour light and/or dark alternating cycle with a mean temperature of 22°C to 25°C and humidity conditions of 40% to 60%. The animals were maintained in accordance with the US National Research Council's (NRC) Guide for the Care and Use of Laboratory Animals (NRC, 2011).

4.2.5 Growth Studies

The growth study was conducted over 28 days (November 4th to December 1st, 2018) after an initial three (3) days of acclimatization on standardized laboratory irradiated rat pellets (Hindustan Animal Feeds, Gujarat, India). Rats were weighed using an electronic balance (A&D, model - FX-5000i) with precision to weigh in increments of as small as 0.01 g and randomly distributed to 8 groups of 4 rats each, with average weight among groups not exceeding 5g. Eight diets (six tests, one reference, and one basal) were evaluated. Each group of four rats received the experimental diet in a Completely Randomized Design (CRD). The first group was fed on an unenriched sorghum-wheat bun diet (0% SMP); rats in the second to the sixth group were fed on

sorghum-wheat bun diets enriched at 5, 10, 15, 20 and 25% respectively with SMP, while the seventh group was fed on basal diet and the eighth (control/reference) group, on skimmed milk powder. Experimental diets and clean water were accessible to the animals *ad libitum* throughout the study, and daily records of each rat's food consumption and body weight were taken on alternate days. Each rat received 15 g of diet daily. Studies on Protein Efficiency Ratio (PER), Food Efficiency Ratio (FER), and Net Protein Retention Ratio (NPRR) lasted 10 days because of weight loss in rats fed on a basal diet.

The calculations of protein quality indices of PER, FER, and NPRR were obtained from FAO (2011):

$$\text{Protein Efficiency Ratio (PER)} = \frac{\text{g of weight gain}}{\text{g of protein consumed}} \quad \text{Equation 11}$$

$$\text{Food Efficiency Ration (FER)} = \frac{\text{g of weight gain}}{\text{g of food consumed}} \quad \text{Equation 12}$$

$$\text{NPRR} = \frac{\text{g of weight gain} + \text{g of weight loss in basal diet}}{\text{g of protein consumed}} \quad \text{Equation 13}$$

4.2.6 Rehabilitation Study

The rehabilitation study lasted for 18 days of the growth study, from day 11 to 28 (November 14 to December 1, 2018). The rats fed on a basal diet continuously recorded a significant weight loss in the first 10 days of the digestibility and growth studies (November 4 - 13, 2018), and could not be permitted to lose in excess of 20% of their initial body weights. Thus, on day 11 (November 14, 2018), the basal diet was stopped, and the rehabilitation diet began. During this period, the rats continued to receive a daily diet allowance of 15 g/rat/day of the rehabilitation diet, and the weights of the rats were recorded on alternate days.

4.2.7 In Vivo Digestibility and Protein Quality Evaluation

The digestibility study lasted 5 days, between days 5 and 9 (8th - 12th November 2018) of the growth study. Records of food consumed and what remained unconsumed by

each rat per day were kept and used in calculating the food intake. Total faecal material from each rat was collected daily in a plastic container with a lid and frozen at - 20°C until analyzed. Each group of four rats fed on a similar diet had their faecal material pooled together, dried overnight at 100°C in an air-circulating oven, weighed, and ground using a laboratory mortar and pestle. Faecal nitrogen content was determined by the micro-Kjeldahl method (as described in Chapter Three, Section 3.3, and Sub-section 3.3.2). Faecal material from the group of rats fed on a basal diet was used to calculate the endogenous nitrogen losses. The faecal protein, apparent protein digestibility (APD), and true protein digestibility (TPD) values were calculated from faecal nitrogen and nitrogen intake of the experimental diets.

The calculations of protein quality indices of APD and TPD were obtained from FAO (2007):

$$\text{Apparent Protein (N)Digestibility (APD)\%} = \frac{I - F \times 100}{I} \quad \text{Equation 14}$$

$$\text{True Protein (N)Digestibility (TPD)\%} = \frac{I - (F - F_0) \times 100}{I} \quad \text{Equation 15}$$

Where:

I - Nitrogen intake of the experimental diet

F - Faecal nitrogen loss on the experimental diet

F₀ - Faecal nitrogen loss on a protein-free diet

4.2.8 Protein Digestibility Corrected Amino Acid Score (PDCAAS)

PDCAAS was computed first by determining the TPD of reference and enriched as well as unenriched sorghum-wheat bun diets, followed by the indispensable amino acid (mg/g protein) requirement pattern for children aged between 3 to 10 years old (FAO, 2011).

$$\text{PDCAAS} = \text{TPD} \times \text{Lysine score or limiting amino acid} \quad \text{Equation 16}$$

Amino acid scores of the 9 indispensable amino acids, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan, and Valine were computed using the human reference pattern for amino acid requirements of 3 to 10-year-old children (WHO, 2007).

$$\text{Amino acid score} = \frac{\text{mg of amino acids in 1 g test protein}}{\text{mg of amino acid in requirement pattern}} \quad \text{Equation 17}$$

4.2.9 Digestible Indispensable Amino Acid Score (DIAAS)

DIAAS estimates the available protein quality for regulatory purposes and preferably should be calculated from the ileal digestibility data (Nosworthy, et al., 2017); however, when unobtainable, faecal crude protein digestibility may be used (FAO, 2013). In this study, faecal nitrogen to determine PDCAAS was used to calculate DIAAS as follows:

$$\begin{aligned} &\text{DIAAS} \\ &= \frac{\text{mg of digestible dietary indispensable AA in 1g of dietary protein}}{\text{mg of the same dietary indispensable AA in 1g of the reference protein}} \quad \text{Equation 18} \end{aligned}$$

4.3 Data Analysis

Mean values and standard deviations were used to present the results. Data was analyzed using one-way analysis of variance (ANOVA) with SAS version 9.1, and Least Significant Differences (LSD) were used to differentiate treatments. The significance level was observed at $p < 0.05$.

4.4 Results and Discussion

4.4.1 Growth and Rehabilitation Studies

Results on growth indices of body weight gain, PER, FER, and NPRR for rats fed on diets based on six varieties of buns, a reference diet, and a basal diet are presented in Table 4.3. Enrichment with SMP significantly ($P < 0.05$) improved PER values of the complementary diets from 0.21 in the unenriched sorghum-wheat buns diet to 2.70 in the sorghum-wheat bun diet enriched at 25% with SMP. Protein Efficiency Ratio is an

important measure used to determine protein quality in diets (Babji, Fatimah, Ghassem, & Abolhassani, 2010). Diets whose PER values are within the casein threshold of 2.7 are recommended as an excellent source of protein (Hoffman & Falvo, 2004). An unenriched sorghum-wheat bun diet had a zero PER, which is thought to be the cause of the rats' weight stagnation. These results are consistent with those reported in a study by Serrem, de Kock, Oelofse, and Taylor (2011b), where rats fed on a sorghum biscuit diet did not show any increase in weight compared to a 10% weight increase in rats fed on a sorghum-soy diet, and attributed the improvements in growth rate to the high lysine content of legume protein. Improved protein and energy intake in diets enriched with SMP could promote recovery in children affected by PEM.

The FER of the sorghum-wheat bun diet enriched at 25% with SMP was equivalent to the reference diet at 0.27, in contrast to the unenriched sorghum-wheat bun diet that recorded a zero FER. The lower FER of the unenriched sorghum-wheat bun diet was probably because of the low quality of protein in the diet. Following similar studies, Mosha and Bennink (2004) obtained an FER of 0.003 with pure maize meal and attributed it to the poor quality of protein in the diet that did not support any growth, leading to weight loss in rats. Diets with FER values within the casein threshold of 0.27 are recommended as an excellent source of supplement diets (Onabanjo et al., 2009). This value is equivalent to that obtained in the present study for the sorghum-wheat bun diet enriched at 25% with SMP and the reference diet. Thus, enrichment at 25% with SMP produced an excellent diet with a dietary quality similar to casein. A higher FER is a significant attribute of quality in complementary diets that limits the bulk of food consumed to meet the nutritional requirements of children (Serrem et al., 2011b).

The Net Protein Retention Ratio (NPRR) is a protein quality indicator that takes into account weight loss in rats fed a basal diet to the PER value (Oibiokpa et al., 2018). Enriching with SMP increased the NPRR value from 1.45 in the unenriched sorghum-wheat bun diet to 3.78 in the diet enriched with 25% SMP. A higher NPRR value is an indicator of better protein quality for growth maintenance purposes (Oibiokpa et al., 2018). Earlier, Olanrewaju et al. (2024) showed that rats fed a beef-based diet had a greater NPRR, indicating that a significant amount of the absorbed protein was of

higher quality and hence retained by the rats. Mosha and Bennink (2004) found that fortifying maize meal with beans and sardine increased the NPRR from -0.40 to 0.86. Protein quality was higher in both the reference and SMP enriched diets, resulting in good weight gain in experimental animals.

Table 4.3: Growth Indices of Body Weight, PER, FER, and NPRR of Rats Fed on Eight Formulated Diets in the First 10 Days of the Rat Bioassay Studies

Diets	Indices			
	PER	FER	NPRR	Body weight (g)
S-WB 0% SMP	0.21 ^f ±0.11	0.02 ^d ±0.07	1.45 ^e ±0.31	2.18 ^g ±0.10
S-WB 5% SMP	2.05 ^e ±0.02	0.21 ^c ±0.05	3.27 ^d ±0.81	21.25 ^f ±0.05
S-WB 10% SMP	2.35 ^d ±0.18	0.23 ^{bc} ±0.09	3.53 ^{cd} ±1.06	24.93 ^e ±0.18
S-WB 15% SMP	2.41 ^c ±0.16	0.24 ^{bc} ±0.06	3.57 ^c ±0.65	26.15 ^d ±0.09
S-WB 20% SMP	2.62 ^b ±0.12	0.26 ^{ba} ±0.08	3.75 ^b ±0.38	29.24 ^c ±0.04
S-WB 25% SMP	2.70 ^{ba} ±0.07	0.27 ^a ±0.07	3.78 ^a ±0.87	31.21 ^b ±0.11
Control Diet	2.72 ^a ±0.09	0.27 ^a ±0.09	3.77 ^a ±0.43	32.35 ^a ±0.13
Basal Diet	-	-0.11 ^f ±0.04	-	-11.05 ^h ±0.07

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at (p<0.05) as assessed by the Least Significant Difference.

S-WB - sorghum-wheat buns; SMP - Snail meat powder

Mean weight loss of 19% body weight was recorded in rats fed on the basal diet, whereas those fed on the reference diet and SMP enriched diets gained between 21.25 g and 32.35 g body weight (Table 4.3) in the first 10 days and between 54.30 g and 69.59 g (Figure. 4.1) at the end of the 28 days' growth study. This is indicative of being on a positive protein diet. Mosha and Bennink (2004) showed that complementation of cereal flours with beans and sardines significantly improved their ability to support the growth and rehabilitation of emaciated rats. Similarly, Serrem et al. (2011b) established that a sorghum biscuit diet fortified with soy flour promoted weight gain equivalent to rats fed on a casein diet. The rats fed on an unenriched sorghum-wheat bun diet showed stagnated weight gain during the digestibility studies and at the end of the 28-day growth studies. It has been demonstrated that feeding rats on a pure maize meal diet only leads to weight loss (Kamau et al., 2017) and that rats fed on a pure sorghum biscuit diet did not gain any weight (Serrem et al., 2011b). Upon rehabilitation of rats previously fed on a basal diet with a sorghum-wheat bun diet enriched at 25% with SMP, a steady increase in weight gain of up to 53% higher was

obtained (Figure 4.1) in 18 days. These results suggest that enriching with SMP improved the protein quality of sorghum-wheat buns, as exhibited by positive growth and maintenance of emaciated rats whose requirements for sulfur-containing amino acids are higher than humans (Sikalidis & Stipanuk, 2010); hence, it may gradually contribute to a catch-up weight gain in undernourished children.

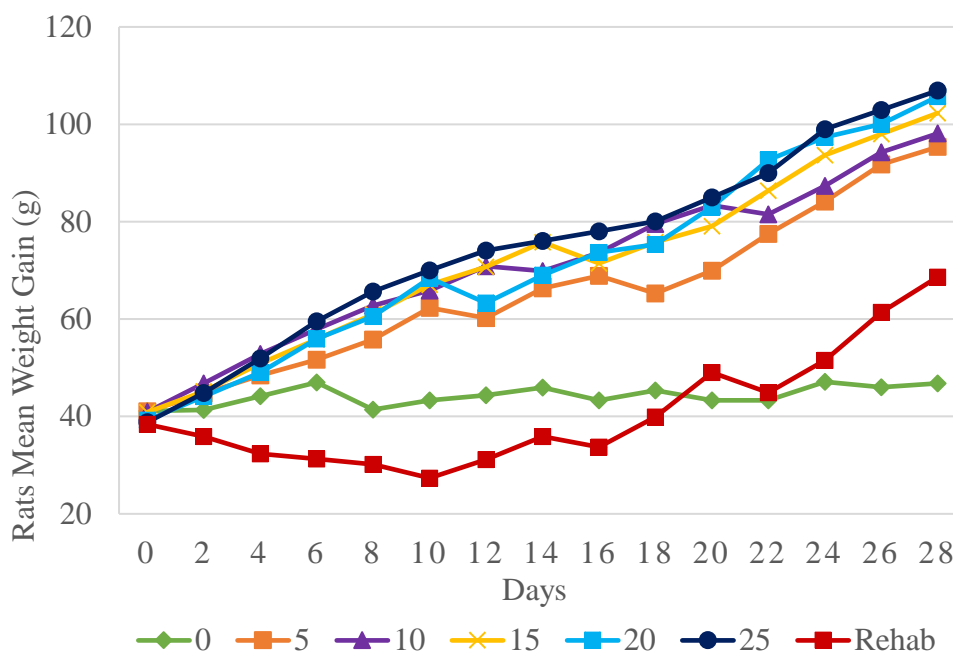


Figure 4.1: Mean Weight Increase in Rats Fed on Unenriched and Snail Meat Powder-Enriched Sorghum-Wheat Bun Diets for 28 Days, Showing Rehabilitation

4.4.2 In-Vivo Protein Digestibility

There was a significantly higher ($P < 0.05$) food and protein intake in rats fed on sorghum-wheat bun diets enriched with SMP and in the reference diet than in the unenriched sorghum-wheat bun diet (Table 4.4). This was perhaps due to the enhanced quality of the aromatic indispensable amino acids, such as phenylalanine and tryptophan, in the diets that encouraged consumption (Hui, 2006). On the other hand, a reduced food and protein intake of rats fed on a basal diet might have resulted from an imbalance in some essential nutrients (Porres, et al., 2002). Earlier, Kamau et al. (2017) established that the type and quantity of protein in the diet influence the amount

of food consumed. Blatt, Roe, & Rolls (2011) concluded that a diet low in protein caused considerably low food intake and a deficiency in protein in weanling rats, resulting in low weight gain, wasting, and in severe cases, death. The amount of food consumed influence both the protein and energy intake, which are important in promoting growth and development in young children.

The faecal weight of rats fed on an unenriched sorghum-wheat bun diet was 43% higher than in rats fed on a reference diet (Table 4.4). This could be due to reduced digestibility of the diet caused by thermal effects on sorghum, which leads to the unavailability of kafirin protein and the formation of enzyme-resistant starch during cooking. These changes result in decreased digestibility and increased faecal volume (Serrem et al., 2011b). Previous reports have indicated that a high faecal bulk is common in rats fed cereal-based starches. For example, Kamau et al. (2017) observed that grain-based diets high in soluble fiber contributed more to dense faecal mass than diets rich in insoluble fiber. Serrem et al. (2011b) also showed that rats fed a sorghum biscuit diet produced between 52% and 62% more faecal bulk than rats fed either casein or sorghum-soy composite biscuit diets. It is postulated that a high faecal bulk results from a large quantity of unabsorbed residue in the diet, which promotes increased faecal excretion (Kamau et al., 2017). Rats fed on sorghum-wheat bun diets enriched with SMP produced similar faecal weights, but these were significantly lower than those fed on unenriched sorghum-wheat bun diets (Table 4.4). Earlier, Serrem et al. (2011b) found that diets containing similar amounts of total dietary fibre might differ in their ability to increase faecal weight. Protein retention in rats fed on the reference diet was 7% higher, and 38% higher than in rats fed on a sorghum-wheat bun diet enriched at 25% with SMP and on an unenriched sorghum-wheat bun diet, respectively (Table 4.4).

Table 4.4: Protein Intake, Faecal Weight, Protein Output, and Protein Retention of Rats Fed on the Eight Diets

Diets	Indices (g)				
	Food intake	Protein intake	Faecal Weight	Faecal protein output	Protein retention
S-WB 0% SMP	50.83 ^g ±1.67	6.35 ^g ±0.23	4.12 ^a ±0.11	0.93 ^a ±0.17	5.42 ^g ±0.13
S-WB 5% SMP	56.36 ^f ±2.09	7.05 ^f ±0.36	3.37 ^b ±0.18	0.78 ^b ±0.11	6.27 ^f ±0.12
S-WB 10 SMP	57.79 ^e ±2.02	7.22 ^e ±0.47	3.35 ^{bc} ±0.33	0.73 ^{bc} ±0.07	6.49 ^e ±0.62
S-WB 15% SMP	58.69 ^d ±1.49	7.34 ^d ±0.65	3.35 ^{bc} ±0.26	0.73 ^{bc} ±0.13	6.61 ^d ±0.40
S-WB 20% SMP	59.43 ^c ±1.60	7.43 ^c ±0.26	3.33 ^{cd} ±0.11	0.61 ^c ±0.27	6.82 ^c ±0.64
S-WB 25% SMP	60.58 ^b ±1.68	7.57 ^b ±0.54	3.24 ^d ±0.17	0.58 ^d ±0.12	6.99 ^b ±0.27
Control diet	63.25 ^a ±2.06	7.91 ^a ±0.04	2.89 ^e ±0.11	0.43 ^e ±0.06	7.48 ^a ±0.23
Basal Diet	49.87 ^h ±1.72	-	0.71 ^f ±0.15	-	-

Values are means ± standard deviations. Values followed by the same letter superscripts in the same column are not significantly different at (p<0.05) as assessed by the Least Significant Difference. S-WB - sorghum-wheat buns; SMP - snail meat powder

4.4.3 Protein Nutritional Quality

Table 4.5 shows the apparent protein digestibility (APD) and true protein digestibility (TPD) of rats fed diets based on six different bun varieties, a reference diet, and a basal diet. The APD values of reference diet and sorghum-wheat bun enriched diets were significantly high at $\geq 86\%$ with minor variances among diets. It may be concluded from the high protein retention and low faecal protein output results that the reference diet and SMP enriched diets are considerably more digestible protein sources. This is because the APD takes the difference between the nitrogen ingested and nitrogen excreted in the faeces of the test animals (WHO, 2007). The APD values close to those obtained in the present study have also been reported for other complementary diets, such as sorghum-soy biscuits (Serrem et al., 2011b). The TPD of the unenriched sorghum-wheat bun diet was 11% lower than the reference diet, whereas enrichment at 5% to 25% with SMP increased TPD by 93.79% and 95.38%, respectively. The increase in TPD could be attributed to higher protein quality, which increased the digestibility of the food. Mosha and Bennink (2004) established TPD values of between 82% and 94% in some complementary foods formulated from cereal bean-sardine mixtures. Faris and Takruri (2002) noted that TPD in the casein diet, which is expected to be the highest, was about 95%. This value is consistent with the 95.38% observed in the sorghum-wheat bun diet enriched at 25% with SMP. Enrichment with SMP increased digestibility to levels that could meet nutritional needs for catch-up growth and maintenance.

Table 4.5: Indices of Protein Quality in the Eight-Formulated Diet

Indices	Diets							
	0%	5%	10%	15%	20%	25%	Control diet	Basal diet
APD (%)	81.17 ^e ±0.57	86.17 ^d ±0.76	86.68 ^{cd} ±0.67	87.22 ^c ±0.67	87.71 ^c ±0.46	88.28 ^b ±0.38	90.05 ^a ±0.45	-
TPD (%)	87.48 ^e ±0.24	93.79 ^f ±0.38	94.12 ^e ±0.62	94.55 ^{cd} ±0.55	94.95 ^c ±0.39	95.38 ^b ±0.62	96.63 ^a ±0.78	-

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at (p<0.05) as assessed by the Least Significant Difference.

APD - Apparent Protein Digestibility

TPD - True Protein Digestibility

4.4.4 Protein Evaluation from PDCAAS

PDCAAS is the method used to determine the quality of protein in foods, which reflects the capability of a protein to deliver the required indispensable amino acids and nitrogen to the human body (FAO, 2013). The index includes protein digestibility, indicated as the true digestibility of the test protein measured in a rat bioassay (Schaafsma, 2005). This method was adopted to effectively predict the credibility of proteins that might score a low PER and not support growth, but may be adequate for maintenance purposes (Oibiokpa et al., 2018). Table 6 indicates the quantities of indispensable amino acids in reference diets and test diets in relation to the FAO (2011) reference pattern for 3 to 10-year-old children. The reference diet scored the highest PDCAAS of 1.0 and was not deficient in indispensable amino acid lysine with respect to the requirements for children aged 3-10 years.

Enrichment improved PDCAAS from 0.45 in the unenriched diet to 0.78 in the diet enriched with 25% SMP, an equivalent of a 73% increase in PDCAAS. Sorghum-wheat bun diets enriched at 20% and 25% with SMP scored a PDCAAS in the range recommended by the Codex Alimentarius Commission-recommended a minimum value of 0.70 for food products developed for children (Lewis, 2012). Previous studies have used PDCAAS to make available data on the potential of complementary foods as protein sources. For instance, Kamau et al. (2017) reported a PDCAAS of 0.53 in a 100% maize meal diet that improved with fortification to 0.70. Likewise, Serrem et al. (2011) noted a PDCAAS of 0.87 in sorghum biscuit diet fortified at 50% with defatted soy flour and concluded that fortification with soy flour improved the PDCAAS of sorghum biscuits threefold. In addition, Mosha and Bennink (2004) found PDCAAS of between 0.77 and 0.90 for cereal-bean-sardine meals formulated for preschool children.

Table 4.6: Amino Acid Score for Control and Test Diets in mg/g Protein with FAO (2011) Requirement Pattern for Children Aged 3 - 10 Years

Amino acids	Diets					FAO, 2011		3-10 years
	Milk powder	0%	5%	10%	15%	20%	25%	
Histidine	27.13	24.58	26.93	29.28	31.63	33.98	36.33	16
Isoleucine	60.51	38.90	40.48	42.77	44.71	46.64	48.58	30
Leucine	97.95	117.04	121.10	125.15	129.21	133.26	137.32	61
Lysine	79.31	25.18	28.05	30.92	33.79	36.66	39.53	48
Met + Cys	34.32	36.79	38.34	39.88	41.43	42.97	44.52	23
Phe + Tyr	69.58	75.87	79.70	83.53	87.36	91.19	95.02	41
Threonine	45.13	36.90	38.28	39.66	41.04	42.42	43.80	25
Tryptophan	14.10	14.03	14.28	14.54	14.80	15.06	15.32	6.6
Valine	66.92	49.03	52.58	56.14	59.69	63.25	66.80	40
Protein (%)	36.16	9.93	11.97	13.63	15.58	17.75	20.51	
Total	494.95	418.32	437.39	461.87	483.66	505.43	527.22	290.6
TPD (%)	96.63	87.48	93.79	94.12	94.55	94.95	95.38	
Limiting AA	None	Lysine	Lysine	Lysine	Lysine	Lysine	Lysine	
Lysine Score	1.65	0.52	0.58	0.64	0.70	0.76	0.82	
PDCAAS	1.0	0.45	0.54	0.60	0.66	0.72	0.78	

Indispensable amino acid scores for the skimmed milk powder, sorghum flour, and wheat flour were obtained from the USDA (2018), and snail meat from Adeyeye and Afolabi (2004). Amino acid reference pattern for children aged 3 - 10 years was obtained from FAO (2011). M + C - Methionine + Cysteine (Sulfur AA), P + T - Phenylalanine + Tyrosine (Aromatic AA).

4.4.5 Protein Evaluation Form DIAAS

FAO (2013) has recommended DIAAS to substitute PDCAAS in estimating protein quality in diets to overcome the limitation where the highest value a protein can attain is 1.0 or 100%, meaning a score above 100% of indispensable amino acids is truncated to 100%. This limits information on the expected efficiency of individual protein sources in balancing the poor proteins in mixed diets (Schaafsma, 2000). Therefore, unlike PDCAAS, the DIAAS values are calculated by multiplying the digestibility of each indispensable amino acid by the concentration of that amino acid in the protein and then comparing these values to a scoring pattern (Rutherfurd, Fanning, Miller, & Moughan, 2015). DIAAS is not truncated, thus enabling the ranking of all dietary proteins by their quality, which has great potential in expounding on many aspects of protein nutrition and could be of value in stipulating the context of dietary recommendations and formulation of a diet plan (Wolfe et al., 2016).

DIAAS values in this present study were determined based on the lysine score of the reference diet and test diets, because it is the first limiting amino acid in diets of children containing cereals (FAO, 2013). The DIAAS values ranged from 44% in the unenriched sorghum-wheat bun diet to 69% in the sorghum-wheat bun diet enriched at 25% with SMP (Table 7). These diets did not meet the lowest DIAAS value of 75% suggested to ascertain the quality of protein in diets (FAO, 2011). The lysine content of the sorghum-wheat bun diet might be improved to meet the indispensable amino acid needs in children aged 6 months to 3 years by considerably enhancing fortification to above 25% with SMP for the buns to be utilized as solitary protein source. These results concur with those obtained by Abelilla, Liu, and Stein (2018) for DIAAS in oat protein concentrate for children 6 months to 3 years and older children, adolescents, and adults at 56% and 67% and determined lysine as the first limiting amino acid among these age groups. DIAAS values in the range of 46% and 73% have been reported in other cooked Canadian pulses (Nosworthy, et al., 2017). The reference diet may be considered an excellent protein source based on its DIAAS value of greater than 100% (FAO, 2011).

Table 4.7: Protein intake of the Control and Test Diets (mg/g Protein) with the Amino Acid Requirement Based on Pattern For Children

Amino acids	Diets						
	Milk powder	0%	5%	10%	15%	20%	25%
Histidine	1.36	1.23	1.35	1.46	1.58	1.70	1.82
Isoleucine	1.89	1.22	1.27	1.34	1.40	1.46	1.52
Leucine	1.48	1.77	1.83	1.90	1.96	2.02	2.08
Lysine	1.39	0.44	0.49	0.54	0.59	0.64	0.69
Methionine + Cysteine	1.27	1.36	1.42	1.48	1.53	1.59	1.65
Phenylalanine + Tyrosine	1.34	1.46	1.53	1.61	1.68	1.75	1.83
Threonine	1.46	1.19	1.23	1.28	1.32	1.37	1.41
Tryptophan	1.66	1.65	1.68	1.71	1.74	1.77	1.80
Valine	1.56	1.16	1.22	1.31	1.39	1.47	1.55
IAA Ref. Ratio	1.27	0.44	0.49	0.54	0.59	0.64	0.69
DIAAS (%)	127 (SAA)	44 (Lys)	49 (Lys)	54 (Lys)	59 (Lys)	64 (Lys)	69 (Lys)

Indispensable amino acid scores for the skimmed milk powder, sorghum flour, and wheat flour were obtained from the USDA (2018) and snail meat from Adeyeye and Afolabi (2004). DIAAS was calculated using TPD. Bolded values reflect the first limiting amino acid. DIAAS values were determined based on the least value of the “digestible IAA reference ratio” expressed as a percentage for each reference pattern. M + C - Methionine + Cysteine (Sulfur AA), P + T - Phenylalanine + Tyrosine (Aromatic AA).

Source: (FAO, 2013)

4.5 Conclusions

Enrichment with SMP significantly promotes growth in rats and improves NPRR, PER, TPD, and PDCAAS of sorghum-wheat buns to levels considered potential for use as complementary or rehabilitation diets. However, the diets do not meet the lowest DIAAS value of 75% suggested to ascertain the quality of protein in diets. The sorghum-wheat bun diet fortified at 25% with SMP has a protein nutritional quality with the highest potential to promote catch-up growth, as measured by PER. Therefore, it has the greatest potential for use as a complementary food to alleviate PEM in young children.

CHAPTER FIVE

EFFECT OF INCORPORATION WITH SNAIL MEAT POWDER ON SENSORY ATTRIBUTES AND CONSUMER ACCEPTABILITY OF SORGHUM-WHEAT BUNS

5.1 Introduction

Currently, sub-Saharan Africa is experiencing a significant population surge, driven by the growth and development of small urban settlements into larger towns and cities (Okpala, 2009). This has led to a 'nutrition transition' as consumer demand for staple foods has declined, with an increase in the desire for more convenient products, such as bakery items, which are now considered important sources of nutrients in the diet (Saranraj & Geetha, 2012). Wheat flour is the main ingredient in baking because of its unique qualities of holding and retaining water vapour and carbon dioxide, resulting in the spongy texture of baked foods (Odedeji et al., 2014). However, the bakery industry is at present faced with the challenge of increased wheat prices because of reduced agricultural land due to urbanization (Polat et al., 2016) and unfavourable climatic conditions in the tropics (Opara et al., 2013). This has generated interest in the utilization of alternative cereal flours such as sorghum in the formulation of baked products (Salim et al., 2017).

Sorghum is an important drought-resistant crop that thrives well in marginal lands where other cereals have failed (Njinju et al., 2022) and is a principal source of protein and energy for millions of resource-underprivileged households in developing countries (Hariprasanna & Rakshit, 2017). Primarily, its grains are ground into flour and consumed in the form of thin or stiff porridge (Anyango, de Kock, & Taylor, 2011), but may also be incorporated in wheat flour at varying proportions to enhance dough volume, gas retention, viscoelastic properties, and crumb uniformity of baked foods (Esteller et al., 2005). Conversely, sorghum's nutritional quality is low owing to its major storage protein kafirin, which is inferior in the indispensable amino acid lysine (Serrem et al., 2011a) and has low digestibility in wet cooking (Tasie & Gebreyes, 2020). Therefore, blending with highly digestible protein foods could

enhance the nutritional value by providing more amino acids for absorption on proteolysis (Serrem et al., 2011b).

Formulation of baked products from low-lysine cereals incorporating SMP has been proposed as one of the most sustainable approaches to enhance protein nutritional quality in the diet (Tanyitiku, 2022). Snail meat is an excellent source of protein that equals other conventional animals in indispensable amino acid lysine (Ghosh et al., 2017) and is an important source of vitamins (Nkansah et al., 2021) and minerals (Ohimain et al, 2024). Notwithstanding, snail meat is underutilized in the diets of most Kenyans and the African continent due to cultural repugnance, lack of familiarity, and poor attitude toward its consumption (Meyer-Rochow, 2009). Therefore, consumption of snails may be enhanced through integration into the modern diet through enrichment. Blending cereals with snail meat results in nutritional compensation (Burger & Zhang, 2019). Buns are valuable fortification vehicles due to their relatively noble eating quality and shelf life potential (Sharma, Punia, & Khetarpaul, 2013).

New food products developed for children must be evaluated by children themselves, exploiting simple, but more reliable methods to measure preference (Patterson & Beeren, 2011) on repeated exposure to reinforce acceptability (Wiejzen, Zanstra, Alfieri, & de Graaf, 2008). Facial scales are more effective with children (Latorres, Mitterer-Dalton, & Queiroz, 2016) as they employ images that stimulate attention with respect to sensory acuity (Popper & Kroll, 2005). Sigh et al. (2018) demonstrated food acceptability in 4 to 10-year-old children, and Simons et al. (2019) concluded that 8 to 9-year-olds were more consistent in describing their liking. No previous studies have developed lexicons to describe buns fortified with SMP using a trained panel. Likewise, no studies have employed 8 to 9-year-olds on repeated exposure to determine the long-term acceptability of buns fortified with SMP. This study evaluated the effect of incorporation with SMP on sensory attributes and consumer acceptability of sorghum-wheat buns.

5.2 Materials and Methods

5.2.1 Experimental Design

Descriptive sensory and consumer acceptability with children studies followed a Randomized Complete Block Design (RCBD) that evaluated six variations of buns as treatments, which were randomized and replicated thrice with panelists as units and sessions as blocks. Adult consumer studies were based on a Completely Randomized Design (CRD) approach. Randomized three-digit codes were assigned to the bun for blinding purposes, with sample arrangement on trays randomized for each panelist. The evaluation process was also randomized, with evaluators coming to the evaluation room at random to evaluate samples for acceptability.

5.2.2 Materials for Buns

Materials utilized in the formulation and development of buns are as presented in Chapter Three, Section 3.2, sub-section 3.2.1.

5.2.3 Formulation and Preparation of Buns

The procedures of Ayo and Nkama (2003), in line with an acceptable cereal blend of sorghum and wheat flour at the ratio of 7:3, were used. Flour for buns formulation was prepared by replacing a part of sorghum-wheat flour with 5, 10, 15, 20, and 25% of SMP. Six varieties of sorghum-wheat buns were formulated according to the procedure developed by Arora and Saini (2016) as described in Chapter Three, Section 3.2, sub-section 3.2.4, and those with 0% SMP served as the control. Buns were allowed to cool to room temperature, after which they were weighed and packed in separate zip-lock plastic bags.

5.3 Sensory Evaluation

5.3.1 Descriptive Sensory Evaluation

A total of 8 (eight) trained panelists from both genders were recruited through an advertisement to participate in a descriptive study of sorghum-wheat bun fortified with

SMP. The panel was selected following the principle proposed by Lawless and Heymann (2010) to have committed individuals aged between 18 and 64 years who were non-smokers and did not suffer from any food allergies to participate in the study. Those who responded attended an orientation session and were subjected to three different screening tests to determine their sensory acuity. The tests included the identification of basic sweet, sour, bitter, salt, and umami tastes as described by Civile et al. (2024), aroma identification, and a test to identify differences in sensory attributes that described the taste, aroma, flavour, and appearance of buns. Before the tasting exercise, the panelists were asked to fill in a consent form that informed them of the nature of the samples they were to evaluate. The panelists were trained in 12 sessions, each lasting about 2 hours per day, over 3 weeks. The generic descriptive method described by Lawless and Heymann (2010) was used to execute the descriptive sensory profiling of buns. During the training, the panelists described the differences that existed between samples and food items and were used as references to clarify the sensory attributes. Panelist agreement was evaluated through a series of tests during the training. The panelists generated descriptors that were grouped under appearance, aroma/smell, flavour, texture, and aftertaste, with their definitions and reference standards to anchor the scale ends. Evaluation of buns was carried out over three days in three sessions lasting about 45 minutes each day. During each session, all six formulations of buns were randomly presented to each panelist as a ¼ bun in a glass ramekin covered with cling film on a white tray, accompanied by a toothpick, serviette, carrot slices, and a plastic tumbler filled with distilled water for cleansing the palate between tasting of the samples. Each sample was labeled with a random three (3)-digit code, and the order of sample presentation was randomized. In addition, each panelist received a written methodology of assessment and a list of descriptors with their definitions. Reference samples were available to the panelists throughout the evaluation. The evaluation session was conducted in a food laboratory with each panelist seated at an individual station where they were not able to see each other. The 23 descriptors (Table 5.1), developed by the panelists during their training, were used to rate the six samples on a 10-point graphic rating scale to measure the intensity of individual attributes. Results were entered manually into the ballot.

Table 5.1: Descriptive Sensory Attributes and Their Definitions

Attributes	Definition	Reference	Rating
Appearance			
Crust colour intensity	Colour intensity of the crust ranges from light brown to dark brown.	Vanilla cake = 0 Chocolate brownie cake = 10	Not dark = 0 Very dark brown = 10
Crust glossiness	Light reflection on the surface	Oatmeal bread = 0 White bread = 10	Not glossy = 0 Very glossy = 10
Roughness of crust	Degree of roughness as perceived on the top surface of the crumb	White bread = 0 Oat meal bread = 10	Not rough = 0 Very rough = 10
Evenness of crust	Degree of evenness on the top surface	Bread crust = 0 cookies = 10	Not even = 0 Very even = 10
Compactness	Degree of denseness of particles on the top surface	White bread = 0 Cookies = 10	Not compact = 0 Very compact = 10
Sponginess	Extent of air pockets contained in the sample	White bread = 0 Cookies = 10	Not spongy = 0 Very spongy = 10
Fineness of crumb	Degree of smallness of particles on the surface perceived by light	White sorghum grain = 0 Mustard seeds = 10	Not fine = 0 Very fine = 10
Aroma/Smell			
Bread aroma	Aroma impression of bread and crumb after baking	Stiff porridge = 0 White fresh bread = 10	No bread aroma = 0 Intense bread aroma = 10
Malty aroma	Intensity of aroma associated with fermented yeast	Pancake = 0 Yeast bread = 10	No malty aroma = 0 Intense malty aroma = 10
Roasted meat aroma	Intensity of the aroma associated with roasted meat	Boiled meat = 0 Roasted meat = 10	No roasted meat aroma = 0 Intense roasted meat aroma = 10
Fried fish aroma	Intensity of the aroma associated with fried fish	White fresh bread = 0 Fried fish = 10	No fried fish aroma = 0 Intense fried fish aroma = 10
Cooked mushroom aroma	Intensity of the aroma associated with cooked mushrooms	Cookies = 0 Cooked mushrooms = 10	No mushroom aroma = 0 Intense mushroom aroma = 10
Flavour			
Sweet flavour	Intensity of aroma associated with sugars	Distilled water without sucrose = 0 5% Sucrose in distilled water = 10	No sweet flavour = 0 Intense sweet flavour = 10
Starchy flavour	Intensity of flavour associated with cooked Irish potatoes	Cooked Fresh peas = 0 Cooked Irish potatoes = 10	No starchy flavour = 0 Intense starchy flavour = 10

Attributes	Definition	Reference	Rating
Fried fish flavour	Intensity of the flavour associated with fried fish	White fresh bread = 0 Fried fish = 10	No fried fish flavour = 0 Intense fried fish flavour = 10
Malty flavour	Intensity of flavour associated with fermented cereals	Pancake = 0 White fresh bread = 10	No malty flavour = 0 Intense malty flavour = 10
Texture			
Crusty texture	Noise made in the first bite of the sample between the molars.	Pancake = 0 Oat meal bread = 10	Not crusty = 0 Very crusty = 10
Chewy texture	Resilience of the sample perceived during mastication	Queen cake = 0 Oat meal bread = 10	Not chewy = 0 Very chewy = 10
Crumbly texture	Ease with which the sample is broken into smaller particles when chewing.	Pancake = 0 Cookies = 10	Not crumbly = 0 Very crumbly = 10
Aftertaste			
Grainy residues in the mouth	The degree to which the mouth contains small particles after all sample has been swallowed	Pancake = 0 Roasted maize meal flour = 10	No grainy residue in mouth = 0 Intense grainy residue in mouth = 10
Malty flavour	Intensity of the flavour associated with fermented yeast	Pancake = 0 Yeast bread = 10	No malty flavour = 0 Intense malty flavour = 10
Fried fish flavour	Intensity of the flavour associated with fried fish	White fresh bread = 0 Fried fish = 10	No fried fish flavour = 0 Intense fried fish flavour = 10

Supa loaf white bread (Mini Bakeries, Nairobi, Kenya) and Cookies (Paul's Bakery, Eldoret, Kenya)

5.3.2 Consumer Evaluation by Adults

The panel was recruited through an advert to select a sample of 60 consumers. Those who responded were asked to fill out a consent form informing them about the nature of the samples and to ascertain their commitment to participate in a consumer panel to evaluate the six formulations of buns. Only those consumers who indicated their liking for buns and did not suffer from any food allergies were allowed to participate. In the end, a random sample of twenty-four (24) males and thirty-six (36) females, aged

between 20 and 35 years, was selected. Each consumer was provided with a sample of six formulations of buns, a carrot, and a glass of distilled water to cleanse their palates before and in between the tasting, all on a white tray. The consumers were asked to rate their degree of liking for appearance, aroma, flavour, colour, and texture on a nine-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. The minimum value of 1 denoted not intense or not much, and the maximum point of 9 denoted very intense or very much (Civille et al., 2024).

5.3.3 Consumer Evaluation by 8 to 9-Year-old School-Children

Written consent to carry out the study was sought from parents/guardians, informing them about the purpose, procedures, activities, risks, and benefits of their children being involved in the study. Those children whose parents/guardians signed the consent form to allow them to participate in the study were the only ones involved. The children were also informed that they could withdraw from the study at any point if they wanted to, without giving any reasons. The study was age-specific, so the screening selected 60 children, both boys and girls aged between 8 and 9 years, who did not suffer from any food allergies. The study followed the policy guidelines by Schenk and Williamson (2005) on children's inclusion in research. A one-hour orientation session at 10:00 am for five (5) days was conducted to help the children familiarize themselves with how to use a seven-point facial scale. The seating arrangement was designed to provide four (4) groups of 15 children each. Four research assistants who were able to speak both English and Swahili were involved in handling each group. It was explained to the children that the faces on the scale are linked to super good, really good, good, maybe good or maybe bad, bad, really bad, and super bad.

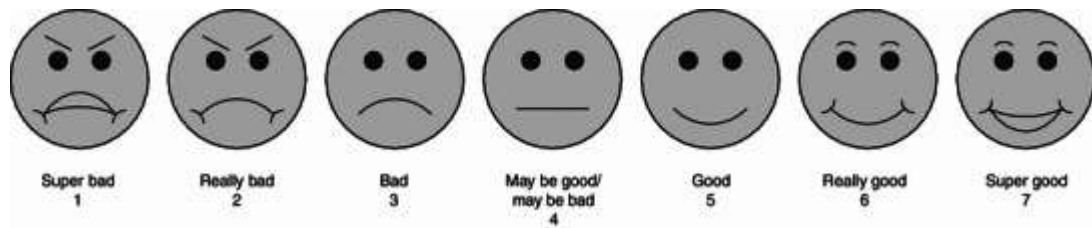


Figure 5.1: Seven-Point Facial Scale Used by 8 to 9-Year-Old School-Children for Hedonic Categorization of Sorghum-Wheat Buns

Source: (Civille et al., 2024)

During the orientation, two types of mangoes, one that children generally like (sweet-ripe) and one that they generally do not like (sour-green), labeled with a 3-digit blind code, were used as test samples. The children were instructed to remove the label from the mango and place it above the face corresponding to how they felt about the mango they had tasted, with the liked mango label on a super good face and the disliked mango label on a super bad face. Bottled water to cleanse the palate before and in between tasting was also provided. Evaluation of buns was carried out in two sessions of 30 minutes each over three (3) days. During the first session, each group of children was randomly presented with six formulations of buns randomly labeled with three (3) digit codes, and the order of presentation was also randomized. Each $\frac{1}{4}$ of the six formulations of buns was presented to each panelist on a white tray, in a glass ramekin covered with cling film, in addition to a toothpick, a serviette, carrot slices, and a plastic tumbler filled with distilled water for cleansing the palate between tasting of samples. The children tasted each bun, starting from left to right, then removed the coding labels and placed them on the scoring sheet slightly above the face that corresponded with their feelings. A similar procedure was repeated for three (3) days at the same time. On each of the three days before the tasting began, procedures for evaluation were demonstrated to the children.

5.4 Data Analysis

The descriptive panel mean scores for sensory attributes were determined by two-way analysis of variance ANOVA with samples as fixed effect and panelists as a random effect. Principal Component Analysis (PCA) of significant sensory attributes from

means across panelists was performed using a correlation matrix with buns in rows and descriptors in columns. Consumer evaluation data were analyzed using a one-way analysis of variance (ANOVA). Means for all analyses were compared using Fisher's least significant difference (LSD). Box and whisker plots were used to illustrate consumer hedonic score distributions for buns. Significance was tested at $P \leq 0.05$.

5.5 Ethical Considerations

Permission to conduct consumer studies with children was granted by parents/guardians, and those children who voluntarily accepted and whose guardians signed a consent form that informed them of the nature of the samples and the activities involved in the study were included. Written consent was sought from participants before the study commenced.

5.6 Results and Discussion

5.6.1 Descriptive Sensory Evaluation

Analysis of variance (F-Values) for bun profile data of 23 attributes scored by the descriptive panel showed significant differences ($p \leq 0.05$) between all the bun formulations (Table 5.2). The data was further analyzed by Principal Component Analysis (PCA) to determine systematic variations and principal relationships among sensory attributes of buns prepared by replacing part of sorghum-wheat flour with 5, 10, 15, 20, and 25% SMP. The first two principal components explained 99% of the total variation among the six formulations of buns (Figure 5.2a). Factor 1 explained 98% of the total variation and separated buns based on the proportion of SMP added, with 0-10% SMP on the right and 15-25% SMP on the left. Factor 2 accounted for the remaining 1% of the variation and separated the buns based on the physical appearance, with the not-dark bun at the top right.

Buns incorporated at 15, 20, and 25% with SMP were associated with dark brown crust, fine crumb, sponginess, cooked mushroom and roasted meat aroma, fried fish and roasted meat flavour, crumbly texture, and fried fish aftertaste (Figure 5.2b). The dark crust could be attributed to the maillard reaction based on the composition of buns

that produced brown polymers, which contributed to the colouration of the buns (Serrem et al., 2011a). Previously, Niaba et al. (2013) demonstrated that supplementing with defatted termite flour resulted in a darker crust colour. Blending with SMP also leads to a smooth dough consistency during kneading that increases pore formation in the crumb after baking, bringing about sponginess, fine crumb, and crumbly texture of buns.

The cooked mushroom, roasted meat, and fried fish flavours and aroma in buns may have been activated by thermal activities on odourants such as 1-octen-3-one, 2-acetylthiazole, and tetradecanal present in processed snail meat (Lasekan, Muniady, Lin, & Dabaj, 2018).

Sensory attributes of crust compactness, evenness, roughness, and glossiness, bread and malty aroma, starchy, sweet and malty flavour, crusty and chewy texture, and malty aftertaste were perceived in buns substituted at 0, 5, and 10% with SMP (Figure 5.2b). These attributes were negatively correlated with fine crumb and spongy appearance, cooked mushroom and roasted meat aroma, fried fish and roasted meat flavour, crumbly texture, and fried fish aftertaste. Compactness and evenness of crust may be ascribed to reduced pore sizes due to high fibre in buns on decreasing substitution with SMP that limited expansion in gas cells (Collar, Santos, & Rosell, 2007). Crust roughness could be associated with increased grainy particles at higher concentrations of sorghum-wheat flour in the dough for making buns. In contrast, crust glossiness could have improved due to starch gelatinization and dextrin formation (Altamirano-Fortoul, Le-Bail, Chevallier, & Rosell, 2012). Sweet, malty, starchy, and bread aroma and flavour of buns may have resulted from dough kneading and fermenting, as well as the thermal process of baking. A study by Ganzle, Loponen, and Gobbetti (2008) noted that dough mixing elicited odourants in breadcrumbs, while baking developed flavour compounds in the crust. The crusty and chewy texture also increased with an increasing proportion of sorghum-wheat flour in the dough. These results are in agreement with those reported by Khan, Rafiq, Saini, Hossain, and Rafiq (2024), who demonstrated that gradual substitution with flaxseed into wheat cookies increased the hard texture characteristics associated with crustiness and chewiness.

Table 5.2: Mean Scores for Sensory Attributes of Buns as Evaluated by a Trained Descriptive Sensory Panel (n=8)

ATTRIBUTES	Buns						F Value
	0%	5%	10%	15%	20%	25%	
Appearance							
Crust colour intensity	3.38 ^a ±0.65	5.08 ^b ±0.83	5.63 ^c ±0.49	6.71 ^d ±0.46	7.92 ^e ±0.41	8.92 ^f ±0.28	319.44*
Crust glossiness	8.08 ^f ±0.58	7.21 ^e ±0.51	6.58 ^d ±0.50	5.46 ^c ±0.66	3.96 ^b ±0.75	3.29 ^a ±0.62	226.41*
Roughness of crust	1.46 ^a ±0.78	1.25 ^a ±1.11	2.13 ^b ±0.95	2.75 ^c ±0.61	3.29 ^d ±0.62	3.63 ^d ±0.49	36.14*
Evenness of crust	6.33 ^f ±0.56	5.58 ^e ±0.50	4.92 ^d ±0.28	3.88 ^c ±0.54	3.50 ^b ±0.51	3.17 ^a ±0.38	168.03*
Compactness	6.50 ^e ±0.51	5.50 ^d ±0.66	5.08 ^c ±0.50	4.08 ^b ±0.65	4.00 ^b ±0.59	3.17 ^a ±0.38	111.61*
Sponginess	3.92 ^a ±0.41	4.50 ^b ±0.51	5.08 ^c ±0.50	5.63 ^d ±0.58	6.42 ^e ±0.78	7.25 ^f ±0.68	105.59*
Fineness of crumb	4.17 ^a ±0.38	4.50 ^b ±0.51	4.92 ^c ±0.50	5.88 ^d ±0.34	6.58 ^e ±0.50	7.33 ^f ±0.56	166.25*
Aroma/Smell							
Bread aroma	8.82 ^f ±0.58	7.63 ^e ±0.65	6.88 ^d ±0.61	6.33 ^c ±0.48	5.50 ^b ±0.51	4.83 ^a ±0.48	136.80*
Malty aroma	7.21 ^f ±0.83	6.38 ^e ±0.82	5.79 ^d ±0.83	5.29 ^c ±0.75	4.50 ^b ±0.59	4.00 ^a ±0.72	58.08*
Roasted meat aroma	0.08 ^a ±0.28	1.54 ^b ±0.59	2.75 ^c ±0.53	3.67 ^d ±0.64	4.38 ^e ±0.58	5.21 ^f ±0.59	287.48*
Fried fish aroma	0.17 ^a ±0.38	1.92 ^b ±0.65	2.50 ^c ±0.51	4.33 ^d ±0.64	5.17 ^e ±0.56	6.08 ^f ±0.50	391.85*
Cooked mushroom aroma	0.67 ^a ±0.70	1.46 ^b ±0.59	1.96 ^c ±0.46	2.63 ^d ±0.58	3.04 ^e ±0.46	3.46 ^f ±0.59	80.33*
Flavour							
Sweet flavour	7.96 ^f ±0.55	7.33 ^e ±0.48	6.71 ^d ±0.55	6.21 ^c ±0.51	5.50 ^b ±0.51	4.83 ^a ±0.48	121.32*
Starchy flavour	5.75 ^e ±0.44	5.25 ^d ±0.44	5.08 ^d ±0.28	4.33 ^c ±0.48	4.08 ^b ±0.28	3.58 ^a ±0.50	92.03*
Roasted meat flavour	0.08 ^a ±0.28	1.96 ^b ±0.46	2.79 ^c ±0.51	3.67 ^d ±0.64	4.38 ^e ±0.58	5.21 ^f ±0.59	296.25*
Fried fish flavour	0.17 ^a ±0.38	1.92 ^b ±0.65	2.50 ^c ±0.51	4.33 ^d ±0.64	5.17 ^e ±0.56	6.08 ^f ±0.50	391.85*
Malty flavour	5.46 ^f ±0.59	4.88 ^e ±0.61	4.21 ^d ±0.59	3.83 ^c ±0.64	3.17 ^b ±0.70	2.38 ^a ±0.58	78.95*
Texture							
Crusty texture	6.50 ^e ±0.51	5.50 ^d ±0.66	5.08 ^c ±0.50	4.08 ^b ±0.65	4.00 ^b ±0.59	3.17 ^a ±0.38	111.61*
Chewy texture	5.75 ^e ±0.44	5.25 ^d ±0.44	5.08 ^d ±0.28	4.33 ^c ±0.48	4.08 ^b ±0.28	3.58 ^a ±0.50	92.03*
Crumbly texture	3.17 ^a ±0.38	4.00 ^b ±0.59	4.08 ^b ±0.65	5.08 ^c ±0.50	5.50 ^d ±0.66	6.50 ^e ±0.51	111.61*
Aftertaste							
Grainy residues in the mouth	3.75 ^f ±0.44	3.25 ^e ±0.44	2.92 ^d ±0.28	2.33 ^c ±0.48	2.08 ^b ±0.50	1.83 ^a ±0.38	71.06*
Malty flavour	4.50 ^f ±0.59	3.96 ^e ±0.46	3.21 ^d ±0.59	2.83 ^c ±0.64	2.17 ^b ±0.70	1.42 ^a ±0.65	82.96*
Fried fish flavour	0.00 ^a ±0.00	1.13 ^b ±0.54	1.54 ^c ±0.51	2.88 ^d ±0.74	3.50 ^e ±0.78	4.04 ^f ±0.75	151.92*

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at (p≤0.05) as assessed by Fischer's least significant test. * Significantly different at (p<0.05).

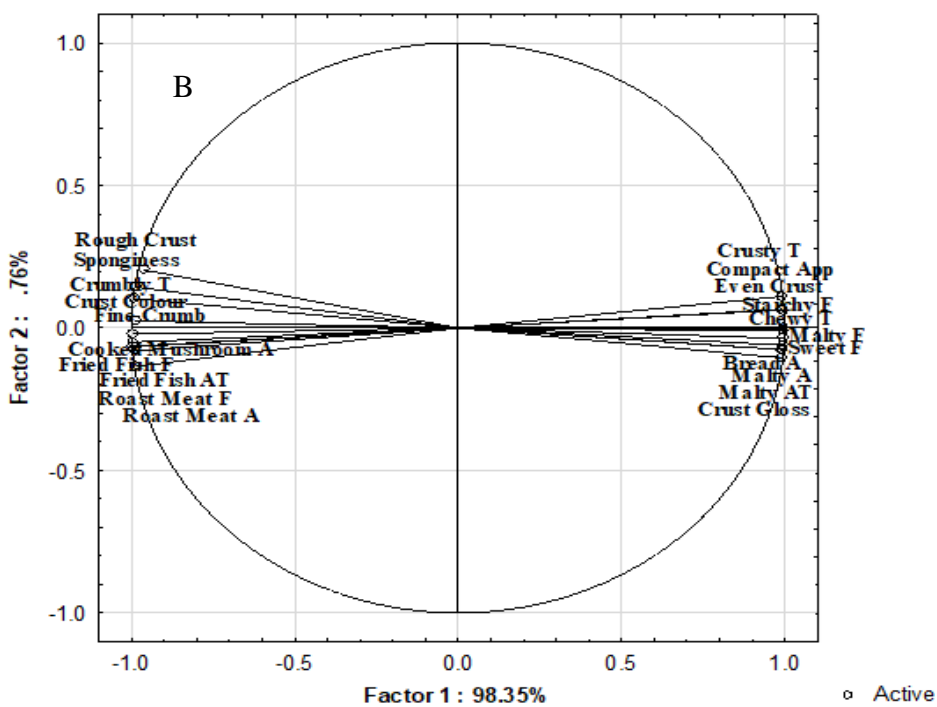
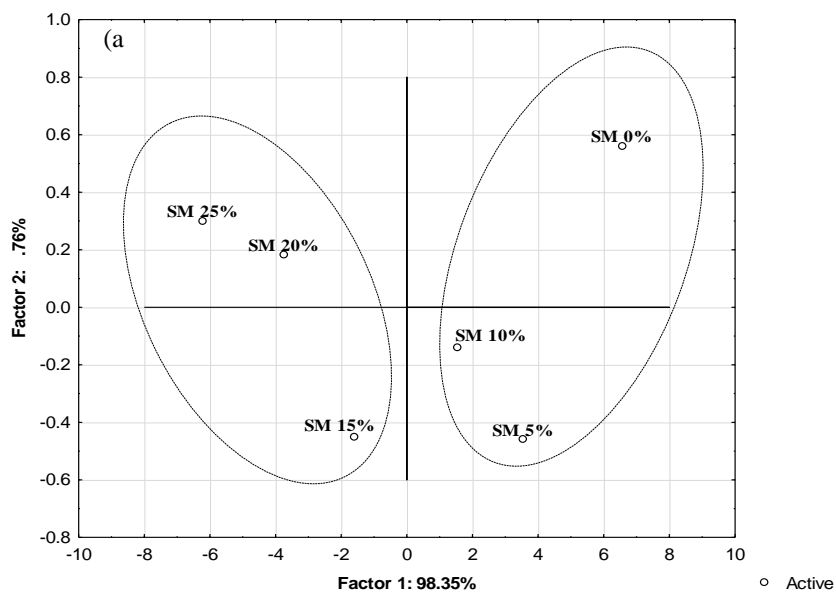


Figure 5.2: Principal Component Analysis (Correlation Matrix) of Variations in Smp-Incorporated Buns

- (a) Plot of the first two principal component scores of the buns
- (b) Plot of the first two principal component loading projections of sensory attributes

Acronyms:

A - Aroma, T - Texture, F - Flavour, APP - Appearance, AT – Aftertaste, SM – Snail meat

5.6.2 Consumer Evaluation by Adults

Adult consumer perceptions of the appearance, aroma, flavour, and texture of buns are presented in Table 3.

Table 5.3: Mean Scores for Sensory Attributes of SMP-Incorporated Buns as Evaluated by Adult Consumers (n=60)

Buns	Appearance	Aroma/Smell	Flavour	Texture
S-WB 0% SMP	7.80 ^e ±0.90	7.17 ^e ±1.20	7.25 ^e ±1.08	4.95 ^a ±1.62
S-WB 5% SMP	7.42 ^e ±0.72	6.82 ^d ±0.91	6.92 ^{cd} ±0.79	5.17 ^a ±1.38
S-WB 10% SMP	6.92 ^d ±1.14	6.52 ^d ±1.26	6.68 ^c ±0.87	5.98 ^b ±0.97
S-WB 15% SMP	6.37 ^c ±1.46	6.10 ^c ±1.07	5.63 ^b ±1.38	6.37 ^b ±1.01
S-WB 20% SMP	5.82 ^b ±1.64	5.58 ^b ±1.49	5.20 ^a ±1.42	6.98 ^c ±1.03
S-WB 25% SMP	5.35 ^a ±1.25	5.12 ^a ±0.88	4.97 ^a ±1.04	7.37 ^d ±1.07

Values are means ± standard deviations. Values followed by the same letter superscripts in the same row are not significantly different at ($p \leq 0.05$) as assessed by Fischer's least significant test. SWB - Sorghum-Wheat Buns; SMP - Snail Meat Powder

Blending sorghum-wheat buns at 20 and 25% respectively with SMP resulted in low consumer scores in attributes of appearance, aroma, and flavour. Low consumer rating for appearance may be attributed to the dark crust and crumb colour of the buns. Other researchers have reported similar results. For instance, Mridula, Gupta, and Manikantan (2007) established a lower consumer acceptability for the dark-coloured sorghum-wheat composite biscuits. Similar results were also reported by Serrem et al. (2011a) for sorghum and bread wheat biscuits supplemented with defatted soy flour. Consistently, acceptability in the flavour and aroma of sorghum-wheat buns declined with increased quantity of SMP in the dough. This is attributable to consumer unfamiliarity with SMP as an ingredient in baking. Earlier, Malik, Aremu, Bayode, and Ibrahim (2011) assessed the nutritional and organoleptic properties of snail meat and other livestock meats and determined that consumers vastly appreciated the aroma and flavour of the food they were familiar with, such as beef and chicken, unlike snail meat.

The control bun was rated high by adult consumers in all aspects except texture, perhaps caused by high fibre in sorghum-wheat composite dough, which limited the expansion of gas cells, leading to the production of a compact and hard-textured bun.

These findings are in agreement with Eimam, Amir, and Mustafa (2008), who stated that bread substituted with wheat bran had a tough, crumbly texture attributable to enhanced fibre. The texture of the control bun could also have been influenced by increased moisture retention in dough during mixing (Gomez, Ronda, Blanco, Caballero, & Apesteguia, 2003). Buns substituted at between 15 and 25% with SMP scored high in consumer rating for texture. Cakmak et al. (2013) found that replacing part of white and whole wheat bread with chicken meat and chicken meat powder at increasing concentrations resulted in bread with the highest consumer ranking in texture.

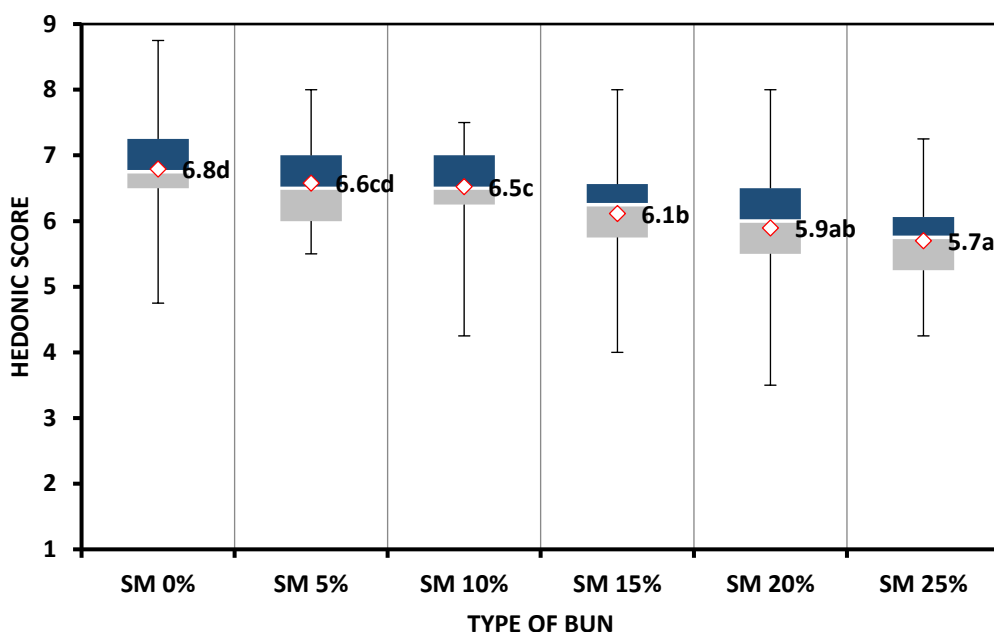


Figure 5.3: Effect of Incorporating Sorghum–Wheat Bun with SMP on Total Quality as Evaluated by Adult Consumers (n=60)

^{abcd} = Mean values with different letter superscripts differ significantly ($p \leq 0.05$) as assessed by Fisher's least significant test. The dark shaded area is the higher percentile value above which 75% of ratings fell. The light-shaded area is the lower percentile area where 25% of ratings fell. The median is the thin line between the two shaded areas where 50% of values fell above and 50% below.

Hedonic rating on total quality by adult consumers indicates that all bun formulations were preferred above average (Figure 5.3). However, buns substituted between 15 and

25% with SMP scored slightly lower on quality, probably because of consumer unfamiliarity with intense dark colour due to increased concentration of SMP in dough. Previously, Mridula et al. (2007) established a low rating on the total quality of soy-fortified wheat biscuits owing to increased dark colour on incorporation with sorghum flour at a high proportion.

5.6.3 Consumer Evaluation by 8 to 9-Year-old School-Children

Results on the effect of incorporating SMP on liking sorghum-wheat bun as evaluated by 8 to 9-year-old school children on repeated exposure are shown in Figure 5.4. Liking of sorghum-wheat bun supplemented with SMP improved over time as children were repeatedly exposed to the products. This may be explained by the fact that children were not familiar with SMP as a basic ingredient in baking at the initial evaluation, since conventional buns are prepared from wheat and/or other cereal flour. These results are consistent with the findings of Kramer, Leshner, and Meiselman (2001), who observed that foods repeatedly consumed subsequently result in a high rating from the minimum score when first introduced. Similar findings have been reported by Serrem et al. (2011a) for consumer tests of sorghum and bread wheat biscuits supplemented with defatted soy flour on repeated exposure with 8 to 9-year-old schoolchildren.

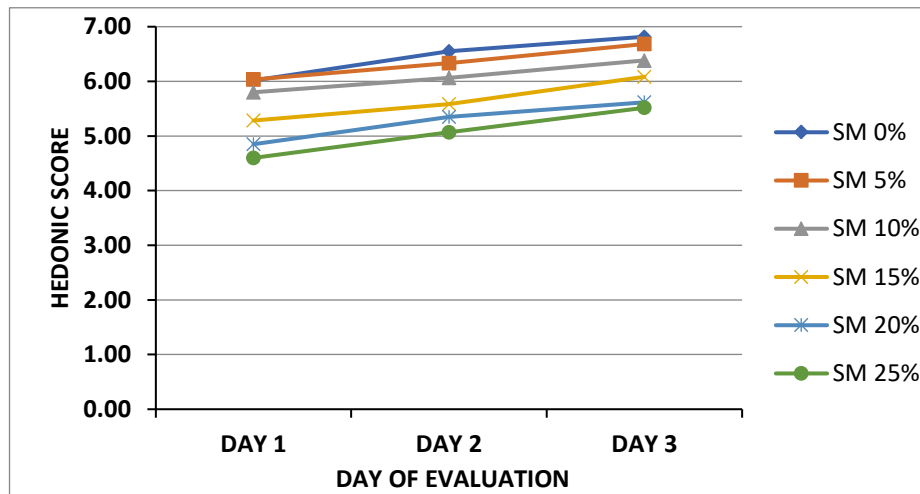


Figure 5.4: Effect of Incorporation with SMP on Liking of Sorghum-Wheat Buns as Evaluated by 8 to 9-Year-Old School Children (n = 60) on Repeated Exposure

Correspondingly, repeated exposure did not significantly change children’s liking of the control bun over time. A possible explanation is that buns formulated from a dough of staple cereals such as sorghum and wheat have sustained acceptability. Findings from previous studies have reported similar results in consumer liking. For example, Hetherington, Pirie, and Nabbs (2002) revealed that consumer preference for staple cereal bread did not change over three weeks on repeated exposure. Therefore, food liking in children might be stimulated by other internal and external factors relating to what they like, know, and want to eat. For instance, Scaglioni et al. (2018) found that parental eating habits and food choices influence the food liking and preference of their children. As a result, parents should set a good example by exposing their children to a variety of health-enhancing foods, taking into account their socioeconomic and educational aspects.

Figure 5.5 shows findings on the effect of incorporating buns with SMP on consumer agreement as determined by 8 to 9-year-old schoolchildren. The shorter distribution along the bar line of the graph in this study indicates agreement among children on a score for buns, and the results were consistent. These results agree with the findings of Simons et al. (2019), who established that children of 8 to 9 years old were more consistent in describing their liking for food products. Positive hedonic ratings of buns fortified with SMP indicate that the children were not bored with the samples.

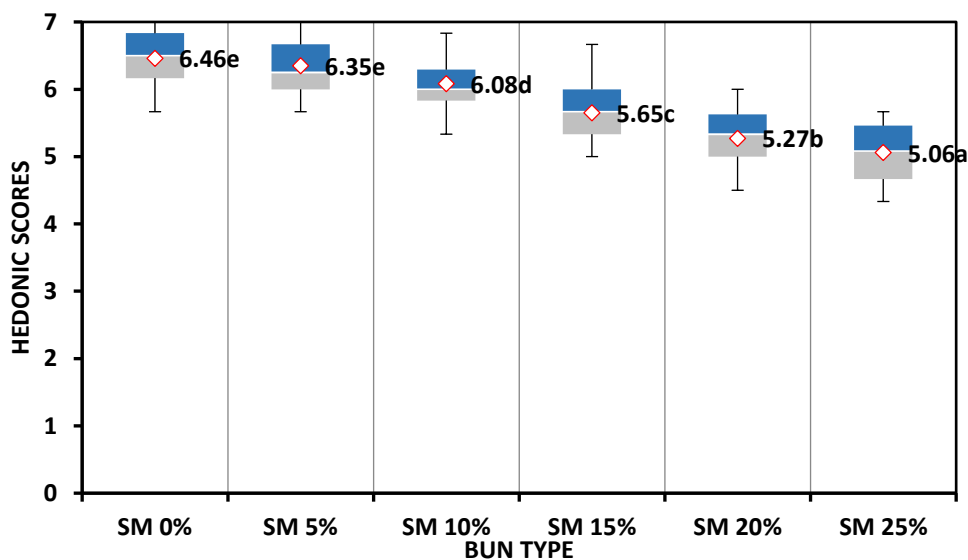


Figure 5.5: Effect of incorporating sorghum-wheat buns with SMP on agreement among consumers as evaluated by 8 to 9-year-old school children (n = 60)

abcde = Mean values with different letter superscripts differ significantly ($p \leq 0.05$) as assessed by Fisher's least significant test. The dark shaded area is the higher percentile value above which 75% of ratings fell. The light-shaded area is the lower percentile area where 25% of ratings fell. The median is the thin line between the two shaded areas where 50% of values fell above and 50% below.

5.7 Conclusion

Compositing sorghum-wheat with SMP imparts positive consumer attributes of fine crumb, spongy, and crumbly texture, while reducing proportions of SMP in buns results in compact and rough crust and chewy texture. Buns formulated from sorghum-wheat flour blended with SMP have reasonably high acceptability, and 8 to 9-year-old school-children could sustain their acceptability over time on repeated exposure as supplementary rich sources of protein for alleviating the menace of PEM in sub-Saharan Africa.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Compositing sorghum-wheat flour with SMP is beneficial in formulating buns of superior protein and mineral qualities in proportion to the amount of SMP added. It imparts positive physical characteristics such as higher density, yield, and weight, while also reducing bun hardness and baking loss. Enriching with only 5% of SMP significantly improves *in vitro* protein digestibility by 29% compared to the control.

Enriching the sorghum-wheat buns with SMP between 5% and 25% keeps the total aerobic bacterial count below the International Microbiological Standards recommended maximum of 10^3 cfu/g for dry and ready-to-eat foods. It also keeps mould counts below the World Food Program's recommended limit of 10^5 cfu/g. As well, improves the keeping quality of the buns compared to the control.

Enrichment with SMP at 25% significantly enhances growth in rats, PER to near casein threshold of 2.7, which is recommended for an excellent source of protein, promotes NPRRR, TPD, and PDCAAS to slightly above the minimum 0.70 recommended in food products for children, as well as weight gain upon rehabilitation of rats that were initially fed a basal diet.

Principal Component Analysis of 23 attributes for buns scored by a descriptive sensory panel explains 99% of the total variation of the formulated buns. Factor 1 explains 98% of the variation and differentiates the buns based on the proportion of SMP, while factor 2 accounts for 1% and distinguishes the buns based on their physical appearance. Enrichment imparts positive consumer attributes of fine crumb, spongy, and crumbly texture in contrast to the compact and rough crust and chewy texture of unenriched buns.

6.2 Recommendations

1. Substituting sorghum-wheat buns at 10% with SMP has the potential to provide the recommended 13 g/100 g of protein per day in the diet of children. As a result, enrichment of sorghum-wheat buns with SMP enhances protein quality to levels considered complementary compared to cereal buns.
2. Enriching the sorghum-wheat buns with SMP between 5% and 25% improves the shelf life and maintains the total aerobic bacterial count below 10^3 cfu/g, recommended for dry and ready-to-eat foods.
3. The sorghum-wheat bun diet enriched at 25% with SMP exhibits a high protein nutritional quality, evidenced by positive growth and maintenance of emaciated rats whose requirements for sulfur-containing amino acids are higher compared to humans. This diet shows great potential as a complementary diet to promote catch-up growth and alleviate PEM in undernourished children.
4. Buns formulated from sorghum-wheat flour blended with SMP have reasonable acceptability among school-aged children who could sustain their acceptability over extended periods on repeated exposure as a supplementary rich source of protein that can help alleviate PEM in sub-Saharan Africa.

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APPENDICES

Appendix I: Application Form for Serving in a Trained Sensory Panel

APPLICATION FORM FOR SERVING IN A TRAINED SENSORY PANEL

1. Full name and surname -----
2. Your residential address? -----

3. Telephone or mobile cell No. -----
4. E-mail address -----
5. Your age? -----

6. Gender	Male	Female
7. Occupation?		
8. Are you a registered student?	Yes	No
If yes, the course, year of study, and the hours you are available.		
9. Are you employed?	Yes	No
If yes, state the time and day of the week you are available.		

10. Please evaluate your ability to read, speak, and write English on the following scale:

Poor Fair Average Good Excellent

11. Are you allergic to anything?	Yes	No
If yes, give details.		
12. Please specify any specific food product/s that you prefer not to consume.		
13. Do you smoke?	Yes	No
If yes, how many cigarettes per day?		
14. Will you be available for the taste panel	Yes	No
15. Have you ever been on any sensory evaluation panel?	Yes	No
If yes, where/when/to evaluate what?		

19. Will you be able to attend the screening sessions?		
	Yes	No
20. If you are available for the screening sessions, which of the following time/s would be suitable?		
10:00 – 11:00 Hours	Yes	No
13:00 – 14:00 Hours	Yes	No
21 In not more than 20 words, write down why you think we should choose you for our sensory panel		

I declare that the information furnished above is correct and true to the best of my knowledge.

Signature

Date

Appendix II: Sensory Evaluation Consent Form

SENSORY PANELIST CONSENT FORM

Sensory evaluation of buns

Thank you for your willingness to potentially participate in a sensory evaluation of different sorghum-wheat buns enriched with snail meat powder

Date of Participation:

Voluntary Nature of Participation: I understand that participation in this project is completely voluntary, and I do not have to participate in this sensory project if I do not agree to participate; hence, I can withdraw my participation at any time.

Risks to the individual: I understand that I will evaluate different sorghum-wheat buns enriched with snail meat flour using descriptive sensory evaluation. I note that people who are allergic to eating meat products should avoid these products.

Medical Liability: I understand that no financial compensation will be paid to me in connection with any physical injury or injury in the unlikely event of physical injury or illness as a direct or indirect result of my participation in this sensory project.

Confidentiality: participants are not required to reveal any confidential information. All responses to questions will be treated confidentially. Responses to sensory questions via the evaluation form are tracked using numbers only. These numbers are not in any way related to the participant's name.

If you have any questions about this sensory project, contact Fredrick Agengo at 0722 – 267536.

I HAD THE OPPORTUNITY TO READ THIS CONSENT FORM AND ASK QUESTIONS ABOUT THE SENSORY PROJECT, AND I AM PREPARED TO PARTICIPATE IN THIS PROJECT.

Participant's Signature

Date

Participant's Name, *please print clearly*

Sensory Panel Leader Signature

Date


Appendix III: Descriptive Sensory Evaluation

SCREENING TESTS

TEST 1

Name: _____ Date:

Identify the taste of each of the papers.

TEST 2

Name: _____ Date:

Identify the following flavours by smelling them. Enter the code of the sample you have identified against the flavour.

Perceived flavour	Code
Lemon flavour	
Caramel flavour	
Almond flavour	
Pineapple flavour	
Chocolate flavour	
Orange flavour	

TEST 3

Name: _____

Date:

You are provided with five samples of biscuits. Please take a sip of water before you start tasting and between tasting the different samples. Using your terms, show how the biscuits are different in taste, flavour, texture, and appearance.

	713	710	708	715	722
TASTE					
FLAVOUR					
TEXTURE					
APPEARANCE					

Appendix IV: Descriptive Sensory Panel Evaluation Sheet

WELCOME TO THIS TASTING SESSION

SCHOOL OF FOOD AND NUTRITION SCIENCE

**JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND
TECHNOLOGY**

Instructions

REMEMBER to take a sip of water and eat a piece of carrot before you start tasting

PANELIST CODE

PANELIST NAME

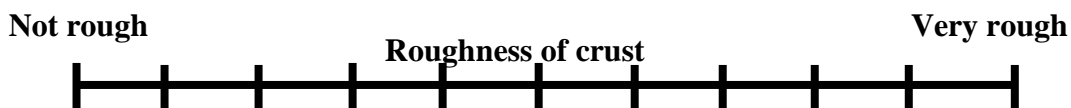
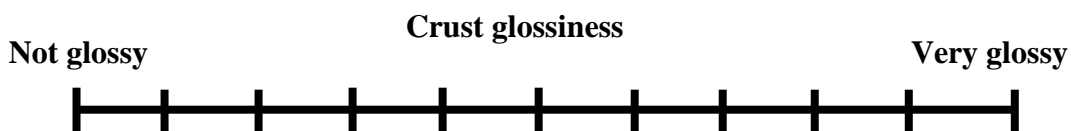
ENTER TRAY NO.

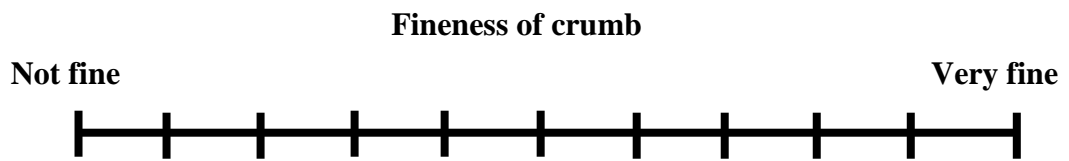
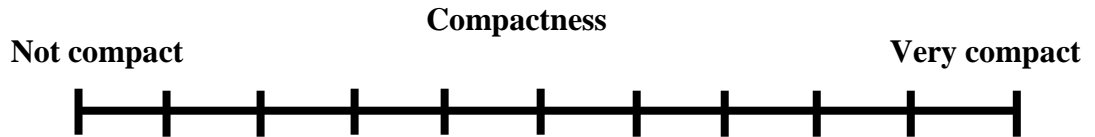
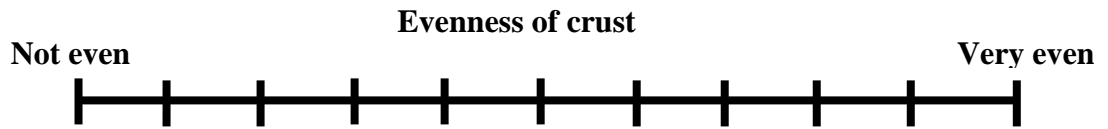
Instructions

You are provided with six (6) samples of buns. Please taste the samples in the order presented from left to right. Take a sip of water and eat a piece of carrot before you start tasting and between tasting the different samples. Circle the relevant bar on the scale provided for each attribute.

Question 1:

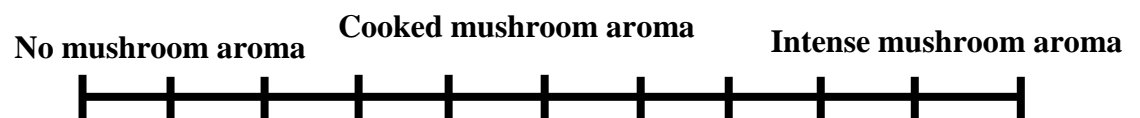
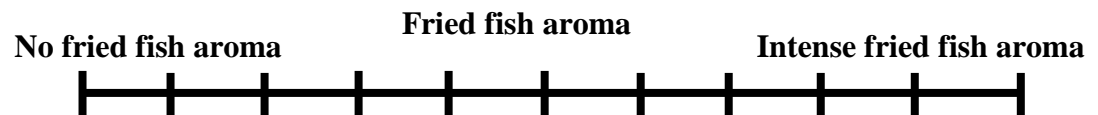
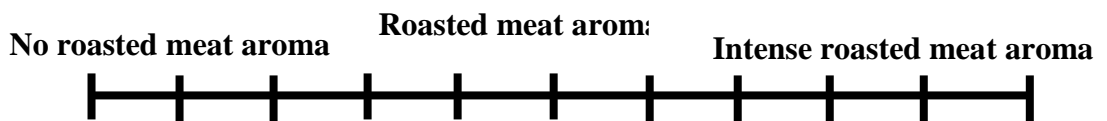
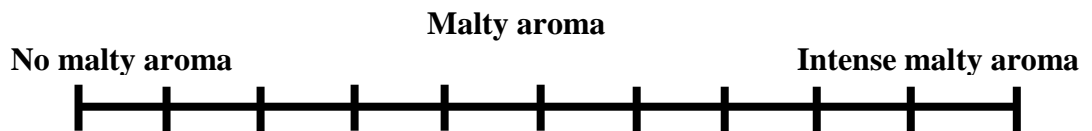
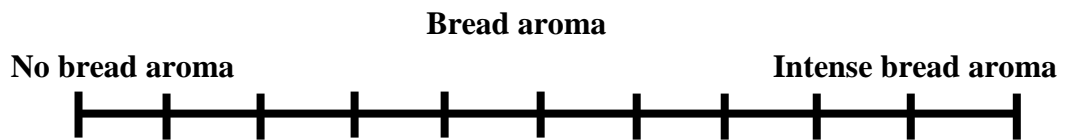
Look at the sample and rate the following appearance descriptors





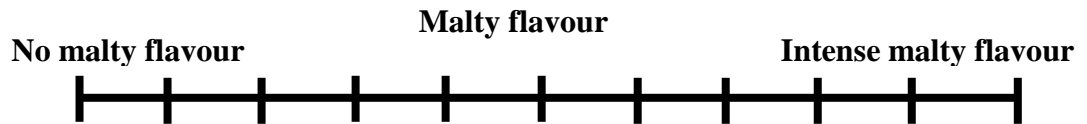
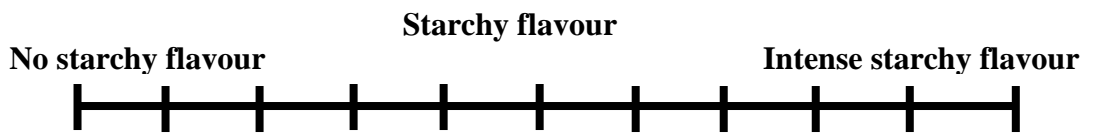
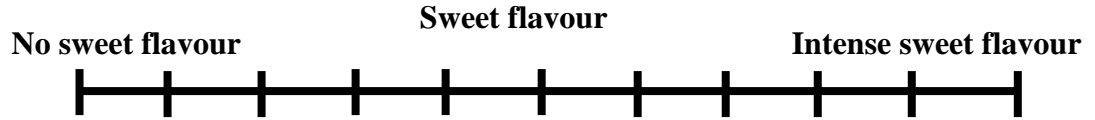
Question 2:

Smell sample using short sniffs and rate the intensity of the following aroma descriptors



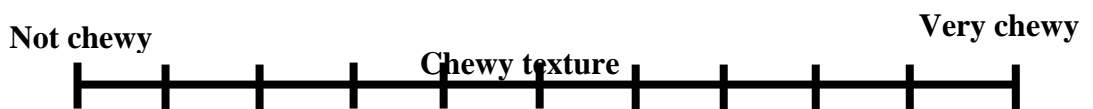
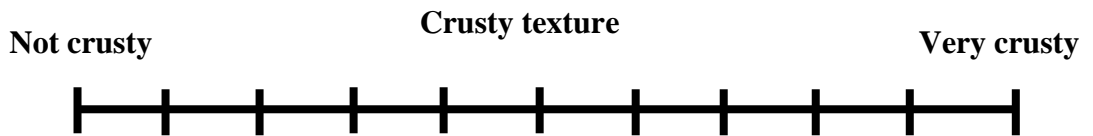
Question 3:

Taste sampleand rate the intensity of the following flavour descriptors



Question 4:

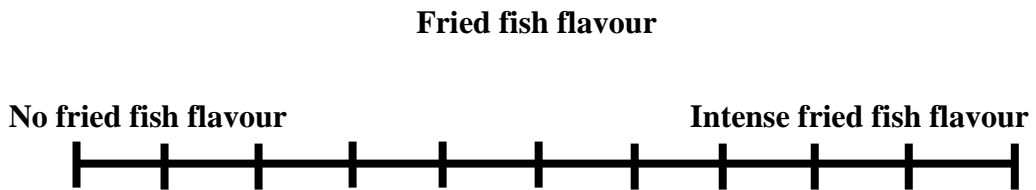
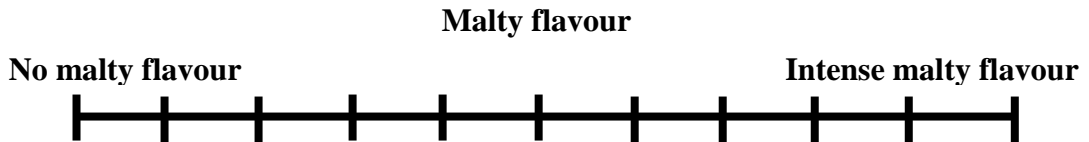
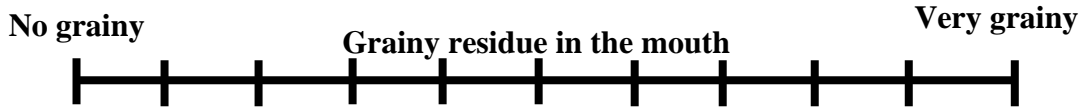
Taste sample and rate the intensity of the following texture descriptors





Question 5:

After swallowing the samples, rate the aftertaste.....



Any other Comments:

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