EFFECT OF PIGEON PEA AND SORGHUM FLOUR SUPPLEMENTATION ON THE PHYSICO-CHEMICAL, PROTEIN DIGESTIBILITY, SENSORY PROPERTIES AND SHELF LIFE OF MILLET FLOUR

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for an award of a diploma or conferment of a degree in this or any other University.

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Recommendations

This thesis has been examined, passed and submitted with our approval as the University supervisors.

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DEDICATION

I dedicate this thesis to my husband Johnson Kyalo and my daughters Faith Mawia and Isabel Mumbe, whose continued support has kept me motivated and encouraged to keep moving.

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ABSTRACT

Malnutrition is a major health problem in many parts of the world. Protein-energy malnutrition (PEM) remains a significant health issue among children in many parts of Kenya. The aim of this study was to utilize locally available sorghum, pearl millet, and pigeon peas in the formulation of a protein-rich complementary flour to contribute to reduced PEM among children under 5 years in Tharaka Nithi, Kenya. This study adopted a nested design with two factors; pigeon pea level and sorghum level nested in pigeon pea level. For shelf life study an additional factor was introduced which was storage time in days. Preparation of the blends included 5 ratios of Pigeon peas (0, 15, 30, 45, 60% of the total flour blend), and 3 levels of sorghum (0, 20, 40% of the millet-sorghum flour mix). These blends were then analysed for physicochemical properties, protein digestibility, sensory properties and shelf life. The sensory evaluation of flour blends was carried out with informed consent of the respondents who voluntarily participated in sample assessment. Data on physico-chemical properties, protein quality, titratable acidity, pH and sensory evaluation was subjected to analysis of variance (ANOVA) and significant means separated via Tukey's Honest Significant Difference (HSD). Data on the willingness to buy the different blends was analysed using the Kruskal Wallis test. Microbial data was log transformed and subjected to ANOVA. All data was analysed using Minitab software at $P < 0.05$. The addition of pigeon peas to the millet-sorghum-pigeon peas composite blend significantly ($P < 0.001$) increased all functional properties except bulk density while sorghum significantly affected swelling capacity ($P = 0.019$), water holding capacity ($P=0.001$), gelling temperature ($P < 0.001$), and tapped density ($P = 0.002$). Addition of pigeon peas significantly ($P < 0.001$) increased the protein content from 11.845% to 16.016% and digestibility of the flour blends from 34.95% to 46.34%. Sensory evaluation revealed that the addition of pigeon peas significantly ($P < 0.001$) lowered the taste (3.862 to 3.420), flavour (3.908 to 3.299), viscosity (4.000 to 3.270) and texture (4.035 to 3.420) rating and general acceptability of porridge (3.690 to 3.339) prepared from the composite blends. Sorghum significantly ($P < 0.001$) increased colour (2.897 to 4.224), taste, flavour and overall acceptability of the flour blends. Sensory evaluation revealed that the samples containing 34% sorghum and 15% pigeon peas performed best in all sensory attributes as well as in overall acceptability. The average relative humidity and temperature during storage was 55.494% and 25.225 ^{0}C, respectively. The addition of pigeon peas to the blends significantly ($P < 0.001$) increased the Titratable acidity (0.1862 to 0.245g/l) of the composite blends which indicated a gradual deterioration of the flour over the storage period. The initial mean yeasts and mold counts were 2.252 Log CFU/g respectively which were below the East African Community recommended safety limit for yeast and Mold counts in millet flour (4 Log CFU/g). However. This number rose within the first 16 days to 2.628 log cfu/g, then began dropping to (0.492 log cfu/g. This can be explained by the increasing acidity of flour, change in the pH, reduced relative humidity and oxygen supply in the storage container. It is therefore possible to produce pigeon pea containing flour product that is safe for human consumption and that can last for two months and above. These outcomes demonstrate the potential of pigeon peas, sorghum, and millet in creating protein-rich porridge flour and hence improving protein intake for children under 5 years. This study encourages the utilization of pigeon peas to improve the protein content of energy dense cereal grains occasionally used in complementary diets.

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LIST OF ABBREVIATIONS AND ACRONYMS

AACC	American Association for Clinical Chemistry
BMI	Body Mass Index
CP	Total crude protein
FAO	Food Agriculture Organization
FC	Foam capacity
FS	Foam stability
GI	Glycaemic index
LSD	Least significant difference
MUAC	Mid Upper Arm Circumference
PDCAAS	Protein digestibility-corrected amino acid score
PEM	Protein Energy Malnutrition
RDA	Recommended Dietary Allowance
RDI	Recommended Dietary Intake
SPSS	Statistical package for social sciences
UNICEF	United Nations Children's Fund
WFP	World Food Programme
WHO	World Health Organization

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

The general health of a society can be greatly affected by the state of nutrition among its population making nutrition and diet a subject that cannot be overlooked. Supplying the body with nutrients in adequate quantities enables it to function properly. These nutrients are categorized as either macronutrients (carbohydrates, protein, lipids) or micronutrients (vitamins, and minerals) (Gush et al., 2021). The quantities required vary greatly among different ages and gender as well. It is, therefore, necessary to analyse the constituents of one's diet to ensure these nutrients are provided and also match the daily requirements of the body (Bender & Cunningham, 2021). Before the start of complementary feeding at the age of six months, these nutrients are provided from breastmilk (Lutter et al., 2021). However, these nutrients need to be supplemented from external sources, particularly the introduction of solid foods during complementary feeding at the sixth month of age. It is very critical to check the suitability of the foods introduced compared to the nutritional needs of the child to avoid malnutrition in children (Lutter *et al*., 2021) .

Malnutrition can manifest as either under-nutrition or over-nutrition. Under-nutrition occurs when the diet a person consumes does not meet their body's requirement for growth and development whereas over-nutrition occurs when an individual consumes an excess of a particular nutrient (Gudu *et al.*, 2020). Undernourishment is the leading cause of disease and death, particularly in low and middle-income nations.

Child malnutrition remains a significant global concern, impacting millions of young lives (Agostoni et al., 2023). Malnutrition kills over 3 million children under the age of five yearly throughout the world (UNICEF, 2023). According to UNICEF (2023), an estimated 45 million children under the age of five are wasted, 148 million have stunted growth and development as a result of a chronic lack of healthy food in their diets, and 37 million are overweight around the world. Stunting, wasting, low birthweight, and anaemia cases are more prevalent in poor and lower-middle-income nations (FAO, 2022). Childhood obesity is also on the rise, with about 38 million children classified as overweight across the world (Higashi et al., 2022). Factors such as poverty, conflict, and food insecurity contribute to these issues, especially in low- and middle-income countries (Agostoni et al., 2023).

The COVID-19 pandemic further strained nutrition services, hindering access to essential food and healthcare (Higashi et al., 2022). Addressing child malnutrition requires comprehensive strategies, including improving food systems, promoting breastfeeding and dietary diversity, and ensuring equitable access to resources. Global collaboration and targeted interventions are vital to combat malnutrition in children, ensuring healthier futures and breaking the cycle of poverty and illness.

Thousands of children in Kenya are suffering from moderate acute malnutrition, some of whom are affected by severe acute malnutrition (UNICEF, 2022). In Kenya, under-nutrition accounts for approximately 35,000 deaths every year among children under the age of 5 years (Gudu *et al.*, 2020). According to the Kenya Demographics and Health survey (KDHS, 2022), 18% of children under the age of 5 are stunted and 5% are wasted in Kenya. Furthermore, 21% of children under 5 years are stunted in Tharaka Nithi County alone. Without proper interventions, these cases could be fatal claiming thousands of lives of children aged below 5 years in Kenya each year (UNICEF, 2022).

The foods introduced during complementary feeding determine the nutritional status of the child. In this case, a child may become malnourished if one or more nutrients are not supplied in the required quantities. However, several factors determine a child's nutritional status. These include the availability of varieties of foods, the economic status of the family, accessibility, and cultural beliefs and practices. Additionally, the economic capability and knowledge of the caregivers also play a key role in the quality of food a child consumes (Adedeji et al., 2018). Malnutrition has been reported to be higher in rural areas as compared to urban areas (UNICEF, 2017).

Food products may not be available even though people have the resources due to regional location and production, weather, and climate influences on food production. In dry areas, for example, vegetable production is not done and people are limited to drought-resistant crop production. In such a case, diet is dictated by available foods (Adedeji *et al.*, 2018). For instance, in pastoral regions, animal products make up the greatest proportion of their diet in the form of meat, milk, and blood. Similarly, in arid and semi-arid areas, drought-resistant cereals such as sorghum (S*orghum bicolor*), and millet (*Pennisetum glaucum*), sorghum perform better and the likelihood of them being used in complementary feeding is quite high (Adedeji *et al.*, 2018). However, these cereals are energy-dense with low protein. When these cereals are used alone in complementary feeding, they pose a high risk of the child suffering from protein energy malnutrition and micronutrient deficiencies. Consequently, protein-energy malnutrition among children below five years of age, who are following such a diet is likely to be high, calling for interventions to reduce the risk by bringing in alternative protein sources. Additionally, it is necessary to look at what is locally available and how it could be used to intervene in this case. However, most weaning porridges are made with either millet or sorghum alone which is insufficient to achieve desired nutritional quality (Adepeju & Ibironke, 2019). Furthermore, there is insufficient data concerning the precise influence of incorporating pigeon pea flour into sorghum and millet composite flour, particularly in the context of mitigating protein energy malnutrition in children under 5 years old residing in semi-arid regions of Kenya. In this study locally available cereals like sorghum and millet were used to formulate a protein rich product by supplementing it with locally available legume (pigeon peas).

Knowledge of nutrition and the concept of a balanced diet also play a key role in the general nutritional status of children. However, there is a possibility of lack of such knowledge among care givers making it hard to make informed decisions on what to feed a child and also in identifying insufficiencies in the foods. As a result, they follow the old patterns of feeding. For instance, feeding children cereal-based porridge alone or green bananas hence inadequate provision of protein for child’s growth. According to Gudu *et al.* (2020), child feeding practices are one of the major causes of malnutrition among children under five years old in Kenya. In their research, Gudu *et al.* (2020), they found out that, 84 percent of children who had age-inappropriate anthropometric measurements were under-nourished. In some parts of Kenya, protein sources may be available but underutilized. For instance, in the eastern Kenya, pigeon pea production is high but cases of malnutrition still exist (Jeevarathinam & Chelladurai, 2020).

Kenya is among the highest pigeon peas (*Cajanus cajan*) producers in Africa, (Kaoneka, 2016). This legume has about 21–25 percent of protein, 1.6% fat, and 7%

fibre (Kaoneka, 2016). It is also a good source of calcium 0.2mg, iron 4mg, as well as vitamin A at 1.65mg per 100g portion. It is also an affordable source of nutrients, especially for the poor when combined with other grains and legumes. It supplies essential amino acids as it is a rich source of protein, dietary fibre, thiamine, magnesium, phosphorous, potassium, copper, and manganese, it also provides an adequate amount of iron and selenium (Anjulo et al., 2020). It also has good amounts of riboflavin, folic acid, and niacin, making it a nutritious food source (Anjulo *et al.*, 2020).

This study is aimed at addressing protein energy malnutrition among children from six months up to 5 years of age. According to the UNICEF (2022), in Kenya, there are significant differences in the distribution of child malnutrition among counties. In Kitui and West Pokot counties for instance, stunting is as high as 46% UNICEF (2022). Disease and poor diets, especially between the ages of 6 to 23 months, are major contributors to childhood malnutrition. Food insecurity, poor care methods, and detrimental social norms are all contributing factors.

As children grow, their requirements change according to age (Corkins *et al.*, 2016). It is therefore necessary to pay attention to these changes to ensure healthy growth and development. According to Garlick (2006), the safe levels of protein intake are 1.43 g/kg/day at 6 months and 0.91 g/kg/day at 10 years. This level of protein should be provided to ensure adequate growth and development.

Sorghum is available in most low rain zones and tends to be a popular complementary feeding option for many mothers. According to Jimoh and Abdullahi (2017), the chemical composition of sorghum is 11.5% protein, 2.7% fat, 72% carbohydrate, and 1.3% fibre. It also contains minerals like Sulphur at 0.25%, phosphorus 0.21%, potassium 0.15%, magnesium 0.07% and calcium 0.03%. Being rich in carbohydrates, the ratio of other nutrients is low. As a result, it is not a sufficient source of nutrients especially protein when used alone. It therefore needs to be complemented by high-protein foods to ensure the consumers are meeting their recommended dietary requirement for protein. In cases where the grain is used alone, protein malnutrition is likely to manifest affecting the growth and development of the population (Jimoh & Abdullahi, 2017).

Millet, on the other hand, is a grain belonging to the grass family and is consumed widely in Asia and the African continent as well (Jimoh & Abdullahi, 2017). Its popularity lately is, partly due to its gluten-free benefit hence a good fit for those having celiac disease and non-celiac gluten intolerance. It can be consumed either in whole or ground form (Jimoh & Abdullahi, 2017). It is drought and pest-resistant with a capacity to grow in poor soil and harsh environmental conditions. Nutritionally, it is a starchy grain hence a good source of energy required by the body for normal functioning. It also proves to be a superior source of basic amino acids and calcium than other cereals (Jimoh & Abdullahi, 2017). It contains 7-12% protein, 2-5% fat, 65-75% carbohydrates, and 15-20% dietary fibre (Rajalakshmi et al., 2021). Nevertheless, its utilization alone has the potential to cause protein malnutrition since it is low in protein content and quality (Jimoh & Abdullahi, 2017). This makes a good choice for this complementary feeding formula as it brings along calcium, necessary for bone formation, as well as amino acids.

Tharaka Nithi County is classified as a semi-arid region. Although the prevalence of poor or borderline food consumption was reported as occurring between 5-10%, its classification of stunting prevalence by the WHO is still very high (30.0% - 39.9%). In addition, the rates of acute malnutrition are alarming with the potential for deterioration (FAO, 2022). Thus, there is a need for intervention to enable mothers to utilize resources readily available to make nutritious complementary foods for their children.

There is limited information in the current literature regarding the specific impact of pigeon pea flour supplementation on the physicochemical properties, sensory properties, protein digestibility, and shelf life of sorghum and millet composite flour, especially in the context of addressing protein energy malnutrition among children under 5 years of age in semi-arid regions of Kenya. Additionally, there is a lack of comprehensive studies that consider the combined effects of pigeon pea flour with sorghum and millet on these parameters, which are crucial for the development of nutritious complementary foods for children in resource-constrained settings. Therefore, this study aimed to utilize locally available sorghum, millet, and pigeon peas in the formulation of a protein-rich complementary feeding flour.

1.2 Statement of the Problem

Malnutrition is a global public health issue, resulting in stunting, wasting, anaemia, obesity, developmental delays, and micronutrient deficiencies among others, especially in children under five years of age. In Kenya, undernutrition in young children is linked to poor maternal and infant feeding practices, food shortages due to climate, and lack of knowledge about balanced diets. Solely consuming millet or sorghum is insufficient for protein needs. Low-income families face challenges in accessing animal proteins to complement local crops like bananas, maize, and millet. Locally available, protein-rich foods such as pigeon peas could help improve nutrition when combined with cereals. However, limited research exists on how adding pigeon pea flour to sorghum and millet affects nutritional value, sensory properties, digestibility, and shelf life, particularly for combating malnutrition in children under five in Kenya's semi-arid regions.

1.3 Objectives

1.3.1 General objectives

To determine the physicochemical properties, protein digestibility, sensory properties, and shelf life of sorghum, millet, and pigeon peas composite flour.

1.3.2 Specific objectives

i. To determine the physico-chemical properties of composite flours containing varying levels of sorghum, millet, and pigeon peas.
ii. To determine the protein digestibility of composite flours containing varying levels of sorghum, millet, and pigeon peas.
iii. To determine the sensory properties of porridge prepared from composite flours containing varying levels of sorghum, millet, and pigeon peas.
iv. To determine the shelf-life of composite flours containing varying levels of sorghum, millet, and pigeon peas.

1.4 Study Hypotheses

Ho_1: Addition of pigeon pea flour has no statistically significant effect on the physico-chemical properties of sorghum, millet and pigeon peas composite flour.

Ho_2: Addition of pigeon pea flour has no statistically significant effect on the protein digestibility of sorghum, millet and pigeon peas composite flour.

Ho_3: Addition of pigeon pea flour has no statistically significant effect on the sensory quality of sorghum, millet and pigeon peas composite flour.

Ho_4: Addition of pigeon pea flour has no statistically significant effect on the shelf-life of sorghum, millet and pigeon peas composite flour.

1.5 Justification of the Study

Protein-energy malnutrition is a significant public health issue both locally and globally, especially in arid and semi-arid areas due to poor complementary feeding practices among children under 5 years of age (Gudu *et al.*, 2020). Some families in arid and semi-arid areas such as Makueni County, Kitui County, and Tharaka Nithi county, among others, in Kenya may not afford animal proteins to complement the energy-rich maize, millets, and sorghums that are locally available and commonly used in complementary foods for children (Anwar et al., 2024). Despite the high production of protein-rich pigeon peas in these areas, they remain underutilized in complementary feeding (Kaoneka, 2016). Mothers in these regions often lack the knowledge and resources to provide a balanced diet for their children which precipitates to protein energy malnutrition. Utilizing locally available ingredients to produce affordable, nutrient rich complementary foods for children under five years has potential to promote food nutrition security advancing the fight against protein energy malnutrition. The use of locally available ingredients has potential to offer a lasting sustainable option to increasing nutrient intake among children resulting in improved growth and better health outcomes. This research seeks to formulate a protein-rich porridge flour by combining pigeon peas with millet and sorghum, offering a sustainable solution to combat malnutrition and meet the nutritional needs of children in resource-limited regions.

1.6 Definition of Terms

Supplementation: Supplementation refers to the addition of specific nutrients or food sources to a diet to enhance its nutritional value. In this study, it involves incorporating pigeon peas into sorghum millet porridge flour to increase the overall protein content.

Composite Flour: Composite flour is a mixture of two or more different types of flour, often combined to enhance nutritional value, improve functionality, or alter sensory characteristics. In this study, composite flour will refer to the blend of sorghum millet flour and pigeon pea flour used to create a nutrient-rich porridge.

Flour Blend: Flour blend is a specific mixture of various flours that may be combined for improved nutritional content. In this study, the flour blend will specifically denote the combination of sorghum millet flour and pigeon pea flour aimed at increasing protein content and overall nutritional quality.

Physicochemical Properties: Physicochemical properties refer to the physical and chemical characteristics of a substance that affect its behavior and functionality. In this study, physicochemical properties of the composite flour included protein content and functional properties of composite flours.

Functional Properties: Characteristics of flour that affect its behaviour in food preparation, such as water absorption index, water holding capacity, solubility, bulk density, foaming capacity, foam stability, least gelling concentration and gelatinization temperature.

Sensory Evaluation: A systematic assessment of the sensory attributes of food, including taste, texture, aroma, and appearance.

Protein Quality: Refers to the measure of the protein's ability to provide essential amino acids necessary for growth and development.

Nutritional Status: Nutritional status is a measure of the health and well-being of individuals based on their nutrient intake and overall dietary habits.

Malnutrition: A condition resulting from insufficient, excessive, or imbalanced nutrient intake, leading to health issues such as protein-energy malnutrition (PEM).

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Malnutrition in Children

Children under the age of five go through a time of fast growth in their muscles, organs, body tissues, and brain development (Lutter *et al.*, 2021). The dietary requirements of new-borns, older children, and adults are vastly different (Martorell, 2017). Some of the factors influencing their growth and development include the availability of a balanced diet and sanitation among others (Smith & Shively, 2019). As a result, a wide spectrum of essential nutrients must be supplied to establish and maintain a nutritional balance despite the small portions that children take per meal (Haines *et al.*, 2019). A healthy diet and approach to food concerns are essential, especially if the children are to remain healthy, and free from a variety of health and developmental issues. Obesity, stunted growth, iron deficiency, specific vitamin deficiencies, dental cavities, and developmental delay are among problems that young children face now and, in the future, (Haines *et al.*, 2019; Scaglioni *et al*., 2018; Smith & Shively, 2019). During this age, parents have the opportunity to contribute to the future health and general potential of their children. It is therefore important to take a closer look at what they feed their children (Scaglioni *et al.*, 2018).

Caregivers in arid and semi-arid regions often lack the knowledge and resources to provide a balanced diet for their children which results to protein energy malnutrition. Thus, although raw ingredients that can potentially enhance nutrient intake among children are available locally, children are often fed on energy dense food products (Adedeji et al., 2018). Utilizing these locally available ingredients such as pigeon peas to produce affordable, nutrient rich complementary foods for children under five years has potential to promote food nutrition security advancing the fight against protein energy malnutrition. However, limited research exists on how adding pigeon pea flour to energy dense cereals such as sorghum and millet affects nutritional value, sensory properties, digestibility, and shelf life, particularly for combating malnutrition in children under 5 years of age.

Normal development is split into four stages: prenatal, infancy, childhood, and pubertal (Triantafyllou & Roberts, 2022). Nutrition is crucial at all stages of development, but especially during the infantile period when the rate of growth is faster than at any other time of life (Kostecka et al., 2020). Therefore, there is need for adequate nutrition to be provided to the child to avoid deficiencies. The nutritional composition of complementary foods is very important and cannot be ignored if malnutrition is to be avoided.

Nutritionally, pigeon peas are a rich source of protein providing a good amount of the essential amino acids, fibre, vitamins, and minerals among other compounds that are essential for human health. Compared to meat, it is a cheaper source of protein, and thus, can be used to supplement the traditional cereal-based diets for both infants and adults in Kenya. According to Anjulo *et al.* (2020), the protein content of pigeon peas in their study on the determination of selected metals and nutritional compositions of pigeon peas cultivated in Wolaita Zone, Ethiopia was 13.28% to 25.79% crude protein. In addition to the high levels of protein, pigeon peas have been reported to contain crude fibre 9.8–13.0%, potassium, phosphorus, calcium, manganese, sodium, zinc, iron, and copper (Amarteifio et al., 2002; Anjulo et al., 2020).

In another study, conducted by Marete (2015), producing an instant formula containing sorghum and pigeon peas, the protein content of three varieties of pigeon peas was analysed, and the results of peas from three counties were compared. In this research, the protein content of pigeon peas from Tharaka Nithi was obtained. These are, the *Ndombolo* variety with 19.08 percent, *Mbaazi II* had 19.11 percent and KAT60/8 had 16.94 percent protein, (Marete, 2015). Thus, considering their abundance in the eastern region, and their potential nutritional value, pigeon peas may be used to improve the protein and nutritional composition of baby foods. However, this legume has not been exhausted adequately as a possible intervention to the continually reported cases of malnutrition in children.

According to Jimoh and Abdullahi (2017), the chemical composition of sorghum is 11.5% protein, 2.7% fat, 72% carbohydrate, and 1.3% fibre. It also contains major minerals like Sulphur at 0.25%, phosphorus 0.21%, potassium 0.15%, magnesium 0.07%, and calcium 0.03% (Rajalakshmi *et al*., 2021). Being rich in carbohydrates, the ratio of other nutrients is low. Thus, when used as the sole source of nutrients for young children, it subjects them to the risk of protein malnutrition (Jimoh & Abdullahi, 2017). Even though sorghum is common its use brings up the question of the quality of protein therein as well as the presence of tannins and phytates. As a result, different research work has been done on improving protein quality as well as increasing the digestibility of the product formulated. For instance, Marete (2015), analysed tannin concentration before and after fermenting and malting sorghum grain and discovered a significant reduction from 3.18 mg/100 g – 5.36 mg/100 g to about 2.25 mg/100 g on the composite product. Phytates are also reduced following fermentation and malting.

According to Mweu (2017), the protein content of pearl millet is greater than maize and it has a relatively high vitamin A content. The amount of amino acids present indicates the protein quality. Brown rice had a significantly low protein content at 8.5 % compared to that of millet at 13.4%, and maize at 11.4%. Generally, the protein content of the cereals was lower compared to that of already determined values. The reasons for this disparity can be explained by the likely variety difference, the analytical method used, as well as the different moisture content may also have accounted for the differences recorded. In addition, processing could also affect the protein content in a cereal (Yankah *et al.*, 2020).

Its popularity lately is partly due to its gluten-free benefits hence a good fit for those having celiac disease and non-celiac gluten intolerance. It can be consumed either in whole or ground form (Jimoh & Abdullahi, 2017). It is drought and pest-resistant with a capacity to grow in poor soil and harsh environmental conditions. Nutritionally, it is a starchy grain hence a good source of energy required by the body for normal functioning. It also proves to be a superior source of basic amino acids and calcium than other cereals (Jimoh & Abdullahi, 2017; Mweu, 2017). This makes a good choice for this complementary feeding formula as it brings along calcium, necessary for bone formation, as well as amino acids.

Millet has also been reported to contain a high concentration of phenolic chemicals, including ferulic acid and catechins. These chemicals safeguard your body from damaging oxidative stress by acting as antioxidants. Ferulic acid has been linked to wound healing, skin protection, and anti-inflammatory activities in animal studies. Catechins, on the other hand, bind to heavy metals in circulation, preventing metal poisoning. It is high in fibre and non-starchy polysaccharides, two forms of non-digestible carbohydrates that aid with blood sugar regulation. This cereal also has a low glycaemic index (GI), which means it can be used to control blood sugar levels. It contains approximately 9.5% protein, 3.5% fat, 70% carbohydrates and 17.5% dietary fibre (Rajalakshmi *et al*., 2021). This information is summarized in Table 1. Nevertheless, its utilization alone has potential to cause protein malnutrition since it is low in protein content and quality (Jimoh & Abdullahi, 2017).

Table 1: Mean proximate composition of pearl millet, sorghum and pigeon peas

Constituent	Pearl millet (%)	Sorghum (%)	Pigeon peas (%)
Carbohydrates	70	72	62.78
Protein	9.5	11	21.70
Fat	3.5	2.7	1.49
Fiber	17.5	2.7	11

Sources: Anjulo et al. (2020); Jimoh and Abdullahi (2017); Rajalakshmi et al. (2021)

About 26% of Kenyan children under the age of five, suffer stunted development. Furthermore, those underweight are estimated at 11 percent, with 4% being wasted (UNICEF, 2022). According to the Kenya Demographic and Health Survey of 2014, stunting prevalence in Tharaka Nithi County is categorized as medium, standing between 20 to 29.9% (UNICEF, 2017). Currently, the need for protein sources is a significant problem, and the demand may increase in the future owing to population growth. Food items made from an economical and low-cost source, such as pigeon pea, might be an effective and alternative strategy to satisfy world ever swelling demand and hunger (Jeevarathinam & Chelladurai, 2020).

Sometimes food products are available but mothers have to travel long distances to access these products which is expensive. This forces them to offer only what is locally available which may not meet the nutritional requirements of the children. For instance, children may be fed on pounded green bananas, pure sorghum, millet or maize porridge. These foods are high in carbohydrates and low in proteins. Continued intake without supplementation result in protein deficiency with poor growth evident. Using pigeon peas as a source of protein will help alleviate the burden of malnutrition. On the other hand, pigeon peas being locally available, they become economical to use in enriching a child’s diets.

Generally, it is not practical to assess everyone's nutritional status. As such several groups have been prioritized. These groups include; Children under 2 years of age, especially if they are not breastfed, the elderly, pregnant mothers or up to 6 months postpartum, and people experiencing unintentional weight loss. Malnutrition in early age can be avoided by providing them with a sufficient supply of nutritious and safe supplemental meals (WHO, 2012). According to several researchers, a caregiver's knowledge, attitude, and behaviours are critical to a child's nutritional result. Breakfast, regardless of age, jumpstarts the body's metabolism, assisting in the burning of calories throughout the day.

Underweight, stunting, and wasting are the three basic indices used to characterize undernutrition (De Onis et al., 1993). They indicate distinct histories of malnutrition to the child. Linear growth retardation (stunting), which occurs largely in the first 2-3 years of life, is typically related with recurrent exposure to unfavourable economic situations, poor sanitation, and the combined effects of inadequate energy and nutrient intakes and illness. The frequency of childhood obesity, is also increasing all across the world (Sanal et al., 2021; WHO, 2012).

Childhood malnutrition has a cascade effect on immunological function, which leads to increased susceptibility to infection, particularly gastrointestinal and respiratory diseases, which leads to higher child mortality (Marti et al., 2001). Improvements in dietary practices, such as adhering more closely to infant feeding guidelines, exclusive breastfeeding in the first 6 months of life, introduction of appropriate solid foods at 6 months, frequent feedings, and continuation of breastfeeding for up to 2 years, can lead to easier malnutrition recovery. Other healing measures include the inclusion of micronutrients such as Vitamin A, iron, zinc, and iodine, the continuance of more nutritious diets after infancy, and avoiding diarrhoea and infections caused by contaminated food and unsanitary, cold, and damp environments (Sanal *et al*., 2021).

In a study done by Sanal *et al*. (2021), involving 300 mothers, half from rural set up and the other half from urban setting, three study characteristics were used, that is age, level of education, and employment status. In this study, mothers' understanding of micronutrients was high in both urban and rural contexts. Micronutrients were known to be important to 82% of rural mothers and 94% of urban mothers. The inclusion of fruits, vegetables, nuts, grains, and so on was also widely established in complementary feeding. This demonstrates that the addition of fruits and vegetables during complementary feeding supplies the body with a high number of micronutrients and helps in overcoming malnutrition, and 89% of mothers in their survey understood that the inclusion of fruits and vegetables was good to the child.

Maternal education has been proposed as a potent and substantial predictor of child health status (Sanal *et al.*, 2021). Usually, mothers can only utilize what they have access to. Thus, it is important to develop foods based on locally available resources as most rural communities may not have access to processed complementary foods. There is need to study available raw materials from different locations to establish complementary mixtures that can cheaply help alleviate malnutrition in Kenya.

2.2 Functional Properties of Food Products

Functional properties influence how components behave when they are being prepared and cooked, as well as how they impact the final product's appearance, texture, and flavour (Awuchi et al., 2019). The production applicability of different food products depends heavily on these qualities. These properties include; swelling capacity, oil and water absorption capacities, emulsion activity and stability, foam capacity and stability, gelatinization, bulk density, dextrinization, preservation, denaturation, coagulation, formation of gluten, gelling, shortening, plasticity, flakiness, moisture retention, aeration, and sensory attributes. Other functional characteristics of food items and flour consist of solubility, water retention, elasticity, foaming ability, absorptive capacity for fat and foreign particles, emulsification, hydration (water binding), viscosity, cohesion, and adhesion (Awuchi et al., 2019).

The structure, quality, texture, nutritional content, acceptability, and/or appearance all contribute to its functional properties. A food’s organoleptic, physical, and/or chemical qualities typically dictate its functional attribute. Additionally, the components of food material, particularly the carbohydrates, proteins, fats and oils, moisture, fibre, ash, and other ingredients or food additives added to the food, such as sugar alcohols, as well as the structures of these components, influence the functional properties of foods and flours (Awuchi et al., 2019). The functional qualities of flours may also be impacted by mycotoxins, such as patulin found in grains. Every component has a specific purpose in cooking; for example, starch (flour) is mostly used to thicken and also browning; egg proteins can act as an emulsifier, thickener, and foaming agent; Fats and oils play a key role in food aeration, emulsions and shortening (Awuchi et al., 2019).

The primary cause of gelatinization, browning, dextrinization, gelation, and other processes is starch. The primary causes of foaming, browning, emulsification, coagulation, denaturation, etc. are proteins. Emulsification, aeration, and shortening are mostly caused by fat. While one element may have a small impact on a functional attribute, two or more constituents may have the same influence (Awuchi et al., 2019). The majority of the procedures that foods go through cause some of their useful qualities to start. Take heating, for instance granules of starch form a suspension in cold liquid instead of dissolving.

2.3 Protein Digestibility

Protein digestibility refers to the ability of the body to break down and absorb the proteins in food. It is a measure of the quality of the protein, as not all proteins are equally digestible (Bessada et al., 2019). Proteins are made up of long chains of amino acids, and in order for the body to use these amino acids, the protein must first be broken down into smaller peptides and amino acids by enzymes in the stomach and small intestine. Some proteins are more easily broken down than others, and therefore are considered to be more digestible.

Some of the factors that affect protein digestibility include the type of protein, the processing method, and the presence of other substances in the food that can interfere with protein breakdown, such as antinutrients (Bessada *et al*., 2019). Animal proteins are generally more digestible than plant proteins. However, the digestibility of plant proteins can be improved by cooking, sprouting, or fermenting them. Protein digestibility-corrected amino acid score (PDCAAS) is a method that is used to evaluate the quality of proteins based on their amino acid composition and digestibility. Proteins that score a 1.0 are considered to be the most digestible and of the highest quality. Protein digestibility is an important consideration for individuals with certain medical conditions, such as malabsorption disorders, and for those who have difficulty digesting certain types of proteins.

There are several methods that can be used to analyse protein digestibility, including: In vitro methods: These methods use enzymes and simulated stomach and intestinal conditions to measure the extent to which a protein is broken down. They can be used to evaluate the effect of processing methods on protein digestibility. Animal assays: These methods use animals, such as rats or pigs, to measure protein digestibility. The animals are fed the protein, and the amount of protein that is digested and absorbed is then measured. Human assays: These methods use human volunteers to measure protein digestibility. The volunteers are fed the protein, and the amount of protein that is digested and absorbed is then measured.

Protein Digestibility Corrected Amino Acid Score (PDCAAS). This method is used to evaluate the quality of proteins based on their amino acid composition and digestibility (Sargin *et al*., 2021). The PDCAAS is calculated by comparing the amino acid requirements of humans with the amino acid content of the protein. Proteins that score a 1.0 are considered to be the most digestible and of the highest quality (Sargin *et al*., 2021). True digestibility: This method is used to measure the percentage of protein that is digested and absorbed by the body. It is determined by measuring the amount of nitrogen in the urine and faeces after a person has consumed a test protein (Oba et al., 2019).

It is worth noting that each method has its own advantages and limitations. For example, In vitro methods are simple, rapid, inexpensive and less invasive but not fully simulating the human digestion process (Bryan & Classen, 2020). Animal assays are more realistic but could be affected by species-specific variations. Human assays are the most realistic but are more expensive and time-consuming. PDCAAS (Fenollosa et al., 2020)s widely used, but it has its own limitations too.

2.4 Sensory Evaluation of Flours

Sensory evaluation is a scientific discipline that involves the systematic and objective assessment of the sensory attributes of a product, such as appearance, taste, aroma, texture, and overall acceptability, by trained or consumer panellists. This evaluation provides valuable insights into the sensory properties of the product and helps in understanding consumer preferences and acceptance (Marques et al., 2022). The type of sample involved determines the attributes that can actually be analysed sensorially.

For instance, it is not practical to analyse the taste of a flour sample that is not cooked, hence not edible. There are several methods that can be used in this analysis. These include: descriptive analysis (Marques *et al*., 2022), consumer sensory testing, texture analysis (Guiné, 2022), and aroma and flavour profiling (Yu et al., 2022).

2.4.1 Importance of sensory analyses in the context of composite flours:

Sensory evaluation is of paramount importance in assessing the quality and acceptability of composite flours. As composite flours are blends of different flours or ingredients, understanding how sensory attributes change with varying compositions is crucial. It helps in determining the optimal mixture that ensures the final product meets consumer expectations and preferences. Sensory evaluation also aids in identifying any off-flavours, textures, or undesirable sensory attributes that may arise due to the addition of pigeon pea flour or other ingredients.

2.5 Shelf-Life of Flours:

The keeping quality of flours refers to their ability to maintain their original quality and remain free from spoilage or deterioration over time. Several factors affect the keeping quality of flours, including moisture content, storage conditions, microbial activity, and the presence of anti-nutritional factors according to (Bonciu et al., 2022). One of the main things impacting flour's shelf life is its moisture content. Elevated moisture content can encourage the development of mold and bacteria and possible health hazards (Alegbeleye et al., 2022). Lower moisture content flours are less prone to microbiological growth, which means they often have a longer shelf life. Flours should have a moisture level of no more than 14% to ensure maximum shelf life. Additionally, too much moisture can cause clumping and lower the perceived quality of the flour (Alegbeleye *et al*., 2022).

Controlling temperature, humidity, and exposure to light are essential elements. In order to stop microbial development and degradation from accelerating, flour needs to be stored in cool, dry environments (Alconada & Moure, 2022). Elevated temperatures have the potential to oxidize flour lipids, resulting in rancidity and off tastes. Restrictions on humidity stop the flour from absorbing too much moisture (Alconada & Moure, 2022).

Another important factor affecting the shelf-life of flour is microbial activity. If flour isn't stored correctly, microorganisms including molds, bacteria, and yeast can grow. If ingested, these microorganisms present serious health hazards and can cause spoilage (Kamboj et al., 2020). To reduce microbiological contamination, it is essential to maintain good sanitation during the production and packaging of flour. It's also crucial to regularly check the microbiological load to make sure the flour stays within safe and acceptable quality limits (Kamboj *et al*., 2020).

Packaging has a big impact on how long a product lasts. Despite being widely used, paper packaging is permeable and can allow moisture in, which encourages the growth of microorganisms. Alternative packaging techniques that limit moisture absorption can be used to increase shelf-life. These techniques lessen the exposure to oxygen and moisture, two important elements in food spoilage (Fadiji et al., 2023). Airtight, moisture-proof containers can also help preserve flour quality by shielding it from outside environmental influences (Fadiji *et al*., 2023).

Another crucial factor in determining shelf life is chemical stability. Flour's chemical composition may change with time, resulting in reduction in quality. Rancidity resulting from lipids oxidation, and other characteristics of flour can be changed by enzymatic activity (Vinutha *et al.,* 2022). The flour's shelf life can be extended and chemical changes slowed down by adding antioxidants and other preservatives (Thakur et al., 2022).

It is crucial to regularly test the moisture content, microbiological load, and chemical stability in order to monitor quality over storage time (Thakur *et al*., 2022). Strict hygiene regulations must be adhered to during the production, processing, and packaging stages in order to prevent infection (Holah, 2023). Flour may be kept safe and of high quality by teaching consumers how to store it at home. This includes using it within its best-before date and storing it in a cool, dry place (Zielińska et al., 2020). Shelf-life can be assessed using different methods such as microbiological analysis, chemical analysis, and physical evaluation: sensory evaluation and accelerated aging tests.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Site

This study was carried out at Chuka University, Department of Food Technology and the Animal Science laboratories. The formulation of flour blends, analysis of the functional properties of flour blends, sensory evaluation and shelf-life study were undertaken in the food technology laboratory while protein digestibility analysis was carried out in the animal science laboratory.

3.2 Experimental Design

A nested design with two factors was used: pigeon peas level (0, 15, 30, 45 and 60%) and sorghum level (3 levels) nested in pigeon pea levels, for objective 1, 2 and 3. A nested factorial design was employed for objective 4, with the following factors: storage period (days), pigeon pea level (0, 15, 30, 45 and 60%) and sorghum level (3 levels) nested in pigeon peas.

3.3 Preparation of Millet, Sorghum and Pigeon Peas Individual Flours

Pearl millet, sorghum and pigeon peas were procured from Chuka open-air market, Tharaka Nithi County, Kenya. Preparation of the different flours followed the method outlined by Arukwe et al. (2022) with modifications. The grains were sorted followed by further cleaning to remove broken kernels and foreign matter (Figure 1 and Figure 2). The grains were then washed using clean water to remove dirt and dust followed by oven drying to a moisture content between (11-13)%. Before drying, pigeon peas were soaked overnight (12 hours) to reduce the levels of anti-nutrients through dissolution and leaching followed by boiling for 30 minutes at 100^0C (Arukwe et al., 2022). The dry grains were then milled to a fine flour with a laboratory hammer mill fitted with a 0.8 mm screen. The ground flours then used immediately in sample formulation to get the different flour blends.

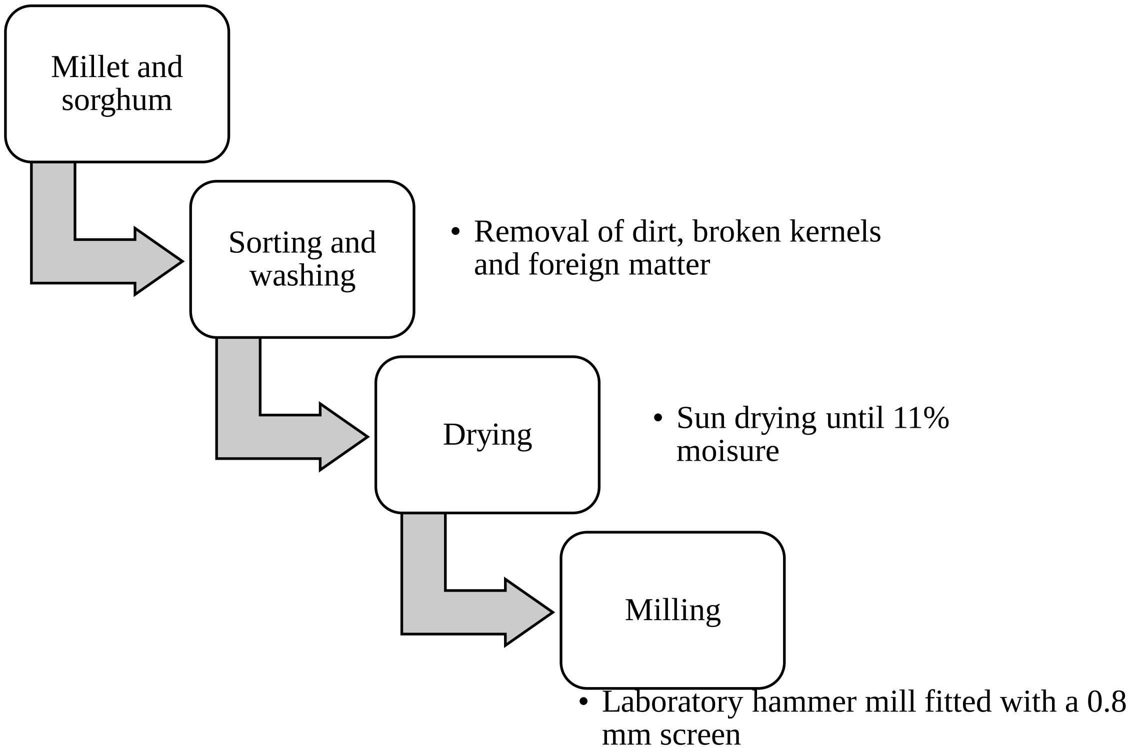

Figure 1: Preparation process for millet and sorghum flours

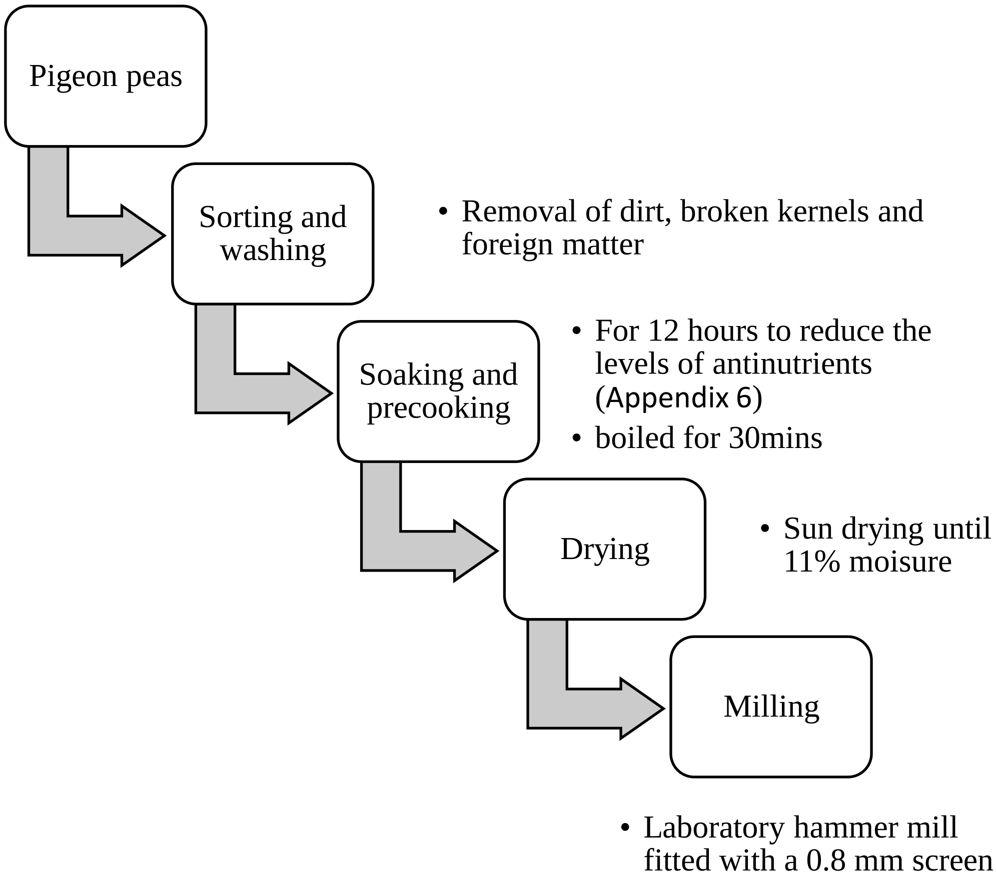

Figure 2: Preparation process for pigeon pea flour

In the case of pigeon pea, which involved soaking and precooking, the clean legumes were Soaked in clean water overnight (or for at least 8 hours), which softened, and reduced cooking time. After soaking the grains were rinsed off then boiled using a sauce pan for 30 minutes, to cook them adequately but not marshy, for ease of handling during drying (Arukwe et al., 2022). Draining of the boiling water followed by instant cooling using cold water was done followed by oven drying for 48 hours at 70^{o}C. The dry peas were transferred into an airtight container and stored in a cool dry place awaiting milling.

3.3.1 Formulation of Flour Blends

The millet, sorghum and pigeon peas flours were combined in the ratios (millet: sorghum: pigeon peas) shown in Table 3. The formulation process was done as follows: first, pre-mix blends containing 0%, 20% and 40% sorghum in millet were prepared.

Next, for each pre-mix blend, sorghum-millet blend was substituted with 0%, 15%, 30%, 45% and 60% pigeon pea flour. This resulted in 15 flour blends which were stored in paper packaging bags awaiting further analysis.

Table 2: The ratios of millet, sorghum and pigeon pea flour blends

Blend label	Pigeon peas%	Sorghum %	Millet %
s0p0	0	0	100
s20p0	0	20	80
s40p0	0	40	60
s0p15	15	0	85
s20p15	15	17	68
s40p15	15	34	51
s0p30	30	0	70
s20p30	30	14	56
s40p30	30	28	42
s0p45	45	0	55
s20p45	45	11	44
s40p45	45	22	33
s0p60	60	0	40
s20p60	60	8	32
s40p60	60	16	24

Whereby blend labels represent the following; s0p0: 0% sorghum, 0% pigeon peas, s0p15: 0% sorghum, 15% pigeon peas, s0p30: 0% sorghum, 30% pigeon peas, s0p45: 0% sorghum, 45%pigeon peas, s0p60: 0% sorghum, 60%pigeon peas, s20p0: 20% sorghum, 0%pigeon peas, s20p15: 20% sorghum, 15%pigeon peas, s20p30: 20% sorghum, 30%pigeon peas, s20p45: 20% sorghum, 45%pigeon peas, s20p60: 20% sorghum, 60%pigeon peas, s40p0: 40% sorghum, 0%pigeon peas, s40p15: 40% sorghum, 15%pigeon peas, s40p30: 40% sorghum, 30%pigeon peas, s40p45: 40% sorghum, 45%pigeon peas, s40p60: 40% sorghum, 60%pigeon peas.

3.3.1 Packaging and storage conditions for flour samples

After preparation (blending), the composite flours blends (15) containing the optimal level of protein were immediately aseptically packaged into paper packaging bags, which are breathable and most ideal for flour products. Each packet containing approximately 250 grams of composite flour. After packaging, samples were stored at room temperature (20-25 °C) for up to 65 days. The packs were stored in an airtight plastic container which was only opened during sample collection. Replicate samples were collected for analysis on days 0, 14, 28, 42 and 60. During packaging, samples were packed to be used once (once opened, samples were not stored back for any shelf-life test). Therefore, each blend had 5 packets to fit the different analysis periods.

3.3.1 Sample preparation for sensory evaluation

The porridge was prepared using 200g flour to 1.5L water, and cooking while continuously stirring with a wooden spoon. Each sample was allowed to cook for 20-25 minutes. (Phan et al., 2014). Samples were then cooled to 30-35^{0}C. Approximately 30g of each sample was served in clear cups labeled with three-letter codes and submitted to panelists for evaluation. In this work, 60 untrained panelists were used.

3.4 Determination of the Functional Properties of the Different Composite Flours Containing Sorghum, Millet and Pigeon Peas

3.4.1 The foam capacity and foam stability

The foam capacity (FC) and Foam stability (FS) were determined as described by Chandra et al. (2015). A 1.0 g composite flour sample was added to 50 ml distilled water adjusted to 30 ± 2 °C in a graduated cylinder. The suspension mixed and shaken for about 5 min to foam, then the volume of foam at 30 s after whipping measured and expressed as foam capacity (Equation 3.1).

Equation 0.1.

$$Foam\ capacity\ (\%) = \left(\frac{V1 - V2}{V2}\right) x100$$

where, V1 is volume of foam after mixing and V2 is the volume of foam before mixing

Afterwards, the samples were stored for 1 hour and the volume of foam recorded again to determine foam stability. Form stability was reported as the amount of foam after mixing and storing for 1 hour as a percentage of initial foam volume as described by Chandra *et al.* (2015), (Equation 3.2).

Equation 0.2.

$$Foam\ Stability\ (\%) = \left(\frac{V1 - V2}{V2}\right) x100$$

where, V1 is Volume of foam after mixing and storing for 1 hour and V2 is Volume of foam before mixing

3.4.2 Bulk density

Bulk density was determined as described by Oyim et al. (2022). 50 grams of composite flour were measured into a graduated measuring cylinder, and the volume obtained recorded. The bottom of the cylinder was gently tapped on a laboratory bench several times until there was no further diminution of the sample level and the final volume recorded. The bulk density was then calculated as the weight of sample per unit volume of sample (g/cm). The ratio of mass of an untapped powdered by its volume, which ncludes the inter-particulate air spaces volume contribution, is the powder's bulk density. (Barai, 2020).

3.4.3 Water holding capacity

Water holding capacity was determined according to the method described by Oyim *et al*. (2022). 10 ml of distilled water was mixed with 1 g of sample in a pre-weighed centrifuge tube, vortexed, and left to stand at room temperature for 24 h. After which, centrifugation at 688 × g for 15 min was done, then the supernatant decanted and the residue weighed, dried at 80˚C and reweighed. The WHC was then expressed as grams of water per gram of dry flour sample.

3.4.4 Water absorption index and Water solubility index

Similarly, water absorption index and Water solubility index were determined as described by Oyim *et al.* (2022). Ground sample (1 g) was weighed into pre-weighed centrifuge tubes, and 10 ml of distilled water added. The tubes were then vortexed and left to stand at room temperature (25˚C) for 24 h. The tubes were shaken and centrifuged at 688 ×g for 15 min. The supernatant portion was decanted into pre-weighed Petri-dish and dried at 105˚C for 12 hours. The weight of the remaining gel in the tube was taken as the water absorption index. Calculation of water solubility index was done using the formula outlined in Equation 3.3.

Equation 3.3.

$$Water\ solubility = \frac{W1 \times 100.}{W2} x100$$

where, W1 is the weight of dissolved solids in the supernatant and W2 is the weight of dry sample.

3.4.5 Swelling capacity

Samples weighing 1 g were placed in graduated cylinders and the initial volumes recorded. Ten ml of distilled water at room temperature (25˚C) was added to each of the flour samples and mixed. Samples were then tapped gently to eliminate air and let to stand for 24 h, and the final volume noted as described by Oyim *et al*. (2022). Swelling capacity was calculated as shown in Equation 3.4.

Equation 3.4.

$$Swelling\ capacity = final\ volume\ wet\ residue - \ initial\ volume\ dry\ sample$$

3.4.6 Determination of the least gelation concentration

The least gelation concentration was evaluated as described by Chandra *et al*. (2015). Composite flour dispersions containing 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 30 % (w/v) were prepared using 5 ml distilled water. All dispersions were heated at 90 °C for 1 hour in a water bath. The contents were then cooled for 2 hours at 10 ± 2 °C. The least gelation concentration was determined as the concentration of composite flour at which the sample from the inverted tube did not slip. To calculate the weight of the sample in grams for composite flour dispersions containing different percentages (w/v) using 5 mL of distilled water, the formula outlined in Equation 3.5 was used.

Equation 3.5.

$$Weight\ of\ sample\ (g)\ = Percentage\ (w/v)\ \times Volume\ of\ water\ (mL)100$$

$$Weight\ of\ sample\ (g)\ = 100Percentage\ (w/v)\ \times Volume\ of\ water\ (mL)$$

3.4.7 Determination of gelatinization temperature

A composite flour sample (1 gram) was weighed accurately in triplicate and transferred to 20 ml screw capped tubes into which 10 ml of water was added. The samples prepared was heated slowly in a water bath until they formed a solid gel. At complete gel formation, the respective temperature was measured and taken as the gelatinization temperature as described by (Ahaotu et al., 2021).

3.5 Determination of the Protein Quality of Composite Flours Containing Varying Levels of Sorghum, Millet, and Pigeon Peas.

3.5.1 Determination of crude protein content of composite blends

Crude protein content was determined through the kjeldahl method (AOAC, 2000). Flour samples were digested at 420 ^{o} C with concentrated Sulphuric acid, potassium sulphate and a metal catalyst (copper (II) sulphate), followed by distillation. Concentrated boric acid was used to trap ammonia gas. Titration with 0.1N hydrochloric acid was done with suitable coloured pH indicator used. Total crude protein (CP) was calculated (Equation 3.6). Crude protein (%) content was calculated by multiplying the % nitrogen content with a conversion factor (Fujihara et al., 2008).

Equation 3.6.

$$N^{*}\ \% = \frac{[(\text{ml acid} * \text{ N acid}) - (\text{ml blank} * \text{ N base})] - (\text{ml base} * \text{ N base}) * 1.4007}{\text{Weight of sample in grams}}$$

$$\text{CP} = 6.25 * N^{*}$$

where, 6.25 is the conversion factor, N is the normality and *N* is the Nitrogen content

3.5.2 In vitro Protein digestibility of flour blend containing optimum levels of sorghum, millet and pigeon peas flour

Protein digestibility was determined following the method described by (Ouma et al., 2022). In the digestion tube, 0.5 g of protein containing sample was suspended in a 9.5 ml of 0.1M HCl and mixed with 5mg pepsin (1:3000; activities 0.8 Anson units/mg, Mumbai, India) in 0.5 ml 0.1M HCl and covered. The mixture was incubated in a shaker water bath at 37°C for 2 h. The solution was neutralized by adding 10 ml 1.0M phosphate buffer (pH 8.0) followed by addition of trypsin (Pankreasprotease; activity min 200 FIPU/g, Merck Darmstadt, Germany) (100:1 ratio of substrate/enzyme ratio, w/w). The digestion tubes were covered and incubated again in the water bath at 37°C for 2 h. Enzyme activity was terminated by adding equal volumes (10 ml) of trichloroacetic acid (10% w/v). Samples were immediately transferred to a freezer (-25°C) for 20 min after which, samples were vortexed for 15min (2500 g, 20°C) and left for 1 h to settle. The supernatant was decanted and the residue transferred into moisture dish and dried at 105°C for 3 h. About 0.2 g residue was weighed and the nitrogen content of the residue was determined by Kjeldahl nitrogen analysis. The % nitrogen of the residue was determined as shown in Equation 3.7.

Equation 3.7.

$$\%N = (1.4007(VBL - VB)\ \times 100)/(W \times 1000)$$

Where: VBL is the volume of the blank titre, W is the weight of the sample and VB is the volume of the base.

Protein digestibility was calculated by getting the difference between the total amount of protein and the residual amount of protein after pepsin and trypsin digestion divided by the total amount of protein and expressed as a percentage (Equation 3.8).

Equation 3.8.

$$\%Digestibility = ((TAP - RAP)/TAP)\ \times 100$$

where: TAP is total amount of protein and RAP is the residual amount of protein

3.6 Determination of the Sensory Quality of Porridge Prepared from Composite Flours Containing Sorghum, Millet and Pigeon Peas at Different Levels.

3.6.1 Sensory evaluation

Sensory evaluation of porridge was done by 60 untrained panellists. The panellists were sampled from Chuka University community comprising of staff and students Appendix 1. Being an untrained panel, the panellists were informed of the product and the purpose of the analysis, and how to assess the product using the score card provided. The panellists were also provided with distilled water to cleanse their palate after tasting each sample.

The cooked porridge samples were subjected to sensory evaluation to determine the general sensory characteristics and acceptability. The porridge was assessed in terms of color, taste, flavour, viscosity, consistency, texture, overall acceptability and willingness to buy. The five-point hedonic scale was used (Scale: 1-dislike extremely; 2-dislike moderately; 3-neither like nor dislike; 4-like moderately; 5-like extremely) to access color, taste, flavour, viscosity, consistency, texture, overall acceptability Appendix 2. Ranking scale (0-10; where 0-Not willing to buy and 10 -Most willing to buy) was used to access willingness to buy Appendix 2.

3.7 Determination of the Shelf-Life of the Composite Flour Containing Optimum Levels of Sorghum, Millet and Pigeon Peas Flour

3.7.1 Microbiological quality of flour samples for shelf-life test

Enumeration for yeast and Molds was performed to estimate the shelf life of flours. Determination of yeast and Mold counts was done following the method outlined by Tournas et al. (2001) in the Food and Drug Administration's bacteriological analysis manual. From the diluted solutions, 1 ml of each diluted sample was pour-plated to determine the yeasts and Mold counts onto chloramphenicol yeast glucose agar with chloramphenicol added to inhibit bacterial growth. Incubation of inoculated plates done at 20-25 °C for 5 days. Visible colonies were counted and recorded and results expressed as cfu/g. This was later transformed into log form during statistical analysis.

3.7.2 Analysis of Titratable acidity and pH of composite flour

Titratable acidity was determined following AACC Approved Method 02-02.02, and expressed as mg of KOH used to neutralize the free fatty acids from 100 g of composite flour. Alcohol-phenolphthalein solution (0.04%) prepared by adding 0.4 g phenolphthalein to 1 litre of ethyl alcohol (95%) was used as indicator. The pH was determined using a pH meter following AACC Approved Method 02-52.01.

Exactly 10 grams of flour sample was weighed accurately and transferred into a conical flask, or a 100 ml beaker.100 ml of distilled water was added to the flask followed by stirring to uniformize. These wet samples were allowed to settle for about 30 minutes then filtered. Exactly 10ml of the filtrate was titrated against 0.1 N sodium hydroxide (NaOH) solution until a permanent pink colour was observed. 2-3 drops of phenolphthalein indicator were used. The same filtrate was used for pH measurement and the procedure repeated for all the blends.

Equation 3.9.

$$Titratable\ acidity\ = \frac{N\ of\ NaOH * titre\ vol * 75}{Sample\ Volume}$$

where N is the normality of the NaOH used in titration, while 75 is a conversion factor.

3.7.3 Moisture content analysis

A representative sample of the composite flour was taken and weighed accurately, then placed in a dry moisture dish, and oven dried 105°C for 3 hours until its weight remains constant. The weight of the dried sample was recorded. The moisture content was then calculated as shown in Equation 4.0.

Equation 4.0.

$$Moisture\ content\ (\%) = \left[\frac{(initial\ weight\ -\ final\ weight)}{initial\ weight}\right] x100$$

3.8 Data Analysis

All data analysis was carried out using Minitab, version 21.2. For objective 1 and 2, analysis of variance (ANOVA) was carried out to determine the effect of adding pigeon peas and sorghum to millet on the functional properties of the millet-sorghum-pigeon peas composite flour. A nested design with two factors was used: pigeon peas and sorghum nested in pigeon peas. Mean separation was done using Tukey's Honestly Significant Difference (HSD) test. For objective 3, hedonic data was subjected to analysis of variance as recommended by Gámbaro and McSweeney (2020) and mean separation using Tukey's Honestly Significant Difference (HSD) test. A nested design was also employed. Data on willingness to buy any of the flour blends (preference ranking) was treated as nonparametric data and analysed using Kruskal-Wallis H Test to establish if the addition of pigeon peas and sorghum affected the willingness to buy the various flour blends. Means separation was done using Dunn’s test. The statistical model for objective 1, 2 and 3 was as shown in Equation 4.1:

Equation 4.1:

$$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \epsilon_{ijk}$$

where:

Y_{ijk} is the response variable for the k-th replicate within the j-th sorghum level nested within the i-th pigeon peas level

μ is the overall mean of the response variable across all treatment combinations

α_i is the effect of the i-th pigeon peas level (i = 1, 2, 3, 4, 5)

$\beta_{j(i)}$ is the effect of the j-th sorghum level nested within the i-th pigeon peas level

ϵ_{ijk} is the rand om error associated with the k-th replicate within the j-th sorghum level nested within the i-th pigeon peas level

Data for objective four was subjected to analysis of variance to determine the effect of storage (days), pigeon pea level and sorghum level on the pH, acidity and yeast and Mold counts in the millet-sorghum-pigeon peas composite flour. Mean separation was also conducted using the Tukey's Honestly Significant Differences (HSD) test. The data for yeast and Mold counts was log transformed (Log_{10}) before analysis. The design employed for objective 4 was a nested factorial design with the following factors: storage period (days), pigeon pea level, and sorghum level nested in pigeon pea levels. The statistical model for objective 4 was as shown in Equation 4.2:

Equation 4.2:

$$Y_{ijkl} = \mu + \tau_i + \alpha_j + \beta_{k(j)} + (\tau\alpha)_{ij} + \epsilon_{ijkl}$$

where:

Y_{ijkl} is the response variable for the l-th replicate within the k-th sorghum level nested within the j-th pigeon peas level for the i-th storage period

μ is the overall mean of the response variable across all treatment combinations

τ_i is the effect of the i-th storage period (i = 1, 2, ..., S)

α_j is the effect of the j-th pigeon peas level (j = 1, 2, 3, 4, 5)

$\beta_{k(j)}$ Effect of the k-th sorghum level nested within the j-th pigeon peas level

$\tau\,\alpha_{ij}$ is the interaction effect between the i-th storage period and the j-th pigeon peas level

ϵ_{ijkl} is the random error associated with the l-th replicate within the k-th sorghum level nested within the j-th pigeon peas level for the i-th storage period

The findings were reported in the form of means accompanied by their corresponding standard error of the mean. Bar graphs and line charts were used in graphical illustrations. All statistical tests were performed at significance level of P=0.05.

3.9 Ethical Consideration

Ethical review and approval were conducted by the Chuka University Institutional Ethics Review Committee (NACOSTI/NBC/AC-0812; Appendix 3) and permission to conduct research granted by the National Commission for Science, Technology and Innovation [(NACOSTI), License No: NACOSTI/P/24/32564, Appendix 4]. The research was carried out with informed consent of the respondents who voluntarily participated in the sensory evaluation of the study. Participants from the university were informed on the study objective, the contents of the samples being analysed, and that their contribution was going to be used for research purposes only. The participants were given the opportunity to decide whether to participate or not.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Determination of the Functional Properties of Composite Flours Containing Varying Levels of Sorghum, Millet and Pigeon Peas

The results showing the effect of adding sorghum and pigeon peas to a composite flour blend containing millet as the base ingredient on the functional properties are shown in Table 3 and Table 4a and b, respectively. Analysis of variance tables showing the coefficient of variation are shown in Appendix 5.

4.1.1 Foam capacity and foam stability

The addition of pigeon peas significantly increased foam capacity from a mean of 9.379% for 0% pigeon peas to 18.659% ($P < 0.05$) for 60% pigeon peas (Table 3). It also increased foam stability from 29.440±1.53 % to a mean percentage of 50.270±3.070 % (Table 3). However, sorghum addition did not affect foam capacity and stability (Table 4). Although the addition of sorghum did not affect foam stability, adding pigeon peas improved the foam stability with highest significant increase being recorded for samples containing 60% pigeon peas (50.270±3.070). Nonetheless, increasing pigeon peas beyond 30 percent did not record a statistically significant increase in foam stability.

Pigeon pea flour used in this study had a high protein content (18.885%) Table 7Table *7*: Protein content of sorghum, millet and pigeon peas flours. Thus, the addition of pigeon pea flour to millet and sorghum flour directly translates to more protein content. The high protein from pigeon peas is responsible for the high foam capacity and stability reported in samples containing pigeon peas. Proteins are known to improve the foaming capacity of products by lowering the surface tension of the liquid medium during whipping or vigorous shaking. These proteins also help keep air bubbles suspended and reduces the rate of coalescence. Foods that have foamed have better texture and appearance. For instance cakes have a very appealing mouthfeel and they have added eggs that are whipped into a foam. Breads, cakes, whipped creams, and sponges are examples of food systems that need to have high foaming capacity and stability. On the other hand, meals like crackers, biscuits, and cookies need low foaming capacities and stability (Arukwe et al., 2022). Proteins also help keep air bubbles suspended and reduces the rate of coalescence (Awuchi et al., 2019).

The findings are consistent with previous research on the functional properties of flour blends. For instance, Ohizua *et al.* (2017) while studying the nutrient composition, functional, and pasting properties of flour blends from unripe cooking banana, pigeon pea, and sweet potato reported that foam capacity dropped as the pigeon peas flour inclusion percentage dropped. The ability of flour to foam is measured by its foaming capacity, which is reliant on the availability of flexible protein molecules that lower water's surface tension during whipping (Atuna *et al*., 2023).

According to Awuchi et al. (2019), the possibility of flours with high foaming capacity producing large air bubbles surrounded by thinner, less flexible protein films resulted in the collapsing of these air bubbles and thus reducing foam stability. This may not always be the case as different protein function differently and thus, some proteins may foam heavily with smaller more stable bubbles as in the case of this study.

The above findings on various blends of sorghum, millet, and pigeon pea flour are also consistent with those of Olagunju et al. (2020), which showed how partial substitution of *acha* and pigeon pea flours for whole wheat affected the rheological characteristics of composite flours and bread quality (Olagunju *et al*., 2020). According to their study, adding pigeon peas increased the foam capacity, which is consistent with the considerable increase in foam capacity that was seen when samples containing 60% pigeon peas were used. Additionally, the addition of pigeon peas improves the foam stability, which is consistent with the higher bread quality ascribed to the protein-enriched composite flours (Olagunju *et al*., 2020).In this study, the foam capacity was directly proportional to foam stability ($P < 0.001$) (Table 5). Thus, samples with higher foam stability values had higher foam capacities. This was expected because the protein is responsible for both foaming properties and the foam stability.

Table 3: The effect of pigeon peas level on functional properties of the millet-sorghum-pigeon pea composite flour

	Pigeon Peas levels					
	0	15	30	45	60	P Value
Foam capacity (%)	9.379±0.800^{c}	10.398±0.398^{c}	13.133±0.370^{b}	15.150±0.444^{b}	18.659±0.826^{a}	<0.001
Foam stability (%)	29.440±1.530^{b}	42.040±2.000^{a}	47.420±1.590^{a}	47.352±0.969^{a}	50.270±3.070^{a}	<0.001
Swelling capacity (cm^3)	2.972±0.148^{d}	3.591±0.163^{c}	4.412±0.186^{b}	4.902±0.124ab	5.144±0.149^{a}	<0.001
Water absorption index (%)	159.180±2.900^{c}	168.490±5.230^{c}	197.310±3.900^{b}	205.250±2.970^{b}	225.200±2.120^{a}	<0.001
Water holding capacity (g/g)	1.729±0.425^{c}	2.026±0.054^{bc}	2.407±0.217^{ab}	2.486±0.034^{ab}	2.730±0.021^{a}	<0.001
Gelling temperature (^{0}C)	73.250±2.960^{d}	75.400±0.994^{c}	77.317±0.381^{b}	79.385±0.418^{a}	77.183±0.865^{b}	<0.001
Solubility (%)	4.977±0.200^{c}	6.060±0.287^{bc}	6.130±1.110^{bc}	7.785±0.386^{ab}	9.002±0.511^{a}	<0.001
Tapped density (g/cm^3)	0.793±0.007^{c}	0.809±0.007^{bc}	0.810±0.007^{bc}	0.821±0.014^{b}	0.847±0.010^{a}	<0.001
Bulk density (g/cm^3)	0.498±0.012^{a}	0.492±0.011^{a}	0.490±0.008^{a}	0.490±0.014^{a}	0.501±0.014^{a}	0.845

Values indicate mean ± standard error. Means along the row having different superscripts are significantly different ($P < 0.05$).

Table 4a: The effect of sorghum addition on functional properties of composite flour blends containing millet, sorghum and pigeon peas

Pigeon pea level	Sorghum Level	Swelling Capacity	Water Absorption Index	Water Holding Capacity	Gelling Temperature	Solubility
0	0	2.656 ± 0.156^{e}	152.130 ± 3.460^{a}	0.950 ± 0.078^{c}	64.3 ± 0.0^{g}	5.503 ± 0.404^{a}
	20	3.382 ± 0.147^{de}	167.140 ± 0.290^{a}	1.172 ± 0.018^{bc}	80.1 ± 0.1^{ab}	4.669 ± 0.112^{a}
	40	2.877 ± 0.064^{e}	158.280 ± 0.000^{a}	3.065 ± 0.00^{a}	75.4±0.2e	4.758 ± 0.076^{a}
15	0	3.327 ± 0.202^{de}	163.150 ± 4.180^{a}	1.990 ± 0.001^{abc}	72.4±0.3f	6.250 ± 0.159^{a}
	17	4.063 ± 0.000^{cd}	171.200 ± 15.100^{a}	2.008 ± 0.185^{abc}	77.6 ± 0.5^{cd}	6.535 ± 0.351^{a}
	34	3.382 ± 0.147^{de}	171.100 ± 11.000^{a}	2.080 ± 0.066^{abc}	76.2 ± 0.1^{de}	5.395 ± 0.618^{a}
30	0	4.118 ± 0.000^{cd}	199.7000 ± 3.610^{a}	2.318 ± 0.094^{ab}	78.1 ± 0.9^{bcd}	8.399 ± 0.321^{a}
	14	4.853 ± 0.441^{abc}	203.380 ± 9.730^{a}	2.641 ± 0.782^{a}	77.0 ± 0.8^{de}	4.000 ± 2.940^{a}
	28	4.265 ± 0.147^{bc}	188.830 ± 2.490^{a}	2.263 ± 0.021^{ab}	76.9 ± 0.0^{de}	5.977 ± 0.035^{a}
45	0	5.000 ± 0.000^{abc}	209.920 ± 0.657^{a}	2.546 ± 0.009^{a}	80.4 ± 0.4^{a}	8.035 ± 0.292^{a}
	11	4.853 ± 0.441^{abc}	201.600 ± 8.310^{a}	2.450 ± 0.096^{a}	78.3 ± 0.2^{abcd}	8.460 ± 0.462^{a}
	22	4.853 ± 0.147^{abc}	204.230 ± 5.190^{a}	2.461 ± 0.054^{a}	79.5 ± 0.45^{abc}	6.859 ± 0.751^{a}
60	0	5.441 ± 0.147^{a}	226.260 ± 1.170^{a}	2.748 ± 0.033^{a}	75.2 ± 0.100^{e}	10.280 ± 0.800^{a}
	8	5.294 ± 0.000^{ab}	222.880 ± 0.005^{a}	2.699 ± 0.002^{a}	76.6 ± 0.1^{de}	9.007 ± 0.072^{a}
	16	4.697 ± 0.009^{abc}	226.470 ± 7.620^{a}	2.744 ± 0.064^{a}	79.8 ± 0.2^{ab}	7.721 ± 0.067^{a}
	P Value	0.019	0.689	0.001	<0.001	0.093

Values indicate mean ± standard error. Means along the column having different superscripts are significantly ($P < 0.05$) different.

Table 4b: The effect of sorghum addition on functional properties of composite flour blends containing millet, sorghum and pigeon peas

Pigeon	Sorghum	Bulk Density	Tapped Density	Foam Capacity (%)	Foam Stability (%)
0	0	$0.501±0.001^{a}$	$0.775±0.006^{d}$	$7.666±0.714^{a}$	$27.610±2.920^{a}$
	20	$0.479±0.007^{a}$	$0.813±0.007^{bcd}$	$9.810±2.000^{a}$	$29.810±2.190^{a}$
	40	$0.514±0.038^{a}$	$0.791±0.003^{cd}$	$10.664±0.571^{a}$	$30.900±4.020^{a}$
15	0	$0.525±0.004^{a}$	$0.813±0.007^{bcd}$	$9.405±0.406^{a}$	$40.220±5.270^{a}$
	17	$0.468±0.013^{a}$	$0.791±0.003^{cd}$	$10.624±0.541^{a}$	$42.860±4.390^{a}$
	34	$0.483±0.002^{a}$	$0.823±0.01^{abcd}$	$11.165±0.541^{a}$	$43.040±2.810^{a}$
30	0	$0.488±0.007^{a}$	$0.794±0.000^{cd}$	$13.847±0.268^{a}$	$48.870±2.850^{a}$
	14	$0.476±0.000^{a}$	$0.813±0.013^{bcd}$	$12.375±0.669^{a}$	$45.340±3.390^{a}$
	28	$0.507±0.019^{a}$	$0.823±0.01^{abcd}$	$13.178±0.669^{a}$	$48.050±3.390^{a}$
45	0	$0.481±0.009^{a}$	$0.807±0.013^{cd}$	$14.224±0.604^{a}$	$46.830±2.830^{a}$
	11	$0.459±0.004^{a}$	$0.794±0.013^{cd}$	$15.19±0.846^{a}$	$46.830±1.420^{a}$
	22	$0.531±0.007^{a}$	$0.862±0.000^{ab}$	$16.036±0.483^{a}$	$48.390±1.560^{a}$
60	0	$0.499±0.022^{a}$	$0.83±0.003^{abcd}$	$16.598±0.923^{a}$	$46.290±6.720^{a}$
	8	$0.469±0.017^{a}$	$0.84±0.007^{abc}$	$19.090±1.200^{a}$	$51.510±5.970^{a}$
	16	$0.535±0.009^{a}$	$0.870±0.0230^{a}$	$20.289±0.923^{a}$	$53.010±5.970^{a}$
	P Value	0.11	0.002	0.08	0.979

Values indicate mean ± standard error. Means along the column having different superscripts are significantly ($P < 0.05$) different

Table 5: Linear correlation coefficients between the functional properties of composite flour blends containing millet, sorghum and pigeon peas flour

	Foam Capacity	Foam Stability	Swelling Capacity	Water Absorption Index	Water Holding Capacity	Gelling Temperature	Solubility	Bulk Density	Least Gelling concentration
Foam Capacity	1.000 (0.000)								
Foam Stability	0.699 (0.000)	1.000 (0.000)							
Swelling Capacity	0.398 (0.029)	0.516 (0.004)	1.000 (0.000)						
Water Absorption Index	0.561 (0.001)	0.647 (0.000)	0.917 (0.000)	1.000 (0.000)					
Water Holding Capacity	0.287 (0.124)	0.289 (0.121)	0.652 (0.000)	0.656 (0.000)	1.000 (0.000)				
Gelling Temperature	0.134 (0.480)	0.235 (0.212)	0.534 (0.002)	0.485 (0.007)	0.319 (0.085)	1.000 (0.000)			
Solubility	0.561 (0.001)	0.586 (0.001)	0.534 (0.002)	0.544 (0.002)	0.491 (0.006)	0.195 (0.301)	1.000 (0.000)		
Bulk density	-0.068 (0.723)	0.124 (0.513)	-0.203 (0.283)	-0.137 (0.472)	0.070 (0.715)	-0.135 (0.478)	-0.054 (0.775)	1.000 (0.000)	
Least gelling concentration	0.075 (0.693)	0.262 (0.162)	-0.415 (0.022)	-0.216 (0.251)	-0.191 (0.313)	-0.167 (0.379)	-0.057 (0.763)	0.394 (0.031)	1.000 (0.000)

Data presented as correlation coefficients with the P Value for each coefficient presented in brackets.

4.1.2 Swelling capacity

The addition of pigeon peas flour significantly (P < 0.019) increased swelling capacity of flour blends from a mean of 2.972± 0.148 for 0% pigeon pea to 5.144± 0.149 for 60% peas (Table 3). The significant increase in the swelling capacity of the flour blends with the addition of pigeon pea flour suggests that pigeon pea has properties that promote water absorption and expansion during hydration. This is due to the higher content of dietary fibers, starch, and proteins in pigeon pea, which are known to enhance the water-binding capacity of flours. Similarly, swelling capacity significantly (P < 0.001) increased with increase in sorghum level from a mean of 2.656 for 0% sorghum to 3.382 in samples containing 40% sorghum. Similarly to the case for pigeon peas, sorghum added to the level of fiber and starch in the flour blends which enhanced water absorption and the swelling of the flours.

According to Ronie and Hasmadi (2022), the endogenous protein and lipid in flour can interact with amylose to form amylose-protein and amylose-lipid complexes. These interactions can influence swelling properties, the water solubility index, gelatinization temperature, and the rate of retrogradation can be attributed to the interactions between millet, sorghum, and pigeon pea components which could have influenced the overall swelling capacity. The significant increase in swelling capacity with the addition of pigeon peas, particularly at 60%, could be attributed to the high protein content of pigeon peas. Proteins can enhance water absorption and retention, thus increasing swelling capacity.

These results are similar to another study by Okin et al. (2021), who also observed an increased swelling capacity with increase in the amount of pigeon peas in sorghum; pigeon pea cookies. In another study by Arukwe et al. (2022) similar results were obtained. It is therefore indicative of the ability of protein addition to improve the swelling capacity of the product. Swelling capacity quantifies the capability of starch to absorb water and swell (Atuna *et al.*, 2023).

4.1.3 Water absorption index

However, pigeon pea addition significantly increased it from159.180 to 225.200± 2.120. The sample containing 60% pigeon peas recorded the highest water absorption index of 225.200. The significant increase in the water absorption index (WAI) with the addition of pigeon pea flour, particularly reaching the highest value of 225.200 for the 60% pigeon pea blend, suggests that pigeon pea has a strong capacity to retain water. This is due to its high content of hydrophilic compounds such as proteins, starches, and dietary fibers, which can bind water more effectively. As more pigeon pea was added, these components increased, leading to a greater water absorption index. Additionally, pigeon pea's structural composition, including its starch granules and fiber network, can facilitate better water retention compared to the other components in the blend. Addition of sorghum did not affect water absorption.

Okin *et al.* (2021), also observed an increased WAI with increase in the amount of pigeon peas in sorghum; pigeon pea cookies. The ability to absorb water indicates the degree of granular integrity and the number of accessible molecular surfaces for the binding of water molecules. Therefore, the observation regarding the water absorption index can be associated to the blends' protein and carbohydrate concentration (Adeola et al., 2017). Adeola *et al.* (2017), reported similar results to those obtained in this study on sorghum where water absorption and swelling capacity did not vary significantly with addition of different ratios of other ingredients. According to Atuna *et al.* (2023) WAI is a useful metric for determining how much water starchy materials can absorb at a specific temperature.

4.1.4 Water holding capacity

Water holding capacity was significantly (P <0.001) influenced by addition of sorghum and pigeon peas. 100% Millet flour blend had a water holding capacity of 0.950± 0.078, which increased to significantly higher values as blending continued such that a blend with 40% sorghum and 60% pigeon peas had 2.744± 0.064. Similarly, addition of pigeon peas significantly (P < 0.001) increased the water holding capacity from 1.729± 0.425 to 2.730±0.021. Particle size, protein content and quality, moisture content, and amount of starch degradation are some of the physical and chemical elements that affect the water absorption of flour (Pang et al., 2021; Sharma et al., 2020). The increase in WHC can therefore be attributed to the higher content of proteins, and possible starch damage which may have occurred during milling. This may also suggest the possibility of more starch degradation occurring in pigeon pea and sorghum during milling as compared to millet.

This result is similar to that obtained by Shanthakumar et al. (2022). In their study, they reported an increase in water holding capacity with addition of peas. Increase in protein content results in an increase in water absorption index which may also affect the water holding capacity. Pigeon peas are rich in proteins, which have high water absorption capacities. The hydrophilic nature of these components allowed them to attract and retain water molecules more effectively and hence the slight increase in water holding capacity.

4.1.5 Water solubility

Solubility reduced with increase in sorghum levels with lowest solubility being reported for sample containing 40% sorghum, even though these changes were not significant. The addition of pigeon peas had a significant ($P < 0.001$) increase in solubility from 4.977±0.200 to 9.002±0.511 in sample blends with 60 percent pigeon peas. This increase can be explained by the higher levels of soluble proteins and fibers in pigeon peas, which promote water interaction and dissolution. Additionally, starch damage could have occurred in pigeon peas during milling, further increasing the ability of starch to absorb more water and dissolve in solution. The insignificant decrease in solubility with increase in sorghum levels can be attributed to the high concentrations of tannins and other polyphenolic chemicals found in sorghum which have been shown to decrease protein solubility through protein complex formation (Ishaq *et al*., 2024).

In another study by Batariuc et al. (2021), it was determined that the solubility of sorghum flour reduced with heat processing. This adds to the factors that cause a reduction in solubility of sorghum flour (Batariuc et al., 2021). Compared to the proteins in other grains, such as millet, these proteins in sorghum are by nature less soluble (Ishaq *et al*., 2024). As a result, the blend's overall solubility drops as the amount of sorghum in the mixture increases. As legumes, pigeon peas are high in proteins, which are often more soluble than those found in cereal grains. The protein profile of pigeon peas, which includes albumins and globulins known for their high water solubility, can be linked to the high solubility found with higher pigeon pea concentration (Ishaq *et al*., 2024).

4.1.6 Bulk and tapped density

Sorghum levels as well as pigeon pea levels did not significantly affect bulk density of the flour blends. Sorghum levels (P=0.002) had a significant effect on tapped density of the flour blends, whereby, tapped density increased from 0.775±0.006 in a 100% millet flour sample, to 0.870±0.023 in a 40% sorghum 60% pigeon pea flour. Samples containing highest amount of pigeon peas (60%) also had the highest significant ($P < 0.001$) tapped density of 0.847±0.010 compared to 0% pigeon pea blends with 0.739±0.007. The outcomes regarding bulk and tapped density can be explained by the differing structural properties of sorghum and pigeon pea. Sorghum levels did not significantly affect bulk density likely because its particles have similar packing behaviour to millet. However, sorghum significantly increased tapped density, indicating that it promotes tighter particle packing when subjected to tapping or compaction. This could be due to sorghum's slightly denser or more compressible particle structure compared to millet. The increase in tapped density with higher pigeon pea levels can be attributed to the higher protein and fiber content of pigeon pea, which increases the blend's ability to compact under tapping pressure, leading to the highest tapped density in the 60% pigeon pea blend. This means that flour samples containing both pigeon peas and sorghum occupy larger spaces upon compaction, possibly due to the nature of particles obtained during milling. This suggests that pigeon pea and sorghum flours are porous and not dense. They would therefore require larger storage and processing containers.

This outcome is contrary to the results from another study by Abolaji et al. (2019), who studied the functional properties of composite blend containing sorghum, soybean and African yam bean, and reported a significantly higher bulk density in 100% sorghum sample compared to the different blended formulations. Differences in ingredients, blending ratios, and density measurement methods likely explain the contrasting results. According to Hasmadi et al. (2020), low bulk density would be beneficial when creating weaning meals. Bulk density (BD) results are used to assess the handling requirements, flour heaviness, and kind of packaging materials appropriate for food storage and transit.

4.1.7 Gelling temperature

The addition of both sorghum and pigeon peas significantly ($P < 0.001$) affected the gelling temperature of flour blends. Gelling temperatures gradually increased with addition of pigeon peas with the highest significant ($P < 0.001$) temperatures being reported for samples containing 45% pigeon peas with a gelling temperature of 79.385±0.418. Further increase in pigeon peas significantly reduced the gelling temperatures 77.183±0.865. Sorghum was observed to significantly ($P < 0.001$) influence gelling temperature, even though, there was no distinct trend of an increase or a decrease.

The changes in gelling temperatures with the addition of sorghum and pigeon peas can be explained by the composition and interaction of starch and protein in the flour blends. Pigeon pea contains higher levels of protein and fiber compared to millet and sorghum, which can interfere with the starch gelatinization process, leading to an initial increase in gelling temperature. The highest gelling temperature (79.385°C) was observed at 45% pigeon pea, likely due to an optimal balance between starch and protein content that increased the thermal energy required for gelatinization. However, further increases in pigeon pea content (above 45%) likely introduced excess protein or fiber, which could disrupt the starch network, reducing the gelling temperature to 77.183°C. This reduction might be due to pigeon pea's proteins absorbing more water or interacting with starch in a way that lowers the thermal stability of the gel.

In the case of sorghum, it significantly influenced gelling temperature without a clear trend, which can be due to its complex starch structure and varying amylose-to-amylopectin ratio. Sorghum starches tend to have more resistant or slowly digestible properties, which can cause irregular changes in gelling temperature. The absence of a distinct pattern might indicate that sorghum’s impact on gelatinization is more dependent on its interaction with other flour components, such as millet or pigeon pea, rather than its concentration alone.

These results implies that the addition of pigeon peas affects the composite blend's gelation behaviour. The rise in gelling temperature suggests that when the amount of pigeon pea increases, a greater temperature is needed for gel formation. This gelatinization temperature varies based on many factors such as the type of plant where the starch came from, water content, pH, salt concentration, sugar, protein, and fat in the flour samples, among others. Unmodified native starches can begin to swell at temperatures ranging from 55°C to 85°C (Awuchi et al., 2019). By modifying the network structure and stability, modifications in polysaccharide hydration and protein conformation can impact the gelation temperature (Yang *et al*., 2021). Understanding how the inclusion of pigeon peas affects gelling temperature can help in optimizing processing parameters and product quality, in order to achieve desired textural qualities and gelation outcomes by adjusting processing variables, such as heating and cooling speeds (Yang *et al*., 2021). Furthermore, ingredient selection and formulation techniques for the development of gel-based goods with customized features and functions can be informed by knowledge of changes in gelling temperature.

Gelatinization temperature is the temperature at which starch undergoes gelatinization (Awuchi et al., 2019). Similar findings were reported by Kusumaningtyas et al. (2024) who reported gelatinization temperatures averaging between 79.85 to 83.25 while studying the physicochemical characteristics of flour blends based on modified cassava flour and pigeon pea (*Cajanus cajan*) flour as ingredient of analog rice.

4.1.8 Least gelling concentration

The addition of sorghum to the blend displayed reducing effect in the least concentration to achieve gelling ranging from 0.85 in 0% sorghum blends to 0.5 g/5ml in blends with sorghum except for the sample containing 60% pigeon peas and 16% sorghum with 1.1grams/5ml (Figure 1)*Figure 3*. This is a clear indication that sorghum starch has good gelling properties and hence the lower amounts of flour needed to make a solid gel. The deviation noted in the samples containing 60% pigeon peas and 16% sorghum requires further investigation. When it comes to incorporation of pigeon peas to the blends, there was a significant ($P < 0.05$) reduction in the least gelling concentration from 0.77g/5ml in 0% pigeon peas to 0.60 g/5ml in 45% pigeon peas and 0.75g/5ml (Figure 4).

The results suggest that sorghum's starch contributes significantly to the gelling properties of the flour blends, as seen by the reduction in the least gelling concentration (LGC) with increasing sorghum levels. Sorghum's starch likely has a higher amylose content, which is known for enhancing gel formation at lower concentrations. As a result, blends with sorghum required less flour to achieve gelling, except for the blend containing 60% pigeon peas and 16% sorghum, where a higher LGC of 1.1 g/5ml was observed. This outlier may indicate that high levels of pigeon pea protein and fiber could interfere with the starch's gelling ability, possibly by competing for water or disrupting starch-protein interactions. The exact cause of this deviation requires further investigation, as it could involve specific interactions between sorghum and pigeon pea components.

On the other hand, the incorporation of pigeon peas generally led to a reduction in LGC up to 45% pigeon pea, followed by an increase at higher concentrations. This trend suggests that while pigeon pea initially enhances gelling, likely due to its proteins supporting the gel structure, excessively high amounts may interfere with starch's ability to form a gel, resulting in higher LGC values. The increased fiber and protein content in high-pigeon-pea blends could hinder the uniform hydration of starch, thus requiring more flour to form a gel at concentrations beyond 45% pigeon pea.

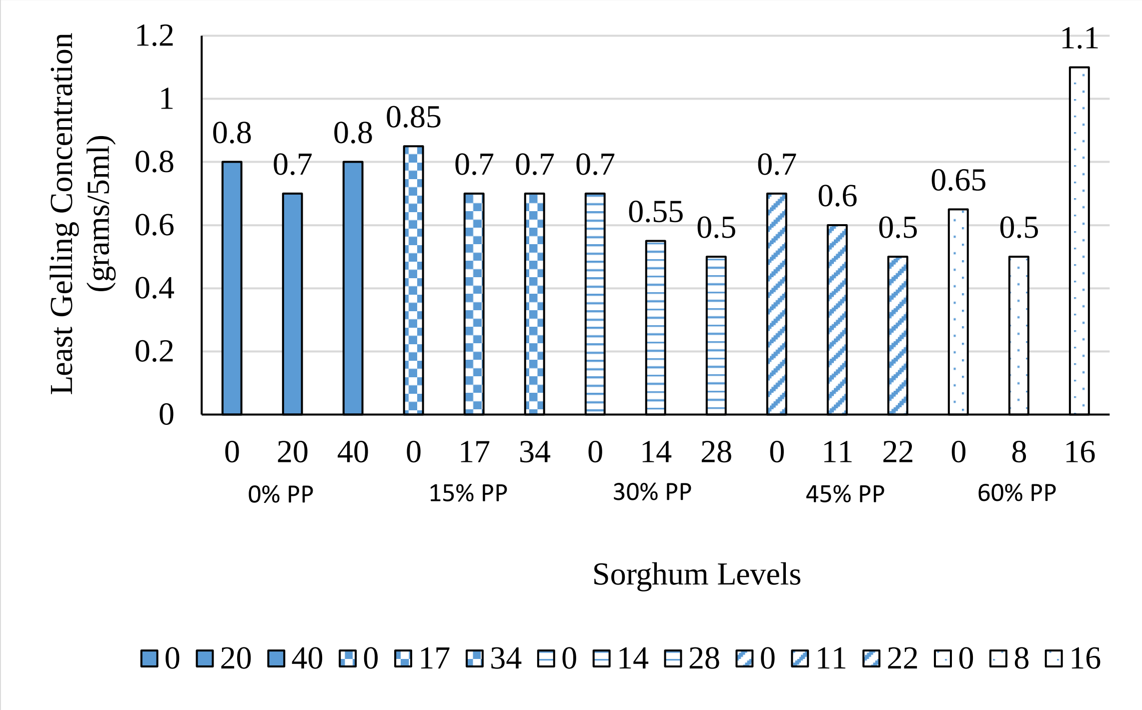

Figure 3: A plot of the mean least gelling concentration of the flour blends at various sorghum addition levels

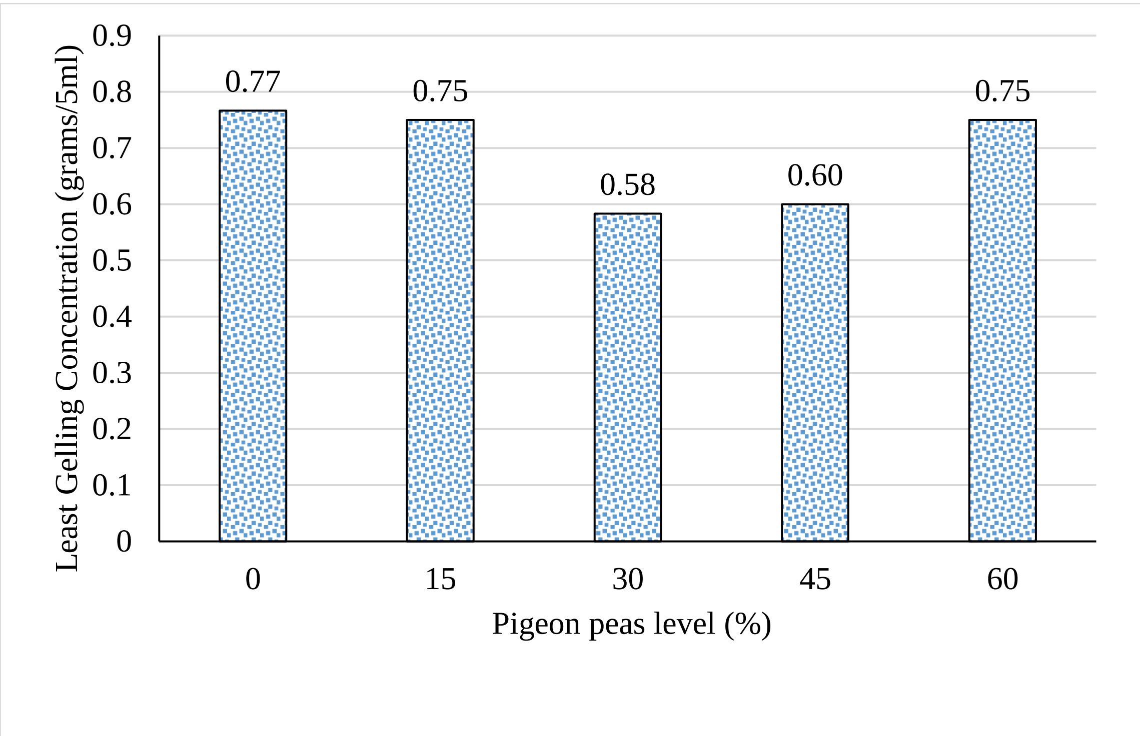

Figure 4: A plot of the mean least gelling concentration of the flour blends at various pigeon pea addition levels

The least amount of flour required to make a gel in a given volume of water is measured by least gelation concentration Hasmadi *et al.* (2020). The proportional ratios of their structural constituents, such as protein, carbohydrates, and fats, vary from flour to flour. As the percentage of pigeon pea flour included increased, least gelling concentration reduced gradually Hasmadi *et al.* (2020). As the concentration of protein increases, the binding forces interact more effectively, improving the flour's gelling ability.

The process of gelatinization involves the breakdown of starch molecules' intermolecular connections in the presence of heat and water, which increases the amount of water that can be absorbed by the hydrogen bonding sites (hydroxyl hydrogen and oxygen) (Modipuram, 2013). As a result, the starch granules dissolve completely in the water. Water has the property of plasticizing. When heated in a liquid such as water, starch granules absorb the liquid, swell, and burst, increasing the viscosity (stickiness) of the starch, (Modipuram, 2013).

4.2 Protein Quality of Composite Flours Containing Varying Levels of Pigeon Peas, Sorghum and Millet.

The results of protein content and protein digestibility of composite flours containing varying levels of sorghum, millet and pigeon peas are shown in Table 6 and Table 8.

Table 6: The effect of adding pigeon peas on protein content and protein digestibility of millet-sorghum-pigeon peas composite flour

		Protein Digestibility%	Protein content
Pigeon peas levels	0	34.950 ± 3.81^{c}	11.845 ± 0.0298^{e}
	15	38.207 ± 0.945^{bc}	12.888 ± 0.0243^{d}
	30	39.989 ± 0.819^{abc}	13.93 ± 0.0212^{c}
	45	45.25 ± 1.01^{ab}	14.973 ± 0.0213^{b}
	60	46.34 ± 1.73^{a}	16.016 ± 0.0245^{a}
P-Values		<0.001	<0.001

Values indicate mean ± standard error. Means down the same column having similar superscript are not significantly different ($P \leq 0.05$).

Table 7: Protein content of sorghum, millet and pigeon peas flours

Flour	Protein content (%)
Millet	11.75
Sorghum	12.225
Pigeon peas	18.885

Addition of pigeon peas significantly (P < 0.001) increased the protein content and digestibility of the different blends. Pigeon peas had an average of 18.887% protein content (Table 7), which explains the increasing pattern in protein content of the blends. As additional peas are added, the digestibility significantly increased. The highest percentage of digestibility was recorded for 60% peas blends with a mean of 46.34%, and the lowest for 0% peas (34.95%).

Table 8: The effect of adding sorghum on protein content and protein digestibility of millet-sorghum-pigeon peas composite flour

Pigeon pea level	Sorghum level	Blend Label	Protein content (%)	Protein Digestibility (%)
0	0	s0p0	11.75±0.00g	27.459±1.65a
	20	s20p0	11.845±0.018fg	33.383±0.834a
	40	S40p0	11.94±0.036f	44.007±10a
15	0	S0p15	12.807±0.013e	37.849±1.91a
	17	S20p15	12.888±0.007de	36.799±0.637a
	34	S40p15	12.968±0.021d	39.972±2.01a
30	0	S0p30	13.864±0.025c	40.737±0.786a
	14	S20p30	13.929±0.014c	41.897±0.111a
	28	S40p30	13.997±0.013c	37.333±1.34a
45	0	S0p45	14.922±0.038b	47.353±2.75a
	11	S20p45	14.973±0.029b	45.017±0.167a
	22	S40p45	15.025±0.022b	43.381±0.847a
60	0	S0p60	15.979±0.05a	50.215±3.99a
	8	S20p60	16.015±0.043a	45.283±1.99a
	16	S40p60	16.053±0.038a	43.51±1.97a
P-Values			<0.001	0.078

Values indicate mean ± standard error. Means down the same column having different superscript are significantly different (P < 0.05).

Sorghum addition had no significant effect on the protein digestibility of the different blends (Table 8). However, addition of sorghum significantly P < 0.001) improved the protein content of the flour blends with the highest influence being found in the samples containing 40% sorghum. The lowest protein content (average of 11.75 % protein) (Table 7) and digestibility was observed in pure millet sample. Although the protein content of sorghum was lower than that of pigeon peas, it was higher than that of millet (Table 7) which explains the increase in protein content with addition of sorghum at 40% level. The lack of influence on the digestibility of the protein is possibly due to the low quantities added in the flour blends as compared to the levels of millet and peas.

This pattern indicates that increasing the percentage of peas in the composite blend significantly ($p < 0.001$) improved the mixture's total protein digestibility. When compared to certain other grains or legumes, peas are considered to contain a comparatively higher quality of protein and to be more digestible (Bessada *et al.,* 2019). Consequently, it is possible that adding more peas to the blend is a factor in the blend's better digestion. Additionally, having precooked the peas, improved the digestibility of protein in the pigeon peas as it potentially reduced antinutrients factor concentrations (tannins and phytic acid) (Yu et al., 2020).

Digestibility as a protein quality test can be used to estimate or predict protein bioavailability when the food is consumed. In essence, it's a measurement of a protein's susceptibility to proteolysis. Since a high-digestibility protein would deliver more amino acids for absorption via proteolysis, it has a higher nutritional value than a low-digestibility protein. Increased protein digestibility would give the customer much-needed protein in mixed diets with marginal or low protein levels and high sorghum percentages. Enhancing the availability of nutrients in sorghum is essential for ensuring food security.

There are wide variations in the digestibility of proteins across different foods. These variations are caused by factors such as the type of protein, the food matrix, the molecular interactions between proteins and other food components (food formulation), processing and storage conditions, and other factors (Orlien *et al*., 2023). Various methods have been utilized to evaluate in vitro protein digestibility (IVPD), with variations in the enzyme assay and quantification technique employed (Orlien *et al*., 2023).

This outcome is consistent with those obtained by Krause *et al.* (2022), who studied in vitro digestion of protein and starch in sponge cakes formulated with peas. In their work peas sponge cakes had more protein bio accessible to the digestive enzyme compared to wheat and pure starch sponge cakes (Krause *et al*., 2022).

4.3 Sensory Quality of Porridge Prepared From Composite Flours Containing Varying Levels of Sorghum, Millet and Pigeon Peas

A five-point hedonic scale was used to rate the different composite blends' sensory qualities based on six criteria: colour, flavour, taste, texture, viscosity and overall acceptability (Table 9a and b, and Table 10). The blends were also assessed in terms of willingness to buy. The different blends were prepared into porridge and subjected to 5-point hedonic scale testing for the different attributes, to assess people's perception of the different blends.

Table 9a: The effect of sorghum level on the sensory properties of the sorghum, millet and pigeon peas blends

Pigeon pea level	Sorghum Level	Blends label	Colour	taste	Flavour
0	0	s0p0	2.897±0.193[fg]	3.207±0.179[de]	3.414±0.169[bc]
	20	s20p0	3.983±0.129[abcd]	4.034±0.152[abc]	4.017±0.124[ab]
	40	s40p0	4.517±0.105[ab]	4.345±0.142[a]	4.293±0.154[a]
15	0	s0p15	2.879±0.183[g]	3.155±0.174[de]	3.345±0.157[bc]
	17	s20p15	3.879±0.137[bcd]	3.224±0.163[de]	3.121±0.154[c]
	34	s40p15	4.552±0.089[a]	4.328±0.111[a]	4.017±0.124[ab]
30	0	s0p30	3.121±0.156[fg]	3.276±0.147[de]	3.293±0.159[bc]
	14	s20p30	3.828±0.116[cde]	4.155±0.122[ab]	3.914±0.131[ab]
	28	s40p30	4.414±0.092[abc]	3.759±0.144[abcde]	3.793±0.139[abc]
45	0	s0p45	3.207±0.151[efg]	3.293±0.170[cde]	3.466±0.164[bc]
	11	s20p45	3.931±0.104[abcd]	3.448±0.150[bcde]	3.362±0.145[bc]
	22	s40p45	3.983±0.122[abcd]	3.379±0.175[cde]	3.500±0.164[bc]
60	0	s0p60	3.379±0.167[defg]	3.897±0.172[abcd]	3.672±0.178[abc]
	8	s20p60	3.534±0.126[def]	3.224±0.159[de]	3.086±0.171[c]
	16	s40p60	4.224±0.121[abc]	3.138±0.160[e]	3.138±0.166[c]
		P-value	<0.001	<0.001	<0.001

Values presented indicate mean ± standard error. Means along the column having different superscript are significantly different (P < 0.05).

Table 9b: The effect of sorghum on the sensory properties of the sorghum, millet and pigeon peas flour blends

Pigeon pea Level	Sorghum level	Blends label	Viscosity	texture	Acceptability
0	0	s0p0	3.707±0.179[a]	3.793±0.161[a]	3.086±0.183[c]
	20	s20p0	4.086±0.166[a]	4.017±0.158[a]	3.741±0.153[abc]
	40	s40p0	4.207±0.143[a]	4.293±0.132[a]	4.241±0.114[a]
15	0	s0p15	3.879±0.141[a]	3.759±0.142[a]	3.172±0.171[c]
	17	s20p15	3.983±0.147[a]	4.690±0.718[a]	3.241±0.152[c]
	34	s40p15	4.293±0.125[a]	4.328±0.124[a]	3.983±0.131[ab]
30	0	s0p30	3.672±0.129[a]	3.810±0.114[a]	3.362±0.161[bc]
	14	s20p30	3.810±0.133[a]	3.828±0.139[a]	3.672±0.140[abc]
	28	s40p30	3.879±0.133[a]	3.914±0.126[a]	3.500±0.160[bc]
45	0	s0p45	3.483±0.146a	3.603±0.145[a]	3.310±0.154[bc]
	11	s20p45	3.448±0.140[a]	3.569±0.135[a]	3.448±0.137[bc]
	22	s40p45	3.034±0.169[a]	3.224±0.165[a]	3.034±0.152[c]
60	0	s0p60	3.379±0.151[a]	3.793±0.139[a]	3.655±0.166[abc]
	8	s20p60	3.138±0.164[a]	3.155±0.149[a]	3.190±0.173[c]
	16	s40p60	3.293±0.167[a]	3.310±0.162[a]	3.172±0.152[c]
		P-Value	0.055	0.088	<0.001

Values presented indicate mean ± standard error. Means along the column having different superscript are significantly different (P < 0.05).

Table 10: The effect of pigeon peas on sensory properties of the sorghum, millet and pigeon peas composite blends

	Pigeon peas levels					P-Value
	0	15	30	45	60	
Colour	3.799±0.099[a]	3.770±0.097[a]	3.787±0.082[a]	3.707±0.078[a]	3.713±0.085[a]	0.881
Taste	3.862±0.098[a]	3.569±0.096[ab]	3.730±0.084[ab]	3.374±0.095[b]	3.420±0.098[b]	<0.001
Flavour	3.908±0.091[a]	3.494±0.088[bc]	3.667±0.085[ab]	3.443±0.091[bc]	3.299±0.101[c]	<0.001
Viscosity	4.000±0.095[a]	4.052±0.080[a]	3.787±0.076[a]	3.322±0.089[b]	3.270±0.093[b]	<0.001
Texture	4.035±0.088[a]	4.259±0.248[a]	3.851±0.073[ab]	3.466±0.087[b]	3.420±0.089[b]	<0.001
Acceptability	3.690±0.095[a]	3.466±0.092[ab]	3.512±0.089[ab]	3.264±0.086[b]	3.339±0.096[ab]	0.009

Values presented indicate mean ± standard error. Means along the row having different superscripts are significantly different (P < 0.05).

4.3.1 Individual composite blend evaluation

According to the results presented in Table 9b, 40% sorghum with no pigeon peas (s40P0) and 40% sorghum and 15% pigeon peas (s40p15), performed best in all the different attributes ratings. These two blends, however, were not significantly different from 20% sorghum and 15% pigeon peas (s20p15), ($P < 0.05$). Analysis showed that sorghum addition significantly increased the hedonic rating for colour, taste, flavour, and general acceptability, with 40% sorghum blend scoring the highest for all attributes. Pigeon peas significantly affected taste, flavour, viscosity, texture, general acceptability, and the willingness to buy the different flour blends.

The improvement in hedonic ratings with sorghum addition can be attributed to sorghum's unique flavour profile and natural colour, which enhanced the appeal of the products. Sorghum's slightly sweet and flavour complemented other ingredients, resulting in a more favourable taste and flavour perception. Additionally, the presence of natural pigments in sorghum contributed to the higher colour ratings, further enhancing the product's visual appeal. In contrast, while pigeon peas contributed valuable nutrients, their strong, beany flavour influenced consumer preferences, as this legume had a pronounced taste that could not be universally preferred. The impact of pigeon peas on texture and viscosity was also notable, likely due to the starch and fiber content, which contributed to the less viscous consistency of the blends with increase in pigeon pea level. This change in viscosity could have influenced both the mouthfeel and thus the reduction in overall acceptability of the product.

Interestingly, despite the influence of pigeon peas on taste and texture, the blends still received positive ratings for general acceptability, suggesting that consumers were willing to tolerate some textural differences in favour of the nutritional benefits offered by pigeon peas. This was further evidenced by the significant effect of pigeon peas on willingness to buy, indicating that the health-conscious consumer base valued the blends' nutritional composition, even if the sensory attributes were slightly altered.

None of the blends was disliked rather most analysts had a neutral rating of ‘neither like nor dislike’. This gives the indication that these blended flours have a potential of getting accepted in the market with further refining based on the above findings. Different quantities of both pigeon and sorghum affected the performance of the resulting porridge in sensory. This however can be improved by reconstituting a blend that optimizes the good contribution of pigeon peas and the good attributes of sorghum. Similarly, the amount of pigeon peas flour added, having impacted the sensory attributes negatively, could be optimized to a lower quantity in order to tone down the obvious bean flavour and texture.

According to Anaemene Doris et al. (2023), pigeon peas flour inclusion gradually reduced the sensory score of the complementary diets. In the study, the sensory scores were lower than those of commercial complementary foods available. This outcome rhymes with the ones obtained in this study (Anaemene Doris et al., 2023). This outcome was similar to the one reported by Ige (2017), who studied the Physicochemical, pasting and sensory characteristics of complementary foods formulated from plantain, pigeon pea and maize flours.

4.3.2 General appearance of the porridge (Colour)

There was a significant variation in the colour of the porridge prepared from the different blends. S40p15 had the most preferred colour with a mean rating of 4.552. This blend was, however, not significantly ($P < 0.05$) different at, level of significance from s40p0, s40p30, s40p45, s40p60, s20p45, and s20p0. There was a significant change in colour liking with changing proportions of sorghum and pigeon peas with the best liking being for S40P15, followed by s40p0 and s20p0, representing like moderately, on the hedonic scale. Adding more sorghum improved the colour liking ($P <0.001$), as shown in Table 9a. This explains the higher rating for all samples that had more sorghum. The presence of natural pigments in sorghum likely contributed to the higher colour ratings, which enhanced the product's visual appeal.

This outcome was also observed in another study, that evaluated the colour liking of fermented sorghum blended with roasted pigeon peas at different percentages, Okin *et al*. (2021). On the other hand, Pigeon peas did not significantly influence the colour rating of the flour blends ($P < 0.05$). The mean rating ranged between 3.799 and 3.707 as seen in Table 10. The addition of pigeon peas slightly lowered the colour rating although there was no significant difference between the different blends. Pigeon peas generally have a beige to light brown colour, depending on the variety. Thus, they could not dramatically alter the visual appeal of composite flour blends compared to more vibrant ingredients like sorghum which had deeper pigmentation.

All the different flour blends were liked moderately in the 5-point hedonic scale. This effect could be explained by the characteristic colour of red sorghum, which on blending the samples, assumed the dominant colour of sorghum. Increasing the quantity of the sorghum, intensified the colour, making it distinct from the rest of the blends. Millet and pigeon pea flour colours were less intense. As a sensory attribute that influences food acceptance and selection, appearance is very crucial as it forms part of the first impression a consumer gets about a given food product (Meijer *et al*., 2021).

4.3.3 Porridge taste

There was a significant ($P < 0.05$) difference in the taste of the different flour blend porridges. S40p0 blend ranked highest for taste with a mean of 4.345 (like moderately) as shown in Table 9a and b. On comparing the means, this blend was not significantly different from s20p0, s0p60, s20p30, s40p15 and s40p30 blends. The addition of pigeon peas significantly ($P < 0.001$) lowered the taste rating although there was no significant difference between (0, 15, and 30) % of pigeon peas containing blends (Table 10). The Mean rating was between 3.374 and 3.862. This outcome can be attributed to the fact that pigeon peas have a characteristic taste and smell that cannot easily be masked by the millet and sorghum proportion (Okin et al., 2021). This may have altered the taste resulting in a decrease in taste rating with increase in pigeon pea addition. Adding sorghum on the other hand, significantly improved the taste rating of the samples. With mean scores between 3.366 for the s0p0 sample (0% sorghum) and 3.79 (40% sorghum) as in Table 9a. This could be explained by the fact that panellists were familiar with porridge made from sorghum and millet but not pigeon peas. Thus, the new taste imparted by the addition of pigeon peas may have caused the panellist to give it lower ratings on account of being a foreign taste in porridges.

Taste is a crucial feature that is used as a criterion to access sensory aspects in food. In this instance, it would encourage the child's acceptance of the meal. This becomes very important to this study as the major aim is to produce a nutritious product to help alleviate malnutrition. Indeed, a product would probably not be accepted even if it was aesthetically pleasing and satisfied nutritional needs but lacked flavour Abolaji et al.

(2019). This corresponds to the expected outcome as the ingredients used had distinct taste which were different from the base material (millet).

4.3.4 Flavour of the porridge

In Table 9a and b, S40P0 blend ranked highest in terms of porridge flavour (4.239), where the blend's flavour was moderately liked. The lowest mean was for S20P15 (3.121). S20P0, S0P60, S20P30, S40 P15 and S40P30 blends were not significantly different from the highest ranked (best) blend. When the effect of sorghum (Table 9a) and pigeon peas (Table 10) on the flavour was analysed, the outcome showed that, addition of pigeon pea significantly lowered the flavour rating ($P < 0.001$). Okin et al. (2021) also reported lower flavour rating compared to wheat cookies and those with sorghum. However, there was no significant difference between 0% and 30% pigeon pea containing blends. Blends with zero pigeon peas were more preferred in terms of flavour with a mean rating of 3.908 which represents moderately liked. Sorghum addition significantly ($P < 0.001$) improved the flavour of the flour blend making the blends with high sorghum content were more likable. In this study, increasing sorghum content translated to an equal reduction in millet content, given that at any given time, the millet: sorghum ratio was 100%. Out of which, pigeon pea substitution was done. The high rating for samples that did not have pigeon peas in them is possibly because the addition of pigeon peas came in with added pigeon pea beany flavour which the panellists were not conversant with.

Nonetheless, the flavour ratings for samples containing pigeon peas up to 30% had an average rating of 4 corresponding to "moderately like" in the hedonic scale similar to the sample containing no pigeon peas which had the highest amount of sorghum added (40%). This shows that although the addition of pigeon peas may have lowered the flavour rating, the use of pigeon peas in the blend at levels below 30% my not adversely affect the flavour of the finished product. This is promising as the addition of pigeon pea has profound improvement in protein quality and content.

4.3.5 Blend viscosity

Out of the 15 blends, s40p15 has the most liked porridge in terms of viscosity/consistency of porridge (4.293 at $P < 0.05$). S40p45 had the lowest mean rating (3.034). As seen in Table 9a and b, s0p45, s0p60, s20p45, s20p60, s40p45, and s40p60 were significantly different from the most preferred blend in terms of viscosity. There was no significant difference in viscosity between 0% pigeon peas containing blends and 30% pigeon pea blends with means ranging between 4.000 and 3.787 representing like moderately in the hedonic scale. Further addition, beyond 30% of pigeon pea flour significantly lowered the viscosity rating of the flour blends (porridge) with the mean rating reducing to 3.270 representing ‘neither like nor dislike’. Even though adding sorghum had a positive influence on the product viscosity, this increase was not significant at $P < 0.05$. In a comparison between s0p0 (100% millet) and s40p0 (60% millet and 40%sorghum), there is an evident increase in the mean rating for viscosity, even though both weren’t significantly different. The reduction in viscosity with addition of pigeon peas is possibly due to the reduction in starch with addition of pigeon peas which may have increase the fiber content of the blend with a reduction in starch content. In addition, pigeon peas starch characteristic were different from the starch characteristics of the other ingredients in the blend which may have altered gelatinization of starch in the blend as reported earlier in 4.1.8.

4.3.6 Blend texture

All the porridges were liked moderately when tasted for texture, except s20p45, s20p60, s40p45, and s40p60 which were neither liked nor disliked as shown in Table 9. There was no significant difference in texture for 0%, 15%, and 30% pigeon pea blends. Further addition, beyond 30% pigeon pea flour significantly ($P < 0.001$) lowered the texture rating of the flour blends. Sorghum did not have a significant effect on the texture (mouth feel) of the different blends. Mouth feel plays a critical role in determining how much food a child will eat when it comes to complementary foods. The flavour of pigeon peas may be the reason why the panellist’s rank of likeness for all the qualities fell between "dislike slightly" and "neither like nor dislike." The particular quality of sorghum flour in the manufacture of complementary foods may have contributed to its greater acceptance than other prepared samples (Abolaji et al. (2019). The texture of the porridge may be influenced by the particle size of the individual flours. As reported earlier, addition of pigeon peas altered the composition of the blends with possible influence on the gelling properties and the viscosity of the blends. This is possibly the reason for the lowered texture ratings with increase in pigeon peas in the flour blends.

4.3.7 Overall acceptability

S40p0 had the highest mean rating, even though it was not significantly different from 40% 40% sorghum with 15% pigeon peas, 0% sorghum with 60% pigeon peas, 20% sorghum with no pigeon peas, and 20% sorghum with 30% pigeon peas (Table 10), the highest overall acceptability rating was reported in the blends without pigeon peas, (0%) which was not significantly different from 15% and 30% pigeon peas. This was an indication that consumers preferred porridges without pigeon peas. However, none of the blends were disliked, with mean acceptability ratings ranging from 3.339 to 3.690 for pigeon pea levels between 0% and 60%, indicating a neutral response. Sorghum had a significant influence on the general acceptability with means for 40% sorghum flour blends being more acceptable. This is potentially because of the appealing colour, flavour and taste of sorghum containing blend as earlier reported.

This observation is consistent to that of Okin *et al.* (2021) who observed decrease in overall acceptability rating with increase in pigeon pea level from 0 to 40% while evaluating the quality of cookies made using fermented sorghum blended with roasted pigeon peas at different percentages. In another study, samples with highest amount of pigeon peas in composite blends containing unripe banana, moringa seeds and pigeon peas ranked lowest in overall acceptability (Popoola & Oluwamukomi, 2023). The mean rating for the different blends was 3.317 to 3.586, representing neither like nor dislike on the hedonic scale. This is promising as it presents an opportunity for improvement to higher rating levels on the hedonic scale. It is crucial that complementary food formulations have an adequate calories to match the dietary preferences of young children. Nonetheless, the sensory quality determines uptake and thus more research can be done to optimize the nutrients with an improvement in sensory appeal of blends containing pigeon peas.

4.3.8 Willingness to buy

The results of the effect of pigeon peas level and sorghum level on willingness to buy millet-sorghum-pigeon peas composite flour blends are shown in Table 11 and Table 12, respectively. Kruskal Wallis H test revealed that there were significant ($P < 0.001$) differences in willingness to buy flour blends with addition of both sorghum and pigeon pea flours. When panellists were asked to rate their willingness to buy the different blends, on a scale of (1-10), 0% pigeon pea blend got the highest mean ranking, which was not significantly different from 15% pigeon peas (Table 11). However, all the flour blends scored an average rating and above. Only blends with 40% sorghum flour and 45%, and 60% pigeon pea flour scored below 5 (Table 12). Panellists were more willing to buy s40 even though this sample did not differ significantly from those with s20 and s0. From this study, it was evident that consumers would prioritize sorghum-millet product either without pigeon peas or with low amount of pigeon peas. This supports earlier argument that lower levels of pigeon pea are more accepted due to their comparable sensory qualities to the sorghum – millet flour blends.

Table 11: Effect of pigeon peas on willingness to buy millet-sorghum-pigeon peas composite flour blends

pigeon peas	N	Median*	Average score	Mean Rank
0	172	7	7.029	505.4
15	171	6	6.037	445.2
30	170	6	5.92	436.6
45	171	5	5.339	373.7
60	171	5	5.379	378.7
Overall	855	P < 0.001		428

**Testing the Null hypothesis:* H_0*: All medians are equal.*

Table 12: Effect of sorghum on willingness to buy millet-sorghum-pigeon peas composite flour blends

Blends label	N	Median	Mean Rank	Average score
s0p0	58	6	396.3	5.466±0.358
s0p15	57	6	396.7	5.465±0.322
s0p30	57	6	418.4	5.737±0.314
s0p45	57	6	389.7	5.474±0.290
s0p60	57	6	465.9	6.158±0.349
s20p0	57	7	533.7	6.860±0.290
s20p15	57	5	391.9	5.561±0.273
s20p30	57	6	465	6.175±0.272
s20p45	57	5	386.9	5.526±0.269
s20p60	57	5	341.8	5.018±0.315
s40p0	57	8	588	8.810±1.520
s40p15	57	7	547	6.982±0.231
s40p30	56	6	426.2	5.821±0.307
s40p45	57	5	344.5	4.982±0.310
s40p60	57	5	328.6	4.877±0.325
Overall	855	P < 0.001	428	

**Testing the Null hypothesis:* H_0*: All medians are equal.*

4.4 Shelf-Life of Composite Flours Containing Varying Levels of Sorghum, Millet, and Pigeon Peas.

4.4.1 Temperature and humidity conditions during storage of the composite flour blends.

As shown in Figure 5, the storage temperature fluctuated between 23.257 ^{0}C and 27.012^{0}C. The average storage temperature was 25.225 ^{0}C. Mean daily relative humidity fluctuated between 57.140 and 54.552%, with a mean relative humidity of 55.494%. This is due to the storage of flour samples in an airtight container. As a result, the relative humidity in this study was fairly constant showing minor fluctuations but remaining between 54-58%. Temperature showed fluctuation as affected by the ambient temperatures during storage.

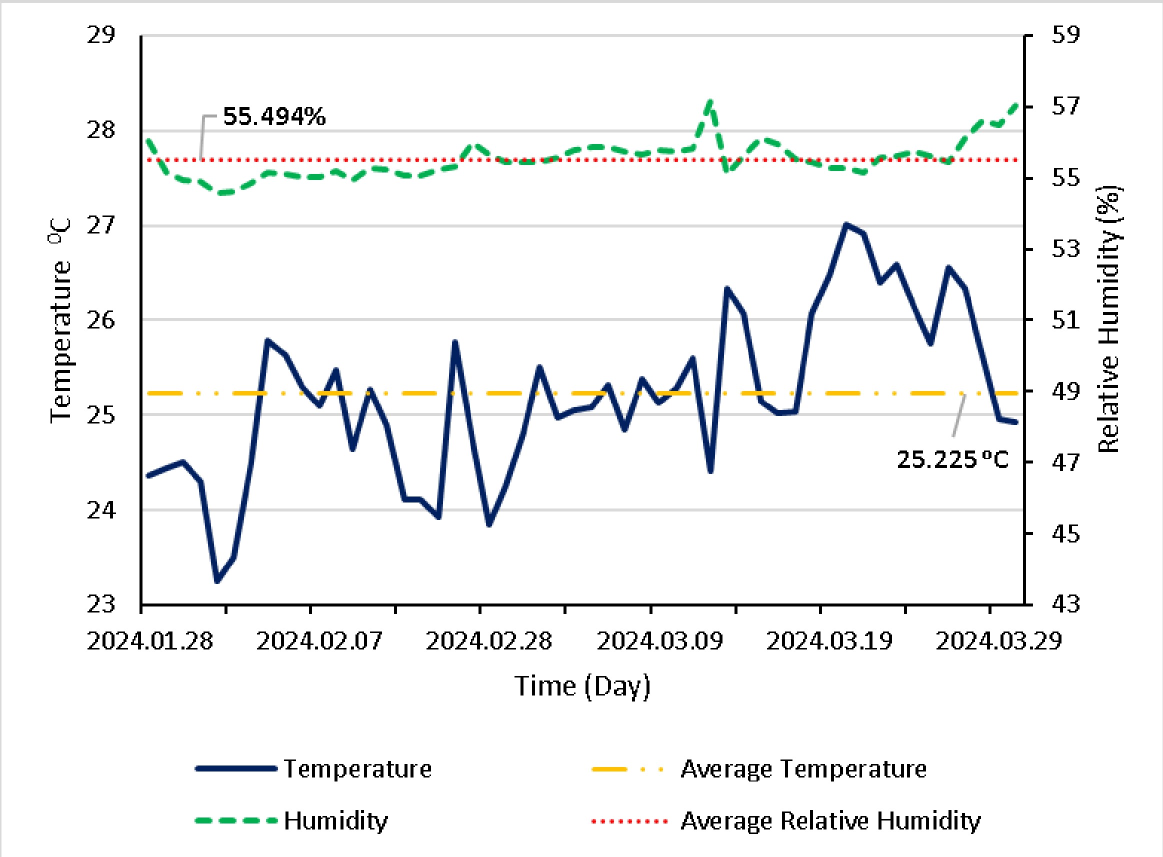

Figure 5: The mean daily temperature and humidity throughout the 65 days of flour storage.

The shelf life and storability of flour are influenced by multiple factors. Physical, chemical, and biological changes in stored flour are influenced by extrinsic elements like temperature, package, gases, and vapours, as well as intrinsic factors like water content and composition (Forsido et al., 2021). Increased humidity can cause moisture to be absorbed, which can hasten spoilage and encourage the growth of microorganisms. In addition, higher air temperature may increase the specific humidity making water more available for chemical and microbial reactions (Lancelot et al., 2021).

The mix of materials and the movement of moisture and oxygen within the packaging have an impact on the quality attributes of composite products when they are stored. A food product's stability is often determined by the methods used during manufacturing and the environment under which it is stored (Asadzadeh *et al*., 2014). Nonetheless, an increase in temperature accelerates the rate of deterioration reactions (chemical and microbiological) in foods (Forsido *et al.*, 2021). Understanding the impact of storage temperature, relative humidity and packaging materials on the physico-chemical, microbiological, and sensory qualities of the stored flour is vital to maximizing its potential in food preparation, either alone or in combination with other components (Forsido *et al*., 2021).

The ability of different packing materials to withstand moisture and oxygen varies, thus selecting the right material is essential (Asadzadeh *et al.*, 2014). The airtight plastic container was used to store flour samples packed in paper packaging material which explains the low humidity levels throughout the storage period. The recommended relative humidity (RH) for storing flour, including millet, sorghum, and pigeon pea flour, typically falls within 50% to 60%. Higher relative humidity may increase the level of moisture in the flour whereas lower humidity might cause moisture loss from the flour (Lancelot *et al*., 2021). In both cases, the quality of the product may be affected. For instance, higher moisture in flour has been linked to higher incidences of toxigenic Molds and the presence of mycotoxins in flour.

4.4.2 Titratable acidity and pH

The addition of pigeon peas to the blends at different levels significantly ($P < 0.001$) increased the titratable acidity of the composite blends. The acidity at the beginning of storage was lower at a mean of 0.125 (1.25g/L) which increased over the storage time to 0.2775 (2.775g/L) (Figure 6). The addition of pigeon peas to the flour blends significantly ($P < 0.001$) reduced the pH of the blends (Figure 6), with the highest pH being observed for samples with no pigeon peas. Pigeon peas contain organic acids such as malic acids, which contribute to the overall acidity of the blends. As the proportion of pigeon peas in the blend increases, the levels of these organic acids also increases, leading to a significant rise in Titratable acidity. Nonetheless, flour from pigeon peas is more prone to oxidative breakdown which also potentially produces acidic products which could have increased the levels of acidity in the flour with increasing pigeon peas level. This however requires further studies to establish.

In Figure 7, the pH of the different flour blends significantly ($P < 0.001$) reduced over time from day 1 (pH of 6.5482) to the 65th day (pH of 6.3238). The mechanisms contributing to the observed increase in Titratable acidity in flour varies depending on factors such as storage conditions, flour type, and processing method. During storage, factors like temperature, moisture content, and exposure to oxygen can promote microbial fermentation, leading to a gradual accumulation of acids. This explains the observed increase in titratable acidity during storage. The higher acidity over time suggested ongoing metabolic activity or slow fermentation processes that progressively increased the acid content of the flour blends.

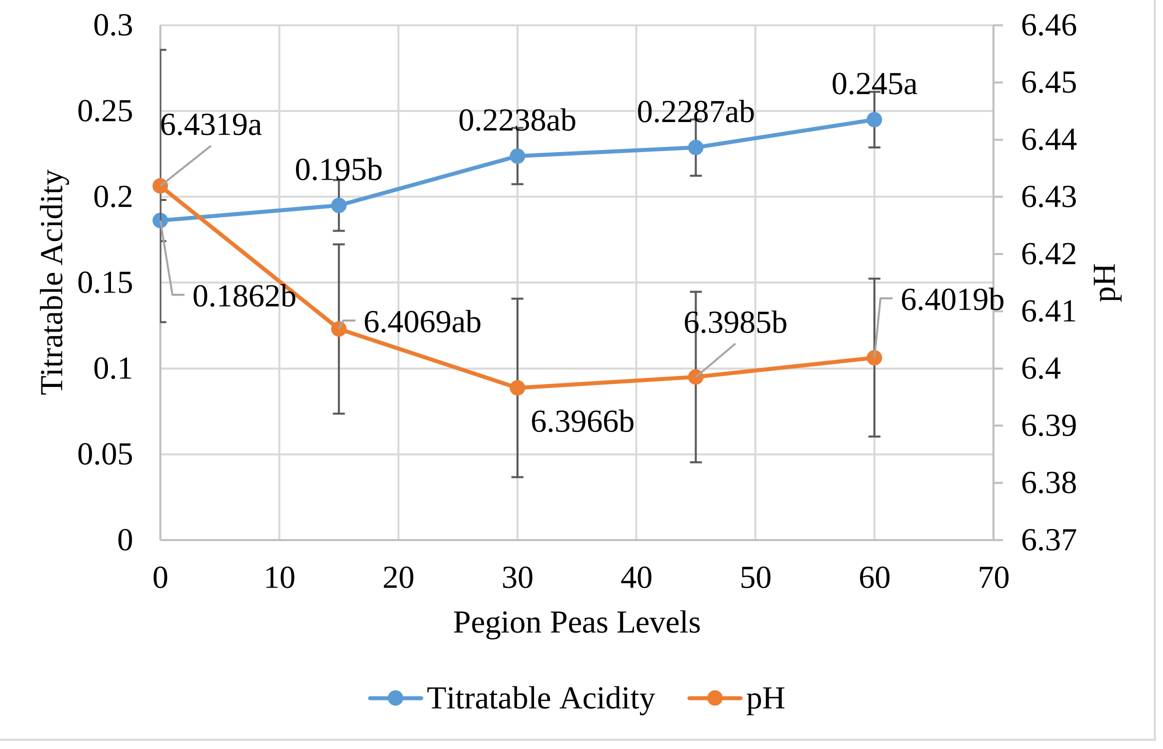

Figure 6: The effect of pigeon pea addition on the mean titratable acidity and pH of flour blends over the 65 days of storage. Values plotted above indicate mean ± standard error. Means along the row having different letters are significantly different ($P < 0.001$).

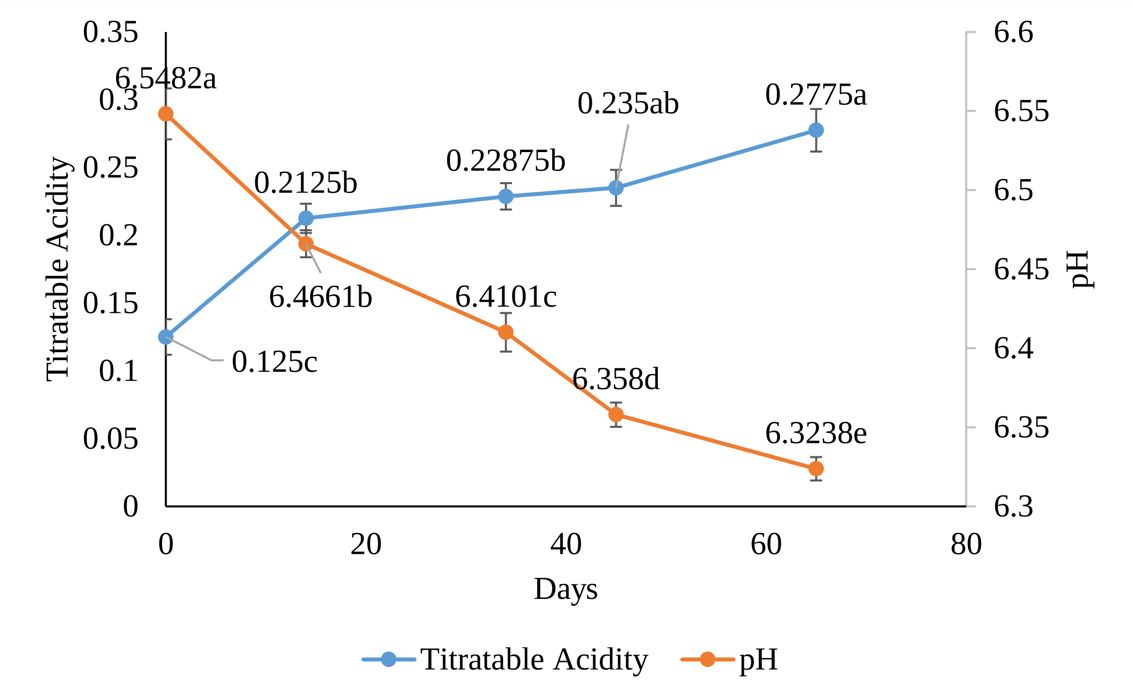

Figure 7: Mean titratable acidity and pH over 65 days of storage. Values plotted indicate mean ± standard error. Means along the row having different letters are significantly different ($P < 0.001$).

Sorghum addition on the other hand significantly ($P < 0.001$) increased the acidity levels of the blends with highest mean acidity values (0.311±0.025) being recorded for samples containing 20% sorghum (Table 13). Further investigation revealed that, within each level of sorghum addition, the acidity increased with increase in pigeon pea level further supporting the argument that pigeon peas were the key contributors to the changes in acidity of the flour blends. Nonetheless, another key contributor to this outcome could have been microbial activity. Microorganisms present in a product like bacteria and fungi, upon metabolizing carbohydrates in the flour, can produce organic acids such as lactic acid and acetic acid, which can increase the titratable acidity. Factors such as temperature and humidity during storage influence microbial growth and enzymatic activity, thereby affecting the rate of acid production in flour. Similarly, natural aging processes during storage, which can lead to enzymatic and chemical changes could also be the reason for this outcome. For instance, amylases and proteases can break down starches and proteins into simpler compounds, including sugars and amino acids. Subsequent microbial action on these compounds leads to the production of organic acids, contributing to increased acidity. Enzymes present in flour, particularly during milling, catalyse reactions that lead to the production of organic acids. For example, lipases can break down lipids into fatty acids, which can further undergo oxidation to produce organic acids. As shown in Table 13, there was a significant ($p < 0.001$) effect on the titratable acidity of the flour blends with addition of sorghum. However, the effect did not show a specific pattern to conclude an increase or a decrease in acidity.

Table 13: Mean effect of sorghum addition on titratable acidity and pH of flour blends throughout the storage period

Pigeon	Sorghum	Blend	Titratable Acidity	pH
0	0	s0p0	0.188 ± 0.017^{b}	6.383 ± 0.056^{bcd}
15	0	s0p15	0.169 ± 0.022^{b}	6.379 ± 0.026^{cd}
30	0	s0p30	0.214 ± 0.035^{b}	6.366 ± 0.027^{d}
45	0	s0p45	0.199 ± 0.025^{b}	6.395 ± 0.029^{bcd}
60	0	s0p60	0.199 ± 0.032^{b}	6.398 ± 0.027^{bcd}
0	20	s20p0	0.173 ± 0.025^{b}	6.436 ± 0.03^{abc}
15	17	s20p15	0.24 ± 0.031^{ab}	6.396 ± 0.021^{bcd}
30	14	s20p30	0.225 ± 0.031^{ab}	6.408 ± 0.028^{bcd}
45	11	s20p45	0.248 ± 0.032^{ab}	6.398 ± 0.028^{bcd}
60	8	s20p60	0.311 ± 0.025^{a}	6.401 ± 0.024^{bcd}
0	40	s40p0	0.199 ± 0.021^{b}	6.477 ± 0.03^{a}
15	34	s40p15	0.176 ± 0.018^{b}	6.446 ± 0.026^{ab}
30	28	s40p30	0.233 ± 0.021^{ab}	6.415 ± 0.026^{bcd}
45	22	s40p45	0.24 ± 0.029^{ab}	6.403 ± 0.023^{bcd}
60	16	s40p60	0.225 ± 0.011^{ab}	6.406 ± 0.024^{bcd}
P-Value			<0.001	<0.001

Values presented indicate mean ± standard error. Means along the column having different superscript are significantly different (P < 0.05).

4.4.3 Yeast and Mold

The results of microbiological analysis for yeast and Mold count both, during storage and as affected by the addition of pigeon peas in composite blends are shown in Table 13. The initial average contamination levels at the beginning were 1.886 and 1.652 Log CFU/g for yeasts and Mold counts respectively. These were below the limits established for yeast and Molds counts in millet flour (4 Log CFU/g) according to the EAS (2011) standards. This suggests that the microbial quality of raw materials as well as the processing steps established for this product development were adequate in ensuring the microbiological quality established in standards for these flours were met. Other researchers have reported lower contamination of yeasts and Mold in flour formulations containing pigeon peas (Anaemene, 2020; Mohamed et al., 2022). In their study on complementary foods containing roasted and fermented pigeon peas, Anaemene Doris et al. (2023) reported no growth of molds until the fourth week only in fermented pigeon peas containing product. The level of initial contamination is dependent on the quality of the ingredients and the processing techniques applied. This may explain the initial contamination level reported in this study and why it was different from the study by Anaemene Doris et al. (2023).

Table 14: The mean yeast and mold count in composite flour containing millet, sorghum, and pigeon peas as influenced by time, and the pigeon pea level

		Yeasts count	Molds count	Yeast and Mold Count
Day	1	1.886±0.182^{a}	1.652±0.174^{a}	2.252±0.185^{ab}
	16	2.152±0.244^{a}	1.453±0.232^{a}	2.628±0.23^{a}
	34	1.083±0.204^{b}	1.024±0.205^{ab}	1.567±0.227^{b}
	45	0.19±0.111^{c}	0.302±0.119^{c}	0.492±0.155^{c}
	65	0.441±0.141^{bc}	0.369±0.121^{bc}	0.628±0.162^{c}
P Value		<0.001	<0.001	<0.001
Pigeon peas	0	1.032±0.204^{a}	0.935±0.184^{a}	1.417±0.219^{a}
	15	1.204±0.214^{a}	1.285±0.205^{a}	1.711±0.229^{a}
	30	1.363±0.225^{a}	1.009±0.187^{a}	1.628±0.23^{a}
	45	1.097±0.212^{a}	0.75±0.182^{a}	1.357±0.232^{a}
	60	1.286±0.218^{a}	1.037±0.208^{a}	1.685±0.237^{a}
P Value		0.769	0.264	0.609

Means along the column having different superscripts are significantly different (P < 0.05). Values presented indicate mean ± standard error.

Table 15: The mean yeast and mold count in composite flour containing millet, sorghum, and pigeon peas as influenced by sorghum level

Pigeon	Sorghum	Yeasts count	Molds count	Yeast and Mold
0	0	0.805±0.319a	0.653±0.251a	1.109±0.335a
	20	1.397±0.388a	1.064±0.364a	1.944±0.407a
	40	0.894±0.354a	1.088±0.34a	1.197±0.38a
15	0	1.286±0.386a	1.15±0.354a	1.893±0.396a
	17	1.153±0.345a	1.457±0.352a	1.808±0.378a
	34	1.174±0.401a	1.249±0.377a	1.433±0.429a
30	0	1.192±0.405a	1.139±0.352a	1.737±0.419a
	14	1.487±0.368a	0.753±0.29a	1.691±0.367a
	28	1.41±0.415a	1.135±0.338a	1.457±0.429a
45	0	1.424±0.426a	0.719±0.342a	1.71±0.455a
	11	0.542±0.294a	0.611±0.278a	0.754±0.339a
	22	1.325±0.35a	0.92±0.337a	1.608±0.383a
60	0	1.657±0.387a	0.91±0.336a	1.992±0.385a
	8	1.082±0.377a	0.894±0.355a	1.424±0.428a
	16	1.119±0.376a	1.308±0.399a	1.64±0.431a
P Value		0.545	0.916	0.281

Means along the column having different superscripts are significantly different (P < 0.05). Values presented indicate mean ± standard error.

Adding pigeon peas or sorghum did not significantly affect yeast and mold counts (Table 14 and Table 15). However, yeast and mold count significantly (P < 0.001) reduced during the storage of composite flour blends. In the beginning days 1-16 days, there was an observed increase (Figure 8), even though this was not statistically significant. However, beyond day 16, the contamination levels significantly (P < 0.001) reduced until day 45. Beyond this point, there was an observed increase in both the yeasts and molds. Although there was an initial increase in yeasts and Mold counts, in both studies, further storage resulted in a decrease in contamination levels. This can be attributed to factors like the storage conditions adopted for this study. Initially, the microbial load could have increased due to the availability of optimal conditions for growth. However, as storage continued, unfavourable conditions for microbial survival (low moisture, decrease in oxygen levels, and increase in carbon dioxide) may have led to the reduction in yeast and Mold counts. The storage of the flour samples in an airtight container at nearly constant low humidity may have resulted in a reduction in the moisture level of the grain as well as oxygen levels which may have negatively impacted the growth of yeasts and Molds. This shows that with proper consideration on the packaging and provision of controlled environmental storage of the flour, its shelf life could be enhanced. Uchechukwu-Agua et al. (2015) reported similar trends while studying the effects of storage conditions on the microbial quality of cassava flour.

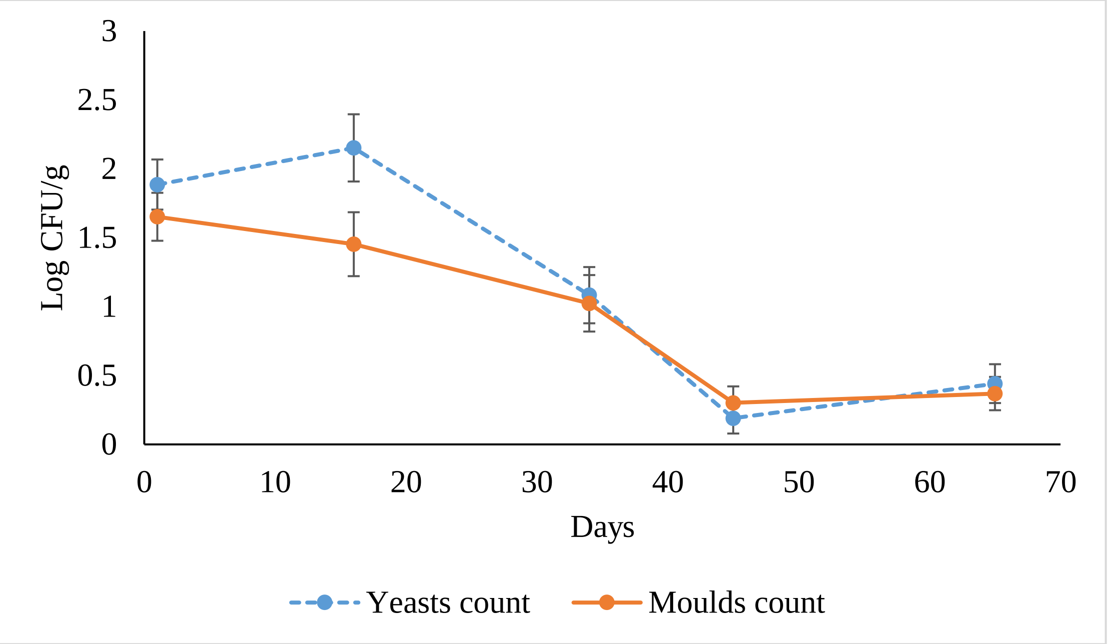

Figure 8: Mean log CFU/g of yeast and mold counts in composite flour blends over 65 days. Values plotted indicate mean ± standard error.

In Figure 8, there was a slight increase in yeast and Mold counts beyond day 45. As observed earlier in Figure 5, the average relative humidity towards the end of the 65 days was higher than the beginning possibly due to the opening of the airtight container during sample collection. This could have been the cause of the increase post 45th day as the storage conditions changed favouring growth and multiplication of the yeast and Molds.

According to the EAS (2011) the recommended limit for yeast and Molds counts in millet flour is 4 Log CFU/g. The composite flour blend samples containing millet, sorghum, and pigeon peas had yeast and Mold counts (2.252 Log CFU/g) below the recommended maximum, indicating their suitability for human consumption. Furthermore, at the end of the storage period, samples were all below the maximum recommended limit indicating that, based on microbial count, the samples were still fit for human consumption.

CHAPTER FIVE
SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Findings

The purpose of this study was to determine the physicochemical properties, protein quality, sensory quality, and shelf life of sorghum (S*orghum bicolor*), millet (*Pennisetum glaucum*), and pigeon peas (*Cajanus cajan*) composite flour. For objective 1, 2 and 3 a nested design with two factors was used: pigeon peas level (0, 15, 30, 45 and 60%) and sorghum level (3 levels) nested in pigeon pea levels while a nested factorial design was employed for objective 4 with the following factors: storage period (days), pigeon pea level ((0, 15, 30, 45 and 60%)) and sorghum level (3 levels) nested in pigeon peas.

The first objective sought to determine the functional properties of composite flours containing varying levels of sorghum, millet, and pigeon peas hypothesizing that the addition of pigeon pea flour will have no statistically significant effect on the functional properties of millet-sorghum composite flour. The addition of sorghum and pigeon peas to millet significantly influenced the physicochemical properties of the composite flours. Sorghum addition notably affected solubility, tapped density gelling temperature and least gelling concentration. On the other hand, pigeon pea addition impacted all the functional properties tested except for the bulk density of the resulting flour blends. These findings suggest that sorghum and pigeon peas can be strategically used to modify the functional properties of complementary flours, potentially improving their nutritional profile and application in food formulations. Pigeon peas therefore may require to be taken into account when being used in such formulations to achieve the desired outcome.

The second objective sought to determine the protein quality of composite flours containing varying levels of sorghum, millet, and pigeon peas, hypothesizing that the addition of pigeon pea flour will have no statistically significant effect on the protein quality of millet-sorghum composite flour. The evaluation of protein quality revealed that the inclusion of pigeon peas significantly enhanced the protein content and digestibility of the composite flours. With an average protein content of 18.887%, and being a common food crop grown in Tharaka Nithi County, pigeon peas proved to be a valuable addition to the blends, addressing the critical issue of protein malnutrition.

Thus, pigeon peas have the potential to serve as a key addition in complementary food formulations. This could potentially contribute to better growth and development outcomes for children in Tharaka Nithi County.

The third objective sought to determine the sensory quality of porridge prepared from composite flours containing varying levels of sorghum, millet, and pigeon peas, hypothesizing that the addition of pigeon pea flour will have no statistically significant effect on the sensory quality of millet-sorghum composite flour. Sensory evaluation of the porridge made from composite flours indicated that certain blends, particularly those with 40% sorghum and 15% pigeon peas, received the highest ratings in terms of colour, taste, flavour, and general acceptability. Sorghum improved hedonic ratings across various attributes, while pigeon peas influenced the color, taste, flavour, and overall acceptability. The evaluation also showed that the rating for the blends with 30% Pigeon peas were neither liked nor disliked. This gives an indication of a neutral feeling to the new blend, possibly due to the preformed idea of the common complementary porridges in existence. It therefore demonstrates that it is possible to create nutritious and palatable complementary foods that are likely to be well-received by both children and caregivers, ensuring better adherence to improved feeding practices.

The fourth objective sought to determine the shelf-life of composite flours containing varying levels of sorghum, millet, and pigeon peas, hypothesizing that the addition of pigeon pea flour will have no statistically significant effect on the shelf-life of millet-sorghum composite flour. The shelf-life analysis showed that the addition of pigeon peas at different levels increased the titratable acidity of the composite blends over time, which indicated continued deterioration of the flours during the storage time. Initial contamination levels of yeasts and Molds were within acceptable limits. These results are crucial for formulating plans to increase composite flours' shelf lives, guaranteeing their safety and nutritional value over time. In real-world situations, the successful deployment of these complementary foods depends on microbial control and effective storage conditions.

These mixes retain acceptable sensory attributes and useful shelf-life features in addition to addressing the nutritional deficiencies like protein-energy deficiency. The findings of the study offer a strong basis for creating locally sourced, long-lasting solutions to raise Kenyan children's nutritional status. To guarantee widespread adoption and a long-term influence on public health, future initiatives should concentrate on increasing production and teaching communities about the advantages and preparation of these composite flours.

5.2 Conclusion

Looking at the outcomes of this study, the following conclusions can be made: One, the addition of sorghum affected all functional properties significantly, except foam capacity and stability, water absorption index and water holding capacity. On the other hand, Pigeon pea did not affect the bulk density and water holding capacity of the blends but had a significant influence on the other functional properties. It is therefore necessary to optimize the quantities of sorghum and pigeon to yield a product with good functional characteristics. The digestibility of the different blends significantly increased with increase in pigeon pea quantities. The highest percentage of digestibility was recorded for 60% peas blends. This shows the potential of pigeon peas in formation of protein rich foods in the fight against malnutrition.

Samples, s40P0 (40% sorghum with no pigeon peas and s40p15 (40% sorghum and 15% pigeon peas), had the best sensory quality characteristics. These two blends did not differ from s20p30 (20% sorghum and 30% pigeon peas). Despite these three blends being most preferred, it was evident from the mean ratings that other blends also fell close to the most preferred ones. It therefore indicates the potential of adoption of pigeon pea at 15-30% in composite blends. The initial average contamination levels of all flour blends at the beginning were below the recommended limit for yeast and Molds counts in millet flour. Adding pigeon peas or sorghum did not affect yeast and Mold counts. However, yeast and mold count reduced during the storage of composite flour blends. The addition of pigeon peas increased the titratable acidity of the composite blends. This was a clear indication of gradual deterioration of quality of flour over time. Exploration of different packaging methods and storage could better preserve the quality of such flours.

5.3 Recommendations of the study

5.3.1 Practice recommendations:

i. Explore and adopt improved packaging methods to preserve the quality of composite flours,
ii. Educate consumers on the benefits of pigeon pea-containing blends.
iii. Encourage the utilization of pigeon peas to improve the protein content of energy dense cereal grains.

5.3.2 Policy recommendations

i. Develop and promote guidelines that encourage the inclusion of pigeon pea in composite blends to enhance protein intake.
ii. Implement policies that support the cultivation of sorghum and pigeon peas through subsidies, technical assistance, and market access.

5.3.3 Suggestions for further research

i. Conduct further research to optimize the quantities of sorghum and pigeon pea in composite blends
ii. Investigate the impact of various packaging materials and storage conditions on the shelf-life and quality of composite blends,
iii. Perform long-term studies to assess the impact of consuming pigeon pea-enriched composite blends on malnutrition and overall health.

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APPENDICES

Appendix 1: Introduction and Consent for the Sensory Evaluation

Purpose of the Study

This study is part of my research to optimize these blends for improved nutritional and functional properties, with the aim of developing food products that can help combat malnutrition. The aim of the study is to produce a composite blend that provide adequate protein to children under the age of five. The aim of this analysis is to determine the best performing sample in terms of acceptability, which enables determination of the optimal blend that has improved protein content and also acceptable to the consumer. Knowing acceptability helps gauge the possibility of the target population actually consuming the food product and hence being able to benefit from its improved protein content, hence able to stay away from protein energy malnutrition.

The purpose of this exercise is to evaluate the sensory qualities (such as taste, texture, and overall acceptability) of various composite flour blends. The porridge samples, are prepared from different blends of sorghum, pearl millet and pigeon peas. Your feedback will be invaluable in helping us understand consumer preferences and improve the formulations of these blends.

What to Expect

If you agree to participate, you will be asked to taste several samples of the composite flour blends presented to you as porridge and provide your feedback on their sensory attributes. The evaluation session will take approximately 30 minutes, and will take place at the food technology laboratory.

Confidentiality

Your participation in this study is entirely voluntary, and all responses will be kept confidential. No personal identifying information will be associated with your feedback, and the results will be used solely for research purposes.

Consent

By participating in the sensory evaluation study, you are giving your consent to be part of this research. If you choose not to participate, you will not be included in the study, and there will be no penalty for your decision.

Appendix 2. Sensory Evaluation Score Card

Panellist No:		**Date:**	
Instructions:	You are provided with coded samples. You are required to assess each and where appropriate taste each and indicate on the hedonic scale your level of liking.		

Sensory Attribute: Colour

Sample codes	Like extremely	Like moderately	Neither like nor dislike	Dislike moderately	Like extremely
ASD					
SWE					
REW					
OIE					
FGR					
WQR					
HJU					
WQK					
LDE					
TUI					
OBN					
HBT					
PLK					
XBA					
BXG					

Sensory Attribute: Taste

Sample codes	Like extremely	Like moderately	Neither like nor dislike	Dislike moderately	Like extremely
ASD					
SWE					
REW					
OIE					
FGR					
WQR					
HJU					
WQK					
LDE					
TUI					
OBN					
HBT					
PLK					
XBA					
BXG					

Sensory Attribute: flavour

Sample codes	Like extremely	Like moderately	Neither like nor dislike	Dislike moderately	Like extremely
ASD					
SWE					
REW					
OIE					
FGR					
WQR					
HJU					
WQK					
LDE					
TUI					
OBN					
HBT					
PLK					
XBA					
BXG					

Sensory Attribute: viscosity

Sample codes	Like extremely	Like moderately	Neither like nor dislike	Dislike moderately	Dislike extremely
ASD					
SWE					
REW					
OIE					
FGR					
WQR					
HJU					
WQK					
LDE					
TUI					
OBN					
HBT					
PLK					
XBA					
BXG					

Sensory Attribute: texture

Sample codes	Like extremely	Like moderately	Neither like nor dislike	Dislike moderately	Like extremely
ASD					
SWE					
REW					
OIE					
FGR					
WQR					
HJU					
WQK					
LDE					
TUI					
OBN					
HBT					
PLK					
XBA					
BXG					

Sensory Attribute: overall acceptability

Sample codes	Like extremely	Like moderately	Neither like nor dislike	Dislike moderately	Like extremely
ASD					
SWE					
REW					
OIE					
FGR					
WQR					
HJU					
WQK					
LDE					
TUI					
OBN					
HBT					
PLK					
XBA					
BXG					

Willingness to buy: scale 0-10, where 0-Not willing to buy and 10 -Most willing to buy) was used to access willingness to buy.

Sample codes	**Scale 0-10,** where 0-Not willing to buy and 10 -Most willing to buy) was used to access willingness to buy.
ASD	
SWE	
REW	
OIE	
FGR	
WQR	
HJU	
WQK	
LDE	
TUI	
OBN	
HBT	
PLK	
XBA	
BXG	

Appendix 3. Ethical Review

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18
Direct Line: 0772894438
Email: info@chuka.ac.ke,
P. O. Box 109-60400, Chuka
Website: www.chuka.ac.ke

21st June, 2023

REF: CUIERC/ NACOSTI/401
TO: **Catherine Nzisa Mwangangi**

RE: Effect of Pigeon Pea Flour Supplementation on the Physico-Chemical, Protein Digestibility, Sensory Properties and Shelf Life of Sorghum and Millet Composite Flour

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812.* The approval period is 21st June, 2023 – 21st June, 2024.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC.*
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC.*

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Chuka University is....... ...Inspiring Environmental Sustainability for Better Life

Appendix 4. Research Approval Letter

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **332547**

Date of Issue: **24/January/2024**

RESEARCH LICENSE

This is to Certify that Ms.. Catherine Nzisa mwangangi of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Tharaka-Nithi on the topic: FFECT OF PIGEON PEA FLOUR SUPPLEMENTATION ON THE PHYSICO-CHEMICAL, PROTEIN DIGESTIBILITY, SENSORY PROPERTIES AND SHELFLIFE OF SORGHUM AND MILLET COMPOSITE FLOUR for the period ending : 24/January/2025.

License No: **NACOSTI/P/24/32564**

332547

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

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See overleaf for conditions

Appendix 5. Analysis of Variance (ANOVA) tables for all analysis

Objective1: Determination of the Functional Properties of Composite Flours Containing Varying Levels of Sorghum, Millet and Pigeon Peas

1. **General Linear Model: swelling capacity versus pigeon peas, sorghum**

Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
pigeon peas	4	19.850	4.96251	65.65	0.000
sorghum(pigeon peas)	10	2.481	0.24814	3.28	0.019
Error	15	1.134	0.07559		
Total	29	23.465			

Model Summary

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
0.274938	95.17%	90.66%	80.67%

2. **General Linear Model: WAI versus pigeon peas, sorghum**

Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
pigeon peas	4	17591.6	4397.91	50.76	0.000
sorghum(pigeon peas)	10	630.6	63.06	0.73	0.689
Error	15	1299.5	86.63		
Total	29	19521.7			

Model Summary

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
9.30771	93.34%	87.13%	73.37%

3. **General Linear Model: WHC versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	3.776	0.94397	10.36	0.000
sorghum(pigeon peas)	10	5.597	0.55966	6.14	0.001
Error	15	1.367	0.09111		
Total	29	10.739			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.301849	87.27%	75.40%	49.09%

4. **General Linear Model: gelling temp versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	127.376	31.8441	108.26	0.000
sorghum(pigeon peas)	10	319.320	31.9320	108.56	0.000
Error	15	4.412	0.2941		
Total	29	451.109			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.542344	99.02%	98.11%	96.09%

5. **General Linear Model: solubility versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	60.87	15.218	10.38	0.000
sorghum(pigeon peas)	10	30.94	3.094	2.11	0.093
Error	15	22.00	1.467		
Total	29	113.81			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.21104	80.67%	62.63%	22.68%

6. General Linear Model: bulk density versus pigeon peas, sorghum

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	0.000569	0.000142	0.34	0.845
sorghum(pigeon peas)	10	0.015574	0.001557	3.75	0.011
Error	15	0.006233	0.000416		
Total	29	0.022376			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0203840	72.15%	46.15%	0.00%

7. **General Linear Model: tapped density versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	0.009544	0.002386	12.52	0.000
sorghum(pigeon peas)	10	0.010471	0.001047	5.49	0.002
Error	15	0.002859	0.000191		
Total	29	0.022874			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0138058	87.50%	75.84%	50.00%

8. **General Linear Model: FC versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	335.73	83.933	57.20	0.000
sorghum(pigeon peas)	10	32.43	3.243	2.21	0.080
Error	15	22.01	1.467		
Total	29	390.17			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.21132	94.36%	89.09%	77.44%

9. **General Linear Model: FS versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	1653.97	413.492	12.68	0.000
sorghum(pigeon peas)	10	87.81	8.781	0.27	0.979
Error	15	489.18	32.612		
Total	29	2230.95			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.71069	78.07%	57.61%	12.29%

Objective 2: Protein Quality of Composite Flours Containing Varying Levels of Pigeon Peas, Sorghum and Millet.

1. **General Linear Model: Protein content versus Pigeon (%), Sorghum (%)**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pigeon (%)	4	97.8428	24.4607	10341.16	0.000
Sorghum (%)(Pigeon (%))	10	0.1436	0.0144	6.07	0.000
Error	30	0.0710	0.0024		
Total	44	98.0574			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0486351	99.93%	99.89%	99.84%

2. **General Linear Model: Protein Digestibility% versus Pigeon (%), Sorghum (%)**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pigeon (%)	4	827.6	206.89	7.07	0.000
Sorghum (%)(Pigeon (%))	10	567.6	56.76	1.94	0.078
Error	30	877.4	29.25		
Total	44	2272.6			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.40804	61.39%	43.37%	13.13%

Objective 3: Sensory Quality of Porridge Prepared From Composite Flours Containing Varying Levels of Sorghum, Millet and Pigeon Peas

1. **General Linear Model: color versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	1.27	0.3178	0.30	0.881
sorghum(pigeon peas)	10	255.18	25.5184	23.76	0.000
Error	855	918.40	1.0741		
Total	869	1174.85			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.03641	21.83%	20.55%	19.06%

2. **General Linear Model: taste versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	29.57	7.392	5.24	0.000
sorghum(pigeon peas)	10	133.55	13.355	9.47	0.000
Error	855	1205.21	1.410		
Total	869	1368.33			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.18727	11.92%	10.48%	8.80%

3. **General Linear Model: flavor versus pigeon peas, sorghum**

Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
pigeon peas	4	38.07	9.518	6.92	0.000
sorghum(pigeon peas)	10	74.09	7.409	5.39	0.000
Error	855	1175.98	1.375		
Total	869	1288.15			

Model Summary

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
1.17278	8.71%	7.21%	5.48%

4. **General Linear Model: viscosity versus pigeon peas, sorghum**

Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
pigeon peas	4	95.39	23.847	18.36	0.000
sorghum(pigeon peas)	10	23.52	2.352	1.81	0.055
Error	855	1110.43	1.299		
Total	869	1229.33			

Model Summary

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
1.13963	9.67%	8.19%	6.47%

5. **General Linear Model: texture versus pigeon peas, sorghum**

Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
pigeon peas	4	91.23	22.809	7.36	0.000
sorghum(pigeon peas)	10	51.13	5.113	1.65	0.088
Error	855	2649.81	3.099		
Total	869	2792.17			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.76045	5.10%	3.54%	1.74%

6. **General Linear Model: acceptability versus pigeon peas, sorghum**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	18.82	4.704	3.41	0.009
sorghum(pigeon peas)	10	79.00	7.900	5.73	0.000
Error	855	1177.84	1.378		
Total	869	1275.66			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.17371	7.67%	6.16%	4.40%

Objective 4: Shelf-Life of Composite Flours Containing Varying Levels of Sorghum, Millet, and Pigeon Peas.

1. **General Linear Model: TA versus pigeon peas, sorghum, Day**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	0.07168	0.017920	4.61	0.002
Day	4	0.37796	0.094491	24.31	0.000
sorghum(pigeon peas)	10	0.11897	0.011897	3.06	0.002
pigeon peas*Day	16	0.06697	0.004186	1.08	0.385
Error	115	0.44705	0.003887		
Lack-of-Fit	40	0.33244	0.008311	5.44	0.000
Pure Error	75	0.11461	0.001528		
Total	149	1.08263			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0623487	58.71%	46.50%	29.75%

2. **General Linear Model: PH versus pigeon peas, sorghum, Day**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon peas	4	0.03052	0.007631	4.89	0.001
Day	4	0.68390	0.170976	109.57	0.000
sorghum(pigeon peas)	10	0.07455	0.007455	4.78	0.000
pigeon peas*Day	16	0.09347	0.005842	3.74	0.000
Error	100	0.15604	0.001560		
Lack-of-Fit	40	0.13759	0.003440	11.19	0.000
Pure Error	60	0.01845	0.000308		
Total	134	1.03025			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0395023	84.85%	79.70%	71.01%

3. **General Linear Model: Yeasts count versus pigeon, Sample, Day**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon	4	3.124	0.7810	0.45	0.769
Day	4	141.418	35.3545	20.57	0.000
Sample(pigeon)	10	15.278	1.5278	0.89	0.545
pigeon*Day	16	25.436	1.5897	0.92	0.542
Sample(pigeon)*Day	40	54.240	1.3560	0.79	0.809
Error	165	283.597	1.7188		
Total	239	523.139			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.31102	45.79%	21.48%	0.00%

4. **General Linear Model: Moulds count versus pigeon, Sample, Day**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon	4	7.689	1.9223	1.32	0.264
Day	4	74.613	18.6532	12.84	0.000
Sample(pigeon)	10	6.623	0.6623	0.46	0.916
pigeon*Day	16	22.358	1.3973	0.96	0.501
Sample(pigeon)*Day	40	78.782	1.9696	1.36	0.096
Error	165	239.773	1.4532		
Total	239	429.520			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.20547	44.18%	19.14%	0.00%

5. **General Linear Model: Yeast and Mold versus pigeon, Sample, Day**

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
pigeon	4	4.814	1.203	0.68	0.609
Day	4	170.415	42.604	23.97	0.000
Sample(pigeon)	10	21.698	2.170	1.22	0.281
pigeon*Day	16	39.901	2.494	1.40	0.146
Sample(pigeon)*Day	40	68.947	1.724	0.97	0.528
Error	165	293.258	1.777		
Total	239	598.379			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.33316	50.99%	29.01%	0.00%

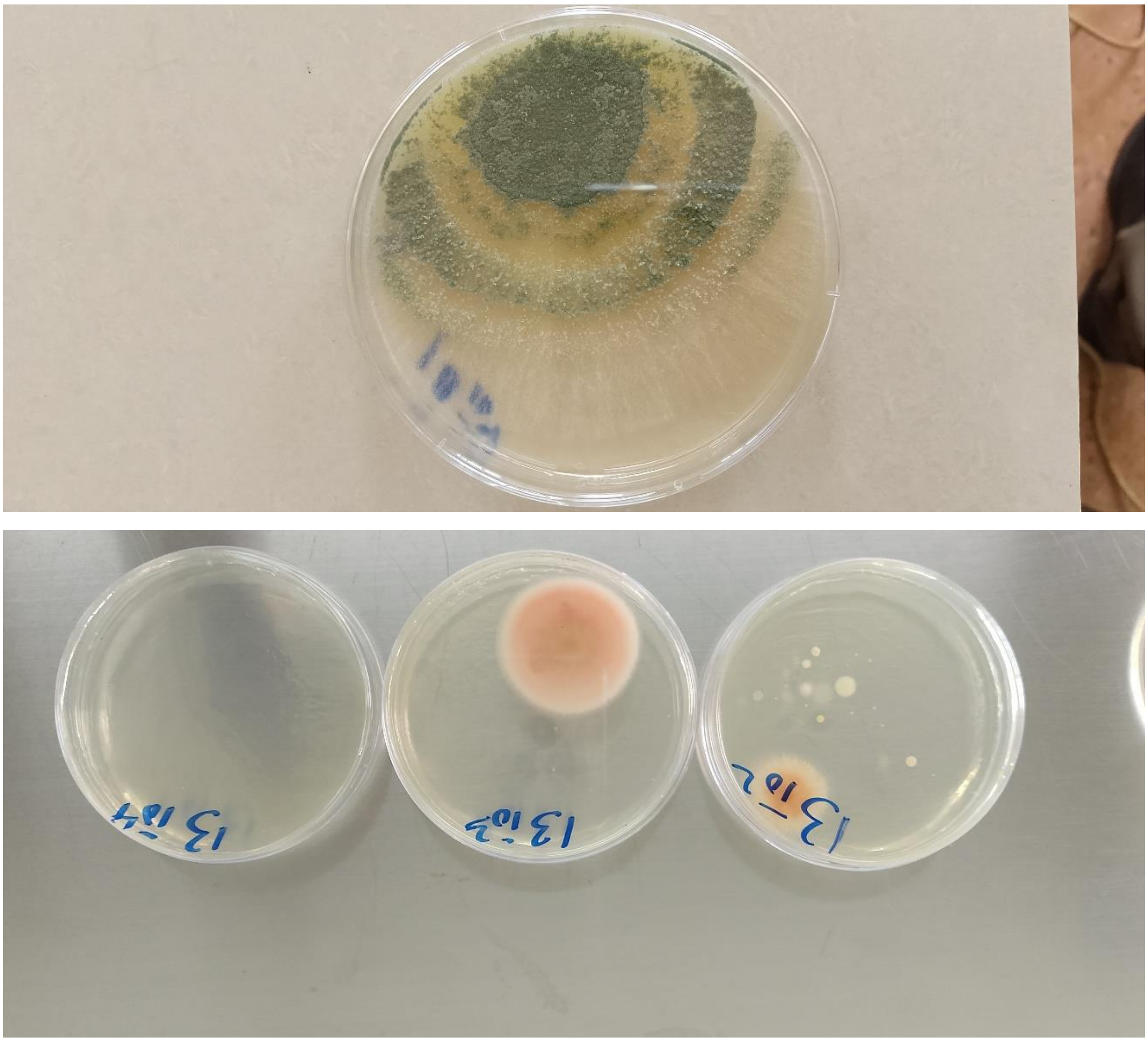
Appendix 6. Pictorial

Soaked pigeon peas

Flour samples packaged before storage

Part of the sensory evaluation panel used in assessment of porridge samples

Determination of functional properties of flour blends



Yeast and mold analysis results in flour samples