

**EVALUATION OF PHYSICOCHEMICAL, FUNCTIONAL AND SENSORY
CHARACTERISTICS OF SELECTED IMPROVED CASSAVA VARIETIES
DEVELOPED THROUGH GAMMA IRRADIATION**

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**A THESIS SUBMITTED TO THE SCHOOL OF AGRICULTURE AND
BIOTECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN COMMUNITY
NUTRITION, UNIVERSITY OF ELDORET, KENYA**

OCTOBER, 2025

DECLARATION

Declaration by the Candidate

This thesis is my original work and has never been presented for the award of an academic degree in any other university and should not be copied, or reproduced in any format without written authority from the author and/or University of Eldoret.

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DEDICATION

To my beloved Husband, Obed Kiplimo Kering

To my dear children Alma Valaroma and Aston Reign

To my lovely parents Philip and Ruth Koskei.

ABSTRACT

Cassava has significant potential for utilization and diversification at household and industrial levels. New varieties (CAS 1, CAS 2, and CAS 3) with proven high yields and disease resistance were previously developed from KME 4 through mutation breeding with gamma irradiation dose rates of 15, 20, and 30 Gy respectively administered at 2 Gy/min. However, the applicability of these varieties in ensuring food and nutrition security has not been comprehensively studied. Consequently, this study sought to evaluate the physicochemical, functional, pasting, and sensory characteristics of flour and products derived from the new cassava varieties. The tests were conducted using standard official procedures. The cassava flour exhibited high lightness (L^*) and whiteness, along with low redness (a^*) and yellowness (b^*). Porridge displayed a lightness (L^*) value indicative of a bright appearance, with a consistent yellowish hue (b^*). Cookies showed distinct lightness (L^*) values, with the top side of the cookies generally exhibiting higher lightness compared to the bottoms, attributed to increased browning from direct heat exposure during baking and Maillard reactions. Browning Index (BI) values reflected a greater degree of browning in the bottoms of the cookies, highlighting the impact of baking conditions on color development. The results indicated that gamma irradiation significantly ($p < 0.05$) increased the levels of carbohydrates, magnesium, zinc, and iron. Conversely, it significantly ($p < 0.05$) decreased the pasting properties, oil absorption, and solubility index. Overall, the cassava varieties developed through gamma irradiation recorded higher mineral content and comparable functional properties to the parent variety. Fourier transform infrared spectroscopy (FTIR) revealed stretching of O-H, C=O, C-O-H, and O-H functional groups in the flours. Water/hydroxyl groups stretching increased due to gamma irradiation leading to higher intensity of peaks in the 3800-3200 cm^{-1} range and it also shifted the peaks at the fingerprint region peaks 473- 927 cm^{-1} . Based on the pasting properties, KME 4 and CAS 1 are more suitable for baking products, KME4, while CAS 2 and CAS 3 are ideal for porridge preparation. Consumer acceptability for porridge was moderately favorable across all varieties, while for cookies, formulation V5 variety (50% cassava and 50% wheat) was the most preferred. In conclusion, gamma irradiation influences were varietal dependent and the products made from these flours have good overall acceptance. As a result, consumers should be enlightened about such products and their role in enhancing food and nutrition security.

ACKNOWLEDGEMENT

A master of science degree has been a stepping stone to transition from being a student to working as a professional researcher with improved research skills, knowledge confidence, and judgment. To me, this has been a life-changing experience with improved depth of knowledge in academia as well as personal growth amidst challenges. The journey has not been easy with a few thumps, but I have had a rewarding experience at every corner of those challenges.

This life-changing journey would not have been possible without the blessing of God Almighty. I am thankful to my husband Obed Kiplimo Kering who has always inspired and encouraged me. Love, you have always had faith in my capacity. It would not have been possible for me to enroll for my master's and start this journey without your support, you had to go through those thumps as well whenever I was having a hard time. You were incredible in managing the time of difficulties and handled family issues with great patience all through my Master's journey. For your continuous moral, and mental support and for always taking care of our beloved Children Alma and Aston, I appreciate you. I love you. To my two wonderful gifts from God my Children Valaroma Alma Kering and Aston Reign Kibet, I am grateful. You are the reason for me doing this, you were patient, kind, and understanding when I was busy with my research. Thank you always and may the God Almighty guide you in your lives. I love you so much. Thank you all

I am grateful to my parents Philip Kipsang Koskei and Ruth Chepkoech Koskei who have always inspired and encouraged me in providing financial and moral support, thanks so much, I appreciate it. To my siblings, Kimurgor Ian, Chesanga Aurelia, Kimengich

Abednego, and last born Malakwen Meshack, I love you guys, and thank you for your support through this journey, this is for you.

I am thankful to all my supervisors and mentors. I would like to thank my lead Supervisor Dr. Heka Kamau for his continuous support and advice throughout my Masters. Not only is he a wonderful human being, but also a very good teacher and mentor. He paid attention to every detail of my research work and turned them outstanding. He encouraged me when I was at a crossroads with completing this study I am forever indebted to you Dr Heka.

I am grateful to my co-supervisors Prof Miriam Kinyua and Dr Emmanuel Ayua who have been very supportive of my research. They mentored me with a positive attitude which is unforgettable. It was not easy for me as a beginner but all my supervisors believed in my capacity and turned my every mistake into a learning point.

Last but not least, my heartfelt thanks go to my colleagues Victor Musi, Sheila Chebichi, Benjamin Namuya, Ann Chebet and Mercy Ngetich who have been very friendly over the past 3 years. Special appreciation to Victor who helped me with the study design and data analysis. I am forever indebted to you my friend for the experiences shared during data collection, analysis and presentations.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AACC- American Association of Cereal Chemists

AOAC - Association of Official Analytical Chemists

BI - Browning Index

CAS - Cassava varieties

CMV - Cassava Mosaic Disease

CV - Coefficient of Variation

DV - Daily Value

FAO - Food and Agriculture Organization

FAOSTAT - Food and Agriculture Organization Statistical Database

Gy - Gray (unit of radiation dose)

HCL - Hydrochloric Acid

HCN - Hydrogen Cyanide

IDD - Iodine Deficiency Disorder

KALRO - Kenya Agricultural and Livestock Research Organization

KME - Parent cassava variety (KME 4)

NUS - Neglected and Underutilized Species

OAC - Oil Absorption Capacity

PV - Peak Viscosity

SB - Set Back

TV - Trough Viscosity

USDA - United States Department of Agriculture

WAC - Water Absorption Capacity

WHC - Water Holding Capacity

WHO - World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Dietary modification is among the strategies to ensure a sustainable food supply to a growing population in the face of climate change (Mora et al., 2020). This involves diversifying from popular conventional staples to more climate-resilient and nutritious food crops (Acevedo et al., 2020). Crops like cassava can be used in the same capacity but can be optimally produced without negatively affecting food and nutrition security or accelerating environmental degradation (Osewe et al., 2021). Cassava, (*Manihot esculenta*) is among the neglected and underutilized species (NUS) with potential dietary modification options. It offers multiple utilization ranging from food to non-food uses and, most importantly, can be a substitute for wheat flour (Kaur et al., 2016).

Cassava is gaining popularity and increase in adoption by farmers due to the root's resilience and adaptability to different drought and nutrient-declining soil conditions (S. Li et al., 2017; Mtunguja et al., 2016). It ranks fourth in consumption among important staple crops globally after rice, wheat, and maize FAO, (2022) and holds a third position for the largest carbohydrate food source below rice and maize (Kinyua & Okwaro, 2021). Cassava has multiple uses at different value chain nodes. For instance, the root is used as food and a cash crop at the homestead level. An average of 71% of the root tuber products are used for human consumption, while the remaining percentage is used in industries such as starch and animal feed (Chepkoech et al., 2015). Farmers generate income by processing it into flour and selling it as fresh or dried roots, aiding in poverty mitigation (FAOSTAT, 2018).

Globally, cassava production has steadily increased in terms of yield and area under cultivation with FAOSTAT 2022) recording a 20% increase in global production between 2010 to 2020 from 251 to 302 million tonnes. Africa accounts for 60% of this production (Oladunmoye et al., 2014). The root has recorded success in adoption, production, and consumption in several African countries like Nigeria. However, its utilization is still not optimized in other regions (Mohidin et al., 2023). In Kenya, cassava production stands below 600,000 tons, with more than 80% of its production happening in coastal, western, and central regions (Githunguri & Njiru, 2021).

Cassava is a significant income-generating root crop for small-scale farmers in Kenya. The cost of producing cassava on a small to medium-scale farm ranges between Kshs 50,000 - 100,000 per hectare while the gross income can range from Kshs 200,000 to Kshs 600,000 per hectare (kilimonews.co.ke/agricultural-products). This can provide a solid return on investment for farmers. Starch production is the predominant industrial application. Kaur et al. (2016) reported that the root could produce 800 g of starch per kilogram of dry matter, making it an efficient and cheap raw material replacing arrow roots as starch feedstock (Marx., 2019). Other industrial products derived from cassava include bioethanol, medicine, feed, cosmetics, and biopolymers (Li et al., 2017)

Despite the numerous benefits associated with cassava, its production and utilization have been hampered by diseases such as cassava mosaic disease (CMV), root rot, and pests such as mites (Kinyua & Okwaro, 2021; Sholihin et al., 2019). Further high amounts of hydrogen cyanide (HCN) in most varieties, above the 10 mg/kg limit set by the World Health Organization (Codex & intergovernmental, 2009) dramatically impact cassava consumption and uptake among the populations (Ouma et al., 2021).

Mutation breeding using gamma rays and efficiency-enhancing mechanisms is effective in addressing some of the challenges in the cassava value chain, besides conferring better nutritional characteristics (Ceballos et al., 2016, 2020; Chaicharoen et al., 2023; Chepkoech et al., 2015; Kinyua & Okwaro, 2021; Sholihin et al., 2019). It involves the alteration of the genetic makeup of an organism without crossing, which helps retain most plant characteristics while altering others such as resistance to pests and diseases (Kinyua & Okwaro, 2021). This technique has been used to produce higher yielding, taller, higher total starch content, mites resistance, and reduced HCN content cassava varieties (Maharani et al., 2015; Ceballos et al., 2016; Sholihin et al., 2019). Mutation breeding has also been adopted and used in producing other food crop varieties such as Irish potatoes (Chepkoech et al., 2022), Dolichos beans (Kamau et al., 2011) and wheat (Kinyua et al., 2000).

Recently, Kenya has developed and commercialized new cassava varieties CAS 1, CAS 2, and CAS 3 through gamma irradiation at the Kenya Agricultural and Livestock Research Organization (KALRO) (Chepkoech et al., 2015). These varieties were selected for their superior attributes, including high resistance to pests and diseases, improved yield potential, and adaptability to diverse environmental conditions. The selection process focused on desirable traits such as tuber size, nutrient content, and processing quality. However, despite the advancements achieved through mutation breeding and gamma irradiation, the nutritional profile and consumer acceptability of the cassava tubers resulting from this process have not been thoroughly explored. Additionally, there is limited information regarding the quality of flour derived from these varieties, appropriate blending ratios for baking, and the types of bakery products that can be effectively

produced using them. This study aims to bridge these gaps by evaluating the physicochemical, functional and sensory characteristics of CAS 1, CAS 2, and CAS 3 in comparison with KME 4. By addressing these overlooked aspects, we seek to provide valuable insights that can enhance the marketability and consumer acceptance of these improved cassava varieties.

1.2 Statement of the Problem

The adoption of cassava as a food security crop in Kenya has been significantly scaled up by the government and other stakeholders due to the increasing food demands of an ever-growing population in the face of climate change. Food and nutrition insecurity in Kenya, which is largely dependent on rain-fed agriculture, is further worsened by the adverse effects of climate change. Staple crops like rice and maize, which are traditionally relied upon, have not seen proportional increases in production. Erratic weather patterns and prolonged droughts have led to declining crop yields, contributing to increased vulnerability among rural communities whose livelihoods are agricultural dependent. Despite practicing Climate-Smart Agriculture (CSA) strategies, many popular conventional crop varieties remain susceptible to these adverse weather conditions and prevalent diseases, limiting their effectiveness in ensuring food security. Consequently, dietary diversification and adoption of indigenous species that are drought, pest and disease resistant is encouraged as a food and nutritional security measure. Cassava (*Manihot esculenta*) is one of such crops. Unfortunately, cassava production and utilization have been challenged by several factors, including infestation by pests, diseases, and tubers with high levels of HCN. Inadequate knowledge of diversified cassava utilization has also

hampered its uptake. To address challenges associated with cassava production, mutation breeding has been adopted.

Through this technology, three improved cassava varieties (CAS 1, CAS 2 and CAS 3) with improved agronomic characteristics were developed from KME4 as the parent. However, to ascertain their application in ensuring food security, the physicochemical and functional characteristics of the improved cassava and their derived products need to be assessed. Further, there is a need to assess the consumer acceptability of such products to ascertain the feasibility of the improved cassava varieties in safeguarding food and nutrition security in Kenya.

1.3 Justification

Findings from this study will provide vital information to farmers regarding attributes of new cassava varieties which will contribute to increased production at the household level. By identifying and promoting these safer varieties, farmers can cultivate cassava that is not only more nutritious but also poses fewer health risks.

Additionally, the study will offer food processors insights into optimal flour blend ratios for producing various baked or fried products using cassava flour. This knowledge will enhance the quality and marketability of cassava-based products, fostering greater integration of cassava into the local food industry.

The government will also benefit from the study by promoting the adoption of elite cassava varieties that demonstrate enhanced resistance to diseases and pests, along with superior nutritional characteristics. This aligns with national goals to address food security challenges in the country.

1.4 Objectives

1.4.1 Broad Objective

To evaluate the physicochemical, functional, and sensory characteristics of three selected improved cassava (*Manihot esculenta*) varieties.

1.4.2 Specific Objectives

1. To evaluate the physicochemical and functional properties of flours developed from three selected improved cassava varieties relative to the parent.
2. To determine the best cassava-wheat flour blend ratio resulting in optimal baking and sensory qualities of subsequent baked products.
3. To assess the consumer acceptability of porridge and cookies made from flours of three selected improved cassava varieties relative to the parent.

1.5 Hypothesis

- i. H_{01} - There is no significant difference in the physicochemical properties of the three selected improved cassava varieties relative to the parent.
- ii. H_{02} - There is no significant difference in the physical properties of cookie blend ratios of the cassava flour with the control (wheat flour)
- iii. H_{03} - There is no significant difference in terms of sensory characteristics of the cassava porridge and cookies from the cassava-wheat blend ratios with the control.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Cassava (*Manihot esculenta*) originated in Brazil and Paraguay and spread through South and Central America (O'Connor, 2013). The crop was introduced to Africa by Portuguese explorers in the 16th century. It gained popularity in West Africa, East Africa and Madagascar (Ceballos et al., 2016). It was then introduced in Asia by the Spanish and distributed throughout tropical Asia by the 19th Century. The crop is essential in Africa, Asia, Latin America, and the Caribbean. It was brought to Kenya through Zanzibar and is cultivated countrywide, although eastern, coastal, and western regions are the primary producers (Githunguri et al., 2015).

2.2 Botany and Taxonomy of Cassava

Manihot esculenta, commonly called cassava manioc, yuca, or tapioca (among numerous regional names) is a woody shrub of the spurge family (O'Connor, 2013).

The best time to harvest cassava, however, varies depending on the genotype (variety) and environmental factors; some are harvested as early as six months after planting, while others are harvested as late as twelve months (Mtunguja *et al.*, 2016)

2.3 Ecological Requirements of Cassava

Being adapted to tropical regions, cassava requires an annual rainfall of 600 mm, high temperatures and solar radiation for optimal leaf development and to allow photosynthesis to take place (Sholihin et al., 2019). Cassava can grow well in high altitudes and low

altitudes. The maximum cassava growth requires temperatures of 25- 29 °C, 0- 1500 m altitude and it is best cultivated in light, sandy loam soils with medium fertility and good drainage (Mtunguja et al., 2016).



Figure 1; A figure showing cassava shrubs. Data sourced from the University of Eldoret (UOE, 2022)



Figure 2; A figure showing cassava roots. Data sourced from University of Eldoret (UOE, 2022).

2.4 Cassava Production.

The cassava root is a source of nourishment for more than 800 million people across the world as a major source of dietary energy (Uarrota et al., 2016). The crop has been appreciated in Eastern and Southern Africa in the recent past due to the poor climatic conditions that have failed other common crops preferred in the regions such as maize and wheat. Cassava ranks as the second most important root crop after the Irish potato and is considered high in production per unit hectare of land and calories compared to maize which is the most preferred staple food (De Groote et al., 2013 and Githunguri & Njiru, 2021). It is also the second-most important crop for starch production worldwide after maize making it vital for the starch processing industries especially in countries around the tropics (Morante et al., 2016).

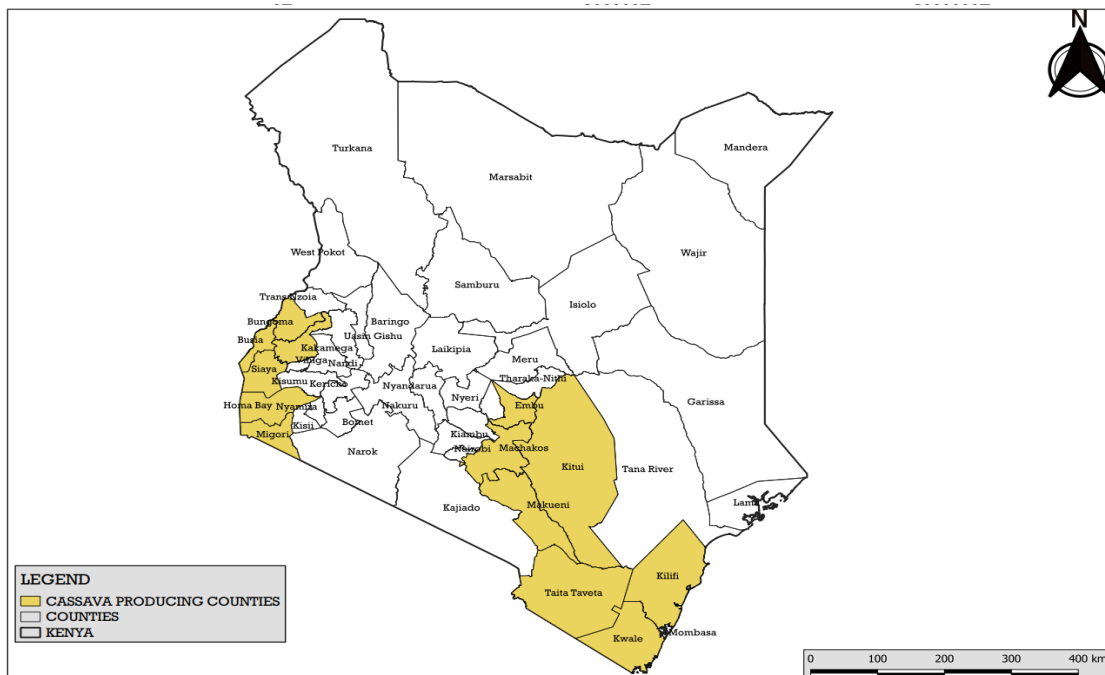


Figure 3; Major cassava-producing zones in Kenya (Data sourced from Kenya Agricultural and Livestock Research Organization (KALRO, 2022)).

Globally, Nigeria is the leading producer of cassava with an annual production of 59 million metric tonnes which is about 18% of the total world production (Rasaq et al., 2020). On average, Kenya produces about 500,000 tons of fresh cassava roots annually (Githunguri & Njiru, 2021). Biophysical factors less impact cassava production; hence its yield directly correlates with the size of land under cultivation and the variety (Lynam et al., 2012). Although Kenya produces less total cassava compared to leading cassava-producing nations, its yield per unit area (such as per hectare) is higher. Figure 2.4 compares cassava production per unit area for Kenya, Nigeria, and the world (FAOSTAT, 2022).

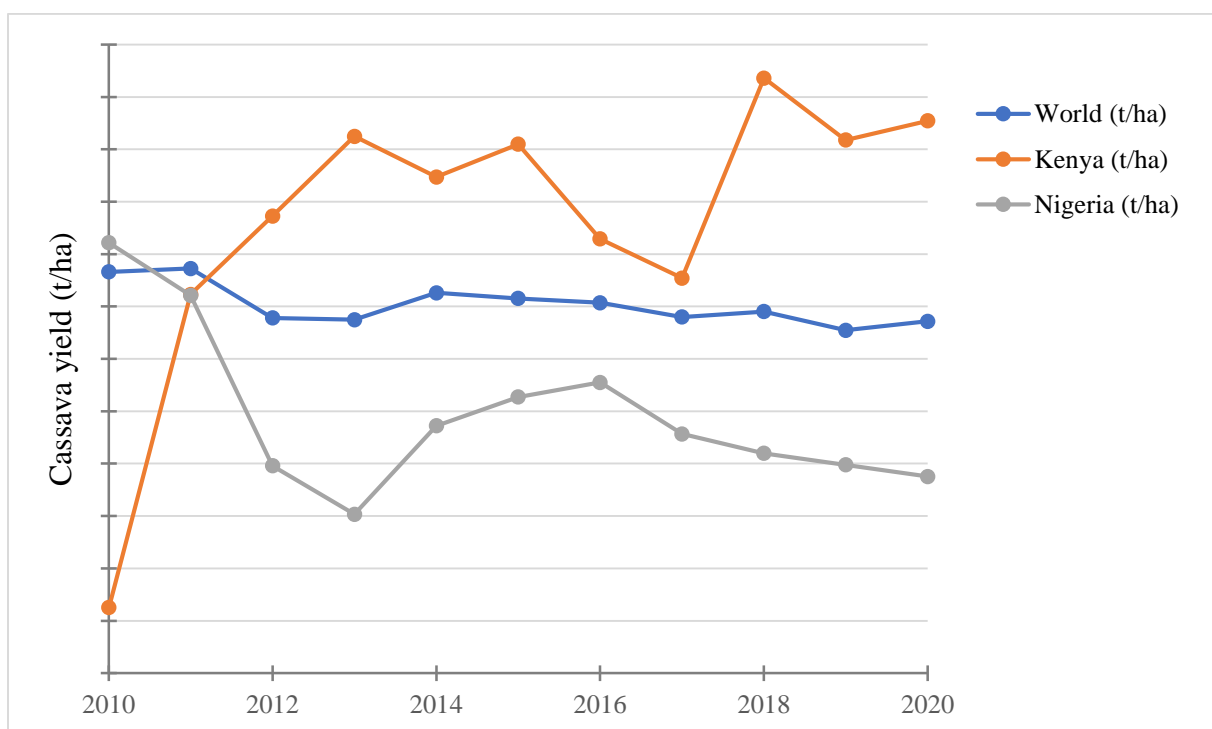


Figure 4; Cassava production per unit area (Data obtained from FAOSTAT 2022)

2.5 Cassava Consumption

Globally, the consumption of cassava is projected to rise, occasioned by declining production of other food crops and a need to diversify nutrition sources to embrace climate-tolerant ones (Ikuemonisan & Akinbola, 2021). More than 80% of cassava produced in Africa is for subsistence. Preparation and cooking involve making flour, often blended with other flour for porridge and *ugali* (Githunguri & Njiru, 2021). Cassava is a versatile crop that can be transformed into various products, including pastes and crisps, serving as popular fast foods in both rural and urban areas. Fried cassava chips, for example, are widely enjoyed snacks that are easily prepared and commonly found in local markets and restaurants (Ouma et al., 2021). In Kenya, these chips, known locally as "mogo" or "kachori," are often thinly sliced, fried to a crispy texture, and seasoned with chili and lime, making them a flavorful treat (Abong et al., 2016). Other common cassava products, especially in West Africa, include; fermented and ponded cassava (*fufu*) flakes, macaroni, and roasted roots (Falade & Kolawole, 2013). The increasing need for high-quality cassava flour in different food and pastry industries has increased cassava's value and potential as an economical crop for small-scale farmers hence the increase in production (Ironi et al., 2019).

Cassava roots and leaves are the main edible parts of the plant and are considered the most nutritious parts of the cassava plant (Panghal et al., 2021) The roots are used for food and animal feed, while leaves are eaten as vegetables in some cultures (Ceballos et al., 2016). The western region of Kenya ranks first in the consumption of cassava across the country, consuming more than 60% of the total nationwide production. While central and coastal regions consume about 30% and 10%, respectively (Kiura et al., 2010). In the regions

mentioned, cassava ranks second as the most preferred staple food after potatoes and maize respectively which is the reason for sustaining the high production (Odero & Whyte, 2004).

2.6 Utilization of Cassava in Kenya

Cassava is mainly considered a carbohydrate root crop containing comparatively more starch than other food crops (Odedeyi et al., 2022). About 90% of cassava grown in Kenya is consumed, 6% is used in the formulation of animal feeds, and the remaining is processed into several industrial products Mulu-Mutuku et al. (2013). Cassava is often perceived as a low-status or "poor man's" food, which has limited its adoption as a staple in major urban areas. Instead, it is more commonly consumed in snack forms, such as crisps and fried cassava chips, rather than being a primary food option. Cassava roots are mainly dried and mixed with other cereals like maize, millet, and sorghum, then milled into flours (Njue & Wawire., 2021). The flour is used to prepare *ugali* or porridge consumed by all household members (Wanjala et al., 2016). A study by Bilate et al. (2023) indicates that cassava utilization consists of home consumption (51.87%), market use (43.68%), and animal feed (4.26%), with processing methods including boiling and flour cooking. Additionally, cassava is processed into mocaf flour by fermenting it with lactic acid bacteria, enabling the production of bread, noodles, and cakes (Daemo et al., 2023). Cassava is majorly utilized in Kenya as a food crop. It is processed into flour used to make *ugali*, a thick porridge or it is boiled (Githunguri & Njiru., 2021). The cooking quality of cassava depends on the varieties and the interaction of the environment and climate in which the crop is grown. Three major categories are recognized regarding cooking quality, and they include non-cookable which comprises bitter varieties of cassava that are only applicable for industrial use (Ngeve., 1998). The second category comprises glassy root varieties whose

classification comes from how they appear after cooking. They are also characterized by difficulty chewing regardless of the degree of cooking. The third category is the mealy cassava which comprises sweet varieties that soften quickly after cooking and are floury in texture (Mugalavai et al., 2018). Bio-fortification of cassava with other products such as wheat flour and orange-fleshed sweet potato (OFSP) flour in bread production has been studied as a way to improve its utilization and also to improve nutritional value, such as increasing beta carotene content (Masrikhiyah., 2021). Given that the crop is considered a poor man's diet, minimal research has been conducted in Kenya concerning how consumers would accept the different modifications

2.7 Nutrient Composition of Cassava

The nutritional composition of cassava roots is highly varied depending on several factors including the location of production, variety, environmental factors, and also the age of the plant at the time of harvest (Hasmadi et al., 2020).

2.7.1 Carbohydrates

Cassava is predominantly composed of carbohydrates making it a significant energy source (Hasmadi et al., 2020). In a 100-gram serving of cooked cassava, approximately 40 grams of carbohydrates are present, which accounts for about 80% of its total caloric content (USDA, 2023). Cassava starch is a vital carbohydrate source characterized by its unique composition of glucose polymers, primarily amylose (17–25%) and amylopectin (75–83%), which vary depending on genetic traits, environmental conditions, and post-harvest processing methods (Wang et al., 2023). Compared to cereal starches like wheat or rice, cassava's lower amylose content contributes to its rapid digestibility, as linear amylose chains form resistant crystalline structures that slow

enzymatic hydrolysis, while branched amylopectin is more accessible to digestive enzymes such as α -amylase (Adeyanju et al., 2024). This structural distinction makes cassava starch highly digestible, with studies showing that in vitro starch digestibility reaches asymptotic levels faster (within 2–4 hours) under high-temperature processing (e.g., 90°C) or puffing conditioning (PU), which disrupts hydrogen bonds between starch molecules and enhance gelatinization (Conde et al., 2022). The digestibility of cassava starch is further influenced by processing techniques like mechanical crushing (MC) which retains more native starch granules with intact semi-crystalline structures, whereas steam conditioning (SC) alters granule integrity, increasing surface area and amylase susceptibility (Conde et al., 2022). These modifications are critical for applications requiring smooth texture and stability, such as gluten-free products, where cassava's low amylose content prevents excessive gel rigidity and ensures a desirable mouthfeel (X. Wang et al., 2023). Additionally, cassava starch's functional enhances its utility in diverse food systems, from baked goods to animal feed, by tailoring digestibility profiles to meet specific nutritional or industrial demands (Adeyanju et al., 2024). Overall, cassava's starch composition and processing plasticity position it as a versatile ingredient in both human and animal nutrition, balancing digestibility with functional performance.

2.7.2 Protein

The protein content in cassava is relatively low, with about 1.5 grams per 100 grams (USDA, 2023). Because of this, cassava is not a sufficient source of protein when consumed as a staple diet. In order to meet nutritional needs, other protein sources must be included in the diet because the protein in cassava lacks some essential amino acids (Khajarearn & Khajarearn, 1992). In addition to being scarce, the protein in cassava is

deficient in some vital amino acids. In particular, cassava lacks lysine, an essential amino acid required for the synthesis of proteins, hormones, and enzymes. In order to maintain healthy skin and connective tissues, lysine is essential for immune system function, calcium absorption, and the synthesis of collagen and elastin (Zidenga *et al.*, 2017). Methionine and cysteine are sulfur-containing amino acids that are essential for metabolism and protein synthesis. According to Zidenga *et al.* (2017) methionine is necessary for the start of protein synthesis and serves as a precursor for cysteine, which is crucial for detoxification and antioxidant defense. Relying exclusively on cassava for protein intake can result in nutritional gaps because of these deficiencies, which could have an impact on general health and wellbeing.

Because of its low protein content and insufficient amino acid profile, cassava must be supplemented with other foods high in protein. The low protein intake of vulnerable populations has been linked to their dependence on cassava as a staple diet. An observational study conducted in Kenya and Nigeria found that 53% of Kenyan children who consumed large amounts of cassava had inadequate protein intake. Dietary diversity had an inverse relationship with this (Stephenson *et al.*, 2010).

2.7.3 Fats

Raw cassava contains approximately 0.28 g/100 g while cooked contains 0.3 g/100 g of fat. (Oyeyinka *et al.*, 2019). This low-fat content indicates that cassava does not significantly contribute to dietary fat intake. Cassava contains both monounsaturated and polyunsaturated fatty acids. Notably, oleic acid (C18:1) is the primary monounsaturated fatty acid, constituting approximately 35.9% of the total fatty acids. Linoleic acid (C18:2),

a polyunsaturated fatty acid, accounts for about 15.7% of the total fatty acids (Dangarembizi et al., 2015). According to a study by Królikowska et al. (2022), the complexation of cassava starch with fatty acids such as oleic and linoleic acid enhances its functional properties. The presence of oleic acid not only improves the stability and texture of cassava-derived products but also increases the percentage share of fatty acids in the total composition. This implies that although cassava has a low fat content, its nutritional qualities and uses in food technology can be altered by its interactions with specific fatty acids.

The low-fat content in cassava means that it does not provide a significant source of essential fatty acids or contribute substantially to overall dietary fat intake (Hasmadi *et al.*, 2020). However, the unsaturated fats present can have beneficial effects on cardiovascular health when included as part of a balanced diet. Health organizations recommend replacing saturated fats with unsaturated fats to reduce the risk of heart disease (Królikowska *et al.*, 2022).

2.7.4 Dietary Fiber

Cassava contains approximately 2 grams of dietary fiber per 100 grams (USDA, 2023). This fiber content is lower than that of many whole grains and legumes, but it is still good for digestive health. For example, whole grains can provide between 6 to 12 grams of fiber per 100 grams, making them more effective in promoting digestive health and preventing constipation (Slavin, 2013).

2.8 Minerals in Cassava

Cassava is a widely consumed root vegetable known for its high carbohydrate content. However, it also provides several essential minerals that contribute to its nutritional profile.

They include;

2.8.1 Calcium

Calcium is an essential mineral important for bone health, muscle function, and nerve transmission. In cassava, the calcium content is relatively low, providing about 0.18 g/100 g of cooked cassava, which accounts for approximately 2% of the Daily Value (DV) (USDA, 2023). While cassava can contribute to calcium intake, it is not a significant source compared to dairy products or leafy greens. Adequate calcium intake is crucial for maintaining bone density and preventing osteoporosis (Ayetigbo et al., 2018)

2.8.2 Magnesium

Magnesium plays a vital role in numerous biochemical reactions in the body, including energy production, protein synthesis, and muscle function. Cassava contains about 27 g/100 g of magnesium contributing approximately 5% of the Daily value DV (USDA, 2023). Magnesium deficiency can lead to various health issues such as muscle cramps, fatigue, and increased risk of chronic diseases like hypertension and type 2 diabetes (Micha et al., 2017). The presence of magnesium in cassava can support overall metabolic health when included as part of a balanced diet (Ayetigbo et al., 2018)

2.8.3 Iron

Iron is crucial for the formation of hemoglobin in red blood cells and plays a vital role in oxygen transport throughout the body. Cassava contains approximately 0.5 mg/ 100 g, which provides about 3% of the DV (USDA, 2023). However, cassava's iron content is relatively low compared to other sources such as red meat or legumes. Iron deficiency can

lead to anemia, characterized by fatigue and weakness (Ayetigbo et al., 2018). Therefore, individuals relying heavily on cassava should consider incorporating other iron-rich foods into their diets to meet their nutritional needs.

2.8.4 Zinc

Zinc is an essential trace mineral involved in numerous biological functions including immune response, protein synthesis, and wound healing. Cassava contains about 0.3 mg of zinc per 100 grams, providing around 2% of the DV (Dada., 2016). While this amount contributes to overall zinc intake, it is lower than that found in meat, shellfish, legumes, and seeds. Zinc deficiency can impair immune function and slow down growth and development in children (Bayata., 2022).

2.9 Functional Properties of Cassava Flour

Functional properties are essential in determining how food components behave during processing and cooking, directly influencing the final product's texture, appearance, flavor, and other characteristics. Cassava flour, known for its versatility, is widely used in various industries such as food, pharmaceuticals, and textiles. Its functional properties are key to its suitability in different applications.

2.9.1 Water holding capacity

One of the most significant functional properties of cassava flour is its water-holding capacity (WHC). Studies have shown that cassava flour exhibits a high WHC compared to other cereal flours, ranging between 1.12 and 1.30 mL/g (AACC et al., 2009; Agbemafle, 2019). This high WHC is attributed to its starch composition, lower retrogradation tendencies, and favorable melting properties creating a matrix that can absorb and retain

water effectively. Amylopectin's branched structure and phosphate groups facilitate the formation of a sponge-like network that traps water, enhancing the starch's ability to hold water (Agbemafle, 2019). This property is crucial in food applications, such as in meat products or baked goods, where maintaining moisture is important. The addition of up to 10% cassava flour to cereal composites has been found to increase the overall water absorption capacity of the mixture (Verma et al., 2023).

2.9.2 Oil absorption capacity

The oil absorption capacity (OAC) of cassava flour is influenced by its starch granules' lipophilic nature and protein content. Flour soaks up oil because starches naturally attract fats, effectively trapping them (Dudu et al., 2020). Proteins contribute too - their structure allows them to grab onto oils, boosting absorption (Ezekiel et al., 2007). Oil absorption and retention are facilitated by a mechanism that involves the interaction of hydrophobic protein regions with lipophilic sites on starch granules. Furthermore, treatments such as drying or covering flour bits with proteins from sources like whey or soybeans alters how they behave, making them even better at capturing and keeping oil (Agbemafle, 2019). This characteristic is crucial for food formulations because it influences shelf life, texture, and flavor retention, especially in baked goods and other processed foods.

2.9.3 Swelling power

Cassava flour swells more than wheat flour - between 10.48 to 12.04 times as much. This happens because cassava contains more starch, also its starch pieces don't stick together very tightly (Hasmedi et al., 2020). Cassava blends swell up nicely they absorb lots of liquid, so baked goods turn out denser yet less brittle. Solubility? It varies by type, generally

between 11% and nearly 21% (Kayode et al., 2021). This rise can improve baked goods' overall quality by influencing dough cohesiveness and texture.

2.9.3 Bulk density

Cassava flour isn't as dense as wheat flour - wheat typically measures around 0.80 g/cm³, whereas cassava falls between 0.40 and 0.70 g/cm³ (Hasmadi et al., 2020). Because cassava contains less protein or fat, it weighs less, so it works well when creating lighter foods packed with nutrients. However, things such as how much fiber exists, how fine the grains are, alongside water levels impact density; more water means greater weight (Hasmadi et al., 2020).

2.10 Pasting Properties of the Cassava Flour

Pasting properties describe how starches behave when subjected to heat and water, playing a crucial role in determining the texture, consistency, and stability of various food products. For cassava flour, the key pasting properties include peak viscosity, breakdown, and final viscosity.

Peak viscosity refers to the highest viscosity reached by cassava starch during heating in the presence of water, reflecting the starch's capacity to absorb water and swell. Because of how its tiny parts are built, cassava flour generally gets much thicker than most other starchy powders when heated. It also thickens better, becoming jelly-like with ease (Oladunmoye et al., 2014). The high peak viscosity is particularly useful in applications such as soups, sauces, and baked goods that require thickening. Studies reveal more cassava starch within flour mixes boosts how thick they get when heated a sign. Water uptake was better, likewise starch became more fully gelatinized (Abiodun & Abimbola,

2014). When cassava flour has a high peak viscosity, it works great in foods needing body - think sauces or fillings Good food especially when making things without gluten - hinges on this step (Otegbayo et al., 2013).

Viscosity breakdown tells you how much thicker a starch mixture gets before it thins out. Viscosity often reaches its highest point through ongoing heat application alongside forceful mixing. Cassava flour doesn't quite hold its thickness like some others; instead, its starches get puffy. These materials don't hold up well when exposed to both high temperatures alongside forceful pressure (Hasmadi et al., 2020). If pastes flow poorly - too thick, really - they become unstable during manufacturing; therefore, viscosity matters a lot. Techniques employing starches built to withstand digestion have been explored (Lu et al., 2020). For things such as cakes - where keeping a good shape is vital - cassava flour helps stabilize them. Properties that readily separate give a benefit - they keep moisture levels right while avoiding complete disintegration into tiny bits of starch (Oladunmoye et al., 2014).

Once starch thickens with heat, its final viscosity reveals how fluid - or not - it becomes as it chills. It is a key indicator of the starch's ability to form a stable gel and retain structure after cooling, which is important in products like puddings, porridges, and other foods that may be consumed cold or reheated (Lu et al., 2020). Cassava flour generally shows high final viscosity, which is beneficial for creating firm, stable textures in products (Omenai et al., 2024). This high final viscosity is attributed to cassava's strong water-binding capacity and low retrogradation tendency, making it suitable for products where texture retention is critical over time (Abiodun & Abimbola, 2014; M. Li et al., 2023). High final viscosity

also enhances the quality of gluten-free baked goods, as it contributes to the formation of consistent textures without the need for gluten (Wanjala et al., 2016).

2.11 Cassava Associated Health Concerns

Cassava faces a real threat from fungi due to the conditions where it grows (de Oliveira *et al.*, 2022). Similar to staples like rice likewise maize, these crops are susceptible to fungal issues throughout their journey - from field to table to pantry (Adebayo, 2023). Research indicates that *Aspergillus* alongside *Fusarium* are key culprits when it comes to cassava contamination. Fumonisin, poisons produced by *Fusarium* mold, build up and harm people. Consuming cassava containing these toxins links to cancers alongside several health issues (Frolova, 2023). Controlling contamination from bacteria or fungi demands careful quality checks, cleanliness, likewise proper food handling (Manjula *et al.*, 2009; Ono & Taniwaki, 2021).

Improperly prepared cassava can cause iodine deficiencies because cyanide hinders how the body absorbs iodine - this then results in goiters (Abuye et al., 1998). Cyanide, liberated from within cassava, obstructs iodine intake by the thyroid; consequently, less iodine appears in urine while goiter rates climb.

Kenyan scientists crafted new cassava types containing less of a naturally occurring toxin, aiming to improve public health (Mugalavai, Yabann, *et al.*, 2018). Alongside this, time-honoured techniques - fermenting, roasting, careful peeling, then pounding - effectively lower cyanide, making the root vegetable safer to eat.

2.12 Sensory Evaluation and Consumer Acceptability of Cassava Products

We experience food through five senses - taste, feel, aroma, vision, hearing - which help us judge its traits. Experts call this sensory evaluation (Lawless & Heymann, 2010). Where folks cultivate cassava, they generally welcome it into their diets - though preferences shift depending on location. Take Kenya, for example; in drier areas unsuitable for many crops, cassava now feeds communities (Dele, 2001).

Research into different cassava foods – from the root itself to thinner porridges and flour blends – reveals what people like. Specifically, how something tastes, feels when eaten, also its look really matters to whether folks will choose it, according to Eriksson *et al.* (2014). Additionally, Obi *et al.* (2019) discovered that mixing cassava flour with others - wheat, for example - made baked items more appealing, improving how they tasted. Consequently, crafting cassava recipes considering what people locally enjoy seems vital for sales success.

Additionally, sensory evaluation should occur at multiple stages throughout the product life cycle, as recommended by (Mihafu et al., 2020). This multi-disciplinary approach can guide product development, improvement, and grading, providing valuable insights into consumer preferences and market viability. Evaluating new cassava varieties (CAS 1, 2, and 3) and their parent variety (KME 4) through sensory analysis can offer early indications of their potential acceptance in the consumer market.

2.13 Effect of Gamma Irradiation on Cassava Physicochemical, Functional and Sensory Characteristics

An isotope releases energy as light - that's gamma irradiation. People employ this technique to kill microbes, thereby keeping food, beauty products, and their containers safe (Handayani & Permawati, 2017). Moreover, scientists apply it to cassava plants, encouraging new variations alongside improved characteristics. Gamma rays alter how starch behaves - it dissolves easier while becoming less thick. Consequently, this makes it better for use in foods (Verma et al., 2023). Moreover, pairing gamma radiation alongside genetic tools speeds up improvements to cassava; scientists have created versions yielding more crops with greater starch levels ((Khumaida *et al.*, 2015) Indeed, these rays also helped produce cassava packed with beta carotene, a vital ingredient for antioxidants, by triggering mutations. Researchers created three new types of cassava using gamma rays. These rays are key to improving cassava - they help develop plants better suited for eating, animal food, or manufacturing. Therefore, understanding how these rays affect both the new varieties also their origins is important.

2.13.1 Effects of Gamma Irradiation on the Cassava Nutrients

Cassava is a vital staple food in many tropical regions, valued for its high carbohydrate content. However, the nutritional quality of cassava can be influenced by various processing methods, including gamma irradiation.

2.13.1.1 Impact on Starch Composition

As reported by Asare & Darfour. (2024), exposing cassava to gamma ray's changes how much starch it holds. They found that between 5 to 20 kGy of radiation lowered levels of both amylose - a type of carbohydrate - and overall carbohydrates within the cassava starch itself. For instance, amylose dropped from 20.21% in untreated cassava down to only 13.27% after receiving the maximum radiation amount. Irradiating cassava starch with

gamma rays changes how it behaves - how easily it dissolves, swells up when wet, and how our bodies digest it. Essentially, the radiation snips apart the chains that make up the starch, shortening them. Because of this, the starch blends into water better. This breakdown means enzymes can work on it more readily, which is useful if you need a starch that mixes well (Kumar et al., 2017).

Gamma irradiation's impact on how much a substance swells isn't simple; it shifts with the details. Usually, swelling goes down as radiation levels climb - especially within starches already treated with heat - because components break apart, limiting water uptake (Sunder et al., 2022). Yet, occasionally research shows swelling actually rises when doses get quite high (over 5 kGy), seemingly because alterations in structure let water seep further inside (Verma et al., 2023).

Lowering amylose levels changes how cassava starch thickens or forms pastes – important qualities when used in foods (Asare & Darfour, 2024). Also, gamma irradiation usually improves how easily our bodies digest this starch because it lowers amylose while also chopping up large starch structures. Consequently, digestive enzymes gain better access, speeding things up yet lessening the amount of starch that remains undigested, especially with greater radiation exposure (Oyeyinka et al., 2019).

2.13.1.2 Effects on Protein

Cassava protein shifts with gamma irradiation - research indicates a notable change in both how much protein exists within it, likewise its qualities Gamma rays demonstrably alter cassava's proteins. Studies show exposing cassava starch to radiation – between 5 to 10 kGy – boosts its protein (Khumaida et al., 2015; Sunder *et al.*, 2022).. It seems gamma rays break down larger proteins, yielding simpler building blocks like peptides alongside amino

acids because of newly formed free radicals. This happens by snipping those connections holding proteins together. When proteins get zapped with gamma rays, things fall apart – bonds weaken, structures unravel, so they dissolve easier. Consequently, this breakdown helps us digest protein better, releasing amino acids our bodies can actually use.

How proteins respond to gamma rays hinges on the amount of radiation they receive, altering both their shape also how well they work (Bahraini et al., 2017). A small dose 2 Gy - might actually boost protein amounts while making them easier to break down because subtle shifts in form allow digestive enzymes better access. While moderate exposure - up to 10 Gy - boosts protein levels, exceeding that amount damages them. Too much radiation alters proteins, causing them to clump together or unravel, ultimately losing their usefulness. Radiation breaks crucial connections within proteins, which then impacts how well they work. Therefore, while some radiation helps, too much causes problems. This structural change can expose hydrophobic regions, making proteins more susceptible to aggregation or degradation (Wang et al., 2018).

2.13.1.3 Effect on Fats

Cassava is characterized by its low-fat content, typically around 0.47% in tuber samples (Momchilova et al., 2023). Gamma irradiation has been found to decrease fat content significantly; for instance, at a dose of 10 kGy, fat content can drop to 0.19% (Momchilova et al., 2023). Gamma irradiation significantly impacts the lipid content of cassava by breaking down lipids into smaller components such as fatty acids and glycerol. This reduction in fat content is a direct result of radiation exposure, which cleaves triglycerides into these smaller molecules. Consequently, the alteration in fat content also affects the fatty acid profile, as observed by Olotu et al. (2014).

Furthermore, gamma irradiation promotes lipid oxidation, which is a critical factor in altering the composition of unsaturated fatty acids. Lipid oxidation involves the formation of free radicals that initiate peroxidation, leading to the degradation of unsaturated fats (Olotu et al., 2014). This process not only changes the fatty acid profile but also affects the nutritional quality and stability of cassava products (Olotu et al., 2014). Overall, gamma irradiation's effects on lipid breakdown and oxidation are intertwined, influencing both the quantity and quality of lipids in cassava.

Studies show a curious thing about fats: though some hold up well when treated just right, too much radiation actually messes with their quality. When fats break down, oils get more acidic - a sign they're going bad (Dikkala & Shirisha, 2018). Interestingly, radiation also lowers the fat content in foods like cassava; this could be good if you're watching calories or trying to eat less fat (Saad & Kabbashi, 2014). Lowering fat isn't always a win. It causes fats to decompose, shifting their composition - affecting how nutritious they are (I. Asare & Darfour, 2024). Though less fat seems good, this process invites oxidation while making vulnerable fats less stable. Healthy unsaturated fats degrade when overexposed, creating unwanted compounds that might negate any benefit from lower overall fat (Saad & Kabbashi, 2014)

2.13.1.4 Effects on Dietary Fiber

The dietary fiber content in cassava is approximately 2 g/ 100 g, primarily consisting of insoluble fiber (El-Moneim et al., 2022). Cassava has around 2 grams of fiber per 100 grams, mostly the kind that doesn't dissolve in water. Gamma rays break down the connections holding these fibers like cellulose likewise hemicellulose using bits created during the process. Irradiation breaks down fibers, making them easier to dissolve also

boosting how well they feed good gut bacteria (Choi et al., 2012). Though research focusing on certain soluble fibers isn't extensive, irradiation generally allows gut microbes greater access to fiber, possibly leading to better digestion (Choi et al., 2012). Furthermore, it boosts resistant starch in cassava; this then serves as food for helpful gut bacteria, supporting healthy digestion too (Asare & Darfour, 2024). How much things shift hinges on the amount of gamma rays applied. A little radiation (1–5 kGy) might tweak the fiber's makeup, possibly making it dissolve easier -yet doesn't really break it down. However, a strong blast (10–20 kGy) thoroughly damages its structure, shifting how easily it dissolves versus remaining solid (Asare & Darfour., 2024).

2.13.2 Influence on Mineral Bioavailability

Food exposed to gamma rays doesn't lose nutrients; instead, it could help our bodies absorb minerals more easily. Study indicate overall mineral amounts stay about the same after irradiation, yet the way these foods are structured may shift, allowing us to benefit from those minerals more effectively (Osae., 2001)

2.13.2.1 Calcium Content

Food gamma irradiation typically doesn't change how much calcium is present - even in foods such as cassava - with amounts up to 10 Gy having little impact (Osae, 2001). Though irradiation can boost calcium absorption by diminishing compounds that block it, like phytic acid (Chepkoech et al., 2022). Yet, larger doses, specifically 15–20 Gy, sometimes cause a dip in calcium levels. Gamma rays generally keep calcium amounts stable, perhaps even making it easier for the body to absorb because they alter how the food is built (Suriya et al., 2017).

2.13.2.2 Magnesium Content

Food - even cassava - doesn't usually lose much magnesium when exposed to gamma rays. Research with things like faba beans shows that small amounts of this type of radiation keep magnesium levels stable; indeed, cooking or radiating these beans didn't notably change how much magnesium they held (Khan et al., 2018). Irradiation helps your body get more from magnesium found in food. It does this by altering the food itself, specifically breaking down substances that lock up magnesium – think of phytic acid as a mineral thief. With fewer blockers, magnesium is freed to be absorbed while you digest (Janthanasakulwong & Yoksan, 2024). Cassava shows consistent magnesium levels even after gamma irradiation. Likewise, research on legumes demonstrates minimal impact from small amounts of gamma radiation on their magnesium - according to (Osae, 2001)

2.13.2.3 Zinc Content

The effects of gamma irradiation on zinc content can vary between different food matrices. Some studies reveal that while the total zinc levels in cassava may remain unchanged, the bioavailability of zinc could improve due to the breakdown of phytates substances known to inhibit zinc absorption (Ayetigbo et al., 2018; Osae, 2001). This phenomenon highlights the potential benefits of gamma irradiation in enhancing the nutritional benefits of cassava and similar foods.

2.13.2.4 Iron Content

Iron content in cassava is generally stable when exposed to gamma irradiation. Nevertheless, as with zinc, irradiation may positively influence iron bioavailability (Asare & Darfour, 2024). It can effectively reduce antinutritional factors, such as phytates, which typically bind iron and hinder its absorption (Osae, 2001). This enhancement is significant

for improving the nutritional value of cassava, particularly for populations that rely heavily on it as a dietary staple (Janthanasakulwong & Yoksan, 2024).

2.13.3 Effects of Gamma Irradiation on the Functional Properties of Cassava Flour

Gamma irradiation is a type of ionizing radiation widely used in food processing to induce mutations, sterilize food products, and improve the shelf life of crops. When applied to cassava, gamma irradiation can significantly affect its functional properties, which are crucial for determining its usability in various food applications. These functional properties include water absorption capacity, oil absorption capacity, swelling power, solubility, and pasting properties.

2.13.3.1 Water Absorption Capacity (WAC)

Cassava flour soaks up water when we cook with it - that's its water absorption capacity. Exposing the flour to gamma rays changes how well it does this, dismantling the tiny building blocks within the starch. Consequently, the flour becomes better at holding onto water (Agyei-Amponsah et al., 2015). Gamma rays, from 10 to 50 kGy, seem to boost water-holding capacity smaller bits of starch created by the radiation provide more places for water to cling. Yet, go beyond that, deliver a bigger dose, then too much damage to the starch actually lowers its ability to absorb water.

2.13.3.2 Oil Absorption Capacity (OAC)

Exposing cassava flour to gamma rays changes how much oil it soaks up, because it modifies the outer layer - specifically, how water-repellent the tiny bits inside become. When exposed to small to medium amounts of radiation, cassava flour develops more of a desirable compound - this enhances taste also texture in things such as pastries or chips

(Ocloo et al., 2012). This effect is due to the exposure of hydrophobic groups within the starch granules, which are otherwise buried in the starch matrix (Mandal et al., 2020).

2.13.3.3 Swelling Power

Swelling power is the capacity of starch granules to expand when exposed to water and heat. Gamma irradiation generally reduces the swelling power of cassava starch. This decrease occurs because irradiation disrupts the crystalline structure of the starch granules, limiting their ability to absorb water and swell. Studies show that swelling power decreases with increasing gamma radiation doses due to partial depolymerization of amylopectin and the weakening of hydrogen bonds that normally stabilize the starch granule structure (Chisenga, Workneh, Bultosa, & Alimi, 2019)(Raffi et al., 2014; Chisenga et al., 2019). This reduction in swelling power is important in controlling the texture of products like sauces, soups, and batters.

2.13.3.4 Solubility

Solubility refers to the extent to which starch granules dissolve in water upon heating. Gamma irradiation tends to increase the solubility of cassava starch, particularly at higher doses (Ocloo et al., 2012). The increase in solubility is attributed to the breakdown of amylose and amylopectin molecules into smaller fragments, which are more readily dissolved in water. The increased solubility of the cassava that was radiated can have an advantage in food products requiring rapid breakdown and consistency, such as instant foods and beverages (Raffi et al., 2000).

2.13.3.5 Bulk Density

An essential functional characteristic for handling and packing cassava flour is bulk density. Because radiation exposure can cause the starch granules to break down and form

fine particles, gamma irradiation can lower the bulk density of cassava flour (Agyei-Amponsah et al., 2015). This lower bulk density makes irradiated cassava flour suitable for applications in lightweight food formulations such as instant powders and low-calorie products.

2.13.4 Effect on Pasting Properties

The pasting characteristics of cassava flour, such as its peak, breakdown, and final viscosities, are also impacted by gamma irradiation. According to research, gamma irradiation tends to lower the peak viscosity of cassava flour because it partially depolymerizes the starch molecules, reducing their capacity to hold water and limiting their ability to swell during the gelatinization process (Abdullah et al., 2018). This viscosity reduction is especially important for applications that call for a lower viscosity, like making some baked goods or extruded products. Furthermore, gamma irradiation reduces the breakdown and final viscosities, which makes the starch paste less stable when cooled (Chisenga, Workneh, Bultosa, & Laing, 2019)..

2.13.5 Influence of Gamma Irradiation on the Acceptability of Cassava Products

Gamma irradiation is increasingly recognized as an effective method for improving the safety and quality of food products, including cassava (Arapcheska et al., 2020). This technique utilizes high-energy gamma rays to reduce microbial load and extend the shelf life of food items, thereby addressing common concerns related to spoilage and foodborne illnesses (Arapcheska et al., 2020). By minimizing microbial contamination, gamma irradiation enhances the overall safety of cassava products, making them more appealing to consumers who prioritize food safety (Indiarto et al., 2023).

Gamma irradiation can significantly enhance the sensory qualities of cassava products by modifying their chemical and physical properties. One notable effect is the breakdown of starch molecules into simpler sugars, which can increase the sweetness and improve the taste profile of cassava-based dishes (Maherani et al., 2016). This process involves the cleavage of glycosidic bonds within starch granules, leading to the formation of more easily digestible sugars that enhance palatability. Additionally, gamma irradiation can reduce the viscosity of cassava flour suspensions by breaking down starch granules into smaller fragments, making them easier to mix and process (Asare & Darfour, 2024). This reduced viscosity enhances the versatility of cassava flour in various culinary applications.

Furthermore, gamma irradiation can alter the color and appearance of cassava products. The formation of new chromophores or the degradation of existing pigments can result in changes in color, such as increased yellowness, which can affect consumer perception and preference (Katunzi & Fortunatus, 2022). Texture modifications are also significant, as the structural changes in starch granules can lead to a softer or more pliable texture, making cassava flour more suitable for different uses (Kilewela & Fortunatus, 2022). These sensory enhancements are crucial for market success, as consumers often prioritize products with appealing taste, texture, and appearance.

Consumer studies have indicated that products with improved sensory qualities are more likely to be accepted and purchased because enhanced attributes such as taste, texture, and aroma make food products more appealing and enjoyable to consume (Maherani et al., 2016). For example, irradiated cassava flour can serve as a substitute in traditional recipes, potentially leading to greater consumer acceptance in regions where cassava is a staple.

The enhanced quality can help bridge the gap between traditional food preferences and the growing demand for safer, longer-lasting food options.

2.14 Summary of the Literature Review

This literature review focuses on the physicochemical and sensory characteristics of improved cassava varieties that have been developed using gamma irradiation. Cassava is a crucial staple food in many regions, yet its acceptance can be limited by factors such as spoilage and sensory qualities. Gamma irradiation has emerged as a promising technique to enhance the safety, shelf life, and overall quality of cassava products.

Studies have shown that this method can prevent spoilage, making cassava a more reliable food source (Indiarto et al., 2023; Sholihin et al., 2019). Furthermore, physicochemical analyses reveal that gamma irradiation can alter the starch composition and improve the nutritional profile of cassava varieties, leading to enhanced cooking and processing qualities (Aidoo et al., 2022).

Sensory evaluation studies highlight that gamma-irradiated cassava varieties exhibit improved attributes such as flavor, aroma, and texture. Research by Katunzi-Kilewela & Fortunatus. (2022) demonstrated that these enhancements lead to higher consumer acceptability, indicating a positive response to products that are both safe and organoleptically appealing. The improvements in sensory characteristics are particularly important, as they align with consumer preferences and can drive market adoption of these improved varieties.

Overall, the literature underscores the potential of gamma irradiation not only to enhance the safety and shelf life of cassava products but also to improve their physicochemical and

sensory properties. This dual benefit supports the development of cassava varieties that meet both nutritional and consumer demands, promoting greater utilization of this vital crop in diverse culinary applications. As the food industry continues to seek innovative solutions, the integration of gamma irradiation in cassava processing represents a promising avenue for enhancing food quality and safety.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Design

The study employed a Completely Randomized Design (CRD) with three replicates to evaluate the physicochemical properties, functional characteristics, and sensory qualities of three cassava varieties in comparison to their parent tubers. The linear model that accounts for the overall mean, treatment effects, and random error terms is shown below;

$$Y_{ij} = \mu + T_i + \sum ij$$

Y_{ij} is the observation,

μ is the overall mean,

T_i is the effect of the i -th treatment,

$\sum ij$ is the random error term, assumed to be normally distributed with mean zero

3.2 Materials

Cassava tubers from four varieties of cassava were obtained from the Kenya Agricultural and Livestock Research Organization (KALRO) in Marigat, Baringo County. Cassava variety KME 4 was selected among previously developed mutant varieties (Chepkoech et al., 2015) based on its good agronomic quality such as high tuber yield and resistance to pests and diseases. CAS 1, 2, and 3 were developed from KME 4 using gamma irradiation on the stem cuttings using 15, 20, and 30 grays respectively each at 2 Gy/min.

Commercially available wheat flour (EXE all-purpose flour, Unga Limited, Kenya), sugar (Kabras Limited, Kenya), margarine (Prestige, Bidco, Kenya), and baking powder (Chapa andazi, Bidco, Kenya) were procured from the local supermarket in Eldoret, Kenya.

3.2.1 Sample Preparation

Freshly harvested cassava roots for each variety were hand-sorted to remove spoiled and bruised ones. They were washed to remove accumulated dirt using running tap water, peeled manually using a kitchen knife, and then washed using distilled water. They were sliced using a kitchen knife into small pieces for easier processing.

3.2.2 Preparation of cassava flour

The cassava flour was prepared following the steps laid out by FAO (2004) with slight modifications (Figure 3.1). The slices of cassava from section 3.2.1. were grated using a motorized cassava grater and oven-dried at 60 °C (Memmert-854, Memmert GmbH + Co, Germany) for 48 h. The dehydrated grits were grounded into flour using a disc attrition mill (Munson, Model SK30-SS, USA). The flours obtained from CAS 1, CAS 2, CAS 3, and KME 4 were placed in air-tight containers and stored at room temperature (25 °C) awaiting further testing.

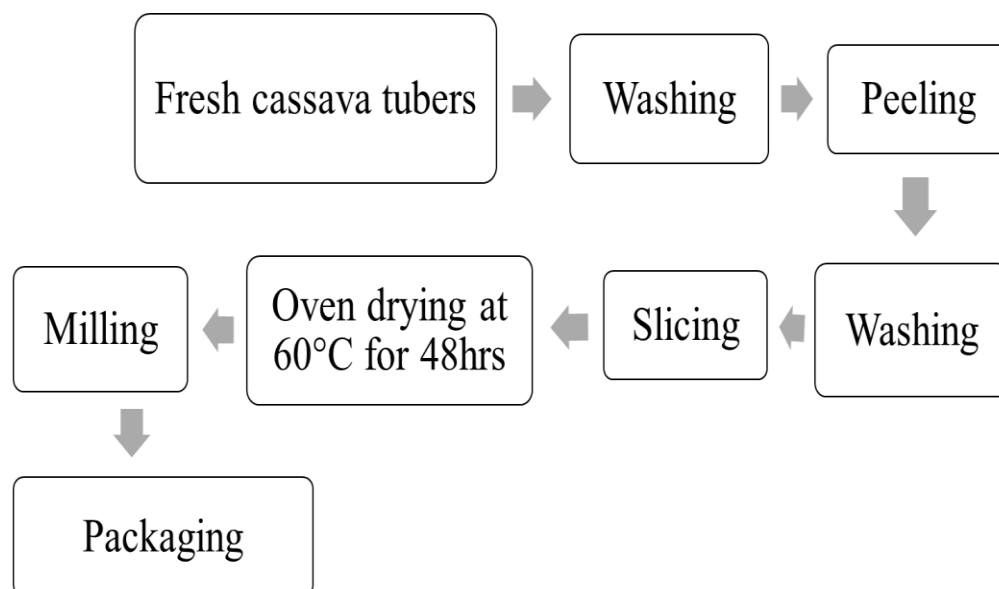


Figure 5: Flow Diagram of Cassava Flour Preparation

3.3 Physical Characteristics of the Cassava Flour

3.3.1 Colour

The colour of the cassava flour was determined using a hand-held colorimeter (PCE-TCR 200, PCE Instrument, China) as described by Osewe et al. (2021). The colourimeter was calibrated using standard white and black tiles. Five grams (5 g) of each flour sample were accurately weighed into the sample cup. The color measurements were taken for the values of L^* (lightness), a^* (changes from green to red), and b^* (changes from blue to yellow). Color readings of each sample were measured at six distinct locations.

3.3.2 Browning Index

The browning index was derived from the CIE-Lab values from section 3.2.1 using the formulae below (Cazzaniga & Linares, 2021).

Equation 2

$$BI = [100(x - 0.31)]^{0.17},$$

$$\text{Where } x = a^* + 1.75L^* / (5.645L^* + a^* - 3.012b^*)$$

Where:

L^* = Lightness value (0 = black, 100 = white)

a^* = Red-green value (positive values indicate red, negative values indicate green)

b^* = Yellow-blue value (positive values indicate yellow, negative values indicate blue)

3.4 Determination of Cassava Proximate Composition

3.4.1 Sample Preparation

The nutrient content of all three cassava varieties and the parent was analyzed using the prepared potato flour and each parameter was measured in triplicate.

3.4.2 Moisture Content

Cassava flour moisture content was determined by the oven drying method described in the AOAC (2000) method No 925.10. Briefly, 5 g of each flour sample was measured in triplicate and placed in dry aluminum dishes. The dishes were then placed in a preheated oven at 105 °C (Mettler-854, Mettler GmbH + Co, Germany) for 12 h until a consistent weight was achieved. Subsequently, the samples were chilled in a desiccator and their weight was measured. The moisture content was determined using the following formula;

$$\text{Moisture (\%)} = \frac{\text{weight of the original sample (5.0 g)} - \text{the weight of the dried sample (g)}}{\text{weight of the original sample (5.0g)}} \times 100$$

3.4.3 Crude Protein

The Kjeldahl method (AOAC, 2000) method No 960.52 was employed to determine the crude proteins. Two (2) g of each flour sample were weighed in triplicates and measured into digestion flasks. Subsequently, 20 ml of sulphuric acid with a concentration of 1.84 g/ml, 5 g of potassium sulfate, and 1 g of copper sulfate were introduced as catalysts for the reaction. The combination was subjected to heat within a fume chamber until the color changed to blue, signifying the completion of digestion. The solution obtained was chilled and then put into a volumetric flask with a capacity of 10 ml. The flask was filled to the brim with distilled water. Approximately 10 ml of the solution was then transferred to a distilling flask, to which 15 ml of a 1 M NaOH solution was added. A distillation process was conducted to yield approximately 60 ml of distillate. A mixed indicator was then added, and standard hydrochloric acid (HCl) was used for titration. The titration was considered complete when the color changed to orange. The protein content was determined using the following calculation;

$$\% \text{ Nitrogen} = (x \text{ moles})/1000 \times ((V_s - V_b))/\text{mg} \times 14\text{g}/\text{moles} \times 100$$

Where; V_s is the volume of sample titre

V_b is the volume of blank titre

M_g is the weight of the sample

X moles is the molarity of HCL

$$\% \text{ protein} = \%(\text{N}) \text{ nitrogen} \times \text{protein factor (6.25)}$$

3.4.4 Ash Content

The ash content of the various flours was measured using the gravimetric method as described by AOAC (2010) method No 923.03. The silicon crucibles (Acetron, Fujian Acetron Mew Materials SiO₂, China) were preheated and subsequently cooled in a desiccator (Top-180mm, Huida Medical, China) before being weighed. Each flour sample was precisely weighed in triplicate, with a mass of 5 g, and placed into pre-weighed crucibles. The crucibles were then heated at a temperature of 550 °C for 24 h. The remaining substances in the crucible were cooled in a desiccator at the ambient temperature, and their ultimate weight was measured using a scale (Mettler PC 4400, Mettler-Toledo International Inc, Switzerland). The percentage ash content of the samples was calculated based on the dry matter using the following formula;

$$\% \text{ Ash Content} = \frac{Z-X(g)}{Y-X(g)} \times 100$$

Where:

X = Weight of empty crucible

Y = Weight of crucible + sample

Z = Weight of crucible + ash

3.4.5 Crude Lipid Content

The crude lipid content of cassava flour was evaluated using the Soxhlet extraction method (AOAC, 2000) with method number 920.29. The total lipid content was quantified using the following formula;

$$\text{Crude lipids (\%)} = \frac{W_f - W_d \text{ (g)}}{W_s \text{ (g)}} \times 100$$

W_f = Weight of the flask with the dried residue after incineration

W_d = Weight of the flask with the dried residue and its support after drying

W_s = Weight of the dry residue and its support after incineration

3.4.6 Crude Fibre Content.

The crude fibre content of the sample was measured using the standard AOAC, (2000) analytical method number 962.09. Each flour sample, 5 g was measured and placed into a round bottom boiling flask along with 200 ml of 0.3 M sulfuric acid. The solution was heated for 30 min using a reflux apparatus. The heated solution was permitted to cool and then passed through a Whatman filter paper number 4. The residue was combined and heated with 100 ml of a 0.25 M solution of sodium hydroxide using a reflux apparatus for 30 min, followed by filtration. The compounds that could not dissolve were dried in an oven (Memmert-854, Memmert GmbH + Co, Germany) until they reached a consistent weight at a temperature of 100 °C. The desiccated specimen was subjected to incineration in a muffle furnace, and the percentage of fiber was measured according to the following equation;

$$\% \text{ Crude fibre} = \frac{\text{Weight of the dried residue} - \text{Weight of the ash}}{\text{Weight of the sample}} \times 100$$

3.4.7 Carbohydrates Content

The total carbohydrate content of each flour was calculated using the difference method, as outlined by the Food and Agriculture Organisation (FAO, 1998) and the Association of Official Analytical Chemists (AOAC, 2000), and the results were given by;

$$\% \text{ Carbohydrates} = 100 - (\% \text{ moisture} + \% \text{ protein} + \% \text{ ash} + \% \text{ fat} + \% \text{ crude fibre}).$$

3.4.8 Determination Specific Minerals Determination.

The analysis of flour-specific minerals was conducted using AOAC (2000) method No 985.35. The ash produced from section 3.4.4 was dissolved in a graduated volumetric flask containing 15 ml of 0.5 N nitric acid. The solution was filled to the 100 ml mark with 0.1 N nitric acid and then filtered using Whatman filter paper number 4 (Whatman, USA). The individual minerals were determined using an atomic absorption spectrophotometer (AA-6200, Shimadzu Corporation, Japan). The flame source employed for mineral detection was air-acetylene. The absorbance of iron, zinc, calcium, and magnesium was measured at wavelengths of 248.3, 213.9, 422.7 and 285.2 nm, respectively. Calibration curves were created by plotting absorbance values against known concentrations of standards for each element. These curves were then utilized to determine the concentration of individual minerals in the samples. The technique was conducted in triplicate for each flour sample. The mineral content was measured using the subsequent formula;

$$\text{Mineral element (mg/100g)} = (\text{reading value in ppm} \times \text{dilution factor}) / (\text{sample weight}) \times 100$$

3.5 Determination of Flour Functional Properties

3.5.1 Water Absorption Capacity (WAC)

The water absorption capacity (WAC) of the flour was determined using the procedures outlined by Gborie et al. (2022). Approximately 3 g of each variety of cassava flour was weighed and placed in a centrifuge tube. Then 40 ml of distilled water was added to the tube and shaken thoroughly to ensure the flour was fully hydrated. The sample was agitated for about 1 h at room temperature and then centrifuged (Thermo Scientific, Megafuge 8, Germany) at 3,000 rpm for 15 min. The free water was decanted from the pellet, drained and the resulting pellets were weighed. The WAC was calculated using the formula below;

$$\text{WAC} = \frac{\text{Weight of Absorbed water}}{\text{Weight of initial flour}} \times 100$$

3.5.2 Oil Absorption Capacity (OAC)

For oil absorption capacity, approximately 2 g of each cassava flour sample was precisely weighed and combined with approximately 20 ml of soybean oil. The mixture was swirled in a centrifuge tube that had been pre-weighed, and the shaking was done for approximately 1 h at room temperature. The solution was subjected to centrifugation using the Thermo Scientific Megafuge 8 from Germany at a speed of 300 rpm for 30 min. The liberated oil obtained from the sample was extracted and the tube was emptied to isolate the oil on the surface, which was then measured by weight. The OAC was calculated using the following equation;

$$\text{OAC} = \frac{\text{Weight of sediment}}{\text{weight of sample}} \times 100$$

3.5.3 Swelling Power

The determination of cassava flour's swelling power and water solubility was conducted following the procedures outlined by Agbemafle. (2019). One (1) gram of each sample was weighed and mixed with 10 ml of distilled water in a test tube and heated at temperatures of about 85°C for one hour while mixing constantly. The solution was cooled and equilibrated at room temperature and then centrifuged (Thermo Scientific, Megafuge 8, Germany) at 1600 rpm for 30 min. The supernatant was decanted after which the sediment was weighed to compute the swelling power as shown below;

$$\text{Swelling power (g/g)} = \frac{\text{Weight of the Sediments}}{\text{Weight of initial flour}}$$

3.5.4 Water Solubility

To determine water solubility, 1 g of each sample was measured and placed in a clean and dry test tube. Then, 20 ml of distilled water was added to the test tube. The mixture was heated to 60 °C in a water bath for approximately 30 min without any agitation. The samples were thereafter subjected to centrifugation at a speed of 1600 revolutions per minute for 10 min. The liquid portion was isolated, dehydrated, and measured in terms of weight. The solubility in water was determined by employing the following formula;

$$\text{Solubility (\%)} = \frac{\text{Dried supernant Weight}}{\text{Weight of flour}} \times 100$$

3.5.4 Bulk Density

The flour's bulk density was determined using the procedures outlined by Hasmadi et al. (2020) and Kayode et al. (2021) with minor adjustments. A 250 ml graduated cylinder was filled with exactly 100 g of each flour sample. The bottom of the cylinder was repeatedly tapped on a stable surface until a consistent volume was obtained, recorded as the packed

bulk volume. The procedure was conducted in triplicate for each sample, and bulk density was determined by dividing the initial weight of the sample by its volume and expressed in g/ml.

3.6 Determination of Pasting properties of the flour

The pasting properties of the flour samples were analyzed using a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty Ltd, Australia). The process began by measuring 2.5 g of flour, which was then placed into a completely dry container. Next, 25 ml of distilled water was added to the flour, and the mixture was blended thoroughly to achieve a homogeneous slurry. This canister was securely inserted into the Rheo Lab QC.

The analysis involved heating the slurry from used at 50 °C for 1 min and slowly heated to 95 °C at 6 °C per min, held at that temperature for 2.7 min, before cooling from 95 to 50 °C at 6 °C per minute and holding at that temperature for 2 min. The rate of temperature increase and decrease was maintained at a consistent 11.25 °C per minute throughout the process.

The pasting profile was analyzed using the Anton Paar Rheo Compass™ shear test demo program, which was connected to a computer for data collection and analysis. Key measurements computed in the analysis included peak viscosity, trough viscosity, breakdown viscosity, final viscosity, set back viscosity, peak duration, and pasting temperature. The viscosity values were quantified in Rapid Viscosity Units (RVU).

3.7 Fourier Transform Infrared (FTIR) Spectroscopy of the Flours

The Fourier transform infrared (FTIR) spectra of the flours were analyzed using an FTIR spectrophotometer (Bruker Alpha model (Germany)). In summary, one (1) mg of each

sample was combined with 10 mg of potassium bromide (KBr) powder. The mixture was then compressed using a specialized die at a pressure of 10,000 psi, resulting in the formation of a disc. The calibration process utilized KBr as a blank, and the spectra were obtained within a range of 400–4000 cm^{-1} .

3.8 Preparation of Cassava Porridge for Sensory Evaluation

Cassava flour prepared as explained in section 3.2.2 was used to prepare porridge from all the varieties (CAS 1, CAS 2, CAS 3, and KME 4). Porridges (10%) solid were prepared as described by Kikafunda et al., (1998) with some modifications. One (1) liter of water was boiled in a stainless steel cooking pot. Next, 100 ml cold water was added to the flour to make a slurry which was then added to the boiling water while stirring. Cooking was continued for 15 min stirring every 5 min. After preparation, the porridges were kept warm in a thermos flask (40–50 °C).

3.8.1 Colour and Browning Index of the Cassava Porridge

The colour and browning index of the cassava porridge was evaluated as described in sections 3.3.1 and 3.4.2 respectively. To prepare the samples for colour measurements, half a cup of porridge from each variety was allowed to cool to room temperature before undergoing colour measurements and the derived values was used to compute the browning index.

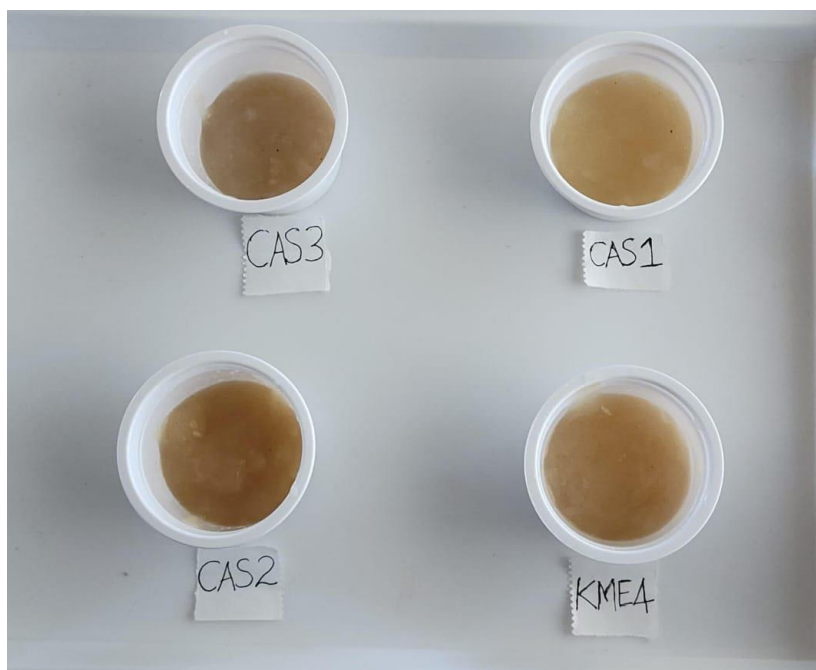


Figure 6: Colour of Thin Cassava Porridge

3.9 Composites Flours Formulation Using Mixture Model Design

Cassava flour prepared in section 3.2.2 was used in an experimental design used to formulate the composite flour for cookie preparation. KME 4, and CAS 1 were selected because rheological tests revealed that they had the least setback viscosity and hence lower tendency to retrograde, a trait desired in baked products while wheat flour served as a control. The design was a three-component augmented Simplex Centroid Design which was carried out using statistical software Design-Expert version 8.0.3 (State - Ease, Inc.2010 Minneapolis, USA). A total of 200 g was used in the preparation of cookies. The proportion of each flour was expressed as a percentage of the mixture as shown below;

$$\sum X_i = C_1 + X_2 = 100 \text{ g or Where: } \sum X_i = K_1 + X_2 = 100 \text{ g}$$

Where C_1 is the CAS 1 cassava flour

X_2 is wheat flour

K₁ is KME 4 Cassava flour

X₁ is the total formulation of the cassava and wheat flour of either CAS 1 or KME 4.

Table 3. 1: Mixture Model Design used to Produce 200g Flour for each Formulation

Sample	CAS 1(C1)	WHEAT(X2)	KME 4(K1)	WHEAT(X2)
V1	50	50		
V2	60	40		
V3	40	60		
V4			50	50
V5			60	40
V6			40	60

CAS 1 was developed from KME 4 by exposure to 15 Gy. KME 4 parent variety. Wheat flour served as control.

The formulation of cassava and wheat for the preparation of cookies was;

V1- 50% CAS 1 flour 50% Wheat flour

V2- 60% CAS 1 flour 40% Wheat flour

V3- 40% CAS 1 flour 60% Wheat flour

V4- 50% KME 4 flour 50% Wheat flour

V5- 60% KME 4 flour 40% Wheat flour

V6- 40% KME 4 flour 60% Wheat flour

Control (V7)- Wheat 100%

3.10 Preparation of Cassava Cookies

Cookies were prepared according to the method proposed by Aziah et al, (2012) with slight modifications. First, 100 g margarine was creamed with 100 g sugar until it became fluffy, this was then followed by adding an egg and other dry ingredients (1/2 tsp salt, 1/2 tsp baking powder, and 200 g flour). The dough was thoroughly kneaded with hands for five minutes and then rolled manually to the thickness of 5 mm using a rolling pin. The sheeted dough was cut with a star-shaped cookie cutter and baked on a greased tray for 15 min at 160 °C in an oven (Tlac Tl100a-Rml, Kenya). The cookies were cooled at room temperature for 30 min before packing them in an airtight plastic container awaiting the sensory evaluation panel. Cookies made from 100% wheat flour with the same processes and quantities of ingredients as above served as control.

3.10.1 Colour and the Browning Index of the Cookies

The colour and the browning index of the cookies were evaluated following the procedure described in sections 3.3.1 and 3.3.2 respectively. Five samples of cookies from each variety were used to measure colour.

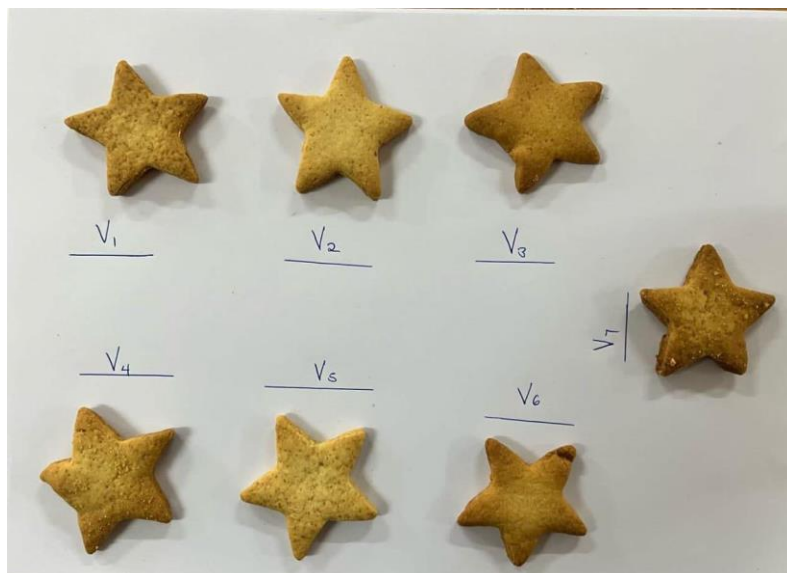


Figure 7: Colour of the Cassava - Wheat Blend Cookies

3.11 Consumer Acceptability Tests

The sensory evaluation was conducted using a nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) as described by Nyamayi et al. (2022) to assess key attributes including taste, texture, aroma, appearance, and overall acceptability. The evaluation of porridge and cookies was conducted on separate days by consumer panels drawn from the University of Eldoret main campus in Eldoret, Kenya. The porridge evaluation involved 54 participants on the first day, while the cookie evaluation included 61 participants on the second day. An ethical consideration form was signed by participants to be able to conduct the evaluation. Both panels assessed the sensory attributes of the products, such as appearance, aroma, taste, texture, and overall acceptability. To ensure unbiased results, the samples were labeled with random three-digit code numbers generated by computers and presented in a randomized order to the panelists. Participants were instructed to cleanse their palates with water between samples and were

asked not to make comments during the evaluation process to avoid influencing the opinions of other panelists.



Figure 8: Tray Set-up for sensory Evaluation of the cookies

3.11 Data Analysis.

The data collected from the sensory evaluation and physicochemical analyses were subjected to descriptive statistics using R software version 4.3.2. To evaluate cassava as a source of variation, the data were analyzed using one-way analysis of variance (ANOVA). Statistical significance between mean values was determined at a threshold of $p < 0.05$, and results are presented as mean \pm standard deviation (SD). To differentiate the means of flour quality indicators, Tukey's Honest Significant Difference (HSD) multiple comparison method was employed.

The distribution of Fourier Transform Infrared (FTIR) spectra was presented using graphs, allowing for the visualization of relationships between the samples based on their spectral

characteristics. Correlation analysis was also conducted to assess the associations between the functional and chemical properties of the flour.

CHAPTER FOUR

RESULTS

4.1 Colour of the Cassava Flour

Table 4. 1: Colour of the Cassava Flours Generated from the Tubers.

Variety	Lightness(L^*)	Redness(a^*)	Yellowness(b^*)	Hue angle(H^*)	Chroma(C^*)	Browning Index
KME 4	79.24±1.78 ^a	2.32±2.13 ^a	13.32±4.03 ^a	81.18±5.00 ^b	13.57±4.36 ^a	1.70±1.2 ^a
CAS 1	78.60±1.17 ^a	5.09±0.68 ^b	16.52±1.28 ^a	72.91±1.03 ^a	17.29±1.41 ^a	1.71±0.1 ^a
CAS 2	82.34±2.50 ^a	3.71±0.93 ^{ab}	11.83±3.30 ^b	72.29±2.45 ^a	12.41±3.39 ^a	1.72±0.4 ^a
CAS 3	77.62±5.18 ^a	4.96±0.74 ^{ab}	15.55±3.11 ^a	71.79±4.83 ^a	16.37±2.89 ^a	1.72±0.4 ^a

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy respectively all at 2 Gy/min.

Table 4.1 summarizes the mean values for each color attribute across varieties. In terms of lightness, CAS 2 exhibited the highest mean value (82.34±2.50), while CAS 3 denoted the lowest (77.62±5.18). Generally, irradiation doses did not alter lightness significantly though there was a trend of reduction with an increase in dosage levels. For redness, KME 4 recorded the lowest mean value (2.32±2.13 and did not significantly differ from CAS 2 (3.71±0.93) and CAS 3 (4.96±0.74), yet it was significantly different from CAS 1 (5.09±0.68). Further, yellowness showed no significant differences across the varieties.

In terms of hue angle, KME 4 (81.18±5.00) displayed a significantly higher mean hue angle, distinguishing it from the other varieties. Finally, in terms of chroma, CAS 1

achieved the highest mean value (17.29 ± 1.41), which was not significantly different from CAS 2 (12.41 ± 3.39) and CAS 3 (16.37 ± 2.89).

The browning index values for the cassava porridge samples were consistent across all tested varieties and parent tubers, ranging from 1.70 to 1.72. The data highlights no significant differences in browning across various products, underscoring the impact of gamma irradiation and formulation on the degree of browning.

4.2 Proximate Composition of Cassava flours

Table 4. 2: Proximate Composition of the Cassava Flours (g/100g)

Variety	Moisture	Ash	Lipids	Fiber	Protein	Carbohydrates
KME 4	7.37 ± 0.06^a	2.13 ± 0.15^{ab}	1.67 ± 0.09^a	7.02 ± 0.33^b	2.12 ± 0.25^a	79.70 ± 0.60^{ab}
CAS 1	8.58 ± 0.28^{ab}	1.77 ± 0.15^a	2.17 ± 0.13^b	5.6 ± 0.22^a	1.54 ± 0.17^a	80.39 ± 0.40^b
CAS 2	7.77 ± 0.84^{ab}	1.75 ± 0.17^a	1.83 ± 0.02^a	6.67 ± 0.28^b	1.58 ± 0.41^a	80.40 ± 0.46^b
CAS 3	9.00 ± 0.61^b	2.38 ± 0.23^b	2.02 ± 0.03^b	6.60 ± 0.58^b	1.981 ± 0.19^a	78.02 ± 1.41^a

Values are means \pm standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy respectively all at 2 Gy/min.

The proximate composition of cassava flours from various varieties is summarized in Table 4.2. Moisture content significantly varied among the cassava varieties, with CAS 3 exhibiting the highest moisture level at $9.00 \pm 0.61\%$. In contrast, KME 4 had the lowest moisture content at $7.37 \pm 0.06\%$. The ash content, which reflects the mineral composition of the flours, varied as well. CAS 3 demonstrated a significantly different ash content

compared to CAS 1 and CAS 2, suggesting variations in mineral content due to the gamma irradiation process.

The lipid content varied across the samples, with CAS 2 and KME 4 showing significant differences compared to CAS 1 and CAS 3. CAS 1 had the highest lipid content at $2.17 \pm 0.13\%$, while KME 4 had lower values. Generally, there was a trend of increase of lipids upon irradiation. In terms of fiber, no significant differences were observed among the varieties. CAS 1, CAS 2, and KME 4 reported similar fiber levels (ranging from 5.60% to 7.02%), while CAS 3 had a slightly lower value at $6.60 \pm 0.58\%$. Protein levels showed some variability, with CAS 3 having the highest protein content at $1.981 \pm 0.19\%$. However, this was closely followed by CAS 2 ($1.58 \pm 0.41\%$) and CAS 1 ($1.54 \pm 0.17\%$). KME 4 had the highest protein content at $2.12 \pm 0.25\%$, but no significant differences were detected among the varieties.

As expected the carbohydrate content remained relatively high across all varieties, with KME 4 showing a significantly lower percentage ($79.70 \pm 0.60\%$) compared to CAS 1 ($80.39 \pm 0.40\%$) and CAS 2 ($80.40 \pm 0.46\%$).

4.3 Micronutrient Content of the Cassava Flours

Table 4. 3: Micronutrient Content of the flours (mg/100g)

Variety	Magnesium	Calcium	Zinc	Iron
KME 4	55.23 ± 0.49 ^b	62.84 ± 0.12 ^a	1.407 ± 0.04 ^c	3.677 ± 0.07 ^c
CAS 1	48.73 ± 1.19 ^a	63.22 ± 0.55 ^a	1.024 ± 0.06 ^a	2.707 ± 0.05 ^a
CAS 2	55.23 ± 0.43 ^b	64.33 ± 0.15 ^b	1.180 ± 0.03 ^b	3.054 ± 0.06 ^{ab}
CAS 3	64.78 ± 2.22 ^c	62.93 ± 0.13 ^a	1.322 ± 0.05 ^c	3.410 ± 0.34 ^{bc}

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy respectively all at 2 Gy/min.

Table 4.3 presents the micronutrient content of various cassava flour varieties, focusing on magnesium (Mg), calcium (Ca), zinc (Zn), and iron (Fe) concentrations. The results highlight significant differences in mineral content across the different varieties. Although the magnesium content varied greatly between the varieties, CAS 3 had the highest concentration at 64.78 ± 2.22 g/100g. However, with 48.73 ± 1.19 g/100g of magnesium, CAS 1 had the lowest content. The majority of the varieties did not exhibit any notable variations in calcium levels, which were generally constant. The calcium content of CAS 2 was slightly higher at 64.33 ± 0.15 g/100g than that of KME 4 (62.84 ± 0.12 g/100g) and CAS 1 (63.22 ± 0.55 g/100g). KME 4 had the highest zinc level at 1.41 ± 0.04 g/100g, followed by CAS 3 at 1.32 ± 0.05 g/100g. The zinc content showed significant variability. At 1.02 ± 0.06 g/100g, CAS 1 had the lowest zinc content, on the other hand. Notably,

CAS 1's iron content significantly differed from that of KME 4 but did not show significant differences when compared to CAS 2 (3.05 ± 0.06 g/100g).

4.4 Functional Properties of the Flours

The functional properties of cassava flour namely, water absorption index (WAI), water absorption capacity (WAC), oil absorption capacity (OAC), solubility, swelling power, and bulk density, are summarized in Table 4.4. In terms of water absorption index (WAI), CAS 3 demonstrated the highest value (1.48 ± 0.01), significantly differing from the other varieties. KME 4 followed closely with a WAI of 1.23 ± 0.00 , while CAS 1 and CAS 2 had lower values (1.21 ± 0.00) and (1.27 ± 0.01) respectively. In summary, there was somewhat increase in WAI as gamma irradiation doses increased.

Table 4. 4: Functional Properties of the Cassava Flour

Variety	WAI ¹	WAC ²	OAC ³	Solubility	Swelling Power	Bulk Density
KME 4	1.23 ± 0.00^b	1.34 ± 0.04^a	117.60 ± 0.00^c	3.21 ± 0.14^a	14.71 ± 0.35^c	0.76 ± 0.01^a
CAS 1	1.21 ± 0.00^a	1.40 ± 0.00^a	119.10 ± 0.28^d	3.05 ± 0.07^a	13.28 ± 0.27^{ab}	0.70 ± 0.05^a
CAS 2	1.27 ± 0.01^c	1.25 ± 0.07^a	115.30 ± 0.28^b	3.01 ± 0.01^a	14.01 ± 0.06^{bc}	0.69 ± 0.02^a
CAS 3	1.48 ± 0.01^d	1.65 ± 0.07^b	113.30 ± 0.28^a	2.91 ± 0.03^a	12.71 ± 0.00^a	0.69 ± 0.07^a

Values are means \pm standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy respectively all at 2 Gy/min. ¹Water Absorption Index, ²Water Absorption Capacity and ³Oil Absorption Capacity

For water absorption capacity (WAC), all varieties demonstrated similar values, except for CAS 2, which had a significantly lower WAC (1.25 ± 0.07). KME 4 (1.34 ± 0.04) and CAS

1 (1.40 ± 0.00) exhibited comparable WAC values. The oil absorption capacity (OAC) was highest in CAS 1 (119.10 ± 0.28), followed by KME 4 (117.60 ± 0.00), with CAS 3 exhibiting the lowest value (113.30 ± 0.28).

The solubility of the flours showed no significant differences across varieties. Similarly, bulk density remained constant across all samples, with values ranging from 0.69 to 0.76 g/cm. However, the swelling power showed significant variation, with CAS 3 (12.71 ± 0.00) and KME 4 (14.71 ± 0.35) exhibiting higher values compared to CAS 1 and CAS 2.

4.5 Pasting Properties of the Cassava Flours

The pasting properties of cassava flour are shown in Table 4.5. The key metrics assessed included peak viscosity (PV), trough viscosity (TV), breakdown (BD), final viscosity (FV), setback (SB), peak time, and pasting temperature (PT).

Peak Viscosity (PV) is a critical indicator of the maximum viscosity the flour can achieve during the heating cycle. Among the varieties, KME 4 exhibited significantly highest peak viscosity at 278.53 ± 0.67 , followed by CAS 1 (275.73 ± 0.13), CAS 3 (273.81 ± 0.96), and CAS 2 (269.26 ± 0.71).

Table 4. 5: Flour Pasting Properties of the Flour

Varieties	KME 4	CAS 1	CAS 2	CAS 3
PV (cP)	278.53 ± 0.67 d	275.73 ± 0.13^c	269.26 ± 0.71^a	273.81 ± 0.96^b
TV (cP)	97.47 ± 1.98^a	210.69 ± 1.75^c	198.33 ± 0.42^b	196.10 ± 5.35^b
BD (cP)	54.37 ± 0.63^c	42.07 ± 0.56^a	46.85 ± 0.06^b	46.93 ± 0.04^b

FV (cP)	468.96±0.53 ^d	398.46±1.52 ^a	411.11±1.25 ^b	432.84±4.66 ^c
SB (cP)	404.77±0.99 ^c	213.47±0.50 ^a	255.90±3.64 ^b	249.49±4.73 ^b
PT (min)	7.88±0.10 ^c	5.24±0.02 ^a	5.38±0.06 ^a	5.72±0.06 ^b
PT (°C)	88.49±0.16 ^d	83.45±0.11 ^a	84.30±0.17 ^b	84.99±0.01 ^c

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30Gy respectively.

PV - Peak viscosity,
 TV - Trough viscosity,
 BD - Break down,
 FV - Final viscosity,
 SB - Set back,
 Peak time(min) - Pasting time
 PT(°C) - Pasting temperature
 Cp- Centipoise.

Trough Viscosity (TV) values revealed significant differences among the varieties, with KME 4 having the lowest trough viscosity (97.47 ± 1.98). The values of CAS 2 and CAS 3 were 198.33 ± 0.42 and 196.10 ± 5.35 , respectively, whereas CAS 1 had a significantly higher value (210.69 ± 1.75). The difference between high and low thickness varied quite a bit. Unlike the samples labeled CAS 1 (42.07 ± 0.56), CAS 2 (46.85 ± 0.06) likewise CAS 3 (46.93 ± 0.04), sample KME 4 showed a much higher breakdown - specifically, 54.37 ± 0.63 .

Cassava types differed quite a bit in how thick they became after cooling - a measure of their starchiness. KME 4 was noticeably thicker (468.96 ± 0.53) than CAS 1 (398.46 ± 1.52), likewise CAS 2 (411.11 ± 1.25), also CAS 3 (432.84 ± 4.66).

Texture matters - a lot - when making the final product. How thick something gets after cooling, called Final Viscosity, varied widely depending on the cassava used. KME 4 ended up thickest (468.96 ± 0.53) while CAS 1 was least viscous (398.46 ± 1.52), followed by CAS 2 (411.11 ± 1.25) likewise CAS 3 (432.84 ± 4.66). Different starches behave uniquely upon cooling, ultimately creating gels of varying firmness. Paste thickness - how much it stiffens with chilling - followed suit. CAS 1 thickened the least (213.47 ± 0.50), conversely, KME 4 became noticeably thicker when cold (404.77 ± 0.99). Peak time, or the amount of time needed to heat to maximum viscosity, also varied significantly. While CAS 1 (5.24 ± 0.02) and CAS 2 (5.38 ± 0.06) reached peak viscosity more quickly, KME 4 took the longest (min) (7.88 ± 0.10).

These variations may reflect differences in starch granule stability or amylopectin crystallinity.

Finally, pasting temperature (PT) was significantly different across the varieties, with KME 4 requiring significantly highest temperature (88.49 ± 0.16 °C) for pasting while CAS 1 (83.45 ± 0.11 °C) had the lowest.

4.6 Fourier Transform Infrared (FTIR) Spectroscopy

Figure 4.1 shows FTIR spectra of different cassava varieties namely KME 4, CAS 1, CAS 2 and CAS 3. These spectra reveal how cassava samples absorb infrared light, giving insight into the molecular bonds and functional groups present in the starches of cassava. The peaks are observed at several wavelengths. KME 4 shows peaks between the wavenumbers $2000\text{--}3800\text{ cm}^{-1}$ when compared to the other varieties (CAS 1, CAS 2, CAS 3), which were exposed to different doses of gamma irradiation (15, 20, and 30 Gy respectively).

The absorbance peaks observed at 3000–3700 cm^{-1} are commonly associated with O-H stretching, indicative of water or hydroxyl groups. Peaks observed at 1563.11–1827.27 cm^{-1} could represent C=O stretching, possibly from carboxyl groups while those observed at 483–1258 cm^{-1} are associated with C-O, C-C stretching, or bending vibrations in starch molecules. Finally, the wavelength of 1663–1827 cm^{-1} is possibly related to amide or C=O stretching vibrations, which can indicate protein or starch components. In summary, relative to the control, O-H stretching was more pronounced in irradiated samples.

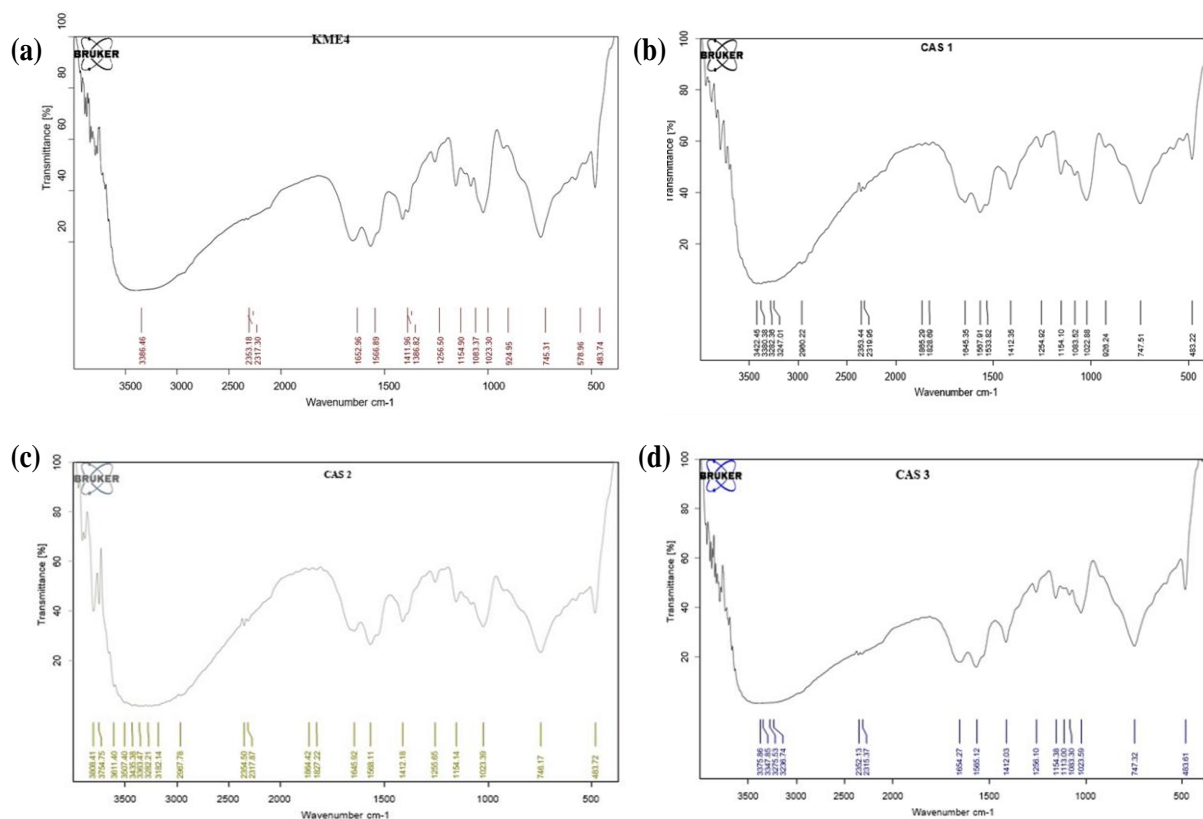


Figure 9: FTIR Spectra of KME 4(a), CAS 1(b), CAS 2(c), CAS 3(d)

Table 4. 6: Band Assignment of Cassava Flour from FTIR

N	Functional groups	Wave				
		Length	KME 4	CAS 1	CAS 2	CAS 3
1	O – H stretching hydroxyl group	3000-		3380.38,3422.45,	3808.41,3182.14	3347.85,3375.86
		3500	3386.46	3282.38,3247.01	3363.47,3435.38	3275.53,3236.74
2	C = O stretching	1560-				
		1567	1566.89	1567.91	1563.11	1565.12
3	C – H bending vibration of alkyl chains	483	483.73	483.22	483.72	463.61
4	C-O-C stretching vibration of glycosidic bonds	1154	1023.3	1154.1	1154.14	1154.38
5	O – H stretching carboxyl groups	3500-				
		3800	-	-	3611	-

4.7 Correlation Coefficient of the Chemical and Functional properties of cassava flour

The correlation matrix (Table 4.7) summarizes the relationships between various chemical and functional properties of cassava flour. Final viscosity and setback showed a very strong positive correlation ($r = 0.93$, $p < 0.01$) indicating that as the final viscosity increases, the setback also increases. Final viscosity and crude fiber show a significant positive correlation ($r = 0.72$, $p < 0.01$) the data shows that higher levels of crude fiber in cassava flour are associated with increased final viscosity. Final viscosity and crude protein were positively correlated ($r = 0.71$, $p < 0.01$) indicating that increased protein levels correlate with higher final viscosity. Oil absorption capacity (OAC) and setback showed a significant negative correlation ($r = -0.66$, $p < 0.05$) implying that higher oil absorption capacity is linked to lower setback values. OAC and crude lipids displayed a positive correlation ($r = 0.74$, $p < 0.05$) suggesting that flours with higher lipid content can absorb more oil. Setback and crude lipids displayed a strong negative correlation ($r = -0.85$, $p < 0.01$) showing that as crude lipid levels setback viscosity values decreased. Setback and crude fiber demonstrated a negative correlation ($r = -0.62$, $p < 0.05$) indicating that flours with higher fiber content have lower setback values. Setback viscosity and crude protein exhibited a negative correlation ($r = -0.67$, $p < 0.05$) this shows that higher protein levels are associated with lower setback values.

Table 4. 7: Pearson Correlation Coefficient between Chemical and Functional Properties of Cassava Flour

	Final				Crude			
	WAC	OAC	Viscosity	Setback	Moisture	Lipids	Fibre	Protein
WAC	1	-0.477	0.101	0.47	-0.061	-0.433	0.198	-0.394
OAC		1	-0.02	-0.66	0.386	.736*	-0.679	0.189
Final viscosity			1	.934**	-0.402	-.726**	.720**	.706*
Setback				1	-.623*	-.854**	.668*	0.575
Moisture					1	.698*	-0.379	-0.261
Lipids						1	-.713**	-0.391
Crude fibre							1	.644*
Protein								1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

4.8 Physical Characteristics of Cassava Flour Products

4.8.1 Colour of Thin Porridge

Table 4. 8: Colour of the Cassava Thin Porridge

Variety	Lightness(L^*)	Redness(a^*)	Yellowness(b^*)	Hue angle(H^*)	Chroma(C^*)	Browning Index
KME 4	16.42 ± 0.30^b	3.20 ± 0.37^a	4.83 ± 0.09^a	56.58 ± 2.68^a	5.80 ± 0.27^a	76.74 ± 0.21^a 121.05 ± 0.1
CAS 1	14.01 ± 0.99^a	4.42 ± 0.66^b	6.52 ± 0.41^b	55.99 ± 3.02^a	7.89 ± 0.65^b	2^b 118.84 ± 0.3
CAS 2	13.83 ± 0.15^a	4.34 ± 0.54^b	6.44 ± 0.72^b	55.89 ± 5.98^a	7.80 ± 0.39^b	2^b 146.05 ± 0.6
CAS 3	13.42 ± 0.17^a	5.50 ± 0.29^c	7.14 ± 0.48^b	52.34 ± 2.85^a	9.02 ± 0.34^c	6^c

Values are means \pm standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy respectively all at 2 Gy/min.

The results for the color attributes of cassava thin porridge from the varieties are summarized in Table 4.8. The data revealed notable differences in various color metrics among the cassava varieties, particularly emphasizing the significant impact of gamma irradiation on color characteristics. In terms of lightness (L^*), KME 4 exhibited the highest mean value (16.42 ± 0.30), significantly differing from CAS 1 (14.01 ± 0.99), CAS 2 (13.83 ± 0.15), and CAS 3 (13.42 ± 0.17). Overall, thin porridges made from flour obtained from

irradiated samples had darker colors as shown by reduced lightness values as lightness values closer to zero are darker while those closer to 100 are lighter.

The measure for redness (a^*) showed significant increases due to irradiation, particularly between CAS 3 (5.50 ± 0.29) and KME 4 (3.20 ± 0.37). The highest impact was observed in CAS 3, which was subjected to the highest irradiation dose of 30 Gy. For yellowness (b^*), CAS 1, CAS 2, and CAS 3 did not differ significantly from each other but exhibited a significant difference compared to KME 4, the control which had the least yellowness value (4.83 ± 0.09).

The hue angle (H^*), did not differ significantly across all varieties. The chroma values (C^*) significantly increased during irradiation with a greater increase being observed at 30 Gy, while CAS 1 (7.89 ± 0.65) and CAS 2 (7.80 ± 0.39) did not differ significantly from each other.

The browning index of the cassava varieties developed through gamma irradiation exhibited progressively higher browning indices in porridge but was not significantly different. CAS 1 records a browning index of (121.05 ± 0.12) while CAS 3 shows the highest index at (146.05 ± 0.66).

4.8.2 Colour of the Cookies

The colour attributes of the top side of cookies from various formulations are summarized in Table 4.9 and that of the bottom are summarized in Table 4.10. The data highlights notable differences in color metrics among the cookie varieties, indicating the impact of formulation on these characteristics. In terms of lightness (L^*), the formulations exhibited values ranging from 51.23 ± 1.70 for the control made exclusively using wheat flour to

61.26 ± 1.34 for V2, with significant differences noted among most varieties ($p < 0.05$). The redness (a^*) values ranged from 2.95 ± 1.74 in V2 to 8.10 ± 0.63 in V5, with significant differences observed among most varieties. For yellowness (b^*), no significant differences were observed across the varieties. The hue angle (H^*) and chroma (C^*) values also displayed significant differences among the cookie varieties. The browning index of the cookie's top side shows browning indices that range from 1.63 ± 2.65 in V2 to 1.76 ± 0.5 in V4. Notably, V3 and V6 exhibit slightly higher indices of 1.68 ± 1.22 and 1.67 ± 2.34, respectively and they were significantly different from the other formulations. The bottom of the cookies demonstrates a wider range of browning indices, from 1.74 ± 0.9 in V2 to 1.86 ± 2.98 in V6.

Table 4. 9: Colour of the Top of Cookies made from Wheat-Cassava Flour Blend

Variety	Lightness(L^*)	Redness(a^*)	Yellowness(b^*)	Hue angle(H^*)	Chroma(C^*)	Browning Index
V1	52.63 ± 2.55 ^{abc}	8.06 ± 1.07 ^d	27.82 ± 0.77 ^a	73.83 ± 2.31 ^a	28.98 ± 0.60 ^{abc}	1.74±1.35 ^b
V2	61.26 ± 1.34 ^e	2.95 ± 1.74 ^a	27.51 ± 0.95 ^a	84.00 ± 3.31 ^d	27.71 ± 1.15 ^{ab}	1.63±2.65 ^a
V3	55.78 ± 2.21 ^{bcd}	5.88 ± 1.50 ^{bcd}	28.94 ± 0.60 ^a	78.56 ± 2.79 ^{abc}	29.56 ± 0.76 ^{bc}	1.68±1.22 ^a
V4	58.06 ± 2.24 ^{de}	3.53 ± 1.34 ^{ab}	27.32 ± 0.58 ^a	82.69 ± 2.65 ^{cd}	27.57 ± 0.71 ^a	1.76±0.5 ^b
V5	52.43 ± 2.99 ^{ab}	8.10 ± 0.63 ^d	28.89 ± 1.26 ^a	74.29 ± 1.78 ^a	30.01 ± 1.07 ^c	1.73±1.0 ^b
V6	56.82 ± 1.50 ^{cd}	5.35 ± 0.69 ^{abc}	28.55 ± 0.30 ^a	79.39 ± 1.35 ^{bcd}	29.06 ± 0.32 ^{abc}	1.67±2.34 ^a
Control	51.23 ± 1.70 ^a	7.28 ± 1.13 ^{cd}	27.50 ± 1.79 ^a	75.11 ± 2.63 ^{ab}	28.48 ± 1.68 ^{abc}	1.73±1.07 ^b

Values are means \pm standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. V1- 50% CAS 1 flour 50% Wheat flour; V2- 60% CAS 1 flour 40% Wheat flour; V3- 40% CAS 1 flour 60% Wheat flour; V4- 50% KME 4 flour 50% Wheat flour; V5- 60% KME 4 flour 40% Wheat flour; V6- 40% KME 4 flour 60% Wheat flour; Control- Wheat

Table 4. 10: Colour of the Bottom of the Cookies.

Variety	Lightness(L^*)	Redness(a^*)	Yellowness(b^*)	Hue angle(H^*)	Chroma(C^*)	Browning Index
V1	47.81 \pm 3.30 ^{ab}	10.08 \pm 1.60 ^a	25.74 \pm 1.10 ^a	68.61 \pm 3.52 ^a	27.69 \pm 0.92 ^a	1.80 \pm 1.2 ^b
V2	53.47 \pm 2.86 ^c	10.42 \pm 5.89 ^a	26.80 \pm 1.90 ^{ab}	69.68 \pm 9.23 ^a	29.07 \pm 3.87 ^a	1.74 \pm 0.9 ^a
V3	43.80 \pm 1.83 ^a	11.41 \pm 0.99 ^a	25.44 \pm 1.02 ^a	65.86 \pm 1.51 ^a	27.89 \pm 1.22 ^a	1.86 \pm 0.87 ^c
V4	50.35 \pm 4.82 ^{bc}	9.95 \pm 1.12 ^a	27.14 \pm 0.68 ^{ab}	69.85 \pm 2.53 ^a	28.93 \pm 0.27 ^a	1.78 \pm 0.34 ^b
V5	45.27 \pm 1.51 ^{ab}	11.65 \pm 0.70 ^a	27.93 \pm 0.52 ^b	67.35 \pm 1.46 ^a	30.27 \pm 0.41 ^a	1.84 \pm 1.34 ^{ab}
V6	44.8 \pm 1.04 ^{ab}	12.12 \pm 0.52 ^a	26.41 \pm 0.70 ^{ab}	65.34 \pm 1.25 ^a	29.06 \pm 0.59 ^a	1.86 \pm 2.98 ^c
Control	47.62 \pm 2.04 ^{ab}	9.99 \pm 1.02 ^a	25.64 \pm 0.92 ^a	68.21 \pm 2.98 ^a	27.54 \pm 1.02 ^a	1.80 \pm 1.65 ^b

Values are means \pm standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. V1- 50% CAS 1 flour 50% Wheat flour; V2- 60% CAS 1 flour 40% Wheat flour; V3- 40% CAS 1 flour 60% Wheat flour; V4- 50% KME 4 flour 50% Wheat flour; V5- 60% KME 4 flour 40% Wheat flour; V6- 40% KME 4 flour 60% Wheat flour; Control- Wheat

The sensory evaluation results for the porridge made from different cassava flour varieties are summarized in Table 4.11. Each variety was assessed based on five attributes: appearance, taste, texture, aroma, and overall acceptability. Generally, there were no

significant differences in sensory characteristics across all the porridges tested. In overall acceptability, CAS 2 had the highest mean scores across all sensory attributes, followed closely by CAS 3 and CAS 1. The Attribute Scores showed CAS 2 scored the highest (7.16 ± 1.87) in the appearance while KME 4 had the lowest score (6.93 ± 1.73).

4.9 Consumer Acceptability of Thin Porridge and Cookies

4.9.1 Sensory Evaluation of Cassava Thin Porridge

Table 4. 11: Sensory Evaluation of the cassava thin porridge

Variety	Appearance	Taste	Texture	Aroma	Acceptability
KME 4	$6.93 \pm 1.73a$	$6.29 \pm 2.38a$	$7.16 \pm 2.25a$	$6.98 \pm 1.81a$	$7.11 \pm 2.04a$
CAS 1	$6.95 \pm 2.09a$	$6.78 \pm 1.94a$	$7.42 \pm 2.11a$	$6.95 \pm 1.98a$	$7.22 \pm 1.95a$
CAS 2	$7.16 \pm 1.87a$	$7.25 \pm 1.65a$	$7.53 \pm 1.73a$	$7.20 \pm 1.97a$	$7.36 \pm 1.74a$
CAS 3	$7.15 \pm 1.68a$	$7.18 \pm 1.89a$	$7.58 \pm 1.69a$	$7.40 \pm 1.77a$	$7.53 \pm 1.72a$

Values are means \pm standard deviation. Means with different superscript letters along the same column are significantly different at $p \leq 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy respectively all at 2Gy/min.

Similar trends were observed in taste with CAS 2 scoring the highest (7.25 ± 1.65) and KME 4 the lowest (6.29 ± 2.38). CAS 2 (7.53 ± 1.73) and CAS 3 (7.58 ± 1.69) were rated best for texture, while KME 4 had the lowest score (7.16 ± 2.25). CAS 3 (7.40 ± 1.77) ranked highest for aroma score, while KME 4 (6.98 ± 1.81). CAS 3 received the highest acceptability score (7.53 ± 1.72), closely followed by CAS 2 (7.36 ± 1.74) and KME 4 (7.11 ± 2.04). Although CAS varieties (1, 2, and 3) consistently scored higher than KME

4, there were no significant differences in mean scores for any of the attributes among the varieties.

4.9.2 Sensory Evaluation of the Cassava-Wheat Blend Cookies

The sensory evaluation of cassava-wheat blend cookies highlights the potential of cassava flour as a partial substitute for wheat flour, with substitution levels and cassava variety playing critical roles in determining sensory quality. The control cookies made entirely from wheat flour achieved the highest overall acceptability score (7.94 ± 0.98), excelling in all sensory attributes, including appearance, aroma, texture, and taste. This superior performance reflects the familiarity and favorable functional properties of wheat flour in baked goods. However, cookies made with a 50% cassava substitution demonstrated comparable sensory attributes, particularly for CAS 1 (7.82) and KME 4 (7.80), suggesting that cassava flour can be successfully incorporated at moderate levels without significantly compromising quality.

Table 4. 12: Sensory Evaluation Cassava- Wheat blend cookies

Variety	Appearance				Overall acceptability
	Appearance	Aroma	Taste	Texture	
V1	7.94 ± 0.89 ^b	0.90 ^{cd}	8.04 ± 0.93 ^d	7.96 ± 0.90 ^{cd}	7.82 ± 1.02 ^{cd}
V2	7.58 ± 1.07 ^b	1.10 ^{bc}	1.28 ^{bc}	7.20 ± 0.90 ^{ab}	7.24 ± 1.10 ^{bc}
V3	7.58 ± 0.73 ^b	7.42 ± 0.97 ^c	0.90 ^{cd}	7.4 ± 0.88 ^{bc}	7.54 ± 0.79 ^{cd}
V4	7.96 ± 0.97 ^b	1.31 ^{bc}	1.34 ^{cd}	7.72 ± 0.93 ^{bcd}	7.80 ± 1.14 ^{cd}
V5	6.86 ± 1.85 ^a	6.42 ± 1.31 ^a	6.34 ± 1.79 ^a	6.58 ± 1.57 ^a	6.50 ± 1.46 ^a
V6	7.46 ± 1.32 ^a	1.15 ^{ab}	1.51 ^{ab}	7.16 ± 1.33 ^{ab}	6.72 ± 1.42 ^{ab}
Control	8.12 ± 0.72 ^b	8.10 ± 0.81 ^d	1.00 ^{cd}	8.08 ± 0.88 ^d	7.94 ± 0.98 ^d

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.05$ as assessed by Tukey's HSD. V1- 50% CAS 1 flour 50% Wheat flour; V2- 60% CAS 1 flour 40% Wheat flour; V3- 40% CAS 1 flour 60% Wheat flour; V4- 50% KME 4 flour 50% Wheat flour; V5- 60% KME 4 flour 40% Wheat flour; V6- 40% KME 4 flour 60% Wheat flour; Control- Wheat

The control cookies received the highest taste rating (7.94 ± 0.98), followed by V1 (7.82) and V4 (7.80). Unwanted flavors were introduced by higher substitutions; V2 received a

score of 7.24, while V5 received the lowest score of 6.50. These patterns were evident in all sensory attributes' overall acceptability scores. Cookies with a 50% substitution of CAS 1 or KME 4 performed competitively, scoring 7.82 and 7.80, respectively, while the control cookies received the highest score (7.94 ± 0.98). This proves that baked goods with acceptable and desired sensory qualities can be made with a moderate substitution of cassava. The overall acceptability scores for both CAS 1 (7.24) and KME 4 (6.50) significantly decreased when the substitution level was raised to 60%, indicating the drawbacks of using larger amounts of cassava flour because of the effects they have on texture, flavor, and appearance.

CHAPTER FIVE

DISCUSSIONS

5.1 Physicochemical of the Cassava Flour Properties

5.1.1 Colour of the Cassava Flours

The colour values of the cassava flours are presented in Table 4.1. The data indicates that there are no significant differences in lightness (L^*) among the cassava varieties tested ($p < 0.05$). This finding implies that the intrinsic lightness of the cassava roots remains relatively stable despite exposure to varying levels of gamma radiation. This study disagrees with the findings of Ahmed et al, (2014) as their study reported a significant difference in the lightness as gamma irradiation increased from 0-15 Gy on the Indian Chestnut. This study indicates that consistent lightness across the varieties may be advantageous for consumer acceptance, as brightness is often associated with freshness and high quality in food products.

Redness (a^*) quantifies the extent of red coloration in the flour. CAS 3 irradiated at 30 Gy had the highest redness value which was significantly different from KME 4 ($p < 0.05$) and indicated a more pronounced red hue. The increased redness in CAS 3 may be attributed to the formation of new pigments, such as carotenoids, as a result of gamma irradiation. Gamma radiation stimulates the production of reactive oxygen species (ROS), which act as signaling molecules that can enhance metabolic pathways associated with carotenoid synthesis (Abomohra et al., 2016). The presence of ROS can trigger protective mechanisms in plants, leading to increased carotenoid accumulation as a defense against oxidative stress (Abomohra et al., 2016). Irradiation may promote the synthesis or stabilization of

carotenoids, leading to increased red pigment content in the flour (Reddy & Viswanath, 2019). A study by Tran et al. (2022) agrees with these findings as it shows that gamma irradiation at 10 Gy significantly increased the levels of carotenoids and anthocyanins, leading to enhanced red pigmentation in the roots. This finding supports the notion that gamma radiation can effectively enhance the red pigmentation in cassava roots, aligning with the observations that radiation treatments can modify the biochemical composition of plants to improve color intensity (Tran et al., 2022).

The yellowness value (b^*) indicates the degree of yellow pigmentation in the cassava roots. The data shows that CAS 2 had the lowest yellowness values, which was significantly different from the other varieties ($p < 0.05$). The irradiation doses in CAS 1 and CAS 3 may have led to significant chlorophyll degradation, allowing carotenoids to become more prominent and thus increasing yellowness (Tran et al., 2022). Gamma irradiation can lead to the degradation of chlorophyll, the green pigment found in plants. As chlorophyll breaks down, it can release various chromophores and precursors that contribute to the formation of yellow pigments, such as carotenoids. The breakdown of chlorophyll reduces green coloration, allowing the yellow hues from carotenoids to become more prominent, thereby increasing the yellowness value in the flour (Ognyanov et al., 2022). A study by Song et al. (1998) agrees with these findings as it found that gamma irradiation led to significant degradation of chlorophyll in carrot juice, which in turn allowed the carotenoids to become more visible. Higher yellowness is often associated with the presence of carotenoids, which are known for their health benefits, including antioxidant properties (Ayetigbo et al., 2018). The increased yellowness in CAS 1 and CAS 3 may indicate a higher concentration of these beneficial pigments, which could enhance the nutritional profile of the flour.

Yellow hues are also associated with certain desirable flavors like sweet and buttery and can enhance the overall sensory experience for consumers. This could enhance the visual appeal of cassava products from CAS 1 and CAS 3, making them more attractive to consumers.

The hue angle (H^*) represents the overall color perception, with lower values indicating a shift towards red and yellow hues and higher values indicating greener hues. KME 4 had the highest hue angle significantly different from the other varieties ($p < 0.05$) suggesting a greener hue, while CAS 1, CAS 2, and CAS 3 exhibited lower hue angles, indicating a shift towards more yellowish and red tones. Gamma irradiation can induce the degradation of chlorophyll. As chlorophyll degrades, the green color diminishes, allowing other pigments, such as carotenoids and anthocyanins, to become more prominent. This degradation results in a lower hue angle, indicating a shift towards yellow and red hues (Ognyanov et al., 2022). The breakdown of chlorophyll reduces the green component of the color profile, which is reflected in the higher hue angle of KME 4 compared to the lower hue angles of CAS 1, CAS 2, and CAS 3. A greener hue (as seen in KME 4) may be perceived as under-baked, unripe, or less visually appealing could lead to lower appeal in certain contexts especially in baked products like cookies (Cazzaniga & Linares, 2021). In contrast, CAS 1, CAS 2, and CAS 3, with their lower hue angles, indicate a shift towards more vibrant yellow and red hues, enhancing visual appeal and potentially increasing consumer attraction and expectations of high-quality products.

5.1.2 Proximate Composition of the Cassava Flour

5.1.2.1 Moisture Content

The proximate composition of the flour is represented in Table 4.2. The moisture level of the different cassava types varied between 7.37% and 9.0%. CAS 3 had the highest moisture content of 9%, which was significantly different ($p < 0.05$) from KME 4, which had the lowest moisture content of 7.37% an indication that moisture content increased with the increase in irradiation doses. Gamma irradiation may cause structural alterations in cassava flour, which could change the flour's hydration characteristics and may increase its hygroscopic properties. The molecular configuration changes can create more sites for water molecules to interact, leading to higher moisture absorption by the flour. In contrast, Verma et al. (2023) demonstrated that moisture content was decreased as the irradiation doses increased from 7.87% (0Gy) to 6.37 %, (10Gy) due to the adsorption-desorption process on the cassava starch. Differences in the moisture content can also be due to variety (Nilusha et al., 2021). All the varieties had lower moisture content compared to 10.9% (USDA, 2023). Overall, the present study indicates that the flours had moisture levels <13% across all varieties which is the recommended level of moisture in flours as moisture content above 13% allows microbial growth and caking hence spoilage (Kumar et al., 2017). The low moisture content in KME 4, CAS 1, and CAS 2 signifies microbiological resilience, resulting in extended shelf-life and stability of food products made from these flours.

5.1.2.2 Ash Content

The cassava flour had an ash level ranging from 1.75 to 2.38 g/100 g as shown in Table 4.2. CAS 3 had the highest ash content of 2.38 g/100 g significantly different from the other

varieties ($p < 0.05$). The ash content of cassava flour increased as the irradiation doses increased. This could be attributed to the impact of gamma irradiation on the accessibility of minerals in the flour as irradiation disrupts the interactions between minerals and other components of the flour, such as proteins and carbohydrates (Bamidele & Akanbi., 2013). This results in enhanced solubility easier extraction and bioaccessibility of certain minerals, contributing to an increase in the ash content of the flour. Similar trends were shown by Khan et al. (2018) and Verma et al. (2023) on peaches (5 Gy) and cassava starch (0-10 Gy) upon irradiation. Ash content is an important measure of mineral content, which plays a vital role in several physiological processes in the human body. It provides information about the amount and concentration of essential minerals like calcium, magnesium, sodium, and potassium, which are necessary for maintaining healthy bones. CAS 3 exhibited the highest ash level among the other kinds, suggesting a greater concentration of minerals.

5.1.2.3 Lipids Content

The lipid content of the different cassava flour cultivars exhibited a range of 1.67-2.12 g/100 g as shown in Table 4.2. CAS 1 had the highest lipid content significantly differing ($p < 0.05$) from the other varieties. The increase in lipid content with the increase in irradiation doses could be because irradiation may induce structural changes in the lipid complexes of cassava flour, altering their chemical properties by breaking down the interactions between lipids and proteins in the flour and enhancing its solubilization making lipids more accessible for extraction and quantification (Asare & Darfour, 2024). The lipids levels recorded in this study are higher compared to the 0.49 g/100 g recommended by USDA, (2023). CAS 2 and CAS 3 had lipids $>1\%$ which is higher than

the studies done by Nilusha et al. (2021) that recorded <1% lipids in cassava varieties in Sri Lanka. According to Wheatley et al. (2003), low lipid content (<1%) in cassava flour results in reduced starch-lipid and amylose-lipid complex formation. This, in turn, increases the swelling power, solubility, and susceptibility to granule disruption of the flour, as the complexes are not present to inhibit these properties. Lipids play a vital role in energy provision and absorption of fat-soluble vitamins like A, D, E and K (Morgan & Choct, 2016) highlighting the nutritional significance of lipid content in cassava-based products aside from soups and porridge.

5.1.2.4 Fiber Content

The fiber content range was 5.60 - 7.02 g/100 g. CAS 1 exhibited the least fiber content of 5.6 g/100 g, while KME 4 had the most fiber content of 7.02 g/100 g as indicated in Table 4.2. CAS 1, 2, and 3 fiber content was less than that of KME 4 indicating that gamma irradiation decreased the fibre content. This could be due to the possibility that irradiation caused the degradation of fiber to small particles and altered the solubility of fiber components, making them more susceptible to extraction, resulting in lower measured fiber content. Verma et al. (2023) showed that fiber content increased due to irradiation from 2.0 -3.2 from 0-10 Gy irradiation doses due to the decrease of moisture and fat content. Mostly, the fiber amounts recorded in this study are far below the recommended daily dietary fiber intake is 25-30 g. This indicates that individuals relying solely on these cassava varieties may not meet their daily fiber requirements. Therefore, it is essential to source fiber from other food sources and consider supplementation to boost fiber intake for optimal digestive

health and to reduce the risk of chronic diseases like diabetes and cardiovascular diseases (Onodu et al., 2018).

5.1.2.5 Protein Content

Regarding protein content, variations were observed among the cassava flour varieties that ranged from 1.54 to 2.12%. The results in Table 4.2 indicate that cassava flour protein content can vary significantly depending on the variety and that higher irradiation doses may lead to a slight increase in protein content. This can be explained by the structural changes induced by gamma irradiation on the protein molecules such as crosslinking by the formation of covalent bonds between protein molecules and aggregation of the protein molecule where they form larger, higher molecular weight complexes (Li et al., 2020) resulting in higher protein content. These findings agree with the study by Asare and Darfour (2024) that protein contents showed no significant difference ($p > 0.05$) with the increase of irradiation. USDA, (2023) reported the amount of protein in cassava flour as 0.92% indicating a higher protein amount in the developed varieties suggesting an improvement in the protein profile of these varieties.

5.1.2.6 Carbohydrates Content

Carbohydrate content showed variability among the varieties and ranged from 79.0 - 81.02% with CAS 3 exhibiting the highest carbohydrate content significantly different from the other varieties. From the results, it is noted that an increase in irradiation dosage led to an increase in carbohydrate content. This is possibly due to gamma irradiation-induced mutations that led to enhanced yield attributes and starch content (Sudarmonowati et al., 2021; Verma et al., 2023). Researchers have shown that gamma irradiation at various doses results in higher amylose content and yield in irradiated cassava lines compared to

controls (Khumaida et al., 2015). This process allows for the generation of mutant lines with significantly higher starch content and yield, addressing the limitations of conventional breeding methods (Verma et al., 2023). The study findings on carbohydrate content are contrary to the findings of Asare & Darfour (2024) where an increase in irradiation doses decreases the carbohydrate content due to the differences in the starch composition (amylose-amylopectin ratio) and structure among cassava varieties, which may influence the susceptibility to degradation or modification by irradiation. Lower carbohydrate varieties (CAS 1) may offer benefits in managing blood sugar levels, while higher carbohydrate varieties may require closer monitoring for individuals with specific dietary needs (CAS 2 and 3).

5.1.3 Mineral content of the cassava flour

Results for the mineral content in cassava flour are shown in Table 4.3. Magnesium, zinc, and iron content ranged from 48.73- 64.78 mg/100 g, 1.02-1.40 mg/100 g, and 2.70-3.67 mg/100 g respectively. CAS 3 had the highest magnesium content significantly differing from the other varieties. On the other hand, KME 4 displays the highest levels of zinc and iron content, which are significantly different from the other types ($p < 0.05$). According to the results, gamma irradiation decreased the levels of magnesium, zinc, and iron in all the irradiated varieties compared to the original variety, KME 4. This reduction may be because irradiation can enhance the attachment of these minerals to anti-nutrients found in cassava flour such as phytates and oxalates (Samtiya et al., 2020). This binding has the potential to decrease the solubility and bioavailability of magnesium, zinc, and iron. Despite the findings of Verma et al. (2023) which suggested that gamma irradiation did not have a substantial impact on magnesium content, this study observed a decline in

magnesium levels. Magnesium values observed in this study exceeded the values reported by FAO, (2022) at 33.6mg/100g. Magnesium is a crucial micronutrient as it is a co-factor in over 300 metabolic reactions in the human body (Long & Romani, 2014). Zinc is crucial for optimal immune system functionality, aiding in the defense against infections and diseases (Bayata, 2022) while iron is an indispensable mineral that plays a vital role in multiple physiological processes, such as red blood cell formation, oxygen transportation, and energy generation (Ayetigbo et al., 2018). Given that KME 4 has the highest mineral content among the cassava flour varieties mentioned, incorporating this variety into the diet can help maintain a healthy immune response and support essential bodily functions. However, it is important to note that varieties CAS 1, CAS 2, and CAS 3 may also contribute to magnesium, zinc, and iron intake, but at lower levels. Fortification of these flours with minerals remixes and fortification of cassava flour with other products can help boost the low amounts of these minerals (Udoro et al., 2021)

Calcium content ranged from 62.84 - 64.33 mg/100 g. CAS 2 had the highest content that was significantly different from the other varieties ($p < 0.05$). The variation in the calcium content across all the varieties may be due to irradiation that can modify the solubility of minerals in cassava flour by disrupting the interactions between other flour components in the cassava flour hence the increase and decrease depending on the variety. The calcium content was lower than the average values recorded by (USDA, 2023) of 75mg/100g across all varieties. The importance of calcium in improving skeletal health is well-established as mentioned by Heaney. (2002). Calcium is essential for the development and upkeep of robust bones and teeth, and a lack of it can result in osteoporosis. CAS 3 had the highest calcium concentration, which can make a more substantial impact on fulfilling the body's

calcium requirements and perhaps offer health advantages. On the other hand, CAS1, KME 4, and CAS 2 have lower calcium levels, which may not be adequate for maintaining ideal bone health.

5.2 Functional properties of the cassava flour

5.2.1 Solubility Index and Swelling Power

The solubility and swelling power of the cassava flour are presented in Table 4.4. The results imply that the flour's solubility rose in direct proportion to the increased radiation exposure levels. Smaller molecules with a lower molecular weight are created when the glycosidic bonds in starch chains are broken by gamma irradiation. In the end, this procedure makes cassava starch more soluble in water (Atrous et al., 2017). The starch chains' glycosidic bonds are broken by the high-energy gamma rays, which lowers the molecular weight and produces smaller, more soluble fragments that increase solubility (Sunder et al., 2022). Furthermore, the depolymerization of starch molecules—especially amylopectin—during irradiation is responsible for an increase in solubility (Kumar et al., 2017). Asare & Darfour, (2024) found that the solubility index of cassava starch increased significantly from 20.21% (control) to 27.54% when gamma irradiation doses were increased from 5 to 20 Gy. According Sunder et al. (2022) these findings are consistent with earlier research on a variety of starch sources, including potatoes.. The results suggest that products with a need for rapid dissolution, such as sauces, soups, and gravies, could gain advantages from utilizing varieties with higher solubility like CAS 1, 2, and 3. On the other hand, products that require a slower dissolution rate, such as specific types of bread, crackers, or snacks, might be more suitable for varieties with lower solubility like CAS 1, CAS 2, and CAS 3.

Gamma irradiation decreased the swelling power in CAS 1 and CAS 3 comparison to the parent (KME 4). CAS 2 had the highest swelling power among the daughter varieties, whereas CAS 3 had the lowest. Under the influence of gamma irradiation, the differences in swelling power between the cassava varieties may result from compositional changes like decreased amylose and carbohydrate content, as well as structural changes like depolymerization of amylopectin chains and degradation of starch granules (Tran et al., 2022). According to earlier research, cassava has a low concentration of amylose, indicating a weak intermolecular interaction (Schirmer et al., 2013). Research has indicated a negative relationship between the amount of amylose in cassava and its capacity to swell in the presence of liquid (Schirmer et al., 2013). A study has shown a negative correlation between the amount of amylose present and the ability of cassava to swell when exposed to liquid (Chisenga, Workneh, Bultosa, & Laing, 2019). Starches that have a lower amylose percentage, such as cassava, demonstrate a greater ability to swell in comparison to starches with a higher amylose level (Chisenga, Workneh, Bultosa, & Laing, 2019). This is probably because a lower amylose content reduces structural interference, allowing the semi-crystalline amylopectin regions to hydrate and swell freely during gelatinization. In contrast, a higher amylose content restricts swelling by forming stiff networks that prevent granule hydration. (He et al., 2023).

The solubility and swelling power of starch-based foods determine their textural, thickening, and pasting properties. This implies that, in contrast to the daughters (CAS 1, CAS 2, and CAS 3), KME 4 will produce food products with superior texture and pasting qualities.

5.2.2 Water and Oil Absorption Capacities

The data presented in Table 4.4 indicated that the water absorption capacity (WAC) varied between varieties. Water Absorption Capacity (WAC) is a measure of the quantity of water that is taken in by the flour when provided with a minimal amount of water (Vasconcelos et al., 2017). With the exception of CAS 2, where the WAC decreased as the irradiation dosages increased, the WAC capacity showed a positive correlation with the increase in gamma irradiation. Varietal differences or the presence of amylose and amylopectin components may be the cause of the cassava flour's decreased water absorption capacity (Jombo et al., 2021).

About 22–23% of cassava flour is made up of amylose, which is highly soluble in water and does not gel. However, amylopectin, which makes up roughly 76-77% of cassava flour, is less soluble but gels when combined with water (Rasaq et al., 2020). The cassava flour's water absorption capacity (WAC) may be impacted by the balance between these two starch components. Starches with a higher amylose content and lower degrees of gelatinization absorb more slowly than those with a higher amylopectin content (Liu et al., 2006).

The increase in WAC for CAS 1 and CAS 3 due to increased irradiation doses can be attributed to the decomposition of starch molecules by irradiation into simpler forms that exhibit a greater affinity for water. Furthermore, the process of gamma irradiation causes the glycosidic linkages in starch chains to be disrupted, resulting in the formation of smaller molecules with reduced molecular weight. This eventually enhances the ability of cassava starch to dissolve in water (Asare & Darfour, 2024). Besides starch, amino acid influences WAC. In their study, Dereje et al. (2020) observed that polar amino acids, which have a

strong attraction to water molecules, have a positive effect on the water absorption capacity (WAC) of cassava flour. A study conducted by Verma et al. (2023) confirms these findings by demonstrating a rise ranging from 1.72% to 1.97% when the dosage or irradiation is increased from 0 to 10 Gy. Increased water absorption capacities (WACs) enhance the ability to incorporate additional water during the manipulation or processing of dough and food products (Jisha et al., 2010). Thus, flours derived from CAS 3 and CAS 1 may be the appropriate choice for convenient dough manipulation.

Oil Absorption Capacity (OAC) also increased as the irradiation doses increased. The values evaluated for cassava flour (OAC) exhibited an increase ranging from 113% to 119% as the irradiation dosage was raised from 15 to 30 Gy. The rise in OAC can be ascribed to the partial denaturation of proteins in reaction to irradiation, leading to the exposure of a greater number of nonpolar protein residues inside the molecules. This in turn strengthens the interaction between the protein and oil (Zhang et al., 2019). These results affirm the finding by Verma et al. (2023) that showed an increase of OAC on cassava starch with an increase in irradiation from 1.80-1.99 g/g at 0-10 Gy. According to Godswill. (2019), low protein content in cassava flour is attributed to low OAC as protein has a high positive correlation to OAC. OAC is a crucial metric for assessing a flour's capacity to retain flavor. The differences in the hydrophilic components of the samples may be the cause of the variation in the OAC values (Chauhan et al., 2019). The hydrophilic components (proteins and carbohydrates) increase with decreasing OAC. As a result, the CAS 3 flour sample might be more lipophilic than the others. In lipid-based product formulations, high OAC flours are frequently used to maintain flavor and enhance other sensory attributes like mouthfeel (Aidoo et al., 2022). Furthermore, it improves the

absorption of fat-soluble vitamins in foods that are fortified with lipids.. Therefore, CAS 3 could be a superior option in food compositions that necessitate the preservation of flavor and the absorption of fat-soluble substances to improve the overall quality of the product.

5.2.3 Bulk Density

The porousness of food products is determined by bulk density (BD). It depends on the amount of moisture, the size of the particle, and the starch content of the flour (Otondi et al., 2020). The BD of the cassava flours ranged from 0.69-0.76% as shown in Table 4.4 and were not significantly different ($p>0.05$). The values from the daughter varieties (CAS1, 2, and 3) were lower than those of the parent KME4 indicating that gamma irradiation reduced bulk density. The decrease in bulk density after gamma irradiation of the cassava flour varieties indicates a change in the physical properties of the flour. Gamma irradiation may lead to alterations in the particle size distribution of the cassava flour. The changes in particle size can affect the packing arrangement of the flour particles, leading to a decrease in bulk density (Chisenga, Workneh, Bultosa, & Laing, 2019b). This is corroborated by Asare and Darfour (2024) who showed that irradiation did not affect the BD of the cassava starch. Anosike et al., and Dereje et al., (2020) mentioned that BD lower than 1g/ml can be used in the manufacturing of weaning foods that are less bulky and have high energy. Similarly, it facilitates marketing, transportation, and easy storage because of its low volume of packaging materials required to store the flour (Dereje et al., 2020). This implies that CAS 1, CAS 2, and CAS 3 cassava flour varieties, are suitable for the production of weaning foods. The lower bulk density would reduce bulkiness and increase the energy density of the weaning foods, providing more nutrients per unit volume and they are also easy to transport and market.

5.3 Pasting Properties of Cassava Flour

The pasting properties of flours are presented in Table 4.5. Pasting properties are an important functional property that measures the ability of flours to form a paste (Aidoo et al., 2022). Peak viscosity (PV), trough viscosity (TR), breakdown viscosity (BD), final viscosity (FV), setback viscosity (SV), and pasting temperature are some of the variables that affect these characteristics. Between the control and irradiated (CAS1, 2, and 3) samples, the flours' peak, final, and setback viscosities significantly decreased, particularly as the irradiation levels rose.

The stability of starch, as well as its capacity to absorb water and swell at high temperatures prior to physical breakdown, are indicated by the peak viscosity of flour (Nyawose et al., 2022). Peak viscosity (PV) decreased with increasing gamma ray exposure, with KME 4 having the highest PV and CAS 2 the lowest. This implies that starch molecules undergo radiolytic cleavage in response to gamma radiation, resulting in the formation of smaller fragments. Due to their inability to absorb water as well as intact granules, these fragments have a lower swelling power and contribute less to peak viscosity (Anosike et al., 2020).

Trough viscosity reflects on the flour's capacity to influence batter during baking (Bakare et al., 2014). Trough viscosity (TV) is lowest for KME 4 (97.47 ± 1.98) and highest for CAS 1 (210.69 ± 1.75) and are significantly different. This indicates that the minimum viscosity after peak viscosity is reached is lower in the non-irradiated KME 4 variety. High trough viscosity flours can be easy to batter as compared to those with low trough viscosity. In this regard, CAS 1,2 and 3 can be easily applied to the baking industry due to their high trough viscosity values (Khakasa et al., 2023)

Breakdown viscosity (BD) is highest in KME 4 (54.37 ± 0.63) and lowest in CAS 1 (42.07 ± 0.56) showing significant differences suggesting that the paste of the non-irradiated variety is less resistant to shearing (Farasara et al., 2014). The breakdown viscosity highlights the extent to which the formed paste is unstable due to shear showing the degree of disruption of starch granules under mechanical stress (Awoyale et al., 2020). The higher setback viscosity in KME 4 indicates that its starch granule is more resistant to disruption under shear stress. This could be beneficial in applications where the starch needs to maintain its structure and stability, such as in food products that require a specific texture or consistency.

Final viscosity illustrates the characteristics of cooled gels formed after retrogradation (Nyawose et al., 2022). Final viscosity (FV) is highest in KME 4 (468.96) and lowest in CAS 1 (398.46), implying that the paste of the non-irradiated variety has higher viscosity after cooling. The high final viscosities recorded in Table 4.5 for KME 4 indicate that the starch paste from KME 4 is more resistant to cooling than the other varieties. This shows that flour from this cassava (KME 4) can easily be used to produce mashed products due to the viscosity of the paste and fewer flour will be used in the process.

The temperature at which starch granules are disrupted is known as the pasting temperature, and the amount of time needed for them to swell and decompose under shear stress is known as the peak time (Awoyale et al., 2020). Results from Table 4.5 show that CAS 1, CAS 2, and CAS 3 had a lower peak time and temperature compared to those of KME 4. The lower pasting time and pasting temperature for CAS 1, 2, and 3 flours indicate that products made from these cassava varieties require less cooking time unlike those prepared from KME 4.

The effects of gamma irradiation on the pasting properties of cassava flours have been documented by different studies that focused on the characteristics of amylose and amylopectin starch granules. For instance, a study by Verma et al. (2023) on cassava starch exposed to gamma irradiation showed decreased pasting temperature, peak viscosity, and final viscosity. Another study by Ito et al. (2018) also noted that irradiated cassava flour exhibited decreased pasting parameters such as the peak, trough, setback, final viscosity, and pasting temperature due to the depolymerization of the starch granule resulting in molecular weight and size reduction that decreases the water absorption. Findings from these studies corroborate the current study findings where the peak, final, break down and setback viscosities were significantly reduced after irradiation.

5.4 Fourier transform infrared (FTIR) spectroscopy

Figure 4.1 displays the FTIR spectra of the cassava flour, while Table 4.6 provides the interpretation of the peaks. The FTIR spectrum displays the bands that correspond to the stretching, bending, and deformation of the main functional groups found in the starch granule (Abdullah et al., 2018). The absorbance peaks observed in the wavelength range of $3000\text{--}3700\text{ cm}^{-1}$, $1563.11\text{--}1827.27\text{ cm}^{-1}$, $483\text{--}1258\text{ cm}^{-1}$, and $1663\text{--}1827\text{ cm}^{-1}$ in all samples in the spectra indicate the presence of O-H, C-O-C, C-H, and C=O functional groups in cassava flours, respectively. The prominent features seen at 3386.46 cm^{-1} (KME4), 3380.38 cm^{-1} (CAS 1), 3808.41 cm^{-1} (CAS 2), and 3275.53 cm^{-1} (CAS 3) are most likely caused by the stretching vibration of the O-H bonds in water molecules present in the sample (Kizil et al., 2002). Water is frequently found in cassava flour, and these peaks show that water is present in all cassava varieties. The C-O-C stretching vibration of glycosidic bonds is probably the cause of the intensity of the peaks at $1563\text{--}1567\text{ cm}^{-1}$ in

all varieties (Gul et al., 2016). These groups may indicate the presence of starch or other carbohydrates in all varieties of cassava flours (Kizil et al., 2002). The fingerprint region's prominent bands at 483 cm^{-1} and 747 cm^{-1} represent the alkyl chains' C-H bending vibration. (Kizil et al., 2002). The fingerprint region's prominent bands at 483 cm^{-1} and 747 cm^{-1} are indicative of the alkyl chains' C-H bending vibration. The presence of starch in the various types of cassava is indicated by these bands. The C=O stretching vibration of carboxyl or ester groups is most likely the cause of the peaks seen between 1663 and 1827 cm^{-1} . These groups' presence may be a sign that the sample contains lipids, proteins, or other organic molecules (He et al., 2020). CAS 1, CAS 2, and CAS 3 have more peaks in the range 3800-3200 cm^{-1} range than KME 4, indicating more hydroxyl groups being stretched in the daughters (Ezekiel et al., 2007). Gamma irradiation can impact the hydrogen bonding network and molecular interactions inside the starch granules of CAS 1, CAS 2, and CAS 3. This can increase in the presence of water/hydroxyl groups, leading to the observed higher intensity of peaks in the 3800-3200 cm^{-1} range. The fingerprint region below 1500 cm^{-1} shows more peaks in CAS 1, 2, and 3 compared to KME 4, indicating changes in the starch structure. Also, CAS 2 and 3 have more peaks in the 1800-1500 cm^{-1} range indicating more carboxyl/ester groups. These changes could be due to irradiation that can induce modifications at the molecular level leading to structural rearrangement in the starch granules. This FTIR analysis shows that gamma irradiation shifted the peaks of absorbance at the fingerprint region and increased the peaks at 3000-3800 cm^{-1} of CAS 1, CAS 2, and CAS 3.

5.5 Correlation Coefficient of the chemical and functional properties of cassava flour

The Pearson correlation coefficients between different parameters are shown in Table 4.7 correlation matrix. The correlation coefficients reflect the degree and direction of linear correlations between pairs of variables. The study found a positive connection ($r=0.72$, $p=0.05$) between crude fiber and final viscosity, indicating that as the fiber content increases, the final viscosity of the starch paste increases. Fibre can interact with starch, which can impact the way starch behaves when heated and mixed with liquid, and also contributes to the overall thickness of a substance (Ayedigbo et al., 2018). This interaction occurs through the formation of hydrogen bonds between the hydroxyl groups of fiber polysaccharides and starch. This process aids in enclosing starch granules, hence restricting their expansion and transformation into a gel-like state (Chaplin, 2003). Crude protein had a positive correlation with final viscosity ($r=0.706$, $p=0.05$). Proteins can interact with starch and thus influence its pasting behavior, the presence of proteins can limit starch swelling and lead to higher final viscosities by limiting the absorption of water into the starch granule this delays the pasting temperature resulting in higher final viscosity (Oppong et al., 2021). In addition, proteins can form complexes with amylose, further contributing to increased viscosity (Ayedigbo et al., 2018). These connections emphasize the intricate relationship between starch, fiber, and protein in influencing the ultimate thickness of cassava flour. The findings indicate that the makeup of cassava flour, namely the levels of vulnerable starch, fiber, and protein, can greatly impact the characteristics of starch, fiber, and proteins in terms of pasting and rheological properties. This aligns with the findings by Ocheme et al. (2018). The substantial positive association observed between oil absorption capacity (OAC) and crude lipid content ($r = 0.736$, $p = 0.05$) can be attributed to the interaction between the hydrophobic portions of proteins specifically, the

nonpolar side chains of hydrophobic amino acids and the hydrocarbon chains of lipid molecules, facilitated by van der Waals interactions and hydrophobic effects. This binding mechanism allows proteins to entrap and hold onto lipids effectively, thereby increasing the overall OAC and facilitating the absorption and retention of oils in food systems (Torres-Sánchez et al., 2023). Furthermore, there were significant negative correlations between setback and moisture content ($r = -0.623$ $p = .05$). Higher moisture content can hinder starch re-association process by increasing the mobility of starch molecules and reducing the likelihood of amylose re-formation. This results in lower setback viscosity values (Gborie et al., 2022).

5.6 Physical Characteristics of Cassava Products

5.6.1 Colour of the Cassava Thin Porridge.

The color attributes of the porridge varieties are shown in Table 4.8 Lightness (L^*) measures the brightness of the porridge usually on a scale of 0-100, with values below 50 lighter and those above lighter. Porridge made from KME 4 exhibited the highest lightness value significantly different from those made from the other varieties ($p < 0.05$). Porridges from all varieties had lower lightness values, indicating a trend toward darker colors in these irradiated varieties. The lower lightness values in CAS 1, CAS 2, and CAS 3 porridges compared to that of KME 4 suggest that gamma irradiation and subsequent cooking can lead to a darkening of cassava porridge color. This effect may be attributed to the Maillard reaction, which involves the interaction between amino acids and reducing sugars under the influence of irradiation and cooking. The Maillard reaction can produce brown pigments, contributing to the reduced lightness observed in the irradiated varieties (Tambalo et al., 2023). A study by Ramos et al. (2023) aligns with this study as it reported

a significant decrease in luminosity (lightness) in whole sorghum flours subjected to gamma irradiation. Researchers found flour became darker because enzymes sped up changes within its natural components, resulting in a deeper color when exposed to radiation - particularly noticeable in sorghum porridge. Color greatly impacts what people buy; generally, consumers favor paler shades in foods such as Ugali (Hasmadi et al., 2020). The redness values showed a significant range, with CAS 3 having the highest) and KME 4 the lowest. Irradiated cassava porridge turns redder than non-irradiated versions, hinting that gamma rays boost its color. Perhaps this happens because radiation creates reddish pigments - maybe carotenoids during preparation (Reddy & Viswanath, 2019). Kuan et al. (2013) suggests that gamma irradiation can lead to the formation of new pigments through the interaction of radiation with food components. This can occur through oxidation processes or reactions between amino acids and sugars (Ognyanov et al., 2022). The pronounced red hue in CAS 3 may enhance the visual appeal of the porridge, as red hues are often associated with good flavor.

Yellowness (b^*) measures the yellow hue of the porridge. CAS 1, CAS 2, and CAS 3 exhibited significantly higher yellowness values compared to KME 4 ($p < 0.05$). The higher yellowness values in the irradiated varieties indicate that gamma irradiation can promote the formation of yellow pigments, such as carotenoids, in cassava porridge (Ognyanov et al., 2022). This effect may enhance the visual appeal and perceived nutritional quality of the porridge, as yellow hues are often associated with the presence of beneficial compounds like antioxidants (Ayedigbo et al., 2018). A study by Verma et al. (2023) agrees with this finding as it shows the yellowness value increased from 9.14 for the non-irradiated sample to 12.28 at 10 Gy irradiation doses.

5.6.2 Colour of the Cassava Cookies

Tables 4.9 and 4.10 show the colour variables of different flour blend cookies, including varying proportions of CAS 1 flour and wheat flour as well as KME 4 flour and wheat flour.

The higher chroma in blends like V5 suggests a greater concentration of colour pigments, making them appear more vibrant. This vibrancy can be attributed to the interaction between the pigments present in the cassava and wheat flours, as well as the overall structure of the flour matrix, which enhances light absorption and reflection (Lund & Ray, 2017). Flour blends with a higher proportion of cassava flour often exhibit the highest lightness (L^*), resulting in a brighter color. This is likely due to the partial substitution of wheat flour with cassava flour, which dilutes the gluten content and slows the rate of gluten network formation, leading to a lighter color. Chisenga et al., (2019) agree with this finding as the incorporation of cassava flour into wheat flour would lead to increased lightness resulting in to increase in lightness in the final product. Additionally, the fiber content from the cassava flour may have increased the fiber-water interactions, contributing to the lighter appearance.

5.6.3 Browning Index

Tables 4.1, 4.8, 4.9 and 4.10 show the browning index of flour, porridge, and cookies of new cassava varieties. The Browning Index (BI) is a measure used to assess the degree of browning in food products, often associated with enzymatic reactions and non-enzymatic browning processes such as the Maillard or caramelization reactions (Lund & Ray, 2017). The browning index for the cassava flour showed no significant difference ($p < 0.05$) while that of the porridge showed a significant difference ($p < 0.05$). When cassava porridge from

CAS 3 received a hefty dose of gamma radiation, it darkened considerably. This darkening correlates with a substantial jump in BI, hinting that both the Maillard reaction alongside caramelization were boosted by the radiation. As the control variety with no irradiation, KME 4 has the lowest BI indicating minimal browning, this serves as a baseline for comparison showing that without the influence of gamma irradiation, the natural browning processes are limited (Tamanna & Mahmood, 2015).

5.8 Sensory Evaluation of Cassava Thin Porridge and Cassava Blend Cookies

5.8.1 Consumer acceptability of the Thin Porridge.

Consumer acceptability of the cassava porridge from the new varieties and parents was evaluated through sensory evaluation. Table 4.11 shows that the cassava porridge from three varieties (CAS 1, CAS 2, and CAS 3) sensory attributes including appearance, taste, texture, aroma, and overall acceptability had no significant difference ($p < 0.05$). This suggests that consumers rank these varieties similarly regarding these sensory characteristics, which may imply that the processing methods (gamma irradiation) or the inherent qualities of the cassava itself contribute to a consistent sensory profile across these varieties. Research on cassava porridge aligns with this study as it highlighted that sensory attributes such as taste and texture are critical for consumer preference, but when varieties are processed similarly, their sensory profiles can be quite similar leading to no significant differences in acceptability scores among them (Katunzi-Kilewela & Fortunatus, 2022). Gamma irradiation did not affect consumer acceptability and this aligns with the studies by Castell-Perez & Moreira, (2021) and Maherani et al, (2016) that highlight the effectiveness of this processing method without compromising sensory qualities especially when applied as a pre-harvest technique as was in this study. This study supports the

conclusion that gamma irradiation can be effectively utilized in food processing without compromising consumer acceptability, particularly when consumers are well-informed about the benefits and safety of irradiated products.

5.8.2 Consumer Acceptability of Cookies

The results in Table 4.12 show the results of sensory scores for cookies produced at different levels of composite flours and compared to the control. Appearance is one of the major factors in determining consumer acceptance of the food product. The scores rated for V5 (60% KME 4 flour 40% Wheat flour)

and V6 (40% KME 4 flour 60% Wheat flour) were significantly ($p < 0.05$) lower than the other samples. The low rating might be attributed to the brightness of color that might not be visually appealing to the consumers as cookies with a golden brown color and a uniform shape are considered the best that enhances their overall attractiveness which was the case with V7 control (100% wheat). Resulting in having the highest appearance score (Suriya et al., 2017).

Another key attribute is the taste. Cookies made from V5 (60% KME 4 flour 40% Wheat flour) were significantly ranked lower in taste while those from V1 (50% CAS 1 and 50% wheat) ranked highly. This could have resulted in a balanced taste that complemented the other sensory attributes of the cookies, enhancing the overall taste experience for the consumers (Ubbor & Akobundu, 2009). Further, the interaction between the ingredients in the CAS 1 and the wheat flour blend in V1 could have created a harmonious flavor profile that stood out during the sensory evaluation, resulting in a higher taste score (Chandra et al., 2015). The low scores from V5 and V6 in the taste of the cookies might be associated

with the aftertaste reported by the respondent. The attribute of a "root crop" aftertaste in these samples might have significantly impacted the taste perception of the cookies, leading to lower scores for these specific samples. Several researchers have reported that higher substitution of wheat flour with cassava flour in biscuits was associated with a beany flavor "root" aroma and aftertaste (Bakare et al., 2014). Varieties with a higher proportion of cassava flour (V5, V6) scored lower for aroma compared to those with a higher wheat flour content (V1, V2, V3, V4). Wheat flour contains more proteins and other compounds that can contribute to the development of desirable aroma and flavor compounds during baking through Maillard reactions and caramelization (Ali, 2012; Ochieng et al., 2023).

In contrast, cassava flour has a relatively bland and neutral aroma profile, lacking the complex aromatic compounds found in wheat flour (Sobhan et al., 2014). As the proportion of cassava flour increases in the cookie formulations, the overall aroma and flavor profile become more muted and less appealing to the sensory panelists. Cassava flour has a relatively bland and neutral aroma profile, lacking the complex aromatic compounds found in wheat flour (Ochieng et al., 2023). This is evident in the lower aroma scores for the cookie varieties with higher cassava flour content (V5, V6) compared to those with a higher wheat flour content (V1, V2, V3, V4). This is likely due to the inherent flavor characteristics of cassava, which do not complement the typical wheat-based aroma and taste profile that consumers expect in baked goods (Ubbor & Akobundu, 2009).

V5 and V6, with higher cassava flour content, scored lower for overall acceptability compared to the other varieties. This can be attributed to the beany flavor, "root" aroma, aftertaste, texture differences, and potentially less appealing color and appearance compared to the varieties with a more balanced blend of cassava and wheat flour or those

made entirely with wheat flour (Ubbor & Akobundu, 2009). Additionally, the high acceptance of V1, V4, and V7 can be attributed to the balanced flavor profile, texture and mouthfeel, color and appearance, and the rich aroma and flavor profile of wheat flour (Aziah et al., 2012)

The control cookies made with 100% wheat flour (V7) scored highly in appearance, aroma, and texture, with an overall acceptability of 7.94. This could be because cookies from wheat flour are a common and familiar product. This finding is in agreement with the study by Sobhan et al. (2014) that the control (100% wheat flour Biscuits) were highly acceptable overall compared to the other cassava-wheat blend biscuits. From the results, it is evident that cookies made from KME 4 flour scored less in all aspects compared to CAS 1. Cookies made from CAS 1 flour are likely to have specific attributes influenced by the cassava variety, potentially offering a unique texture profile. Cookies made from KME 4 flour may exhibit a different texture compared to those made from CAS 1 flour due to the specific properties of this cassava variety.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION.

6.1 Conclusion

This study revealed a significant difference in cassava flour's chemical, functional, and sensory properties. The proximate composition indicated that all developed varieties generally had comparable carbohydrate levels, but variations in protein, lipids, and fiber content were noted. Higher irradiation doses were associated with increased moisture content, particularly in CAS 3, suggesting alterations in flour structure that enhance hydration capacity

Functional properties, including water and oil absorption capacities, increased with higher irradiation while solubility decreased with higher irradiation. This showed that flour from CAS 1 had favorable characteristics for food applications. Pasting properties further indicated that KME 4 exhibited higher peak viscosity, while CAS 1 demonstrated a well-balanced performance in terms of stability and texture.

The FTIR spectra show that gamma irradiation caused significant changes in the functional groups and molecular structure of cassava starch. The increased oxidation (C=O) and reduced intensity in hydroxyl-related peaks suggest that gamma irradiation both degraded and reorganized the starch molecules, affecting their physicochemical properties.

Sensory evaluations highlighted that cookies made with CAS 1 flour achieved high acceptability scores, particularly in taste and texture, outperforming those made with KME 4. Control cookies made with 100% wheat flour scored the highest overall. This suggests that cassava varieties, particularly CAS 1, can serve as effective alternatives to traditional

wheat flour, providing unique sensory attributes and potentially enhancing the nutritional profile of baked goods.

Overall, the findings underscore the potential of irradiated cassava varieties as valuable ingredients in food formulation, particularly for products where texture, taste, and moisture retention are critical.

6.2 Recommendations

Policymakers should promote and fund research into the effects of gamma irradiation on various food crops, particularly cassava. This could lead to the development of new flour varieties with enhanced nutritional and functional properties, benefiting both producers and consumers.

Establishing quality standards for cassava flour based on its chemical and functional properties can help guide manufacturers in producing high-quality products. This will ensure consistency in flour performance across different applications.

Food manufacturers should consider incorporating gamma-irradiated cassava flour, particularly CAS 1, into their products. This flour shows promising sensory qualities and nutritional benefits, which could attract health-conscious consumers and diversify product offerings.

Local stakeholders, including farmers, processors, and consumers, can enhance the acceptance and utilization of these varieties in local food systems by increasing awareness about their nutritional benefits and culinary versatility.

Further research should explore the long-term effects of different irradiation doses on the nutritional quality and shelf life of cassava flour. This could provide insights into optimal processing conditions.

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APPENDICES

Appendix 1: Sensory Evaluation Score Sheet

Date of evaluation

Product evaluated

Name of evaluator

Please evaluate the food samples provided and indicate the degree of liking for the appearance, aroma, texture, taste and overall acceptability. Enter the scores under the samples in the scoring sheet using the numerical score provided on the scorecard below.

9-point hedonic scale

Quality	Score
Extremely good	9
Very good	8
Good	7
Below good/above fair	6
Fair	5
Below fair/above poor	4
Poor	3
Very poor	2
Extremely Poor	1

Appendix II: Invitation Letter

Invitation to Participate in a Sensory Evaluation Panel – Cassava Products

Dear Staff and Students,

We invite you to participate in a sensory evaluation panel to assess cassava-based products, specifically cassava porridge and cassava cookies.

The sensory test will take place at the Family and Consumer Science food laboratory at the University of Eldoret in May 2023. Your participation will require approximately 1.5 hours per day for one week. This evaluation aims to assess the taste, flavor, color, and overall acceptability of the cassava products prepared by researchers in the department. Your valuable feedback will contribute to the development of improved cassava-based food options for both farmers and the food processing industry.

Participation is entirely voluntary, and you may withdraw from the panel at any time. Participants must be 18 years or older. Those with food allergies, sensitivities, or dietary restrictions due to medication should not participate. Your responses will be kept confidential.

Attached are the consent form and letter of information for your review. We appreciate your time and look forward to your participation. For more inquiries or concerns feel free to contact Valentine Chebitok (Phone No; 0700664296 and email valentinechebitok@yahoo.com).

Student Name: Valentine Chebitok SAGR/FCS/M/002/21

Supervisors: Dr. Heka Kamau, Prof. Miriam Kinyua Dr. Emmanuel Ayua.


Appendix III: Similarity



University of Eldoret

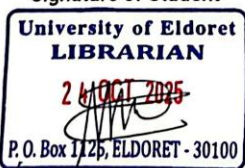
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Department	Type here ..
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Paper Title	EVALUATION OF PHYSICOCHEMICAL, FUNCTIONAL AND SENSORY CHARACTERISTICS OF SELECTED IMPROVED CASSAVA VARIETIES DEVELOPED THROUGH GAMMA IRRADIATION
Similarity	7%
Paper ID	4571900
Total Pages	140
Submission Date	2025-10-24 12:20:33

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