

**NUTRITIONAL COMPOSITION, TECHNOLOGICAL PROPERTIES, AND  
SENSORY CHARACTERISTICS OF IMPROVED PIGEON PEA [*Cajanus cajan* (L.)  
Millsp.] VARIETIES GROWN IN MACHAKOS COUNTY, KENYA**

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**A Research Thesis Submitted to the Graduate School in Partial Fulfilment of the  
Requirements for the Master of Science Degree in Food Science of Egerton University**

**EGERTON UNIVERSITY**

**SEPTEMBER, 2025**

## DECLARATION AND RECOMMENDATION

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

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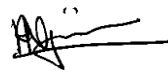
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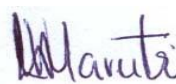
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## **DEDICATION**

To my dear spouse Rachael Muthoni, son Ethan and daughter Amara.

## **ACKNOWLEDGEMENT**

I extend my gratitude to Egerton University for granting me an opportunity and a conducive environment to pursue my Master's degree. I would also like to thank the MasterCard Foundation and RUFORUM through the 'Transforming African Agricultural Universities to Meaningfully Contribute to Africa's Growth and Development' (TAGDev) programme at Egerton University for the sponsorship to pursue my Master's degree. In addition, I extend my sincere appreciation to the Kenya Agricultural and Livestock Research Organization (KALRO) Katumani and Egerton University Seed Unit for the provision of research materials. Furthermore, I am grateful to the management of the University of Nairobi, Kabete Campus, for allowing me access to their laboratory facilities for conducting my laboratory experiments. I am indebted to my esteemed supervisors, Dr. Peninah Ngoda and Dr. Lydia Waswa, whose mentorship has been invaluable from the inception of proposal development to the culmination of the thesis. Their mentorship, knowledge, and steadfast encouragement have been instrumental in molding my academic and professional development. I extend heartfelt thanks to Dr. Nobert Wafula for his guidance and expertise in data analysis, which has been instrumental in deriving meaningful insights from my research findings. I would be remiss not to acknowledge the unwavering support of my beloved wife, Rachael Muthoni, whose encouragement and understanding have been a constant source of strength throughout this journey. Her moral support has been indispensable in overcoming challenges and staying focused on my goals. Finally, I express my gratitude to my colleagues and classmates, particularly those in the Department of Dairy, Food Science, and Technology at Egerton University. Their camaraderie, collaboration, and shared experiences have enriched my academic journey and made the pursuit of knowledge a rewarding and fulfilling endeavour. In conclusion, I am deeply grateful to all individuals and institutions who have played a part, directly or indirectly, in shaping my academic and professional journey. Your guidance and motivation have proven indispensable, and I am dedicated to applying the acquired expertise and competencies toward fostering substantial progress in Africa's advancement and prosperity.

## ABSTRACT

Food insecurity and poor nutrition remain major challenges, particularly in Arid and Semi-Arid Lands (ASALs), where more than 4 million people face an eminent problem of acute food insecurity. Pigeon pea, a resilient pulse crop, offers a promising solution due to its adaptability and high protein content. Research institutions in Kenya have developed improved pigeon pea varieties with desirable agronomic traits. However, limited data exist on their nutritional composition, technological and sensory characteristics. This study determined the nutritional composition, technological properties and sensory characteristics of six improved and one control pigeon pea varieties grown in Machakos County. The experiment was set in a Completely Randomized Design (CRD). Data was analysed using on PROC GLM procedure of the statistical analysis systems (SAS) version 9.1.3. Analysis of variance (ANOVA) was conducted at 95% confidence level and Tukey's honestly significant difference (HSD) applied for mean separation. Proximate analysis revealed significant variations ( $p < 0.05$ ) across varieties: moisture (8.67–10.71%), fibre (7.26–8.75%), ash (3.99–5.51%), protein (24.52–31.16%), fat (1.19–1.92%), and carbohydrates (44.64–52.63%). Mineral content was notably high particularly for zinc (54.26–74.31 ppm), iron (143.45–367.25 ppm), and phosphorous (2191.06–2909.00 ppm). Cooking significantly reduced antinutrients (tannins, phytates, and phenolics) with Egerton Mbaazi 2 showing the highest tannin reduction (57.6%). Technological properties also varied significantly. The control variety (ICEAP 00554) had the highest volumetric expansion before cooking (VEBC) and water absorption capacity (WAC), while KARI Mbaazi 2 exhibited the highest volumetric expansion after cooking (VEAC). KAT60/8 had the highest TSS at 26.67%, correlating positively with VEBC/VEAC ( $r = 0.76$ ) and VEBC/D/RgD ( $r = 0.89$ ). There was a significant variation in the sensory attributes with the Principle Component Analysis (PCA) explaining 58.8% of the total variation. Egerton Mbaazi 2 variety scored highest (5.88) in overall acceptability whereas KARI Mbaazi 1 variety was least preferred (4.50). While pigeon peas provide ample protein, they also contain notable levels of antinutritional factors such as phytates and tannin. These compounds can be reduced through cooking, although the process may lead to some nutrient loss. Sensory evaluation highlights consumer preference for specific varieties, emphasizing the need for breeding programs to only prioritise agronomic performance but also desirable sensory and nutritional traits. Conclusively, improved pigeon peas varieties demonstrate a strong potential to improve nutrition through value-added foods and alternative protein sources. Furthermore, their adaptability to ASALs regions positions them as a viable crop for generating income among low-income farming communities in these regions.

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## **LIST OF ABBREVIATIONS AND ACRONYMS**

<b>ANFs</b>	Anti-nutritional Factors
<b>AOAC</b>	Association of Official Analytical Chemists.
<b>ASALs</b>	Arid and Semi-Arid Lands.
<b>CRD</b>	Completely Randomized Design.
<b>FAO</b>	Food and Agriculture Organization for United Nations.
<b>FEWS</b>	Famine and Early Warning Systems.
<b>HTC</b>	Hard to Cook Phenomenon.
<b>KALRO</b>	Kenya Agricultural and Livestock Research Organization.
<b>KCSAP</b>	Kenya Climate Smart Agriculture Project.
<b>PEM</b>	Protein Energy Malnutrition.
<b>SAS</b>	Statistical Analysis Systems.
<b>TAGDev</b>	Transforming African Agricultural Universities to Meaningfully Contribute to African Growth and Development.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background information

Food insecurity and malnutrition persist as critical issues, especially within arid and semi-arid lands (ASALs). Forecasts suggest that around 670 million individuals globally will continue to experience hunger in 2030, amounting to roughly 8% of the world's population (FAO, 2021). According to the FAO (2020), Africa is the leading continent in the prevalence of food-insecurity where about 346.4 and 452 million people suffer from severe and moderate food insecurity, respectively. An estimation of about 4.1 million Kenyans living in the arid and semi-arid lands are experiencing acute food insecurity (FEWS NET, 2022). Most of the population in ASALs also depends on food assistance from the government and humanitarian organizations (FEWS NET, 2022). In Kenya, ASALs cover about 83% of the land and experience seasonal rainfall with occasional drought leading to crop failure (Shisanya *et al.*, 2011). Millions of people residing in ASAL regions live below the poverty line, with their livelihoods depending primarily on rain-fed agriculture (Choudhary *et al.*, 2013). Further, people living in ASALS experience low levels of economic development, increased vulnerability to diseases, and acute food shortages which significantly contribute to severe acute malnutrition, morbidity, and mortality (Parmesan, 2022).

One strategy for mitigating food shortages in ASALS is to encourage the cultivation and consumption of crops that can thrive in harsh environmental conditions, such as pulses. Pulses such as pigeon pea (*Cajanus cajan* [L.] Millsp.) are especially important for protein intake, contributing up to 80% of dietary protein in developing countries, compared to just 43% in developed nations (Paroda, 1995). Pigeon pea, a significant legume predominantly cultivated and consumed in semi-arid regions of Asia and Africa (Saxena *et al.*, 2002), stands out due to its resilience to drought. This attribute renders it an environmentally and climate-change-friendly crop (Musokwa & Mafongoya, 2020). Pigeon pea is the third most important legume in Kenya, in terms of production acreage and consumption, after beans (*Phaseolus vulgaris* L) and cowpea (*Vigna unguiculata*) (Awika & Duodu, 2017). Pigeon pea is mainly produced in the Eastern region of Kenya, with Machakos, Makueni, Kitui, Meru and Embu Counties accounting for about 99% of the total national production (Nagarajan *et al.*, 2008). Pigeon pea is a highly nutritious food crop that contains a good source of carbohydrates and proteins. For instance, it contains crude protein (17.62- 25.45%); crude fat (1.41-2.93%); carbohydrate (49.68-60.48), and ash (3.05-5.00%) (Kachare *et al.*, 2019). Pigeon pea is also rich in minerals

such as potassium, calcium, phosphorous, iron, zinc, manganese, and water-soluble vitamins especially thiamine, riboflavin, niacin (Adepoju *et al.*, 2019; Saxena *et al.*, 2010). Pigeon peas are mostly consumed as a snack (boiled green pods); stew made from green, dried, and dehulled splits; pigeon peas mixed with corn/maize to make ‘githeri’ and alternatively, boiled and mashed with potatoes to make a delicious and very tasty meal (Zahra *et al.*, 2020). However, consumption of pigeon peas is hindered due to their bland and repetitive taste, lack of knowledge surrounding preparation, unavailability due to inadequate storage and processing technologies and the dependency on the rain-fed agriculture (Figueira *et al.*, 2019; Majili *et al.*, 2020).

However, notwithstanding its substantial nutritional and satiating properties, appealing flavour when properly prepared, and affordability, pigeon pea consumption remains largely confined to lower-income households (Fasoyiro *et al.*, 2010). Therefore, if the nutritional value of pigeon peas is well determined and utilized as human food, it can go a long way in alleviating malnutrition, particularly Protein Energy Malnutrition (PEM) and micronutrient deficiencies (Gichohi-Wainaina *et al.*, 2022). However, like other pulses, the nutritive value of pigeon pea is diminished by the occurrence of antinutritional factors (ANFs) that includes tannins, phytates, phenolics, flavonoids and alkaloids (Francis *et al.*, 2001). To enhance its nutritional quality and increase its consumption, various processing techniques have been employed, including pre-soaking, boiling in water followed by seasoning with oil and spices, and toasting the seeds are used (Ghadge *et al.*, 2008).

Technological properties of pigeon peas also contribute to the first commercial criterion, being determinant to assure sensorial quality (Ibarzal., 2004; Wood, 2017). This involves determining water absorption before and after cooking, cooking time, percentage of maceration and soluble solids in the broth, volumetric expansion after soaking and cooking and lastly grain density differences (Olalekan & Bosede, 2010). Water absorption in grain processing affects the cooking time. Moreover, a hard-to-cook phenomenon in pulses such as pigeon peas affects the cooking quality, time, and, consequently, the sensorial quality of the product (Theologidou *et al.*, 2018). Therefore, technological properties are important factors to consider when selecting new varieties of pigeon peas.

Improved varieties of pigeon pea have been bred to address biotic and abiotic stresses while increasing yield potential. Early-stage assessment of their nutritional, functional, and sensory characteristics is essential to promote varietal adoption. To promote optimal human health and nutrition for the low-income populations in the arid and semi-arid lands (ASALs); it is

important to promote production and consumption of new pigeon pea varieties with not only good agronomic properties, but also with optimal nutritional properties which include high nutrient retention and low antinutritional factors. Therefore, there is need for more research on the newly improved pigeon peas varieties with regards to their nutritional quality, technological properties, consumer acceptability, and nutrient retention after cooking. Thus, the aim of this study was to determine the nutritional, technological and sensory properties of improved pigeon pea varieties grown in Machakos County, Kenya.

## **1.2 Statement of the problem**

Growing apprehensions regarding the consequences of global climate change and its potential repercussions on agriculture have spurred investigations aimed at cultivating crops resilient to extreme environmental stresses. These improvements are majorly directed at enhancing agronomic traits of pigeon peas. Despite the introduction of new improved pigeon pea varieties that have good agronomic properties, these newly improved varieties are yet to undergo evaluation to determine their nutritional composition, technological properties and sensory characteristics. The study aimed to determine the nutritional, technological and consumer acceptability of improved pigeon pea varieties grown in Machakos County, Kenya.

## **1.3 Objectives of the study**

### **1.3.1 General objective**

To contribute to improved food and nutrition security by evaluating the characteristics of improved pigeon pea varieties developed for human food.

### **1.3.2 Specific objectives**

- i. To determine the nutritional and antinutritional composition of improved pigeon pea varieties grown in Machakos County, Kenya.
- ii. To determine the technological properties of improved pigeon pea varieties grown in Machakos County, Kenya.
- iii. To determine the sensory characteristics of improved pigeon pea varieties grown in Machakos County, Kenya.

## **1.4 Hypotheses of the study**

- i. There is no significant difference in the nutritional and antinutritional composition of improved pigeon pea varieties grown in Machakos County, Kenya.
- ii. There is no significant difference in the technological properties of improved pigeon pea varieties grown in Machakos County, Kenya.

- iii. There is no significant difference in sensory characteristics of improved pigeon pea varieties grown in Machakos County, Kenya.

### **1.5 Justification of the study**

Pigeon pea is an important crop grown and utilized for food in semi-arid tropics and sub-tropic regions. It is highly nutritious pulse rich in essential nutrients including proteins and minerals (calcium, iron and phosphorous) which if well utilized, could help mitigate food insecurity and malnutrition among ASALs communities. Evaluating the nutritional, technological, and sensorial appeal amongst improved pigeon peas has not been done to the best of our knowledge. Availing information regarding the nutritional attributes of improved pigeon pea varieties may enhance consumption thus promoting nutritional and food security to the people. It will also increase productivity thus promoting sustainable agriculture. The sale of pigeon peas will increase household income thus improved livelihoods. The accrued benefits will be utilized in development of pigeon pea-based food industries. The fast-cooking pigeon peas varieties will reduce tree felling hence protecting the environment and contribute to averting climate change.

### **1.6 Scope of the Study**

Seven improved and one control pigeon pea varieties were selected by breeders from Kenya Agricultural and Livestock Research Organization (KALRO), Katumani and Egerton University. The selected varieties of pigeon pea grains were subjected to analyses to determine nutritional, antinutritional, technological, and sensory properties.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

To ensure food security for future generations, there is need to turn to plant varieties that exhibit increased stress tolerance, higher yields, and enhanced nutrient content (Godfray *et al.*, 2010b). The world is currently facing a significant threat to food security, both now and in the future, due to the exponential growth of the population and the decrease in available land for food production. To support this fast-increasing population and influence sustainability, it is estimated that food production must be increased by at least 70% by the year 2050 (Godfray *et al.*, 2010a). Natural calamities related to climate change, such as drought, salinity and extreme temperatures pose great challenges to farmers (Raza *et al.*, 2019). Abiotic and Biotic stresses such as pests, diseases and nematodes are a great threat to farmers as they lower the output while increasing production costs (Haggag *et al.*, 2015).

#### **2.2 Botany and origin of pigeon peas crop**

Pigeon pea is a perennial legume belonging to the kingdom (Plantae), division (Magnoliophyta), class (Magnoliopsida), order (Fabales), family (Fabaceae), genus (Cajanus), species (*C. cajan*) and with the scientific name; *cajanifolius* (Mula *et al.*, 2011). Its extensive taproot system allows pigeon pea to extract water and nutrients from deeper soil layers, enabling robust growth under arid conditions. Due to its exceptional drought tolerance, pigeon pea is regarded as a critical pulse crop for ensuring food and feed security in low-rainfall regions, making it particularly suitable for smallholder farmers in such environments (Abebe, 2022). The plant can reach heights of up to 5 meters, bearing spirally arranged trifoliolate leaves along its stems. It produces yellow flowers that are about 2-3 cm long and occurs in terminal and auxiliary racemes. The pods are flat and green in colour, can be hairy, dark purple or streaked and carries 2-9 seeds per pod. The harvesting period for pigeon pea is from 6-9 months after planting (Karri *et al.*, 2017).

According to Van der Maesen (1990), it is believed that the pigeon pea originated from South Asia and appeared in West Africa, which is considered a second major centre of origin at around 2000 BC. Later, it was taken to west India in 1692 through slave trade where it was used to feed birds, hence the name pigeon pea.

#### **2.3 Cultivation and production of pigeon peas**

Pigeon pea is widely adopted and grown in semi-arid tropical regions of the developing world, including Asia, Africa, Latin America and the Caribbean (Sharma *et al.*, 2011). According to

Karri *et al.* (2017), India is the largest producer (81.49%) and consumer of pigeon peas, accounting for up to 80% of the world's production. The production and acreage of pigeon pea is on the rise in Africa, to an extent that it may become the primary high-protein vegetable and legume in Sub-Saharan Africa (Jones *et al.*, 2002). It is widely adopted by many smallholder farmers in developing countries including Kenya, where it is a crucial food security legume widely adopted in the ASALs of Eastern Kenya (Fasoyiro *et al.*, 2005). Pigeon pea is often grown in low-cost locations in developing countries where it is well known for supplying food proteins, and it significantly increases food and feeds security (Martínez-Villaluenga *et al.*, 2010).

## **2.4 Uses of pigeon peas**

### **2.4.1 Pigeon pea as human food**

Pigeon pea seeds can be consumed either as fresh (immature) or dried (mature), and they contain healthy amounts of carbohydrates, proteins, vitamins, minerals, and essential amino acids (Syed & Wu, 2018). Pigeon pea grains whether dry or green can be boiled and fried and eaten as snack or accompanied with other foods such as rice or eaten as a main dish with the frequency of utilization is increasing during the harvesting season as opposed to the lean season (Majili *et al.*, 2020). Consumption preference based on either dry whole grain, green grains and Dhals with 21 % preferring to consume it while green, 47 % as dry whole grain and 16 % as dry Dhals (Majili *et al.*, 2020). In Kenya, pigeon peas are mixed with corn/maize to make 'githeri' as a meal. Alternatively, it is boiled and mashed with potatoes to make a scrumptious meal. A composite of pigeon pea, sweet potato and wheat flour can be used to make healthy and nutritious cakes (Olatunde *et al.*, 2019).

### **2.4.2 Pigeon pea as animal feed**

During the dry season when other forage crops have dried up due to lack of rainfall, pigeon peas supply green forage for animal feed (Sloan *et al.*, 2009). Pigeon pea seeds and their by-products including the leaves, pods, and seeds have enough proteins and are used as animal feed (Kouris-Blazos & Belski, 2016). Similarly, pigeon pea and maize grain seeds were successfully used in a chicken feed combination in Hawaii (Phatak *et al.*, 1993). According to Orwa *et al.* (2009), honeybees aggressively consume pigeon peas pollen, producing distinctively greenish honey in the comb.

### **2.4.3 Pigeon pea as a climate smart crop**

The foliage and young stems may be harvested and applied as green manure to augment soil fertility (Adarsh & Giffy, 2019). The crop's capacity for nitrogen fixation renders it an effective green manure resource, with the majority of assimilated nitrogen translocated to the maturing seeds post-anthesis. Pigeon pea is documented to fix approximately 40 kg ha<sup>-1</sup> of atmospheric nitrogen, thereby contributing substantial organic matter to the soil (Esilaba *et al.*, 2021). Furthermore, through piscidic acid secreted in root exudates, it mobilizes otherwise inaccessible phosphorus within the rhizosphere (Cheboi *et al.*, 2019).

### **2.4.4 Pigeon pea as a medicinal crop**

Besides the above use of pigeon pea, the presence of flavonoids and polyphenols makes it have medicinal properties which have health benefits. Flavonoids are secondary metabolites in plants and hence play an important role in plant protection (Pal *et al.*, 2011). Pigeon pea germplasm is genetically different and diverse in the biological properties that determine the nutritive and medicinal value (Al-Saeedi & Hossain, 2015). According to Trinidad *et al.* (2010), extracts from pigeon pea leaves contain high antioxidant levels used to treat conditions such as diabetes, fever, dysentery, hepatitis, and measles. Additionally, pigeon pea root extracts are used as a fever reliever and as de-wormers while fresh seeds from pigeon peas are crucial for treating urinary system problems. Immature pigeon pea seeds have been recommended for nephrotic disorders, the clotting process as well as treating chest and lung problems (Abebe, 2022).

## **2.5 Factors hindering utilization of pigeon pea in Kenya**

Green pigeon pea has highly digestible protein compared to the dry pulse, though the dry pulse is one of the best legume sources of dietary iron (15mg/100g) (Adepoju *et al.*, 2019). Matured dried pigeon pea seeds are hard to cook, and thus require soaking overnight, then cooking for 2-3 hours in a pot until they become soft to improve digestibility. Many people find these processes tedious and time-consuming, hindering maximum utilization pigeon pea (Adepoju *et al.*, 2019). Due to increased availability in households during the harvest season, the consumption of pigeon pea is usually greater than the recommended dietary amount of 30g per person per day during this period (FAO, 2012). On the other hand, during the lean season, the mean intake of pigeon peas is 18g per person per day which is less than the amount recommended by FAO (2012). This is as a result of unavailability due to inadequate storage and processing technologies and also the dependency on the rain-fed agriculture (Majili *et al.*, 2020).

As a nutritious and affordable pulse, pigeon pea seasons affect its sustainable consumption among households. The fact that it is mostly consumed as a stew made from green, dried, dehulled splits, this limits its consumption due to the monotonous taste (Majili *et al.*, 2020). Lack of knowledge and poor nutrition education on the nutritional value and how to prepare different pigeon pea recipes due to lack of exposure to different cooking techniques also limit its consumption. Post-harvest losses, pests and disease infestations also affect the appearance and quality of pigeon pea grains, further limiting its utilization as a nutritious pulse (Majili *et al.*, 2020).

## 2.6 Nutritional profile of pigeon peas

Pigeon peas are highly nutritious, providing substantial amounts of proteins, minerals, and carbohydrates, and are commonly incorporated into cereal-based rural diets that often lack sufficient protein (Odeny, 2007). Both dry and green pigeon pea grains serve as valuable sources of carbohydrates, proteins, lipids, and minerals, contributing significantly to human and animal nutrition (Abebe, 2022). The proximate composition ranges include: dry matter 86.6–88.0%, crude protein 19.0–21.7%, crude fat 1.2–1.3%, crude fibre 9.8–13.0%, and ash 3.9–4.3%. Mineral contents (mg/100 g dry matter) are as follows: K 1845–1941, P 163–293, Ca 120–167, Mg 113–127, Na 11.3–12.0, Zn 7.2–8.2, Fe 2.5–4.7, and Cu 1.6–1.8 (Table 2.1) (Amarteifio *et al.*, 2002).

**Table 2.1:** Nutritional profile of raw and cooked pigeon peas (per 100g)

Composition	Units/100g	Raw (dry grains)	Cooked
<b>Proximate</b>			
Water	g	10.59	68.55
Energy	Kcal	343	121
Protein	g	21.7	6.76
Total Lipids (fat)	g	1.49	0.38
Carbohydrates	g	62.78	23.25
Fibre, total dietary	g	15	6.7
<b>Minerals</b>			
Calcium	mg	130	43
Iron	mg	5.23	1.11
Magnesium	mg	183	46
Phosphorus	mg	367	119

Potassium	mg	1392	384
Sodium	mg	17	5
Zinc	mg	2.76	0.9
<b>Vitamins</b>			
Vitamin C	mg	0	0
Thiamine	mg	0.643	0.146
Riboflavin	mg	0.187	0.059
Niacin	mg	2.965	0.781
Vitamin B6	mg	0.283	0.05
Folate	µg	456	111
Vitamin A	IU	28	3

**Source:** Nasir and Sidhu (2012).

### 2.6.1 Carbohydrates

Pigeon pea primarily comprises soluble sugars, starch, and dietary fibre as its key carbohydrates. Sekhon *et al.* (2017) reported mean concentrations of total soluble sugars, starch, and total soluble proteins at 43.66 mg/g, 360.51 mg/g, and 204.54 mg/g, respectively. In contrast, Sharma *et al.* (2011) determined a soluble sugar content of 31 mg/g in mature dry grains. Starch levels in both mature and immature seeds vary from 272.70 mg/g to 521.28 mg/g Saxena *et al.* (2002), with overall starch composition ranging between 41% and 53% of seed dry weight (Trinidad *et al.*, 2010). The dietary fibre fraction, encompassing both soluble and insoluble forms, contributes to reduced blood cholesterol and moderated glycaemic response. Notably, pigeon pea roots contain 21.8 g/100 g soluble fibre and 19.4 g/100 g insoluble fibre (Mallillin *et al.*, 2008).

### 2.6.2 Proteins

Pigeon pea is the favourite legume for smallholder farmers in ASALs due to its high content of proteins ranging from 18-25%, calories, and essential vitamins and minerals for human nutrition. It is a good source of protein for vegetarian-based diets (Abebe, 2022). Proteins are the second most important component of pigeon pea, with 21.7 g/100 g of protein in ripe (dry) seeds (Abebe, 2022). Soluble protein in pigeon pea is reported be range from 170.37 to 251.16 mg/g (Sekhon *et al.*, 2017).

### 2.6.3 Fats

Crude fat content in pigeon peas varies across studies: 1.2–1.3% (Amarteifio *et al.*, 2002), 1.41–2.93% (Kachare *et al.*, 2019), and 0.993–1.75% (Anjulo *et al.*, 2020). The lipid fraction

is predominantly saturated (69.04%), with unsaturated fatty acids accounting for 30.69% and linolenic acid completely absent; caprylic, lauric, oleic, and eicosanoic acids occur only in trace amounts (Ade-Omowaye *et al.*, 2015). Immature green seeds contain approximately ten times more fat than mature seeds (Kachare *et al.*, 2019). Among saturated fatty acids, palmitic acid is the most abundant in both mature and immature seeds, comprising 15–25% of neutral lipids, 20–40% of glycolipids, and 26–30% of phospholipids (Abebe, 2022).

#### 2.6.4 Vitamins, minerals and amino acids

Pigeon pea grains are rich in both macro- and micronutrients, along with vitamins. Immature green seeds contain approximately five times more vitamin A and three times more vitamin C than mature dry seeds (Kachare *et al.*, 2019). Ash content ranges from 3–4%, with amino acid profiles including lysine (1.2–1.4 g/16 g N), methionine (0.1–0.3 g/16 g N), and cysteine (0.3–0.5 g/16 g N) (Lawn & Troedson, 1990). Adepoju *et al.* (2019) reported that pigeon pea is a substantial source of potassium, calcium, phosphorus, iron, zinc, manganese, and copper.

#### 2.6.5 Pigeon peas nutrient comparison to other pulses

Pigeon pea nutrients in comparison to other pulses is not significantly different, for example protein content is the same as that of chickpea and closer to that of cow pea and green pea (Table 2.2) (Miano *et al.*, 2020). This shows that Pigeon pea can be used as an alternative pulse for the dry semi-arid lands and will provide the required nutrition.

**Table 2.2:** Comparison of nutritive of value pigeon pea to other pulses

Component	Legume grain					
	Pigeon pea	Chickpea	Cowpea	Lentil	Green pea	Carioca bean
<b>Starch (%)</b>	30.8–36.2	46.5	50.3	51.5	20.3	36.2
<b>Protein(%)</b>	17.1–20.1	20.1	23.4	24.2	22.5	20.7
<b>P (g/kg)</b>	2.07–2.62	2.51	3.03	2.94	2.83	3.8
<b>K (g/kg)</b>	7.28–9.28	11.6	12.8	8.7	10.2	8.0
<b>Ca (g/kg)</b>	1.31–2.35	1.97	1.76	1.20	1.10	0.76
<b>Mn(mg/kg)</b>	16.7–24.9	19	17	16	22	20.7
<b>Fe (mg/kg)</b>	24.5–31.9	30	26	31	23	43
<b>Zn (mg/kg)</b>	28.4–44.6	68	51	44	32	41.3
<b>Total Fiber %</b>	23.2–33.1	20	20	19	20	28.7

Source: Miano *et al.* (2020)

## 2.7 Antinutritional factors in pigeon peas

Pulses are crucial for nutritional and commercial uses worldwide since they are rich in protein and fibre content, have a long shelf life and are also easy to store (Abebe, 2022). Their nutritional value is however, limited by the presence of antinutritional factors such as enzyme inhibitors, including trypsin and chymotrypsin proteinase inhibitors, flatulence factors, phytic acid, lectins and saponins (Komarnytsky *et al.*, 2011). Most organs of storage, including seeds (Leguminosae and Graminae), contain between 1 to 10% of their total protein, which is made up of inhibitors of several enzymes (Sanhita & Dutta, 2009). As a result, it is believed that their primary role is in plant defence, endogenous proteinase control, and prevention of unintended proteolysis (Birk, 2003). The function of trypsin and chymotrypsin inhibitors, which, if improperly inactivated, during processing, reduces the digestibility of proteins, and lead to micro-nutrient (Iron, Manganese) deficiencies (Parca *et al.*, 2018). A study by Trinidad *et al.* (2010) showed that trypsin inhibitors are a defence mechanism against insect assault. For instance, the protease inhibitor structure contains 30–40% of the cysteine in bean protein (Shen *et al.*, 2004). Digestion in the small intestine resistant to protease inhibitors, and by attaching to proteases, it can boost bowel removal activity (Cierpicki *et al.*, 2000).

Mature pigeon pea seeds contain trace amounts of dietary inhibitors like Phyto-lectins, polyphenols, and enzyme inhibitors (Table 2.3). The ripe seeds of pigeon peas contain numerous food inhibitors, including trypsin, chymotrypsin, alkaloids, and tannins (Onwuka, 2006). Dietary inhibitors found in pigeon pea seeds come in various forms in different pigeon pea cultivars or shades (Satheesh Naik *et al.*, 2022).

**Table 2.3:** Dietary inhibitors in pigeon pea (leaf, stem, and seeds).

Dietary inhibitors	Amount in g/100g
Alkaloids	2.65 ± 0.01
Phenolics	3.82 ± 0.15
Flavonoids	2.11 ± 0.03
Saponin	6.35 ± 0.96
Tannin	0.23 ± 0.01

**Source:** Sahu *et al.* (2014)

An example is the red pigeon pea, which has three times as many polyphenols as the white pigeon pea seeds and this includes antinutritional substances such as phytic acid, amylase and protein inhibitors. Conversely, the formation of tannin–protein complexes in pigeon pea

cultivars reduces crude protein degradability, limits amino acid availability, and elevates faecal nitrogen excretion. Though the number of polyphenols found in pigeon peas is small compared to that in soybeans and beans, if consumed in large amounts, they can inhibit digestive enzymes like trypsin, chymotrypsin and amylases. Therefore, chemical soaking, germination and composting are methods used for decreasing these toxins (Abebe, 2022).

Pigeon peas has also been found to possess non-digestible oligosaccharides, including raffinose, which exhibit both advantageous and disadvantageous characteristics. The latter includes the induction of flatulence in both humans and animals, as noted by (Gangl & Tenhaken, 2016). The quantification of total  $\alpha$ -galactoside contents in mature seeds of pigeon peas, African yam beans, and jack beans was conducted by Oboh *et al.* (2000). The seeds were ranked in decreasing order based on their total  $\alpha$ -galactoside contents, with African yam beans having the highest content (3.84 mg/ 100 mg<sup>-1</sup>), followed by cream pigeon peas (3.52 mg/ 100 mg<sup>-1</sup>), jack beans (2.83 mg/ 100 mg<sup>-1</sup>), and brown pigeon peas (2.34 mg/ 100 mg<sup>-1</sup>). The research findings indicated that jack beans and African yam beans were primarily composed of stachyose, whereas pigeon pea contained verbascose as the dominant oligosaccharide. Additionally, it has been recently reported that resistant starch and other fermentable oligosaccharides have a positive impact on the composition of gastrointestinal microbiota. According to Ende (2013), inclusion of these substances in human diets is advisable for the prevention of cancer in the digestive tract.

The degree of reduction of raffinose family oligosaccharides is dependent on the method of food preparation utilized. Various food processing techniques, such as soaking, germination, decortications, fermentation, cooking, and utilization of enzymes like  $\alpha$ -galactosidase, have been found to considerably augment the soluble dietary fibre fraction while decreasing the levels of  $\alpha$ -galactosides, thereby improving the food's digestibility (Aguilera *et al.*, 2009). Nonetheless, the aforementioned techniques for food processing are characterized by a protracted duration and result in nutrient depletion, occasionally accompanied by challenges in consumer acceptance. Consequently, various breeding strategies have been employed to choose cultivars that exhibit a reduced amount of raffinose and stachyose (Obendorf & Górecki, 2012; Redekar *et al.*, 2020) from a breeding standpoint.

## **2.8 Determination of technological properties of pulses**

The evaluation of technological properties in legume grains, including pigeon pea, encompasses measurements of water absorption before and after cooking, cooking time, maceration percentage, soluble solids in the broth, volumetric expansion following soaking and

cooking, and variations in grain density (Olalekan & Bosede, 2010). In nations such as Brazil, assessments of technological quality are mandatory for registering new pulse cultivars in the National Cultivar Registry (Silochi *et al.*, 2016). Consequently, hydration and cooking kinetics represent critical parameters in the selection of novel varieties.

### **2.8.1 Cooking time**

Cooking time determined by minimum penetration force is not different to those of other pulses as it about 20 minutes at 98 °C (Miano *et al.*, 2020). Cooking is important when preparing pigeon pea grains for consumption in order to improve digestibility of pigeon pea. Soaking the dried pigeon pea grains before cooking shows an increase in the moisture content from 11.99-30.01% in 90 minutes and this contributes to the texture of the pigeon pea starch. High water absorption rates in seeds are associated with good cooking quality that is, reduced cooking time (Akinoso, 2017). Beyond inherent genetic variation in cooking duration, environmental conditions prevalent during plant growth and grain maturation significantly influence outcomes and contribute to genotypic differentiation (Carbonell *et al.*, 2003; Ribeiro *et al.*, 2007; Rodrigues *et al.*, 2004, 2005b). In a study of 22 common bean genotypes, Bordin *et al.* (2010) recorded cooking times ranging from 19.5 to 47.5 minutes (mean: 33.3 minutes) in the 2006/2007 season and from 17.5 to 28.0 minutes (mean: 23.4 minutes) in the 2007/2008 season, following an 8-hour pre-soaking period.

### **2.8.2 Nutrient retention**

Retention of macronutrients is higher in pressure-cooked pulses, particularly when the cooking water is not discarded. In contrast, boiling followed by decanting the water result in considerable nutrient losses. Notably, both boiled and pressure-cooked samples where the cooking water is retained exhibit greater nutrient preservation (Adepoju *et al.*, 2019). Among the different cooking methods, boiling in an open pan without discarding the water result in the highest mineral content, with pressure cooking under similar conditions ranking second. This outcome was anticipated, as discarding the cooking water contributes to the loss of water-soluble minerals (Adepoju *et al.*, 2010). The decline in crude protein content in pigeon pea may be attributed to increased moisture absorption during cooking and the leaching of soluble protein fractions into the cooking water (Eltayeb *et al.*, 2010).

### **2.8.3 Hydration properties**

The hydration characteristics of pulses involve intricate processes influenced by factors such as seed composition, moisture levels, and seed coat structure, in addition to environmental variables related to cultivation, harvest, and storage conditions (Lee *et al.*, 2023). These

hydration attributes significantly impact grain processing by modulating cooking duration and extraction yield. Furthermore, the hard-to-cook defect represents a prevalent issue in pulses, directly impairing cooking performance and duration, which in turn compromises the sensory attributes of the final product (Theologidou *et al.*, 2018). Miano *et al.* (2020) reported hydration capacities in selected pigeon pea lines ranging from 57.2% to 99.7% and concluded that lines exhibiting reduced hydration likely experience physical dormancy attributable to seed coat impermeability to water.

## **2.9 Sensory evaluation of pulses**

The Institute of Food Technologists (IFT) characterizes sensory evaluation as a scientific field that evokes, quantifies, examines, and interprets human reactions to food items via the senses of vision, audition, tactility, olfaction, and gustation (IFT, 2007). Consumer acceptance studies commonly involve large cohorts of semi-trained or untrained participants. As a result, sensory assessment is pivotal in evaluating the commercial viability of newly developed pigeon pea varieties.

Sensory assessment of pulses generally falls under two broad categories: objective and subjective evaluation. These approaches incorporate principles from various disciplines, including food science, psychology, engineering, agronomy, statistics, and the biological sciences. Objective methods rely on trained panellists to assess sensory characteristics, while subjective approaches involve direct participation from consumers to evaluate products (IFT, 2007). To achieve success in food product development and quality improvement, it is essential to establish a clear relationship between sensory attributes and factors such as chemical composition, physical properties, formulation, and processing conditions. This integration enhances the likelihood of producing food items that meet consumer preferences (Sharif *et al.*, 2017).

Consumer preferences for pigeon pea displayed statistically significant differences ( $p < 0.05$ ) in key attributes such as visual appearance, colour, aroma, and seed softness. On a 7-point hedonic scale, podded pigeon pea achieved a mean score of 6.3, indicating high approval, while blanched samples earned 6.0. Mean scores for podded, blanched, and oven-dried preparations, along with seed tenderness, were 5.6, 6.6, and 6.1, respectively. The superior ratings for podded and oven-dried samples were associated with elevated sugar concentrations (4.25 mg/100 g) measured 22 days following initial treatment. Comparable scores for taste and overall liking

imply that post-harvest treatments and 22-day storage effectively maintained desirable sensory characteristics (Ojwang *et al.*, 2021).

Post-harvest drying methods are meant to extend the grain's shelf life despite affecting the grain quality. Thermal treatment reduced moisture levels in pigeon peas, reducing seed tenderness (Ikegwu, 2021). Additional results from the study by Ojwang *et al.* (2021) found a significant difference ( $p < 0.05$ ) in the effects of treatment on the tenderness of the pigeon pea seed. Oven drying treatment reduced the pigeon pea tenderness compared to blanching and freezing methods (Ojwang *et al.*, 2021).

## CHAPTER THREE

### NUTRITIONAL AND ANTINUTRITIONAL COMPOSITION OF IMPROVED PIGEON PEA (*Cajanus cajan*) VARIETIES GROWN IN MACHAKOS, KENYA

#### Abstract

Pigeon pea consumption can enhance food and nutrition security, especially among people in ASAL areas. It contains high protein content, which, if consumed as part of diets, can help alleviate the burden of malnutrition, particularly Protein Energy Malnutrition. To address food insecurity and enhance nutrient availability, breeding of pigeon peas for improved agronomic traits has been advocated. However, despite the development of new varieties, their nutritional and antinutritional qualities still need to be evaluated. Therefore, this study aimed to evaluate the proximate composition, mineral content and antinutritional factors of improved pigeon pea varieties in Machakos County. The analysis included five improved pigeon pea varieties (Egerton Mbaazi 1, KARI Mbaazi 1, Mituki, Egerton Mbaazi 2 and KAT 60/8) and ICEAP 00554 (control). The laboratory experiment was conducted at the Food Chemistry Laboratory, Department of Food Science Nutrition and Technology, University of Nairobi. The experiment was arranged in a Completely Randomized Design (CRD). Data was analysed using on PROC GLM procedure of the statistical analysis systems (SAS) version 9.1.3. Analysis of variance (ANOVA) was conducted at 95% confidence level. Tukey's honestly significant difference (HSD) was utilized to establish the differences among means. The proximate analysis of pigeon pea samples revealed significant variations ( $p < 0.05$ ) across various parameters. Moisture content ranged from 8.67% to 10.71%, fibre (7.26 % to 8.75%), ash (3.99% to 5.51%), crude protein (24.52% to 31.16%), crude fat (1.19% to 1.92%), and carbohydrates (44.64% to 52.63%). Overall mineral content was high, with zinc ranging from 54.26 ppm to 74.31 ppm, iron (143.45 ppm to 367.25 ppm), and phosphorous (2191.06 ppm to 2909.00 ppm). Cooking significantly reduced the levels of antinutrient factors (tannins, phytates, and total free phenolics) in all analysed pigeon pea varieties ( $p < 0.05$ ). Tannins experienced the most significant reduction across all varieties, with Egerton Mbaazi 2 showing the highest reduction at 57.6%, followed closely by Mituki (56.4%), ICEAP 00554 (53.6%), KAT60/8 (50%), and KARI Mbaazi1 (28.6%). Notably, ICEAP 00554 showed the highest levels of antinutrients and the lowest mineral retention compared to the analysed improved pigeon pea varieties, suggesting that breeding enhances the nutritional value and reduces antinutritional factors in pigeon peas. Therefore, improved pigeon pea varieties can be used in value-added foods and as alternative protein sources for populations residing in arid and semi-arid areas.

### 3.1 Introduction

Pigeon pea (*Cajanus cajan*), a key legume crop, holds the sixth position in global production following peas, faba beans, lentils, chickpeas, and dry beans (Fatokimi & Tanimonure, 2021). It is grown across 5.4 million hectares worldwide, generating an annual output of 4.49 million tons. Cultivation spans roughly 82 countries, with South Asia and India accounting for approximately 90% of the total area (FAO, 2022). In Africa, the crop is primarily concentrated in eastern and southern zones, occupying 0.56 million hectares. It plays a vital role in countries including Malawi, Kenya, Uganda, Mozambique, and Tanzania. FAOSTAT (2022) data indicate that Kenya's pigeon pea yield reached 8,215 kg/ha, with total production amounting to 104,010 metric tons from 126,617 hectares. Cultivation of pigeon peas in Kenya is concentrated around four counties, namely Machakos, Kitui, Makueni and Embu (Mbeere), as well as coastal regions. In Kenya, about 80% of the land mass is classified as semi-arid lands, and the communities that reside there live below the poverty line and depend on rain fed agriculture (Choudhary *et al.*, 2013). Therefore, Pigeon pea is an important grain legume grown in arid and semi-arid lands (ASALs) (Saxena *et al.*, 2002). This is due to its ability to withstand long periods of drought due to its deep roots that enable it to penetrate and acquire nutrients from the deeper soil layers and the osmotic adjustment in the leaves (Subbarao *et al.*, 2000).

Pigeon pea is grown for their nutritious grains, especially the protein content, which, if consumed as part of diets, can help alleviate the burden of malnutrition, particularly Protein Energy Malnutrition in the ASALs (Gichohi-Wainaina *et al.*, 2022). The protein in pigeon pea pulses is an inexpensive alternative to proteins from animal source foods (ASFs), which in most cases is elusive and very expensive for people with low socioeconomic status (Seetha-Anitha *et al.*, 2019). Pigeon peas is rich in amino acids, minerals such as iron and magnesium, and water-soluble vitamins; thus, incorporating pigeon peas into diets could enhance the intake of these nutrients (Seetha-Anitha *et al.*, 2019), consequently contributing to the alleviation of malnutrition. Additionally, pigeon pea grains have medicinal properties since they contain flavonoids and polyphenols which are a major component of traditional medicines in China and India (Saxena *et al.*, 2010).

Despite their beneficial nutritional, agronomic and medicinal properties, pigeon pea grains contain antinutritional factors (ANFs) such as enzyme inhibitors (trypsin, amylase and chymotrypsin proteinase inhibitors), flatulence factors, phytic acid, lectins and saponins (Komarnytsky *et al.*, 2011), which make nutrients bio-unavailable for body use.

The breeding of pigeon peas has been promoted to address the challenge of food insecurity and improve the availability of nutrients. Those technologies include developing pigeon pea varieties with improved agronomic traits such as the ability to withstand drought, salinity, pests, and disease tolerance (Cheboi & Kimurto, 2022; Ojwang *et al.*, 2021). While the breeding process has resulted in the development of new, improved pigeon pea varieties that have good agronomic properties, these newly improved varieties are yet to go through the evaluation process to determine their nutritional and antinutritional quality. Therefore, this study aimed to determine the nutritional and antinutritional composition of improved pigeon pea varieties grown in Machakos, Kenya.

## **3.2 Materials and methods**

### **3.2.1 Study location description and sample selection**

The study materials were sourced from the Kenya Agricultural and Livestock Research Organization (KALRO) Katumani Research Centre in Machakos County (1° 35' S, 37° 14' E) and Egerton University, Njoro (0° 22' 11.0" S, 35° 55' 58.0" E). Laboratory analyses were performed at the Guildford Dairy Institute, Department of Dairy and Food Science and Technology, Egerton University, and the Food Chemistry Laboratory, Department of Food Science, Nutrition and Technology, University of Nairobi. Five improved pigeon pea varieties: KARI Mbaazi 1, KAT 60/8, and Mituki were obtained from KALRO Katumani, while Egerton Mbaazi 1, Egerton Mbaazi 2, and the control variety ICEAP 00554 were collected from Egerton University. Detailed descriptions of each variety are provided in Appendix III.

### **3.2.2 Sample preparation**

Samples of mature, dried grains of the selected pigeon pea varieties (500g each) were prepared for analysis by cleaning and sorting according to (Biana *et al.*, 2020). Each pigeon pea variety selected was then thoroughly mixed to get a homogenous sample.

### **3.2.3 Preparation of pigeon pea flour for nutrient analysis**

#### ***a) Preparation of Raw Pigeon Pea Flour***

Two hundred and fifty (250) grams of raw pigeon pea grains of each selected variety were milled using a Microphyte lab disintegrator model Fz102 (Tianjin, China), fitted with 500- $\mu$ m, sieve. The raw flour samples were then stored in airtight plastic containers and kept under refrigeration at  $8 \pm 2^\circ\text{C}$  awaiting analyses.

### ***b) Preparation of cooked pigeon pea flour***

For each variety, 250 g of clean, sorted dry pigeon pea grains were immersed in 1 L of distilled water and soaked for 16 hours at 20 °C. The soak water was subsequently discarded, and the hydrated grains were transferred to an open aluminum pot containing fresh distilled water. Cooking was performed at 93.5 °C on an electric hot plate for the duration previously established for each variety. Water lost to evaporation was replaced with hot distilled water as needed. Upon completion of cooking, the grains were dried in an oven at 45 °C until the moisture content reached 10–12%. The dried, cooked grains were then milled into flour using a Microphyte laboratory disintegrator (Model Fz102, Tianjin, China). The resulting flour was placed in airtight plastic containers and stored under refrigeration at 8 ± 2 °C until proximate and nutrient analyses were conducted.

#### **3.2.4 Determination of moisture content**

Moisture content of pigeon pea samples was quantified using the oven-drying procedure outlined in AOAC (2005) method 967.19. For each variety, 3 g of raw and cooked pigeon pea flour were accurately weighed in triplicate into pre-dried crucibles using an analytical balance. The samples were placed in an oven at 105 °C for 3 hours. Upon removal, the dried samples were transferred to a desiccator for cooling to ambient temperature. Weighing was repeated until constant weight was achieved, and moisture loss was recorded. The percentage moisture content was calculated on a dry-weight basis as the mean weight loss following drying, according to the formula provided below:

$$\% \text{ MC} = \frac{(\text{weight of pan} + \text{wet sample}) - \text{weight of pan} + \text{dry sample}}{\text{weight of sample}} \times 100 \quad (1)$$

#### **3.2.5 Crude protein determination**

Crude protein content of the pigeon pea was determined using Kjeldahl Association of Official Agricultural Chemists (AOAC, 2005) method number 978.04. One gram of raw and cooked pigeon pea flour for every sample was measured accurately using an analytical balance and transferred into the digestion tube in triplicates. Approximately 10 ml of concentrated sulphuric acid was added to each tube in the presence of selenium catalyst, and then samples were digested at 410 °C for 1 hour and 30 minutes until the blue colour was obtained. The samples were then cooled, and the digest diluted with distilled water. After digestion in the Kjeldahl flask, the resulting digest underwent steam distillation with a 40% NaOH solution to liberate ammonia, which was subsequently captured in a boric acid solution containing methylene blue and methyl red indicators. Approximately 10 mL of distillate was collected and titrated with

0.02 N HCl until the endpoint was reached, indicated by a colour shift to orange. The volumes of acid consumed for both the sample and blank titrations were recorded. Crude protein content was determined by multiplying the percentage of nitrogen by the conversion factor 6.25, according to the following formula:

$$\text{Nitrogen (\%)} = M_{\text{HCl}} \times \frac{\text{Corrected Acid volume}}{\text{weight of sample}} \times \frac{14gM}{\text{Mol}} \times 100 \quad (2)$$

Where: Corrected acid volume = (ml acid for sample – ml acid for blank), M HCl is the Normality of HCl, 14 is the atomic weight of nitrogen, and 6.25 is the conversion factor on the assumption that the sample will contain 16% nitrogen.

$$\% \text{ Protein} = \% \text{ Nitrogen} \times 6.25 \quad (3)$$

### 3.2.6 Crude fat determination

The crude fat content of pigeon pea samples was quantified using the Soxhlet extraction procedure outlined in AOAC (2005) method 930.09. Five grams of oven-dried pigeon pea flour were weighed in triplicate, transferred to an extraction thimble, and overlaid with a layer of defatted cotton wool. The thimble was positioned within a pre-cleaned, oven-dried, and pre-weighed round-bottom flask ( $W_1$ ). Precisely 25 mL of petroleum ether was introduced into the extraction chamber. Extraction was conducted for 6 hours using an Electro-thermal Soxhlet apparatus (Model: EME 6250/CF; Cole Parmer, England). Upon completion, the solvent was recovered via evaporation, the flask was dried in a desiccator, and reweighed ( $W_2$ ). The percentage crude fat was computed using the following formula:

$$\% \text{ Crude fat} = \frac{(W_2 - W_1)}{W} \times 100 \quad (4)$$

Where;  $W_2$ = Weight of the dried flask with the sample,  $W_1$ =Weight of the dried flask and  $W$ = Weight of the dried sample

### 3.2.7. Ash content determination

The ash content of raw and cooked pigeon pea flour was determined with reference to (AOAC, 2005) method number 930.05. Five grams (5g) of each of pigeon pea flour samples was accurately weighed using an analytical balance into a tarred crucible. The crucibles were placed into a muffle furnace where the samples were incinerated to ash for 12 – 18 hours at 550 °C. The incinerator temperatures were brought to below 250°C, then the samples were removed from the incinerator using a pair of tongs and cooled in a desiccator before weighing.

Percentage ash content was calculated as:

$$\% \text{ Crude ash} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100 \quad (5)$$

### 3.2.8 Crude fibre determination

The crude fibre content of pigeon pea flour was assessed following AOAC (2005) method 987.10. A 2 g sample was accurately weighed into a 600 mL graduated beaker. To this, 100 mL of boiling distilled water and 100 mL of 2.04 M sulphuric acid were added, after which the total volume was adjusted to 200 mL with additional boiling distilled water. The mixture was maintained at this volume and boiled gently for 30 minutes on a hot plate. Filtration was then performed using a funnel fitted with a light packing of glass wool, and the retained residue was rinsed thrice with boiling distilled water. The residue, along with the glass wool, was quantitatively returned to the beaker. Approximately 100 mL of boiling distilled water and 25 mL of 1.78 M potassium hydroxide were introduced, and the volume was again brought to 200 mL with boiling distilled water. This suspension was boiled for an additional 30 minutes while maintaining constant volume. The mixture underwent a second filtration through glass wool, followed by three washes with boiling distilled water and three subsequent rinses with small volumes of ethanol. The residue and glass wool were then transferred quantitatively to a porcelain crucible, dried at 105 °C for 2 hours in an air oven, cooled in a desiccator, and weighed. The crucible was subsequently placed in a muffle furnace at 600 °C for 2 hours to ash the organic matter, cooled, and reweighed. Crude fibre content was calculated and reported as a percentage of the original sample on a dry-weight basis.

$$\% \text{ Crude fibre} = \frac{(W_1 - W_2)}{W} \times 100 \quad (6)$$

Where;  $W_1$  = Weight of the sample after drying,  $W_2$  = weight of the sample after ashing and  $W$  = Weight of the dry sample

### 3.2.9 Carbohydrate determination

The total carbohydrate of Pigeon pea varieties was determined by the differential method where;

$$\% \text{ Carbohydrate} = 100\% - (\% \text{moisture} + \% \text{protein} + \% \text{fat} + \% \text{ash} + \% \text{crude fibre}) \quad (7)$$

### 3.2.10 Determination of mineral contents

The mineral composition of pigeon pea varieties was determined according to the procedure outlined in AOAC (2005). One gram of each sample was digested using 5 mL of concentrated nitric acid ( $\text{HNO}_3$ ) and 1 mL of concentrated perchloric acid ( $\text{HClO}_4$ ). The mixture was sealed and allowed to predigest overnight at ambient temperature, then heated at 100 °C for 8 hours in an oven. After cooling to room temperature within a fume hood, the digest was analyzed via

atomic absorption spectrophotometry (Thermo Jarrell Ash Corporation, Model 6) equipped with a photomultiplier tube (PMT) detector to quantify calcium (Ca) at 766.5 nm, zinc (Zn) at 510 nm, and iron (Fe) at 880 nm. Phosphorus (P) content was measured using a UV-visible spectrophotometer (JENWAY 7315) with a photodiode detector at 422.7 nm.

### **3.2.11 Determination of total phenolic content**

The total phenolic content in pigeon pea flour was determined using the method described by Agboola *et al.* (2009). A 100 mg sample of flour was defatted via ultrasonication in 1 mL of petroleum ether for 30 minutes. The suspension was centrifuged at  $29,600 \times g$  for 3 minutes under refrigerated conditions, after which the supernatant was removed. The defatted residue was then successively extracted with 1 mL portions of 80% methanol, 50% methanol, and 70% acetone (acidified with 1% HCl) using ultrasonication for 30 minutes per extraction step. The pooled extracts were diluted to a final volume of 5 mL. Phenolic compounds were quantified using the Folin-Ciocalteu method (Singleton *et al.*, 1999), with absorbance recorded at 765 nm on a UV-visible spectrophotometer. A calibration curve was established using catechin hydrate standards (20–100  $\mu\text{g}$ ), and total phenolics were reported as mg catechin equivalents per gram of sample on a dry-weight basis.

### **3.2.12 Determination of phytic acid content**

Phytic acid levels were measured via the phytate precipitation technique outlined by Makkar *et al.* (2007). Separate 500 mg portions of raw and cooked pigeon pea flour from each variety were used. Extraction involved adding 50 mL of 3% trichloroacetic acid (TCA) to the samples, followed by 40 minutes of shaking on a Ratek Orbital Incubator (Ratek Instruments, Boronia, Victoria, Australia). The suspensions were centrifuged at  $3,000 \times g$  for 10 minutes in an Eppendorf centrifuge (Model 5804, Eppendorf, Hamburg, Germany). A 10 mL portion of the supernatant was placed in a 50 mL centrifuge tube, and 4 mL of  $\text{FeCl}_3$  solution was added promptly. The tubes were immersed in boiling water for 45 minutes, centrifuged again at  $3,000 \times g$  for 10 minutes, and the supernatant was discarded.

The resulting precipitate underwent two washes by dispersion in 25 mL of 3% TCA, heating in boiling water for 10 minutes, and centrifugation at  $3,000 \times g$  for 10 minutes. A further rinse was conducted with 20 mL of distilled water. The precipitate was resuspended in 5 mL of distilled water, supplemented with 3 mL of 1.5 N NaOH, and diluted to 30 mL with distilled water before heating in boiling water for 30 minutes. Filtration was performed using Whatman No. 2 filter paper (8  $\mu\text{m}$  pore size), followed by rinsing with 70 mL of hot distilled water. The

precipitate was solubilized in 40 mL of hot 3.2 N HNO<sub>3</sub> in a 100 mL volumetric flask; the filter paper was washed with distilled water, and the rinsings were added to the flask. After cooling to ambient temperature, the volume was adjusted to 100 mL with distilled water.

A 5 mL aliquot was transferred to a second 100 mL volumetric flask, mixed with 65 mL of distilled water and 20 mL of 1.5 M potassium thiocyanate (KSCN), and brought to 100 mL with distilled water. Absorbance was measured at 480 nm within 1 minute on a spectrophotometer (Pharmaspec UV-1700, Shimadzu, Japan). A reagent blank substituting distilled water for the sample was prepared. Standard iron (III) nitrate solutions were used to generate a calibration curve, from which iron content (µg) was determined, enabling calculation of phytate phosphorus.

$$\text{Phytate P mg/100g} = \frac{\text{Fe } (\mu\text{g}) \times 15}{\text{Weight of sample (g)}} \quad (8)$$

### 3.2.13 Determination of condensed tannin content

Condensed tannins were quantified using the modified HCl-methanol vanillin assay as outlined by Price *et al.* (1978). Raw and cooked pigeon pea flour samples (0.25 g each) were separately weighed into 100 mL conical flasks, to which 10 mL of 4% HCl in methanol (v/v) was added. The suspensions were agitated for 20 minutes on a Ratek Orbital Incubator (Boronia, Victoria, Australia) and subsequently centrifuged at 2,060 × g for 20 minutes at ambient temperature using an Eppendorf centrifuge (Model 5804, Eppendorf, Hamburg, Germany). One millilitre of each extract was combined with 5 mL of freshly prepared vanillin-HCl reagent in a clean test tube. The reagent was formulated immediately prior to use by combining equal volumes of 1% (w/v) vanillin in methanol and 8% (v/v) concentrated HCl in methanol. Absorbance was measured at 500 nm using a UV/VIS spectrophotometer (Pharmaspec UV-1700, Shimadzu, Japan) precisely 20 minutes after reagent addition. Corresponding sample blanks, prepared by substituting the vanillin solution with 4% HCl in methanol, were included to correct for background interference. Catechin served as the reference standard, and condensed tannin content was reported as milligrams of catechin equivalents per 100 mg of sample.

### 3.3 Experimental design and statistical analysis

A Completely Randomized Design (CRD) was used with the following statistical model:

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij} \quad (9)$$

where;  $Y_{ij}$ = the observation of the dependent variable of raw and cooked pigeon pea grains and proximate analysis,  $\mu$  = Overall mean responses,  $\bar{u}_i$ = The effect of  $i^{\text{th}}$  variety and  $\epsilon_{ij}$ = Random error component.

Goodness-of-fit tests (Kolmogorov–Smirnov and Cramér–von Mises) were applied to assess the normality of the data distribution. Statistical analyses were performed using SAS version 9.1.3 (SAS, 2006). Analysis of variance (ANOVA) was conducted via the PROC GLM procedure. The effect of cooking on proximate composition of pigeon pea varieties was evaluated using paired t-tests implemented through PROC TTEST. Multinomial logistic regression was carried out with PROC LOGISTIC to compare the performance of improved varieties against the control (ICEAP 00554). Pairwise Pearson correlation coefficients were computed to examine relationships among response variables for the improved pigeon pea varieties. All analyses were conducted at a 95% confidence level, with mean separations determined using Tukey’s honestly significant difference (HSD) test.

### **3.4 Results and discussion**

#### **3.4.1 Proximate analysis of raw improved pigeon pea varieties**

Results of proximate analyses of improved pigeon pea varieties are presented in Table 3.1. Moisture content ranged from 8.67% to 10.71% for all pigeon pea varieties. While there was significant difference ( $p < 0.05$ ) in moisture content between Mituki, Egerton Mbaazi 2 and ICEAP 00554 varieties, no significant differences ( $p > 0.05$ ) were observed in moisture content between Egerton Mbaazi 1, KARI Mbaazi 1 and KAT60/8. Fiber content of improved pigeon pea ranged from 7.26 to 8.75 %. Egerton Mbaazi 1 had the highest fibre content followed by Egerton Mbaazi 2 (8.41%) and KAT 60/8 (7.89%) that were significantly different ( $p < 0.05$ ) while Mituki had the least fibre content. Ash content ranged from 3.99% to 5.51%. ICEAP 00554 recorded the highest ash content followed by Egerton Mbaazi 2 (4.65%), with KAT 60/8 having the least ash content. Egerton Mbaazi 1, Mituki and Egerton Mbaazi 2 did not have significant differences in ash content ( $p > 0.05$ ). Crude protein of improved pigeon pea varieties ranged from 24.52% to 31.16%. Egerton Mbaazi 1 had the highest crude protein followed by KARI Mbaazi 1 (28.65%) and Mituki (25.98%) that were significantly different ( $p < 0.05$ ). Crude fat content of improved pigeon peas ranged from 1.19% to 1.92%. Mituki variety recorded the highest fat content closely followed by ICEAP 00554 (1.81%) but not significantly different ( $p > 0.05$ ). KAT 60/8 recorded the lowest fat content. Carbohydrates component of pigeon peas ranged from 44.64% to 52.63%. The ICEAP 00554 recorded the

highest carbohydrates followed by Egerton Mbaazi 2 (51.02%) while Egerton Mbaazi 1 had the lowest.

The variation in the proximate composition of the pigeon pea samples could be attributed to genetic factors, variety, methods of processing samples, weather conditions during growth, seed storage, crop production input, and polyphenols presence that affect the protein quality (Digbeu *et al.*, 2018; Miano *et al.*, 2019). Generally, Pigeon pea varieties are rich in protein (containing >21% protein) as demonstrated by the results of this study. This corroborated the results from previous studies (Aruna & Devindra, 2016; Cheboi *et al.*, 2019; Olagunju *et al.*, 2018; Talari & Shakappa, 2018; Saxena *et al.*, 2010). Evidence from the results showed that improved pigeon peas varieties are nutritionally superior compared to the ICEAP 00554 (control). This could be attributed to the breeding, which results in the improved varieties with large quantities of utilizable amino acids (Saxena *et al.*, 2018). Due to its high protein content, previous studies have indicated that pigeon pea protein can be used as a novel ingredient in meat products like sausages as a binder (Li, 2019; Mora & Andres, 2015). The protein eases water molecules binding to its polar groups thus increasing its strength as well as sausage's textural properties.

Carbohydrate content of the improved pigeon varieties ranged from 44-52%, with starch comprising a major fraction. Other carbohydrate components found in pigeon pea include non-starch polysaccharides and other derivatives known as oligosaccharides. The oligosaccharides possess  $\alpha$ -galactosidic bonds that lead to the production of flatus carbohydrates, that remain undigested in the human body since the body lacks the necessary enzymes for their breakdown (Singh, 2017). These types of carbohydrates instead undergo anaerobic fermentation producing carbon dioxide, hydrogen and traces of methane which cause abdominal discomfort and may lead to diarrhoea (Mutuyemungu *et al.*, 2023). Starch is composed of amylopectin and amylose, with past research noting significant variations in amylose fraction of starch (Tiwari & Singh, 2012). Starches are useful in various food applications as they easily withstand heat treatments and are highly stable when subjected to mechanical shearing. For this reason, Singh (2010) alluded that pigeon pea starches can be potential alternative for cross-linked starches. The degree of starch retrogradation is affected by amylose content; the higher the retrogradation the more resistant the starch becomes towards the amylase enzyme. This causes a reduction in glycaemic index thus low postprandial glycemia and insulinemia (Singh, 2017).

The hulls of pulse grains are the major source of water-insoluble fibres while their cotyledons contain oligosaccharides, resistant starch, and substantial quantities of soluble fibres with

slower digestion rates (Singh *et al.*, 2017). The dietary fibre in pigeon peas is mainly in the forms of cellulose, hemicellulose, and pectin among others (Nwadike *et al.*, 2018). Dietary fibre is essential for efficient digestion as it is partially or fully fermented and positively impacts physiological activities in the human body. Therefore, inclusion of improved pigeon peas varieties in diets of individuals is important in managing bowel control, reduction of blood cholesterol levels, cancer prevention as well as cardiovascular diseases (Hayat *et al.*, 2014; Messina, 2014). Dietary fibre intake has also been linked with lower risk of diabetes mellitus in humans (Reynolds *et al.*, 2020).

Further analysis revealed significant variation in crude fat content among the analyzed pigeon pea varieties. The main saturated fatty acids found in pigeon peas varieties is palmitic acid which makes up of 26-30% of the phospholipids, 20-40% of the glycolipids and 15-25% of the neutral lipids. Talara and Shakappa (2018) reported linoleic acid (C18:2) as the most abundant polyunsaturated fatty acid (PUFA) found in pigeon pea. Oleic, caprylic, eicosanoic, lauric fatty acids are also present but in small amounts. Among the pigeon pea varieties, the control (ICEAP 00554), stood out with the highest ash content. This indicates that less improved ICEAP 00554 is abundant in essential minerals like potassium, phosphorus, calcium, iron, and magnesium, while maintaining relatively low levels of sodium (Kunyanganga *et al.*, 2013).

**Table 3.1:** Proximate analysis of raw improved pigeon pea varieties

Variety	Moisture (%)	Fibre (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrates (%)
<b>Egerton Mbaazi 1</b>	10.51 ± 0.13 <sup>a</sup>	8.75 ± 0.03 <sup>a</sup>	4.27 ± 4.27 <sup>bc</sup>	31.16 ± 0.17 <sup>a</sup>	1.34 ± 0.03 <sup>bc</sup>	44.64 ± 0.35 <sup>c</sup>
<b>KARI Mbaazi 1</b>	10.50 ± 0.05 <sup>a</sup>	7.75 ± 0.12 <sup>c</sup>	4.09 ± 0.08 <sup>c</sup>	28.65 ± 0.14 <sup>b</sup>	1.45 ± 0.06 <sup>bc</sup>	47.56 ± 0.03 <sup>d</sup>
<b>MITUKI</b>	10.01 ± 0.08 <sup>b</sup>	7.26 ± 0.06 <sup>d</sup>	4.64 ± 0.16 <sup>b</sup>	25.98 ± 0.44 <sup>c</sup>	1.92 ± 0.18 <sup>a</sup>	50.21 ± 0.23 <sup>c</sup>
<b>KAT60/8</b>	10.71 ± 0.15 <sup>a</sup>	7.89 ± 0.05 <sup>c</sup>	3.99 ± 0.02 <sup>c</sup>	25.83 ± 0.20 <sup>c</sup>	1.19 ± 0.01 <sup>c</sup>	50.41 ± 0.27 <sup>bc</sup>
<b>Egerton Mbaazi 2</b>	9.46 ± 0.06 <sup>c</sup>	8.41 ± 0.10 <sup>b</sup>	4.65 ± 0.01 <sup>b</sup>	24.95 ± 0.08 <sup>d</sup>	1.52 ± 0.02 <sup>b</sup>	51.02 ± 0.16 <sup>b</sup>
<b>ICEAP 00554 (Control)</b>	8.67 ± 0.20 <sup>d</sup>	7.39 ± 0.07 <sup>d</sup>	5.51 ± 0.19 <sup>a</sup>	24.52 ± 0.10 <sup>d</sup>	1.81 ± 0.01 <sup>a</sup>	52.63 ± 0.10 <sup>a</sup>

**Key:** Tukey's honestly significant difference (HSD). Values along the column followed by different superscript letter notations are significantly different ( $p \leq 0.05$ ). The values are mean ± standard error.

### 3.4.2 Antinutrients content of raw improved pigeon pea varieties

The antinutrients content of improved pigeon pea varieties are shown in the Table 3.2. The tannins in pigeon peas ranged from 0.25mg/100g to 0.97mg/100g where ICEAP 00554 had the highest and Egerton Mbaazi 1 the lowest tannin levels. Egerton Mbaazi 2 and KAT60/8 did not differ significantly in tannins levels ( $p>0.05$ ). The total free phenolics of pigeon peas varied significantly among pigeon pea varieties ( $p<0.05$ ). The control (ICEAP 00554) recorded the highest level of total free phenolic content (0.54mg/100g) while Egerton Mbaazi 1 had the least content (0.18mg/100g). Similarly, phytates levels varied significantly among the tested varieties with Mituki having the highest amounts (12.27mg/100g) ( $p<0.05$ ), followed by KAT 60/8 (11.41 mg/100g) and ICEAP 00554 (10.62 mg/100g) The control (ICEAP 00554) recorded the highest tannins (0.97 mg/100g) and total free phenolics (0.54 mg/100g) compared to the improved pigeon pea varieties. Phytates were considerably higher in all pigeon pea varieties compared to tannins and total free phenolics.

Antinutrients generally form compounds with essential nutrients, consequently reducing the bioavailability of those nutrients (Aruna & Devindra, 2016). Phenols are antinutrients naturally produced in plants during growth and development to act as a shield against biotic and abiotic stresses (Gautam *et al.*, 2020). The Phenols amounts varied in the different varieties analysed in this study and this could be due to differences in varieties, storage conditions, maturity period and environmental factors (Panche *et al.*, 2016). The phenolic components are found in the hulls of the pigeon peas thus milling reduces their content alongside other nutrients in the seed coat, like protein, fibre, calcium, zinc iron and zinc (Nasir & Sidhu 2012). Higher concentrations of phenolic components in consumed pigeon peas hinder protein digestibility. Off flavours such as alcohols, aldehydes, ketones, pyrazines, acids, and sulphur compounds in pigeon peas varieties may arise from phenolic acids when thermally degraded (Roland *et al.*, 2017). Phenolic components are highly reactive thus bind with proteins lowering the bioavailability of essential amino acids in the body as this can be both an irreversible and reversible reaction (Frazier *et al.*, 2010; Hagerman & Butler, 2010).

The improved pigeon pea varieties exhibited lower tannin concentrations ( $<0.66\text{mg}/100\text{g}$ ), in contrast to the control variety which had a concentration of 0.97 mg/100g, nearing the lethal dose threshold ( $\geq 1.05\text{ mg}/100\text{g}$ ) (Balogun, 2013; Talari & Shakappa, 2018). Tannins offer defence mechanisms in plants, form hydrogen bonds with proteins and have the ability to chelate with metal ions thus inhibiting protein digestibility and mineral absorption (Beebe *et al.*, 2015). Therefore, varieties with higher tannin contents may have diminished nutritional

values as tannins form complexes with their digestive enzymes and starches and this reduces their palatability (Hagerman & Butler, 2010). From this study, the low levels of tannins, free total phenolics and phytates attributes of the improved pigeon pea varieties investigated show their potential as alternative in developing nutrient dense foods and restructured meat products.

Despite the negative impacts of antinutritional components, they still possess some benefits to the human health. For example, phenolic compounds exhibit antioxidant properties hence are an important aspect in biological body functions such as immune system activation while phytates have been associated with protection of DNA against damage (Schlemmer *et al.*, 2009).

**Table 3.2:** Antinutrients content of raw improved pigeon pea varieties

Variety	Tannins (mg/100g)	Phytates (mg/100g)	Total free Phenolics (mg/100g)
<b>Egerton Mbaazi 1</b>	0.25±0.00 <sup>e</sup>	8.71±0.03 <sup>f</sup>	0.18±0.00 <sup>f</sup>
<b>KARI Mbaazi 1</b>	0.28±0.01 <sup>d</sup>	9.17±0.08 <sup>e</sup>	0.20±0.00 <sup>e</sup>
<b>MITUKI</b>	0.55±0.01 <sup>c</sup>	12.27±0.05 <sup>a</sup>	0.32±0.00 <sup>d</sup>
<b>KAT60/8</b>	0.64±0.00 <sup>b</sup>	11.41±0.03 <sup>b</sup>	0.52±0.00 <sup>b</sup>
<b>Egerton Mbaazi 2</b>	0.66±0.01 <sup>b</sup>	10.27±0.19 <sup>d</sup>	0.51±0.00 <sup>c</sup>
<b>ICEAP 00554</b>	0.97±0.00 <sup>a</sup>	10.62±0.01 <sup>c</sup>	0.54±0.01 <sup>a</sup>

Key: Tukey's honestly significant difference (HSD). Values along the column followed by different superscript letter notations are significantly different ( $p \leq 0.05$ ). The values are means  $\pm$  standard error.

### 3.4.5 Mineral content of raw improved pigeon pea varieties

The results for mineral content of raw improved pigeon pea varieties are presented in Table 3.3. The calcium and zinc content were significantly different across all the improved pigeon pea varieties ( $p < 0.05$ ) varieties, with a few exceptions in iron and phosphorous content. While phosphorus had the highest concentration in all varieties, zinc had the lowest levels concentrations among all the varieties investigated. Iron content ranged from to 143.45 ppm in Egerton Mbaazi 1 to 367.25 ppm in ICEAP 00554. On the other hand, calcium content in Egerton Mbaazi 2 was the highest at 509.58 ppm and lowest in ICEAP 00554 at 238.56 ppm. KARI Mbaazi 1 was the second highest in calcium content, followed by KAT60/8 and Mituki. Zinc content ranged from 54.26 ppm to 74.31 ppm with Mituki and ICEAP 00554 having the lowest and highest contents, respectively. Egerton Mbaazi 2 and KARI Mbaazi 1 showed the highest phosphorus content, with 2909.00 ppm and 2730.66 ppm, respectively. In contrast,

ICEAP 00554 (control) had the lowest phosphorus content at 2191.06 ppm. However, ICEAP 00554 boasted higher iron (367.25 ppm) and zinc (74.31 ppm) content compared to any other mineral.

In general, all pigeon pea varieties displayed higher phosphorus concentrations, indicating that they could be considered as valuable sources of essential minerals (Soetan *et al.*, 2010). Zinc concentration on the other hand were lower than the other minerals investigated in the study. The recommended daily intake (RDI) of zinc is 15mg and this is increased to 25mg for nursing mothers and 20 mg for pregnant women (Santos *et al.*, 2020). Zinc deficiency is majorly associated with slow growth rate in children and poor wound healing (Karanja *et al.*, 2015). It is utilised in the body in RNA and DNA synthesis for cell division, maintaining normal reproductive health, bone growth and development, cell growth and repair. As much as zinc can also be found in other foods such as leafy vegetables, zinc deficiency remains a major public health in Kenya, necessitating the mandatory requirement for all flour millers to fortify flours with up to 2.0-3.0 mg/100g of zinc (Muriuki *et al.*, 2014). Deficiency of essential minerals in the body have been linked to hidden hunger, biological pathways imbalance and cardiovascular diseases. However, pigeon peas as a pulse are believed to supply adequate amounts of essential minerals needed by the body to meet its nutritional requirement (Singh, 2017). In addition, consumption of pigeon peas is recommended for minimising the risks of chronic diseases like coronary heart diseases, obesity, and type-2-diabetes (Roland *et al.*, 2017).

**Table 3.3:** Mineral content of raw improved pigeon pea varieties

Variety	Iron (ppm)	Calcium (ppm)	Zinc (ppm)	Phosphorous (ppm)
<b>Egerton Mbaazi 1</b>	143.45±0.59 <sup>e</sup>	318.94±1.30 <sup>e</sup>	58.45±0.06 <sup>d</sup>	2416.71±94.70 <sup>b</sup>
<b>KARI Mbaazi 1</b>	180.66±2.78 <sup>c</sup>	451.90±2.76 <sup>b</sup>	55.86±0.39 <sup>e</sup>	2730.66±57.78 <sup>a</sup>
<b>MITUKI</b>	147.29±0.58 <sup>de</sup>	331.94±0.04 <sup>d</sup>	54.26±0.52 <sup>f</sup>	2505.55±51.15 <sup>b</sup>
<b>KAT60/8</b>	154.03±0.49 <sup>d</sup>	432.66±2.26 <sup>c</sup>	62.62±0.09 <sup>c</sup>	2525.73±11.46 <sup>b</sup>
<b>Egerton Mbaazi 2</b>	294.91±0.31 <sup>b</sup>	509.58±3.33 <sup>a</sup>	64.90±0.56 <sup>b</sup>	2909.00±43.21 <sup>a</sup>
<b>ICEAP 00554</b>	367.25±6.42 <sup>a</sup>	238.56±8.26 <sup>f</sup>	74.31±0.10 <sup>a</sup>	2191.06±32.44 <sup>c</sup>

**Key:** Tukey's honestly significant difference (HSD). Values along the column followed by different superscript letter notations are significantly different ( $p \leq 0.05$ ). The values are mean ± standard error.

### 3.4.6 Effect of cooking on proximate analysis of pigeon peas

The results on the effects of cooking on proximate analysis are summarized in Table 3.4. The findings showed significant increase in fibre content in all the analysed pigeon pea varieties ( $p < 0.05$ ). Increase in fibre content was highest in KARI Mbaazi 1 (38.32%), followed by KAT 60/8 (27.12%) and ICEAP 00554 (25.98%). Egerton Mbaazi 1 recorded the least increase in fibre content after cooking (4.46%).

On the other hand, cooking led to a decrease in ash and protein content in pigeon pea varieties. There was a significant reduction in ash content after cooking in all the varieties ( $p < 0.05$ ) except for KAT60/8. The highest reduction in ash content was observed in ICEAP 00554 (by 37.21%), followed by Mituki (by 31.90 %) and Egerton Mbaazi 1 (by 29.27%). The change in ash content in KAT60/8 variety after cooking was however not significantly different ( $t_{(4)} = -2.02$ ,  $p = 0.1130$ ). Similarly, the protein content reduced significantly after cooking in all investigated pigeon pea varieties. Egerton Mbaazi 1 recorded the highest loss in protein (22.56%), followed by KARI Mbaazi 1 (18.60%) and KAT 60/8 (9.72%). Protein leakage in ICEAP 00554 variety was very minimal (4.53%) but significantly different after cooking ( $p < 0.05$ ).

Fat content in cooked pigeon pea varieties increased significantly in all varieties ( $p < 0.05$ ) except in Mituki variety (3.13%), which was however not statistically significant ( $p = 0.7530$ ). Similarly, the carbohydrates content increased significantly in all varieties after cooking except in KAT 60/8 and ICEAP 00554 varieties. Egerton Mbaazi 1 pigeon pea variety recorded the highest increase in carbohydrate content after cooking (18.01%).

Cooking is a processing method mostly used in preparation of pigeon pea grains and can influence the product positively or negatively with various changes occurring both intrinsically and extrinsically. The changes that occur in pigeon pea due to the cooking process include protein denaturation and intracellular starch gelatinization, followed by seed softening which is due to partial solubilisation or plasticization of middle lamellae separating the cotyledons (Biana *et al.*, 2020). Cooking of pigeon pea seeds depends on heat transfer and imbibition of water. However, nutrient retention and cooking are solely determined by the structure, size, and composition of the pigeon peas seed. The observed reduction in protein contents of all pigeon peas varieties investigated could be attributed to varietal or environmental differences of cultivars (Ceyhan *et al.*, 2012). Another probable cause could be loss of water-soluble amino acids diffusing into the cooking water during cooking. A study by Sood *et al.* (2002), reported a similar trend in protein content reduction by 10% - 20% in pigeon pea, climbing bean

chickpea after steaming. Further, the higher temperatures that the pigeon peas seeds were subjected to during the thermal processing could have caused protein denaturation. Findings from a previous study by Sheriful (2002) recorded significant reduction in protein contents of stored oven dried and frozen garden peas. Cooking as a thermal treatment disintegrates the protein in the pigeon peas into amino acids and changes the protein structure (Farinde *et al.*, 2018). While all the other pigeon pea varieties indicated a significant increase in carbohydrates content after cooking, there was an exception in the KAT 60/8 and ICEAP 00554 varieties which showed carbohydrate reduction. The sharp decrease may have been due to leaching of starch in the cooking water. Similar studies have reported carbohydrate reduction during cooking in processed velvet, brown beans and white beans grown in Nigeria (Alayande, 2012; Bamigboye & Adepoju, 2015). Farinde *et al.* (2018) linked the reduction in carbohydrate content following thermal treatment to the ease of hydrolysis of carbohydrates, making them water-soluble and allowing them to diffuse into the cooking broth. Boiling also causes mono and disaccharides which are known to be low molecular weight carbohydrates be lost in cooking water contributing to their significant loss (Bamigboye & Adepoju, 2015).

All the pigeon peas varieties showed a sharp increase in fibre content after cooking due to variable effects including the disruption in cellular components like lignin, hemicellulose, pectin cellulose, and gum of the pigeon grains. Brigide *et al.* (2014) opined that thermal treatment causes interaction of lipids and proteins leading to quantitative and qualitative changes in dietary fibre composition.

The variation in fat content of the tested pigeon pea varieties was evident after cooking, with either a decrease or increase in content among the different analysed varieties. This disparity could have arisen from differences in agronomic practices, cultivation environment and varietal differences. The reduction in this case however was attributed to leaching of fat into cooking broth during boiling. The decrease in ash content observed in other pulses after cooking is attributed to the thermal treatment, which results in the leaching of both macro and micro food elements into the broth (Jayalaxmi *et al.*, 2015; Saulawa *et al.*, 2014).

**Table 3.4:** Effect of cooking on proximate analysis of pigeon peas

<b>Variety</b>		<b>Fibre (%)</b>	<b>Ash (%)</b>	<b>Protein (%)</b>	<b>Fat (%)</b>	<b>Carbohydrates (%)</b>
<b>Egerton</b>	Cooked	9.14 (9.11- 9.18)	3.02 (2.97-3.07)	24.13 (23.58-24.68)	2.06 (1.72-2.39)	52.68 (51.70-53.66)
<b>Mbaazi 1</b>	Raw	8.75 (8.61- 8.89)	4.27 (4.08-4.45)	31.16 (30.44-31.88)	1.33 (1.22-1.45)	44.64 (43.13-46.14)
	t-value	12.12	-27.80	-33.45	8.76	19.27
	<b>p-value</b>	<b>0.0003</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.0009</b>	<b>&lt;0.0001</b>
<b>KARI</b>	Cooked	10.72 (10.20-11.24)	3.28 (3.19-3.36)	23.32 (23.00-23.64)	1.99 (1.87-2.11)	52.11 (51.81-52.43)
<b>Mbaazi 1</b>	Raw	7.75 (7.25-8.25)	4.09 (3.77-4.41)	28.65 (28.05-29.25)	1.45 (1.18- 1.72)	47.56 (47.41-47.71)
	t-value	17.74	-10.46	-33.82	7.74	56.91
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.0005</b>	<b>&lt;0.0001</b>	<b>0.0015</b>	<b>&lt;0.0001</b>
<b>MITUKI</b>	Cooked	9.05 (8.83-9.27)	3.16 (2.67-3.64)	24.20 (22.74-25.65)	1.86 (1.74-1.97)	52.19 (50.19-54.19)
	Raw	7.26 (7.01-7.51)	4.64 (3.93-5.34)	25.98 (24.10- 27.85)	1.92 (1.16-2.67)	50.21 (49.20-51.21)
	t-value	23.04	-7.42	-3.23	-0.34	3.81
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.0018</b>	<b>0.0320</b>	<b>0.7530</b>	<b>0.0190</b>
<b>KAT60/8</b>	Cooked	10.03 (9.04-11.02)	3.59 (2.75-4.43)	23.32 (22.70- 24.54)	2.1 (1.55-2.65)	43.80 (43.31-44.28)
	Raw	7.89 (7.68-8.10)	3.99 (3.89-4.09)	25.83 (24.97-26.68)	1.19 (1.17-1.21)	50.41 (49.23-51.59)
	t-value	9.08	-2.02	-3.84	7.16	-22.30
	<b>p-value</b>	<b>0.0008</b>	<b>0.1130</b>	<b>&lt;0.0001</b>	<b>0.0020</b>	<b>&lt;0.0001</b>
<b>Egerton</b>	Cooked	9.35 (8.63-10.07)	3.37 (3.08-3.65)	23.51 (23.30-23.72)	2.07 (1.38-2.75)	52.35 (51.73-52.97)
<b>Mbaazi 2</b>	Raw	8.41 (7.96-8.86)	4.65 (4.58-4.71)	24.95 (24.61-25.28)	1.52 (1.42-1.62)	51.02 (50.35-51.69)
	t-value	4.77	-18.83	-15.63	3.41	6.26

	<b>p-value</b>	<b>0.0088</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.0271</b>	<b>0.0034</b>
<b>ICEAP</b>	Cooked	9.31 (8.60-10.02)	3.46 (3.06-3.86)	23.41 (22.92-23.89)	2.20 (2.18-2.22)	52.50 (50.82-54.17)
<b>00554</b>	Raw	7.39(7.08-7.70)	5.51 (4.67-6.34)	24.52 (24.11-24.93)	1.81 (1.74-1.87)	52.63 (52.19-53.06)
	t-value	10.69	-9.55	-7.53	25.16	-0.32
	<b>p-value</b>	<b>0.0004</b>	<b>0.0007</b>	<b>0.0017</b>	<b>&lt;0.0001</b>	<b>0.7629</b>

**Key:** Paired sample t-test. Values are mean (95% Confidence Interval)

### 3.4.7 Effect of cooking on mineral content of improved pigeon peas

Effect of cooking on mineral content of pigeon peas is summarized Table 3.5. Cooking resulted in a significant reduction in mineral contents, including iron, calcium, zinc, and phosphorus ( $p < 0.05$ ). Generally, iron content was the most lost mineral in all the pigeon pea varieties during the cooking process. The iron content in ICEAP 00554 pigeon peas variety reduced by 76.1% followed by Egerton Mbaazi 2 (72.3%). The remaining varieties including KARI Mbaazi 1, KAT60/8, Mituki and Egerton Mbaazi 1 had iron reduction of up to 49.5%, 46.2%, 45.2% and 38.9%, respectively.

KAT60/8 lost the most percent calcium (57.31%), followed by KARI Mbaazi 1 (41.70%), Egerton Mbaazi 2 (31.05%), while the least calcium loss was observed in Mituki and Egerton Mbaazi 1 at 4.71% and 8.37%, respectively. While the ICEAP 00554 had the greatest loss of zinc (35.12%), Egerton Mbaazi 1 had the least losses of zinc at 4.05%. The amount of phosphorous lost after cooking was high in KAT60/8 (16.57%) followed by Egerton Mbaazi 2 (16.03%), with ICEAP 00554 (control) having the least phosphorous loss (0.39%).

Comparing the mineral losses by percentages, overall phosphorus was the least mineral lost across all the varieties investigated. ICEAP 00554 pigeon pea variety lost the most mineral during cooking having highest percentage losses in both iron and zinc at 76.1% and 35.12%, respectively. Pulses usually require relatively longer cooking time which often depends on softness of the pulse grains. The variety of cooked pigeon peas affect mineral content and cooking time which affects iron, zinc and calcium concentrations (Silva *et al.*, 2017). Micronutrients are lost during cooking due to chemical degradation (oxidation and isomerization) and physical loss, through the leaking of soluble solids into broth (Bechhoff, 2017).

Minerals and proteins availability may also be diminished because of antinutritional compounds like tannins, phytates and phenolic acids that impact mineral bioavailability (Samtiya *et al.*, 2020). The difference in mineral content before and after cooking was quite evident in all pigeon pea varieties. Zinc deficiency leads to major losses of human potential and immunity impairment and development (Hussain *et al.*, 2022). Thus, retention of these minerals like zinc is important for consumers who solely rely on these foods especially in ASALs areas. The control (ICEAP 00554) exhibited the most significant decrease in iron concentrations, with a reduction of 76.1%, possibly attributed to diffusion into the broth. After thermal treatment, Egerton Mbaazi 2 demonstrated the highest levels of calcium, zinc, and

phosphorous, making it a promising pigeon pea variety for cultivation due to its increased availability of micronutrients post-cooking. This shows the ability of Egerton Mbaazi 2 to retain the mineral nutrients compared to other varieties. ICEAP 00554 however had the poorest retention of both calcium and zinc which may have resulted from excessive leaching into the broth (Wang *et al.*, 2010).

For consumption and retention of minerals, selection of the pigeon pea varieties with high mineral and protein contents and low cooking time before and after thermal treatment is desirable in overcoming mineral deficiencies among individuals depending on these foods. Hence, incorporating pigeon pea into diets could help alleviate the iron deficiency faced by 60% of the global population (White & Broadley, 2009).

**Table 3.5:** Effect of cooking on mineral content of pigeon peas

Variety	Test	Iron	Calcium	Zinc	Phosphorous
<b>Egerton</b>	Cooked	87.70 (87.41-87.98)	292.23 (283.37-301.08)	56.08 (55.87-56.29)	2029.4 (1875.80-2183.1)
<b>Mbaazi 1</b>	Raw	143.45 (140.9-145.99)	318.94 (313.33-324.55)	58.45 (58.19-58.71)	2416.7 (2009.30-2824.20)
	t-value	-93.62	-10.96	-30.37	-3.83
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.0004</b>	<b>&lt;0.0001</b>	<b>0.0187</b>
<b>KARI</b>	Cooked	91.30 (89.82-92.76)	263.48 (251.06-275.90)	51.66 (50.58-52.74)	2340.60 (2286.30-2394.9)
<b>Mbaazi 1</b>	Raw	180.66 (168.71-192.61)	451.90 (440.01-463.78)	55.86 (54.20-57.52)	2730.7 (2482.1- 2979.3)
	t-value	-31.94	-47.16	-9.11	-6.60
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.0008</b>	<b>0.0027</b>
<b>MITUKI</b>	Cooked	80.74 (75.14-86.34)	316.29 (314.93- 317.64)	52.98 (51.59-54.37)	2355.2 (2256.80-2453.50)
	Raw	147.29 (144.78-149.8)	331.94 (331.75-332.12)	54.26 (52.00-56.51)	2505.6 (2285.5-2725.60)
	t-value	-46.65	-49.27	-7.69	-2.68
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.0015</b>	<b>0.0550</b>
<b>KAT60/8</b>	Cooked	82.88 (81.85-83.91)	184.71 (175.59-197.83)	55.47 (53.24-57.69)	2079.40 (2054.1-2104.70)
	Raw	154.03 (151.12-156.14)	432.66 (422.93-442.38)	62.62 (62.23-63.00)	2525.70 (2476.40-2575.00)
	t-value	-130.29	-65.34	-13.63	-34.65
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.0002</b>	<b>&lt;0.0001</b>
<b>Egerton</b>	Cooked	81.55 (80.53-82.57)	351.33 (339.60-363.06)	62.39 (60.68-65.10)	2443.80 (2131.40-2756.20)
<b>Mbaazi 2</b>	Raw	294.91 (293.57-296.25)	509.58 (495.27-523.89)	64.90 (62.49-67.31)	2929.00(2723.1-3094.90)
	t-value	-545.05	-36.81	-2.55	-5.51

	<b>p-value</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>0.0635</b>	<b>0.0053</b>
<b>ICEAP</b>	Cooked	87.56 (86.43-88.69)	173.30 (159.99-186.6)	48.21 (47.10-49.31)	2182.5 (2165.6- 2199.40)
<b>00554</b>	Raw	367.25 (339.61-339.88)	238.56 (203.02-274.09)	74.31 (73.86-74.56)	2191.10 (2051.50- 2330.60)
	t-value	-43.51	-3.94	-94.19	-0.26
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.0170</b>	<b>&lt;0.0001</b>	<b>0.8058</b>

**Key:** Paired sample t-test. Values are means (95% Confidence Interval)

### 3.4.8 Effect of cooking on antinutrient contents of pigeon peas

The effects of cooking on the antinutrient content in the different varieties of pigeon peas is as shown in Table 3.6 below. Cooking led to significant reduction of antinutrient factors (tannins, phytates and total free phenolics) in all pigeon pea varieties analysed ( $p < 0.05$ ). Tannins were the most reduced antinutrient factors in all the varieties investigated, with the highest reduced by 57.6% in Egerton Mbaazi 2 followed closely by Mituki (56.4%), ICEAP 00554 (53.6%), KAT60/8 (50%) and KARI Mbaazi 1 (28.6%). In contrast, Egerton Mbaazi 1 exhibited a twofold increase in tannin concentrations following the cooking process. The total free phenolic content experienced a substantial decrease of 46.8% in Mituki, whereas in KAT60/8, the reduction was comparatively modest, at 15.4%. Conversely, Egerton Mbaazi 1 exhibited the smallest reduction in phytates, with only a marginal decrease of 0.1%, whereas Mituki experienced a considerably higher percentage loss of 37.9%. On average, the reduction of the antinutritional factors after thermal treatment were greatest in the Mituki variety recording 56.4%, 46.8% and 37.9% reduction in tannins, total free phenolics and phytates respectively. Cooking is a normal processing method that has been applied since time in memorial to improve the nutritional value pulse proteins while inactivating their heat sensitive antinutritional factors (Kaur *et al.*, 2024). Cooking therefore improves pigeon peas palatability by reducing the anti-nutritive components (condensed tannins, glycosides, phytates and polyphenols) which also improves their texture and appearance. The reduction of total free phenolics of up to 46.8% might have been due to phenols binding structurally to available macromolecules during thermal processing to form low assayable phenols which are influenced by method of extraction and sample particle size (Syeunda *et al.*, 2019). Naczki and Shahidi (2004) attributed this reduction of analysed phenols to binding with other macromolecules like proteins and interference of reducing substances during pigeon pea cooking.

Tannins on the other hand may form complex compounds with proteins through hydrogen bonding and hydrophobic interactions during cooking of the pigeon pea grain. Complex formation reduces protein digestibility when consumed hence the Egerton Mbaazi 1 variety that showed an increased tannin content after cooking may not be suitable. Syeunda *et al.* (2019) suggested that tannin concentration reduction results in formation of protein-tannin complex that is more digestible, and the breakdown of condensed tannins form low molecular weight components that may improve quality. Tannins are also known to chelate zinc and iron irreversibly and thus interfering with their absorption in the body (Zawistowski & Kopeć, 2022). Tannin depolymerisation, polymerisation, degradation of pro-anthocyanidins and

binding of leuco-anthocyanidins to proteins during cooking may have also caused their reduction in the varieties mentioned (Taylor & Duodu, 2015). Thermal degradation of tannins during cooking of the pigeon peas could have resulted in formation of simpler flavanol compounds according to a study carried out on sorghum tannin (Awika *et al.*, 2003). Tannins affect grain palatability and digestibility and its reduction upon cooking was anticipated to improve the varieties' nutritional value. The results of this study corroborate the findings of Onu and Madubuike (2006) which reported that cooking significantly removed the anti-nutritional factors in raw wild cocoyam (*Caladium bicolor*) corms.

Prolonged cooking time may reduce concentration of phytic acid. The conditions could explain the disparity in phytic acid levels in the pigeon peas varieties. However, the decrease after cooking the pigeon peas is because of phytase, an endogenous enzyme that effectively breaks down phytate to inositol and inorganic phosphorous (Traore *et al.*, 2004). A similar study Fabbri and Crosby (2016) reported phytate content reduction in boiled vegetables despite phytates being heat stable and attributed the decrease to prolonged heat treatment.

Phytates are strong chelating agents of proteins, minerals like zinc and phosphorous forming complexes and heat application could have promoted the chelation process thus reducing the phytate contents in the analysed pigeon peas varieties. These complexes reduce mineral (zinc and potassium) bioavailability by inhibiting protease and amylase enzymes (Goncalves *et al.*, 2016).

**Table 3.6:** Effect of cooking on antinutrient analysis of pigeon peas

		<b>Tannins</b>	<b>Phytates</b>	<b>Total Free Phenolics</b>
<b>Egerton</b>	Cooked	0.57 (0.55-0.58)	8.70 (8.09-9.31)	0.11 (0.10-0.12)
<b>Mbaazi 1</b>	Raw 1	0.25 (0.23-0.26)	8.71 (8.60-8.82)	0.18 (0.18-0.18)
	t-value	-67.88	-1.07	-14.91
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.9479</b>	<b>0.0001</b>
<b>KARI</b>	Cooked	0.20 (0.18-0.22)	8.53 (8.06-9.00)	0.12 (0.11-0.13)
<b>Mbazi1</b>	Raw	0.28 (0.26-0.30)	9.17 (8.85-9.49)	0.20 (0.19-0.22)
	t-value	-1.10	-4.82	-3.51
	<b>p-value</b>	<b>0.3349</b>	<b>0.0086</b>	<b>0.0246</b>
<b>MITUKI</b>	Cooked	0.24(0.22-0.25)	7.62 (7.23-7.99)	0.17 (0.16-0.18)
	Raw	0.55 (0.53-0.57)	12.27 (12.06- 12.48)	0.32 (0.32- 0.32)
	t-value	-47.00	-46.67	-70.62
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
<b>KAT60/8</b>	Cooked	0.32 (0.28-0.35)	7.51 (6.89-8.13)	0.44 (0.42-0.46)
	Raw	0.64 (0.62-0.65)	11.41 (11.26-11.56)	0.52 (0.52-0.52)
	t-value	-33.94	-26.27	-19.21
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>	<b>&lt;0.0001</b>
<b>Egerton</b>	Cooked	0.28 (0.26-0.30)	8.24 (8.14-8.34)	0.30 (0.29-0.30)
<b>Mbaazi 2</b>	Raw	0.66 (0.59-0.72)	10.27 (9.43-11.20)	0.51 (0.49-0.52)
	t-value	-24.09	-10.40	-58.80
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.0005</b>	<b>&lt;0.0001</b>
<b>ICEAP</b>	Cooked	0.45 (0.38-0.51)	9.64 (8.72-10.56)	0.30 (0.29-0.31)
<b>00554</b>	Raw	0.97 (0.95-0.98)	10.62 (10.58-10.66)	0.54 (0.52-0.57)
	t-value	-34.88	-4.57	-37.95
	<b>p-value</b>	<b>&lt;0.0001</b>	<b>0.0103</b>	<b>&lt;0.0001</b>

**Key:** Paired sample t-test. Values are means (95% Confidence Interval)

### 3.4.9 The relationship between proteins, minerals and antinutritional factors of improved pigeon pea varieties

The results of the relationship between proteins, minerals and antinutrients are presented in Table 3.7. The correlation analysis revealed significant findings among various nutrient components in improved pigeon pea varieties. A substantial positive moderate relationship ( $r=0.58$ ) was observed between phytates and tannins content, indicating that a unit increase in

either phytates or tannins would result in a 58% increment in both variables. Similarly, total free phenolics and proteins content exhibited a very strong positive correlation ( $r=0.81$ ), suggesting that when either total free phenolics or proteins increase, there is an expected rise in either factor by 81%.

Furthermore, iron showed a moderate positive relationship with tannins ( $r = 0.48$ ) and with phytates ( $r = 0.63$ ), both of which are considered antinutrients. Regarding mineral components, both zinc and phosphorus exhibited moderate positive correlations with calcium at  $r = 0.58$  and  $r = 0.61$ , respectively. An increase in zinc and calcium would lead to a 58% increment in both factors, while an increase in phosphorus and calcium would result in a 61% increment of either factor. These positive correlations suggest a close inherent and genetic association between these mineral pairs, indicating that they can be simultaneously enhanced via breeding.

There was a significant moderate negative correlation ( $r = -0.57$ ) between phytates and proteins, implying that a unit increase in either phytates or protein contents would lead to a 57% decrease in either factor. Calcium also showed a significant strong negative relationship with both protein ( $r = -0.81$ ) and total free phenolics ( $r = -0.65$ ), indicating that a unit increase in calcium or protein would reduce either factor by 81%. Additionally, a unit increase in calcium or total free phenolics in the grain would cause a 65% decrease in both factors.

Moreover, zinc exhibited a strong negative correlation with phytates ( $r = -0.54$ ) and iron ( $r = -0.70$ ), suggesting that an increment in either zinc or phytates concentrations in the grain would bring about a 54% reduction in both factors. This observation aligns with the understanding that phytates form complexes by binding zinc in the gastrointestinal tract, inhibiting its absorption and bioavailability in the body (Hummel *et al.*, 2020; Silva *et al.*, 2017).

**Table 3.7:** Correlation coefficients ( $R^2$ ) of proximate parameters of cooked improved pigeon pea varieties in Machakos County

	<b>Protein</b>	<b>Tannins</b>	<b>Phytates</b>	<b>Total free phenolics</b>	<b>Iron</b>	<b>Calcium</b>	<b>Zinc</b>	<b>Phosphorous</b>
Protein	1.000							
Tannins	-0.143 <sup>ns</sup>	1.000						
Phytates	<b>-0.569*</b>	<b>0.581*</b>	1.000					
Total Free Phenolics	<b>0.814**</b>	-0.084 <sup>ns</sup>	-0.194 <sup>ns</sup>	1.000				
Iron	-0.326 <sup>ns</sup>	<b>0.480*</b>	<b>0.626**</b>	-0.241 <sup>ns</sup>	1.000			
Calcium	<b>-0.805**</b>	-0.087 <sup>ns</sup>	0.170 <sup>ns</sup>	<b>-0.654**</b>	-0.233 <sup>ns</sup>	1.000		
Zinc	-0.026 <sup>ns</sup>	-0.397 <sup>ns</sup>	<b>-0.544*</b>	-0.027 <sup>ns</sup>	<b>-0.697**</b>	<b>0.575*</b>	1.000	
Phosphorous	-0.462 <sup>ns</sup>	<b>-0.695**</b>	-0.170 <sup>ns</sup>	-0.310 <sup>ns</sup>	-0.276 <sup>ns</sup>	<b>0.611**</b>	0.456 <sup>ns</sup>	1.000

**Key:** Pearson correlation analysis. Values are correlation coefficients significant *ns*-not significant, *\**-significant at  $p<0.05$ ; *\*\**- Significance at  $p<0.0001$ ; *\*\**- Significance at  $p<0.01$

#### **3.4.10. Logistic regression odds ratio estimates**

Table 3.8 shows the effect of cooking on the nutritional characteristics and antinutrient components of the improved pigeon pea varieties with reference to the ICEAP 00554 which was the control variety. The results show that there were no significant ( $p>0.05$ ) differences in the phytates, tannins, total free phenolics and zinc concentrations between the raw and cooked improved pigeon peas varieties with reference to ICEAP 00554 variety. These findings indicate that the improved pigeon peas varieties and ICEAP 00554 variety did not differ in these parameters. However, the protein content did not significantly reduce ( $p>0.05$ ) in all improved pigeon pea varieties except in KAT 60/8. Calcium and iron content was significantly different in all improved pigeon pea varieties ( $p<0.05$ ) in reference to control (ICEAP 00554). However, there was no significant difference ( $p> 0.05$ ) in phosphorus content for KARI Mbaazi 1 variety after cooking.

**Table 3.8:** Logistic regression odds ratio estimates for selected parameters

Effect	Variety		Antinutrients				Minerals			Proximate Protein
			Phytates	Tannins	Total free phenolic	Calcium	Iron	Phosphorous	Zinc	
Raw vs.	Egerton	PE	1.071 <sup>ns</sup>	1.00 <sup>ns</sup>	1.00 <sup>ns</sup>	<b>0.800</b> <sup>***</sup>	<b>2.557</b> <sup>***</sup>	<b>0.843</b> <sup>**</sup>	1.490 <sup>ns</sup>	0.805 <sup>ns</sup>
Cooked	Mbaazi 1	CL	0.499-2.303	0.489-2.046	0.489-2.046	0.698-0.916	2.084-3.137	0.803-0.885	1.105-2.009	0.512-1.266
Raw vs.	Egerton	PE	0.887 <sup>ns</sup>	1.00 <sup>ns</sup>	1.00 <sup>ns</sup>	<b>0.602</b> <sup>***</sup>	<b>1.156</b> <sup>***</sup>	<b>0.843</b> <sup>**</sup>	1.601 <sup>ns</sup>	0.986 <sup>ns</sup>
Cooked	Mbaazi 2	CL	0.420-1.871	0.489-2.046	0.489-2.046	0.530-0.684	0.951-1.406	0.805-0.883	1.199-2.138	0.619-1.572
Raw vs.	KARI	PE	0.952 <sup>ns</sup>	1.00 <sup>ns</sup>	1.00 <sup>ns</sup>	<b>0.509</b> <sup>*</sup>	<b>2.117</b> <sup>*</sup>	0.860 <sup>ns</sup>	1.440 <sup>ns</sup>	0.857 <sup>ns</sup>
Cooked	Mbaazi 1	CL	0.448-2.023	0.489-2.046	0.489-2.046	0.445-0.581	1.736-2.581	0.821-0.901	1.063-1.951	0.542-1.356
Raw vs.	KAT	PE	0.682 <sup>ns</sup>	1.00 <sup>ns</sup>	1.00 <sup>ns</sup>	<b>0.372</b> <sup>***</sup>	<b>2.252</b> <sup>**</sup>	<b>0.826</b> <sup>***</sup>	1.377 <sup>ns</sup>	<b>1.346</b> <sup>*</sup>
Cooked	60/8	CL	0.322-1.445	0.489-2.046	0.489-2.046	0.323-0.428	1.834-2.764	0.788-0.867	1.023-1.853	0.862-2.101
Raw vs.	Mituki	PE	0.625 <sup>ns</sup>	1.00 <sup>ns</sup>	1.00 <sup>ns</sup>	<b>0.832</b> <sup>***</sup>	<b>2.287</b> <sup>***</sup>	<b>0.944</b> <sup>***</sup>	1.677 <sup>ns</sup>	0.975 <sup>ns</sup>
Cooked		CL	0.297-1.316	0.489-2.046	0.489-2.046	0.727-0.951	1.859-2.813	0.900-0.989	1.243-2.263	0.614-1.548

Variety ICEAP 00554 is in reference category; PE-Point Estimate; CL- 95% Wald Confidence Limits; \*\*\*- Significance at p<0.0001.

\*\* - Significance at p<0.01; \* - Significance at p<0.05; ns - Not significant

### **3.5. Conclusions**

The study found significant variation in proximate composition, mineral and antinutrient content among all analysed pigeon pea varieties, indicating the influence of weather conditions, variety, and maturity stage on physicochemical parameters. Despite high protein contents, pigeon pea varieties exhibited considerable antinutritional factors, such as phytates and tannins, which limit their utilization by forming complexes with proteins and minerals. Cooking reduced these antinutrients but also led to decreases in proteins, minerals, and other compounds. Therefore, the assayed improved pigeon pea varieties hold potential for value-added foods and as alternative protein sources for populations residing in arid and semi-arid areas. The study recommends that further research should focus on developing cooking methods that preserve the nutritional content of pigeon peas while effectively reducing antinutritional factors.

## CHAPTER FOUR

### TECHNOLOGICAL PROPERTIES OF IMPROVED PIGEON PEA VARIETIES IN MACHAKOS COUNTY

#### **Abstract**

Pigeon peas, a type of pulse, hold immense potential to improve the health and nutrition of people in arid and semi-arid lands. Unlocking this potential depends heavily on understanding their technological properties. These properties, such as hydration rate, volumetric expansion, and cooking time, directly influence processing and ultimately determine the accessibility and acceptability of pigeon peas as a food source. However, there is limited information on technological properties of improved varieties. The study aimed to determine technological properties of improved pigeon pea varieties grown in Machakos County. Seven improved pigeon pea varieties were sourced from KALRO Katumani (KARI Mbaazi 1, KARI Mbaazi 2, Mituki, KAT /60/8 and ICEAP 00850) and Egerton University (Egerton Mbaazi 1, Egerton Mbaazi 2) and ICEAP 00554 as a control variety. These varieties were tested for water absorption, volumetric expansion, density, cooking time and total soluble solids in the broth. The experiment was arranged in a Completely Randomized Design (CRD) replicated three times. Data analysis was conducted using SAS software version 9.1.3 (SAS, 2006). Means separation was done using Tukey's honestly significant difference (HSD) at 95% Confidence Level. There were significant differences in water absorption, volumetric expansion, density, total soluble solids and cooking time among the improved varieties ( $p < 0.05$ ). ICEAP 00554 variety had the highest VEBC at 64%, significantly different from others ( $p < 0.05$ ). KARI Mbaazi 2 exhibited the greatest VEAC at 11%, followed by KAT60/8 at 10%. ICEAP 00554 also showed the highest water absorption capacity (125.48%), with significant differences in WACBC compared to other varieties. KAT60/8 had the highest TSS at 26.67%, correlating positively with VEBC/VEAC ( $r = 0.76$ ) and VEBC/D/RgD ( $r = 0.89$ ). Cooking time in minutes was shortest for Mituki (46.0) and KAT 60/8 (55.7) and longest for KARI Mbaazi 1 and ICEAP 00850 (160.0). All the varieties showed high total soluble solids ranging from 10.5 to 26.7% that indicates potential to select varieties with desired flavour profiles. Improved pigeon pea varieties (Mituki and KAT60/8) displayed desired technological properties alongside the control (ICEAP 00554). These findings inform the specific culinary applications and nutritional needs which enhance utilisation of pigeon peas as food. Further research is needed to determine the impact of the technological properties on the digestibility and glycaemic index of pigeon peas.

## 4.1 Introduction

Pigeon pea (*Cajanus cajan*) is one of the most predominant pulses in the tropical and subtropical countries in the world (Varshney *et al.*, 2010). Pigeon pea grain is endowed with proteins and dietary minerals (Adenekan *et al.*, 2018), it is also rich in carbohydrates, fibre and fat content (Kaur *et al.*, 2007; Oloyo, 2004; Saxena *et al.*, 2010; Tekale *et al.*, 2016). Research has demonstrated that pigeon pea grain has similar nutritional composition to other well-known legumes (Tiwari & Singh, 2015). Therefore, can be used as an alternative food and feed supply for different environmental conditions. Households consume pigeon peas in complement with cereals due to their high amino acid profile after dehulling (Narasimha *et al.*, 2004). Dehulling improves protein and cooking quality, digestibility, and palatability of the pea grain. Physical factors such as size and wholesomeness of the seed and cotyledon split influence the cooking time and utilization

Pigeon pea grains possess a hard to cook phenomenon which means longer cooking time thus limiting its consumption (Theologidou *et al.*, 2018). The phenomenon is caused by the seed coat, which is low in nutrients, high in fibre with low digestibility (Fasoyiro *et al.*, 2005). Cooking characteristics are the first commercial criterion, being determinant to assure sensorial quality (Ibarz, *et al.*, 2004; Wood, 2016). Cooking time measurement is therefore a major quality factor in evaluating the pigeon peas. Hydration or soaking grain is a long process of grain processing and influences the cooking time and nutrient extraction efficiency (Miano, *et al.*, 2020). The grains can be soaked before cooking or directly cooked in their raw state. The two processes change the chemical and physical structure of the grain controlling the starch gelatinisation, water diffusion into the grain, dimensional and geometrical soluble solid leaching into cooking broth (Sayar *et al.*, 2016). Volumetric expansion and linear swelling of the pea seed are vital attributes for the design and analysis of the process. Therefore, both hydration and cooking kinetics are important factors to be considered during the selection of new varieties. Soaking and cooking procedures reduce the concentrations of antinutrients in the pigeon peas thus minimizing the food safety incidents related to hard-to-cook phenomenon.

The high energy consumption caused by hard to cook phenomenon occur as a result of high temperature gelatinization transitions, poor dispensability of grain granules and restricted swelling during water disintegration (Hoover & Ratnayake, 2002). Starch gelatinization is determined by temperature, moisture and shear thus affects the starch functionality digestion in the body (Wang & Copeland, 2012). For acceptability and utilization of pigeon peas therefore, it is worthwhile to investigate technological, functional, physical, and nutritional

properties of different pigeon peas varieties to determine their suitability (Adebowale & Lawal, 2004).

When developing new cultivars, whether to enhance nutritional value or agronomic performance, it is equally essential to assess their technological properties to ensure successful adoption by consumers and processors. Information pertaining the technological aspects of improved pigeon pea varieties are scanty. Therefore, this study aims at analysing the technological attributes (volumetric expansion, density, total solids and cooking time) of improved pigeon peas varieties in Machakos county, Kenya.

## **4.2 Materials and methods**

### **4.2.1 Study location description and sample selection**

The study materials were collected from Kenya Agricultural and Livestock Organization (KALRO), Katumani Research Centre in Machakos County (1° 35'S and 37° 14'E) and Egerton University, Njoro (0° 22' 11.0" S and 35° 55' 58.0" E). The laboratory analyses were conducted at Guildford Dairy Institute, Department of Dairy and Food Science and Technology, Egerton University and Food Chemistry Laboratory, Department of Food Science Nutrition and Technology, University of Nairobi. Seven improved pigeon peas varieties namely: KARI Mbaazi 1, KARI Mbaazi 2, ICEAP 00850, KAT /60/8 and Mituki (sourced from KALRO-Katumani) while Egerton Mbaazi 1, Egerton Mbaazi 2 and control (ICEAP 00554) variety were collected from Egerton University.

### **4.2.2 Preparation of pigeon pea grains for technological analyses**

Mature dried pigeon pea grains (200 g) were prepared following the protocol of Biama *et al.* (2020). For each variety, the dried grain samples were thoroughly mixed and passed through sieves with apertures of 5.16 × 19.05 mm. Grains exhibiting visible damage from insect infestation or mechanical injury were manually removed prior to further analysis. The selected grains were subsequently stored in sealed plastic containers and maintained at a consistent temperature below 10 °C in a refrigerator until technological evaluations were conducted.

### **4.2.3 Water absorption capacity before and after cooking of pigeon peas**

Water absorption capacity was assessed using the modified procedure outlined by Perina *et al.* (2014). Approximately 30 g of pigeon pea grains were placed in a 250 mL beaker containing 100 mL of distilled water and allowed to soak for 16 hours at ambient temperature. Following the soaking period, the excess water was decanted, the hydrated grains were reweighed, and

the water absorption capacity before cooking (WACBC) was computed using the following formula:

$$WACBC = \frac{mw - dw}{dw} 100 \quad (10)$$

Where **dw** = weight of dry grains; **mw** = grain weight after maceration.

The soaked and drained pigeon pea grains were transferred to a beaker containing 100 mL of distilled water and heated on an electric hot plate for 1 hour. Timing commenced upon the onset of boiling. After cooking, the broth was decanted, and the water absorption capacity after cooking (WACAC) was determined using the following formula:

$$WACAC = \frac{cw - dw}{dw} \times 100 \quad (11)$$

Where **dw** = beginning weight of dry grains; **cw** = weight of grains after cooking.

#### 4.2.4 Volumetric expansion and density of pigeon pea grains

Volumetric expansion and density characteristics of pigeon pea grains were evaluated following the methodology of Perina *et al.* (2014). Ten grams of raw grains were weighed and immersed in distilled water for 16 hours at ambient temperature. After soaking, the water was discarded, and the hydrated grains were reweighed. The grains were then transferred to glass jars, combined with 100 mL of boiling water, and cooked for 1 hour in a small aluminium pan (sufuria). The volume of raw, soaked, and cooked grains was measured using the water displacement method in a 100 mL graduated cylinder pre-filled with 50 mL of water; the volume of displaced water was recorded. Volumetric expansion before cooking (VEBC), volumetric expansion after cooking (VEAC), dry/raw grain density (D/RgD), soaked grain density (SgD), and cooked grain density (CgD) were calculated according to the following formulas:

$$VEBC = \frac{vs - vr}{vs} \times 100 \quad (12)$$

$$VEAC = \frac{vc - vr}{vc} \times 100 \quad (13)$$

$$D/RgD = \frac{dw}{vr} \quad (14)$$

$$SgD = \frac{sw}{vs} \quad (15)$$

$$CgD = \frac{cw}{vc} \quad (16)$$

where; **vr** = volume of water displaced by raw grains, **vs** = volume of water displaced by grains after soaking, **vc** = volume of water displaced by the grains after cooking, **dw** = weight of the dry/raw grains, **sw** = weight of the grains after soaking and **cw**= weight of grains after cooking

#### 4.2.5 Cooking time determination

Cooking time (CT) was determined using a Mattson cooker (Customized Machining and Hydraulics Co., Winnipeg, Canada) on 25 pre-soaked pigeon pea grains in boiling distilled water, following Mukai (2017). The apparatus features a perforated plate with 25 individual wells, each accommodating one grain, and a corresponding 85 g stainless steel rod (2 mm diameter) suspended above each well (Wang & Daun, 2005). Cooking was conducted at 93.5 °C, and the time was recorded when 50% (13th pin) and 80% (20th pin) of the rods had fully penetrated the grains, indicating complete softening for the respective varieties (Wang & Daun, 2005).

#### 4.2.6 Determination of total soluble solids in the broth of cooked pigeon peas

Total soluble solids encompass carbohydrates, organic acids, soluble proteins, lipids, and minerals present in pulses (Hadiwijaya *et al.*, 2020). The content of total soluble solids in the cooking broth (TSSb) was quantified using the procedure adapted from Perina *et al.* (2014). In this method, 10 g of pigeon pea grains were soaked in 100 mL of distilled water for 16 hours. The beakers containing the soaked grains were subsequently heated on a hot plate for the predetermined cooking duration established for each variety during prior cooking trials. The resulting broths were filtered and collected in pre-weighed, clean, dry beakers. These were then dried to constant weight in a forced-air oven at 60 °C. After complete evaporation, the beakers were reweighed, and the total soluble solids in the broth were calculated using the following formula:

$$TSSb (\%) = \frac{(BW + DR) - (BW)}{DW} \times 100 \quad (17)$$

Where BW = beaker weight; DR = dry residue; DW = dry weight of the grains.

#### 4.2.7 Experimental design and statistical analysis

A Completely Randomized Design (CRD) was used with the following statistical model:

$$Y_{ij} = \mu + \bar{u}_i + \epsilon_{ij} \quad (18)$$

where; **Y<sub>ij</sub>**= the observation of the dependent variable of raw and cooked pigeon pea grains and technological properties, **μ** = Overall mean responses, **ū<sub>i</sub>**= The effect of **i<sup>th</sup>** variety and **ε<sub>ij</sub>**= Random error component.

Statistical analysis was performed using the PROC GLM procedure in SAS version 9.1.3 (SAS, 2006) to conduct analysis of variance (ANOVA) at a 95% confidence level. Mean comparisons were carried out using Tukey's honestly significant difference (HSD) test. All analyses were conducted with a significance threshold of  $\alpha = 0.05$ .

### **4.3 Results and discussions**

#### **4.3.1 Volumetric expansion and density of pigeon pea grains of improved pigeon peas**

Volumetric expansion and density of improved pigeon peas are as shown in Table 4.1. There was a consistent increase in the volumetric expansion of pigeon pea grains across all analysed varieties. The Volumetric Expansion Before Cooking (VEBC) was highest in the control variety (ICEAP 00554), reaching 64%, which was significantly different ( $p < 0.05$ ) from all other varieties except Mituki. However, Egerton Mbaazi 1, KARI Mbaazi 1, Mituki KAT60/8, and Egerton Mbaazi 2 did not show significant differences ( $p > 0.05$ ) in VEBC. The KARI Mbaazi 2 variety recorded the lowest volumetric expansion (57.5%) before cooking. After cooking, there was no significant difference ( $p > 0.05$ ) in the volumetric expansion of ICEAP 00554 and Mituki varieties. Remarkably, the KARI Mbaazi 2 variety exhibited the greatest volumetric expansion, with grains expanding by 11%, followed by KAT60/8 at 10% after cooking. Therefore, these varieties are highly recommended for pigeon pea cultivation based on their notable volumetric expansion characteristics.

The volumetric expansion of ICEAP 00850 pigeon pea variety after cooking was significantly different ( $p < 0.05$ ) from all other varieties. However, Egerton Mbaazi 1 and ICEAP 00850 recorded the lowest expansion rates at 4.3% and 3.9% after cooking respectively. Volumetric expansion is a desirable attribute that impacts acceptability of improved pigeon peas varieties. Volumetric expansion influences the water diffusion rate within the pigeon pea grain and is also described as a desirable characteristic for new cultivars acceptability. Similar studies have linked cooking treatment to high grain expansion in pulses (Carbonell *et al.*, 2003; Resende & Corrêa, 2007). Lower lignin content in the pea grain negatively affects the water diffusion rate hence the grain lignification degree (Teixeira *et al.*, 2005). Starch gelatinization occurs during cooking due to water availability caused by soaking (Waraich *et al.*, 2011).

The pigeon peas grain density after cooking and grain density after soaking were less when compared to that of raw/dry grain density (Table 4.1). The dry grain density was highest in the ICEAP 00554 pigeon pea variety (1.35 g/cm<sup>3</sup>) and lowest in the ICEAP 00850 variety (1.21 g/cm<sup>3</sup>). Egerton Mbaazi 1, ICEAP 00850, KARI Mbaazi 1, KARI Mbaazi 2, KAT60/8, Mituki

and Egerton Mbaazi 2 had no significant differences ( $p > 0.05$ ) in terms of raw/dry grain density. Egerton Mbaazi 1 and KAT60/8 pigeon pea varieties were significantly different ( $p < 0.05$ ) from all the remaining six varieties. ICEAP 00554 variety reduced in density by 16.3% after soaking, followed closely by Mituki and Egerton Mbaazi 1 at 13.8% and 13.5% respectively. Least reduction in density after soaking was observed in ICEAP 00850 by 7.4% and KARI Mbaazi 2 by 9.7%. Soaking pigeon pea grains elevates enzymatic cell wall activities leading to changes in pectin polymerization degree hence easier extractability (Soltani *et al.*, 2021). Soaking contributes to reduced cooking time and increased yield of cooking in pulse varieties like common beans (Muroki *et al.*, 2023).

There was a significant difference ( $p < 0.05$ ) in CgD of ICEAP 00850 variety and KAT60/8, Mituki, Egerton Mbaazi 1, ICEAP 00554 varieties. The decrease in density after cooking the grains was highest in ICEAP 00554 (19.3%) followed by Mituki (17.7%) and Egerton Mbaazi 1 (15.9%). ICEAP 00850 variety had the lowest density reduction (7.4%) after cooking compared to all other varieties. It was noted that both soaking and cooking had similar reduction rates in density due to presence of native protopectin in their grains which forms soluble pectin that when subjected to thermal process depolymerise. The depolymerisation allows for rapid water flow through the dicotyledonous cell (Soltani *et al.*, 2021; Zhu *et al.*, 2019).

**Table 4.1:** Effect of variety on volumetric expansion and density of pigeon pea grains of improved pigeon peas

Variety	VEBC (%)	VEAC (%)	D/RgD (g/cm <sup>3</sup> )	SgD (g/cm <sup>3</sup> )	CgD (g/cm <sup>3</sup> )
Egerton Mbaazi 1	60.71±0.69 <sup>b</sup>	63.34±0.17 <sup>c</sup>	1.26±0.02 <sup>bc</sup>	1.09±0.00 <sup>b</sup>	1.06±0.01 <sup>d</sup>
KARI Mbaazi 1	58.95±0.61 <sup>bc</sup>	63.64±0.00 <sup>c</sup>	1.27±0.01 <sup>bc</sup>	1.13±0.01 <sup>a</sup>	1.10±0.01 <sup>abc</sup>
MITUKI	61.44±0.27 <sup>ab</sup>	67.33±0.38 <sup>ab</sup>	1.30±0.02 <sup>ab</sup>	1.12±0.01 <sup>a</sup>	1.07±0.00 <sup>cd</sup>
KAT60/8	60.02±1.09 <sup>bc</sup>	66.03±0.37 <sup>b</sup>	1.25±0.04 <sup>bc</sup>	1.10±0.01 <sup>b</sup>	1.07±0.01 <sup>cd</sup>
Egerton Mbaazi 2	59.70±1.27 <sup>bc</sup>	64.13±0.63 <sup>c</sup>	1.27±0.03 <sup>bc</sup>	1.13±0.00 <sup>a</sup>	1.11±0.01 <sup>ab</sup>
KARI Mbaazi 2	57.47±0.61 <sup>c</sup>	63.81±0.44 <sup>c</sup>	1.24±0.01 <sup>bc</sup>	1.12±0.00 <sup>a</sup>	1.10±0.01 <sup>abc</sup>
ICEAP 00850	58.80±0.96 <sup>bc</sup>	61.07±1.14 <sup>d</sup>	1.21±0.02 <sup>c</sup>	1.12±0.00 <sup>a</sup>	1.12±0.01 <sup>a</sup>
ICEAP 00554	63.96±0.19 <sup>a</sup>	68.38±0.22 <sup>a</sup>	1.35±0.00 <sup>a</sup>	1.13±0.01 <sup>a</sup>	1.09±0.01 <sup>bc</sup>

**Key:** VEBC- Volumetric Expansion Before Cooking; VEAC- Volumetric Expansion After Cooking; D/RgD- Dry/Raw Grain Density; SgD- Grain Density After Soaking; CgD- Grain Density After Cooking. Values along the column followed by different superscript letter notations are significantly different ( $p \leq 0.05$ ). The values are mean  $\pm$  standard error.

#### 4.3.2 Water absorption capacity, cooking time, and total soluble solids in broth

Water absorption capacity, cooking time and total soluble solids results are as presented in Table 4.2 below. The water absorption capacity before cooking of improved pigeon peas varieties ranged between 115.06%-125.48% validating the WAC of 63%-137% earlier reported by Mughli (2017) for improved beans. The water absorption capacity was highest in ICEAP 00554 variety and lowest in KARI Mbaazi 2 before cooking. There was a significant difference ( $p < 0.05$ ) in the WACBC of KARI Mbaazi 2 variety and the other remaining seven varieties tested. The variation noted in WAC was due to differences in environmental and agronomical practises. The characteristics of water absorption showcase the ability of the grain to link with water under circumstances where water is limiting (Singh, 2010). The more imbibed water increases WAC thus acting as a stimulus for cooking permitting cell separation by softening the grain cells. Seed size and seed coat thickness greatly influence water absorption in pigeon pea grains (Biama *et al.*, 2020). The WAC increased by 27.3%, 25.9%, 19.3% and 16.8% after cooking in Egerton Mbaazi 2, KAT60/8, KARI Mbaazi 2 and Mituki varieties respectively. The results indicate that the pigeon pea grains absorbed water corresponding to their weight due to porosity, cotyledon adherence, elasticity, seed coat rigidity and colloidal properties of the grains (Esteves *et al.*, 2002). ICEAP 00850 and KARI Mbaazi 1 varieties recorded the

lowest WAC percentage increase rates at 8.1% and 10.4% among the varieties. High water absorption rates have been attributed to high grain moisture content (Mughi, 2017).

The WACAC of KAT60/8 and Mituki varieties were significantly different ( $p < 0.05$ ) from the other six varieties analysed. However, Egerton Mbaazi 1, KARI Mbaazi 2 and ICEAP 00850 were not significantly different at  $p > 0.05$  in terms of WACAC. Perina *et al.* (2014) attributed the variation in WAC to environmental conditions interference affecting seed coat integrity and physiological quality which consequently cause changes in cooking time and water absorption capacity. Pigeon peas varieties with high WACBC and WACAC are mostly recommended for kitchens and commercial food industries due to higher yields after cooking (Perina *et al.*, 2014). Some studies have observed an inversely proportional relationship between water absorption and cooking time, thus, improved pigeon peas varieties with shorter cooking times will not automatically have higher water absorption capacity *visa vis* (Carbonell *et al.*, 2003; Dalla Corte *et al.*, 2003; Rodrigues *et al.*, 2004). This correlation may exist between lignin concentration, WAC, peroxide activity, and polyphenols in the grain. Water absorption capacity is controlled by hard seed coat mechanism and as well as altered by its thickness. The pigeon pea grain water absorption has been associated with grain flexibility, weight, thickness, cotyledon adhesion, porosity, weight, and colloidal properties (Aghkhani *et al.*, 2012; Buzera *et al.*, 2018). The solids of pigeon pea grains are made of starch whose access to water is elevated by cell wall enzymatic degradation during thermal treatment (Okpala, 2017). When the cell wall is not degraded, the water that is accessible within the grain will still be confined in the endemic hydrophilic polymers. As a consequence, the free granules could favour the grain water absorption capacity.

For the eight samples analysed, there was a greater spread for cooking time in KARI Mbaazi 1 (10.01 minutes), ICEAP 00554 (8.37 minutes) and Egerton Mbaazi 2 (6.4 minutes) results for the rankings at CT 50 and CT 80 allowing for easier recognition of cooking differences. The time taken for 50% of the grain to be pierced was highest in ICEAP 00850 (157.5 minutes) and KARI Mbaazi 1 (150.1 minutes) varieties compared to Mituki (44.6 minutes) and KAT60/8 (57.3 minutes) which recorded the lowest cooking time. However, mean cooking time at 50% CT was significantly different ( $p < 0.05$ ) among the varieties assessed. At 80% CT, the cooking time ranged between to 46 to 160.2 minutes with the lowest cooking time recorded for Mituki and highest cooking time for KARI Mbaazi 2 varieties. Longer cooking times may arise from varietal differences, grain physical parameters and seed characteristics such as flatness and grain thickness (Santos *et al.*, 2016).

Different studies have defined cooking time in different ways. By using a Mattson cooker, Bibi *et al.* (2007) defined CT as time required for 80–100% (at 5 min intervals during boiling) of the seeds to be penetrated while Proctor and Watts (1987) expressed CT as time required for 92% seed penetration by heat. Other studies reported CT as time needed for 60% of the seed penetration, while others defined the 50% and 100% mean cooking time to be the cook point. We can conclude that there is no clear definition of CT (Hsieh, 1993; Wang & Daun, 2005).

Longer cooking times indicate the presence of a tough seed coat and varying levels of resistance within pigeon pea grains. Consequently, this toughness may lead to the phenomenon known as "hard-to-cook," where the resistance to puncture during piercing may be irregular and misleading. This is often observed as piercing plungers struggle to penetrate the soft cotyledons consistently (Latunde-dada, 1993). Hard-to-cook is a defect negatively impacts cooking quality and palatability of the pigeon peas which is associated with seed coat, seed size, texture and swelling capacity of the pea grain (Wood, 2017).

Wood (2017) reported that polishing the probes before testing allows for rapid heat penetration onto the cotyledons leading to faster cooking times while keeping the seed coat intact. As much as cooking is desirable for pigeon pea palatability, longer cooking times leads to more energy consumption, inconveniences and less desirability for processors and consumers (Wood, 2017). KAT60/8 and Mituki varieties that exhibited very short cooking times generate energy savings could be commercially viable and accepted in the production chain. Longer cooking time is associated with high costs of production and reduced nutritional value especially grain protein (Fasoyiro *et al.*, 2005). Factors like humidity and longer storage periods under high temperatures during retail or at farm levels may also result in longer cooking times by causing hard-to-cook phenomenon (Soltani *et al.*, 2021). We can conclude that variety of the improved pigeon pea greatly influences cooking time.

KAT60/8 variety recorded the highest total soluble solids in broth at 26.67% compared to Egerton Mbaazi 1 variety which had 10.5% TSS<sub>b</sub>. However, there was no significant difference in the TSS<sub>b</sub> of ICEAP 00850, KARI Mbaazi 2, Egerton Mbaazi 2, and Mituki pigeon peas varieties. High content of soluble solids in broth was characterized by solids leaching into the boiling water as a result of highly permeable grain seed coat. Leaching contributes to nutrient loss in the cooked grains. Various studies have reported loss of water-soluble nutrients leading to reduced chemical composition (Biyama *et al.*, 2020; Muroki *et al.*, 2023; Syeunda *et al.*, 2021). Carbohydrates are easily hydrolysed and diffused into the cooking broth as it is water soluble (Farinde *et al.*, 2018). Additionally, during cooking mono and disaccharides which are

low molecular weight carbohydrates are diffused into the cooking water thus significantly reducing the carbohydrate content in the grain (Bamigboye & Adepoju, 2015). Through crystallinity loss, granule water absorption, and the loss of intermolecular interactions, the starch portion transforms into native granules, resulting in increased polymer mobility within amorphous areas. (Ratnayake and Jackson, 2007). The total solids diffused into the water increase the solution concentration that influence water absorption (Soltani *et al.*, 2021; Waraich *et al.*, 2011). On the contrary, solute leakage is likely to reduce the affinity of water and its capacity to retain solutes according to osmotic principles. Previous studies have reported that total solids loss through leaching into broth water increased with temperature increase between 20 and 50<sup>0</sup> C but remained constant 70 and 100<sup>0</sup>C which is within the boiling point of water (Sayar *et al.*, 2011). In this study the solid loss content was not taken into consideration, thus if solid contents were added to the seed mass, the behaviour would have been different.

**Table 4.2:** Effect of variety on water absorption capacity, cooking time and total soluble solids

Variety	WACBC(%)	WACAC (%)	50%CT (mins)	80%CT (mins)	TSS <sub>b</sub> (%)
<b>Egerton Mbaazi 1</b>	121.04±0.64 <sup>bc</sup>	135.40±1.43 <sup>cd</sup>	110.52±1.30 <sup>d</sup>	114.15±0.87 <sup>c</sup>	10.53±0.04 <sup>e</sup>
<b>KARI Mbaazi 1</b>	118.47±0.35 <sup>c</sup>	130.84±0.13 <sup>e</sup>	150.14±1.32 <sup>b</sup>	160.21±0.77 <sup>a</sup>	14.10±0.76 <sup>d</sup>
<b>MITUKI</b>	123.49±0.19 <sup>ab</sup>	144.24±0.64 <sup>b</sup>	44.62±4.22 <sup>h</sup>	46.00±1.76 <sup>g</sup>	15.65±0.50 <sup>c</sup>
<b>KAT60/8</b>	125.06±0.10 <sup>a</sup>	157.50±0.33 <sup>a</sup>	57.35±3.18 <sup>g</sup>	55.70±2.19 <sup>f</sup>	26.67±0.32 <sup>a</sup>
<b>Egerton Mbaazi 2</b>	121.54±2.26 <sup>bc</sup>	154.66±1.29 <sup>a</sup>	121.63±1.90 <sup>c</sup>	128.03±0.37 <sup>b</sup>	15.48±0.31 <sup>c</sup>
<b>KARI Mbaazi 2</b>	115.06±1.23 <sup>d</sup>	137.22±2.28 <sup>c</sup>	89.27±0.69 <sup>e</sup>	90.73±0.29 <sup>d</sup>	15.22±0.26 <sup>cd</sup>
<b>ICEAP 00850</b>	123.99±0.26 <sup>ab</sup>	133.98±2.57 <sup>d</sup>	157.50±1.71 <sup>a</sup>	160.13±1.58 <sup>a</sup>	14.41±0.02 <sup>cd</sup>
<b>ICEAP 00554</b>	125.48±0.26 <sup>a</sup>	141.46±2.61 <sup>b</sup>	70.42±0.91 <sup>f</sup>	78.79±0.90 <sup>e</sup>	17.33±0.05 <sup>b</sup>

Tukey's honestly significant difference (HSD). Values along the column followed by different superscript letter notations are significantly different ( $p \leq 0.05$ ). The values are mean  $\pm$  standard error. WACBC- Water Absorption Capacity Before Cooking; WACAC- Water Absorption Capacity After Cooking; CT- Cooking Time; TSS<sub>b</sub>- Total Soluble Solids in broth.

#### 4.3.3 Effect of cooking on technological properties of improved pigeon pea varieties

Table 4.3 presents the effect of cooking on the technological properties of pigeon peas, such as volumetric expansion, density, and water absorption. The average volumetric expansion significantly ( $p < 0.05$ ) increased in all pigeon pea varieties tested after cooking. The volumetric expansion of raw pigeon pea grains ranged from 57.5-64% while that of cooked grains from 61.1-68.4%. The highest percentage volumetric expansion after cooking was observed in KARI Mbaazi 2 (11%), KAT60/8 (10%), Mituki (9.6%) and KARI Mbaazi 1 (8.9%). The Egerton Mbaazi 1 and ICEAP 00850 varieties recorded the lowest percentage volumetric expansion at 4.3% ( $p = 0.0207$ ) and 3.8% ( $p = 0.0001$ ) respectively. There was no significant difference ( $p > 0.05$ ) among the pigeon peas varieties tested in terms of raw grain density. There was a significant general reduction ( $p < 0.05$ ) in densities of pigeon pea grains after cooking. ICEAP 00554 and Mituki grain varieties had the highest percentage density reduction at 19.3% and 17.6% respectively. However, ICEAP 00850 variety recorded the lowest percentage decrease of 7.4%. There was a significant increase ( $p < 0.05$ ) in the water absorption capacity among all the assayed pigeon peas varieties. KARI Mbaazi 2, KAT60/8, ICEAP 00554 and Mituki varieties recorded higher percentages in water absorption capacities at 27.3%, 25.9%, 19.3% and 16.8% respectively.

**Table 4.3:** Effect of cooking on technological properties of improved pigeon pea varieties

Variety		Volumetric expansion	Density	Water Absorption
<b>Egerton Mbaazi 1</b>	Cooked	63.34 (62.60-64.08)	1.06 (1.00-1.12)	135.4 (129.26-141.54)
	Raw	60.71 (57.76-63.67)	1.26 (1.19-1.33)	121.04 (118.3-123.79)
	<i>t</i> -value	3.71	-9.72	9.19
	<b>p-value</b>	<b>0.0207</b>	<b>0.0006</b>	<b>0.0008</b>
<b>KARI Mbaazi 1</b>	Cooked	63.64 (63.64-63.64)	1.10 (1.07-1.12)	130.84 (130.27-131.42)
	Raw	58.95 (56.33-61.56)	1.27 (1.23- 1.31)	118.47 (116.96-119.99)
	<i>t</i> -value	7.72	-15.47	32.83
	<b>p-value</b>	<b>0.0015</b>	<b>0.0001</b>	<b>&lt;0.0001</b>
<b>Mituki</b>	Cooked	67.33 (65.68-68.99)	1.07 (1.07-1.08)	144.24 (141.5-146.99)
	Raw	61.44 (60.29-62.59)	1.30 (1.23-1.37)	123.49 (122.67-124.30)
	<i>t</i> -value	12.56	-13.04	31.23
	<b>p-value</b>	<b>0.0002</b>	<b>0.0002</b>	<b>&lt;0.0001</b>
<b>KAT60/8</b>	Cooked	66.03 (64.43-67.62)	1.07 (1.05-1.20)	157.50 (156.09-158.91)
	Raw	60.02 (55.35-64.70)	1.25 (1.10-1.41)	125.06 (124.61-125.51)
	<i>t</i> -value	5.23	-4.94	94.24
	<b>p-value</b>	<b>0.0064</b>	<b>0.0220</b>	<b>&lt;0.0001</b>
<b>KARI Mbaazi 2</b>	Cooked	63.81 (61.90-65.73)	1.10 (1.07- 1.13)	137.22 (127.41-147.04)
	Raw	57.48 (54.83-60.12)	1.24 (1.22-1.27)	115.06 (109.76-120.37)
	<i>t</i> -value	8.36	-16.95	8.55

	<b>p-value</b>	<b>0.0011</b>	<b>&lt;0.0001</b>	<b>0.0010</b>
<b>ICEAP 00554</b>	Cooked	68.38 (67.44-69.31)	1.09 (1.05-1.13)	141.46 (130.25-152.67)
	Raw	63.96 (63.15-64.77)	1.35 (1.34-1.36)	125.48 (124.35-126.62)
	<i>t</i> -value	15.41	-25.15	6.10
	<b>p-value</b>	<b>0.0001</b>	<b>&lt;0.0001</b>	<b>0.0037</b>
<b>Egerton Mbaazi</b>	Cooked	64.13 (61.43-66.83)	1.11 (1.08-1.13)	154.66 (149.13-160.19)
<b>2</b>	Raw	59.70 (54.23-65.17)	1.27 (1.13-1.40)	121.54 (111.82-131.25)
	<i>t</i> -value	3.12	-5.15	12.75
	<b>p-value</b>	<b>0.0354</b>	<b>0.0067</b>	<b>0.0002</b>
<b>ICEAP 00850</b>	Cooked	61.07 (56.16-55.98)	1.12 (1.08-1.15)	133.98 (122.93-145.03)
	Raw	58.80 (54.68-62.93)	1.21 (1.14-1.28)	123.99 (122.86-125.11)
	<i>t</i> -value	1.52	-5.04	3.87
	<b>p-value</b>	<b>0.2035</b>	<b>0.0073</b>	<b>0.0180</b>

**Key:** Paired sample t-test. Values are means (95% Confidence Interval)

#### 4.3.4 The relationship between different technological properties

The relationship between different technological properties is presented in Table 4.4 below. The correlation analysis showed significant strong positive relationship ( $r = 0.76$ ) between VEBC and VEAC. The results suggest that a unit increase in volumetric expansion before cooking or volumetric expansion after cooking would bring about a unit increment of either factor by 76%. There was also a very strong positive correlation ( $r = 0.89$ ) between volumetric expansion before cooking and dry/raw grain density signifying that for every increase in either VEBC or D/RgD would result in increase of either factor by 89%. The high correlation noted among the traits (VEBC, VEAC, D/RgD, CT, WACAC and TSS) of the assayed pigeon peas conveys how choosing one trait influence the expression of another. VEBC also had a positive relationship ( $r = 0.44$ ) with WACBC which was however a weak correlation. The increase in the VEBC or water absorption capacity before cooking would result into 44% increase in both variables. VEAC also had a notably positive relationship ( $r=0.82$ ) with D/RgD, an indication that any increment in VEAC or D/RgD would cause a rise of up to 82% in either factor. VEAC had a weak positive relationship ( $r =0.44$ ) with WACAC. The values mean that an increase in VEAC or WACAC would lead to a 44% increment in both factors. The findings of this study suggests that soaking influence water availability which reduces cooking time by facilitating gelatinization of starch during cooking (Waraich *et al.*, 2011).

On the other hand, there was a strong negative correlation ( $r = -0.76$ ) between VEAC and cooking time. The value implies that a unit increase in either VEAC or cooking time would lead to a 76% decrease in either component. Assuming all factors are kept constant, the grain volume and size affected cooking time as observed in this study. This is because both heat and moisture will take longer to infiltrate and thermally convert a sizeable mass thereby, a substantial radius to the centre of the grain. Previous studies have reported most pulses with large volumes taking longer time to cook as long as they do not have un-hydratable defects (Wood *et al.*, 2014). Before volumetric expansion, the pigeon pea grain is relatively homogeneous and compact and comprise of intercellular middle lamella, protein bodies, starch granules and clearly demarcated cells with comparatively reduced intracellular matrix (Sreerama *et al.*, 2009).

Furthermore, a significant strong negative correlation was noted between cooking time and total soluble solids. This means that an increment in cooking time or total soluble solids would result in 0.54 decrease in either component. Similarly, a study carried out by Narasimha and

Desikachar (1978) on 16 Indian pigeon pea varieties recorded a significant negative relationship ( $r=-0.98$ ) between total solids and cooking time.

#### **4.3.5 Logistic regression odds ratio estimates for technological properties**

There was no significant difference ( $p>0.05$ ) in water absorption, density, and volumetric expansion among the tested improved pigeon peas varieties (Table 4.5). However, water absorption was insignificantly high in Egerton Mbaazi 2 variety in reference to Variety ICEAP 00554. Pigeon peas proteins play a crucial role in determining the level of hydration during water absorption by forming hydrogen bonds with water attributed to their hydrophilic nature (Perina *et al.*, 2014). The porous, amorphous, and loosely attached cotyledon allows for more water imbibement. Cooking influence various physico-chemical changes in pigeon pea seeds including protein denaturation, starch gelatinization, polysaccharides solubilisation, cementing material found in the cotyledon and softening and breakdown of the middle lamella (Wani *et al.*, 2013). The cooking quality of the pigeon pea varieties were likely affected by seed composition, seed characteristics, cultivar, growing environment, cotyledon characteristics, size and weight which influenced WAC, density, and volumetric expansion on thermal treatment.

Despite the insignificant increment ( $p>0.05$ ) in volumetric expansion among the improved pigeon peas varieties tested, KAT 60/8 variety recorded the highest volume change. The relationship between volumetric expansion and water absorption capacity of the improved pigeon peas varieties are linear within the varieties. Sayar *et al.* (2016) indicated that volumetric expansion with increase in water absorption can be explained by water absorption by starch and proteins. They further reported a linear relationship between water absorption capacities and proteins of eight different varieties of legumes and cereals (Ratkovic & Pissis, 1997). This implies that increase in volume during absorption of water is closely related to protein part of the grain expansion. Variation in volumetric expansion coefficient is likely affected by mechanisms such as leaching soluble solids from grain, starch and proteins during cooking (Sayar *et al.*, 2016).

**Table 4.4:** Correlation coefficients of interaction between technological properties of pigeon peas varieties before and after cooking

	<b>VEBC</b>	<b>VEAC</b>	<b>D/RgD</b>	<b>SgD</b>	<b>CgD</b>	<b>WACBC</b>	<b>WACAC</b>	<b>CT</b>	<b>TSS</b>
<b>VEBC</b>	1.000	<b>0.764**</b>	<b>0.886**</b>	-0.129 <sup>ns</sup>	-0.257 <sup>ns</sup>	<b>0.439*</b>	0.188 <sup>ns</sup>	-0.0386 <sup>ns</sup>	0.102 <sup>ns</sup>
<b>VEAC</b>		1.000	<b>0.816**</b>	-0.026 <sup>ns</sup>	-0.364 <sup>ns</sup>	0.305 <sup>ns</sup>	<b>0.443*</b>	<b>-0.764**</b>	<b>0.416*</b>
<b>D/RgD</b>			1.000	0.053 <sup>ns</sup>	-0.168 <sup>ns</sup>	0.141 <sup>ns</sup>	0.102 <sup>ns</sup>	-0.379 <sup>ns</sup>	0.068 <sup>ns</sup>
<b>SgD</b>				1.000	<b>0.516**</b>	-0.056 <sup>ns</sup>	-0.182 <sup>ns</sup>	0.262 <sup>ns</sup>	-0.167 <sup>ns</sup>
<b>CgD</b>					1.000	-0.050 <sup>ns</sup>	-0.183 <sup>ns</sup>	<b>0.522**</b>	-0.068 <sup>ns</sup>
<b>WACBC</b>						1.000	0.376 <sup>ns</sup>	-0.0287 <sup>ns</sup>	<b>0.419*</b>
<b>WACAC</b>							1.000	<b>-0.0532**</b>	<b>0.698**</b>
<b>CT</b>								1.000	<b>-0.538**</b>
<b>TSS</b>									1.000

Values are correlation coefficients significant ns-not significant, \*Correlation is significant at the 0.05 level; \*\*Correlation is significant at the 0.01 level. VEBC- Volumetric Expansion Before Cooking; VEAC- Volumetric Expansion After Cooking; D/RgD- dry/raw grain density; SgD- Grain Density After Soaking; CgD- Grain Density After Cooking; WACBC- Water Absorption Capacity Before Cooking; WACAC- Water Absorption Capacity After Cooking; CT- Cooking Time; TSS- Total Soluble Solids.

**Table 4.5:** Logistic regression odds ratio estimates

Effect	Variety	Technological properties		
		Water Absorption	Volumetric expansion	Density
Raw vs. Egerton	PE	0.992 <sup>ns</sup>	0.978 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked Mbaazi 1	CL	0.813- 1.210	0.736-1.299	0.104- 9.614
Raw vs. Egerton	PE	1.131 <sup>ns</sup>	1.010 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked Mbaazi 2	CL	0.930- 1.375	0.760- 1.342	0.104- 9.614
Raw vs. ICEAP	PE	0.961 <sup>ns</sup>	0.974 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked 00850	CL	0.788- 1.171	0.731-1.297	0.104- 9.614
Raw vs. KARI	PE	0.982 <sup>ns</sup>	1.006 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked Mbaazi 1	CL	0.804- 1.199	0.756- 1.338	0.104- 9.614
Raw vs. KARI	PE	1.062 <sup>ns</sup>	1.035 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked Mbaazi 2	CL	0.870- 1.296	0.778-1.377	0.104- 9.614
Raw vs. KAT 60/8	PE	1.119 <sup>ns</sup>	1.025 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked	CL	0.921- 1.359	0.772-1.360	0.104- 9.614
Raw vs. MITUKI	PE	1.040 <sup>ns</sup>	1.029 <sup>ns</sup>	1.000 <sup>ns</sup>
Cooked	CL	0.855- 1.266	0.776-1.363	0.104- 9.614

Variety ICEAP 00554 is in reference category; PE-Point Estimate; CL- 95% Wald Confidence Limits; \*\*\*- Significance at  $p<0.0001$ ; \*- Significance at  $p<0.05$ ; ns- Not significant

#### **4.4 Conclusions**

The study demonstrates that cooking and soaking significantly increase volumetric expansion while decreasing density. Cooking time emerges as a critical factor in pigeon pea preparation, with longer durations being costly and time-consuming, thereby constraining pigeon pea utilization. Additionally, all varieties exhibited high total soluble solids, suggesting the potential to select varieties with desired flavour profiles. Improved pigeon pea varieties, including Mituki and KAT60/8, displayed favourable technological properties alongside the control (ICEAP 00554) variety, offering insights into culinary applications and nutritional requirements that enhance pigeon pea utilization. Further research is warranted to assess the impact of these technological properties on pigeon pea digestibility and glycemic index.

**CHAPTER FIVE**  
**SENSORY EVALUATION OF IMPROVED PIGEON PEAS (*Cajanus cajan*)**  
**VARIETIES**

**Abstract**

Pigeon peas is a pulse mostly consumed in the Eastern parts of Kenya in complementary with cereals. The variety and quality of cooked pigeon peas influence their sensory characteristics thus affect consumer acceptability. The objective of the study was to conduct descriptive sensory and consumer acceptability of six improved pigeon pea varieties (Egerton Mbaazi 1, Egerton Mbaazi 2, KAT 60/8, Mituki and KARI Mbaazi 1) and ICEAP 00554 as control variety. Consumer acceptability was scored on a 7-point hedonic scale where 1=dislike extremely to 7=like extremely. Descriptive sensory properties were grouped into appearance, flavour and texture descriptors on a scale of 1-9. The experiment was conducted at Egerton University, Department of Food Science laboratories, arranged in a Completely Randomized Design (CRD). Data was analysed using on PROC GLM procedure of the statistical analysis systems (SAS) version 9.1.3. Analysis of variance (ANOVA) was conducted at 95% confidence level. Tukey's honestly significant difference (HSD) was utilized to establish the differences among means. There was significant difference ( $p < 0.05$ ) in the descriptive mean scores of aroma, astringency, aftertaste, particle residue and stickiness among all the improved pigeon peas varieties. The Principle Component Analysis explained a total variation of 58.8% in improved pigeon pea varieties. KARI Mbaazi 1 variety was least preferred in terms of colour, flavour, texture and taste hence ranked poorly in terms of acceptability. Egerton Mbaazi 2 was highly ranked for colour, taste while KAT60/8 variety was ranked highest in flavour and texture. Egerton Mbaazi 2 variety (5.88) was highly ranked for general acceptability while KARI Mbaazi 1 variety (4.50) was the least preferred. Improving cultivars is essential to enhance the utilization and adoption of pigeon peas, thereby making significant contributions to food security and the livelihoods of communities engaged in pigeon pea cultivation. The study therefore recommends that sensory attributes should be embraced during breeding to augment pigeon pea consumption, marketing, and production.

**5.1 Introduction**

Pigeon peas, an underutilized pulse grown in arid and semi-arid regions of Eastern Kenya, play a crucial role in providing both food security and income in areas with marginal rainfall (Fasoyiro *et al.*, 2010; Satya *et al.*, 2010). Pigeon peas are rich in proteins, dietary fibre, and minerals, pigeon pea varieties offer nutritional benefits comparable to those of groundnuts

(Fasoyiro *et al.*, 2010; Saxena *et al.*, 2010). However, their consumption is hindered by antinutritional factors such as trypsin tannins, phytic acid,  $\alpha$ -galactosides, and phenols, as well as the hard-to-cook phenomenon (Fasoyiro *et al.*, 2010). Thermal treatments like roasting and cooking are commonly employed to reduce these antinutrients (Gujral *et al.*, 2013).

Dehulling and cooking are major preparation methods that not only improve the nutritional value and palatability of pigeon peas but also reduce cooking time (Fasoyiro *et al.*, 2005). Other techniques like soaking and fermentation positively influence grain texture and protein qualities, while also saving cooking time and fuel (Fasoyiro *et al.*, 2005). Despite being favoured by low-income households for its taste and affordability, processing methods like cooking can significantly reduce the nutritional content of pigeon peas.

Understanding consumer preferences is crucial for the development and acceptance of food products (Lawless & Heymann, 2010). However, previous sensory analyses focused mainly on morphological traits of raw pigeon pea seeds, which were not reliable indicators of cooking quality (Mkanda *et al.*, 2007). Factors influencing cooking quality, such as seed composition, variety, growing location, and seed characteristics, interact with genetic factors, leading to diverse cooking qualities and affecting acceptability (Wani *et al.*, 2014; Yeung, 2007).

Considering the limited data on sensory characteristics of improved pigeon pea cultivars in Eastern Kenya, there is a need for comprehensive studies to understand their unique sensory properties and consumer preferences (Armelim *et al.*, 2006; Mkanda *et al.*, 2007). Therefore, this study aims to conduct descriptive sensory analysis and assess consumer acceptability of six pigeon pea varieties grown in Machakos county, Kenya.

## **5.2 Materials and methods**

Six ( $n = 6$ ) improved pigeon pea varieties were purposively sourced from the Kenya Agricultural and Livestock Research Organization (KALRO) Katumani Research Centre, Machakos County ( $1^{\circ} 35' S$ ,  $37^{\circ} 14' E$ ), and Egerton University, Njoro ( $0^{\circ} 22' S$ ,  $35^{\circ} 55' E$ ). The samples were packaged in polythene bags and transported to the food chemistry laboratory at Egerton University. Preparation of the pigeon pea samples was followed by descriptive and consumer sensory evaluations, which were carried out in the sensory evaluation room at the Guildford Institute, Department of Dairy, Food Science and Technology, Egerton University.

### **5.3 Preparation of pigeon pea grains for sensory analyses**

Matured dried pigeon pea grains varieties were cooked according to the determined cooking times in this study. The dried improved pigeon pea varieties were Egerton Mbaazi 1, KAT 60/8, Egerton Mbaazi 2, Mituki, KARI Mbaazi 1, and ICEAP 00554 (control). The samples from each variety (200g) were soaked in distilled water for 16hrs at 20°C. The soaking water was discarded, and the pigeon peas grain were cooked in open pots at temperatures of 93.5°C (the boiling temperature of water in Njoro) until soft.

### **5.4 Descriptive sensory evaluation of improved pigeon peas varieties**

#### ***a) Recruitment and screening of the panellists***

Participants from the Department of Dairy and Food Science and Technology at Egerton University, including students and staff, were recruited for the descriptive sensory evaluation of cooked improved pigeon pea varieties. Selection criteria included availability, willingness to consume pigeon peas, regular intake of the legume, prior involvement in descriptive sensory assessments, and absence of allergies. Panelists' sensory sharpness was evaluated through basic taste identification and triangle discrimination tests (Meilgaard *et al.*, 2007). Invitations were extended via email and telephone to join the sensory assessments. Among the 30 individuals who expressed interest, 15 attended an orientation session, underwent screening, and provided informed consent to proceed. The screening process employed conventional protocols to gauge panelists' proficiency in discerning key sensory characteristics, such as flavor, taste, and appearance, across various cooked pigeon pea cultivars (Tamayo & Tamayo, 2020). Additionally, a lexicon was developed to define the flavor, texture, and visual attributes of the evaluated improved varieties. The final panel comprised eight women and seven men, ranging in age from 19 to 41 years.

#### ***b) Training of the panellists***

The selected panelists underwent three days of training, with daily two-hour sessions conducted in accordance with the generic descriptive analysis method (Einstein, 1991). Throughout these sessions, the pigeon pea varieties were repeatedly presented and discussed to ensure consistent interpretation among panelists. Scale anchors and a standardized lexicon for each descriptor were collaboratively developed, clearly defined, and finalized by the panel (Table 5.1).

#### ***c) Descriptive sensory evaluation protocol***

The pigeon pea varieties were presented in disposable white plastic plates. The descriptive sensory evaluation was performed in individual booths within the sensory laboratory of the Department of Dairy and Food Science and Technology, Egerton University. Each panellist

received six cooked pigeon pea samples across three successive phases, with a five-minute interval between phases. A glass of water was provided to each panellist for palate cleansing before and between samples. Cooked samples were coded, randomized, and served at 40–50 °C. Panellists rated the intensity of sensory attributes using twelve descriptors grouped into appearance, flavour, and texture categories, as defined in the lexicon (Table 5.1). A detailed sensory evaluation form is included in Appendix 2. Intensity was scored on a 1–9 scale. To mitigate carryover effects, a two-minute pause was enforced between samples. Evaluations were replicated across three sessions conducted on consecutive days (Byarugaba *et al.*, 2020).

**Table 5.1:** Lexicons for descriptive sensory evaluation developed by sensory panel to evaluate cooked pigeon peas

<b>Attribute</b>	<b>Definition</b>	<b>Reference</b>	<b>Rating scale</b>
<b>Appearance</b>			
Colour	The intensity of colour ranges from light brown to dark brown.	1- Light like envelope or colour of carton 9- Dark brown like chocolate, roasted coffee beans	1-Light brown 9-Dark brown
Consistency	The extent of visual uniformity of the pigeon pea skin	1- dotted skin 9- uniform skin	1-Dotted 9-Uniform colour
Surface appearance	The degree of the shininess of the surface of the pigeon pea because of boiling.	1- the skin of green bananas 9- green banana leaf	1-Dull 9-Glossy/ Shiny
Size uniformity	How uniform the pigeon pea seeds are in terms of size	1- the skin of green bananas 9- green banana leaf	1-Uneven sizes 9-Even sizes
<b>Flavour</b>			
Aroma	Intensity of aroma typical of boiled pigeon peas	1- Strange aroma 9- natural aroma of cooked pigeon peas	1-Least Intense 9-Very Intense
Sugary	The degree of sweetness associated with table sugar.	1- blunt taste 9- sweet taste	1-Least Intense 9- Very Intense
Aftertaste	how long the after-taste lasts/lingers in the mouth.	1- taste of cooked pigeon peas 9- aftertaste of raw pigeon peas	1-Least intense 9-Very Intense

Astringency	The extent of puckering/shrinking of or drying sensation on the surface and/or edges of the lips, tongue, and mouth	1- unfermented porridge 9- <i>mkwaju</i> , concentrated tea leaves	1-Least intense 9-Very Intense
Texture			
Dryness	The amount of saliva required when chewing	1- freshly baked bread crumb 9- roasted groundnuts	1-Least dry 9-Very dry
Cohesiveness	The extent of how particles tend to agglomerate/stay together during chewing	1- crumbled sample during and after chewing 9- compactness of the sample during and after chewing	1-Crumble 9-Compact
Particles	The quantity of particles left in the mouth	1- absence of particles in the mouth during chewing 9- residues in the mouth during chewing	1-Least 9-Many
Stickiness	The degree to which residues adhere to the teeth during and/or after chewing.	1- no or little residue after chewing 9- residues in the mouth during chewing	1-Less sticky 9 -Highly sticky

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## 5.5 Determination of consumer acceptability of cooked pigeon peas varieties

In-house consumer testing was performed in accordance with the guidelines of IFT (2007) within the Department of Dairy and Food Science and Technology, Egerton University. Pigeon pea varieties were assigned unique codes and served on white plastic plates. A panel of 40 semi-trained participants (17 females and 23 males) evaluated the samples between 11:00–12:00 and 15:00–16:00, assessing flavour, texture, colour, taste, and overall acceptability. Panellists were directed to cleanse their palates with water between samples. Ratings were recorded on a 7-point hedonic scale: 7 = like extremely, 6 = like moderately, 5 = like slightly, 4 = neither like nor dislike, 3 = dislike slightly, 2 = dislike moderately, and 1 = dislike extremely (Lawless & Heymann, 2013). Participants received standardized instructions and adequate time to score each attribute using the provided score sheets (Appendices). All evaluations were conducted at ambient temperature under white illumination.

## 5.6 Experimental design and statistical analysis

A Completely Randomized Design (CRD) was used with the following statistical model:

$$Y_{ij} = \mu + \bar{u}_i + \epsilon_{ij} \quad (19)$$

Where;  $Y_{ij}$  = the observation of the dependent variable of consumer and descriptive sensory properties,  $\mu$  = Overall mean responses,  $\bar{u}_i$  = The effect of  $i^{\text{th}}$  variety and  $\epsilon_{ij}$  = Random error component.

Analysis of variance (ANOVA) was performed to assess statistical significance at a 95% confidence level ( $\alpha = 0.05$ ). Tukey's honestly significant difference (HSD) test was used for mean separation. Data are presented as mean  $\pm$  standard error from three independent replicates. Principal component analysis (PCA) was further employed to profile descriptive sensory attributes, in accordance with Selvaraj *et al.* (2023).

## 5.7 Results and discussion

### 5.7.1 Descriptive sensory analysis

The results of the descriptive sensory evaluation of six cooked improved pigeon pea varieties are presented in Table 5.2. The attributes were grouped into appearance, flavour, and texture. The properties varied significantly among the varieties ( $p < 0.05$ ). Previous study reported that dark pigmented legumes are less preferred as they are linked to hard to cook phenomenon thus require more fuel and energy to cook (Erfatpour & Pauls, 2020). Flavour properties are generally a mixture of aroma and taste (Roland *et al.*, 2017). Also, off-flavour components are present in the legumes thus are inherently produced post harvesting.

### **a) Appearance**

There was no significant difference ( $p>0.05$ ) in the brownness of pigeon peas of Egerton Mbaazi 1, Mituki and Egerton Mbaazi 1 varieties which demonstrated the highest mean score of 6.9, 5.9, 5.2 respectively (Table 5.2). The highest mean score for colour uniformity was demonstrated by Egerton Mbaazi 2 variety which was not significantly different from Mituki, KAT 60/8 and ICEAP 00554 varieties. Colour is an inherent genetic trait and ranges between light pigmentation to dark pigmentation (Saxena *et al.*, 2010). Pigmentation has been linked to free polyphenols concentration (the higher the concentration the darker the pigmentation) and condensed tannins which would explain astringency property in pigeon peas (Awika *et al.*, 2003). The polyphenols contents are reduced by conversion to low molecular components by polyphenol oxidase which is an inherent hydrolytic enzyme (Hejazi & Orsat, 2016). KAT 60/8 (5.48) and Egerton Mbaazi 2 (6.05) varieties were glossier when cooked and were significantly different ( $p<0.05$ ) from other remaining improved varieties. Egerton Mbaazi 1 variety was the duller of all the varieties though was not significantly different from KARI Mbaazi 1 variety. The most even pigeon peas seed size were observed in ICEAP 00554, Egerton Mbaazi 2 and Mituki varieties. However, Egerton Mbaazi 1 had the most uneven seed sizes. The physical attributes such as colour, texture and grain size are vital in the determination of pigeon during the cooking pea acceptability and their acceptability (Schoeninger *et al.*, 2017).

### **b) Flavour**

There was no significant difference ( $p>0.05$ ) in the aroma intensity among all the assayed improved pigeon peas varieties (Table 5.2). However, the intensity of aroma typical of boiled pigeon peas was more intense in Egerton Mbaazi 1 (5.91) variety as a result of volatile compounds but least intense in ICEAP 00554 (5.03) variety. Flavour denotes taste, odour and mouthfeel sensations and boosts eating delight. The aroma attributes in pigeon peas may be due to chemical, enzymatic and non-enzymatic reactions (Mishra *et al.*, 2019). Studies concerning other legumes have associated cooking with a carbonyl 1 compound reaction with amino acid through Strecker degradation process thus forming aroma components like volatile compounds, aldehydes and ketones (Chigwedere *et al.*, 2019). The sweetness was observed to be more intense in ICEAP 00554 (4.5) variety but less in Egerton Mbaazi 1 (3.37) variety. Taste is crucial in food identification, and acceptance. Legumes contain sucrose sugar which is broken down into fructose and glucose during cooking resulting into sweet taste of pigeon peas (Mkanda, 2007). Sucrose also influences starch gelatinization when thermally treated. The extent of puckering or shrinking of the tongue was not significantly ( $p>0.05$ ) different among

the improved pigeon peas varieties tested. However, the puckering sensation was highly intense in the Mituki variety (5.06) and least in KAT 80/6 variety (4.52). This sensation is attributed to phenolic compound interaction with salivary proteins and is dependent on structure and type of the phenolic component (Huang & Xu, 2021). There was no significant difference ( $p > 0.05$ ) in the aftertaste scores for all the improved pigeon peas varieties tested.

### c) *Texture*

There was no significant difference ( $p > 0.05$ ) in the level of dryness of KARI Mbaazi 1, Egerton Mbaazi 1 and ICEAP 00554 varieties when chewed as in table 5.2. However, KARI Mbaazi 1 (5.24) variety was less dryer compared to Egerton Mbaazi 2 (3.87) variety which recorded the lowest mean scores. There was no significant difference ( $p > 0.05$ ) in the cohesiveness of Mituki, KAT 60/8, Egerton Mbaazi 2 and ICEAP 00554 varieties. During mastication the particles of Egerton Mbaazi 2 variety (5.47) were more compact recording highest scores compared to KARI Mbaazi 1 variety (3.56) particles which were the crumbliest of the pigeon peas tested. The compactness was attributed to the moisture properties of the food item being consumed. KARI Mbaazi 1 variety (4.76) variety had the most residues left after chewing while Egerton Mbaazi 2 variety (3.94) had the least residues. However, there was no significant difference ( $p > 0.05$ ) in the particle residues of all the improved pigeon peas varieties tested. Residues in the mouth could have been attributed to peeling pigeon pea skin and tougher seed coats (Mwangwela *et al.*, 2021). The tougher the seed coat the longer disintegration time during mastication. Texture is greatly affected by the seed coat integrity as hard cell walls influence water absorption and starch dispersion during the cooking process thus forming hard texture (Chen *et al.*, 2015; Schoeninger *et al.*, 2017). ICEAP 00554 (4.68) variety was the stickiest (the extent to which residues adhere to teeth during or after chewing) while Egerton Mbaazi 2 variety (3.93) was less sticky. However, there was no significant difference ( $p > 0.05$ ) in the stickiness of the different pigeon peas varieties assayed. Longer storage time for pigeon peas in the retailing stores in high humidity, little exposure to sunlight and high temperatures may result in hard texture in some pigeon peas varieties (Schoeninger *et al.*, 2017).

**Table 5.2:** Appearance, texture and flavour attribute scores for the different cooked improved pigeon pea varieties

Variety	Egerton Mbaazi 1	KARI Mbaazi 1	MITUKI	KAT 60/8	Egerton Mbaazi 2	ICEAP 00554
<b>Brownness</b>	6.10±0.44 <sup>a</sup>	5.90±0.32 <sup>ab</sup>	5.18±0.28 <sup>abc</sup>	0.21±0.40 <sup>cd</sup>	3.97±0.40 <sup>d</sup>	4.94±0.35 <sup>bcd</sup>
<b>Colour uniformity</b>	4.10±0.44 <sup>c</sup>	4.43±0.37 <sup>bc</sup>	5.19±0.38 <sup>ab</sup>	5.86±0.27 <sup>a</sup>	6.00±0.29 <sup>a</sup>	5.40±0.30 <sup>a</sup>
<b>Glossiness</b>	3.59±0.37 <sup>d</sup>	4.27±0.37 <sup>dc</sup>	4.64±0.34 <sup>bc</sup>	5.48±0.34 <sup>ab</sup>	6.05±0.31 <sup>a</sup>	4.94±0.30 <sup>bc</sup>
<b>Size Uniformity</b>	4.87±0.45 <sup>cd</sup>	4.70±0.45 <sup>d</sup>	5.86±0.34 <sup>ab</sup>	5.07±0.33 <sup>bcd</sup>	6.18±0.32 <sup>a</sup>	5.72±0.31 <sup>abc</sup>
<b>Aroma</b>	5.91±0.30 <sup>a</sup>	5.45±0.32 <sup>a</sup>	5.56±0.34 <sup>a</sup>	5.15±0.32 <sup>a</sup>	5.34±0.30 <sup>a</sup>	5.03±0.40 <sup>a</sup>
<b>Sweetness</b>	3.37±0.31 <sup>b</sup>	3.76±0.36 <sup>ab</sup>	4.20±0.38 <sup>a</sup>	4.06±0.35 <sup>ab</sup>	4.04±0.45 <sup>ab</sup>	4.50±0.41 <sup>a</sup>
<b>Astringency</b>	3.22±0.40 <sup>a</sup>	3.32±0.32 <sup>a</sup>	3.35±0.33 <sup>a</sup>	3.12±0.31 <sup>a</sup>	3.43±0.39 <sup>a</sup>	3.40±0.34 <sup>a</sup>
<b>Aftertaste</b>	4.80±0.29 <sup>a</sup>	4.89±0.23 <sup>a</sup>	5.06±0.25 <sup>a</sup>	4.52±0.25 <sup>a</sup>	4.69±0.31 <sup>a</sup>	5.01±0.30 <sup>a</sup>
<b>Dryness</b>	4.74±0.37 <sup>abc</sup>	5.24±0.29 <sup>a</sup>	4.10±0.28 <sup>cd</sup>	4.17±0.36 <sup>bcd</sup>	3.87±0.40 <sup>d</sup>	4.97±0.30 <sup>ab</sup>
<b>Cohesiveness</b>	4.22±0.33 <sup>bc</sup>	3.56±0.32 <sup>c</sup>	4.99±0.30 <sup>ab</sup>	5.29±0.32 <sup>a</sup>	5.47±0.35 <sup>a</sup>	4.70±0.36 <sup>ab</sup>
<b>Particle residue</b>	4.27±0.39 <sup>a</sup>	4.76±0.38 <sup>a</sup>	4.13±0.34 <sup>a</sup>	4.00±0.33 <sup>a</sup>	3.94±0.38 <sup>a</sup>	4.26±0.40 <sup>a</sup>
<b>Stickiness</b>	4.49±0.39 <sup>a</sup>	4.63±0.39 <sup>a</sup>	4.39±0.39 <sup>a</sup>	4.65±0.41 <sup>a</sup>	3.93±0.38 <sup>a</sup>	4.68±0.40 <sup>a</sup>

Values are means of triplicate determinations and are presented as mean± SE. Mean ratings of bean varieties with different letters along the row differed significantly ( $p < 0.05$ )

### 5.7.2 Principal component analysis

The descriptive sensory data was further analysed using a multivariate data analysis design (Principal Components Analysis) to define the influential parameters and systematic variations in cooked improved pigeon pea properties. The principal components (PCs) were obtained to outline the interpretation of the assayed cooked improved pigeon peas varieties by their sensory attributes (Table 5.3). The three principal components explained a total variation of 58.8% in improved pigeon pea samples. The outcome indicated that the first, second and third principal components accounted for 25.8%, 19.7% and 13.3% of the total variation respectively. These results did not have a huge difference from previous studies that reported a total variation of 58.94% for common beans (Muroki *et al.*, 2023) and 63% for yellow beans Bassett *et al.*, 2021.

The relationship between the descriptive properties and PCs is demonstrated by factor loading of rotated varimax (Table 5.3). The sensory attributes and correlation loading plot for assayed pigeon peas showed that the most predominant sensory characteristics that the customers will use to judge the improved pigeon peas include aroma, dryness, particle residue in the mouth, astringency, and size uniformity. The loadings of original responses on PC1, PC2, and PC3 are summarised in Figure 5.1. The measurements in proximity are classified and have positive correlation while measurements that are far apart represent loadings that have negative correlation (180° apart) and opposite to one another (Bassett *et al.*, 2021). Principle component 1 was strongly and positively correlated to astringency, particle residue in the mouth and dryness hence fundamentally measuring the organoleptic characteristics intensification in the assayed pigeon peas.

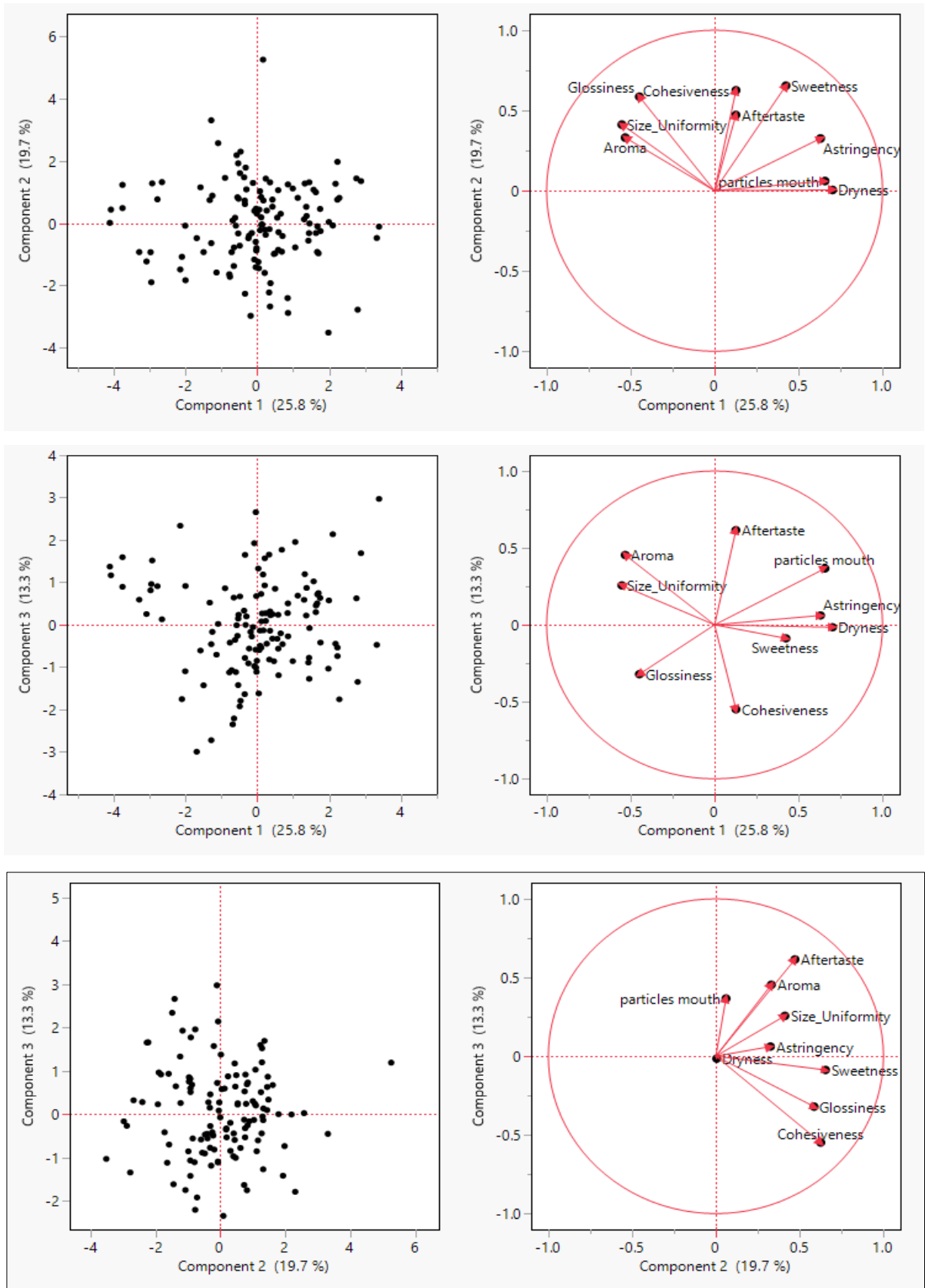
Astringency has been recognised in natural foods including most pulses and is associated with flavour active components known as free phenolic compounds (Jaeger *et al.*, 2015). In contrast, the second PC was negatively correlated to aroma and size uniformity. Principle factor 2 was characterised by glossiness, sweetness and cohesiveness and showed positive correlation. The third PC was characterised by aftertaste and demonstrated strong positive correlation. Apart from taste and aroma, other factors like metallic, pungent (spicy), fatty, astringency (rough, dry) and cool also influence perception of flavour (Lesschaeve & Noble, 2005).

Astringency is caused by lubrication loss in the mouth as a result of interaction between mucins and salivary proteins with non-volatile components in the mouth (Gibbins & Carpenter, 2013). Off flavours may also occur in pigeon peas caused by volatile compounds inherent along the value chain (processing, harvesting or storage). Oxidation of unsaturated fatty acids and

enzymatic reactions have been reported as the main generator of the volatile compounds. Previous studies have linked pea off flavour to amalgamation of different groups of volatile organic compounds including alcohols, 3-alkyl-2-methoxypyrazines, ketones, sulphur containing compounds, aromatic, aldehydes and aliphatic hydrocarbons (Sessa & Rackis, 1977). Flavour is also affected by the textural properties such as hardness, coarseness, smoothness and thickness. Other factors affecting flavour include growing location, cultivar, storage conditions, crop year, market class and species (Malcolmson *et al.*, 2014). Pigeon pea varieties contain saponin which is responsible for bitterness (Heng *et al.*, 2006). Cyanidin and anthocyanidins delphinidin phenols have been associated with colour (blue, purple and red), however, they do not cause off flavours in the peas (Troszynska *et al.*, 2006).

**Table 5.3:** Varimax rotated principal component factor loading for sensory attributes of improved pigeon peas varieties

Sensory attribute	Principle component scores		
	Factor 1	Factor 2	Factor 3
Glossiness	-	0.58594	-
Size Uniformity	-0.55195	-	-
Aroma	-0.53189	-	-
Sweetness	-	0.65437	-
Astringency	0.63016	-	-
Aftertaste	-	-	0.61501
Dryness	0.70206	-	-
Cohesiveness	-	0.62558	-
particles mouth	0.65703	-	-
Proportion of the total variance	<b>25.8%</b>	<b>19.7%</b>	<b>13.3%</b>
Total		<b>58.94%</b>	



**Figure 5. 1:** Biplot of The Loading Factor and Vectors of Principle Components 1, 2 and 3

### 5.7.3 Consumer acceptability

The consumer liking of different pigeon pea genotypes was carried out and presented in Table 5.4 below. There was no noticeable distinction ( $p > 0.05$ ) between the Egerton Mbaazi 2 variety and the KAT 60/8 variety regarding colour. Colour is the most important characteristic in evaluating the overall quality of a food product as it largely affects consumer preference of various products. Colour of pigeon peas is characterised by either darker or lighter seed pigmentation; thus consumers' preference is influenced by pigment intensity in the pigeon pea. There was no significant difference ( $p > 0.05$ ) in the flavour liking of Mituki, Egerton Mbaazi 2, Egerton Mbaazi 1, KAT60/8 varieties in reference to ICEAP 00554 (control).

The flavour characteristics of KARI Mbaazi 1 variety was the least ranked while that of KAT60/8 variety was highly ranked. Flavour of cooked pigeon pea grains is formed through chemical reactions they undergo during cooking. Heterocyclic compounds, aldehydes, sulphur compound, ketones and alcohols form the major flavour compounds in this case (Khrisanapant *et al.*, 2019). The texture liking of Egerton Mbaazi 1 and KARI Mbaazi 1 varieties were significantly different ( $p < 0.05$ ) from other varieties. However, Mituki, KAT 60/8, Egerton Mbaazi 2 varieties were not significantly different ( $p > 0.05$ ) in terms of taste ratings with reference to ICEAP 00554. Muhimbula *et al.* (2011) reported taste as a major parameter for determining food sensory properties and consumer preference. Sometimes, consumers may find a food product visually appealing but may reject the product if the aroma and taste are not appealing. A previous study by Mkanda *et al.* (2007) on other legumes (beans) reported bitter taste in dark striped beans making them unpalatable, which resulted into low consumer preference. The bitterness was attributed to high concentrations of condensed tannins mostly found on the seed coats which is a common occurrence in legumes (Karolkowski *et al.*, 2023).

There was no significance difference ( $p > 0.05$ ) in the general acceptability of Egerton Mbaazi 2, KAT60/8 and Mituki varieties. KARI Mbaazi 1 variety was least preferred in terms of colour, flavour, texture and taste hence ranked poorly in terms of acceptability. Egerton Mbaazi 2 variety was highly ranked for colour, taste while KAT60/8 variety was ranked highest in flavour and texture. Egerton Mbaazi 2 variety (5.88) was highly ranked for general acceptability while KARI Mbaazi 1 variety (4.50) was the least liked. Consumer acceptability of pigeon peas may be influenced by contamination by heavy metals, darkening reactions, pigment degradation which may interfere with attributes like final colour of cooked pigeon peas (Güzel & Sayar, 2012). The visual appeal of any food product is highly influential in the products consumer preference (Karolkowski *et al.*, 2023).

**Table 5.4:** Consumer acceptability of improved pigeon peas varieties grown in Machakos County

Variety	Colour	Flavour	Texture	Taste	General acceptability
<b>Egerton Mbaazi 1</b>	4.70±0.23 <sup>d</sup>	4.93±0.23 <sup>ab</sup>	4.63±0.21 <sup>b</sup>	4.73±0.25 <sup>cd</sup>	4.75±0.24 <sup>c</sup>
<b>KARI Mbaazi 1</b>	4.55±0.26 <sup>cd</sup>	4.53±0.22 <sup>b</sup>	4.38±0.24 <sup>b</sup>	4.68±0.25 <sup>d</sup>	4.50±0.25 <sup>c</sup>
<b>MITUKI</b>	5.28±0.16 <sup>cb</sup>	5.20±0.19 <sup>a</sup>	5.40±0.17 <sup>a</sup>	5.35±0.21 <sup>abc</sup>	5.35±0.17 <sup>ab</sup>
<b>KAT60/8</b>	5.75±0.18 <sup>ab</sup>	5.55±0.19 <sup>a</sup>	5.73±0.19 <sup>a</sup>	5.65±0.17 <sup>ab</sup>	5.60±0.16 <sup>a</sup>
<b>Egerton Mbaazi 2</b>	5.90±0.16 <sup>a</sup>	5.53±0.18 <sup>a</sup>	5.40±0.18 <sup>a</sup>	5.80±0.21 <sup>a</sup>	5.88±0.18 <sup>a</sup>
<b>ICEAP 00554</b>	4.88±0.16 <sup>cd</sup>	5.18±0.21 <sup>a</sup>	5.25±0.22 <sup>a</sup>	5.10±0.20 <sup>cbd</sup>	5.00±0.19 <sup>bc</sup>

Values are means presented as mean ± SE. Mean ratings of bean varieties (along the column) with different letters differed significantly ( $p < 0.05$ )

### 5.8 Conclusions

Sensory evaluation is important in determining consumer preference. Pigeon peas have proven to be a suitable legume in curbing food insecurity and improving livelihoods of communities that depend on the drought resistant crop. Egerton Mbaazi 2 and KAT 60/8 improved varieties scored highly on the consumer preference compared to ICEAP 00554 variety which was the benchmark variety. This implies that there is a possibility to introduce and adopt the improved pigeon peas varieties as they have great nutritional and agricultural characteristics that are acceptable to farmers and consumers. The multiple attributes of sensory characteristics (palatability, texture, appearance, flavour) should be embraced during breeding to augment pigeon pea consumption, marketing, and production.

## CHAPTER SIX

### GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

#### 6.1 Study rationale

Food insecurity, malnutrition, and climate variability remain persistent challenges in Kenya's arid and semi-arid lands (ASALs), where millions are affected by seasonal drought, poor agricultural productivity, and limited access to nutritious foods (FAO, 2021; FEWS NET, 2022). To address these issues, pigeon pea (*Cajanus cajan*), a drought-resilient pulse, offers immense potential due to its adaptability, low production cost, and nutritional richness, particularly in protein, iron, zinc, and phosphorus (Adepoju *et al.*, 2019; Kachare *et al.*, 2019). Despite the introduction of improved pigeon pea varieties with enhanced agronomic traits, limited information exists regarding their nutritional composition, technological and sensory properties which are essential for consumer acceptance, value addition, and dietary diversification (Gichohi-Wainaina *et al.*, 2022; Ojwang *et al.*, 2021). Additionally, consumption is hindered by antinutritional factors (ANFs) such as tannins, phytates, and total phenolics, which interfere with mineral bioavailability (Komarnytsky *et al.*, 2011). Cooking can mitigate these effects but may also lead to nutrient losses. Therefore, this study was designed to evaluate the nutritional, technological, and sensory characteristics of improved pigeon pea varieties grown in Machakos County. The findings are intended to inform breeding programs, guide product development, and promote sustainable utilization of pigeon peas in Kenya's ASAL regions.

#### 6.2 Critical analysis of the methodology

The study was conducted in three phases aligned with its objectives: (i) nutritional and antinutritional composition analysis, (ii) evaluation of technological properties, and (iii) sensory evaluation. A completely randomized design (CRD) was used for all experimental setups. Statistical analysis was conducted using PROC GLM procedures of SAS version 9.1.3, and significance was tested at the 95% confidence level using ANOVA followed by Tukey's HSD for mean separation.

Standard analytical methods were adopted for determining proximate composition (AOAC, 2005), antinutrients, and minerals using appropriate spectroscopic and titrimetric techniques. Technological assessments such as cooking time, water absorption, and volumetric expansion were performed using validated procedures adopted from Perina *et al.* (2014) and Wang & Daun, (2005) while sensory evaluation involved both descriptive analysis and consumer

acceptability based on IFT (2007) protocol. Principal Component Analysis (PCA) was used to interpret sensory data.

## **6.3 General discussion**

### **6.3.1 Nutritional and antinutritional composition**

Improved pigeon pea varieties showed significantly higher nutritional quality compared to the control variety ICEAP 00554. Protein content ranged from 24.52% to 31.16%, suggesting that the improved varieties are excellent sources of plant-based protein. Crude fibre, ash, and carbohydrate contents also varied significantly, supporting their dietary utility and satiety value. Cooking led to decrease protein and ash levels likely due to protein denaturation and nutrient leaching (Eltayeb *et al.*, 2010).

Mineral content was notably high, especially for phosphorus (2191.06–2909.00 ppm), iron (143.45–367.25 ppm), and zinc (54.26–74.31 ppm). Although cooking caused some loss, mineral retention remained adequate for dietary benefit. These findings are in agreement with previous reports on nutrient losses during cooking and the benefits of preserving cooking water (Adepoju *et al.*, 2010).

Antinutrients such as tannins, phytates, and total free phenolics were significantly reduced upon cooking, with tannins showing the highest reduction (up to 57.6% in Egerton Mbaazi 2). ICEAP 00554 consistently recorded the highest ANF levels and lowest mineral content, emphasizing the nutritional improvement achieved through breeding.

### **6.3.2 Technological properties**

The technological performance of pigeon pea varieties varied widely. ICEAP 00554 showed the highest volumetric expansion before cooking, but KARI Mbaazi 2 exhibited the greatest post-cooking expansion. Cooking time was shortest for Mituki and KAT60/8, making them more suitable for domestic and industrial use where fuel efficiency is critical. Water absorption and grain density were also influenced by soaking and cooking, supporting their role in softening and reducing the "hard-to-cook" phenomenon (Theologidou *et al.*, 2018). Total soluble solids in broth correlated with expansion and density changes, influencing both taste and nutritional concentration.

### **6.3.3 Sensory characteristics**

Sensory evaluation revealed clear consumer preferences. Egerton Mbaazi 2 and KAT60/8 scored highest in attributes such as aroma, texture, particle residue, and overall acceptability as compared to control variety (ICEAP 00554). PCA explained 58.8% of the variability in sensory

traits, confirming that genetic differences among varieties significantly influence consumer perception. These results emphasize the need to integrate sensory quality into breeding programs, alongside agronomic and nutritional traits.

#### **6.4 Conclusions**

- i. The improved pigeon pea varieties evaluated in this study demonstrated superior nutritional profiles compared to the control variety, particularly in terms of protein content and essential minerals such as iron, zinc, and phosphorus. Cooking had a dual effect, it enhanced the fibre content and significantly reduced antinutritional factors like tannins, phytates, and phenolics, thereby improving nutrient bioavailability. However, thermal processing also resulted in partial losses of protein and some minerals due to leaching and denaturation.
- ii. Varietal differences had a significant influence on technological properties, including water absorption capacity, cooking time, and volumetric expansion, all of which are important for household and industrial applications.
- iii. Sensory evaluation results revealed that Egerton Mbaazi 2 and KAT60/8 were most preferred by consumers, owing to their enhanced flavour, desirable texture, and overall acceptability.

#### **6.5 Recommendations**

- i. Breeding programs should prioritize both nutritional enhancement and sensory traits to ensure consumer adoption of improved pigeon pea varieties.
- ii. Soaking and other cooking pre-treatments should be promoted at household and industrial levels to reduce cooking time and antinutritional factors.
- iii. Stakeholders should scale up production and marketing of improved varieties like Egerton Mbaazi 2 and KAT60/8 to address food and nutrition insecurity.
- iv. Government and NGOs should support pigeon pea integration in school feeding and community nutrition programs to boost protein intake in ASALs.

#### **6.6 Further research**

- i. In vivo studies are needed to assess bioavailability of iron and zinc in cooked pigeon peas.
- ii. Investigate the impact of alternative cooking techniques (e.g., pressure cooking, fermentation, steaming) on nutrient retention and acceptability.
- iii. Explore consumer acceptability of pigeon pea-based value-added products (e.g., flours, snacks, and protein concentrates).

- iv. Develop breeding lines with reduced antinutritional content and optimized sensory attributes for targeted markets.

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**APPENDICES**

**Appendix I: Consumer acceptability score card**

**Sensory panel recruitment form**

I..... have voluntarily agreed to take part in this study. I understand that I will not directly benefit from this study. I have had the study explained to me and I understand that it entails sensory evaluation of pigeon peas. My participation in this study involves tasting of the boiled pigeon peas and profiling the predetermined sensory properties according to my perception against the standards. I confirm that I am not allergic to product and do not have any issue consuming any of the ingredients contained in food product. I understand that the results will be kept for 3 months after the date of examination and will be treated confidentially. My identity will remain anonymous after the study and this will be done by coding my details.

.....  
Signature of participant

.....  
Date

.....  
Signature of researcher

**Score sheet for sensory analysis**

Panellist code..... Name of Panellist.....  
Date.....

**Instructions:**

You are provided with coded samples. You are required to score and record each sample as per your judgement of the attributes listed on the left side of the table in the appropriate box. You can score 7 = like extremely, 6 = like moderately, 5 = like slightly, 4 = neither like nor dislike, 3 = dislike slightly, 2 = dislike moderately, 1= dislike extremely.

Attribute	Sensory Scale	Sample Codes
<b>Colour</b>	(7= Like extremely to 1= Dislike extremely)	

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<b>Flavour</b>	(7= Like extremely to 1= Dislike extremely)
<b>Texture</b>	(7= Like extremely to 1= Dislike ex tremely)
<b>Taste</b>	(7= Like extremely to 1= Dislike extremely)
<b>General Acceptability</b>	(7= Like extremely to 1= Dislike extremely)
<b>Comments (if any)</b>	

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**Appendix II: Descriptive analysis score card**

**Panellist number** .....

**Date** .....

**Gender:** .....

**Instructions:**

You are provided with 6 coded samples of boiled pigeon peas. You are required to rate each of them as per the threshold of the attributes listed on top of the table in the appropriate box base on a 9-point scale.

**Note:**

- **Please rinse your mouth before starting and also in between when evaluating the samples.**
- **Evaluate the pigeon peas in front of you by looking at it, feeling it and tasting it.**
- **Assign an appropriate score (with 1 being the least and 9 being the very) for each of the listed parameters/components.**

**Pigeon pea specific evaluation**

## APPEARANCE

Colour: Degree of Brownness


Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9
TEW	1 _____ • _____ 9
ABC	1 _____ • _____ 9 Light brown <span style="float: right;">Dark brown</span>

Light like envelope or colour of carton


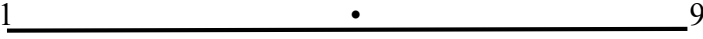

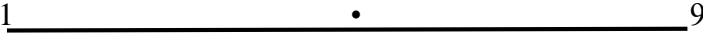


Dark brown like chocolate, roasted coffee beans

Consistency: Degree of visual uniformity of the sample colour






Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9
TEW	1 _____ • _____ 9

ABC	
	Dotted <span style="float: right;">Uniform colour</span>

Surface appearance: Degree of glossiness

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	
CSR	
KWC	
FGD	
TEW	
ABC	 Dull <span style="float: right;">Shiny/Glossy</span>

**Size: Uniformity of size**

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	
CSR	
KWC	
FGD	
TEW	

ABC	1 _____ 4.5 _____ 9 Uneven sizes <span style="float: right;">Even sizes</span>
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**FLAVOUR**

Aroma: aroma associated with boiled pigeon peas

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9
TEW	1 _____ • _____ 9
ABC	1 _____ • _____ 9 Least Intense <span style="float: right;">Very Intense</span>

Sugary: Degree of sweetness associated with table sugar.

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9

TEW	1 _____ • _____ 9
ABC	1 _____ • _____ 9
	Least Intense <span style="float: right;">Very Intense</span>

Astringency: causes puckering/shrinking of the tongue surface.

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9
TEW	1 _____ • _____ 9
ABC	1 _____ • _____ 9
	Least intense <span style="float: right;">Very intense</span>

Very intense like mkwaju, concentrated tea leaves

Aftertaste: how long the after-taste lasts/lingers in the mouth.

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9

FGD	1 _____ 9 •
TEW	1 _____ 9 •
ABC	1 _____ 9 •
	Least intense <span style="float: right;">Very Intense</span>

**TEXTURE**

Dryness: amount of saliva required when chewing

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ 9 •
CSR	1 _____ 9 •
KWC	1 _____ 9 •
FGD	1 _____ 9 •
TEW	1 _____ 9 •
ABC	1 _____ 9 •
	Least dry <span style="float: right;">Very dry</span>

Cohesiveness: how particles tend to agglomerate/stay together during chewing

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ 9 •
CSR	1 _____ 9 •

KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9
TEW	1 _____ • _____ 9
ABC	1 _____ • _____ 9
	Least cohesive <span style="float: right;">Very Cohesive</span>

Particles: quantity of particles left in the mouth

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9
KWC	1 _____ • _____ 9
FGD	1 _____ • _____ 9
TEW	1 _____ • _____ 9
ABC	1 _____ • _____ 9
	Least <span style="float: right;">Many</span>

Stickiness: degree to which residues stick to the teeth.

Sample Code	Please mark the point of score on the score by a slash (/). Midpoint of the line is shown by the dot (•)
DPU	1 _____ • _____ 9
CSR	1 _____ • _____ 9

KWC	1 _____ 9	•
FGD	1 _____ 9	•
TEW	1 _____ 9	•
ABC	1 _____ 9	•
	Least sticky	Very Sticky
General	Comments:	
_____		
_____		
_____		
_____		

**Appendix III. Selected pigeon pea varieties and their characteristics for use in the research study from KALRO-Katumani and Egerton University**

Variety	Characteristics
<b>KARI Mbaazi 1</b>	This is a short duration (Matures in 105-120 days) pigeon pea variety. It is either short or tall when grown at higher altitudes. The plant is compact, normally grown as a sole crop, flowers in 55-70 days and has medium seed weight of 10-12 g/100seeds. The yield potential is 1000 kg/ha or 4.4 bags/acre in one season and 2000 kg/ha or 8.9 bags/acre in two seasons and gives 2- 3 harvests in a year
<b>KARI Mbaazi 2</b>	KARI Mbaazi 2 is a long duration variety which matures in 180-270 days. It is planted in the short rain season (October-November). It mainly a one season variety. It is high yielding with potential grain yield of 1300 kg/ha or 5.8 bags/acre. The plant is taller and stronger at lower altitudes (less than 1000 m) than at higher altitudes. The variety flowers in 60-90 days and has large pod and seed size (18-20 g/100 seeds).

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<b>KAT 60/8</b>	This is a medium duration (Matures in 136-150 days) pigeon pea variety. It is short when grown at high altitudes and tall at lower altitudes. The plant is also compact and is normally grown as a sole crop. It flowers in 95-120 days and the grains are white in colour with brown spots and smaller than long duration local landraces (Tunyai). The yield potential ranges from 1200-1500 kg/ha or 5-7 bags/acre in one season and 3000 kg/ha or 13 bags/acre in two seasons. It has a spreading growth habit and flowering is indeterminate. This allows multiple harvests where soil moisture is adequate. It is susceptible to insect pests mainly pod sucking bugs and pod borers.
<b>MITUKI</b>	This is a medium duration pigeon pea variety which matures in 125-135 days. It can therefore be harvested twice in a year. It has high grain yield (1700 - 3500 kg /ha or 7.5 – 15.6 bags/acre in two seasons) and large pod size thus easy to shell and also large grain size (19 g/100 seeds) (Figure 10). It is rich in iron (70 ppm), tolerant to fusarium wilt and has good ratooning ability
<b>Egerton Mbaazi 1 (EUMDPV0010 4)</b>	This genotype is recommended for low to medium-dry altitude zones (800-1500 m.a.s.l) of Marigat, Machakos, Kerio valley, Kambi ya Mawe, Coastal areas, Mbeere, Kitui, Mwea, Kisumu. Takes approximately 4-5 months to mature. High grain yield of 1.4-2.8 tons /ha. It is resistant to drought, Fusarium wilt and pests. It is Cream in grain colour.
<b>Egerton Mbaazi 2</b>	This genotype is recommended for low to medium-dry altitude zones (800-1600) m.a.s.l Examples: Baringo and Kerio valley. Takes 120-150 Day to mature yielding 1.5-2 tons/ha. It has medium seed size, adaptable to sandy clay soil and loamy soil and medium maturing with good ratoon ability
<b>ICEAP 000554</b>	This is a long duration pigeon pea variety that takes 6-8 months to mature. It grows in medium-dry altitude zones (900-1700) m.a.s.l. it has low yielding of 0.7-0.9 tons/ha. It is also less resistant to pests and diseases with poor ratoon ability.
<b>ICEAP 00850</b>	This is a medium-maturing pigeon pea variety developed by ICRISAT for drought-prone regions. It matures in about 140 days, with flowering occurring around day 118. The variety performs well at altitudes of

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1,000–1,800 meters above sea level, and prefers well-drained sandy loam to loamy soils with a pH of 5.5–7.0. It is sensitive to waterlogging but tolerates drought and resists common diseases like Fusarium wilt and sterility mosaic disease. Yield potential ranges between 1.0–2.3 tonnes per hectare.

Source: Esilaba *et al.*, (2021).

#### Appendix IV: Loading matrix

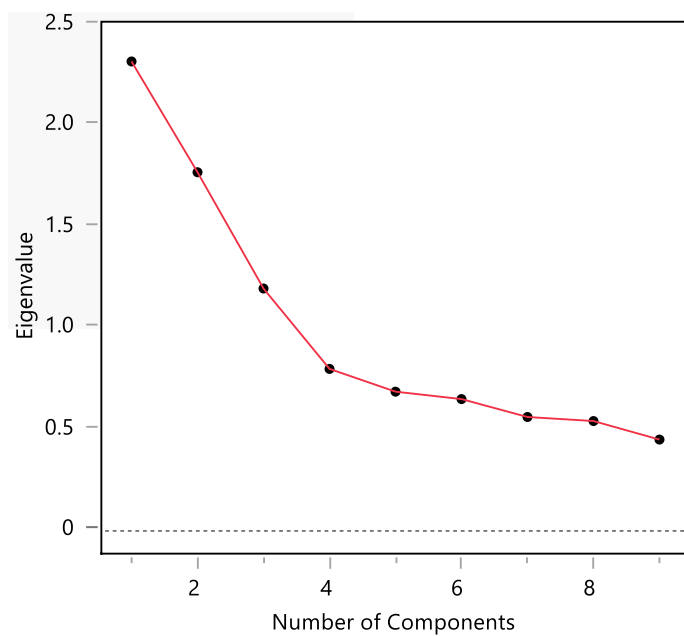
	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9
<b>Glossiness</b>	-	<b>0.585</b>	-	-	0.176	-	-	0.346	0.268
	<b>0.447</b>	<b>94</b>	0.320	0.155	87	0.192	0.262	82	05
	<b>66</b>		37	18		34	96		
<b>Size</b>	-	<b>0.411</b>	0.256	0.110	0.110	<b>0.628</b>	-	0.022	-
<b>Uniformity</b>	<b>0.551</b>	<b>80</b>	36	11	11	<b>09</b>	0.150	30	0.135
	<b>95</b>						27		04
<b>Aroma</b>	-	0.330	<b>0.453</b>	0.355	-	-	<b>0.458</b>	0.084	0.136
	<b>0.531</b>	82	<b>90</b>	83	0.001	0.196	<b>88</b>	84	13
	<b>89</b>				99	78			
<b>Sweetness</b>	<b>0.424</b>	<b>0.654</b>	-	0.207	-	0.061	-	-	0.289
	<b>46</b>	<b>37</b>	0.087	42	0.300	47	0.113	<b>0.387</b>	57
			52		21		99	<b>56</b>	
<b>Astringency</b>	<b>0.630</b>	0.325	0.061	<b>0.517</b>	0.090	-	-	0.215	-
	<b>16</b>	49	31	<b>99</b>	68	0.186	0.205	89	0.305
						17	39		29
<b>Aftertaste</b>	0.126	<b>0.471</b>	<b>0.615</b>	-	0.168	-	-	-	-
	70	<b>97</b>	<b>01</b>	<b>0.469</b>	09	0.245	0.097	0.201	0.152
				<b>70</b>		90	71	68	94
<b>Dryness</b>	<b>0.702</b>	0.004	-	0.014	<b>0.619</b>	0.193	0.191	-	0.221
	<b>06</b>	80	0.015	75	<b>13</b>	22	04	0.018	69
			40					39	
<b>Cohesiveness</b>	0.127	<b>0.625</b>	-	-	-	0.067	<b>0.393</b>	0.020	-
	45	<b>58</b>	<b>0.548</b>	0.224	0.066	62	<b>64</b>	16	0.277
			<b>41</b>	52	70				25

<b>particles</b>	<b>0.657</b>	0.060	0.366	-	-	0.203	0.075	<b>0.421</b>	0.131
<b>mouth</b>	<b>03</b>	55	50	0.237	0.362	98	07	<b>66</b>	51
				61	67				

### Appendix V: Eigenvalue of improved pigeon peas

Eigenvalue	Percent		Cum Percent
<b>2.322082</b>	25.800908		25.800908
<b>1.774284</b>	19.714268		45.515176
<b>1.199350</b>	13.326113		58.841289
<b>0.801869</b>	8.909661		67.750950
<b>0.689313</b>	7.659030		75.409979
<b>0.652626</b>	7.251400		82.661379
<b>0.564099</b>	6.267766		88.929145
<b>0.544003</b>	6.044482		94.973627
<b>0.452374</b>	5.026373		100.00000

### Appendix VI: Scree plot



**Appendix VII: ANOVA table for proximate analysis**

Source of variation	D F	Moisture	Fibre	Ash	Protein	Fat	Carbohydrates	Energy
Variety	5	1.8431 <sup>*</sup> **	1.0035 <sup>*</sup> **	0.9199 <sup>*</sup> **	19.6158 <sup>*</sup> **	0.2312 <sup>*</sup> **	24.4646 <sup>***</sup>	42.9640 **
Rep	2	0.1054	0.0051	0.0048	0.0400	0.0015	0.1873	8.3308
Error	10	0.0359	0.0206	0.0427	0.1672	0.0216	0.1351	5.1030
R <sup>2</sup>	-	0.9633	0.9606	0.9152	0.9832	0.8429	0.9891	0.8194
C.V	-	1.9003	1.8169	4.5677	1.5233	9.5634	0.7439	0.7085

**Appendix VIII: ANOVA table for antinutrients and minerals**

Source of variation	D F	Tannins	Phytates	Total Free Phenolics	Iron	Calcium	Zinc	Phosphorus
Variety	5	0.2143 ***	5.3696 ***	0.0816 ***	26498.869 4 <sup>***</sup>	30465.201 4 <sup>***</sup>	162.107 6 <sup>***</sup>	106366.830 9 <sup>***</sup>
Rep	2	0.0000 4	0.0368	0.0000	5.9800	31.2017	1.1485	101.1883
Error	10	0.0002	0.0211	0.0000	28.8013	49.9731	0.2256	10763.1220
R <sup>2</sup>	-	0.9983	0.9922	0.9992	0.9978	0.9967	0.9972	0.8965
C.V	-	2.4051	1.3952	1.4477	2.5008	1.8574	0.7694	4.0741

**Appendix IX: ANOVA table for Technological Properties**


Sou rce of vari atio n	D f	VEB C	VEA C	D/R gD	SgD	CgD	WAC BC	WAC AC	50% CT	80% CT	TSS
Vari ety	7	11.6 332*	16.92 41**	0.0 050	0.00 05**	0.00 11*	38.10 43**	283.31 04***	5260.6 258***	5785.4 564***	65.34 02**
		*	*	*	*	*	*				*
Rep	2	0.56 55	0.366 4	0.0 000	0.00 07	0.00 00	0.014 79	47.594 6	0.1593	0.2045	0.145 1
Erro r	1 4	2.08 08	0.913 8	0.0 014	0.00 01	0.00 21	3.141 4	2.9756	16.755 8	5.4431	0.449 1
R <sup>2</sup>	-	0.73 92	0.903 1	0.6 495	0.84 31	0.73 08	0.858 5	0.9804	0.9937	0.9981	0.986 5
C.V	-	2.39 89	1.477 1	2.9 073	0.74 64	1.32 69	1.455 6	1.2156	4.0861	2.2387	4.143 1

# Appendix X: Research permit

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## Appendix XI: Publication abstract

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### Technological Properties of Improved Pigeon Pea Varieties in Machakos County, Kenya

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#### Abstract

Pigeon peas, a type of pulse, have immense nutritional potential to improve health in arid and semi-arid regions. However, unlocking this potential relies heavily on understanding their technological properties, such as hydration rate, volumetric expansion, and cooking time. These properties directly influence processing, accessibility, and acceptability as a food source. However, there is limited information on technological properties of improved varieties. The study aimed to determine technological properties of improved pigeon pea varieties grown in Machakos County. Seven improved pigeon pea varieties namely: KARI Mbaazi 1, KARI Mbaazi 2, ICEAP 00850, KAT 60/8, Mituki, Egerton Mbaazi 1, Egerton Mbaazi 2 and ICEAP 00554 (control variety) were used in this study. These varieties were tested for water absorption capacity (WAC), volumetric expansion, density, cooking time (CT) and total soluble solids (TSS) in the broth. The experiment was arranged in a Completely Randomized Design (CRD) replicated three times. Data analysis was conducted using SAS software version 9.1.3 (SAS, 2006). Means separation was done using Tukey's honestly significant difference (HSD) at 95% Confidence Level. There were significant differences in water absorption capacity (WAC), volumetric expansion, density, TSS, and CT among the improved varieties ( $p < 0.05$ ). The control variety, ICEAP 00554, demonstrated the highest volumetric expansion before cooking (VEBC) at 64%, significantly surpassing the other varieties ( $p < 0.05$ ). KARI Mbaazi 2 exhibited the greatest volumetric expansion after cooking (VEAC) at 11%. Additionally, control variety recorded the highest water absorption capacity (125.48%), which was significantly greater compared to the improved pigeon pea varieties. Cooking time in minutes was shortest for Mituki (46.0) and KAT 60/8 (55.7) and longest for both KARI Mbaazi 1 and ICEAP00850 at 160 minutes. All the varieties showed high TSS ranging from 10.5 to 26.7% indicating the potential to select varieties with desired flavour profiles. Improved pigeon pea varieties (Mituki and KAT60/8) displayed desired technological properties alongside the control variety. These findings inform the specific culinary applications and nutritional needs which enhance utilisation of pigeon peas as food. Further research is needed to determine the impact of the technological properties on the digestibility and glycaemic index of pigeon peas.

#### Keywords

Pigeon Peas, Improved Variety, Technological Property