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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 peas 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

1. Introduction

Pigeon pea (*Cajanus cajan*) is one of the most predominant pulses in tropical and sub-tropical countries in the world [1]. Pigeon pea grain is endowed with proteins and dietary minerals [2], it is also rich in carbohydrates, fibre and fat content [3]-[6]. Research has demonstrated that pigeon pea grain has a similar nutritional composition to other well-known legumes [7]. Therefore, they can be used as an alternative food and feed supply for different environmental conditions. Households consume pigeon peas to complement cereals due to their high amino acid profile after dehulling [8]. Dehulling improves protein and cooking quality, digestibility, and palatability of the pigeon pea grain. Physical factors such as size and wholesomeness of the seed and cotyledon split influence the cooking time and utilization [9].

Pigeon pea grains possess a hard to cook phenomenon which means longer cooking time thus limiting their consumption [10]. The phenomenon is caused by the seed coat, which is low in nutrients, high in fibre with low digestibility [11]. To ensure sensory quality, cooking characteristics are the primary commercial criterion [12] [13]. Cooking time measurement is therefore a major quality factor in evaluating the acceptability and utilization of pigeon peas. Hydration or soaking of grains is a process of grain processing that influences the cooking time and nutrient extraction efficiency [14]. The grains can be soaked before cooking or cooked directly before soaking. These 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 [15]. Volumetric expansion and linear swelling of the pigeon pea seed are vital attributes for the design and analysis of dehulling 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 antinutrient factors in the pigeon peas, minimizing the food safety incidents related to hard-to-cook phenomenon.

Various breeding programs have been put in place to supply farmers with improved cultivar varieties that are pest and disease tolerant, have higher grain yield and with acceptable colour, shape and sheen [16]. 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 [17]. Starch gelatinization is determined by temperature, moisture and shear which affects the starch functionality and digestion in the body [18].

Therefore, in order to enhance the acceptability and utilization of pigeon peas, it is worthwhile to investigate technological, functional, physical, and nutritional properties of different pigeon peas varieties to determine their suitability [19].

When new varieties of pigeon peas are developed, either to improve nutritional content or agronomic culture, it is also important to evaluate their technological characteristics prior to their introduction either to consumers or processors. Information pertaining the technological aspects of improved pigeon pea varieties are scanty. Therefore, this study aimed at analysing the technological attributes (water absorption capacity, volumetric expansion, density, total solids and cooking time) of improved pigeon peas varieties produced in Machakos County, Kenya.

2. Methodology

2.1. Description of Study Location and Sample Selection

The study materials were collected from the Kenya Agricultural and Livestock Organization (KALRO), Katumani Research Centre in Machakos County. Machakos County is located in the Eastern Region of Kenya, bordering Nairobi and Kiambu counties to the west, and lies along coordinates of 1˚35'S and 37˚14'E. In contrast, Egerton University is located in Njoro sub-county, Nakuru County, and lies along coordinates of 0˚22'11.0"S and 35˚55'58.0"E. The laboratory analyses were conducted in Egerton University at the Guildford Dairy Institute and Food Chemistry Laboratory both in the Department of Dairy and Food Science and Technology. Other analyses were done at the University of Nairobi, Department of Food Science Nutrition and Technology. Seven improved pigeon peas varieties namely: KARI Mbaazi 1, KARI Mbaazi 2, ICEAP 00850, KAT/60/8 and Mituki were sourced from KALRO-Katumani, while Egerton Mbaazi 1, Egerton Mbaazi 2 and ICEAP 00554 (control variety) were collected from Egerton University.

2.2. Preparation of Pigeon Pea Grains for Technological Analyses

The different varieties of dried mature pigeon pea grains (200g) were prepared according to method described by Biama *et al.* [20]. The samples were first mixed separately and sieved with sieves with holes (5.16 × 19.05 mm), and visibly damaged grains from insects or mechanical processes were removed before analysis. After selection, the grains were stored in airtight plastic containers and kept in a refrigerator at a stable temperature below 10°C prior to technological analyses.

2.3. Technological Properties

2.3.1. Water Absorption Capacity Before and After Cooking of Pigeon Peas

Water absorption capacity of the pigeon pea grains was determined according to the modified methods described and used by Perina *et al.* [21]. About 30 g of pigeon pea grains sample were placed in a 250 mL beaker with 100mL of distilled water for 16 hrs at ambient temperature to soak. After the soaking period, the water was drained, the grains reweighed, and the water absorption capacity before cooking (WACBC) was calculated using the formula:

$$\text{WACBC} = \frac{\text{mw} - \text{dw}}{\text{dw}} \times 100$$

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

The drained pigeon pea grains were placed in the beaker with 100 mL of distilled water and heated for an hour by an electric hot plate, and the beginning time was recorded when the water began to boil. The broth was drained, and water absorption capacity after cooking (WACAC) was calculated by the formula:

$$\text{WACAC} = \frac{\text{cw} - \text{dw}}{\text{dw}} \times 100$$

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

2.3.2. Volumetric Expansion and Density of Pigeon Pea Grains

Determination of the characteristics related to volumetric expansion and density of the pigeon pea grains were carried out according to the method used by Perina *et al.* [21]. Ten (10) grams of raw dried pigeon pea grains were weighed and soaked in distilled water for 16 hours at room temperature. After the end of the soaking period, the soaking water was discarded and the grains weighed. The grains were then placed in glass jars, to which 100 mL of boiling water was added, and the grains allowed to cook in a small aluminium cooking pan (*sufuria*) for 1 hour. The volume of the raw, macerated and cooked grains was determined using the water displacement principle in a graduated cylinder with a 100 mL capacity containing 50 mL of water, and the volume of displaced water noted. The volumetric expansion of grains before cooking (VEBC), volumetric expansion after cooking VEAC), dry/raw grain density (D/RgD), grain density after soaking (SgD) and grain density after cooking (CgD) were calculated using the formulas:

$$\text{VEBC} = \frac{\text{vs} - \text{vr}}{\text{vs}} \times 100$$

$$\text{VEAC} = \frac{\text{vc} - \text{vr}}{\text{vc}} \times 100$$

$$\text{D/RgD} = \frac{\text{dw}}{\text{vr}}$$

$$\text{SgD} = \frac{\text{sw}}{\text{vs}}$$

$$\text{CgD} = \frac{\text{cw}}{\text{vc}}$$

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

cw = weight of grains after cooking

2.3.3. Cooking Time Determination

Cooking time (CT) was measured using 25 soaked pigeon pea grains with a Mattson cooker (Customized Machining and Hydraulics Co., Winnipeg, Canada) in boiling distilled water [22]. The cooker consists of a plate with 25 wells for individual grains, on top of each well resting a metal pin [23]. Cooking time was recorded as the time taken for 50% and 80 % of the bean grains to be completely pierced with an 85 g stainless steel rod with a 2-mm pin. This was an equivalent of when the 13th and 20th, respectively, of the 25 pins of the cooker had penetrated the bean grain for the different varieties [23].

2.3.4. Determination of Total Soluble Solids in the Broth of Cooked Pigeon Peas

The total soluble solids (TSS) comprise of carbohydrates, organic acids, soluble proteins, fats, and minerals in pulses [24]. The quantity of total soluble solids in the cooking broth (TSSb) was determined based on the method described by Perina *et al.* [21]. According to the adapted method, a 10 g sample of pigeon pea grains were soaked in 100 mL of distilled water for 16 hours. Beakers with the pigeon peas were then heated on a hot plate using the cooking times previously established for each variety in the cooking tests. The broths obtained from the cooking were then filtered and collected in clean, dry beakers of known weights. The beakers with the broths were dried in a ventilated laboratory oven at 60˚C, and after the broth completely dried, the beakers were reweighed. The TSS contents in the broth were determined by the formula:

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

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

2.4. Experimental Design and Statistical Analysis

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

$$Yij = \mu + \breve{\imath}i + \epsilon ij$$

where,

Yij = the observation of the dependent variable of raw and cooked pigeon pea grains and technological properties.

μ = Overall mean responses

ĭi = The effect of i^{th} variety.

ϵij = Random error component.

The analysis was done using PROC GLM procedures of the statistical analysis systems of version 9.1.3 [25] in performing an analysis of variance (ANOVA) test at a 95% confidence level. Differences between means was determined using

Tukey's honestly significant difference (HSD). The analysis was conducted at a 95% confidence interval ($\alpha = 0.05$).

3. Results and Discussions

3.1. Volumetric Expansion and Density of Pigeon Pea Grains of Improved Pigeon Peas

Volumetric expansion and density of improved pigeon pea varieties are as shown in Table 1. There was a consistent increase in the volumetric expansion of pigeon pea grains across all analysed varieties. The VEBC was highest in the control variety (ICEAP 00554), reaching 64%, which was significantly different ($p < 0.05$) from all other varieties except Mituki variety. However, Egerton Mbaazi 1, KARI Mbaazi 1, Mituki KAT60/8, and Egerton Mbaazi 2 varieties 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 since the process 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 [26] [27]. Lower lignin

Table 1. Volumetric expansion and density of different varieties of improved pigeon pea grains.

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

Key: VEBC—Volumetric Expansion Before Cooking; VEAC—Volumetric Expansion After Cooking; Key: D/RgD—Dry/Raw Grain Density; SgD—Grain Density After Soaking; CgD—Grain Density After Cooking. 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.

content in the pigeon pea grain negatively affects the water diffusion rate, hence the grain lignification degree [28]. Starch gelatinization occurs during cooking due to water availability caused by soaking [29]. The pigeon peas grain density after both cooking and soaking were less when compared to that of raw/dry grain density, and was highest in the ICEAP 00554 pigeon pea variety (1.35 g/cm^3) and lowest in the ICEAP 00850 variety (1.21 g/cm^3). Egerton Mbaazi 1, ICEAP 00850, KARI Mbaazi 1, KARI Mbaazi 2, KAT60/8, Mituki and Egerton Mbaazi 2 varieties had no significant differences ($p > 0.05$) in terms of raw/dry grain density. 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 grain density after soaking was observed in ICEAP 00850 by 7.4% and KARI Mbaazi 2 by 9.7% varieties. Soaking pigeon pea grains elevates enzymatic cell wall activities leading to changes in pectin polymerization degree hence easier extractability [30]. Soaking also contributes to reduced cooking time and increased cooking yield in different pulse varieties like common beans [31].

Cooking also had a similar effect as soaking on the pigeon pea grains. There was a significant difference ($p < 0.05$) in CgD of ICEAP 00850, 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 the grains which forms soluble pectin that when subjected to thermal process depolymerise. The depolymerisation allows for rapid water flow through the dicotyledonous cell [30] [32].

3.2. Water Absorption Capacity, Cooking Time, and Total Soluble Solids in Broth

Water absorption capacity, cooking time and TSS results are as presented in **Table 2**. The WAC of improved pigeon peas varieties before cooking ranged between 115.06% - 125.48% validating the WAC of 63% - 137% earlier reported by Mukai [22] for improved bean varieties. The WAC was highest in ICEAP 00554 (125.48%) and lowest in KARI Mbaazi 2 (121.54%) varieties before cooking. There was a significant difference ($p < 0.05$) in the WACBC between KARI Mbaazi 2 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 [33]. 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 also greatly influence water absorption in pigeon pea grains [20]. 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 pigeon pea grains absorbed

Table 2. Water absorption capacity, cooking time and total soluble solids of different pigeon pea varieties.

Variety	WACBC (%)	WACAC (%)	50%CT (minutes)	80%CT (minutes)	TSS_b (%)
Egerton Mbaazi 1	121.04 ± 0.64^{bc}	135.40 ± 1.43^{cd}	110.52 ± 1.30^{d}	114.15 ± 0.87^{c}	10.53.0.04^{e}
KARI Mbaazi 1	118.47 ± 0.35^{c}	130.84 ± 0.13^{e}	150.14 ± 1.32^{b}	160.21 ± 0.77^{a}	14.10 ± 0.76^{d}
Mituki	123.49 ± 0.19^{ab}	144.24 ± 0.64^{b}	44.62 ± 4.22^{h}	46.00 ± 1.76^{g}	15.65 ± 0.50^{c}
KAT60/8	125.06 ± 0.10^{a}	157.50 ± 0.33^{a}	57.35 ± 3.18^{g}	55.70 ± 2.19^{f}	26.67 ± 0.32^{a}
Egerton Mbaazi 2	121.54 ± 2.26^{bc}	154.66 ± 1.29^{a}	121.63 ± 1.90^{c}	128.03 ± 0.37^{b}	15.48 ± 0.31^{c}
KARI Mbaazi 2	115.06 ± 1.23^{d}	137.22 ± 2.28^{c}	89.27 ± 0.69^{e}	90.73 ± 0.29^{d}	15.22 ± 0.26^{cd}
ICEAP 00850	123.99 ± 0.26^{ab}	133.98 ± 2.57^{d}	157.50 ± 1.71^{a}	160.13 ± 1.58^{a}	14.41 ± 0.02^{cd}
ICEAP 00554	125.48 ± 0.26^{a}	141.46 ± 2.61^{b}	70.42 ± 0.91^{f}	78.79 ± 0.90^{e}	17.33 ± 0.05^{b}

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. WACBC—Water Absorption Capacity Before Cooking; WACAC—Water Absorption Capacity After Cooking; CT—Cooking Time; TSS_b—Total Soluble Solids in broth.

water corresponding to their weight due to porosity, cotyledon adherence, elasticity, seed coat rigidity and colloidal properties of the grains [34]. 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 [22].

The WACAC of KAT60/8 and Mituki varieties were significantly different ($p < 0.05$) from the other six pigeon pea varieties analysed. However, Egerton Mbaazi 1, KARI Mbaazi 2 and ICEAP 00850 varieties were not significantly different at $p > 0.05$ in terms of WACAC. Perina *et al.* [21] 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 pea varieties with high WACBC and WACAC are mostly recommended for kitchens and commercial food industries due to higher yields after cooking [21]. 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 [35]-[37]. 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 WAC has been associated with grain flexibility, weight, thickness, cotyledon adhesion, porosity, weight, and colloidal properties [38] [39]. The solids of pigeon pea grains are made of starch whose access to water is elevated by cell wall enzymatic degradation during thermal treatment [40]. 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 (CT) in KARI Mbaazi 1 (10.01), ICEAP 00554 (8.37) and Egerton Mbaazi 2 (6.4) minutes between CT 50 and CT 80 allowing for easier recognition of cooking differences. The time taken (minutes) for 50% of the grain to be pierced was highest in ICEAP 00850 (157.5) and KARI Mbaazi 1(150.1) varieties compared to Mituki (44.6) and KAT60/8 (57.3) which recorded the lowest cooking time. Overall, mean cooking time at 50% CT was significantly different ($p < 0.05$) among the varieties assessed. At 80% CT, the cooking time ranged between 46 to 160.2 minutes, with the lowest and highest cooking times recorded for Mituki and KARI Mbaazi 1 varieties, respectively. Longer cooking times may arise from varietal differences, grain physical parameters and seed characteristics such as flatness and grain thickness [41].

Different studies have defined CT in different ways. By using a Mattson cooker, Bibi *et al.* [42] defined CT as time required for 80% - 100% (at 5 minutes intervals during boiling) of the seeds to be penetrated while Proctor and Watts [43] 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 CT to be the cook point. Therefore, we can conclude that there is no clear definition of CT [23] [44]. In this study, the definitions of 50% and 80% CT using a Mattson cooker were applied because these thresholds provide a balanced understanding of the cooking process and its effects on seed texture and digestibility. 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 [45]. Hard-to-cook is a defect that negatively impacts cooking quality and palatability of the pigeon peas, and is associated with seed coat, seed size, texture and swelling capacity of the grain [9]. Wood [9] 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.

Whilst cooking is desirable for pigeon pea palatability, longer CT leads to more energy consumption, inconveniences and less desirability for processors and consumers [9]. KAT60/8 and Mituki varieties that exhibited very short CTs generate energy savings, and thus could be commercially viable and accepted in the production chain. Longer CT is also associated with high costs of production and reduced nutritional value especially for grain protein [11]. 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 [30].

KAT60/8 variety recorded the highest TSS in broth at 26.67% compared to Egerton Mbaazi 1 variety which had a 10.5% TSS_b. There were, however, no significant differences in the TSS_b 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, as evidenced by various studies that reported loss of water-soluble nutrients leading to reduced chemical composition [20] [31] [46]. Carbohydrates are easily hydrolysed and diffused into the cooking broth as it is water soluble [47]. Additionally, during cooking mono and disaccharides which are low molecular weight carbohydrates are diffused into the cooking water, significantly reducing the carbohydrate content in the grain [48]. 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 [49]. The total solids diffused into the water increase the solution concentration that influence water absorption [29] [30]. On the contrary, solute leakage is likely to reduce the affinity of water and its capacity to retain solutes according to osmotic principles. Sayar [15] reported that total solids loss through leaching into broth water increased with temperature increase between 20 and 50˚C but remained constant at 70 and 100˚C, which is within the boiling point of water and temperature used in this study.

3.3. Effect of Cooking on Technological Properties of Improved Pigeon Pea Varieties

Table 3 presents the results on 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. While the volumetric expansion of raw pigeon pea grains ranged from 57.5% - 64%, that of cooked grains ranged from 61.1% - 68.4%. The highest percentage of volumetric expansion after cooking was observed in KARI Mbaazi 2 (11.0%), followed by KAT60/8 (10.0%), 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.

Table 3. Effect of cooking on technological properties of improved pigeon pea varieties.

Variety		Volumetric expansion	Density	Water Absorption
Egerton Mbaazi 1	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)
	t-value	3.71	−9.72	9.19
	p-value	**0.0207**	**0.0006**	**0.0008**
KARI Mbaazi 1	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)
	t-value	7.72	−15.47	32.83
	p-value	**0.0015**	**0.0001**	**<0.0001**

Continued

Mituki	**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)
	t-value	12.56	−13.04	31.23
	p-value	**0.0002**	**0.0002**	**<0.0001**
KAT60/8	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)
	t-value	5.23	−4.94	94.24
	p-value	**0.0064**	**0.0220**	**<0.0001**
KARI Mbaazi 2	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)
	t-value	8.36	−16.95	8.55
	p-value	**0.0011**	**<0.0001**	**0.0010**
ICEAP 00554	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)
	t-value	15.41	−25.15	6.10
	p-value	**0.0001**	**<0.0001**	**0.0037**
Egerton Mbaazi 2	Cooked	64.13 (61.43 - 66.83)	1.11 (1.08 - 1.13)	154.66 (149.13 - 160.19)
	Raw	59.70 (54.23 - 65.17)	1.27 (1.13 - 1.40)	121.54 (111.82 - 131.25)
	t-value	3.12	−5.15	12.75
	p-value	**0.0354**	**0.0067**	**0.0002**
ICEAP 00850	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)
	t-value	1.52	−5.04	3.87
	p-value	**0.2035**	**0.0073**	**0.0180**

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

Regarding raw grain density, there was no significant difference ($p > 0.05$) among the pigeon peas varieties tested. On the other hand, there was a significant general reduction ($p < 0.05$) in densities of pigeon pea grains after cooking, with ICEAP 00554 (19.3%) and Mituki (17.6%) grain varieties having the highest density reduction percentage. However, ICEAP 00850 variety recorded the lowest percentage decrease of 7.4%.

There was a significant increase ($p < 0.05$) in the WAC among all the assayed pigeon peas varieties. KARI Mbaazi 2 recorded the highest WAC at 27.3%, followed by KAT60/8 (25.9%), ICEAP 00554 (19.3%) and Mituki (16.8%).

3.4. The Relationship Between Different Technological Properties

The relationships between different technological properties of pigeon pea grain varieties is presented in Table 4. The correlation analysis showed a significant

Table 4. Correlation coefficients of interaction between technological properties of pigeon peas varieties before and after cooking.

	VEBC	VEAC	D/RgD	SgD	CgD	WACBC	WACAC	CT	TSS
VEBC	1	**0.764****	**0.886****	−0.129^{ns}	−0.257^{ns}	**0.439***	0.188^{ns}	−0.0386^{ns}	0.102^{ns}
VEAC		1	**0.816****	−0.026^{ns}	−0.364^{ns}	0.305^{ns}	**0.443***	**−0.764****	**0.416***
D/RgD			1	0.053^{ns}	−0.168^{ns}	0.141^{ns}	0.102^{ns}	−0.379^{ns}	0.068^{ns}
SgD				1	**0.516****	−0.056^{ns}	−0.182^{ns}	0.262^{ns}	−0.167^{ns}
CgD					1	−0.050^{ns}	−0.183^{ns}	**0.522****	−0.068^{ns}
WACBC						1	0.376^{ns}	−0.0287^{ns}	**0.419***
WACAC							1	**−0.0532****	**0.698****
CT								1	**−0.538****
TSS									1

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.

strong positive relationship ($r = 0.76$) between VEBC and VEAC. The results suggest that a unit increase in VEBC and VEAC cooking result in unit increment of either factor by 76%. There was also a very strong positive correlation ($r = 0.89$) between VEBC and D/RgD signifying that every increase in either VEBC or D/RgD would result in an increase of either factor by 89%. The high correlation observed among the properties (VEBC, VEAC, D/RgD, CT, WACAC and TSS) of the assayed pigeon pea varieties explains how choosing one trait influence the expression of another. Volumetric expansion before cooking also had a positive relationship ($r = 0.44$) with WACBC which however had a weak correlation. An increase in VEBC or water absorption capacity before cooking would result into 44% increase in both variables. Volumetric expansion after cooking 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. Volumetric expansion after cooking had a weak positive relationship ($r = 0.44$) with WACAC, indicating that an increase in VEAC or WACAC would lead to a 44% increment in both factors. The findings of this study suggests that soaking influences water availability which in turn reduces cooking time by facilitating gelatinization of starch during cooking [29].

On the other hand, there was a strong negative correlation ($r = -0.76$) between VEAC and cooking time with the results implying that a unit increase in either VEAC or cooking time would lead to a 76% decrease in either component. Assuming all factors were kept constant, the grain volume and size affected cooking time as observed in this study. This is because both heat and moisture take longer to infiltrate and thermally convert a sizeable mass thereby, a substantial radius to the centre of the grain. Wood [50] reported that most pulses with large volumes take longer time to cook as long as they do not have un-hydratable defects. 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 [51].

Furthermore, a significant strong negative correlation was observed between cooking time and TSS. This means that an increment in cooking time or TSS would result in a 54.0% decrease in either component. Similarly, a study carried out by Narasimha and Desikachar [52] on 16 Indian pigeon pea varieties recorded a significant negative relationship ($r = -0.98$) between TSS and cooking time.

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 5). However, water absorption was insignificantly high in Egerton Mbaazi 2 variety in reference to ICEAP 00554 variety. 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 [21]. The porous, amorphous, and loosely attached cotyledon allows for more water imbibition. Cooking imparts various physico-chemical changes in pigeon pea seeds including protein denaturation, starch gelatinization, polysaccharides solubilisation, cementing ma

Table 5. Logistic regression odds ratio estimates for selected parameters.

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

terial found in the cotyledon and softening and breakdown of the middle lamella [53]. The cooking quality of the pigeon pea varieties was 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 is linear within the varieties. Sayar *et al.* [15] indicated that volumetric expansion with increase in water absorption can be explained by water absorption by starch and proteins. Furthermore, Ratkovic & Pissis [54] reported a linear relationship between water absorption capacities and proteins of eight different varieties of legumes and cereals. This implies that increase in volume during absorption of water is closely related to the protein part of the grain expansion. Variations in volumetric expansion coefficient are likely affected by mechanisms such as leaching soluble solids from grain, starch and proteins during cooking [15].

4. Conclusion

The study demonstrates that cooking and soaking significantly increase volumetric expansion while decreasing density of improved pigeon pea varieties. Cooking time emerges as a critical factor in pigeon pea grain preparation, with longer durations being costly and time-consuming, thereby constraining pigeon pea utilization. Additionally, all varieties exhibited high TSSs, 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.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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