

Chapter

Harnessing Indigenous Cucurbits for Food and Nutrition Security in Kenya: Focus on Tropical Pumpkin, Horned Melon, and Bottle Gourd

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Abstract

In Kenya, members of the Cucurbitaceae family such as tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*) play important roles in rural agriculture, nutrition, and traditional livelihoods. This study evaluated 15 accessions of cucurbit crops—tropical pumpkin, horned melon, and bottle gourd—collected from diverse regions across Kenya. The primary objective was to identify high-performing accessions suitable for breeding, regional adaptation, and commercialization while also examining market dynamics. Field trials were conducted using a randomized complete block design, and key crop traits were analyzed. Varied statistical tools were applied to evaluate trait variability and relationships among accessions. The results revealed significant differences ($p \leq 0.05$) across accessions, with Tharaka-HML-03, Embu-PMK-01, and Meru-BLG-05 standing out in vine length and fruit production. Principle component analysis (PCA) identified fruit weight and vine length as major contributors to phenotypic variation, while clustering indicated distinct diversity patterns, especially within tropical pumpkin. Market surveys highlighted that tropical pumpkin was the most accessible and affordable crop, whereas horned melon, though scarce, fetched premium prices due to its novelty and health appeal. Bottle gourd was moderately available and most affordable in regions like Meru. Consumer preferences focused on taste, tenderness, and shelf life, while traders valued visual traits and uniformity. The study concludes that integrating agronomic data with market insights provides a solid foundation for breeding programs and commercialization strategies. Recommendations include multilocation trials, enhanced postharvest handling, consumer-focused breeding, and targeted farmer training to promote cucurbit production and value chain development across Kenya.

Keywords: accessions, commercialization, cucurbit, dendrogram, morphological

1. Introduction

1.1 Background information

Cucurbit crops are an integral part of global agriculture, particularly in tropical and subtropical regions where they are cultivated for their nutritional and economic importance. In Kenya, the major cucurbits include pumpkin (*Cucurbita maxima*), butternut (*Cucurbita moschata*), watermelon (*Citrullus lanatus*), cucumber (*Cucumis sativus*), and courgette (*Cucurbita pepo*), which are grown widely for domestic use and export [1, 2]. These crops are rich sources of vitamins, minerals, and dietary fiber [3]. Recent research has highlighted the potential of semi-bush (SB) pumpkin genotypes in intercropping systems, particularly with short-season legumes like beans (*Phaseolus vulgaris*) and cowpeas (*Vigna unguiculata*) [4]. This approach not only improves land-use efficiency but also offers higher overall productivity without compromising the yield of the main pumpkin crop [4, 5].

Horned melon (*Cucumis metuliferus*), commonly known as thorn melon, is a lesser-known cucurbit native to Africa but now gaining international attention due to its adaptability and nutritional profile [5, 6]. The fruit contains high levels of phytochemicals, vitamins, and antioxidants and is also valued for its high water content, making it ideal for arid and semiarid environments [7, 8]. Though edible raw, it can also be processed into juices, yoghurts, and even ice creams [9, 10]. Its decorative appeal further enhances its marketability. Despite these advantages, horned melon remains underutilized due to limited awareness, low consumer acceptance, and insufficient research on its agronomic traits and genetic diversity in Kenya [6, 11].

Cucumber (*Cucumis sativus*), one of the oldest cultivated crops, originated in ancient Egypt and is now a daily staple in many regions, particularly Africa and Asia [12]. It is a rich source of moisture, minerals, and bioactive phytochemicals that support food quality and human health [5, 13]. Along with related species such as horned melon and gherkin (*Cucumis anguria*), cucumber has shown promising adaptability beyond its traditional growing zones [13]. With increasing interest in functional foods and natural health products, cucurbits are now being explored for their potential as nutraceuticals and sources of bioactive compounds from both edible and non-edible parts [7, 13]. This trend supports a circular economy by allowing for the valorization of food waste and increasing the sustainability of food systems [10, 13]. Strategic research, value chain development, and crop improvement efforts are essential to unlock the full potential of these crops.

1.2 Production of tropical pumpkin, horned melon, and bottle gourd in Kenya

1.2.1 Plant taxonomy

1.2.1.1 Tropical pumpkin (*Cucurbita moschata* Duchesne)

Tropical pumpkin, botanically known as *Cucurbita moschata*, belongs to the family Cucurbitaceae, which consists of herbaceous vines native to tropical and subtropical regions. This species is one of the five domesticated *Cucurbita* species, which include *C. pepo*, *C. maxima*, *C. argyrosperma*, and *C. ficifolia* [2]. *C. moschata* is characterized by its trailing vines, large leaves with coarse hairs, and yellow, unisexual flowers. The fruit is variable in size, shape, and color, often possessing thick rinds and sweet, orange flesh rich in beta-carotene [1]. It is especially suited to hot, humid climates

and shows better tolerance to high temperatures and disease pressure compared to *C. maxima* and *C. pepo* [1]. In Africa, it is a staple crop and is valued for both its nutritional content and long storage potential (**Figure 1**).

1.2.1.2 Horned melon (*Cucumis metuliferus* E. Mey. ex Naudin)

Horned melon is a member of the genus *Cucumis*, within the family Cucurbitaceae. It is indigenous to sub-Saharan Africa and has adapted well to various agroecological zones, including semiarid regions [11]. Horned melon is a monoecious or dioecious annual climber that produces distinctive orange-skinned fruits with horn-like spines and green, jelly-like pulp filled with edible seeds [14]. This species is noted for its high drought tolerance and its ability to grow in marginal soils with low fertility [6]. Beyond its traditional consumption in rural Africa, it has attracted global attention for its ornamental value and high levels of bioactive compounds such as phenolics, flavonoids, and antioxidants [7]. Its underutilization has spurred calls for conservation and genetic improvement to fully exploit its potential (**Figure 2**).

1.2.1.3 Bottle gourd (*Lagenaria siceraria* (Molina) Standl.)

Bottle gourd is an ancient domesticated crop that belongs to a different genus within the Cucurbitaceae family. Known for its diverse fruit morphology, ranging from bottle-shaped, round, to elongated shape, it is used for both food and utility purposes such as utensils and musical instruments when dried [3]. It grows as a fast-growing, trailing, or climbing vine with white, funnel-shaped flowers and large fruits



Figure 1.
Tropical pumpkin (Cucurbita moschata) plant and inflorescence.



Figure 2.
Horned melon (Cucumis metuliferus) plant and fruit.

that can weigh several kilograms. While the tender fruits are consumed as vegetables, mature fruits are dried and used as containers or crafts. The crop is highly adaptive, with tolerance to drought and poor soils, making it well-suited for cultivation in arid and semiarid regions [15]. Due to its cultural, nutritional and economic importance, it is considered a multipurpose species with potential for crop improvement (**Figure 3** and **Table 1**).

1.2.2 Production of tropical pumpkin, horned melon, and bottle gourd

The cultivation of tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*) is gaining increasing attention across Africa, especially in Kenya, due to their nutritional value and economic potential. These crops play an important role in supporting food security and rural incomes. Tropical pumpkin, in particular, holds a prominent place in Kenyan agriculture, with an estimated annual production of 300,000 tons, meeting both household consumption and market demands (Food and Agriculture Organization) [16, 17]. Its widespread availability has contributed significantly to nutrition and market systems within the country.

Horned melon remains a relatively new and underutilized crop in Kenya, though interest in its cultivation is growing, particularly in the Rift Valley region. While production data is still limited, the fruit's increasing popularity, driven by awareness of



Figure 3.
Bottle gourd (Lagenaria siceraria) inflorescence and fruits.

Taxonomic rank	Tropical pumpkin (<i>Cucurbita moschata</i>)	Horned melon (<i>Cucumis metuliferus</i>)	Bottle gourd (<i>Lagenaria siceraria</i>)
Kingdom	Plantae	Plantae	Plantae
Phylum (division)	Magnoliophyta (Angiosperms)	Magnoliophyta (Angiosperms)	Magnoliophyta (Angiosperms)
Class	Magnoliopsida (Eudicots)	Magnoliopsida (Eudicots)	Magnoliopsida (Eudicots)
Order	Cucurbitales	Cucurbitales	Cucurbitales
Family	Cucurbitaceae	Cucurbitaceae	Cucurbitaceae
Genus	<i>Cucurbita</i>	<i>Cucumis</i>	<i>Lagenaria</i>
Species	<i>Cucurbita moschata</i>	<i>Cucumis metuliferus</i>	<i>Lagenaria siceraria</i>

Table 1.
Taxonomy of selected cucurbits.

its health benefits, presents a promising opportunity for agribusiness development. In contrast, bottle gourd is a well-established crop in Kenya, appreciated for its culinary uses and medicinal value. Its estimated production stands at 250,000 tons annually [16, 17], positioning Kenya as a notable producer in Africa, though behind global leaders like India. The continued cultivation and market development of these three crops are vital for strengthening Kenya's agricultural sector. Investments in production practices, market infrastructure, and public education could further enhance the sustainability and economic impact of these crops.

1.2.3 Climate and ecological requirements

The ecological and climatic requirements for the successful cultivation of tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*) are similar in that all three crops thrive in tropical and subtropical regions. Tropical pumpkin performs best in warm climates with optimal temperatures ranging between 20°C and 30°C. Growth is inhibited below 10°C, while excessive heat above 35°C can lead to flower drop and fruit deformities. The crop requires fertile, well-drained sandy loam or loamy soils with a pH of 6.0 to 7.0, enriched with organic matter such as compost or well-rotted manure to boost soil fertility and support vigorous growth. Regular moisture is essential, particularly during germination and fruit development, with an estimated requirement of 25 to 35 mm of water weekly. Drip irrigation is often recommended to supply consistent moisture while avoiding waterlogging and root rot [16, 17].

Horned melon shares similar thermal preferences, ideally between 20°C and 30°C, but it demonstrates better tolerance to dry and mildly cool environments, making it suitable for semiarid regions. It requires fertile, well-drained soils with high organic content and a pH of 6.0 to 6.8. Though relatively drought-resistant, horned melon responds well to regular irrigation during flowering and fruit setting, provided overwatering is avoided to prevent root diseases. Its vining nature benefits from trellising, which improves air circulation and helps reduce fungal infections [18]. Bottle gourd, on the other hand, prefers slightly higher temperatures ranging from 25°C to 35°C and grows well in loamy or sandy loam soils that are nutrient-rich and well-drained, with a pH of 6.0 to 7.0. It is moderately sensitive to drought, especially during flowering and fruiting stages, and requires approximately 20 to 30 mm of water per week. Drip irrigation is also suitable for maintaining optimal moisture levels without causing water stress or waterlogging [15, 19].

1.2.4 Crop agronomy

The agronomic practices for tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*) cover essential elements such as cultivation techniques, growth stages, pest control, and harvesting methods. Tropical pumpkin is usually planted during the warm growing season in well-prepared soils rich in organic matter, with recommended spacing of about 1 meter between plants to allow proper aeration and sunlight penetration. Horned melon is either directly sown after the last frost or started in seed trays, requiring 30 to 60 cm spacing between plants and well-drained fertile soils similar to those favored by cucumbers [18]. Bottle gourd is grown during warm seasons, with seeds sown either directly in the field or in nursery beds, spaced 1 to 2 meters apart depending on variety and management system [15]. All three crops require adequate sunlight and nutrient-rich soils for healthy development.

The crops follow similar developmental stages: seedling, vegetative growth, flowering, fruiting, and ripening. Tropical pumpkin reaches maturity within 80 to 100 days after planting, while horned melon matures in about 70 to 90 days and bottle gourd in 60 to 90 days [19, 20]. Pollination, mostly aided by bees and other insects, is critical for fruit formation. Pest management relies on integrated pest management (IPM) practices, including crop rotation, resistant varieties, regular field scouting, and the use of organic pesticides. Tropical pumpkin and bottle gourd are commonly affected by aphids, whiteflies, and fruit flies, while horned melon faces threats from aphids and spider mites. Organic mulching and intercropping are often used to suppress weeds and discourage pest buildup. Harvesting is done once fruits reach physiological maturity—indicated by changes in color and firmness—with careful handling using sharp tools to prevent bruising and preserve quality [18, 19].

Purpose: The purpose of this study was to identify high-performing accessions suitable for breeding, regional adaptation, and commercialization while also examining local consumption trends and market dynamics.

2. Materials and methods

2.1 Description of the study site

The study was conducted at the University of Nairobi Upper Kabete Field Station in Kabete Sub-county, Nairobi County, Kenya, approximately 11 km northwest of Nairobi city center at an altitude of 1940 meters above sea level [21]. The site is characterized by a bimodal rainfall pattern, with annual precipitation ranging from 900 to 1200 mm, long rains occurring from March to May, and short rains between October and December [22]. The mean annual temperature is around 18.7°C, with average maximum and minimum temperatures of 24.5°C and 12.8°C respectively. Potential evaporation averages 1500 mm annually, while actual evapotranspiration is approximately 1000 mm, depending on the season and crop cover. The soils at Upper Kabete are primarily deep, well-drained humic nitisols with a friable clay texture and good fertility, derived from volcanic parent material, making them suitable for diverse crop cultivation [16, 17]. This site serves as a key center for agricultural research and training and offers favorable conditions for cultivating underutilized cucurbits such as tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*), supporting their evaluation for growth performance and agronomic traits under managed field conditions.

2.2 Plant material and seed preparation

Fifteen accessions of underutilized cucurbit crops—tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*)—were selected for this study based on agroecological diversity, availability, and genetic improvement potential. These accessions were sourced from farmers' fields, wild populations, and research institutions across Kenya. For tropical pumpkin, five accessions included local landraces from Western, Eastern, and Central Kenya (KE-PMK-001 to KE-PMK-015), smallholder farms in Embu (Embu-PMK-01), Meru (Meru-PMK-03), KALRO stations (KALRO-PMK-A), and the University of Nairobi (UoN-PMK-05). Horned melon accessions comprised KE-HML-001 and KE-HML-002 (from Kitui and Embu), Kiboko-HML-02 (KALRO), Tharaka-HML-03

(dryland-adapted from Tharaka-Nithi), and Kakuma-HML-01 (a wild type from Turkana). Bottle gourd accessions included KE-BLG-001 and KE-BLG-002 (from Nyanza and Western Kenya), Kisii-BLG-01 (large-fruited), Makueni-BLG-02 (early maturing), and Meru-BLG-05 (used in traditional cooking). Mature fruits were harvested at full ripeness, and seeds were extracted using sterile tools, fermented in clean containers for 3 days to remove mucilage and enhance germination [10], then washed, sun-dried, and winnowed [6]. The seeds were stored under cool, dry conditions until planting, providing a genetically diverse base for evaluating morphological, agronomic, and yield-related traits.

2.3 Experimental design, layout, and market survey

The study aimed to evaluate the genetic diversity, agronomic performance, and market potential of tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*) in selected regions of Kenya, using a combination of field experimentation and market surveys to provide comprehensive insights into both production and commercialization. The field component was conducted at the University of Nairobi Research Farm using a randomized complete block design with three replications. Fifteen accessions—five per species—were selected based on agroecological diversity and availability, including KE-PMK-001 to UON-PMK-05 for tropical pumpkin, KE-HML-001 to Kakuma-HML-01 for horned melon, and KE-BLG-001 to Meru-BLG-05 for bottle gourd. Each accession was planted in 3 × 3 meters plots, with 1-meter alleys to prevent interference, and seeds were spaced at 1 × 1 meter, later thinned to one seedling per hill. Before planting, 30 tons per hectare of well-decomposed farmyard manure and 200 kg per hectare of Triple Super Phosphate were applied. Embu-PMK-01 was planted as a border crop to minimize edge effects. All recommended agronomic practices were applied uniformly, and trials ran across two cropping seasons—October 2023 to January 2024, and March to July 2024—to assess performance under different conditions. The market survey was carried out in Nairobi, Meru, Kisumu, and Kakamega using structured questionnaires and direct interviews with traders and consumers in major markets, including Wakulima, Makutano, Kibuye, and Kakamega Town markets. The survey explored crop availability, supply trends, pricing, consumer preferences, and awareness levels, particularly for horned melon, which remains less familiar in many parts of Kenya.

2.4 Data collection

This study combined field evaluation and a market survey to assess the genetic diversity, agronomic performance, and market potential of tropical pumpkin (*Cucurbita moschata*), horned melon (*Cucumis metuliferus*), and bottle gourd (*Lagenaria siceraria*) in Kenya. Fifteen accessions—five per crop—were evaluated at the University of Nairobi Research Farm using a randomized complete block design with three replications. Morphological and agronomic traits were assessed using a modified descriptor list adapted from the International Plant Genetic Resources Institute (IPGRI), with data collected on qualitative traits such as leaf shape, vine growth habit, and fruit and seed characteristics, as well as quantitative traits including vine length, number of fruits per plant, fruit weight, seed size, and days to flowering and maturity. Observations were made from four tagged plants per plot, and precision instruments such as digital calipers and electronic balances were used for accurate measurement. Complementing the field study, a market survey was carried

out in Nairobi, Meru, Kisumu, and Kakamega through structured questionnaires and interviews with traders, vendors, and consumers in local markets. The survey aimed to identify preferred fruit traits, sourcing patterns, pricing trends, and consumer awareness, with special attention to horned melon, which remains underutilized and less familiar among Kenyan consumers.

2.5 Data analysis

The study combined both field experiments and market surveys to assess the genetic diversity, agronomic performance, and market potential of tropical pumpkin, horned melon, and bottle gourd. Data were collected over two growing seasons and analyzed using two-way Analysis of Variance (ANOVA) to detect significant differences among the 15 accessions, seasonal variations, and their interactions at a 5% significance level. Where significant differences were found, means were separated using the Student's Newman-Keuls test. Pearson correlation analysis was also conducted to explore the relationships among key traits such as vine length, fruit number, and fruit weight.

Both qualitative and quantitative trait data were organized into a matrix for cluster analysis. Genetic dissimilarity among accessions was computed using Euclidean distance, and a dendrogram was generated through the Unweighted Pair Group Method with Arithmetic Mean (UPGMA). Principal Component Analysis (PCA) was also performed to identify the traits that contributed most to the variation among accessions. On the market side, data from four major towns—Nairobi, Meru, Kisumu, and Kakamega—were summarized using descriptive statistics. This included frequencies and percentages to illustrate crop availability, sourcing patterns, price variations, and consumer preferences. Regional comparisons highlighted the most valued traits across different markets. These findings were then integrated with field performance data to provide insights that could guide future breeding programs and support the promotion of improved cucurbit varieties.

3. Results

3.1 Assessment of qualitative and quantitative traits

The results revealed significant differences ($p \leq 0.05$) among the 15 accessions of tropical pumpkin, horned melon, and bottle gourd across all evaluated quantitative and agronomic traits. Main vine length ranged from 240.83 cm in Makueni-BLG-02 to 273.58 cm in Tharaka-HML-03, with Tharaka-HML-03, Embu-PMK-01, and Meru-BLG-05 exhibiting the longest vines, while Makueni-BLG-02 and Kiboko-HML-02 had the shortest. Branch number varied significantly, with Kisii-BLG-01 recording the highest (16.25), followed by Tharaka-HML-03 (16.00) and the lowest values observed in Kakuma-HML-01 (13.58) and KE-PMK-003 (13.92). Fruit number per plant also differed notably, with Tharaka-HML-03 producing the most (15.60), followed by Kisii-BLG-01 (14.00) and Meru-PMK-03 (14.12), while Kiboko-HML-02 (8.80) and Makueni-BLG-02 (9.56) recorded the fewest. Average fruit weight ranged from 198.67 g in KE-BLG-001 to 315.67 g in Meru-PMK-03, with Meru-PMK-03 and UoN-PMK-05 yielding the heaviest pumpkin fruits, and Kiboko-HML-02 and Makueni-BLG-02 having the lightest horned melon and bottle gourd fruits, respectively. Seed size also varied, from 3.30 mm in Makueni-BLG-02 to 4.18 mm

in Tharaka-HML-03, with Tharaka-HML-03 and UoN-PMK-05 having the largest seeds. Rind thickness ranged between 3.16 mm in Makueni-BLG-02 and 4.33 mm in Tharaka-HML-03, with the thickest rinds observed in Tharaka-HML-03 and Meru-PMK-03, and the thinnest in Makueni-BLG-02 and Kiboko-HML-02. These findings confirm considerable genetic variability among the accessions, which is useful for selection and crop improvement (**Table 2**).

The cluster dendrograms illustrate the morphological relationships among accessions of three cucurbit crops—tropical pumpkin, horned melon, and bottle gourd—based on their trait similarities. In the tropical pumpkin group, accessions such as EF/MM1-01, AIW/AIHC-03, and Poohei-03 formed a tight cluster, suggesting high morphological similarity, while ThromMel-03 appeared more distinct. Similarly, in the Horned Melon group, EF/MM1-01 and KuroConMel-01 were closely linked,

Crop and accession	Main vine length (cm)	Branch number	Fruit number	Fruit weight (g)	Seed size (mm)	Rind thickness (mm)
Tropical pumpkin						
Embu-PMK-01	270.33abc	15.83abcd	12.87cde	298.00abc	3.90cde	3.84de
Meru-PMK-03	262.17abcd	14.50cde	14.12abc	315.67ab	4.05abc	4.18ab
KE-PMK-001	255.42def	15.08bcd	10.73efg	284.50bcd	3.66f	3.72ef
KE-PMK-003	248.00fgh	13.92ef	9.85fg	275.33cd	3.58f	3.40h
UoN-PMK-05	266.25abcd	15.17bcd	11.21def	301.67abc	4.12ab	4.05bc
Horned melon						
KE-HML-001	259.67cde	14.66de	13.34bcd	208.33f	3.78def	3.88cd
Tharaka-HML-03	273.58ab	16.00ab	15.60a	224.00ef	4.18a	4.33a
Kiboko-HML-02	245.92h	15.33bc	8.80g	219.67ef	3.50f	3.29i
Kakuma-HML-01	251.17efg	13.58f	10.95efg	232.33de	3.85cde	3.54gh
KEPHIS-HML-05	258.42cde	14.25ef	12.56cde	228.00ef	3.91cde	3.86cd
Bottle gourd						
KE-BLG-001	247.75fgh	15.42bc	11.88def	198.67f	3.61f	3.40h
Kisii-BLG-01	258.00cde	16.25a	14.00abcd	210.50f	3.97bcd	3.82de
Makueni-BLG-02	240.83h	14.17ef	9.56fg	202.00f	3.30g	3.16j
Meru-BLG-05	264.42abcd	14.83cde	12.10def	215.00f	4.00abc	3.90cd
UoN-BLG-06	261.25abcd	15.58abc	13.44abc	218.00ef	3.85cde	3.71ef
P-value	0.031	0.015	0.002	0.007	<0.0001	<0.0001
SE	8.57	0.84	1.17	11.93	0.06	0.11

Means followed by the same letter in a column are not significantly different at $p \leq 0.05$ using Student's Newman-Keuls (SNK) test. SE = standard error.

Table 2.
Variation in quantitative and agronomic traits among cucurbit accessions.

indicating similar traits, whereas ThomMel-03 stood out as the most divergent. For bottle gourd, IAMFo-03 and MAI-001 exhibited close similarity, with EF/BO02-01 and BottleBiG-01 showing moderate to lower similarity. The vertical distances, which represent dissimilarity values, indicate that shorter linkages reflect closer morphological relationships (**Figure 4**).

3.2 Assessment of agronomic traits

Significant variation ($p < 0.0001$) was observed across all agronomic traits among the accessions of tropical pumpkin, horned melon, and bottle gourd. In tropical pumpkin, germination ranged from 89.33% (KE-PMK-003) to 96.67% (Embu-PMK-01), with emergence occurring between 8.83 and 9.67 days. Embu-PMK-01 flowered and matured earliest, while KE-PMK-003 was latest. Horned melon accessions showed germination between 90.17% (Kakuma-HML-01) and 97.83% (KE-HML-001), with emergence, flowering, and maturity also showing significant variation—Kakuma-HML-01 being earliest and Kiboko-HML-02 latest. For bottle gourd, germination ranged from 91.33% to 96.00%, with UoN-BLG-06 emerging, flowering, and maturing earliest, while Makueni-BLG-02 was the latest. These findings highlight substantial genetic diversity in early growth and reproductive timing among the accessions (**Table 3**).

3.3 Principal component analysis (PCA)

The scree plot illustrates the distribution of eigenvalues and cumulative variability for tropical pumpkin, horned melon, and bottle gourd accessions. In all three crops, the first few principal components account for most of the variability, with a steep decline in eigenvalues observed from component 1 to 5. Tropical pumpkin and bottle gourd recorded higher initial eigenvalues compared to horned melon. The cumulative variability approached saturation near component 10 in all crops, with over 90% of total variation explained by the first 7 to 10 components. This indicates that a few principal components capture the majority of variation among accessions for each crop (**Figure 5**).

3.4 Contribution of variables to observed variation in three cucurbit crops

The results in **Table 3** show that across all three cucurbit crops—tropical pumpkin, horned melon, and bottle gourd—the first principal component (F1) accounted

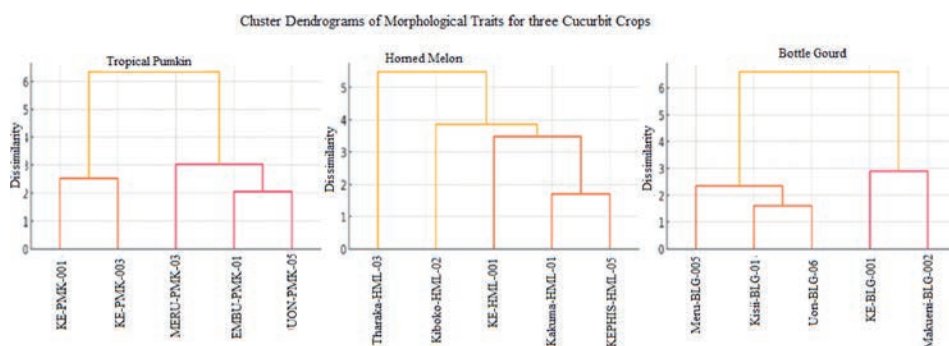


Figure 4.
Cluster dendrogram depicting morphological traits for three cucurbit crops.

Crop	Accessions	Percent germination	Days to emergence	Days to male flowering	Days to female flowering	Days to maturity
Tropical pumpkin	Embu-PMK-01	96.67a	9.00bc	62.50cd	64.00cd	109.33cd
	Meru-PMK-03	93.00ab	9.50ab	64.17bc	66.67bc	112.00bc
	KE-PMK-001	91.50ab	9.67a	65.33ab	67.83ab	114.17ab
	KE-PMK-003	89.33b	9.17bc	66.83a	69.00a	116.50a
	UoN-PMK-05	92.67ab	8.83c	63.00cd	65.33cd	110.83c
	P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	SE	3.984	0.187	0.877	0.854	1.143
Horned melon	KE-HML-001	97.83a	9.33ab	64.67ab	66.00ab	111.00b
	Tharaka-HML-03	95.33ab	9.17ab	63.50bc	64.67bc	109.50bc
	Kiboko-HML-02	92.50bc	9.50a	65.83a	67.50a	113.67a
	Kakuma-HML-01	90.17c	9.00b	62.00c	63.00c	107.33c
	KEPHIS-HML-05	94.67ab	8.83b	63.33bc	65.00bc	110.00bc
	P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	SE	3.472	0.198	0.821	0.744	1.216
Bottle gourd	KE-BLG-001	96.00a	8.83b	62.83bc	64.33bc	109.67c
	Kisii-BLG-01	94.17ab	9.17ab	64.50ab	66.17ab	112.00b
	Makueni-BLG-02	91.33bc	9.33a	65.67a	67.83a	114.83a
	Meru-BLG-05	92.67bc	9.00ab	63.17bc	64.83bc	110.50bc
	UoN-BLG-06	93.83ab	8.67b	61.67c	63.17c	108.33c
	P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	SE	3.812	0.176	0.789	0.799	1.184

Means followed by the same letter within a column are not significantly different based on SNK test at $p \leq 0.05$.
 SE = standard error.

Table 3.
 Variation in agronomic traits of selected cucurbit accessions.

for the highest proportion of total variability, with eigenvalues exceeding 410 and individual variation ranging from 70.63% to 71.21%. The primary contributors to F1 were fruit weight and main vine length, indicating their strong influence on overall agro-morphological variation. The second component (F2) contributed an additional 15.38% to 15.70% of variability and was mainly associated with days to maturity and flowering traits. The third component (F3) was captured between 10.48% and 10.72% of the total variation, primarily influenced by days to male and female flowering and days to maturity. Collectively, the three components explained over 96% of the total variability in each crop, demonstrating a high level of explained variation by the selected agro-morphological traits (Table 4).

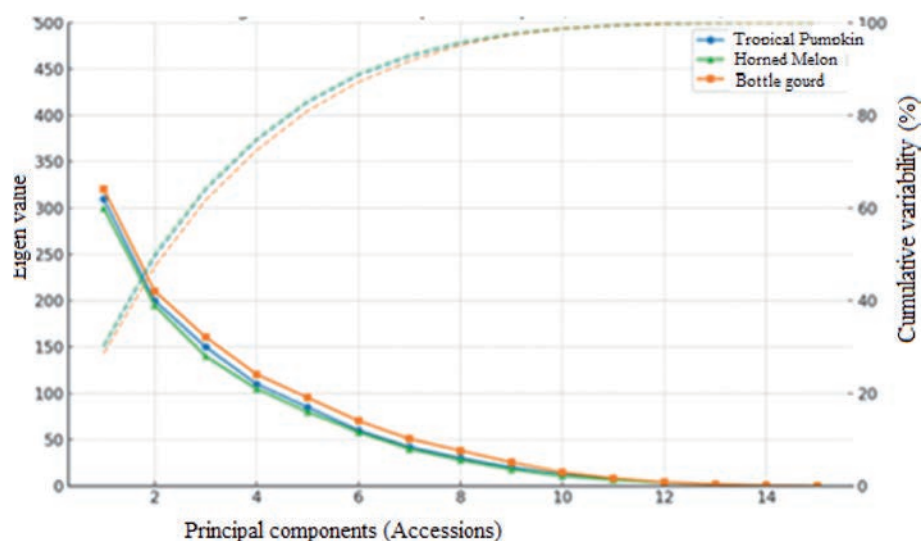


Figure 5.
Scree plot of Eigen values for tropical pumpkin, horned melon, and bottle gourd in Kenya.

Agro-morphological variables	F1 (P)	F1 (M)	F1 (G)	F2 (P)	F2 (M)	F2 (G)	F3 (P)	F3 (M)	F3 (G)
Main vine length	0.310	0.298	0.315	94.21	95.50	95.85	3.220	3.010	3.150
Branch number	0.003	0.005	0.006	0.120	0.115	0.110	0.125	0.120	0.105
Rind color	0.000	0.000	0.000	0.055	0.048	0.050	0.270	0.265	0.260
Fruit shape	0.018	0.016	0.014	0.040	0.045	0.038	0.260	0.255	0.250
Seed shape	0.002	0.003	0.001	0.105	0.115	0.110	0.006	0.007	0.004
Fruit number	0.009	0.007	0.010	0.042	0.048	0.050	0.102	0.101	0.095
Days to seed emergence	0.017	0.021	0.018	0.011	0.013	0.009	0.088	0.085	0.087
Days to male flowering	0.048	0.040	0.043	0.180	0.170	0.160	21.90	22.10	22.00
Days to female flowering	0.005	0.007	0.004	0.190	0.185	0.195	17.60	17.80	17.700
Days to maturity	0.022	0.025	0.018	3.010	2.800	2.700	54.70	55.30	54.90
Fruit weight	98.95	99.10	99.20	0.290	0.320	0.300	0.014	0.016	0.012
Seed size	0.004	0.006	0.003	0.008	0.012	0.009	0.017	0.014	0.016
Rind thickness	0.000	0.001	0.000	0.080	0.070	0.078	0.030	0.029	0.027
Eigenvalue	412.8	410.3	414.12	89.45	91.20	90.65	62.30	61.75	60.98
Variability (%)	70.97	70.63	71.21	15.38	15.70	15.59	10.72	10.63	10.48
Cumulative %	70.97	70.63	71.21	86.35	86.33	86.79	97.07	96.97	97.27

Legend: F1–F3: First three principal components (variability factors), P: tropical pumpkin, M: horned melon, and G: bottle gourd.

Table 4.
Contribution of variables to observed variation in three cucurbit crops.

3.5 Market survey

The study revealed significant differences in market source, availability, and pricing of tropical pumpkin, horned melon, and bottle gourd across Nairobi, Meru, Kisumu, and Kakamega. Tropical pumpkin was the most widely available, sourced locally in all markets, with availability ranging from 80% in Kisumu to 90% in Nairobi, and moderately priced between KSh 80 and 200 per kilogram. Bottle gourd had moderate availability (60–70%) depending on the region, with the lowest price range of KSh 40–90, particularly affordable in Meru. Horned melon, though highest in price (KSh 150–200), was the least available, with presence below 60% in all regions and mostly supplied through specialized urban sources. These market differences reflect variations in supply chains, production intensity, and consumer demand, with statistical tests confirming that the crops differed significantly in availability and pricing (**Table 5, Figure 6**).

The results on consumer preferences and trader priorities reveal distinct patterns for each cucurbit crop. Consumers preferred tropical pumpkin mainly for its taste and shelf life, while traders valued its long shelf life. For horned melon, unique flavor and health benefits were the most important traits to consumers, while traders focused on its attractive color. Bottle gourd was favored by consumers for its tender flesh and ease of cooking, with traders prioritizing uniform shape and size (**Table 6**).

Across the four markets, tropical pumpkin was the most available crop, while horned melon consistently had the highest price. Consumer preferences varied slightly by region—taste and health benefits were emphasized in Nairobi,

Crop	Market	Retail price (KSh/kg)	Availability (%)
Tropical pumpkin	Nairobi	150–200 ^b	90 ^a
Tropical pumpkin	Meru	80–120 ^c	85 ^a
Tropical pumpkin	Kisumu	100–150 ^c	80 ^a
Tropical pumpkin	Kakamega	90–130 ^c	85 ^a
Significance		a > b > c	a > b > c
Horned melon	Nairobi	150–200 ^b	50 ^c
Horned melon	Meru	100–140 ^c	45 ^c
Horned melon	Kisumu	130–160 ^b	55 ^{bc}
Horned melon	Kakamega	140–170 ^b	60 ^{bc}
Significance		a > b > c	a > b > c
Bottle gourd	Nairobi	60–90 ^d	65 ^b
Bottle gourd	Meru	40–60 ^d	70 ^b
Bottle gourd	Kisumu	50–80 ^d	60 ^{bc}
Bottle gourd	Kakamega	55–85 ^d	68 ^b
Significance		a > b > c > d	a > b > c

Superscript letters (^{a, b, c, d}) indicate significance groupings based on ANOVA and post hoc tests; values sharing the same letter are not significantly different ($p \leq 0.05$). Significance rows summarize relative groupings among entries per crop.

Table 5.
 Retail prices, availability, and significance indicators for cucurbit crops.

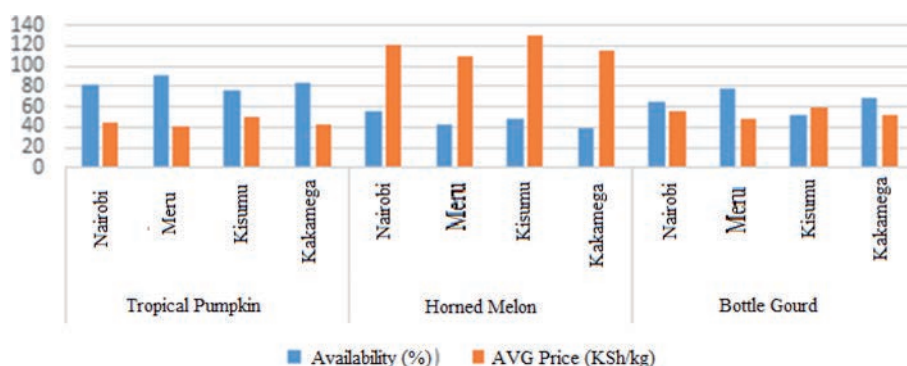


Figure 6.
Availability and average price of the three cucurbits.

Crop	Consumer preferred traits	Trader valued trait
Tropical pumpkin	Taste (78%), shelf life (62%)	Long shelf life (68%)
Horned melon	Unique flavor (65%), health benefits (59%)	Attractive color (72%)
Bottle gourd	Tender flesh (71%), ease of cooking (58%)	Uniform shape and size (61%)

Table 6.
Consumer preferences and traits valued by traders across all markets.

Market	Most available crop	Highest priced crop	Consumer priority	Trader challenge
Nairobi	Tropical pumpkin	Horned melon	Taste and health	Supply consistency
Meru	Tropical pumpkin	Horned melon	Taste and shelf life	Market glut
Kisumu	Tropical pumpkin	Horned melon	Nutrition and price	Storage loss
Kakamega	Tropical pumpkin	Horned melon	Tenderness	Price fluctuation

Table 7.
Comparative summary of market differences.

taste and shelf life in Meru, nutrition and price in Kisumu, and tenderness in Kakamega. Traders faced different challenges in each market, including supply consistency in Nairobi, market glut in Meru, storage losses in Kisumu, and price fluctuation in Kakamega. These findings highlight how consumer demand and trader experiences influence the marketing and promotion of cucurbit crops across different regions (Table 7).

4. Discussion

The evaluation of 15 accessions across tropical pumpkin, horned melon, and bottle gourd revealed significant morphological and agronomic diversity, particularly in traits such as vine length, branch number, fruit yield, fruit weight, seed size, and rind thickness ($p \leq 0.05$). Notable performers included Tharaka-HML-03, Embu-PMK-01, and Meru-BLG-05 for vine length, while Kisii-BLG-01 and Tharaka-HML-03 excelled

in branching and fruit production. Heavier fruits were observed in Meru-PMK-03 and UoN-PMK-05, both pumpkin accessions, while horned melon and bottle gourd tended to have lighter fruits, supporting earlier findings by [23, 24] on cucurbit variability. Seed size and rind thickness also varied significantly, with Tharaka-HML-03 emerging as a strong candidate for breeding due to its consistent performance, echoing insights from [25]. Dendrogram analysis confirmed these patterns, with tropical pumpkin accessions showing both tight and distinct clusters, horned melon displaying moderate diversity, and bottle gourd forming compact groupings—patterns aligned with findings from [26, 27] on agro-morphological clustering in local cucurbits. This morphological variation is significant for breeding programs, as it enables the selection of elite traits suited to specific agroecological zones and market demands. The wide variability observed in traits like fruit weight and maturity duration confirms the adaptability and genetic richness within Kenya's cucurbit germplasm, as previously documented by [28] in participatory varietal selection studies across western Kenya.

The study revealed significant genetic and phenotypic diversity among the 15 cucurbit accessions, as reflected in key agronomic and morphological traits. Tropical pumpkin accessions exhibited notable differences in percent germination, flowering time, and maturity, with KE-PMK-003 maturing latest and Embu-PMK-01 maturing earliest, indicating differential adaptability—a finding consistent with [13], who highlighted maturity variability in Kenyan pumpkin landraces. Horned melon accessions also showed distinct variation, particularly in flowering and germination; Kakuma-HML-01 and Kiboko-HML-02 differed markedly in maturity, while KE-HML-001 recorded superior germination, echoing the adaptive diversity reported by [23] across Kenya's agroecological zones. Among bottle gourd accessions, KE-BLG-001 exhibited the highest germination rates, whereas UoN-BLG-06 was earliest to flower and mature—traits of agronomic value in regions facing weather variability or pest pressure. These findings align with observations by reference [27], who documented maturity variation in local bottle gourd germplasm, supporting the crop's suitability for selective breeding and region-specific cultivation.

Principal component analysis (PCA) served as a powerful tool for distinguishing trait contributions to variation among cucurbit accessions, a method widely employed in similar studies. The dominance of fruit weight and vine length in the first principal component mirrors the findings of [24], who reported fruit size as a key factor in cucurbit diversity. Likewise, flowering and maturity traits, which shaped the second and third components, have been consistently identified in previous analyses as central to adaptation and varietal selection [26, 29]. The application of PCA in this context aligns with approaches used by reference [28], who emphasized the method's value in isolating high-performing lines for breeding. Comparable multivariate studies, such as those by reference studies [23, 25], also underscored the importance of integrating morphological and temporal traits to guide selection decisions. Collectively, these studies support the relevance of PCA in identifying elite accessions and structuring breeding programs aimed at enhancing local cucurbit germplasm.

Market surveys across Kenyan regions have increasingly highlighted the complex interplay between crop availability, pricing, and consumer preferences, findings that are consistent with a growing body of literature on indigenous vegetables and underutilized crops. The observed regional variation in availability—particularly the dominance of tropical pumpkin and limited access to horned melon—reflects patterns documented by [30], who reported that market supply is closely tied to proximity of production zones and cultivation intensity. Similarly, disparities in pricing, with horned melon fetching premium rates due to its scarcity and perceived

health value, align with findings by reference [31], who noted that consumer awareness and product novelty significantly shape pricing trends in fresh produce markets. Furthermore, the differentiated consumer and trader preferences across the three cucurbit crops reinforce trends observed by reference [12], where sensory traits (e.g., taste and texture) and visual appeal (e.g., color and uniformity) were central to product acceptance in urban markets. Collectively, these studies affirm that market potential and crop adoption strategies must consider both agronomic factors and end-user perceptions, particularly when promoting lesser-known crops like horned melon or positioning bottle gourd for cost-sensitive markets.

Comparative assessments of market challenges across regions have been widely acknowledged in agricultural market studies, reinforcing the view that crop marketing success is deeply influenced by localized dynamics. The supply inconsistency in urban areas like Nairobi and post-harvest losses in Kisumu concurs with the finding [30, 32], who emphasized that logistical constraints and infrastructural inadequacies often hinder smallholder access to stable markets. Similarly, the market glut reported in Meru is reflective of challenges reported in Ref. [31], where uncoordinated production and limited value chain integration led to periodic oversupply and waste. Concerns over price fluctuation in places like Kakamega have also been previously attributed to weak aggregation systems and fluctuating consumer demand, as noted in Refs. [21, 31] on staple and horticultural crops. These parallels affirm the need for region-specific interventions, including investment in storage infrastructure, structured marketing channels, and participatory breeding that incorporates both agronomic and market traits. Aligning crop improvement with market realities, as documented in Refs. [32, 33], enhances not only varietal adoption but also the overall sustainability and profitability of cucurbit cultivation in Kenya.

5. Conclusion

The study comprehensively evaluated 15 accessions of tropical pumpkin, horned melon, and bottle gourd across different Kenyan regions, revealing significant agro-morphological and market-based variability with strong potential for crop improvement and market integration. Field results showed notable diversity in traits such as vine length, fruit number, weight, and seed characteristics, with accessions like Tharaka-HML-03, Embu-PMK-01, and Meru-BLG-05 standing out for productivity and growth vigor. Variability in germination, flowering, and maturity across accessions—such as early emergence in Embu-PMK-01 and UoN-BLG-06, and high germination in KE-HML-001—highlighted adaptability to distinct agro-ecological zones [21, 25]. Principal component analysis indicated that a few traits, especially fruit weight and vine length, accounted for over 70% of phenotypic variability, simplifying selection targets for breeding [24, 28]. The market survey showed tropical pumpkin as the most available crop, largely locally sourced, while horned melon, though least available, fetched the highest prices due to its niche demand; bottle gourd was moderately available and most affordable, particularly in Meru. These patterns reflect previous findings that link availability and proximity to pricing and demand [30, 31]. Consumer preferences favored taste, tenderness, and shelf life, while traders prioritized visual traits and uniformity, with regional differences in priorities and challenges such as supply inconsistency and storage losses [32]. These findings align agronomic diversity with market demand, offering a practical framework for varietal selection and commercialization. The integration of field data with

market insights provides a strong basis for developing resilient, high-yielding, and consumer-accepted cucurbit varieties suited to Kenya’s diverse production systems.

6. Recommendations

Based on the identified gaps and areas for improvement, we make several recommendations to enhance cucurbit production and utilization in Kenya. These include conducting multilocation trials to validate the performance of promising accessions across diverse agroecological zones and strengthening postharvest research to reduce storage losses and improve the shelf life of perishable crops like horned melon and bottle gourd. Further, enhancing market linkage studies is crucial to address supply chain challenges and price instability, especially for underutilized crops. Consumer-oriented breeding should also be prioritized to incorporate preferred traits such as flavor, health benefits, tenderness, and ease of cooking of the new varieties. Lastly, there is a need to promote farmer training on improved production practices, seed selection, and value addition to increase yields and income for smallholder growers.

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Conflict of interest

The authors declare no conflict of interest.

Appendix

Cucurbit market survey questionnaire

Section A: Respondent information

Question	Response
Name (optional)	_____
Gender	☐ Male ☐ Female
Age group	☐ 18–25 ☐ 26–35 ☐ 36–45 ☐ 46+
Market location	☐ Nairobi ☐ Meru ☐ Kisumu ☐ Kakamega
Type of respondent	☐ Trader ☐ Consumer
Number of years in trading cucurbits	_____ years

Section B: Availability of cucurbit crops

B1. Which of the following crops do you sell or buy regularly? (Tick all that apply)

- ☐ Tropical pumpkin
- ☐ Horned melon
- ☐ Bottle gourd

B2. How often are these crops available in your market?

Crop	Always available	Sometimes available	Rarely available	Never available
Tropical pumpkin	☐	☐	☐	☐
Horned melon	☐	☐	☐	☐
Bottle gourd	☐	☐	☐	☐

Section C: Source of cucurbit crops

C1. Where do you source the following crops? (Tick all that apply)

Crop	Local farmers	Peri-urban farms	Urban markets	Importers
Tropical pumpkin	☐	☐	☐	☐
Horned melon	☐	☐	☐	☐
Bottle gourd	☐	☐	☐	☐

Section D: Pricing information

D1. What is the average price range for each crop in your market?

Crop	Lowest price (KSh/kg)	Highest price (KSh/kg)
Tropical pumpkin	_____	_____
Horned melon	_____	_____
Bottle gourd	_____	_____

Section E: Consumer preferences

E1. Which traits do your customers prefer most when purchasing cucurbits? (Tick top 2 per crop)

Trait	Tropical pumpkin	Horned melon	Bottle gourd
Taste	☐	☐	☐
Shelf life	☐	☐	☐
Unique flavor	☐	☐	☐
Ease of cooking	☐	☐	☐

Trait	Tropical pumpkin	Horned melon	Bottle gourd
Health benefits	☐	☐	☐
Attractive color	☐	☐	☐
Tender flesh	☐	☐	☐
Uniform shape/size	☐	☐	☐

Section F: Trader challenges and recommendations

F1. What are the main challenges you face when trading cucurbits?

- ☐ Price fluctuations
- ☐ Market glut
- ☐ Inconsistent supply
- ☐ Postharvest losses
- ☐ Low consumer demand
- ☐ Poor storage infrastructure
- ☐ Transport challenges
- ☐ Others: _____

F2. Suggest improvements that would help you trade cucurbits more effectively:

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