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Morphological and Yield Characteristics Diversity among Pumpkin Accessions in Kenya

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Abstract

Genetic diversity and yield potential of Kenyan Cucurbit genotypes is not known. A study was set up to determine the genetic diversity and yield of pumpkin accessions. The experiment was carried out in two field sites using a randomized complete block design with three replications. In the current study, 96 accessions were evaluated for different phenotypic and quantitative traits on the plant, leaves, inflorescence and fruits were recorded. Collected data were statistically analyzed using OriginPro 2022 software. Pearson's correlation coefficient of similarity, Principal component analysis (PCA) and Hierarchical cluster analysis (HCA) were used in data analyses; Pearson's correlation results indicated the number of branches having a highly significant positive correlation at $p \leq 0.001$ with the number of nodes of the first fruit, nodes on the main vine, leaves on main vine, lobes per leaf, vine length, and fruit weight.The weight of healthy fruits was highest in MEG052 (10.00 ± 1.399 Kgs) and lowest in KAPS024 (2.100 ± 1.339) Kgs, with a mean weight of 4.3Kgs. Cluster analysis categorised the accessions based on the parameters into 3 groups. The first to the sixth principal components explained 59.94% of the variations among pumpkin accessions. Analyses on 61 pumpkin accessions indicated the average yield at the University of Eldoret was higher (6.24Kgs) than that of Eldama Ravine (4.22kg). The highest recorded weight of 15.83Kg in UoE was in TUL058 while the lowest was 2.25kg in accession NGE066. A range of variability was observed among the pumpkin accessions for all the scored characteristics. Therefore, these data could be used in breeding programs in Kenya for pumpkin productivity, thus contributing to improved food security.

Keywords: Accession, *Cucurbita, Diversity,* phenotype, yield

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Introduction

Pumpkin belongs to the family Cucurbitaceae, genus *Cucurbita*. It is extensively grown throughout tropical and subtropical countries, with the most common types worldwide being *Cucurbita maxima*, *C. moschata*, and *C. pepo* (Mala et al., 2016). Pumpkins are high-yielding fruits, and their cultivation is inexpensive (Dar et al., 2017). Pumpkin has high nutritional value and is essential for food security. Despite many benefits, it is still considered an orphaned crop in Africa compared to other continents (Gbemenou et al., 2022). Pumpkin production in Africa was as follows: Algeria (420,135 mt), Egypt (406,778 mt), Malawi (368,025 mt), and South Africa (270,486 mt). Algeria, Egypt, Malawi, South Africa, Nigeria, Kenya, Cameroon, Congo, and Niger are among the African countries that value pumpkin production (PROTA, 2018).

Agricultural, pharmaceutical, and food processing industries have developed interests in pumpkin fruits and their derived products due to their nutritional and health-promoting values (Saeleaw & Schleining, 2011). Pumpkins have a diverse variety of food uses depending on their stage of maturity (Bhat, 2013). Immature fruits and leaves are used as vegetables, while all other parts, such as seeds and mature fruits, have varied nutritional values and uses (Bhat, 2013).

According to (Du et al., 2011), *C. moschata* can be cultivated in different agroecological zones and presents great morphological variability in colour and shape of the fruits. A major challenge will be to increase agricultural production in the coming years so that food and nutritional security (Kogo et al., 2021) is a reality for the local population and to meet consumer demands for quality agricultural products .

Acute food insecurity remains elevated in Kenya due to the impacts of drought on crop and livestock production leading to high inflation. In August 2022, Kenya's annual inflation rate hit a five-year high of 8.3 percent, this was driven by increase in prices of food, transport and fuel (Kasoga & Tegambwage, 2022). Access to food is constrained among many poor households, and this is even made worse by the stagnant wages of the people living in urban areas and the shrinking income-earning opportunities facing the inhabitants of rural areas (Ambasa *et al*., 2022). According to Maru *et al*. (2021), pastoralist communities face minimal livestock productivity due to drought which leads to reduced income and diminished food availability.

Despite the promising potential of pumpkin production and possible utilization by households in combating food and nutrition insecurity, there has been limited attention to establish the adaptability, genetic diversity as well as the Cucurbit gene pool of cultivars grown in the target regions; this has made it difficult to evaluate the genetic drift and erosion of the pumpkin accessions (Khoury et al., 2022). The potential genetic variation within neglected and under-utilized pumpkin species (Gwanama *et al*., 2002) is less documented. There is very little research and extension targeted on their adaptability to different agroecological zones as well as the adoption and improvement of the crop (Mathenge, 2009;Ochieng et al., 2017). The rural poor have not adequately embraced the crop due to the lack of awareness of the crops' nutritional and health benefits (Mwaniki, 2003). According to Imathiu, (2021); reduction of overreliance on limited numbers of the major staple food crops in promoting food security can be reduced through the adoption of neglected underutilized species (NUS) of crops.

Despite high morphological and biochemical variability and economic significance of pumpkins, little emphasis is given to its genetic improvement (Kesh and Yadav, 2023). This study aimed at investigating extend of genetic diversity of selected pumpkin accessions using morphological characteristics and also investigate their growth and yield potentials in two agroecological zones. Results from this research would provide insight into the economic benefits of pumpkins due to the knowledge obtained on yield and other morphological attributes. Farmers will use the information acquired on adaptability and yield to realize the full potential of the crop and hence use it to circumvent hunger and poverty related scenarios. Breeders will get an insight on the diversity of the pumpkin accessions and can develop new breeding programs aimed at developing new novel pumpkin varieties.

Materials and methods

Study site

The collected germplasm was planted in two agroecological sites. The sites were the Agricultural training centre- Eldama Ravine in Baringo County and the University of Eldoret in Uasin Gishu County. Agricultural training centre- Ravine is located at latitude of 0.05300 N and a longitude of 35.72980 E. Eldama Ravine is found in the L.H. 3 zone with nitochromic LUVISOL soil type (Kateiya *et al*., 2021). The University of Eldoret experimental plot is located in the Moiben division of Uasin Gishu County. Its latitude and longitudes are 0.55670 N and 35.29720 E, respectively. The soils belong to a high-level structural plains and plateaus, mainly the soils are acidic (pH: 4.5-5.0) and of igneous origin and of low fertility and are underlain with murram. They are classified by USDA classification as Rhodic Ferralsols (Ng *et al*., 2017).

Germplasm collection and experimental design

One hundred and twenty-three mature pumpkin fruits and seeds were collected from Baringo, Elgeyo Marakwet, and Uasin Gishu counties of Kenya. Simple Random Sampling (SRS) method was used in sample collection. Three sub-counties were sampled from which three wards were identified, and samples were collected (Figure 1). The pumpkin fruits were cut open to extract the seeds. The seeds were then dried under the sun and packed in clearly labeled storage papers in readiness for the planting season. Two commercial seeds (Rana 124 and Ranjit 125) were sourced from Agriside Solutions Limited and were used for comparison due to their documented high- yielding and early maturity attributes.

The land was ploughed before sowing during the long rains of 2021. Holes measuring 12-15 inches were dug into the ground. The holes had a standard spacing of 2m x 2m between rows and between the plants (Kiramana & Isutsa, 2017). Diammonium Phosphate was used for fertilization at the rate of 50kgs / ha (Kiramana & Isutsa, 2017). One seed was planted 1 inch deep into each hole. Fungicides, insecticides, and other standard agronomic practices were carried out. Fruits were then harvested upon physiological maturity.

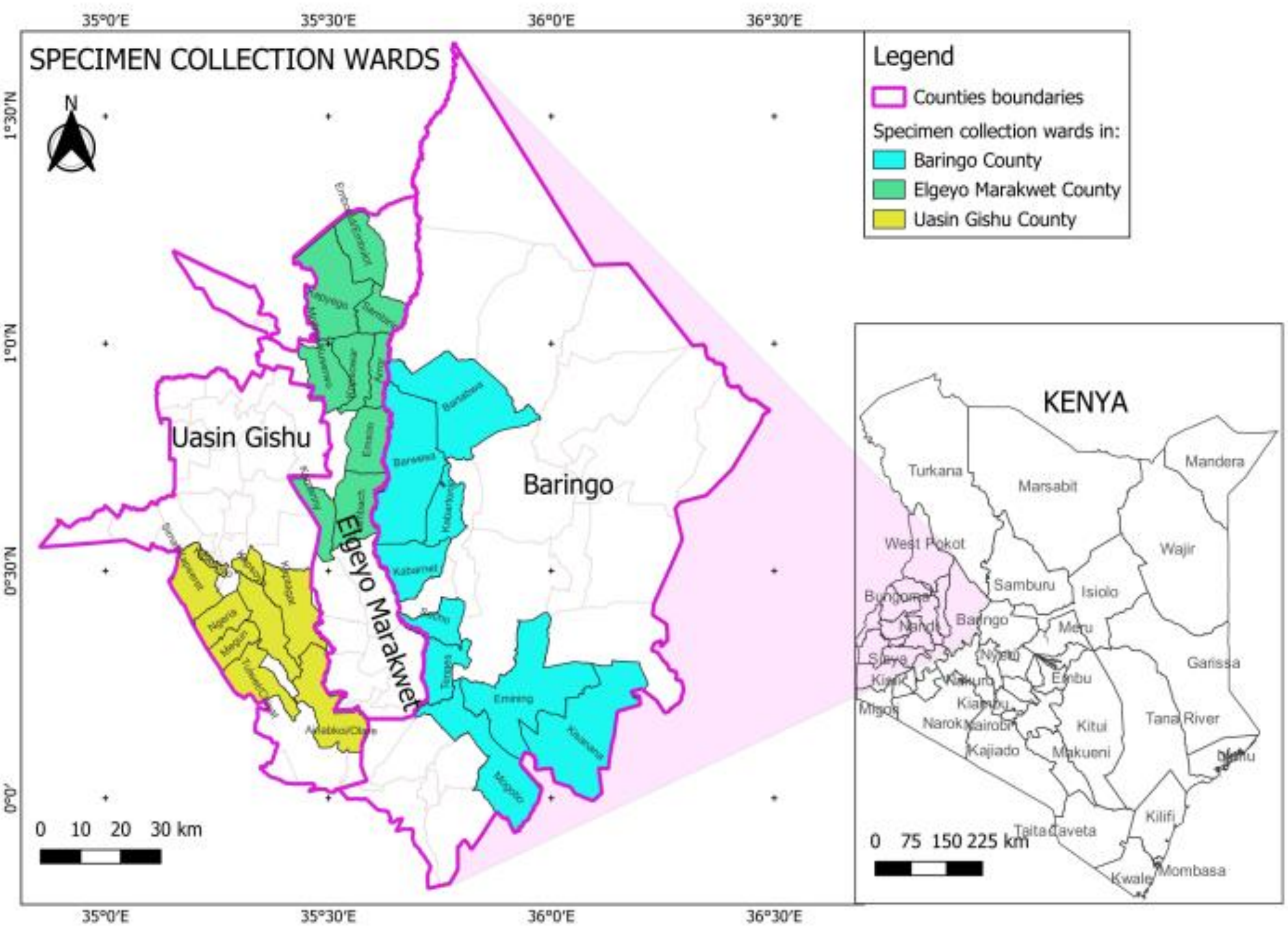

Figure 1: A Map of Kenyan County wards showing the sources of pumpkin accessions

Data collection

There were 96 pumpkin accessions that grew to maturity and had data scored for vegetative, inflorescence, and fruit attributes. Data was collected and recorded according to IPGRI descriptors for cucurbits (IPGRI, 2003). The scored quantitative traits included: Number of: female flowers, male flowers, branches, nodes to 1stfruit, nodes on the main vine, leaves on the main vine, and lobes per leaf. internode length, peduncle length (male), peduncle length (female), central leaf length, central leaf diameter, vine length at ten weeks, plant width, plant height, number of ribs on fruit, weight of healthy fruits per plant, fruit length, fruit width and endocarp length. The qualitative parameters scored were stem colour, leaf pubescence, leaf colour, leaf glossiness, leafiness, branching pattern, flower colour, and blossom end shape.

Sixty-one pumpkin accessions planted in Eldama Ravine and UoE were analyzed for yield and yield–related parameters. The plant population per ha in both sites was 2500/Ha. The yield-related parameters analyzed were: length of main stem, number of plants/accession at harvest, total number of fruits/accession, weight of healthy fruits, fruit length, fruit width, and endocarp length, average fruit weight /one plant in accessions, plant population x average fruit weight of one plant, plant population x average weight of one plant.

Data analysis

Collected data were statistically analyzed using OriginPro® 2022 software, OriginLab Corporation, Northampton, United States. Pearson's correlation coefficient of similarity was calculated to identify genetic similarities among accessions. Principal component analysis (PCA) was computed to identify the most discriminating morphological characters. Hierarchical cluster analysis (HCA) was used to generate a dendrogram and determine the similarity of the accessions based on the parameters. Anova was used to compare the yields between the two sites

Results

Pearson's correlation coefficient of quantitative characteristics.

Pearson's correlation was performed to determine the degree of relationships between the selected parameters. Based on the correlation data, most associations had positive correlations with only one negative association. Female flowers showed a significant positive correlation at $p \leq 0.05$ with male flowers, the node of the first fruit, internode length, peduncle length male, and plant height. Alternatively, the male flower showed a significant positive correlation at $p \leq 0.05$ with the number of branches and leaves on the main vine. In contrast, it had a significant negative association at $p \leq 0.05$ with the number of ribs on the main fruit.

The number of branches per plant showed a highly significant positive correlation at $p \leq 0.001$ with the number of nodes of the first fruit, nodes on the main vine, leaves on maim vine, lobes per leaf, vine length in 10 weeks, and fruit weight. On the other hand, it showed a significant positive correlation with plant height and fruit length. Nodes of the first fruit had a significant positive correlation at $p \leq 0.05$ with nodes on the main vine and plant height. Nodes on the main vine had a significant positive correlation at $p \leq 0.05$ to the fruit weight, while it displayed a highly significant positive correlation at $p \leq 0.001$ with leaves on the main vine, lobes per leaf, and vine length at ten weeks.

The number of leaves on the main vine had a significant positive correlation at $p \leq 0.05$ to fruit weight. It also had a highly significant positive correlation at $p \leq 0.001$ with the lobes per leaf and vine length (m). Lobes per leaf showed a significant positive correlation at $p \leq 0.05$ to central leaf length and a highly significant positive correlation at $p \leq 0.001$ to vine length. Internode length reported a significant positive correlation at $p \leq 0.05$ with central leaf length, vine length at ten weeks, and plant height.

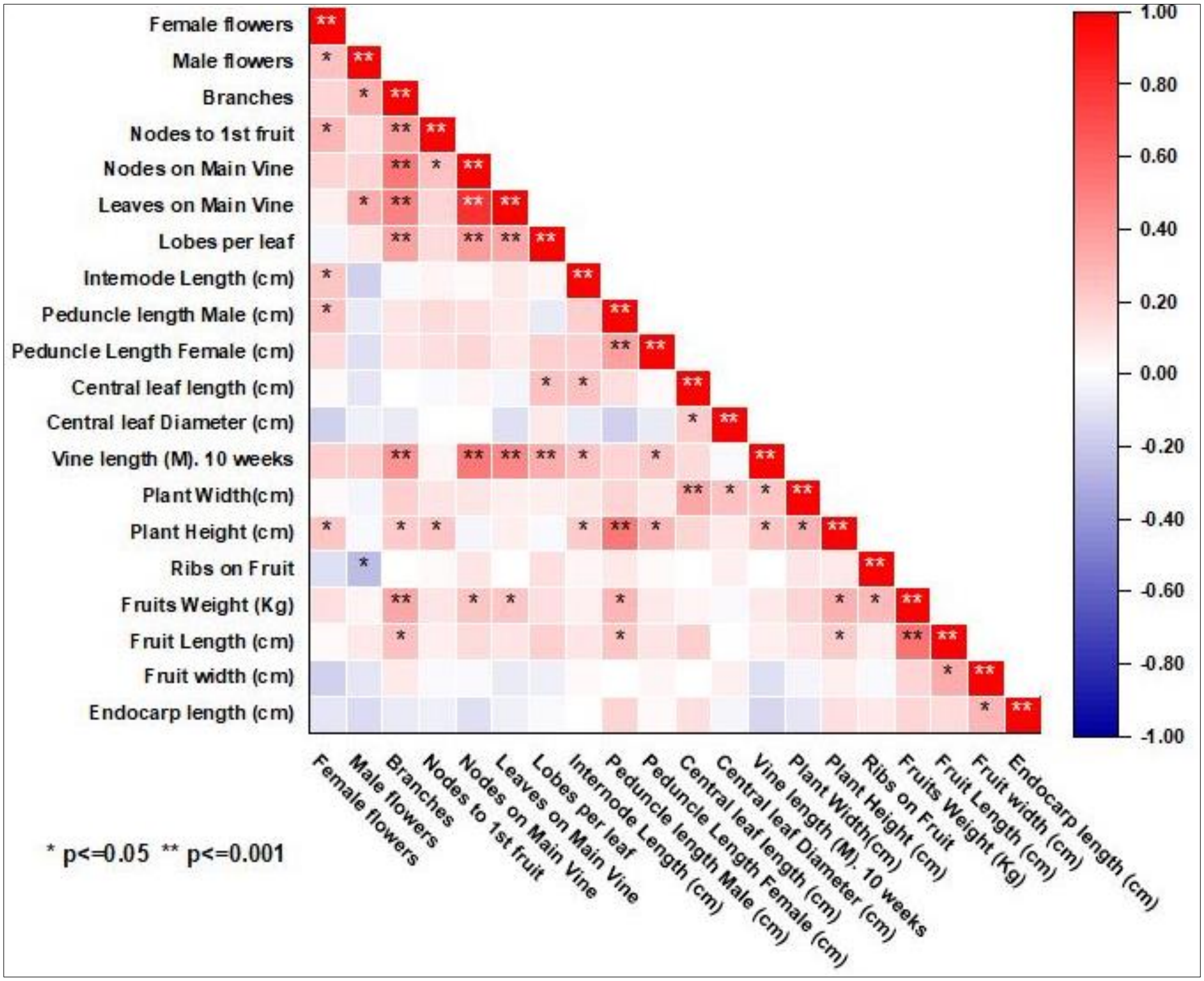

Figure 2. Pearson's correlation coefficient of quantitative characteristics of pumpkin accessions.

*Red colour – positive correlation: Blue colour – negative correlations. The higher intensity of the color in the scale indicates a higher magnitude. Color Key – the intensity of correlation. * Significant relations at p≤ = 0.05; ** highly significant at p≤ = 0.001*

The peduncle length male had a significant positive correlation at p ≤ 0.05 with fruit weight and the fruit length. On the other hand, it had a highly significant positive correlation at p ≤ 0.001 with peduncle length female and plant height. The peduncle length female showed a significant positive correlation at p ≤ 0.05 with vine length at ten weeks and plant height. The peduncle width and plant height had a significant positive correlation at p ≤ 0.05. Also, plant height showed a significant positive correlation at p ≤ 0.05 with fruit weight and fruit length.

The number of ribs on fruit and fruit weight, fruit length, and fruit width; fruit width and endocarp length each had a significant positive correlation at p ≤ 0.05. At the same time, fruit weight and fruit length showed a highly significant positive correlation at p ≤ 0.001.

Variations in quantitative traits of pumpkin accessions

Analysis was done to determine each parameter's minimum, maximum and mean values (Table 1). The results showed that the number of female flowers in all accessions ranged from 2 (KIS 173) to 5.7 (EMS 221) with a mean of 3.5±0.8, while the number of male flowers ranged from 6 (ARR 263) to 27 (KPR 249) with a mean of 16.3±4.1. The nodes to 1st fruit ranged from 13.7 (CHE 258) to 26.7 (SIM 082) with a mean of 20.3±2.8. The nodes on the main vine ranged from 21.3 (KAPS 023) to 37 (SIM 082), with a mean of 30.6±3.2. The number of branches ranged from 14 (KAPS 023) to 34.7 (KAP 010), with a mean of 23.7±3.4. The nodes on the main vine ranged from 21.3 (KAPS 023) to 37 (SIM 082), with a mean of 30.6±3.2. The leaves on the main vine ranged from 21.1(END 181) to 37 (SIM 082) with a mean of 30.3±3.2. Peduncle length Male (cm) ranged from 10.7 (END 183) to 40.7 (KAP 011) with a mean of 19.2±4.8. Plant height (cm) ranged from 16.3 (END 181) to 48 (KAP 011) with a mean of 30.1±6.2. Ribs on fruit ranged from 0 (NGE 066) to 18 (MUG 037) with a mean of 7.5±5.2. Fruit weight (Kg) ranged from 2.1 (SIM 085) to 10 (MEG 052) with a mean of 4.3±1.6.

The weight of healthy fruits was lowest in KAPS024 (2.100 ± 1.339 Kgs) and highest in MEG052 which posted a mean weight of (10.00 ± 1.399 Kgs). The shortest fruit length was recorded in SIM085 (8.33 ± 5.318 cm), and the longest was in MEG052 (52.667 ± 5.318cm). The least fruit width was recorded in SIM085 which measured 5.667 ±3.482 cm. The widest fruits were observed in RANJIT, which measured 31.333 ± 3.482 cm wide. The endocarp length of KBT091 was the shortest, while KAM215 had the longest endocarp. They measured 1.700 ± 0.635 and 5.500 ± 0.635 cm respectively.

Table 1: Descriptive statistics of the 96 pumpkin accessions.

Parameters	Mean	Acc No.	Min.	Med.	Acc No.	Max.
Female flowers	3.5±0.8	KIS 173	2.0	3.3	EMS 221	5.7
Male flowers	16.3±4.1	ARR 263	6.0	15.8	KPR 249	27.0
Branches	23.7±3.4	KAPS 023	14.0	24.0	KAP 010	34.7
Nodes to 1st fruit	20.3±2.8	CHE 258	13.7	20.3	SIM 082	26.7
Nodes on Main Vine	30.6±3.2	KAPS 023	21.3	31.0	SIM 082	37.0
Leaves on Main Vine	30.3±3.2	END 181	21.1	31.0	SIM 082	37.0
Lobes per leaf	4.3±0.7	KAPS 023	3.0	4.3	SIM 082	5.0
Internode Length (cm)	19.8±4.0	KAP 001	10.0	20.0	KBT 091	36.7
Peduncle length male (cm)	19.2±4.8	END 183	10.7	18.3	KAP 011	40.7
Peduncle Length Female (cm)	11.3±8.5	KAP 001	3.0	8.2	KAPS 026	49.0
Central leaf length (cm)	20.1±3.7	KAB 123	14.7	19.3	CHE 255	39.7
Central leaf Diameter (cm)	29.3±5.3	ARR 268	19.3	28.8	KIS 171	50.3
Vine length (M). 10 weeks	7.3±0.9	KAP 001	3.5	7.4	KPR 249	8.8
Plant Width(cm)	55.4±8.2	BAR 131	32.3	56.2	KAPS 021	73.3
Plant Height (cm)	30.1±6.2	END 181	16.3	29.3	KAP 011	48.0
Ribs on Fruit	7.5±5.2	NGE 066	0.0	9.2	MUG 037	18.0
Fruits Weight (Kg)	4.3±1.6	SIM 085	2.1	4.0	MEG 052	10.0
Fruit Length (cm)	22.8±6.1	SIM 085	8.3	21.7	MEG 052	52.7
Fruit width (cm)	18.3±4.0	SIM 085	5.7	17.7	RANJIT	31.3
Endocarp length (cm)	3.4±0.7	KBT 091	1.7	3.3	KAM 215	5.5

***Legend**: Acc. No. = Accession number; Min = Minimum; Max. = Maximum; Med. = Median.*

Growth and yield attributes across agro-ecological sites

Eldama ravine posted higher scores for total number of fruits/accession (6.43) and length of main stem (7.25 m) compared to UoE which recorded 5.97 fruits/accession and 5.61 m respectively. All other parameters were lower in Eldama Ravine than those scored at university of Eldoret site (Figure 3). These included: Numbers of plants/ accession at harvest (1.69 and 2.28), average fruit weight/one plant in accession (4.22 and 4.44 kg), weight of healthy fruits (4.44 and 6.24 kg), fruit length (22.82 and 23.39 cm), fruit width (18.62 and 18.74 cm) and endocarp length (3.26 and 4.13 cm).

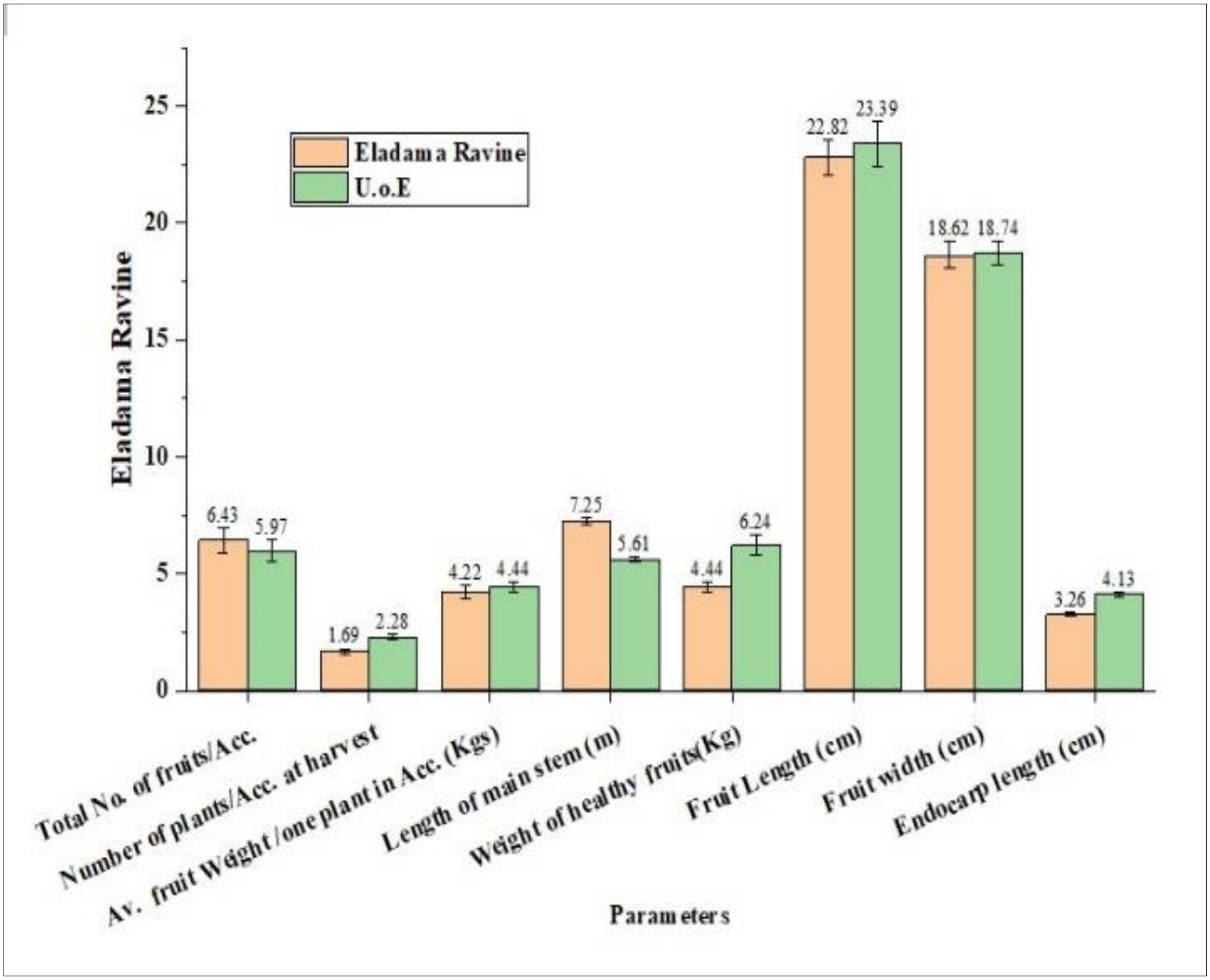

Figure 3: Bar graphs showing yield- related performance at Eldama Ravine and University of Eldoret agro ecological sites

Cluster analysis

The analysis of all morphological and agronomic traits identified three distinct clusters (Figure 4). The first cluster had 93 accessions; the 2nd cluster had one accession (MEG 052), while the third cluster had two accessions (KAPS 026, KAP 011). Based on the results, the most representative observation for the first cluster was NGE 061, the second cluster was MEG 052, and the third cluster was KAP 011 (Figure 4). The clustoid information of the most representative observation means that these accessions represent the general characteristics of the remaining accessions when all parameters are considered. MEG 052 and KAP 011 had the highest fruit weight (Kg) of 10 and 9.17 Kgs, respectively.

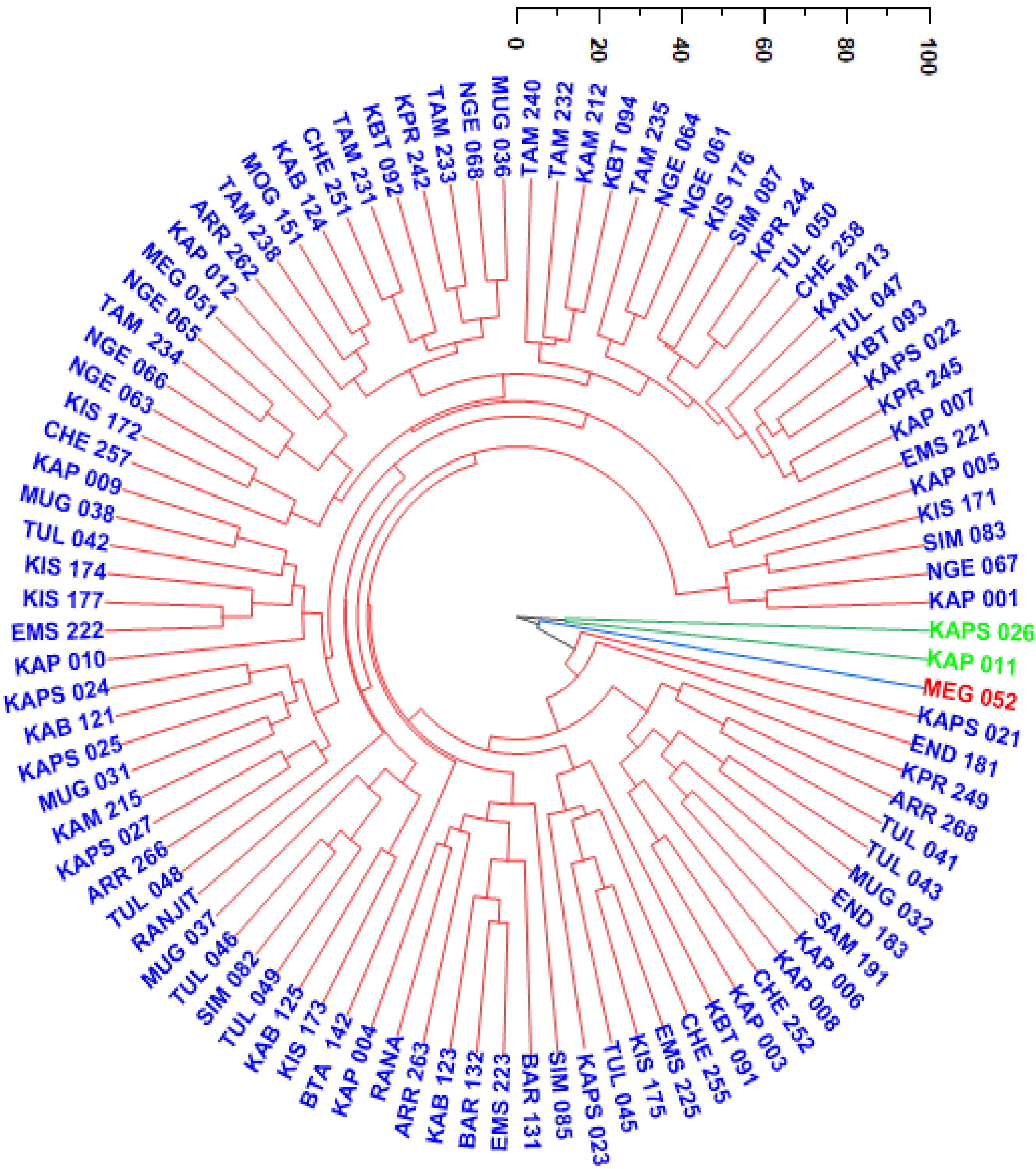

Figure 4: Relatedness dendrogram based on morphological traits and yield traits of 96 pumpkin accessions.

The colours indicate the different clusters. The closer the samples, the higher the level of similarity between them, and they have been clustered using hierarchical clustering (Ward, Euclidean distance)

Principal Component Analysis (PCA) of qualitative characteristics

The first to the sixth principal components contributed 19.11%, 11.68%, 8.71%, 8.15%, 6.52%, and 5.77% of the variations, as shown in Tables 2.

Table 2: Eigenvalues, percentage variances, and cumulative morphological variables

PC	Eigenvalues	% Variance	Cumulative
1	3.82194	19.11%	19.11%
2	2.33535	11.68%	30.79%
3	1.74106	8.71%	39.49%
4	1.62996	8.15%	47.64%
5	1.30433	6.52%	54.16%
6	1.15419	5.77%	59.93%
7	0.99683	4.98%	64.92%
8	0.94564	4.73%	69.65%
9	0.86068	4.30%	73.95%
10	0.80652	4.03%	77.98%
11	0.70909	3.55%	81.53%
12	0.63453	3.17%	84.70%
13	0.57884	2.89%	87.59%
14	0.50491	2.52%	90.12%
15	0.48834	2.44%	92.56%
16	0.38814	1.94%	94.50%
17	0.35661	1.78%	96.28%
18	0.35368	1.77%	98.05%
19	0.29933	1.50%	99.55%
20	0.09004	0.45%	100.00%

The 1st principal component strongly correlates with six variables: branches, nodes of the main vine, leaves on the main vine, lobes per leaf, vine length at 10 weeks, and fruit weight. This suggests that these six criteria vary together and contribute to 19.11% (Table 3) of the variation in the accessions. Therefore, 19.11% of the accessions with many branches also had highest number of the other five variables. 2nd PC variations were brought about by male flowers, nodes on the main vine, leaves on the main vine, peduncle length male (cm), plant height (cm), and endocarp length (cm). The 3rd PC variations were influenced by female flowers, lobes per leaf, peduncle length male (cm), central leaf diameter (cm), fruit length (cm), and fruit width (cm). 4th PC variations can be explained by central leaf length (cm), central leaf diameter (cm), plant width (cm), and fruit weight (Kg), and fruit width (cm). The 5th PC was influenced by male flowers, peduncle length female (cm), central leaf diameter (cm), and ribs on fruit. PC 6 variations were contributed by nodes to 1st fruit, internode length (cm), central leaf length (cm), ribs on fruit, and fruit width (cm).

Table 3: Principal component coefficients values

	Principal Component Coefficients					
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Female flowers	0.18	-0.02	**-0.46**	-0.15	0.18	0.03
Male flowers	0.14	**-0.32**	-0.04	-0.22	**0.42**	0.15
Branches	**0.37**	-0.16	0.12	-0.12	0.15	-0.07
Nodes to 1st fruit	0.21	-0.04	-0.14	-0.09	0.23	**-0.32**
Nodes on Main Vine	**0.37**	**-0.27**	0.13	0.03	-0.20	-0.03
Leaves on Main Vine	**0.35**	**-0.30**	0.11	-0.05	-0.19	0.07
Lobes per leaf	**0.25**	-0.13	**0.26**	0.22	-0.16	0.09
Internode Length (cm)	0.14	0.20	-0.24	0.18	-0.24	**0.33**
Peduncle length male (cm)	0.22	**0.33**	**-0.29**	-0.14	-0.09	-0.06
Peduncle Length Female (cm)	0.19	0.17	-0.22	0.02	**-0.30**	0.03
Central leaf length (cm)	0.12	0.23	0.07	**0.42**	0.16	**0.36**
Central leaf Diameter (cm)	-0.02	0.08	**0.25**	**0.42**	**0.34**	-0.13
Vine length (M). 10 weeks	**0.34**	-0.15	-0.09	0.22	-0.14	0.18
Plant Width(cm)	0.18	0.17	0.00	**0.38**	0.33	-0.16
Plant Height (cm)	0.24	**0.35**	-0.22	-0.01	0.18	-0.12
Ribs on Fruit	0.07	0.17	0.20	0.11	**-0.35**	**-0.58**
Fruits Weight (Kg)	**0.26**	0.22	0.23	**-0.26**	0.07	-0.20
Fruit Length (cm)	0.22	0.24	**0.29**	-0.23	0.15	0.18
Fruit width (cm)	0.01	0.24	**0.35**	**-0.25**	0.05	**0.25**
Endocarp length (cm)	-0.01	**0.30**	0.21	-0.23	-0.13	0.20

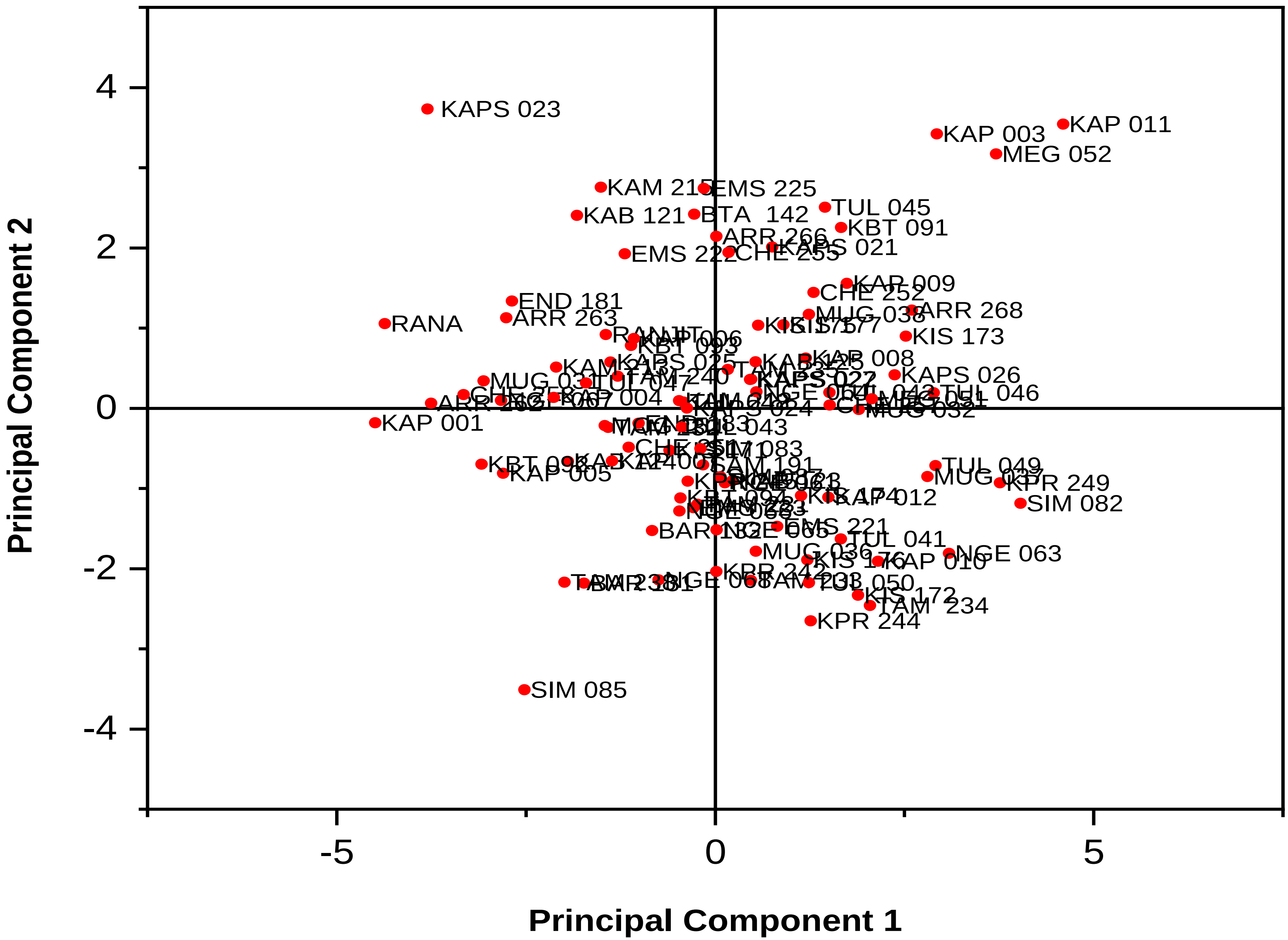

Figure 6: A principal component analysis score plot showing the distribution of pumpkin accessions. X-axis – PCA 1; Y-axis – PCA 2.

The score plots display the distribution of the accessions based on all the twenty variables. The Figure 6 shows that accessions further out away from others are either outliers or naturally extreme observations. Each dot represents a specific accession (for instance KAPS 023, SIM 085, KAP 003, KAP 011 and MEG052). Accessions with some similarity will be similar in the score plot, while accessions much further apart are dissimilar.

Qualitative parameters of 96 pumpkin accessions

Qualitative characteristics were scored for the pumpkin accessions. As shown in Figure 4.
Out of the 96 accessions, stem colour was distributed as follows: dark green, light green and intermediate were 39.6%, 22.9% and 37.5 %, respectively. Leaf characteristics consisted of: colour, pubescence, glossiness, and leafiness.

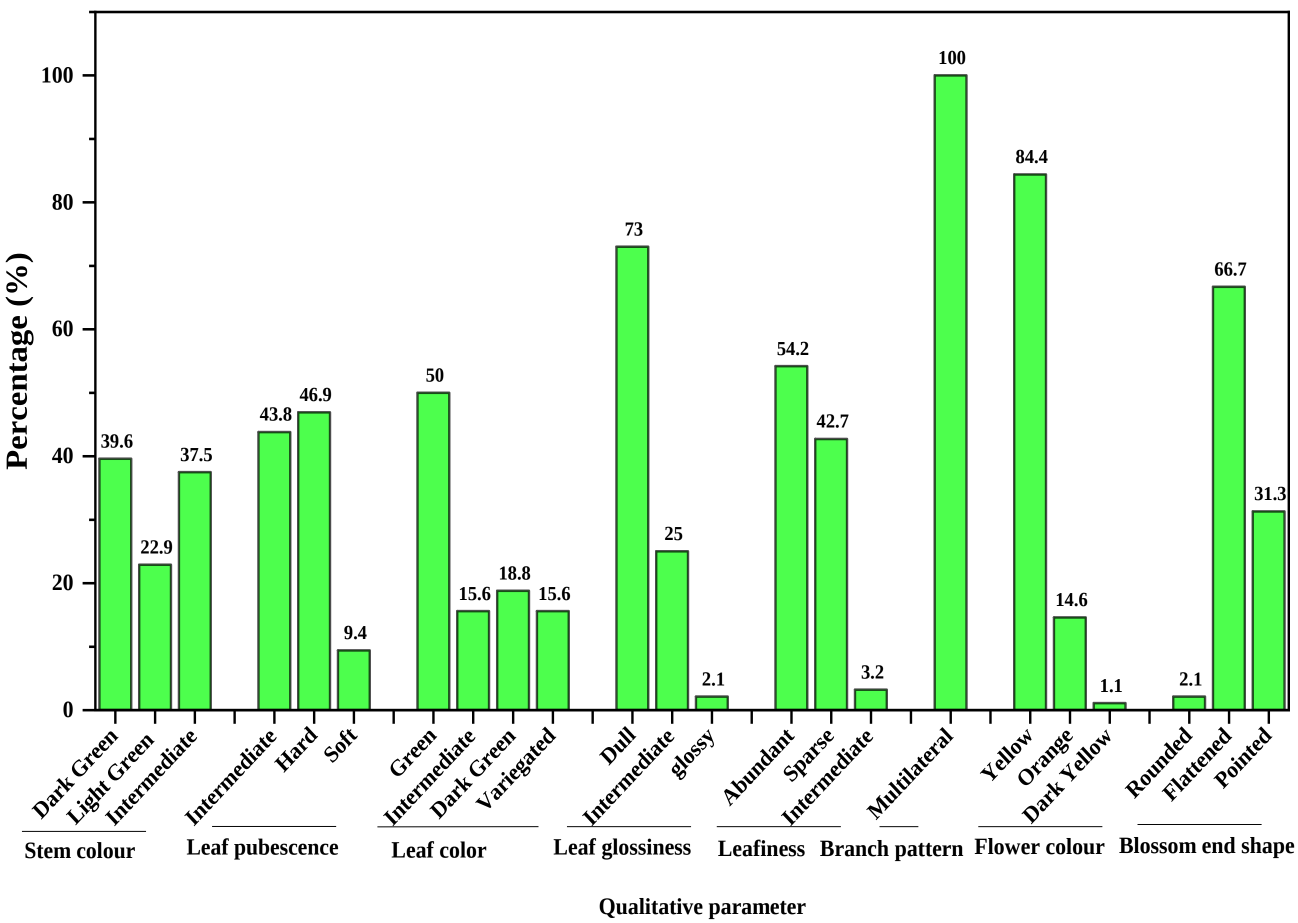

Figure 7: A summary of qualitative characteristics of pumpkin accession

Pumpkin stem colours were distributed as follows: dark green (39.6%), light green (22.9%) and intermediate (37.5%). The following leaf pubescence characteristics was observed: hard (46.8%), intermediate (43.8%) and soft (9.4 %) respectively. The leaf colors were green (50.0%), intermediate (15.6%), dark green (18.8%), and variegated (15.6%). The leaf glossiness was dull (70%), Intermediate (25%), and glossy (2%). Finally, leafiness was abundant or sparse at 54.1%, 42.9%. All accessions had a multilateral branching pattern. The flowers were yellow (85.5%) or orange 14.5% in color. The blossom end shape was flattened (68.8%), and pointed (31.2) % respectively. Combined yield analysis of Eldama Ravine and UoE sites. Sixty one pumpkin accessions planted in Ravine and UoE were analyzed for yield.

Table 4: ANOVA combined output for Eldama ravine and university of Eldoret

Source of variation	Df	Sum Sq.	Mean Sq.	F value	p-value	
Pumpkin accessions	60	1684.4	28.074	5.281	5.28E-15	***
Rep	2	0.2	0.095	0.018	0.982	
Residuals	120	638	5.316			

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

For "Pumpkin accessions," the p-value is very small (5.28E-15 or approximately 0.000000000000005), indicated by "***." (Table 4). This suggests that there are significant differences between the "Pumpkin accessions" groups. In summary, the ANOVA table shows that there are statistically significant differences between the "Pumpkin accessions" groups, as indicated by the very small p-value. However, there are no significant differences between the "rep" groups.

Table 5: Post hoc analysis on yield for Eldama Ravine and University of Eldoret sites

No.	Acc.	Mean
1	MUG038	17.3 ± 1.8^{a}
2	KAP 008	16.1 ± 2.0^{ab}
3	NGE 065	12.2 ± 0.7^{bc}
4	KAPS025	11.1 ± 1.3^{bcd}
5	TUL 048	11.1 ± 4.5^{bcd}
6	NGE 067	9.7 ± 1.3^{bcde}
7	TUL 041	9.4 ± 0.6^{abcde}
8	RANJIT	8.5 ± 0.8^{bcdef}
9	CHE 257	7.3 ± 0.9^{cdef}
10	RANA	7.1 ± 1.9^{cdef}
11	KAB 124	6.7 ± 1.7^{cdef}
12	NGE 063	6.7 ± 1.6^{cdef}
13	KAP 007	6.5 ± 0.4^{cdef}
14	MEG 051	6.5 ± 0.8^{cdef}
15	KAP 010	6.2 ± 2.7^{cdef}
16	KAP 012	6.2 ± 1.5^{cdef}
17	TUL 049	6.0 ± 0.8^{cdef}
18	END 181	5.8 ± 1.0^{cdef}
19	KAP 011	5.8 ± 1.0^{cdef}
20	KAPS022	5.7 ± 0.1^{cdef}
21	TAM 240	5.6 ± 0.9^{cdef}
22	KIS 177	5.5 ± 1.4^{cdef}
23	TUL 043	5.4 ± 0.5^{cdef}
24	TUL 047	5.4 ± 1.5^{cdef}
25	KAM 212	5.3 ± 0.7^{cdef}
26	KAP 009	5.3 ± 0.9^{cdef}
27	KPR 242	5.2 ± 1.2^{cdef}
28	EMS 223	5.1 ± 0.8^{cdef}
29	KAP 003	5.0 ± 0.8^{cdef}

30	EMS 222	4.7±0.1^{cdef}
31	NGE 061	4.7±0.5^{cdef}
32	NGE 064	4.6±1.6^{cdef}
33	SIM 083	4.6±0.6^{cdef}
34	KAPS027	4.6±1.0^{cdef}
35	NGE 066	4.5±1.1^{cdef}
36	KIS 171	4.5±1.3^{cdef}
37	END 183	4.3±0.4^{cdef}
38	TUL 050	4.3±0.8^{def}
39	KAM215	4.0±1.0^{def}
40	ARR 263	4.0±0.3^{def}
41	KBT 091	4.0±0.9^{def}
42	NGE 068	3.9±0.7^{def}
43	CHE 252	3.8±1.3^{def}
44	KAPS024	3.7±0.6^{def}
45	TAM 231	3.7±0.6^{def}
46	TAM 235	3.7±0.9^{def}
47	SIM 085	3.7±0.5^{def}
48	KIS 172	3.7±1.6^{def}
49	KAM213	3.6±1.4^{def}
50	KAPS026	3.3±0.9^{def}
51	MOG151	3.3±1.1^{def}
52	ARR 268	3.2±0.2^{def}
53	MUG031	3.0±0.9^{ef}
54	KIS 174	3.0±1.4^{ef}
55	ARR 266	2.9±0.9^{ef}
56	KBT 092	2.5±0.3^{ef}
57	KAP 001	2.2±0.2^{ef}
58	KPR 244	2.1±0.0^{ef}
59	TAM 234	2.1±0.7^{ef}
60	KAB 125	1.8±0.2^{ef}
61	KIS 173	1.3±0.4^{f}

Comparison between the two sites (two sample t-test)

Table 6: t-test output of two sites

Characteristics	Ravine	UoE	p-value[2]
Yield	4.4(4.3)	6.5 (5.4)	< 0.001
N	N = 183[1]	N = 183[1]	

[1] Mean (SD)
[2] Welch Two Sample t-test

The results show that the mean yield in the "Ravine" group is approximately 4.43, while the mean yield in the "UoE" group is approximately 6.48 (Table 6). The t-test indicates there is strong statistical evidence to suggest that the mean yield in the "Ravine" group is significantly lower than the mean yield in the "UoE" group (Figure 8); (t = -4.0478, df = 364, p-value = < 0.001). Table 5 shows the combined yield analysis between the two sites, MUG 038 gave the highest yielded followed by KAP 008 and the least yield was in KIS 173 accession.

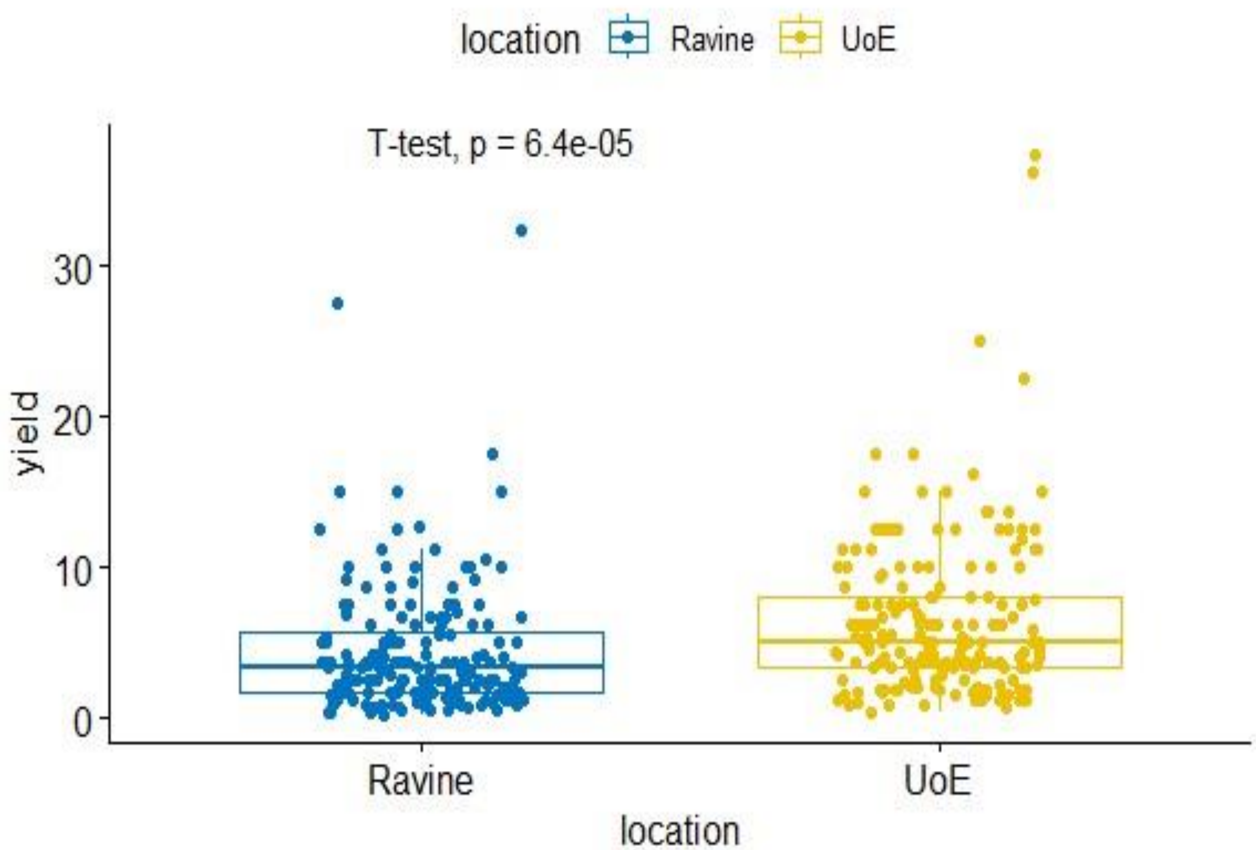

Figure 8: A graphical representation of yields of Eldama Ravine and University of Eldoret.

Discussion

Pumpkin is a traditional crop widely grown for its mature fleshy fruits, seeds, flowers and leaves. It has high yield potential, nutritional value, and a long shelf life (Kesh & Yadav, 2023). The longer the male peduncle, the longer the female peduncle, and the higher the fruit weight, fruit length, and plant height. The accessions with a long female peduncle reported an increased plant height and long vines. The taller the plants; the longer the fruit and the heavier fruits. Ezin *et al*. (2022) reported that the male flower peduncle was longer than the female ones for all varieties. According to OECD (2016), length difference of reproductive organs aid cross-pollination in *Cucurbita moschata*.

In our study, the fruit characteristics such as fruit weight, length, width, and endocarp length were positively linked. Therefore, it could be inferred that the average fruit weight is proportional to the fruit length and diameter. According to (Aruah *et al*., 2010), the number of fruits per plant of Nigerian accessions was 4.67 to 8. (Ahamed et al., 2012) recorded 2 to 16 fruits per plant in northern Bangladesh. (Labrada *et al*., 1997) also reported that among 34 landraces, 25 could produce more than 4–

5 fruits per plant. The high number of fruits per plant at the genotype level of pumpkin in northern Bangladesh could be explained by three factors: improved genotypes, soil fertility, and suitable environmental conditions (Ezin *et al*., 2022).

Our study reported the weight of healthy fruits as 2.1 to 10.0 Kgs, with a mean weight of 4.3Kgs and an average fruit weight per plant per accession to range from 1 to 9.2 Kgs (PROTA, 2018) demonstrated that the average fruit weight depends on the cultivar type, ranging from 1 to 10 kg. Bembe *et al*., (2016) recorded an average fruit weight of 1.80 kg, with individual weights ranging from 1 to 2.5 kg. Taboula *et al*., (2015) stated that fruit weight of *C. moschata* and *C. maxima* can be used as a good criterion for selecting individuals with many seeds.

The smallest fruit width was SIM085 (5.667 ±3.482 cm) while the widest fruit was observed in accession RANJIT, which measured 31.333 ± 3.482 cm the results were similar to those of (Ezin *et al.*, 2022) who reported the length and diameter of fruits ranging from 6.65 to 47.24 cm and 10.12 to 55.84 cm, respectively. (Ahamed *et al*., 2012) showed that fruit diameter varies from 46.3 to 77.1 cm among the pumpkin genotypes in northern Bangladesh. According to (Ezin *et al*., 2022), increasing fruit length and diameter contributes to increasing fruit weight and number of seeds per fruit. Hence, the fruit weight of *Cucurbita moschata* could be used as good criteria for selecting individuals with many seeds. (Priori *et al*., 2018) reported that consumers' critical characteristics during marketing are linked to fresh matter (fruit weight).

The total number of fruits per accession in the current study ranged from 1 to 16, with a mean of 5.97; these results were similar to those of (Ahamed *et al*., 2012) who recorded 2 to 16 fruits per plant in northern Bangladesh. a value that was almost similar but slightly higher than the 1-4 fruits per plant reported by (Ezin *et al*., 2022). Notably, According to (Aruah *et al*., 2010), the Nigerian accessions had a range of fruits per plant of 4.7 to 8. Chaudhari, (2017) indicated that number of fruits per plant, fruit weight, flesh thickness, polar circumferences of fruit and equatorial circumferences of fruit can be used as useful selection criteria to increase fruit yield per plant in pumpkin.

Results in Table 1 show scores of male flowers having a higher mean length than female flowers. In this study, female flowers in all accessions ranged from 2 (KIS 173) to 5.7 (EMS 221) with a mean of 3.5±0.8, while the male flowers ranged from 6 (ARR 263) to 27(KPR 249) with a mean of 16.3±4.1. This study gave the ratio of male to female flowers as 1: 4, the findings were comparable to those of (Mohsin *et al.*, 2016) who reported a high and low male-to-female flower ratio in Bangladesh pumpkin genotypes of 12.11: 4.08 and 10.24: 3.27, respectively. Aruah *et al*., (2010) showed that the highest male-to-female flower ratio within Cucurbita accessions was 66: 8.67, while Agbagwa *et al*., (2007) had a male-to-female ratio of 9: 1 with yellow flowers in Nigerian *Cucurbita moschata* varieties. Generally, the pumpkin accessions had more male flowers than female flowers. According to Lim, 2019 the expression of the male sex is favored by high temperature and long day length. As a result, male flowers are more in number than female flowers. According to (Kesh and Yadav, 2023), the male flowers are on strong five-ridged pedunculate raceme with a long peduncle, while the female flower is always solitary with a short peduncle.

According to OECD (2016), pumpkin has hard and slightly fluted vines. Our results showed that the number of leaves on the primary vine influences fruit weight, lobes per leaf, and the length of the vine. On the other hand, accessions with high lobes per leaf also had long vines, long central leaves, long internodes, and tall plants. Furthermore, the vine length at ten weeks ranged from 3.5 to 8.8 meters with a mean of 7.3, while the leaves on the main vine ranged from 21.1 to 37 with a mean of 30.3±3.2 (Table 1). (Ezin *et al.*, 2022) reported lower vine lengths ranging from 1.0 to 3.07 m and the higher number of leaves that ranged from 24.56 to 95.50 per plant in the tenth week after sowing. Also, (Aruah *et al*., 2010) obtained extensive branch lengths and leaf numbers that ranged from 3.8 to 7.07 m and 97.70 to 210, respectively. The difference in the results could be attributed to the different types and number of accessions and also the mineral fertilizers applied. According to Ezin *et al.*, (2022), high soil fertility stimulates good vine growth and high leaf production. (PROTA, 2018) showed that plant growth of pumpkins is indeterminate under suitable conditions, and vines can exceed 20 m in length.

The present study revealed qualitative diversity in leaf, stem, and flower color (Figure 7), an observation that was in line with the findings of (Aruah et al., 2010) who stated that pumpkin leaves had a high variability. They can be light green, dark green, and variegated in colour. According to (Kiramana & Isutsa, 2017), the leaves of most accessions were green, dark green, and diverse in colour. We report that leaf color in most accessions was green with dull surfaces and abundant leaves. The flower color was yellow with a flattened blossom end shape. The qualitative color description and comparison model of (Falomir et al., 2011) was used for qualitative variables' measurement. These characteristics help distinguish *C. moschata* from other cultivated *Cucurbita* species (Agbagwa, I & Ndukwu, 2004). Morphological characteristics of the leaves, such as shape, size, margin, and color, are diagnostic and essential tools in identifying pumpkins at the genus level (Kiramana & Isutsa, 2017). Qualitative traits such as fruit color and flesh color can be used to distinguish between *C. Moschata* genotypes (Ahamed et al., 2012).

Principal component analysis was used to select fewer principal components that explain the variation in the accessions based on all the variables used. Table 2 shows eigenvalues and the % variance of respective principal components. According to (Darand,2014), eigenvalues above one are considered significant contributions to the variation in data. Therefore, in the variable statement, PC1 to PC6 were include and they contributed 59.93% of the variation and all variables explaining the data. The correlations between the principal components and the original variables were used to interpret these principal components (Table 3). Interpreting the PC is anchored on determining which variables are highly correlated to the specific components (the numbers that are high in magnitude farthest from 0 in either direction). Here we determine the level of correlation above 0.25 to be highly meaningful in each principal component. The first principal component strongly correlated with six variables: branches, nodes of the main vine, leaves on the main vine, lobes per leaf, vine length at ten weeks, and fruit weight. This suggests that these six parameters vary together and contribute to 19.11% (Table 3) of the accession variation. As a result, 19.11% of the accessions with many branches also had high numbers of the other five variables.

Principal component two contributed to 11.68% of the variation in the accessions. These variations were brought about by male flowers, nodes on the main vine, leaves on the main vine, peduncle length male (cm), plant height (cm), and endocarp length (cm). Hence accessions with high male flowers, high number of nodes on the main vine, and high number of leaves on the main vine had low peduncle length for male flowers (cm), low plant height (cm), and low endocarp length (cm). Principal component three contributed to 8.71% of the variation in the accessions. The variation in this component was influenced by female flowers, lobes per leaf, peduncle length male (cm), central leaf diameter (cm), fruit length (cm), and fruit width (cm). Principal component four contributed to 8.15% of the variation in the accessions. The variation can be explained by central leaf length (cm), central leaf diameter (cm), plant width (cm), fruit weight (Kg), and width (cm). Accessions with central leaf length (cm), central leaf diameter (cm), and plant width (cm) exhibited low fruit weight (Kg) and fruit width (cm) and vice versa. Principal component analysis five contributed to 6.52% of the variation in accession. These are male flowers, peduncle length female (cm), central leaf diameter (cm), and ribs on fruit. Here, accession with male flowers and central leaf diameter (cm) had low peduncle length female (cm) and the number of ribs on fruit. The final principal component six, contributed to 5.77% of the accession variation. These are nodes to first fruit, internode length (cm), central leaf length (cm), ribs on fruit, and fruit width (cm). Here, accessions with high/low nodes to the first fruit and ribs on the fruit also had high/low internode length (cm) and central leaf length (cm).

Based on the score plot in Figure 6, accessions with similar characteristics for instance, the KAP accessions are grouped based on growth and yield parameters (Figure 5), while table 1 shows that SIM 085 (2.1kg) had the lowest performance in yield.

Cluster analysis determined the high internal similarity and external heterogeneity between the accessions based on the selected parameters. The 93 accessions in cluster 1 were represented by the accession NGE 061 with a mean fruit weight of 5.33 Kgs; therefore, we can deduce that most accessions in cluster 1 had good yields, the two accessions (RANA and RANJIT) used as controls in the study were found in cluster 1. The second cluster was a singleton (MEG052) yielding 10 Kgs and was ranked as the highest-performing among all the pumpkin accession under this study. Cluster 3 had KAP 011 with a fruit weight of 9.2 Kgs and KAPS 026 that yielded 3.3 Kgs despite having the longest peduncle length female.

Yield Attributes across agro-ecological Zones

The yield of pumpkin accessions in ton /ha was higher at the University of Eldoret than at Eldama Ravine. They yielded fruits whose mean weights were 10.86 tonnes/ha and 9.95 tonnes/ha in Eldama Ravine and the University of Eldoret, respectively. These observations were way below Grubben and Ngwerume's (2004) findings, whose yield for the five largest pumpkin varieties ranged from 49.40 t/ha for Phatso II to 37 ton/ha for Solid Gold. They also reported that Super Herc, Gladiator, Magic Wand, RPX 1626, and ACX 7302 had yields lower than 37 ton/ha. The significantly higher values obtained in KAP 003 (E/R), KAP011 (E/R), NGE 062 (UOE) as well as SAM 192 (UOE) accessions over other pumpkin accessions tested could be attributed to superiority in their genetic constitution concerning vegetative growth and suitability of the accessions to the growing conditions of the study areas. These results were similar to the findings of Majanbu *et al*. (1996); and Ibrahim *et al*. (2000), who reported that the genetic constitution of crop varieties influences their growth characteristics. Shetty and Wehner (1998) reported that cucumber cultivars Poinsett-76 and Sprint-440 performed better than other varieties in vine length. Their good adaptations to the given climatic condition were attributed to the genetic nature of the cultivars. The differences in the growth characteristics of crop varieties, according to Maqsood *et al*., (2004), and Enujeke (2013b and 2013c), were attributed to leaf arrangement, the distribution of leaf surface and crop canopy, the photosynthetic activities of leaves, differences in the chlorophyll content, and also the activity of photosynthetic enzymes. The superiority of the accessions NGE062 (E/R) and RANJIT (UoE) in vegetative growth after planting may have probably been due to their efficiency in exhibiting their good genetic makeup to exploit the newly found favourable agro-climatic conditions within their study areas that promoted their rapid stem growth. These results were in harmony with reports of Akinfoesoye *et al.,* (1997) and Ray and Sinclair (1997), who attributed the growth characteristics of crop species not only to the genetic constitution of the crop but also to the suitable agro-ecological zone, which make them express their complete genetic resources for growth and yield enhancement. Clark *et al*., (1997) reported similar results. They attributed the differences in yield and its components between crop genotypes to variations in genetic structure, mineral concentration, and potential to transport photosynthetic materials within plants. Gavilanez-Slone (2001) reported that fruit weight is proportionate to the amounts of pollen deposited on the stigma. According to other studies, the variation in yield per fruit among cucurbit species and varieties depends on pollination efficiency, the pumpkin growing conditions as well as the area of the country (OECD, 2012; McCormarck, 2005).

Conclusion and recommendation

In conclusion, principal component descriptors that showed a significant difference in the analysis of variance can be used to discriminate the different landraces of pumpkins in Kenya. We found significant variations in the accessions for Phenological and growth parameters through characterizing morphological traits of stems, leaves, flowers, fruits, and seeds of pumpkin accessions which revealed agro-morphological and genetic variability. The fruit colour and shape descriptors, leaf colour, and seed colours showed great phenotypic variability. Pumpkin accessions can be characterized based on their morphological traits. Kenyan pumpkin accessions are high yielding. Therefore, these data could be used in breeding programs in Kenya for pumpkin productivity, thus contributing to improved food security.

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