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First detailed morphological characterisation of qualitative traits of extensive naturalized pumpkin germplasm in Kenya

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Abstract

Pumpkin (*Cucurbita moschata* (Lam.) Poir) is emerging as an important fruit-vegetable in Kenya. However, its economic and nutritional benefits remain under-exploited, while its conservation is threatened owing to limited characterization and utilization. The present study sought to enhance conservation and utilization of the invaluable pumpkin germplasm in Kenya. Subsequently, a survey was done in 2012, leading to collection of 155 accessions, comprising 70 from Kakamega and 85 from Nyeri Counties in Kenya. Characterization was done on-farm in a Completely Randomized Design, replicated three times. Green to orange mature fruit rinds, speckled to striped secondary fruit rinds, smooth to warty fruit surfaces, white to yellow internal flesh, and yellow to pink-red inner and outer flesh resulted. The leaves exhibited variegation, broadly ovate central lobes and outlines, soft pubescence and moderate senescence. The flowers were monoecious and mostly male and early. Nine accessions had early female flowers. Most accessions had orange flowers, globular fruits, second fruit cycle, multilateral branching, dark-green stems, superficial ribbing, small blossom-end scars, and easy seed and placenta separation. Seed colour ranged from cream-yellow to white, seeds were elliptical, sharply or bluntly pointed, with intermediate glossiness and tubercular surfaces. All accessions had large veins, dense adaxial and intermediate abaxial pubescence, pentalobate, shallow lobes and cordate leaves, fruit vein tracks, with peduncles detaching when overripe, and unwinged seeds with no pattern. The variation portrayed by fruits and seeds provides more selection criteria. The unique pumpkin accessions should be conserved to serve as resources for breeding and improvement of desired pumpkin varieties.

Keywords: Accessions; Agrobiodiversity; Cucurbita; Landraces; Phenotype

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1. Introduction

Pumpkin belongs to the family Cucurbitaceae, which has 8 tribes, 118 genera and 825 species (Jeffrey, 1990). It is one of the most morphologically variable genera in the entire plant kingdom (Aruah et al., 2010). The genus *Cucurbita* originated from Central and South America (Grubben and Chigumira-Ngwerume, 2004). There are three economically important *Cucurbita* species with different climatic adaptations (Balkaya et al., 2010a; 2010b). It is often not easy to distinguish *C. moschata* from, *C. pepo* and *C. maxima,* due to similar plant habit (Paris, 2000). *Cucurbita* species are warm season annuals, thriving in hot and humid weather (Aruah et al., 2010). *Cucurbita moschata* is the most heat-tolerant and common species of them all (Grubben and Chigumira-Ngwerume, 2004). Phenotypic diversity is high in fruit shape, size, colour and productivity, flesh quality, colour and thickness, seed number and size, among other characters (Whitaker and Robinson, 1986; Hernandez et al., 2005). Distinction is easiest by observing fruit shape, size, stalk, stems and leaves (Paris, 2000). *Cucurbita* species have spreading growth habit with tendrils at the leaf axils. Leaves are borne singly and lobed. The root system is extensive and shallow. Flowers vary in colour, size and shape, and are monoecious acuminate, and pentamerous with different shades of yellow colour. The flowers are borne on the axils of the leaves, with male and female ones on long and short peduncles, respectively (Aruah et al., 2010). The ratio of male to female flowers ranges from 4: 1 to 17: 1 per plant (Vallejo and Gil, 1998; Agbagwa et al., 2007). The flower ratios ensure cross pollination by bees and endogamy reduction (Whitaker, 1984). Fruit shape varies from cylindrical to globose or ovoid (Grubben and Chigumira-Ngwerume, 2004). The fruits vary in weight and have moderately hard rind, thick, edible flesh and a central seed cavity with numerous tan or soft-white seeds, covered with a protective testa (Robinson and Decker-Walters, 1997).

Morphological description using qualitative characters is used to provide information on genetic variability, identification and classification (Lima et al., 2012) and relationships (Radford, 1986). The characters to a great degree determine divergence of accessions (Borges et al., 2011). Qualitative traits are normally measured, counted, differentiated and documented (Xolisa, 2002), using the minimum list of descriptors (Kristkova et al., 2003). Kenya has a wide array of naturalized pumpkin germplasm, making it a secondary centre of diversity that warrants detailed characterization (Karuri et al., 2010). Presently, little information is available that can be used to delineate and standardize pumpkin accessions in Kenya (Gichimu et al., 2008, Kiramana et al., 2016a; 2016b; Kiramana and Isutsa, 2016; Kiramana et al., 2017; Kiramana and Isutsa, 2017a; 2017b). The present study was thus undertaken to characterize pumpkin accessions collected among smallholder farmers in Kakamega and Nyeri regions of Kenya using qualitative characteristics. This paper presents results of morphological characterization conducted to assess the variation between and within the collected pumpkin accessions. The paper is expected to provide valuable information on the accessions to prospective breeders and other professionals to utilize in creating new cultivars, as well as improve the existing ones.

2. Methodology

2.1. Research site

The 155 accessions collected in Kakamega and Nyeri Counties were planted on 23rd May, 2012 on the Chuka University research farm in a Complete Randomized Design (CRD) in three replications. All the accessions were planted at a standard spacing of 2 m x 2 m. Chuka University research farm lies at 0^{o} 19` S, $37^{o}$ 38` E and 1535 m above sea level. Annual rainfall is about 1,200 mm and bimodally distributed. Annual mean temperature is about 20^{o}C. Soils are mainly humic nitisols, deep, well weathered with moderate to high inherent fertility (Jaetzold and Schmidt, 1983; Jaetzold et al., 2005).

2.2. Site preparation

Land was ploughed and pulverized to a fine tilth using a fork hoe for easy and uniform germination of seeds. Planting holes measuring 60 cm^2 on the top by 60 cm depth were excavated, separating the top soil from the subsoil. The top soil was mixed with 24 kg of farm yard manure (FYM) and put back into each hole, leaving 15.24 cm unfilled portion (Muyekho et al., 2003). The holes were planted with five accessions. Recommended pesticide sprays were used to control pests and diseases. Moles were trapped manually. Weeds were removed when necessary. The plants were rain-fed, but watered with 20 L/hole every week up to fruit maturity, whenever rains failed.

2.3. Morphological characterization

Data recording began 20 days after emergence and was continued up to fruit maturity stage. Five plants per accession were selected and tagged for morphological characterization using IPGRI descriptors (IPGRI, 2003). Certain characters not in the IPGRI descriptor list were added and others in the list were removed. Qualitative characteristics were measured on leaves, stems, roots, inflorescences, fruits and seeds. The colour of fruits, leaves, stems and flowers were measured using a colour chart. Harvesting of mature fruits started on 7th September, 2012 and was continued until 11th October, 2012. Fruits for each accession were harvested separately and stored in raised wooden racks in a store to wait for morphological characterization.

2.4. Data analysis

Photographs were taken during all stages of characterization. Qualitative data were recorded for each accession and grouped in nominal categories. Frequency of qualitative characters was calculated for each descriptor state, numerically coded and expressed as actual and percentage modes to indicate variation of accessions.

3. Results

3.1. Vegetative, stem and root characteristics

Data on vegetative characterstics were recorded on 146 accessions that germinated successfully. Accessions KK-53, NY-75, 82, 104, 105, 108, 110, 121 and 122 did not germinate. Seedling vigour was intermediate, growth habit multilateral and main vine stem colour dark-green in most accessions. Seedling vigour was poor, growth habit determinate and stem colour light-green in few accessions. The growth rate from emergence to flowering (Stage I) was medium, while it was high after flowering (Stage II) in most accessions. Plant size was intermediate, nodes were many on the main vine up to and including the first tendril, and the internodes above the 10th to 15th node on the main vine were long in most accessions. Small, few nodes and short to intermediate internodes occurred in few accessions (Table 1). Internodal roots were present in all the accessions.

3.2. Leaf and inflorescence characteristics

The accessions were either variegated or green-leafed (Plate 1). The leaves were large and veined, with dense or intermediate pubescence on adaxial and abaxial surfaces, respectively. The leaf shape was pentalobate with shallow lobes and cordate base. Leaf outline was either broadly ovate or very broadly ovate. Most accessions had variegated leaves and moderate leaf senescence. Male flowers appeared early in most accessions. The female flowers appeared early in 9 accessions. Flower colour was orange and predominant fruit shape was globular. Second fruit cycle was observed in most accessions, with a few having no second fruiting cycle (Table 2). Flowers were monoecious, with ratio of male to female being mostly male in all accessions.

Table 1. Vegetative and stem characterstics

Character	**Descriptor state**	**Frequency and %**		**Accessions Code**
Seedling vigour	Poor	16	11	**KK** 5, 23, 58 & 60; **NY** 76, 77, 80, 87, 89, 96, 101, 127, 136, 138, 140 & 144
	Intermediate	75	51	**KK** 1-4, 6, 7, 10, 12, 13, 16, 19, 20, 22, 25, 27, 28, 32-40, 44, 45, 54-57, 61, 64, 67 & 69; **NY** 71, 73, 78, 79, 85, 86, 88, 91, 92, 99, 102, 103, 106, 109, 112, 113, 116, 117, 119, 120, 123-126, 128, 129, 133, 135, 137, 139, 142, 143, 145, 146, 149-153 & 155
	Vigorous	55	38	**KK** 8, 9, 11, 14, 15, 17, 18, 21, 24, 26, 29-31, 41-43, 46-52, 59, 62, 63, 65, 66; 68 and 70; **NY** 72, 74, 81, 83, 84, 90, 93-95, 97, 98, 100, 107, 111, 114, 115, 118, 130-132, 134, 141, 147, 148 & 154
Plant growth rate: Stage I	Low	44	30	**KK** 1, 2, 4, 5, 14, 19-21,23, 27, 28,32,39,40,56,58,60 & 64; **NY** 77-80, 87, 89,92, 96, 106, 109,112, 113, 115, 117, 119, 120, 126, 127, 133, 135, 136, 138, 140, 144, 145 & 151
	Medium	83	57	**KK** 3, 6-9, 12, 13, 15-18, 22, 24-26, 29, 30,33-38,41,43-48, 52, 55, 57, 59, 61, 63, 66, 67, 69 & 70; **NY** 71-74, 76, 81, 83-86, 88, 93, 95, 97, 101-103, 107, 116, 118, 123-125, 128-132, 134,137,139, 142, 143,146-150,152-155
	High	19	13	**KK** 11, 31, 42, 49-51, 54, 62, 65 & 68; **NY** 90, 91, 94, 98-100, 111, 114 & 141
Plant growth rate:	Low	27	18	**KK** 1, 15, 16, 18-22, 25, 27, 28 & 41; **NY** 73, 77, 78, 92, 95,107, 109, 116, 127, 132, 136, 144, 145, 148 & 152

Stage II	Medium	52	36	**KK** 5, 14, 17, 24, 26, 33, 35-36, 39, 48, 50, 55-58, 61, 64, 68 & 69; **NY** 74, 81, 86, 88, 89,91,94,98-101,103, 113,115, 118-120, 123, 126, 128-131, 135, 137-138, 143, 147, 149-151 & 155
	High	67	46	**KK** 2-4, 6-13, 23, 29-32, 34, 38, 40, 42-47,49, 51, 52, 54, 59, 60, 62,63, 64-66, 69 &70; **NY** 71, 76, 79,80, 83-85, 87, 90, 93, 96, 97, 102, 106, 111, 112, 114, 117, 124, 125, 133, 134, 139-142,144, 153 & 154
Plant growth habit	Determi nate	44	30	**KK** 15, 16, 18-22, 25, 27, 28, 41, 55 & 61; **NY** 73, 74, 77,78, 84,88,92,100, 101, 107, 113,124, 126-128, 130-132, 134-138, 145-148, 150-152 & 155
	Multilate ral	10 2	70	**KK** 1-14, 17, 23,24, 26, 29-40, 42-52, 54-60, 62-70; **NY** 71,72, 76,79, 80-83, 85-87,89-99, 102,103,106, 109, 111, 112, 114-120,123,125, 129, 133, 139-144, 149, 153 & 154
Stem colour	Light green	9	6	**KK** 14, 15, 18, 20-21, 27 & 28; **NY** 92
	Green	56	38	**KK** 7, 9, 19, 23, 24, 30, 33 & 36; **NY** 77, 78, 81, 84, 85, 88, 94, 95, 100, 101, 107, 109, 113, 115, 117, 125-129, 131, 132, 134-138, 144, 145, 147, 149, 151, 152, 154 & 155
	Dark green	81	55	**KK** 1-6, 8, 10-13, 16, 17, 23, 26, 29, 31, 32, 34, 35 & 37; **NY** 76, 79, 80, 83, 86, 87, 89-91, 93, 96-99, 102, 103, 106, 111, 112, 114, 116, 118-120, 123, 124, 130, 133, 139-143, 146, 148, 150 & 153
Plant size	Small	12	8	**KK** 1, 5, 21, 27, 28, 58, 68 & 69; **NY** 73, 87, 120 & 138
	Interme diate	87	60	**KK** 2-4, 6, 10-17, 19, 22-26, 29, 30, 32-38, 40-44, 47, 48, 50, 52, 56, 57, 59,-61, 63, 64, 66 & 67; **NY** 76, 77, 79, 80, 83, 85, 89, 92, 101, 103, 109, 112, 114, 116, 118, 119, 123, 124, 126-129, 131, 133-137, 139, 140, 142-149, 151, 152, 154 & 155
	Large	47	32	**KK** 7- 9, 18, 20, 31, 39, 45, 46, 49, 51, 54, 55, 62, 65 & 70; **NY** 71, 72, 74, 78, 81, 84, 86, 88, 90, 91, 93-100, 102, 106, 107, 111, 113, 115, 117, 125, 130, 132, 141, 150 & 153
Number of nodes	Few	6	4	**KK** 57; **NY** 81, 92, 93, 146 & 148
	Medium	49	34	**KK** 6-10, 12, 14, 15, 18, 19-24, 27, 32, 35, 36, 40, 47, 52, 55, 59, 60,62 & 63; **NY** 72, 73, 77, 78, 84, 101, 107, 112, 113, 124, 126, 130, 131, 132, 135, 136-138, 141, 142, 145 & 150
	Many	91	62	**KK** 1-5, 11, 13, 16, 17, 25, 26, 28-31, 33, 34, 37-39, 41-46, 48-51, 54, 56, 58, 61, 64-70; **NY** 71, 74, 76, 79, 80, 83, 85-91, 95-100, 102, 103, 106, 109, 111, 114, 115, 116-120, 123, 125, 127-129, 133, 134, 139, 140, 143, 144, 147, 149, 151-155
Interno de length:	Short	2	1	**NY** 136 &138
	Interme diate	22	15	**KK** 4, 26, 33, 38, 57, 60 & 69; **NY** 73, 77, 84, 87, 92, 97, 101, 103, 116, 123, 124, 128, 134, 137 & 146

	Long	122	84	**KK** 1-3, 5-25, 27-32, 34-37, 39, 40 -52, 54-56, 58, 59, 61-68 & 70; **NY** 71, 72, 74, 76, 78, 79, 80, 81, 83, 85, 86, 88-91, 93 - 96, 98, 99, 100, 102, 106, 107, 109, 111, 112 - 115, 117-120, 125 - 127, 129 - 133, 135, 139, 140 - 145, 147-155

Table 2. Leaf and inflorescence characteristics

Character	Descriptor state	Frequency and %		Accession code
Leaf outline	Broadly ovate	108	74	**KK** 1- 18, 23, 24, 26 – 52, 54, 56- 70; **NY** 71, 72, 76, 79- 81, 83, 85-87, 89- 91, 93- 99, 102, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139- 144, 153, 154
	Very broadly ovate	38	26	**KK** 19 – 22, 25, 55; **NY** 73, 74, 77, 78, 84, 88, 92, 100, 101, 107, 113, 124, 126, 127, 128, 130, 131, 132, 134-138, 145- 152 & 155
Central leaf lobe shape	Broadly ovate	100	68	**KK** 1-17, 23, 24, 26, 29- 40, 42- 52, 54, 56- 60, 62-70 **NY** 71, 72, 76, 79-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139- 144, 153 & 154
	Shallowly oblong	27	18	**KK** 14, 15, 18-21, 27, 55 & 61; **NY** 73, 77, 92, 124, 126- 128, 130, 134-136, 138, 146, 148, 150-152 & 155
	Narrowly oblong	19	13	**KK** 16, 22, 25, 28 & 41; **NY** 74, 78, 84, 88, 100, 101, 107, 113, 131, 132, 137, 145, 147 & 149
Leaf pubescence type	Soft	101	69	**KK** 1-13, 17, 23, 24-26, 29-40, 42-52, 54, 56-60, 62-70 **NY** 71, 72, 76, 79-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139-144, 153 & 154
	Intermediate	22	15	**KK** 15, 16, 18, 20, 22, 28, 41 & 61; **NY** 74, 77, 100, 101, 107, 126, 127, 130, 131, 134, 137, 138, 146 & 147
	Hard	23	16	**KK** 14, 19, 21, 27 & 55; **NY** 73, 78, 84, 88, 92, 113, 124, 128, 132, 135, 136, 145, 148-152 & 155
Leaf colour	Green	32	22	KK 15, 16, 18-22, 25, 27, 28, 41; **NY** 73, 77, 78, 84, 88, 92, 101, 107, 113, 126-128, 130, 131, 134-136, 138, 147, 148 & 152
	Dark green	13	9	**KK** 14 & 55; **NY** 74, 100, 124, 132, 137, 145, 146, 149-151 & 155
	Variable	101	69	**KK** 1- 13, 17, 23, 24, 26, 29-40, 42-52, 54, 56-70 **NY** 71, 72, 76, 79-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114- 120, 123, 125, 129, 133, 139-144, 153 & 154
Leaf	Glossy	99	68	**KK** 1-13, 17, 23, 24, 26, 29-40, 42-52, 54, 57-60, 62-70

glossiness				**NY** 71, 72, 76, 79-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139-144, 153 & 154
	Intermediate	30	21	**KK** 14-16, 18-22, 25, 27, 28, 55, 56 & 61; **NY** 84, 92, 100, 107, 126, 130, 131, 134, 135, 145, 146, 148, 149, 151, 152 & 155
	Dull	17	12	**KK** 41; **NY** 73, 74, 77, 78, 88, 101, 113, 124, 127, 128, 132, 136-138, 147 & 150
Leaf Senescence	Slightly visual	14	10	**KK** 6, 8, 9-11, 13, 23, 34, 49, 50, 54, 62, 65 & 69
	Moderate	88	60	**KK** 1-5, 7, 12, 14, 17, 24, 26, 29-33, 35-40, 42-48, 51, 52, 56-60, 63, 64, 66-68 & 70; **NY** 71, 72, 76, 79-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139-144, 149, 153 & 154
	Conspicuous concurrent	44	30	**KK** 15, 16, 18-22, 25, 27, 28, 41, 55 & 61; **NY** 73, 74, 77, 78, 84, 88, 92, 100, 101, 107, 113, 124, 126-128, 130-132, 134-138, 145-148, 150-152 & 155
Male flower	Early	137	94	**KK** 1-18, 20-25, 27-47, 49 - 52, 54-59, 61, 63, 64-70; **NY** 71, 73, 74, 76, 77, 78, 79-81, 83-100, 101-103, 106, 107, 109, 112-120, 123-129, 130-132, 133-143, 145-149, 150-154 & 155
	Intermediate	9	6	**KK** 19, 26, 46, 48, 60 & 62; **NY** 72, 111 & 144
Female flower	Early	9	6	**KK** 26, 39, 46, 48, 60 & 62; **NY** 72, 111 & 144
	Intermediate	78	53	**KK** 1, 5-7, 10, 12, 13, 15, 16, 19-25, 28, 30, 31, 33, 34-36, 38, 40, 42-45, 49, 56-59, 61, 65, 69 & 70; **NY** 74, 78, 79, 80, 83-86, 88- 91, 94, 96, 98-100, 102, 106, 107, 112-115, 117, 118, 125, 126, 128, 129, 131, 134, 137, 141, 145, 147, 149, 150, 153 & 154
	Late	59	40	**KK** 2- 4, 8, 9, 11, 14, 17, 18, 27, 29, 32, 37, 41, 47, 50-52, 54, 55, 63, 64, 66, 67 & 68; **NY** 71, 73, 76, 77, 81, 87, 92, 93, 95, 97, 101, 103, 109, 116, 119, 120, 123, 124, 127, 130, 132, 133, 135, 136, 138, 139, 140, 142, 143, 146, 148, 151, 152 & 155
Flower colour	Yellow-cream	1	1	**NY** 73
	Yellow	4	3	**NY** 102, 147, 150 & 155
	Dark-yellow	40	27	**KK** 15, 16, 18, 19, 20, 21, 22, 25, 27, 28, 41, 55 & 61 **NY** 74, 77, 78, 84, 88, 92, 100, 101, 107, 113, 124, 126-128, 130-132, 134-138, 145, 146, 148, 151 & 152
	Orange	101	69	**KK** 1-14, 17, 23, 24, 26, 29-40, 42-52, 54, 56-60, 62-70 **NY** 71, 72, 76, 79-81, 83, 85-87, 89-91, 93-99, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139-144, 149, 153 & 154

3.3. Fruit characteristics

Data on fruit characters was recorded on 126 accessions that produced fruits. The predominant fruit shape ranged from globular to elongate (Plate 5). Predominant fruit skin colour ranged from green to orange, secondary skin pattern from speckled to striped (Plates 2 and 3), with smooth or warty fruit surfaces at maturity. The colour of internal flesh ranged from white to yellow, and the main and outer fruit flesh colour from yellow to salmon (Table 3). All the accessions had fruit vein tracks with peduncles abscising when overripe. Superficial fruit ribbing, small and obscure blossom scars was observed in most accessions (Table 3).

Table 3. Fruit qualitative characterstics

Character	Descriptor state	Frequency and %		Accessions code
Fruit shape	Globular	38	26	**KK** 2, 6, 7, 10, 17, 23, 24, 26, 35, 37, 39, 40, 45, 50, 52, 54, 55, 58, 61, 63 & 68; **NY** 72, 77, 83, 85, 90, 91, 102, 103, 111, 114, 115, 120, 125, 129, 134, 144 & 153
	Flattened	14	10	**KK** 5, 43, 44 & 56; **NY** 71, 79, 86, 87, 93, 119, 131, 135, 154 & 155
	Elliptical	22	15	**KK** 13, 14, 20, 31, 34, 46, 48, 51, 65 & 69; **NY** 78, 80, 89, 97, 100, 109, 141, 143, 145, 147, 149 & 152
	Pyriform	12	8	**KK** 1, 9, 36, 38, 41, 42 & 70; **NY** 113, 116, 118, 133 & 140
	Ovate	24	16	**KK** 3, 4, 8, 29, 33, 47, 49, 59, 60, 64, 66 & 67; **NY** 81, 96, 98, 99, 106, 112, 117, 123, 126, 128, 139 & 142
	Acorn	11	8	**KK** 15, 16, 18, 19 & 30; **NY** 74, 84, 94, 95, 107 & 148
	Elongate	5	3	**KK** 11, 12, 32, 57 & 62
Second fruit cycle	Absent	27	18	**KK** 14-16, 18-20, 41, 55 & 61; **NY** 74, 77, 78, 84, 100, 107, 113, 126, 128, 131, 134, 135, 145, 147, 148, 149, 152 & 155
	Present	99	68	**KK** 1-13, 17, 23, 24, 26, 29-40, 42-52, 54, 56-60, 62-70; **NY** 71,72, 79-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114-120,123, 125, 129, 133, 139-144, 153 & 154
Predominant fruit skin colour	Cream	7	5	**KK** 15, 45 & 63; **NY** 94, 95, 107 & 117
	Pale green	11	8	**KK** 18 & 50; **NY** 81, 96, 97, 109, 113, 115, 125, 131 & 145
	Green	45	31	**KK** 1-4, 7, 9, 14, 17, 19, 20, 23, 26, 30, 33, 37, 40, 49, 51, 52, 64, 67 & 68; **NY** 72, 74, 78, 79, 83, 85, 90, 103, 111, 112, 114, 116, 118, 123, 128, 133, 135, 139, 140, 148, 149, 152 & 155
	Dark green	43	29	**KK** 5, 6, 8, 11-13, 24, 29-32, 34-36, 38, 39, 42-44, 47, 48, 54, 56, 60, 62, 65, 66, 69 & 70, **NY** 71, 87, 89, 91, 98, 99, 102, 119, 120, 129, 141-143, 153 &

				154
	Blackish -green	10	7	**KK** 10, 46, 57, 58 & 59; **NY** 80, 86, 93, 106 & 144
	Grey	10	7	**KK** 16, 41, 55 & 61; **NY** 77, 84, 100, 126, 134 & 147
Secondary fruit skin colour	Light-yellow	58	40	**KK** 1, 4, 5, 6, 9, 11, 12, 14, 17, 20, 23, 24, 26, 32, 33, 36-38, 42, 43, 49, 51, 52, 54, 56, 64, 65, 67 & 68; **NY** 72, 74, 83, 84, 85, 86, 89-91, 98, 99, 102, 103, 109, 111, 112, 116, 120, 123, 129, 133, 139-142, 145, 149, 153 & 155
	Cream	11	8	**KK** 16, 18, 30, 45 & 50; **NY** 81, 96, 97, 113, 115 & 125
	Pale green	10	7	**KK** 15, 44 & 63, **NY** 94, 95, 107, 117, 126, 134 & 135
	Green	2	1	**KK** 41, **NY** 77
	Orange	41	28	**KK** 2, 3, 7, 8, 10, 13, 29, 31, 34, 35, 39, 40, 46, 47, 48, 55, 57-62, 66, 69 & 70; **NY** 71, 79, 80, 87, 93, 100, 106, 114, 118, 119, 143, 144, 147, 148, 152 & 154
	Grey,	4	3	**KK** 19; **NY** 78, 128 & 131
Primary colour of immature fruit	Light green	17	12	**KK** 15, 18, 45, 50 & 63; **NY** 81, 94-97, 107, 115, 117, 125, 126, 148 & 155
	Intermediate	56	38	**KK** 1-4, 7, 9, 14, 16, 17, 19, 20, 23, 26, 30, 33, 37, 40, 41, 49, 51, 52, 55, 61, 67 & 68; **NY** 72, 74, 77, 78, 79, 83-85, 89, 90, 100, 103, 109, 111-114, 116, 118, 123, 128, 131, 133-135, 139, 140, 145, 147, 149 & 152
	Dark green	53	36	**KK** 5,6, 8, 10, 11,12, 13, 24, 29, 31, 32, 34-36, 38, 39, 42-44, 46-48, 54,56-60, 62,64-66, 69 & 70; **NY** 71, 80, 86, 87, 91, 93, 98, 99, 102, 106, 119, 120, 129, 141-144, 153 & 154
Secondary colour of immature fruit	No. secondary colour	81	55	**KK** 2-8, 10-13, 15, 17- 20, 23, 31, 32, 34, 35, 37-41, 43, 45, 46, 48, 50- 52, 55, 57, 59, 60, 61, 63, 66, 67, 69 & 70; **NY** 71, 81, 83, 85, 87, 89, 90, 93-97, 100, 102, 103, 106, 107, 111, 112, 114, 115, 117-120, 123, 125, 126, 128, 129, 133, 139, 140, 144, 148, 149, 153 & 155
	Light green	26	18	**KK** 1, 9, 14, 16, 26, 30, 33, 49 & 68; **NY** 72, 74, 77, 78, 79, 84, 109, 113, 116, 131, 134, 135, 141, 142, 145, 147 & 152
	Intermediate	19	13	**KK** 24, 29, 36, 42, 44, 47, 54, 56, 58, 62, 64 & 65, **NY** 80, 86, 91, 98, 99, 143 & 154

Table 3. Fruit qualitative morphological characters (Continued)

Character	**Descriptor state**	**Frequency and %**		**Accessions code**
Fruit skin glossine	Dull	37	25	**KK** 9, 10, 14-16, 18- 20, 23, 24, 29, 41, 44, 46, 47, 55, 57-59; **NY** 71, 74, 78, 86, 87, 93, 97, 100, 107, 114, 118, 119, 131, 135, 142, 144, 149 & 152

ss	Intermediate	34	23	**KK** 2, 5, 8, 17, 32, 33, 37, 39, 52, 54, 60, 65, 69 & 70; **NY** 72, 79, 80, 83, 89, 91, 96, 98, 106, 109, 111, 116, 126, 129, 133, 139, 140, 148, 154 & 155
	Glossy	55	38	**KK** 1, 3, 4, 6, 7, 11-13, 26, 30, 31, 34, 35, 36, 38, 40, 42, 43, 45, 48, 49, 50, 51, 56, 61-64, 66, 67 & 68; **NY** 77, 81, 84, 85, 90, 94, 95, 99, 102, 103, 112, 113, 115, 117, 120, 123, 125, 128, 134, 141, 143, 145, 147 & 153
Design produced by secondary skin colour	Speckled	15	10	**KK** 14-16, 18, 19, 55 & 61; **NY** 77, 107, 113, 126, 131, 148, 149 & 155
	Spotted, blotchy	61	42	**KK** 1, 5, 6, 9, 13, 17, 20, 24, 30, 31, 34, 35, 38, 40, 42, 45, 47-51, 54, 56, 57, 62, 63-67, 69 & 70; **NY** 71, 72, 78, 81, 83, 87, 90, 91, 94, 95, 98, 99, 103, 109, 111, 112, 114-117, 119, 120, 123, 125, 129, 133, 139, 140, 147 & 153
	Striped	8	5	**KK** 41; **NY** 74, 84, 100, 128, 134, 135 & 145
	Short streaked	27	18	**KK** 2-4, 7, 8, 11, 12, 23, 26, 29, 32, 33, 36, 37, 39, 43, 46, 52, 60 & 68; **NY** 79, 89, 96, 97, 102, 118 & 143
	Long streaked	15	10	**KK** 10, 44, 58, 59 & 66; **NY** 80, 85, 86, 93, 106, 141, 142, 144, 152 & 154
Fruit Surface	Smooth	39	27	**KK** 2, 4, 5, 9, 26, 34, 39, 42, 49, 56, 63, 66 & 67; **NY** 72, 85, 86, 90, 91, 94, 95, 97, 98, 99, 102, 103, 106, 109, 111, 115, 117, 118, 120, 123, 125, 133, 134, 141, 153 & 154
	Grainy	9	6	**KK** 14 & 19; **NY** 84, 89, 107, 113, 131, 147 & 152
	Finely wrinkled	11	8	**KK** 37; **NY** 77, 79, 80, 96, 114, 116, 119, 140, 143 & 144
	Deeply wrinkled	2	1	**KK** 41 & 61
	Shallowly wavy	50	34	**KK** 1, 3, 6, 7, 8, 10, 11, 12, 13, 17, 23, 24, 29-33, 35, 36, 38, 40, 43-48, 50-52, 54, 57-60, 62, 64, 65, 68, 69 & 70; **NY** 71, 81, 83, 87, 93, 112, 129, 139 & 142
	Rare warts	7	5	**KK** 55; **NY** 74, 100, 126, 128, 148 & 155
	Numerous warts	8	5	**KK** 15, 16, 18 & 20; **NY** 78, 135, 145 & 149
Fruit ribbing	Superficial	50	34	**KK** 1, 2, 4, 5, 11, 14-16, 18-20, 26, 29, 31-33, 39, 46, 48, 49, 55, 59, 61, 68 & 69; **NY** 74, 78, 84, 90, 96, 97, 106, 107, 112, 113, 118, 126, 128, 131, 134, 135, 140, 141, 144, 145, 147-149, 152 & 155
	Intermediate	36	25	**KK** 3, 6, 8, 9, 10, 12, 13, 34-36, 38, 40-43, 45, 52, 54, 57, 60, 62 & 64; **NY** 77, 81, 83, 85, 89, 95, 100, 102, 116, 117, 120, 129, 133 & 139
	Deep	40	27	**KK** 7, 17, 23, 24, 30, 37, 44, 47, 50, 51, 56, 58, 63, 65-67 & 70; **NY** 71, 72, 79, 80, 86, 87, 91, 93, 94, 98, 99, 103, 109, 111, 114, 115, 119, 123, 125, 142, 143, 153 & 154
Shape of fruit ribs	Obtuse	112	77	**KK** 2, 4-20, 23, 24, 26, 29-31, 33-37, 39-46, 48-50, 52, 54, 55, 56, 58-63, 65, 66, 68 & 69; **NY** 71, 72, 74, 77-81, 83-91, 93-100, 102, 103, 106, 107, 111-

				120, 123, 125, 126, 128, 129, 131, 133-135, 140, 141, 143-145, 147-149, 152, 153 & 155
	Intermediate	14	10	**KK** 1, 3, 32, 38, 47, 51, 57, 64, 67 & 70; **NY** 109, 139, 142 & 154
Vein track colour	White	82	56	**KK** 1-5, 9, 11-20, 23, 26, 30-35, 37-40, 42, 47-52, 54, 61, 63-69; **NY** 71, 72, 74, 78, 81, 83-85, 89-91, 94-97, 102, 103, 109, 111, 112, 114-117, 119, 123, 125, 128, 131, 133-135, 140-142, 145, 152, 153 & 155
	Green	44	30	**KK** 6-8, 10, 18, 24, 29, 36, 41, 43-46, 55-60, 62 & 70; **NY** 77, 79, 80, 86, 87, 93, 98, 99, 100, 106, 107, 113, 118, 120, 126, 129, 139, 143, 144, 147-149, & 154
Blossom scar appearance	Obscure	70	48	**KK** 3, 5, 6, 9, 10-13, 17-20, 23, 26, 29, 31-33, 35, 36, 38, 43, 48, 49, 52, 57-60, 62-65, 68 & 69; **NY** 71, 72, 78, 80, 81, 83, 86, 87, 89, 90, 94, 98, 99, 106, 109, 112, 114-117, 119, 120, 128, 129, 135, 139-143, 145, 147-149, & 152
	Intermediate	42	29	**KK** 1, 2, 4, 7, 8, 16, 24, 30, 34, 37, 39, 40, 42, 44-47, 50, 51, 54, 56, 66, 67 & 70; **NY** 79, 85, 91, 93, 95, 96, 100, 102, 103, 107, 111, 118, 123, 125, 134, 144, 153 & 154
	Conspicuous	14	10	**KK** 14, 15, 41, 55 & 61; **NY** 74, 77, 84, 97, 113, 126, 131, 133 & 155
Blossom scar size	Small	69	47	**KK** 1, 3, 5, 9-13, 17-20, 23, 26, 29, 31-33, 35, 36, 38, 42, 43, 48, 49, 52, 57-60, 62-65, 68 & 69; **NY** 78, 80, 81, 83, 86, 87, 89, 90, 94, 98, 99, 106, 109, 112, 114-117, 119, 120, 128, 129, 135, 139, 140-143, 145, 147-149, & 152
	Intermediate	49	34	**KK** 2, 4, 6-8, 15, 16, 24, 30, 34, 37, 39, 40, 44-47, 50, 51, 54-56, 61, 66, 67 & 70; **NY** 71, 72, 79, 84, 85, 91, 93, 95-97, 100, 102, 103, 107, 111, 118, 123, 125, 134, 144, 153, 154, 155
	Large	8	5	**KK** 14 & 41; **NY** 74, 77, 113, 126, 131 & 133

Table 3. Fruit qualitative morphological characters (Continued)

Character	Descriptor state	Frequency and %		Accessions code
Blossom end shape	Depressed	34	23	**KK** 4, 7, 8, 13, 15, 17, 24, 29, 35-37, 39, 41, 43-45, 56, 61, 63, 65, 67 & 70; **NY** 71, 77, 86, 87, 93, 102, 111, 125, 133, 149, 153 & 154
	Flattened	22	15	**KK** 1, 2, 5, 6, 9, 10, 14, 16, 19, 23, 26, 34; **NY** 103, 113, 118, 119, 123, 131, 135, 147, 148 & 152
	Rounded	60	41	**KK** 3, 11, 12, 18, 30-33, 38, 40, 42, 46-52, 54, 55, 57-60, 62, 64, 66, 68 & 69; **NY** 72, 74, 79-81, 83, 85, 89-91, 96-99, 106, 107, 109, 112, 114-117, 120, 129, 134, 139, 140-144
	Pointed	10	7	**KK** 20; **NY** 78, 84, 94, 95, 100, 126, 128, 145 & 155
Stem end	Depressed	31	21	**KK** 2, 5-7, 24, 31, 37, 39, 41, 43, 44, 45, 63 & 65; **NY** 71, 72, 74, 77, 79, 84, 86, 87, 93, 100, 102, 111, 125, 134,

shape				145, 153 & 154
	Flattened	56	38	**KK** 1, 4, 8-10, 13, 14, 16-20, 23, 26, 30, 34-36, 40, 49-52, 54, 56, 58, 61 & 70; **NY** 78, 80, 81, 85, 94, 95, 97, 99, 103, 109, 114, 115, 117, 119, 120, 126, 128, 129, 131, 135, 141-143, 147-149, 152 & 155
	Rounded	11	8	**KK** 46, 47, 55, 59, 66 & 68; **NY** 83, 90, 91, 107 & 144
	Pointed	28	19	**KK** 3, 11, 12, 15, 29, 32, 33, 38, 42, 48, 57, 60, 62, 64, 67 & 69; **NY** 89, 96, 98, 106, 112, 113, 116, 118; 123, 133, 139 & 140
Fruit stem / Peduncle colour	Light green	48	33	**KK** 2, 3, 9, 10, 16, 17, 26, 33, 36, 42, 44-46, 50, 54, 55, 57, 58, 61-63, 66 & 70; **NY** 72, 78, 79, 81, 85, 94-97, 102, 103, 106, 109, 115, 117, 119, 123, 125, 129, 135, 141-144 & 155
	Green	60	41	**KK** 1, 5-8, 11, 13-15, 18-20, 23, 24, 29-32, 34, 35, 37, 39, 41, 43, 47, 49, 59, 60, 64, 67, 68; **NY** 71, 74, 77, 83, 84, 87, 90, 91, 93, 107, 112, 113, 114, 116, 118, 120, 126, 128, 131, 133, 134, 139, 140, 145, 147-149, 152 & 154
	Dark green	18	12	**KK** 4, 12, 38, 40, 48, 51, 52, 56, 65 & 69; **NY** 80, 86, 89, 98, 99, 100, 111 & 153
Internal colour of skin	White	3	2	**KK** 15, 51 & 63
	White	122	84	**KK** 1-7, 9-14, 16-20, 23, 24, 26, 29-50, 52, 54-62, 64-70; **NY** 71, 72, 74, 77-81, 83-87, 89-91, 93-100, 102, 103, 106, 107, 109, 111-120, 123, 125, 126, 128, 129, 131, 133-135, 139-145, 147-149, 152-155
	Yellow	1	1	**KK** 8
Main colour of flesh	Yellow	54	37	**KK** 9, 11, 14, 16, 18-20, 24, 32, 35, 36, 39, 41, 44, 46, 51, 54, 55, 60, 61, 63, 67 & 69; **NY** 74, 77-79, 83-85, 90, 94, 97, 99, 100, 102, 107, 109, 113, 117, 120, 123, 125, 128, 131, 134, 135, 143, 145, 147-149, 152 & 154
	Pale green	1	1	**NY** 155
	Orange (yellow-red)	61	42	**KK** 1, 2, 4-8, 13, 15, 17, 23, 29-31, 33, 34, 37, 38, 40, 42, 43, 45, 47-49, 52, 56, 58, 59, 64-66, 68 & 70; **NY** 71, 72, 80, 81, 86, 87, 89, 91, 95, 96, 98, 103, 106, 111, 112, 114-116, 118, 126, 129, 133, 139, 140, 141, 142 & 153
	Salmon	10	7	**KK** 3, 10, 12, 26, 50, 57 & 62; **NY** 93, 119 & 144
Flesh colour of outer layer	Yellow	23	16	**KK** 19, 20, 55 & 61; **NY** 74, 77, 78, 84, 100, 107, 113, 128, 131, 134, 135, 139, 140, 145, 147-149, 152 & 155
	Orange (yellow-red)	29	20	**KK** 1, 9, 11, 14, 15, 18, 32, 35, 36, 39, 41, 49, 51, 54, 60, 63 & 67; **NY** 79, 83, 85, 90, 97, 99, 102, 109, 112, 117, 126 & 154
	Salmon (pink-red)	74	51	**KK** 2-8, 10, 12, 13, 16, 17, 23, 24, 26, 29, 30, 31, 33, 34, 37, 38, 40, 42-48, 50, 52, 56-59, 62, 64-66, 68-70; **NY** 71, 72, 80, 81, 86, 87, 89, 91, 93-96, 98, 103, 106, 111, 114-116, 118-120, 123, 125, 129, 133, 141-144 & 153

3.4. Seed characteristics

Seed characteristics were recorded in 124 accessions. Two accessions fruits had immature seeds. Ease of seed and placenta separation from fruit was observed in most accessions. Predominant seed coat colour ranged from cream yellow to white (Plate 4). Most accessions had elliptic seeds, either sharply or bluntly pointed at the hilum end. The seeds of most accessions were intermediate in glossiness and had tubercular coat surfaces. Smooth seed coat was found in only a few accessions. The seeds were unwinged with no seed coat pattern in all the accessions (Table 4).

Plate 1. Variation of leaf colour

Plate 2 Variation of fruit skin colour of Nyeri accessions

Table 4. Seed qualitative morphological characters of accessions

Character	Descriptor state	Frequency and %		Accessions Code
Seed & placenta Separation from fruit	Easy	77	62	**KK** 2, 6, 8, 9, 12, 13, 24, 26, 29-32, 35, 39, 40, 42, 44-46, 48-52, 56, 57, 59, 60, 65, 66-68 & 70; **NY** 74, 78, 79- 81, 83, 85-87, 89-91, 93-96, 98, 99, 102, 103, 106, 107, 109, 112-114, 117-120, 123, 129, 131, 133, 134, 139, 140, 142, 145, 147, 148, 153, 154 & 155
	Intermediate	30	24	**KK** 1, 4, 5, 7, 10, 11, 19, 34, 36-38, 43, 54, 58, 62, 63, 64 & 69; **NY** 71, 72, 100, 111, 115, 116, 125, 128, 135, 141, 143 & 144
	Difficult	19	15	**KK** 3, 14-18, 20, 23, 33, 41, 47, 55 & 61; **NY** 77, 84, 97, 126, 149 & 152
Seed size	Intermediate	2	2	**NY** 80 & 141
	Large	96	77	**KK** 1, 2, 4, 5-7, 9-13, 17, 23, 24, 26, 29, 30, 32-35, 37-40, 42, 44-49, 51, 52, 54, 56-60, 62-67, 69 & 70; **NY** 71, 72, 74, 78, 79, 81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 112, 114-120, 123, 125, 126, 128, 129, 133, 135, 139, 140, 142, 143, 144, 148, 153, 154 & 155
	Very Large	28	23	**KK** 3, 8, 14, 15, 16, 18- 20, 31, 36, 41, 43, 50, 55, 61 & 68; **NY** 77, 84, 100, 107, 111, 113, 131, 134, 145, 147, 149 & 152
Seed shape	Narrow-elliptic,	21	17	**KK** 9, 10, 15, 39, 52, 56, 64 & 70; **NY** 81, 89, 93-95, 99, 102, 103, 109, 139, 140, 142, & 143
	Elliptic,	67	54	**KK** 1-7, 12, 13, 17, 23, 24, 26, 29-33, 35, 37, 38, 40, 42, 44-49, 51, 54, 59-63, 65-67 & 69; **NY** 71, 72, 79, 80, 83, 86, 87, 90, 91, 96-98, 111, 112, 114-117, 119, 120, 123, 125, 126, 129, 144, 153 & 154
	Broad-elliptic	38	31	**KK** 8, 11, 14, 16, 18-20, 34, 36, 41, 43, 50, 55, 57, 58 & 68; **NY** 74, 77, 78, 84, 85, 100, 106, 107, 113, 118, 128, 131, 133-135, 141, 145, 147, 148, 149, 152 & 155
Seed shape at hilum end	Sharply pointed	34	27	**KK** 2, 6, 7, 9, 10, 13, 15, 19, 24, 30, 33, 37, 39, 46, 47, 49, 50, 55 & 56; **NY** 77, 81, 83, 89, 95, 96, 98, 100, 102, 109, 114, 120, 143, 144 & 153
	Bluntly pointed	92	74	**KK** 1, 3-5, 8, 11, 12, 14, 16-18, 20, 23, 26, 29, 31, 32, 34-36, 38, 40-45, 48, 51, 52, 54, 57-70; **NY** 71, 72, 74, 78, 79, 80, 84-87, 90, 91, 93, 94, 97, 99, 103, 106, 107, 111-113, 115-119, 123, 125, 126, 128, 129, 131, 133, 134, 135, 139-142, 145, 147-149, 152, 154 & 155
Predominant seed coat colour	White	2	2	**KK** 7 & 55
	Yellow-white	28	23	**KK** 2, 3, 9, 10, 12, 13, 23, 24, 31, 33, 34, 38, 48, 50, 57, 58, 62, 68 & 69; **NY** 71, 95, 97, 116, 118, 120, 133, 139 & 141
	Cream yellow	70	56	**KK** 1, 4-6, 8, 11, 17, 26, 29, 30, 32, 35-37, 39, 40, 42-47, 49, 51, 52, 54, 56, 59, 60, 63-67 & 70; **NY** 72, 79, 80, 81, 83, 85-87, 89-91, 93, 94, 96, 98, 99, 102, 103, 106, 109, 111, 112, 114, 115, 117, 119, 123, 125, 129, 140, 142, 143, 144, 153 & 154

	Light-brown	12	10	**KK** 18, 20 & 61; **NY** 77, 84, 100, 107, 113, 131, 134, 135 & 155
	Brown	14	11	**KK** 14-16, 19, 41; **NY** 74, 78, 126, 128, 145, 147, 148, 149 & 152
Seed coat surface	Smooth	24	19	**KK** 7, 14-16, 18, 20, 41, 55 & 61 **NY** 74, 77, 84, 100, 107, 113, 126, 128, 131, 134, 135, 145, 148, 149 & 155
	Tuberculer	102	82	**KK** 1-6, 8-13, 17, 19, 23, 24, 26, 29-40, 42-52, 54, 56-60, 62-70 **NY** 71, 72, 78-81, 83, 85-87, 89-91, 93-99, 102, 103, 106, 109, 111, 112, 114-120, 123, 125, 129, 133, 139, 140, 141, 142, 143, 144, 147, 152, 153 & 154
Seed surface glossiness	Dull	48	39	**KK** 5, 7-9, 11, 13, 17, 19, 23, 29, 31, 32, 33, 36, 39, 45, 46, 49-51, 54, 57, 59, 65, 66, 68 & 70; **NY** 71, 72, 80, 85, 87, 89, 90, 91, 93, 98, 99, 102, 106, 111, 114, 117, 118, 129, 139, 140 & 154
	Intermediate	56	45	**KK** 1-4, 6, 10, 12, 15, 24, 26, 30, 34, 35, 37, 38, 40, 42-44, 47, 48, 52, 56, 58, 60, 62-64, 67 & 69; **NY** 79, 81, 83, 84, 86, 94-97, 103, 109, 112, 113, 115, 116, 119, 120, 125, 131, 133, 141- 144, 147 & 153
	Glossy	22	18	**KK** 14, 16, 18, 20, 41, 55 & 61; **NY** 74, 77, 78, 100, 107, 123, 126, 128, 134, 135, 145, 148, 149, 152 & 155
No. of seeds per fruit	< 100	12	10	**KK** 17-20, 41 & 52; **NY** 123, 126, 128, 147, 149 & 152
	>100	114	92	**KK** 1-16, 23, 2426 29-40, 42-51, 54-70; **NY** 71, 72, 74, 77-81, 83, 84-87, 89- 91, 93, 94-100-103, 106, 107,109, 111-120, 125, 129, 131, 133-135, 139-145, 148, 153, 154 & 155

Plate 3. Variation of fruit skin colour of Kakamega accessions

Plate 4. Variation of seed appearance

Plate 5. Variation of fruit shape: A) Globular; B) Flattened; C) Ovate; D) Elongate; E) Acorn; F) Pyriform; G) Elliptical

4. Discussion

4.1. Vegetative, stem and root characteristics

In the present study, the failure of 9 accessions to germinate was attributed to poor seeds collected during the survey in which seed quality was not guaranteed. Seedling vigour of accessions varied from poor to vigorous. This was attributed to seed sizes of different accessions. Studies by Ndoro et al. (2012), reported various seed sizes affecting seedling vigour. High seedling vigour was observed during the early stages of growth in green-leafed cultivars. This was attributed to their large seed size. The local accessions were more vigorous after flowering due to adaptation to local environment and the silvery variegated leaves that reflect excess sun rays to reduce high temperature and evapo-transpiration (Brown, 2002). Temperature regulates rate of physiological processes and influences growth and development of plants. High temperature induces water deficit, causing mineral nutrient deficiency. The local accessions could have acclimated easily in response to endogenous and environmental temperature (Haferkamp, 1988). The poor growth rate observed in green-leafed accessions after flowering could have been due to failure to acclimatize to the prevailing climatic conditions. The green-leafed accessions were more prone to pest attack. Injured plants grew slowly, turned yellow and developed only a few stems per plant. They took time to heal, survive and regain vigour (Haferkamp, 1988).

The growth rate before flower initiation was medium in most accessions, because the seedlings were young and not well adapted to the climactic conditions. It was high after flowering in most accessions, because the accessions had already acclimatized to the growing conditions. Growth rate before flowering of green-leafed accessions was high due to their large seed sizes. Seed size compensates for variation in environmental conditions and enhances productive capacity of a plant. As the seed size increase there is more food reserved in the cotyledon to sustain seedling growth. Food reserves of smaller seeds are quickly exhausted, thereby affecting seedling growth and vigour (Haferkamp, 1988). Growth rate was low after flowering in green-leafed accessions due to poor adaptation to local environmental conditions and exhaustion of seed food reserves.

Most accessions exhibited multilateral branching, while few showed less branching and determinate growth habit. The variations were attributed to genetic composition. Maynard (2007) reported branching at nodes, following the same general pattern of growth as the main stem. The accessions were mostly multilateral, but the green-leafed ones were determinate with leaves senescing early. The green-leafed accessions had also no second cycle of vegetative rejuvenation even after water application. Most accessions had many nodes on the main branch up to and including the first tendril, long internodes above the 10^{th} to 15^{th} nodes, and bushy growth habit, with reduced internodes in the laterals. Maynard (2007) reported that genetic variation dictates internode and vine length. Cultivars with short internodes and vines are regarded either as “bushy”, “semi-bushy”, or “restricted.” The shortness trait is associated with thicker stems, less branching and few tendrils. The stem colour at 50% flowering was dark-green in most accessions. Ajuru and Okoli (2013) observed light-green, highly pubescent stems. All the accessions had roots and tendrils at the internodes. Tendrils arise in the axil or opposite to leaves at nodes (Saboo et al., 2013).

4.2. Leaf and inflorescence characteristics

The leaves of most accessions were green, dark-green and variable in colour. Xiaohua et al. (2011), reported leaf colour ranges from light-green to dark-green. Ajuru and Okoli (2013) reported light-green leaves. The local accessions had variable leaves. Agbagwa et al. (2007) and Saboo et al. (2013) observed leaves with white blotches. The leaf colour is controlled by *M* dominant gene for silver-gray areas in axils of leaf veins. The *M* gene is dominant to *m* for absence of silver-gray (Paris and Brown, 2005). The silvering is caused by air spaces within the palisade cell layer and between that layer and the epidermis (Brown, 2002). The leaves of most accessions were glossy, with moderate senescence. The leaves of most green-leafed accessions showed conspicuous concurrent senescence after flower initiation. This growth habit was attributed to presence of *B* (*Bicolor*) gene that lacked selective suppressor *B* (*Ses-B*) gene (Brown, 2002). The local accessions showed slight to moderate senescence when fruits matured probably due to segregation of *Ses-B* with age of plants as they matured (Brown, 2002). The leaves of all accessions were cordate. Agbagwa et al. (2007) and Ajuru and Okoli (2013) observed large and broadly cordate leaves, respectively. Leaf morphological features such as shape, size, margin and colour, and architectural design are diagnostic and essential tools in pumpkin identification at the genus or species level. The features help to distinguish *C. moschata* from other cultivated *Cucurbita* species (Agbagwa and Ndukwu, 2004). The leaf outline and central leaf lobe shape in most accessions was broadly ovate. Saboo et al. (2013) observed large shallowly lobed, and Ajuru and Okoli (2013) observed broadly ovate leaves. All the accessions had 5 lobes in each leaf. Agbagwa et al. (2007) and Saboo et al. (2013) reported shallowly 5 lobed leaves. Ajuru and Okoli (2013) reported palmately lobed leaves. The leaf pubescence was soft in most accessions. Nesom (2011) reported moderately hirsutulous to puberulent and moderately villous to unicellular-based hairs. Ajuru and Okoli (2013) observed highly pubescent hairs forming a cushion on the adaxial surface of leaves.

The accessions showed variations in colour and earliness of male and female flowers. The flower colour was orange in most accessions. Ahamed et al. (2011) observed yellow flowers in all accessions of *Cucurbita moschata*. The male flowers among accessions were early compared to female flowers. McCormack (2005) observed staminate flowers developing, maturing, and shedding pollen before development of the female flowers. Maynard (2007) reported that several male flowers opened before development of any pistillate flowers, while Agbagwa et al. (2007) reported more numerous male than female flowers. Earliness in female flowering was observed in 9 accessions. McCormack (2005) stated that it was not uncommon for *C. moschata* to bear female flowers first. He also observed summer squash varieties initiating female flowers early. The sequence of floral development in pumpkins helps ensure cross-pollination of the flowers (McCormack, 2005). Flower development is regulated by genetic and environmental conditions such as temperature and day length. It can be modulated by hormones such as gibberellins and ethylene (OECD, 2012). The ratio of female to male flowers was mostly male. Sex expression in cucurbits is influenced by hormones produced within the plant. Gibberellins and ethylene promote staminate and pistillate flower development, respectively. Natural and synthetic auxins promote pistillate flower development (Maynard, 2007). Environmental conditions also play a role in influencing sex expression of flowers, and their development into male or female state. Temperature and day length influence how long a plant remains in the male phase, as well as the ratio of male to female flowers. High temperatures, high light intensity, and long days favour production of male flowers and a longer male phase. Low temperatures, low light intensity and short days favour the development of female flowers. The number of developing fruits already present in a plant also affects the flower ratio (McCormack, 2005). In the present study, the accessions were all monoecious. McCormack (2005) reported monoecious plants in the four major domesticated species of *Cucurbita*.

Agbagwa et al. (2007) observed unisexual, acuminate and actinomorphic flowers with a pentamerous perianth. Maynard (2007) observed monoecious, andromonoecious, gynoecious, and hermaphroditic flowers, male flowers with long peduncles, and female flowers with short peduncles. These observations were similar to those of Ajuru and Okoli (2013), McCormack (2005), and Agbagwa et al. (2007). The floral variations are taxonomically valuable and are used in classification of angiosperms (Nesom, 2011). The variations are as a result of genetic and other factors (Maynard, 2007).

4.3. Fruit characteristics

The accessions had great variation in fruit shape, with the highest being globular. Ahamed et al. (2011), observed elliptical to round and pyriform fruit shapes. Labrada et al. (1997) observed pyriform shapes, with elongate, globular and flat shapes being rare, while Xolisa (2002) reported cylindrical, oblate, flattened, and globular to elliptical fruits. Many other researchers have also observed variations in pumpkin fruit characteristics (Gichimu et al., 2008; Mladenovic et al., 2012; Balkaya et al., 2010b; Du et al., 2011). The genes responsible for fruit shapes are "flatteners" and "elongators" with inhibitors being elongators (Brown, 2002).

Predominant mature fruit colour ranged from green, grey to cream, secondary fruit pattern from speckled, blotchy to striped. Mladenovic et al. (2014), reported predominant fruit colour ranged from green to orange and secondary pattern from speckled to stripe, while Ahamed et al. (2011), reported green, yellow to brown. Primary colour of immature fruits was intermediate between light-green and dark-green, with no secondary colour in most fruits. The fruit colour is controlled by 3 loci (*Gr, Mldg* and *B*). Dominant *Gr* results in green fruits, while the recessive gene confers buff colour. Dominant *Mldg* causes mottled immature fruit colour, while recessive *mldg* results in a non-mottled rind. The *B* (*Bicolor B-1* and *B-2)* gene confers “precocious yellow” colour. The recessive *bb* genotype produces normal green ovaries (Paris and Brown, 2005; Lietzow et al., 2005-2006). *B-2* is dominant and does not produce bicolor fruit when heterozygous. The expression of *B-2* is highly variable with instability being intensified by the environment such that *B-2* can be recessive at times. The orange colour appears due to complementary action of the *B* gene and another gene that inhibits pigmentation when recessive. Thus *A/-B/-* results in orange fruit, *A/-b/b* results in green fruit, *a/aB/-* inhibits pigment formation, resulting in tan fruit, same as *a/ab/b* (Brown, 2002). Depending on the type and number of alleles present at two modifier loci (*Ep-1* and *Ep-2*), the degree of colour can range from bicolor yellow-green to fully yellow (Paris and Brown 2005; Lietzow et al., 2005-2006).

Fruit surfaces ranged from smooth, grained, wavy to warty. Mladenovic et al. (2014), reported fruit skin texture from smooth to warty. Warts are projections of lignified tissue one mature fruits and are controlled by a single gene Warty-fruit *Wt* that is dominant to non-warty-fruit *wt* and complementary to *Hr*. Fruit wartiness is expressed only in the presence of the dominant *Hr* allele (Paris and Brown, 2005). Wartiness is epistatic to hard rind (*Hr*) (Brown, 2002; Schaffer et al., 1986). Hard rind prolongs the storage life of fruits (Brown, 2002). Hard rind gene *Hr* controls the activity of phenylalanine ammonia lyase (PAL) in the fruit rind (Schaffer et al., 1986). PAL is a key enzyme in lignin biosynthesis and only fruits with lignified rinds can have warts (Brown, 2002). Main and outer layer colour of flesh ranged from yellow to salmon (pink-red), while internal flesh colour ranged from white to yellow. The internal flesh colour was green in most accessions. Xiaohua et al. (2011), observed flesh colour range from white to orange, Brown (2002) from white through cream and yellow to various shades of orange, including greenish tints, Mladenovic et al. (2014), from white to orange, and Ahamed et al. (2011), from white to green, orange to deep orange. The main colour of flesh was orange in most of the accessions. The orange flesh is caused by an interaction between fruit colour genes, *L2* (*light fruit coloration-2)*, *B* (*Bicolor)* light intensity fruit coloration, and precocious yellow fruit pigmentation (Brown, 2002; Paris and Brown, 2005). Fruits with dominant alleles at both loci develop orange flesh (Brown, 2002). Bicolor fruits with dominant *L2* develop orange flesh and yellow rind. When the flesh is pale or greenish, the rind is green (Paris, 1994). The dominant allele at *Y* (yellow fruit colour) results in increased carotenoid content in flesh and cream-coloured flesh instead of pale. Intense yellow and orange flesh colours are associated with high carotenoid levels (Brown, 2002). A dominant gene controls intense fruit rind colour, causing chlorophyll accumulation in fruit flesh, turning it greenish or brownish. This gene, if combined with the *B* gene, keeps the flesh orange (Paris, 1994).

Fruit stem/peduncle colour was light-green, green, or dark-green. The dominant allele *D* darkens stems, resulting in green-black stems. Dark-green stems are linked to fruit colour such that plants with persistent white fruits almost always have light-green stems, and plants bearing white fruits that mature green have dark-green stems. An allele D^s causes dark stems. Plants homozygous for D^s have peduncles that are dark-green at the stem end, gradually lightening to yellow at the fruit end. Heterozygous plants have dark stems at the base of the plant, but often have light peduncles (Brown, 2002; Paris, 1996). Fruit stem peduncles abscised when fruits over-ripened in all the accessions. Development of abscission layer at the peduncle is a good indicator of full ripeness (Beaulieu, 2006). Abscission plays an important role in growth of plants and is a strategy for survival by not only discarding unnecessary organs, but also protecting plants by eliminating pathogen-infected organs, and allowing dispersal of seeds by dropping fruits from the main body (Tsukahara et al., 2013). Fruit peduncle abscission depends on and is promoted by ethylene (Pitrat, 2008). Abscission starts with induction of abscission-related transcriptional factors and protein kinases, which activate synthesis and exudation of cell wall catabolic enzymes such as polygalacturonase, β-1, 4 glucanase, and pectinase, causing degradation of intercellular layers and conductive tissues, leading to abscission (Tsukahara et al., 2013). *Cucurbita* species produce very low levels of ethylene, which cause skin colour changes to orange-yellow and stem abscission (Watkins and Nock, 2012). The abscission zone consists of several layers of small cells formed at the base of the leaf or stem during senescence, or during organ growth, allowing detachment of organs as required (Tsukahara et al., 2013).

The fruits blossom scars were obscure, conspicuous, small, intermediate or large. Blossom scars of green-leafed accessions ranged from intermediate, conspicuous or intermediate to large, and those of local accessions from obscure to intermediate, and small to intermediate. Xolisa (2002) observed intermediate to conspicuous blossom scars. Loy (2006) reported considerable variation in size of blossom scars in fruits derived from perfect flowers. They were smaller in fruits from pistillate than in fruits developed from perfect flowers. Fruits derived from pistillate flowers develop small blossom scars because the base of the hypanthium fused to the ovary is small. In perfect flowers, the size of the hypanthium base and resulting blossom scar vary considerably. Monoecious gene is useful in breeding to achieve greater fruit size and small blossom scars. The fruits of accessions were rounded, depressed, flattened or pointed at the blossom end, and flattened, depressed, pointed or rounded at the stem end, similar to observations of Xolisa (2002). All accessions had fruit vein tracks, with most accessions having white and a few green-veined tracks. Fruit ribs were superficial, deep or intermediate, with most accessions having obtuse fruit ribs. Other studies found superficial, intermediate or deep-ribbed fruits, and smooth fruit surfaces (Xolisa, 2002; Mladenovic et al., 2012a). Variability of fruits was low (10%) in most accessions, or high (>25%), indicating homogeneous and heterogeneous population, respectively (Newsom et al., 1993). The ability to regenerate second fruit cycle was observed in most accessions. The green-leafed accessions did not regenerate second fruit cycle, and they also produced few and low-weight fruits. Second fruit cycle regeneration was attributed to genetic influence and adaptability to environmental conditions (Du et al*.,* 2011; OECD, 2012). Cessation of growth of green-leafed accessions was attributed to a recessive gene *de* for determinate plant growth habit (Paris and Brown, 2005).

4.4. Seed characteristics

The seed colour ranged from cream-yellow, yellow-white, brown, light-brown to white. Green-leafed accessions had brown to light-brown seeds. Aruah et al. (2010) observed brown and light-brown seeds. Balkaya et al., (2010a) observed cream tones in most pumpkin populations, including 30% cream, 25% tawny, 17.5% dark-cream, 17.5% light-cream, and 10% brown. Seed and placenta separation was easy in most accessions. McCormack (2005) observed seeds separating from the pulp much easily in some varieties than in others. *Cucurbit* seeds continue to develop even after the fruit is removed from the vine, and if for any reason the fruits are harvested before they are fully mature, they can be stored for 1 to 2 months to allow for further maturation before the seeds are extracted. The seeds need to be separated from the wet and adherent flesh in the hollow cavity of the fruit placenta tissue, washed and dried before they are packaged (Gavilanez-Slone, 2001). The seed size of variegated accessions ranged from intermediate to large, and those of green-leafed accessions from large to very large. Pumpkin seeds are surrounded by several layers of tissue. External layers are derived from the endocarp and generally swell in water. The internal layer is derived from the seed coat testa and develops from the ovule's integument and nucellus (OECD, 2012). The seed shape was elliptic in most accessions. Previous studies reported widely elliptic seeds, spherical or oval seeds (Balkaya et al*.,* 2010a; Ajuru and Okoli, 2013).

The glossiness of seeds was intermediate in most accessions. Green-leafed accessions had smooth and glossy seeds, while the variegated accessions had tubercular and intermediate glossy seeds. The seed testa in *Cucurbita* is a 5-layered structure originating from the outer integument. Seed coat surfaces are either thick or thin. The thin seed coat character is genetically recessive in relation to thick seed coat (Teppner, 2000). The epidermal cell thickness is one cell layer thick, with other species possessing a layer of thick piliferous epidermal cells. All the species, including *C. moschata,* have 3 to 4 layer thick hypodermal cell, thick columnar layer, sclerenchyma and 3 to 7 layer thick chlorenchyma and parenchyma (Agbagwa and Ndukwu, 2004). Thick seed coat is represented by a strong lignification of the first four outer layers. Ripe seeds of this type have the seed coat structure with testa layers, including epidermis, hypodermis, sclerenchyma, aerenchyma and chlorenchyma (Teppner, 2000). Thin seed coats arise due to lack of lignification of the first four outer layers of the cell walls. Full grown but unripe seeds have all the five layers developed. During the late phases of seed development, the epidermis, except testa cells, collapse, hypodermis and sclerenchyma layers are largely or totally resorbed, leaving only a thin, compact, hyaline layer. Outside chlorenchyma, only the thin aerenchyma, no or hyaline remains of hypodermis and sclerenchyma and the hyaline epidermis exist. Basically 5-layered structured ripe thin-coated seeds possess an epidermis, aerenchyma and chlorenchyma testa in addition to the protochlorophyll content. Thin-coated seeds have a deficiency of lignin in hypodermis, sclerenchyma and aerenchyma, and of cellulose in the epidermis (Teppner, 2000). The seeds of all accessions on the present study were unwinged, with no seed coat pattern.

5. Conclusions and recommendations

The present study established that traditional pumpkin landraces can provide the genetic material required for crop improvement. However, documented information associated with these landraces has been insufficient to help identify duplicates and decide how many and which ones represent most of the genetic diversity. The present morphological characterization has provided information that should be used to delineate, standardize, identify and evaluate the pumpkin landraces. The great variability in shape, colour and skin texture of fruits and seeds should be used for improvement of the pumpkins. The rich diversity portrayed by the accessions provides more selection chances for breeding and improvement. Therefore, the highly diverse pumpkin germplasm with the farmers in Kenya should be conserved to serve as resource for improvement and breeding of well-adapted cultivars. Plant breeders and other professionals should take advantage of this information and commence the improvement work.

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