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Characterization of selected cowpea and sesame accessions at Genetic Resources Research Institute (GeRRI) in Kenya: Adding value to the rich collection

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Abstract

Gene banking is the most cost-effective *ex situ* strategy for conserving plant genetic resources. It was developed for the storage of predominantly orthodox seeds. To maintain long-term seed survival and integrity of the conserved germplasm in the genebanks, seed viability testing and regeneration should be done occasionally. The seed viability tests inform which accessions need regeneration. In addition, adequate evaluation and characterization of the conserved germplasm enhances their wider utilization. The Genetic Resources Research Institute (GeRRI) in Kenya and Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI) undertook a joint project entitled *Improvement of Technology on Conservation of Genetic Resources* from 2015 and 2018. Korea-Africa Food and Agriculture Cooperation Initiative was funding the project, while GeRRI was the implementing institution. One of the objectives was to carry out morphological characterization of sesame, millet and cowpea accessions conserved at GeRRI's genebank to promote their conservation and utilization. A total of 376 accessions of two crops (216 cowpeas and 160 sesame) were withdrawn from the conservation unit at GeRRI's genebank and characterized at KALRO's Perkerra field site during the 2018 long rains season. About 78 % of the cowpea accessions had reached 50 % flowering within 60 days after planting. Over 80 % of sesame accessions yielded ≤ 400kg of seeds per hectare. Multivariate analyses were performed to establish similarity patterns. Principal Component Analysis (PCA) showed that four components had eigenvalues >1, accounting for 61.23 % of the total variability among the cowpea accessions. The first four PCs accounted for 63.95 % of the total variability for the sesame accessions. In addition, all the quantitative characters considered were important in describing phenotypic variation in these sesame accessions. The study has shown that there is wide variability among cowpea, as well as sesame accessions, conserved at GeRRI's genebank. All the quantitative characters measured in this study were important in describing phenotypic variation among cowpea and sesame accessions.

Keywords: Accessions, Characterization, Cowpeas, Principal component analysis, Sesame.

Introduction

Plant genetic resources (PGR) play an important role in the development of agriculture. They constitute the foundation upon which agriculture and world food securities are based. They are the raw material for breeding new plant varieties and are a reservoir of genetic diversity. Genetic diversity in the germplasm collections allows them to adapt to changing environments, including new inscet pests, diseases, and climatic conditions. Landraces adapted to optimal local agronomic conditions are probably the crop plant genetic resources that are most at risk of future loss through habitat destruction or by replacement by introduced elite germplasm (Brush, 1995).

Efforts to conserve plant genetic resources were ignited by the realization of the dangers of losing crop genetic resources on agricultural farms, mainly due to modern plant breeding (Hammer and Teklu, 2008; Fu and Somers, 2009). With the development of scientific plant breeding, high-quality and homogenous new varieties were quickly and widely distributed, replacing landraces. The establishment of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, or the Treaty) (Esquinas-Alcázar, 2005) to conserve and utilize these plant genetic resources is a remarkable achievement in the conservation efforts (Gepts, 2006; FAO, 2010).

There are two primary complementary conservation strategies, *in situ* and *ex situ* (Hammer and Teklu, 2008). *In situ* conservation is the conservation of components of biological diversity in their natural habitat. It is the conservation of ecosystems and natural habitats. *Ex situ* conservation is the conservation of components of biological diversity outside their natural habitat. Among the various *ex situ* conservation methods, seed storage in genebanks is the most convenient for long-term conservation of plant genetic resources. Genebanking is the most cost-effective *ex situ* conservation

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strategy (Li and Pritchard, 2009) and was developed for the storage of predominantly orthodox seeds to maintain (in perpetuity) the allelic integrity and identity of a sample (Frankel and Soulé, 1981). Thus, a genebank requires essential infrastructure for short- and long-term seed storage and the efficient management of germplasm from safety backup to regeneration and characterization, germplasm distribution, and data management (Engels and Visser, 2003).

One of the many challenges facing gene banks worldwide is regeneration backlogs and loss of genetic integrity of the conserved germplasm (Yong-Bi Fu, 2017). A major impediment to the successful regeneration of genebank collections is the lack of adequate funds and resources, including skilled staff. Germplasm regeneration and seed viability tests are required to maintain long-term seed survival and germplasm integrity, but they are costly activities. Viability monitoring tests at certain intervals during seed conservation helps in identifying accessions that need regeneration. Given the large volumes of *ex situ* germplasm collections, viability testing may lag behind in under-resourced genebanks. Viability testing is not performed regularly in many genebanks in Africa, and regeneration of stored material is mainly sporadic (FAO, 2010).

Regeneration backlogs have been recognized in many genebanks for many crop species (Engels and Rao, 1998). Another challenge is lack of adequate evaluation and characterization of the conserved germplasm. The general lack of accession-level information is a major constraint to wider utilization of the conserved germplasm (FAO, 2010; Khoury et al., 2010). Most of the conserved germplasm accessions are recorded only with basic descriptors such as passport data, while informative evaluation and characterization data are largely lacking for many genebank collections. Characterization for basic information such as plant height, flower color, and leaf size is largely ignored due to a lack of interest in use. Although information on biochemical traits and disease resistance is highly relevant, these evaluations are costly. Evaluation and characterization efforts require substantial funding, and few genebanks in the world can afford given they are generally underfunded (Clark et al., 1997; Rubenstein et al., 2005).

In Kenya, plant genetic resources are conserved mainly by the Genetic Resources Research Institutes (GeRRI), one of the semi-autonomous institutes of the Kenya Agricultural and Livestock Research Organization (KALRO). The institute (formerly known as the National Genebank of Kenya or genebank) has a national mandate to conserve the country's genetic resources. The institute has amassed slightly over 51,000 (fifty-one thousand) accessions (ecotypes) comprising over two thousand plant species, a majority of which are crop plants. This rich collection includes local and global collections (GeRRI, 2015). The institute periodically undertakes regeneration which is combined with agromorphological characterization of the accessions whose viability has fallen below the minimum conservation standards due to ageing; seeds for long-term conservation at the genebank should have viability >85%. However, due to the sporadic nature of these characterization activities, limited information is generated on the inherent genetic diversity and the potential value of the accessions conserved. This may partially explain the low utilization of the conserved germplasm (GeRRI, 2015). Sporadic regeneration and characterization activities are mainly due to inconsistent and limited funding. About 12,000 accessions have been morphologically characterized since the inception of the genebank in 1987(GeRRI, 2021), and very few have been comprehensively evaluated for performance in the farmers' fields and for tolerance/resistance to biotic and abiotic stresses. Because regeneration and characterization activities are expensive, the institute seeks grants and collaborative projects to fund these undertakings. Reported here is morphological characterization work undertaken through such collaborative efforts.

Between 2015 and 2018, Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI) and GeRRI undertook a joint project entitled *Improvement of Technology on Conservation of Genetic Resources*. Korea-Africa Food and Agriculture Cooperation Initiative funded the project, while GeRRI was the implementing institution. The project's overall objective was to strengthen Kenya's capacity to efficiently and effectively conserve and use plant genetic resources for enhanced livelihoods and food security. The project aimed at promoting the conservation and utilization of millet, cowpea, pearl millet and sesame biodiversity. One of the specific objectives was to carry out morphological, molecular and physiological characterization of sesame, millet and cowpea accessions conserved at GeRRI's genebank. This specific objective was carried out in three financial years, i.e. 2015-2016, 2016-2017 and 2017-2018. At least 1,800 accessions of sesame, millet and cowpea were expected to be fully characterized in these three years. However, only morphological characterization was carried out due to limitations in technical and physical capacity. In the first two years, 1460 accessions comprising finger millet, cowpeas, sesame and pearl millets were characterized. These have been reported elsewhere. In the third year (2017-2018), 376 accessions were characterized at KALRO's Perkerra field site. The accessions comprised of 216 cowpea (*Vigna unguiculata*) and 160 sesame (*Sesamum indicum*). Reported here is work carried out in the third year from December 2017 to November 2018.

Results and Discussion

Cowpeas

Not all cowpea accessions were harvested; some plants either did not germinate or were destroyed in the field. Most cowpea accessions reached 50 % flowering within 51-60 days after planting (Figure 1). Only one accession (GBK-003948) flowered late at 72 days after planting. About 78% of cowpea accessions had first mature pod 71-90 days after planting (Figure 2). Few accessions weighed more than 15 grams per 100 seeds (Figure 3). A hundred seed weight (HSW) ranged from 6 to 20g with an average of 10.2g (Table 1). This is in agreement with a study by Nwofia (2012) who reported a hundred seed weight ranging from 7 to 17g with an average of 12g. Other researchers reported a HSW ranging from 6 to 14g with an average of 10g (Kwadwo et al., 2020). A similar study reported HSW ranging from 7 to 39g with an average of 20 g (Gerrano et al., 2022). Terminal leaflet length varied from 70 to 146 mm while the width ranged from 30.5 to 80.5 mm (Table 1). In another study, cowpea genotypes grown in the field and phenotyped 54 days after planting had terminal leaflet width and length ranging from 32 to 69 and 48 to 125 mm, respectively (Digrado et al., 2022). Kwadwo et al. (2020) reported terminal leaflet length ranging from 31 to 135 mm with an average of 82.4 mm while the width varied from 14 to 95 mm. On average, the cowpeas took 57.2 days from planting to 50 % flowering. In a study by Hutchinson et al. (2017), 28 accessions of cowpeas collected and characterized in the warm coastal parts of Kenya took an average of 42 days from planting to 50 % flowering. Similar results were reported on local Ghanaian cowpea accessions that flowered 39.5 days after planting (Cobbinah et al., 2011). The longer time reported in the current study (57.2) could be due to lower temperature because Perkerra is colder than the Kenyan coast. Days from planting to first mature pod ranged from 62 to 95 (Table1). Other studies reported days from planting to first mature pod varying from 55 to 73 with an average of 64 (Kwadwo et al., 2020). The number of pods per plant ranged from 12 to 57 with an average of 36. Nwofia (2012) reported number of pods per plant ranging from 13 to 83 with an average of 29 while Gerrano et al. (2022) reported a range of 9 to 66 pods per plant with an average of 40. The average pod length reported in the current study was 16.5 cm. Afiukwa (2017) reported an average pod length of 16 cm while Nwofia (2012) reported 20 cm. Highest variance was observed in terminal leaflet length (157.7) followed by the number of pods per plant at 131.4 (Table 1). The % CV ranged from 8.7 (days from planting to 50 % flowering) to 31.8 for number of pods per plant (Table1). High CV indicates a wide variation for a given trait among the different accessions.

The correlation between the terminal leaflet length and terminal leaflet width was 0.5892 (Table 2). This positive correlation indicates that accessions with long leaves also had wide leaf blades. Another study reported a significant and positive correlation (0.71**) between leaf length and width (Gerrano et al., 2022). These two traits are key determinants of leaf area. The Montgomery equation predicts that leaf area is the product of leaf length and width multiplied by a correction factor (Montgomery, 1911). Correlation between days from planting to first mature pod (DM) and number of pods per plant (NPOD) was 0.485. Correlation between duration of flowering (DURFL) and NPOD was 0.597 while between DURFL and DM was 0.482. This indicates that cowpea accessions that took long to mature also had a longer flowering duration resulting in higher yields (more pods per plant). This is expected because the longer the flowering duration the more flowers are produced which later turn into pods after fertilization. The number of pods per plant (NPOD) and the number of locules per pod (NLOCPERPOD) showed a very weak positive correlation of 0.087. Sharma et al. (2017) reported a negative and non-significant (-0.063) correlation between number of pods per plant and number of seeds per pod. There was a weak and negative correlation (-0.0269) between number of pods per plant and pod length (Table 2). Similarly, Mbuma et al. (2021) found a negative and non-significant (− 0.01 ns) correlation between number of pods per plant and pod length and between number of pods and pod width (− 0.04 ns). In addition, Sharma et al. (2017) reported a negative and non-significant (- 0.056) correlation between number of pods per plant and pod length. However, Gerrano et al. (2022) found a positive and significant correlation (0.68**) between number of pods per plant and pod length and between number of pods per plant and pod width (0.56**). There was a weak negative correlation (-0.1055) between pod length and number of locules per pod (Table 2). Mbuma et al. (2021) also found a weak correlation (0.06 ns) between pod length and number of seeds per pod. Sharma et al. (2017) reported a positive and significant (0.363**) correlation between pod length and number of seeds per pod. Similarly, Gerrano et al. (2022) posted a positive and significant (0.82**) correlation between the two traits. Edematie et al. (2021) also posted positive and significant correlations (0.30 *** and 0.41 ***) between the two traits in different segregating populations of cowpeas.

From multivariate analysis, the first seven eigenvalues were highly significant (≤ 0.0001***) and explained 84.16 % of the total variation among the cowpea accessions (Table 3). Principal Component Analysis (PCA) showed that seven components accounted for 84.16 % of the total variability among the cowpea accessions (Table 3). The first four PCs explained 61.232 % of the total variation. The first principal component (PC1) showed strong positive correlation with days from planting to first mature pod (0.791), days from planting to 50% flowering (0.606), duration of flowering (0.787) and number of pods per plant (0.755) (Table 4). Most of the variance in this PC was due to variations in these traits among the cowpea accessions. This PC increases with increasing scores for these characters. This PC describes traits that affect maturity and yields in cowpeas. This PC also correlates positively with all characters except 100 seed weight. The second PC shows strong positive correlation with terminal leaflet length (0.801) and terminal leaflet width (0.820) while the third PC showed strong positive correlation with a hundred seed weight (0.797). A positive correlation between the PCs and any of the studied characters means an increase in that specific principal component will result in positive increase in the relevant character of the plant. Conversely, a negative correlation means an increase in a certain component results in a decrease in some specific character of the plant.

(b) Sesame

Of the 139 sesame accessions that survived, only 4 matured within the first 100 days after planting (Figure 4). Most sesame accessions yielded less than 400 kgs/ha (Figure 5). About 85 % of the sesame accessions had one flower per leaf axil. In a similar study, about 97.1 % accessions of sesame had one flower per axil (Furat and Uzun, 2010). Number of flowers per leaf axil is one of the important determinants of number of capsules per plant. Because number of capsules per plant is a major character contributing to seed yield of sesame (Ibrahim et al., 1983; Osman, 1989), plants with three flowers per leaf axil are an important resource for sesame breeding programs. However, the current study showed a negative and negligible correlation (-0.132) between number of flowers per axil and number of capsules per plant. In addition, the number of flowers per axil had a weak correlation (0.0387) with the number of capsules per axil (Table 5). There was a strong positive correlation between height from the first capsule to tip of the plant and plant height (0.887) and between days to physiological maturity and seeds per capsule (0.547) (Table 5). There was a strong positive correlation between days to physiological maturity and a thousand seed weight (0.508) and between a thousand seed weight (TSW) and seeds per capsules (0.448). This means sesame accessions that took longer to mature had more time to accumulate photoassimilates and hence gave more and heavier seeds, which translated into more yields. There was a positive correlation between seeds per capsule and plant height (0.590) and between a thousand seed weight and plant height (0.533). There was a positive correlation between capsule length and plant height (0.543), between days to physiological maturity and plant height (0.449) and between capsule length and number of capsules per plant (0.405). This means sesame accessions that were tall took long time to mature and they had long capsules. These long capsules had many seeds; correlation between capsule length and seeds per capsule was 0.663. Due to a longer time to maturity, these tall accessions produced many and heavier seeds which translated into more yields. The positive correlation between number of primary

Table 1. Variation in quantitative traits among the cowpea accessions characterized.

Statistics	TLL	TLW	DM	DF	DURFL	PB	PL	NPOD	NLOCPERPOD	FLLENG	HSW
Min	70.0	30.5	62.0	42.0	15.0	5.0	9.6	12.0	9.0	2.2	6.0
Mean	103.9	62.9	78.5	57.2	30.7	9.7	16.5	36.0	14.9	21.7	10.2
Max	146.0	80.5	95.0	72.0	47.0	15.0	22.7	57.0	22.0	25.0	20.0
SD	12.6	8.7	7.4	5.0	6.2	1.9	2.1	11.5	2.3	2.3	2.4
Variance	157.7	75.3	55.0	24.8	38.6	3.5	4.3	131.4	5.1	5.2	5.8
% CV	12.1	13.8	9.4	8.7	20.2	19.1	12.5	31.8	15.2	10.5	23.6

TLL=Terminal leaflet length (mm); TLW= Terminal leaflet width (mm); DM=Days from planting to first mature pod; DF=Days from planting to 50% flowering; DURFL=Duration of flowering (days); PB=Number of primary branches; PL=Pod length (cm); NPOD=Number of pods per plant; NLOCPERPOD=Number of locules per pod; FLLENG=Flower length (mm); HSW=100 seed weight (g).

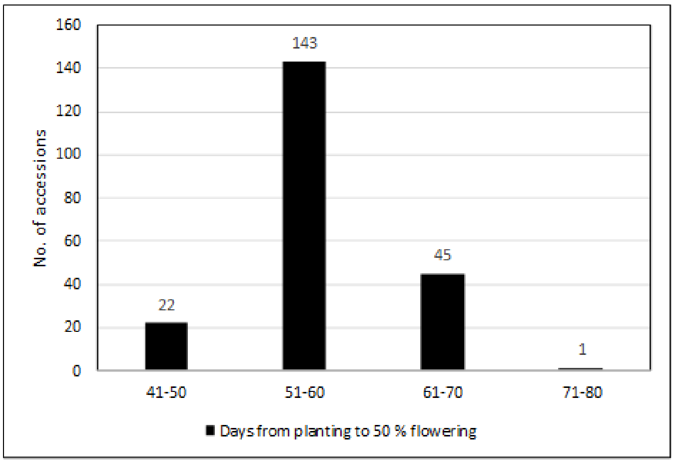

Figure 1. Days to 50 % flowering of the cowpea accessions.

Table 1. Correlation matrix for quantitative traits for cowpeas.

Traits	TLL	TLW	DM	DF	DURFL	PB	PL	NPOD	NLOCPERPOD	FLLENG	HSW
TLL	1.0000										
TLW	0.5892	1.0000									
DM	0.1278	-0.0309	1.0000								
DF	0.0034	-0.0654	0.5735	1.0000							
DURFL	0.2232	0.0535	0.4817	0.2621	1.0000						
PB	0.0455	0.0146	0.2429	0.1337	0.3129	1.0000					
PL	0.1893	0.1955	-0.0128	-0.0305	0.1195	0.0608	1.0000				
NPOD	0.0878	-0.0662	0.4850	0.2852	0.5972	0.2259	-0.0269	1.0000			
NLOCPERPOD	0.1698	0.1255	-0.0716	-0.0025	0.0210	-0.0014	-0.1055	0.0872	1.0000		
FLLENG	0.0729	0.0302	0.1549	0.1393	0.2138	0.1245	0.0128	0.2369	-0.0551	1.0000	
HSW	0.0732	0.0323	-0.0718	-0.1835	0.0559	0.0689	0.0692	0.0423	0.0448	-0.1673	1.0000

TLL=Terminal leaflet length (mm); TLW= Terminal leaflet width (mm); DM=Days from planting to first mature pod; DF=Days from planting to 50% flowering; DURFL=Duration of flowering (days); PB=Number of primary branches; PL=Pod length (cm); NPOD=Number of pods per plant; NLOCPERPOD=Number of locules per pod; FLLENG=Flower length (mm); HSW=100 seed weight (g).

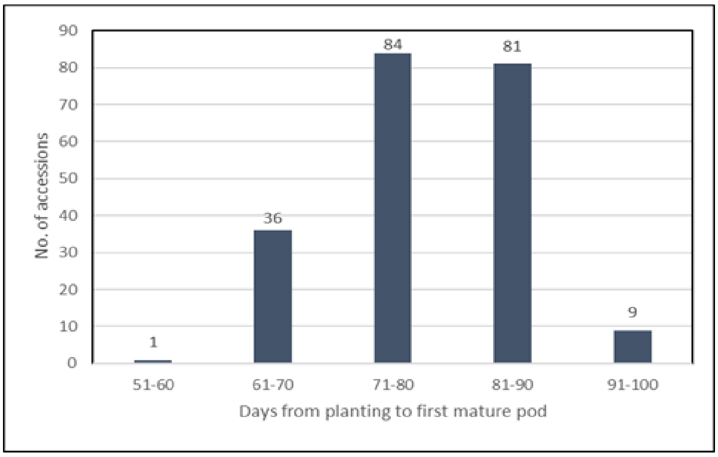

Figure 2. Days from planting to first mature pods of the cowpea accessions characterized.

Table 2. Eigenvalues for cowpea accessions characterized.

Componnts	Eigenvalue	% variation explained	Cumulative % variation	Chi-Square	DF	Prob>Chi Sq
1	2.6421	24.019	24.019	337.273	53.874	<.0001*
2	1.7708	16.098	40.117	207.706	47.661	<.0001*
3	1.1884	10.803	50.921	137.958	40.323	<.0001*
4	1.1343	10.312	61.232	111.929	32.616	<.0001*
5	0.9511	8.646	69.878	81.147	25.548	<.0001*
6	0.8111	7.373	77.252	58.780	19.280	<.0001*
7	0.7599	6.908	84.160	42.086	13.715	0.0001*
8	0.6439	5.854	90.014	21.016	8.911	0.0120*
9	0.3991	3.629	93.642	1.255	5.084	0.9435
10	0.3667	3.334	96.976	0.359	1.815	0.7995
11	0.3326	3.024	100.000	0.000	.	.

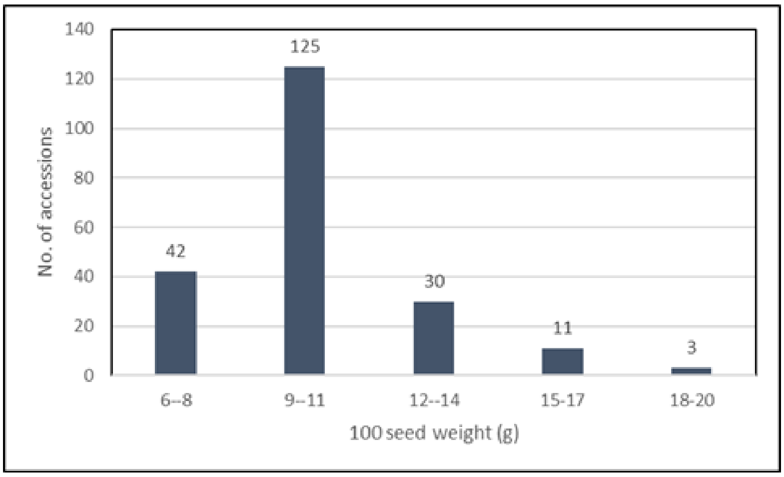

Figure 3. 100 seed weight of cowpea accessions characterized.

branches and plant height (0.492) indicated that the tall plants had many branches and hence were big.

All the eigenvalues were highly significant (<0.0001***) except the last one (Table 6). The first four eigenvalues explained 63.95 % of variation among the sesame accessions (Table 6). The first principal component (PC1) accounted for 38.54 % of the total variation. This principal component (PC1) showed strong positive correlation with number of capsules per axil (0.669), height from the first capsule to tip of the plant (0.847), plant height (0.846), number of primary branches per plant (0.587), number of capsules per plant (0.595), capsule length (0.741), capsule width (0.583), number of locules per capsule (0.619), seeds per capsule (0.749), days from planting to physiological maturity (0.654), and a thousand seed weight (0.689) (Table 7). The variation in PC1 was mainly due to these characters. This PC describes the major plant structural parts that are associated with high economic and biological yield. The PC is positively associated with bigger, taller plants and higher seed yields. Sesame accessions GBK-041424(36) and GBK-030629(93) were negatively associated with PC1 (Figure 6). These accessions had short plants and all other measurements were low. The second PC is not strongly associated with any trait of economic importance (Table 7). This PC is strongly positively associated with leaf angle to the main stem (Table 7; Figure 6). It is also positively associated with number of capsules per axil, height from the first capsule to tip of the plant (cm), plant height at physiological maturity (cm), internode length and number of flowers per axil (Table 7; Figure 6). Accession GBK-041034 (79) which was positively associated with PC2 had a wide leaf angle to the main stem (Figure 6). In the third PC, most of the variation was due to number of flowers per axil (0.817) and capsule width (0.519). If we consider only eigenvalues >1 as significant (Ng'uni, 2011; Sneath and Sokal, 1973; Jeffers, 1967) and that a high coefficient for a trait points to the relatedness of that trait to the respective PC, only the first four principal components were significant. Characters with high coefficients in PC1 to PC4 should be considered as more important since these axes explained 63.95 % of the total variation. The PC analysis also indicated that most of the quantitative characters measured in this study were important in describing phenotypic variation in these sesame accessions. These descriptors could be useful for studying the variability of sesame populations and, could save time and money in identification of accessions of interest.

Materials and methods

Project site

Agro-morphological characterization was conducted at the Apiculture and Beneficial Insects Research Institute (ABIRI)'s experimental farm located at Perkerra in Baringo County, Kenya. The ABIRI is one of the 16 semi-autonomous institutes of KALRO. The field is located on latitude 0^0 28' 30'' N and longitude 35^0 56' 20'' E and at about 1065 meters above sea level. The average annual rainfall is 654 mm with a bimodal distribution while potential evapotranspiration is 1360 mm. A

Table 3. Latent vectors (loading matrix) for cowpea accessions characterized.

	Principal components										
Phenotypic characters	1	2	3	4	5	6	7	8	9	10	11
TLL	0.27867	0.80074	-0.17599	0.10235	-0.06817	-0.05568	-0.18891	-0.04953	-0.36297	0.10309	-0.22682
TLW	0.07859	0.82026	-0.26956	0.03764	-0.05629	0.07703	-0.22789	-0.01978	0.40212	-0.05796	0.14294
DM	0.79122	-0.17284	-0.06734	0.01487	-0.33828	-0.01823	-0.12447	0.05856	-0.13894	0.21495	0.37437
DF	0.60602	-0.28324	-0.29437	0.10473	-0.44591	0.12019	0.03483	0.37536	0.10587	-0.16626	-0.24628
DURFL	0.78691	0.09593	0.21848	-0.05604	0.08782	-0.16187	0.07615	-0.28704	-0.07977	-0.43280	0.07011
PB	0.45897	0.01835	0.32183	-0.18203	0.24393	0.75953	-0.09859	-0.02130	-0.00010	0.05556	-0.05153
PL	0.08469	0.42296	0.00883	-0.64318	-0.14954	-0.01466	0.60121	0.10127	0.00548	0.07470	0.01663
NPOD	0.75516	-0.09665	0.22839	0.14023	0.14307	-0.29366	0.09541	-0.21310	0.25663	0.28634	-0.19872
NLOCPERPOD	0.02906	0.27932	0.11373	0.78650	0.11700	0.14878	0.46936	0.14895	-0.03572	-0.00355	0.10007
FLLENG	0.39171	-0.04791	-0.37710	-0.14352	0.70796	-0.16432	-0.04105	0.38438	-0.03556	-0.00660	0.05016
HSW	-0.05842	0.26187	0.79678	-0.04908	-0.07103	-0.22044	-0.21797	0.43393	0.01980	-0.02939	0.00673

TLL=Terminal leaflet length (mm); TLW= Terminal leaflet width (mm); DM=Days from planting to first mature pod; DF=Days from planting to 50% flowering; DURFL=Duration of flowering (days); PB=Number of primary branches; PL=Pod length (cm); NPOD=Number of pods per plant; NLOCPERPOD=Number of locules per pod; FLLENG=Flower length (mm); HSW=100 seed weight (g).

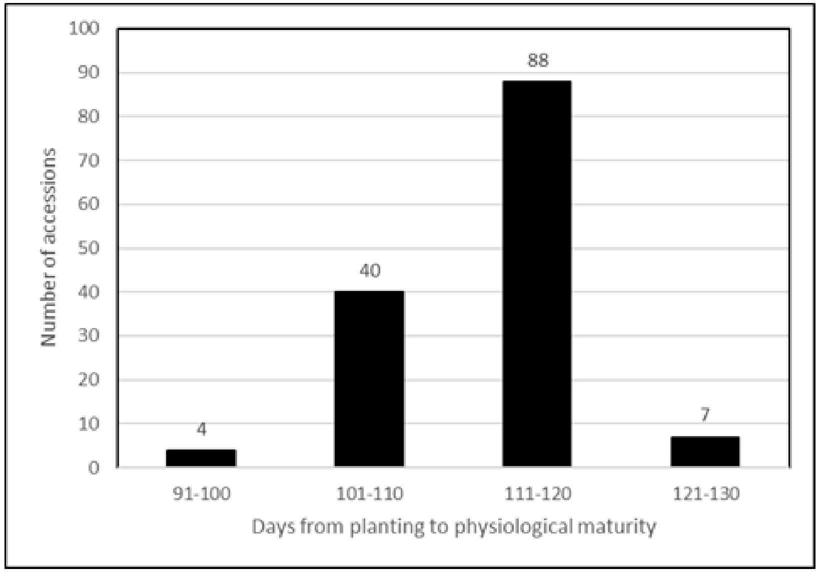

Figure 4. Days from planting to physiological maturity of sesame accessions characterized.

Table 4. Correlation matrix for quantitative traits for sesame.

Traits	NC	HFC	PH	BPP	IN	LA	NFL	NCPL	NL	CL	CW	SPC	TSW	MA
NC	1.0000													
HFC	0.6961	1.0000												
PH	0.6036	0.8865	1.0000											
BPP	0.2666	0.4478	0.4922	1.0000										
IN	0.1551	0.2018	0.1712	0.2358	1.0000									
LA	0.2102	0.1277	0.2039	0.0316	0.1210	1.0000								
NFL	0.0387	-0.0659	-0.0761	-0.0961	-0.0363	0.0260	1.0000							
NCPL	0.3891	0.5240	0.3723	0.3239	0.1734	-0.0707	-0.1323	1.0000						
NL	0.2950	0.3479	0.3881	0.3357	0.0808	-0.0555	-0.0733	0.3420	1.0000					
CL	0.3045	0.4725	0.5428	0.3583	0.1058	-0.0154	-0.0812	0.4047	0.5157	1.0000				
CW	0.3484	0.4195	0.4082	0.1918	0.1782	0.0181	0.1595	0.2469	0.5030	0.4956	1.0000			
SPC	0.3719	0.5279	0.5900	0.4681	0.0572	0.0645	-0.1825	0.3748	0.3898	0.6631	0.2837	1.0000		
TSW	0.4113	0.5165	0.5330	0.3322	0.0553	0.0775	-0.0662	0.3386	0.4200	0.4280	0.3344	0.4477	1.0000	
MA	0.3340	0.4598	0.4487	0.2708	0.1338	0.0142	0.0782	0.2923	0.3413	0.4799	0.3300	0.5474	0.5079	1.0000

NC= Number of capsules per axil; HFC= Height from the first capsule to tip of the plant (cm); PH= Plant height at physiological maturity (cm); BPP= Number of primary branches per plant; IN= Internode length; LA= Leaf angle to the main stem; NFL= Number of flowers per axil; NCPL= Number of capsules per plant; NL= Number of locules per capsule; CL= Capsule length; CW= Capsule width; SPC= Seeds per capsule; TSW= 1000 seed weight; MA= Days to physiological maturity.

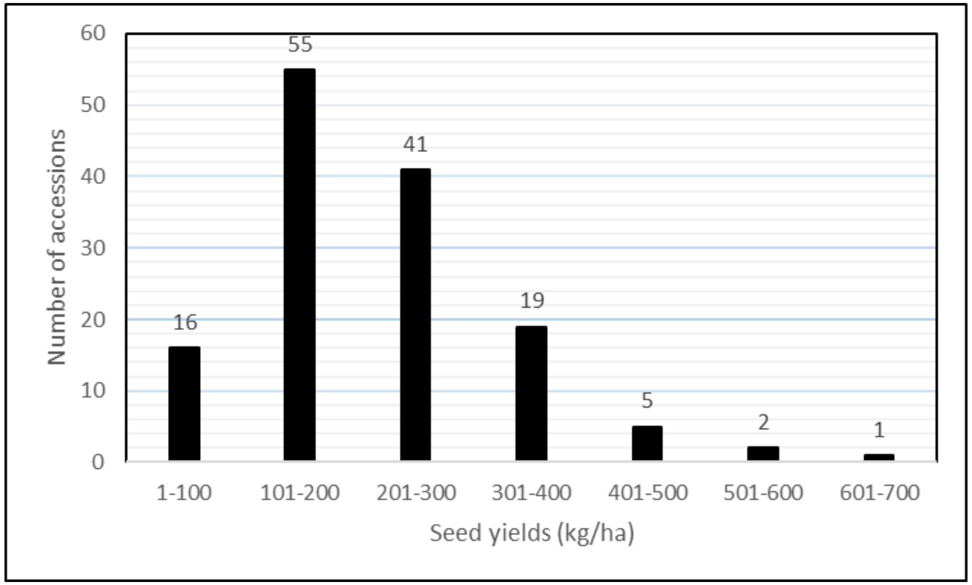

Figure 5. Seed yields (kg/ha) of sesame accessions characterized.

Table 5. Eigenvalues for sesame accessions characterized.

Components	Eigenvalue	% variation explained	Cumulative % variation	Chi Square	DF	Prob>Chi Sq
1	5.3954	38.538	38.538	862.636	87.409	<.0001*
2	1.3133	9.381	47.919	369.651	83.385	<.0001*
3	1.2211	8.722	56.642	322.634	72.126	<.0001*
4	1.0231	7.308	63.949	273.521	61.313	<.0001*
5	0.8768	6.263	70.212	236.111	51.189	<.0001*
6	0.8086	5.775	75.988	206.675	42.005	<.0001*
7	0.6992	4.994	80.982	176.447	33.539	<.0001*
8	0.6235	4.453	85.435	151.276	25.956	<.0001*
9	0.5872	4.194	89.629	127.215	19.349	<.0001*
10	0.4318	3.084	92.714	95.999	13.562	<.0001*
11	0.3600	2.572	95.285	79.952	8.642	<.0001*
12	0.3390	2.421	97.707	67.158	4.708	<.0001*
13	0.2461	1.758	99.464	41.935	1.930	<.0001*
14	0.0750	0.536	100.000	0.000	.	.

Table 6. Latent vectors (loading matrix) for the sesame accessions characterized.

	Principal components													
Phenotypic characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NC	0.66860	0.40994	0.05398	-0.10094	-0.36248	-0.12709	-0.03097	-0.00241	-0.07542	0.32280	0.12149	0.29319	-0.10861	-0.03018
HFC	0.84682	0.26036	-0.08534	-0.06193	-0.28750	0.00920	0.04464	0.04623	-0.17988	-0.06243	-0.06689	-0.19200	0.02806	0.19681
PH	0.84627	0.24010	-0.08781	-0.13578	-0.06019	-0.00015	0.15149	0.03519	-0.24172	-0.09257	0.01382	-0.26925	0.02880	-0.17808
BPP	0.58665	-0.01882	-0.29230	0.20904	0.13258	0.30643	0.56484	-0.18709	0.10595	-0.01254	-0.13844	0.13904	-0.10441	0.00657
IN	0.24541	0.33772	-0.12992	0.80402	0.19504	0.14465	-0.25790	-0.03809	-0.10472	0.02275	0.14570	-0.02048	0.04839	-0.00119
LA	0.11398	0.73301	-0.06523	-0.21542	0.46269	-0.25375	-0.02121	0.06096	0.32968	-0.03172	-0.07457	-0.02414	-0.01785	0.01583
NFL	-0.08627	0.24684	0.81705	0.03095	-0.09983	0.36958	0.20771	0.06022	0.19877	-0.01799	0.14867	-0.06482	0.06020	0.00429
NCPL	0.59511	-0.12757	-0.19861	0.20922	-0.45465	-0.02509	-0.16161	0.16427	0.50985	-0.12125	-0.08744	-0.02239	0.03502	-0.04352
NL	0.61898	-0.36027	0.18760	0.15197	0.13060	-0.38175	0.12898	-0.24398	0.16516	0.33490	0.06409	-0.20784	0.05337	0.01551
CL	0.74144	-0.32128	0.07943	-0.00386	0.23773	-0.05839	-0.00998	0.34349	0.00789	-0.13412	0.24784	-0.00543	-0.28738	0.02483
CW	0.58300	-0.06980	0.51898	0.25066	0.07185	-0.35533	0.03626	0.07594	-0.17124	-0.19969	-0.26558	0.19810	0.07363	-0.01274
SPC	0.74948	-0.19452	-0.18253	-0.21682	0.24466	0.18140	0.01600	0.27405	-0.00116	0.09597	0.10297	0.15051	0.33073	0.01221
TSW	0.68883	-0.05023	0.04866	-0.23428	0.02675	0.03170	-0.20992	-0.53728	0.06066	-0.28685	0.18390	0.10140	0.03427	0.00668
MA	0.65354	-0.11267	0.20759	-0.14668	0.18293	0.40815	-0.39450	-0.04737	-0.00329	0.19218	-0.29056	-0.05678	-0.11340	-0.01410

NC= Number of capsules per axil; HFC= Height from the first capsule to tip of the plant (cm); PH= Plant height at physiological maturity (cm); BPP= Number of primary branches per plant; IN= Internode length; LA= Leaf angle to the main stem; NFL= Number of flowers per axil; NCPL= Number of capsules per plant; NL= Number of locules per capsule; CL= Capsule length; CW= Capsule width; SPC= Seeds per capsule; TSW= 1000 seed weight; MA= Days to physiological maturity.

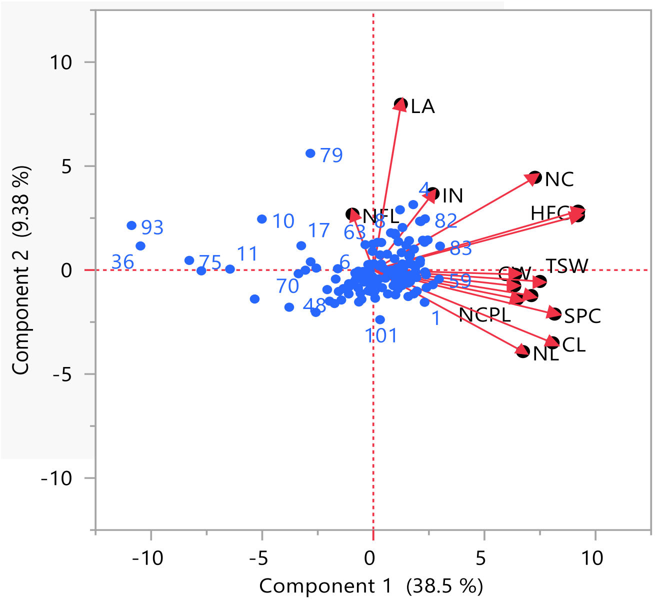

Figure 6. Principal component bi-plot of PC1 and PC 2 showing relationships of the sesame accessions and their quantitative traits. NC= Number of capsules per axil; HFC= Height from the first capsule to tip of the plant (cm); PH= Plant height at physiological maturity (cm); IN= Internode length; LA= Leaf angle to the main stem; NFL= Number of flowers per axil; NCPL= Number of capsules per plant; NL= Number of locules per capsule; CL= Capsule length; CW= Capsule width; SPC= Seeds per capsule; TSW= 1000 seed weight; MA= Days to physiological maturity.

long rainy season occurs between March and May while the short rain season is between October and December (Jaetzold et al., 2006). The mean air temperature ranges from 16.8 to 32.4 ^{0}C with an average of 24.6 ^{0}C. The station is situated in agro ecological zone 5 (LM5) and the major land uses are irrigated and dryland farming, pastoralism involving rearing of cattle, goats, sheep, and camels as well as beekeeping. The soils are volcanic fluvisols of sandy/silty clay loam texture; they are slightly acid to slightly alkaline, fertile with adequate phosphorus, potassium, calcium and magnesium but low in nitrogen and carbon (UNESCO, 1977).

Plant materials

A total of 376 accessions were selected and withdrawn from the conservation unit at GeRRI's genebank for characterization at KALRO's Perkerra field site during the 2018 long rains season. The accessions comprised of 216 cowpea (*Vigna unguiculata*) and 160 sesame (*Sesamum indicum*) (Supplementally Table 1). The choice of the accession was informed by data from documentation section. These accessions had not been regenerated nor characterized despite the fact that they were collected and conserved over 15 years ago. In addition, germination tests conducted at the GeRRI laboratories indicated the accessions had less than 60 % viability.

Field crop management

The land was ploughed and harrowed to a fine tilth and planting was done in June, 2018. Cowpea accessions were planted on plots consisting of four rows measuring 4.4 metres long. Plant spacing was 30cm within rows giving a total of 60 plants per plot. Sesame accessions were planted on four rows and plant spacing was 100cm x 30cm giving a total of 40 plants per plot. Water was supplied throughout the season using furrow irrigation. Weeding, pests and disease management were done as need arose.

Data collection and analysis

Agro-morphological data (for both qualitative and quantitative traits) were collected from crop emergence, maturity upto post-harvesting stage. Data was collected from the 22 middle plants per plot in cowpeas and from the middle 16 plants per plot for sesame. Field and post-harvest characters were described using the International Board on Plant Genetic Resources (IBPGR) descriptors (IPGRI and NBPGR, 2004; IBPGR, 1983). For cowpeas, some of the characters taken were plant growth habit, twinning tendency, leaf colour, pod attachment, flower colour, pod colour, pod curvature, seed shape, seed eye colour, days from planting to 50 % flowering, days from planting to first mature pods, 100 seed weight (g) and number of seeds per plant. For sesame, some of the characters recorded were plant growth habit, lodging susceptibility, stem hairiness, stem branching, leaf hairiness, leaf shape, leaf angle to the main stem, corolla hairiness, corolla colour, capsule dehiscence at ripening, seed coat colour, number of capsules per plant, seeds per capsules, 1000 seed weight, days from planting to physiological maturity, plant height at maturity (cm), and height from the first capsule to tip of the plant (cm). Data were then entered in excel and analyzed using the SAS Statistical software (SAS, 2003). Descriptive statistics and correlation coefficients analysis were computed. Quantitative data were standardized and subjected to principal component analysis (PCA). The PCA and correlation matrices were used to explore the links between the quantitative traits, identify, and define the main characteristics of groups of accessions.

Conclusions

There was wide variability in cowpeas accessions as well as within sesame accessions. These variations could be exploited to develop higher yielding and better adapted varieties. In both cowpeas and sesame, only the first four PC were significant as they had eigenvalues > 1. All the quantitative characters measured in this study were important in describing phenotypic variation in sesame accessions because they had high coefficients in the first four PCs. The same applies to cowpea accessions.

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