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Characterization Of Farmer-Held Bambara Groundnut (VignaSubterranea (L.) Verdc.)Germplasm Collections FromLake Victoria Basin, Kenya Using Qualitative Traits: A Basis For Crop Genetic Improvement.

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Abstract
Bambara groundnut (Vignasubterranea (L.)Verdc.)is the second most important African indigenous grain legume after cowpea. The crop is majorly grown for its food and nutrition provisions and health benefits. Bambara groundnut is currently neglected and underutilized in the Lake Victoria Basin of Kenya. Most cultivars grown by farmers in the Lake Victoria Basin have unknown characteristics. A field study comprising of six farmer-held accessions was carried out during the 2018/2019 cropping season at three agro-ecological zones, within the diverse Lake Victoria Basin in Kenya. The field experiments were conducted at Kenya Agricultural and Livestock Research Organization (KALRO) farms namely, Alupe in Busia, County, Kibos in Kisumu County and at Oyani in Migori County. The trials were conducted to characterize the landraces' qualitative traits. The experimental design used was a Randomized Complete Block Design (RCBD) with three replications. In all the zones, the qualitative characters were the same for individual genotypes. The results showed high phenotypic variations among the accessions. The germplasm had a high proportion of oval leaflet shape (50%), brown pod colours (66.67%), pod shape ending in a point, round on the other side (66.67%), absence of eye pattern (50%) and cream seed testacolour (50%). The Shannon-Weiner diversity index (H') indicated that all phenotypic characters studied amongst the six accessions showed high levels of diversity. Terminal leaflet shape and seed eye pattern had the highest index of 2.0708, followed by pod texture (2.062). The seed testa pattern had the least index (1.6501). The cluster analysis revealed two major clusters. The accessions from Migori were grouped in one cluster, whereas the accessions from Kisumu and Busia counties were also grouped in another cluster. These results may be useful in formulating Bambara groundnut breeding programs in the Lake Victoria Basin, Kenya and beyond, as currently there are no improved cultivars of this crop in Kenya. Effective breeding would boost crop productivity and improve food security. However, morphological traits are not stable; hence, further molecular analysis is required to determine and back up the genetic variations among the accessions as observed in this study.

Key words: *Bambara groundnut, Lake Victoria Basin, accessions, landraces, genetic diversity, qualitative traits, germplasm*

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I. INTRODUCTION

Bambara groundnut (*Vignasubterranea* (L.)Verdc.)is an annual herbaceous grain legume, which belongs to the Vigna botanical family[1]. Bambara groundnut is cleistogamous, natural cross-pollination has never been reported[2,3].Bambara groundnuts originated from West Africa but have become widely distributed throughout the semi-arid zone of sub-Saharan Africa, Malaysia, South, and Central America, some parts of Northern Australia, Sri Lanka, and Indonesia[4,5,6,7].It is the second most important African indigenous grain legume after cowpea (*Vignaunguiculata*)[8]. The cultivation of Bambara groundnut among the communities that cultivate it is driven by the crop's economic importance. The crop has high carbohydrate content (49–64.5%) whose gross energy exceeds that of other common pulses such as cowpea, lentils and pigeon pea[9]. It has protein (15–25.5%) that is far more superior to the proteins of other legumes[1,10,11].The seed is also rich in fats (4.5–7.4%) and fiber (5.2–6.4%)[12,13].It, therefore, provides a complete diet. It also contains nutrients such as K (11.45–19.35 mg/100 g), Fe (5.1–9.2 mg/100 g), Na (2.9–12.0 mg/100 g), and Ca (95.8–99 mg/100 g). The crop has several medicinal and health benefits[7], as well as value chain importance. Bambara groundnut has been neglected due to the introduction of exotic crops such as American groundnut (Arachishypogaea)[14].Neglected crops have the potential to improve food and nutrition security, accessibility and availability of local communities, but require scientific attention to reintroduce them in the cropping system[14].

It is projected that the world population will surpass 9 billion by 2050[7,15]. This implies that food supplies must be doubled to meet the nutritional demands of the rising population. Therefore, there is an urgent need of incorporating neglected food crops[7]such as Bambara groundnut into the major food systems to boost food security, especially in Africa and Asia where the population growth is rapid[1].This therefore calls for intensified breeding programs to be formulated and put in place to ensure improved cultivars, which are adaptable to local environmental conditions are availed to farmers.

Bambara groundnut is a drought-resistant crop that thrives in marginalized soils where other crops don't thrive well[1,16], and can thrive under changing climate[5].Climate change impacts negatively on the global sustainability of food and nutrition[1], hence neglected crops like Bambara groundnut, which is drought resistant, could provide nutritional solutions. It is a low-input crop, whose nitrogen requirements is met through its nitrogen fixation modes[3,7,17]and hence can readily be grown by resource lessfarmers to help supplement expensive animal proteins which are beyond the financial reach of most families in sub-Saharan Africa.

To address climate change and food insecurity, plant breeders are working on crop improvement to diversify crops, enhance crop climate change adaptation, and upgrade underutilized crops to address the food shortage problem[18,19,20]. The knowledge of genetic diversity is critical for crop improvement, and it's an ongoing process in breeding programs used to direct breeding objectives[21], hence there is need of establishing the qualitative morphological characteristics of various Bambara groundnut landraces, as most of the cultivars grown by farmers have unknown characters[20,22,23]. Dwivedi*et al*., (2017)[24] also reported that there are many uncharacterized crop germplasm in national genetic resource centers.

Morphological characterization is a standard procedure used to identify the most critical germplasm collection traits for many crop species[19,25]. Various qualitative characterization studies for Bambara groundnut have been conducted in different countries. For instance, in Tanzania, Ntundu*et al*., (2006)[26]qualitatively characterized 100 accessions, using traits such as terminal leaflet shape, terminal leaflet colour, seed shape, pod colour, pod texture, and pod shape.He observed a high level of diversity of morphological traits useful for utilization in crop improvement programs. Molosiwa (2012)[27], characterized 35 accessions in the agronomy bay in the United Kingdom. He recorded ten qualitative characters and observed that 47.1% of the plants had a bunch type of growth habit, 92.9% had no seed eye pattern, 82.1% of the accessions had no testa pattern, 39.3% had brown pod colour, whereas 64.3% of the accessions had pointed and nooked pod shape. Khan *et al*., (2021)[28] characterized 15 accessions of Bambara groundnut in Malaysia. He reported that 26.67% of the accessions had cream and red seed coats, 86.67% of the accessions had no eye colour, whereas 53.33% of the total accessions had lanceolate terminal leaflets. He observed broad phenotypic diversity amongst the accessions. Esan*et al*., (2023)[13] characterized 15 accessions in Nigeria, and observed that 66.67% of the plants had a bunch type of growth habit, 40% had hair on their stems, 40% had terminal leaflet shape whereas cream seed color had the highest frequency of 60%.

In Kenya, there is minimal research on Bambara groundnut breeding. This is evidenced by the fact that there are improved cultivars of all "major" crops such as maize, beans and American peanut but no established improved cultivars of Bambara groundnut[29,30]. According to Majola*et al*., (2021)[3], Kenya is neither among the major production countries in Africa nor is it a suitable production region in Africa. This report is supported by Ngungi (1995)[29] who observed that in Kenya Bambara groundnut is a minor crop, and ethno-botanical surveys reveal that over the years, production levels have declined rapidly due to neglect in cropping systems despite its ability to provide nutritional balance to resource poor rural population.

In the Lake Victoria basin of Kenya, minimal research has been done to characterize the crop, as the research done focuses mostly on production, food and nutrition provision, and income generation[30,31].Recent research has also focused on the characterization of root nodule bacteria isolated from Bambara groundnut grown in the Lake Victoria Basin[32].Odongo*et al*., (2015)[33] molecularly characterized the Kenyan accessions. They evaluated 105 accessions for genetic diversity using 12 microsatellite markers. Simple Sequence Repeat (SSR) markers were used to study their DNA structures. The landraces were sourced from farmers in Western Kenya Counties of Kakamega, Busia, Bungoma and Vihiga, and the National Gene Bank of Kenya. The results revealed low genetic diversity amongst the evaluated germplasm.

However, the qualitative traits of the farmer-held Bambara groundnut germplasm in the Lake Victoria Basin region of Kenya are not fully characterized and documented. Qualitative characterization of different Bambara groundnut germplasm collections is essential for variety improvement[20]. Qualitative trait studies areimportant since they influence farmer selection, adoption and consumer uptake of the crop in Kenya and in other countries in Africa[30,34,35,36].The qualitative characters also assist to distinguish, classify and name Bambara groundnut landraces in their areas of production[20].Hence the study was conducted to evaluate and document morphological characters from farmer-held landraces using seven qualitative traits related to leaves, pods, and seed traits to generate information needed to establish the Bambara groundnut breeding program for Lake Victoria Basin, Kenya.

II. MATERIALS AND METHODS

Bambara groundnut germplasm collection

Bambara groundnuts used for this study were collected from ten randomly sampled farmers in the Lake Victoria Basin region Counties of Busia, Kisumu and Migori between October and December 2018, just two months after the harvesting period. Four farmers were sampled from Busia, whereas three farmers each were sampled from both Kisumu and Migori. Germplasm selection was based on the germplasm within the farmers' possession as at the time of collection. A total of six Bambara groundnut accessions (Table 1.) were collected and identified at East African Herbarium, Nairobi.Upon collection, the seeds were sorted out based on the accession and air-dried furtherto minimize dampnessand attain a longer post-harvest life.

Bambara groundnut field sites

The seeds were grown at four sites (KALRO-Alupe research fields in BusiaCounty, KALRO-Kibos research fields in Kisumu County, KALRO-Oyani research fields in MigoriCounty within the diverse agro-ecological regions of Lake Victoria Basin. The selection of the study site was by purposive sampling based on the fact that Bambara production in Kenya has been limited to the former Western Province and a lesser extent, former Coastal and Nyanza provinces[29,30].

KALRO-Kibos research fields are found in Kisumu County and occur at longitudes of 34^0 24"13'E and latitudes of 000 03" 01'S, within the lower midland ecological zone (LM 3) with heavy black clay soils (vertisols), fairly typical of the Kano plains[37]. The research fields lies at an altitude of 1173m above the sea level, and the mean annual rainfall is 1419mm[38] and temperature ranges between 16-31^0C[37].

KALRO Oyani research fields occur within the lower midland ecological zone (LM 2), at longitudes 34^0 28" 00'E and latitudes 010 04" 00'S. Soils of Oyani in MigoriCounty are classified as andosols, being well-drained, moderately deep, firm, clay soils on the valleys and poorly drained, deep, dark grey, brown, firm, clay soils in valley bottoms[37].Altitude ranges between 1135-1200m above the sea level with mean temperatures of 22.7-23.30C. Annual rainfall ranges between 900-1100 mm and is bimodal with much (400-480mm) of it falling in the first season between March and May.

KALRO -Alupe Sub-Station in Busia County is a low rainfall zone. The site receives an annual rainfall of between 680.5- 860mm, with a daily temperature range of 16^0C-34^0C[39]. The Alupe research fields are located at longitude 340 7" 50'E and latitude 00 30" 0 N, at an elevation of 1170 meters above sea level[39]. The soils at Alupe have been characterized as ferralo-orthic Acrisol[40].

Table1. Socio-demographic table of Bambara groundnut farmers, in the selected Lake Victoria Basin counties of Western Kenya.

Accessions	**County**	**Sub - county**	**Exact Locality of collection**	**No. of Farmers per locality**	**No. of Farmers per county**	**Gender**	**Age**
K2	Kisumu	Kisumu West	Holo	1	3	F	20-34
K1	Kisumu	Nyando	Ahero	1		F	>50
		Kisumu West	Holo*				
		Kisumu East	Kajulu	1		F	>50
B4	Busia	Matayos	Busende	1	4	F	35-49
		Butula	Bumala	1		M	>50
			Busire	1		F	>50
		Teso South	Amoni	1		F	35-49
B1	Busia	Matayos	Busende*				
		Butula	Bumala*				
M4	Migori	Suna East	God Jope	1	3	M	>50
			Anjego	1		F	35-49
M2	Migori	Uriri	Bware	1		F	>50

Key: 20-34=youthful farmers, 35-49= middle aged farmers, >50 elderly farmers
*means the collection locality similar for both accessions from same county.F (Female), M (Male)

Bambara groundnut field layout

Bambara groundnut planting was done in April 2019, at the onset of long rains. Each accession was planted in a three-row, three-replicated plot. A total of three blocks with eighteen experimental plots were established in each zone. A randomized complete block design was used. The key factor was accessions. The experimental area in each zone was 150m^2 (25 m long × 6m wide). The field layout for each accession consisted of three rows in an area of 1.2m^2. The rows were 1.2 m long with an inter-row spacing of 30cm and intra-row spacing of 20cm, with one plant per hill. Two seeds per hill were sown, and the holes for dibbling in Bambara groundnut seeds were dug using a hoe up to 3cm deep[41]. The seedlings were thinned to one plant per hill 21 days after planting, giving a plant population of about 29 plants/ m^2. Individual plots within a block were separated by 1m, while the blocks were separated from each other by a distance of 2 m. The plants were weeded manually using a hoe to keep weed pressure low, at 3 weeks, 5 weeks and 8 weeks after emergence. Earthing up to cover the young pods was done with a hoe at 3 weeks and 8 weeks after emergence. To control insects, alpha-cypermethrin 10% EC at a rate of 2ml1^{-1} was used two weeks after emergence. To control fungal diseases, dithane M-45 was applied at the rate of 3g 1^{-1} at 4 weeks after planting.

Data collection

Seven qualitative morphological characters such as Terminal leaflet shape at maturity (TLS), Pod colour(POC), Pod texture (POT), Pod shape (POS), Seed eye pattern (SEP), Seed testa pattern (STP) and Seed testacolour (STC) were scored using ten simple randomly selected plants per plot. All border plants were not used in sampling. The standard descriptors for Bambara groundnut[42] was used as a guideline in these phenotypic characterization exercises as described in Table 2. All the pod and seed traits were recorded two months after harvesting, as recommended by IPGRI/IITA/BAMNET 2000[42] while the terminal leaflet shape characterization was done in the tenth week after planting at the fourth node.

Table 2. Some descriptors and classes of qualitative traits of Bambara groundnut

Descriptor and Classes	Classes
Terminal leaflet shape (TLS)	1=Round 2=Oval 3=Lanceolate 4=Elliptic 99=Other
Pod Colour (POC)	1= Yellowish-brown 2= Brown 3= Reddish-brown 4=Purple 5= Black 99= Other
Pod Texture (POT)	1= Smooth 2=Little grooves 3=Much grooved 4= Much folded
Pod Shape (POS)	1=Without a point 2=Round on the other side 3=With nook on the other side 4=Two points on each side 99=Other
Seed Eye Pattern (SEP)	0=No eye pattern 1=Black butterfly-like eye 2=Dark red butterfly-like eye 3= Grey-butterfly like eye 99=Other
Seed Testa Pattern (STP)	0= No testa pattern(plain) 1= Black small dotted spots 2=Dark brown small dotted 3=Black and grey mottles 4=Black and Brown mottles 5=Black marbled spots on cream background 99=Black marbled spots on brown background
Seed TestaColour (STC)	1)Cream 2)Grey 3)Light red 4)Dark red 5)Light brownish red 6) Dark brown 7) Dark purple 8) Black 99) Other

Source: (IPGRI/IITA/BAMNET 2000)[42]

Data Analysis

Phenotypic diversity

The frequency distribution of the qualitative traits was computed using the formula;

$$f_i = \frac{n_i}{N} = \frac{n_i}{\sum_i n_i}$$

Where *fi*is the frequency, *ni* is the number of accessions with a particular trait, and*N*isthe total number of accessions under study. Their percentages were computed using SPSS package version 21, to show how diverse the accessions were phenotypically.

Trait Diversity Index

The estimated Shannon-Weiner diversity index (H') was calculated to show how diverse the phenotypic qualitative traits were. The estimation was based on the phenotypic frequencies for each trait. The Shannon-Weiner diversity Index formula;

$$-\sum_{i-1}^{s}(PilnPi)$$

was used where:

Pi is the proportion of accessions (*n/N*) of individuals of one particular character found (*n*) divided by the number of individuals found (*N*), multiplied by the natural logarithm (ln)summation of the calculation, and *s* is the number of traits.The diversity index was done using R statistical software version 3.3.1. The phenotypic similarity based on qualitative traits was done using all the six accessions, and seven traits each.

Cluster Analysis

The qualitative data was nominalizedandEuclidian distance method was used to calculate the similarity among the six Bambara groundnut accessions. Complete linkage method was used for hierarchical clustering. The resulting dendrogramwas generated using R statistical software version 3.3.1.(RDevelopment Core Team 2016).

III. RESULTS

Phenotypic Diversity

There was no zonation effect on the qualitative traits.All traits were constant for a particular accession irrespective of the zone. This indicates the lower effect of the environment on the qualitative compared to quantitative characters[27].The qualitative traits (seven) evaluated (Table 2)have shownthat there is highvariability among the six Bambara groundnut accessions under study. Out of the six accessions, the oval terminal leaflet shape had the highest frequency at 3,brown was the dominant pod colour with a frequency of 4, whereas majority (4/6) of the pods had a shape ending in a point, round on the other side. Most of the seeds (4/6) had no testa pattern, while majority of seed coats(3/6) were cream in colour (Figure 1).

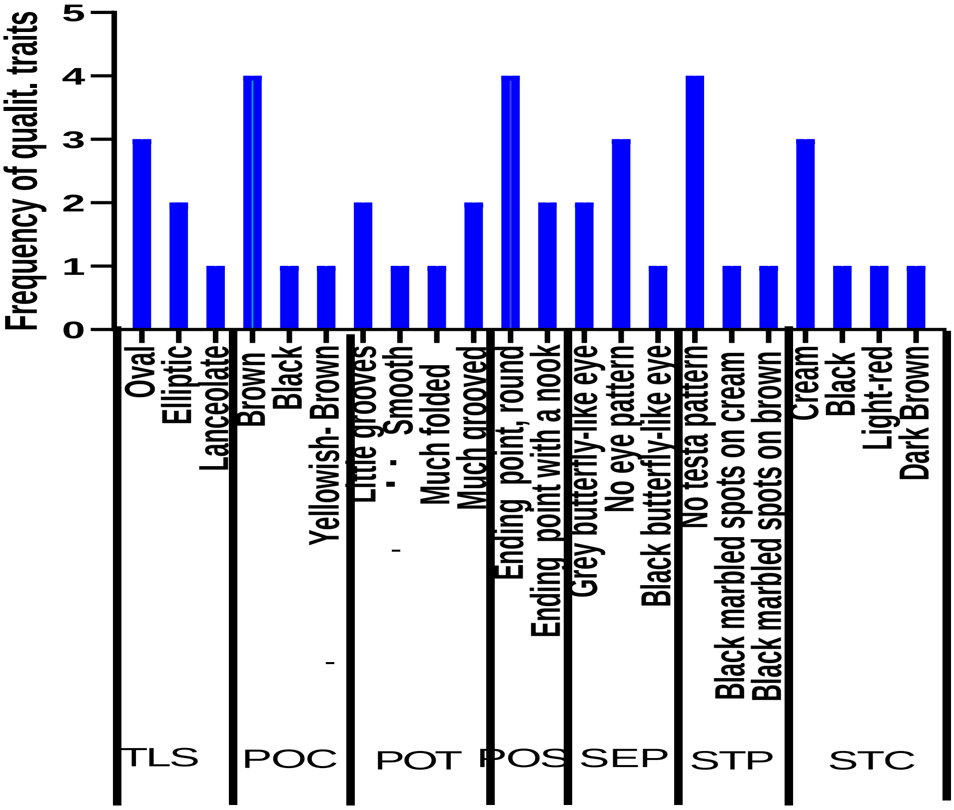

Figure 1.Frequency distribution of qualitative traits in the Bambara groundnut accessions.
KEY: **TLS**-Terminal leaflet shape, **POC**-Pod Colour, **POT**-Pod Texture, **POS**-Pod Shape, **SEP**-Seed Eye Pattern, **STP**-Seed Testa Pattern, **STC**-Seed TestaColour.

Therefore, among the accessions assessed, 50% had an oval-shaped terminal leaflet, 33.33% had an elliptic terminal leaflet shape, and 16.6% had a lanceolate terminal leaflet shape. The pod colours were brown (66.67%), black and yellowish brown each 16.67 % (Table 3). The Pod textures were little grooves and much grooved each had 33.33%, whereas smooth and much folded, each had 16.67%. Pod shape indicated that many had a shape ending in a point, round on the other side (66.67%), whereas 33.33% of the accessions had pods ending in a point, with a nook on the other side. The Seed eye pattern showed that 50% had no eye pattern (simple), 33.33% had grey butterfly-like eye and 16.67% had black butterfly-like eye (Table 3). In seed testapattern, 66.67% had no testa pattern (plain), whereas black marbled spots on a cream background with grey butterfly-like eyes and black marbled spots on a brown background without an eye, each had 16.67% (Figure 2). In the seed testacolour trait, the cream had 50%, whereas black, light red and dark brown each had 16.67%. (Figure 2).

Table 3.Percentage distribution of Qualitative traits in the six Bambara groundnut accessions.

Character	**Description of traits**	**Percentages (%)**
Terminal leaflet Shape	Oval	50.0
	Elliptic	33.3
	Lanceolate	16.7
Pod Colour	Brown	66.7
	Black	16.7
	Yellowish Brown	16.7
Pod Texture	Smooth	16.7
	Little Grooves	33.3
	Much Grooved	33.3
	Much Folded	16.7
Pod shape	Ending point, Round	66.7

	Ending point with a nook	33.3
Seed Eye Pattern	No eye Pattern	50.0
	Grey-butterfly like eye pattern	33.3
	Black- butterfly like eye pattern	16.7
Seed Testa Pattern	No testa pattern	66.7
	Black marbled spots on cream background with grey butterfly like eyes	16.7
	Black marbled spots on brown background without eye.	16.7
Seed TestaColour	Cream	50.0
	Black	16.7
	Dark Brown	16.7
	Light red	16.7

Figure 2.The seed testa pattern andseed testacolour of the six Bambara groundnut germplasm used in the study.

Trait Diversity Index

The Shannon-Weiner diversity index (H') was calculated on the qualitative characters in order to access the genetic diversity among the seven traits. The estimated Shannon-Weiner diversity index (H') for the Bambara groundnut qualitative traits are shown in Table 4. All traits showed a high level of polymorphism (H'>0.500). The indices ranged from H'=1.6501 (seed testa pattern) which was the least to H'=2.0708 (terminal leaflet shape and seed eye pattern) which were the highest, with an average of H'=1.8973. All the traits therefore exhibited the polymorphism phenomena.

Table 4.Shannon-Weiner diversity index (H') showing the phenotypic diversity of seven qualitative characters for the studied landraces in the Lake Victoria Basin, Kenya.

Qualitative Trait	Shannon-Weiner Index (H’)
Terminal Leaflet Shape (TLS)	2.0708
Pod Colour (POC)	1.6784
Pod Texture (POT)	2.062
Pod Shape (POS)	1.8136

Seed Eye Pattern (SEP)	2.0708
Seed Testa Pattern (STP)	1.6501
Seed TestaColour (STC)	1.9356
Average diversity index	**1.8973**

The immense variation identified, based on (H') is important to plant breeders as it can help identify the traits that require improvement in the crop.

Cluster Analysis

The seven qualitative traits were used for the hierarchical cluster analysis of sixgermplasmaccessions. The dendrogramrevealed two main clusters for the germplasmaccessions (Figure3). The accessions from MigoriCountyshowed similarity asthey belong to the samecluster group.

Consequently, the Kisumu and the Busia accessions were broadly clustered together, even though K2 and B4 appeared to be more similar on one hand, and B1 and K1 also similar on the other hand. The Euclidean distance ranged from 0.2 to 1.2 with an increase in dissimilarity.

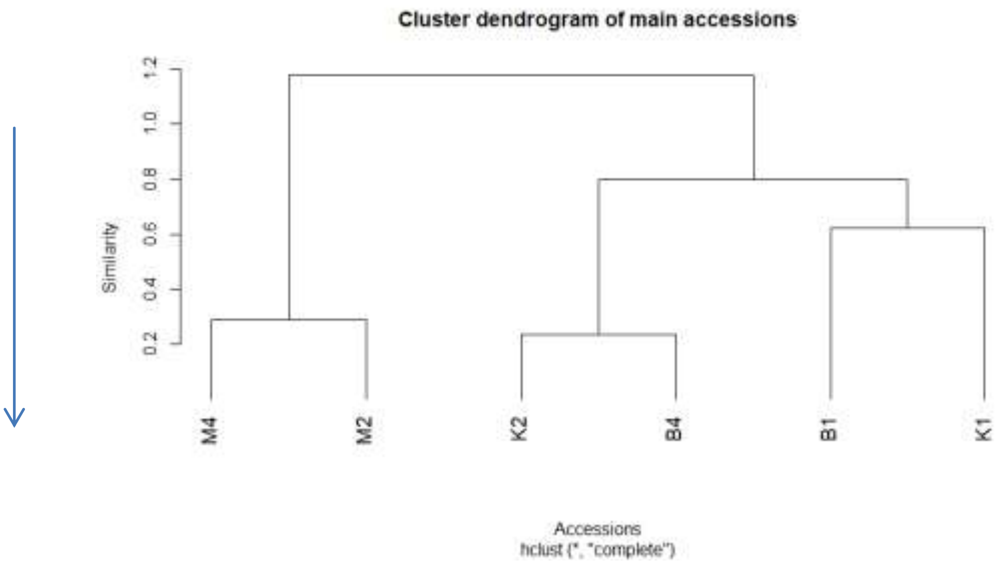

Figure 3. A dendrogram showing the relationship among Bambara groundnut accessions based on their Similarity and Dissimilarity distances.

IV. DISCUSSION

An elaborate presentation and analysis of qualitative characters of farmer-held Bambara groundnut accessions in the Lake Victoria Basin of Kenya have been done. During the collection of the germplasm from the farmers, it was established that this neglected and underutilized crop[35] is mainly planted by women (Table 1), and mostly intercropped with maize and cowpea.This observation made in the Lake Victoria Basin is in line with what Goli, (1995)[43] observed in Zimbabwe, where women intercropped the Bambara groundnut with Millet, peanut, maize, cowpea, cassava and yam. Majola*et al*., (2021)[3] and Halimi*et al*., (2019)[11] observed that in Sub-saharan Africa, Bambara groundnut is viewed as a minor crop, mainly grown by women smallholder farmers. In the Lake Victoria Basin, the majority of the farmers planted the crop at subsistence levels, mainly as food crop with little left for marketing. Aviara*et al*., (2013)[44]concurs with this observation that Bambara groundnut production is primarily at the subsistence levels in Africa.

The six accessions studied showed high variation in qualitative morphological traits. The terminal leaflet shapes were observed as oval, elliptic and lanceolate. The trifoliate leaflets of Bambara groundnut are all narrow. Accordingto Valombola*et al* (2022)[20] and Chai *et al*., (2016)[45] narrow-leavedtype crops are likely to adapt to harsh environments such as drought. Bambara is a drought-resistant crop[1,7],hence its leaf type could be one of its structural adaptations to enable it to survive in areas of water deficit. Most accessions evaluated had oval terminal leaflets (50%), followed by elliptic terminal leaflets (33.33%). Oval and elliptic shaped leaves are large, hence providing a large surface area exposed to light, enabling more light to be trapped, and channeled to the chloroplasts, hence these types of leaves carry out photosynthesis more effectively[46].Valombola*et al*., (2021)[36] in their survey in Namibia also observed that respondents preferred Bambara groundnut with big leaves, as plants with big leaves are likely to give big pods and high yields due to increased photosynthetic capacity. The accessions with lanceolate leaves (16.67 %.) were the least. Plants with lanceolate leaves have been known to survive in semi-arid areas[26,47]. According to Swanevelder, (1998)[8] the Bambara plant does well in light, sandy loams with a pH of 5.0 to 6.5. This type of soil when deeply ploughed gives best yields[8].

Pod colour and texture are important traits in this crop as they help in determining the freshness of Bambara groundnut in the market[20]. The pod colour and texture of Bambara groundnut, therefore, affects consumer uptake and crop utilization. Bambara seed testacolour is an important determinant of yield, nutrient mineral composition and selection criteria of germplasm for planting and breeding programs. In this study fifty percent (50%) of the seed testa were cream. This observation is in agreement with that of Mohammed *et al*., (2016)[35]who in their study observed that cream colour was the dominant seed testacolour.Esan*et al*., (2023)[13], also observed that cream-colouredtesta was the majortestacolour in their study held in Nigeria.

In Zimbabwe, it was established that red and the cream coloured landraces showed more stability in their seed yield than the black landraces[43]. Bamshaiye*et al*., (2011)[47] observed that red seeds were rich in Iron, hence could be useful in areas where iron deficiency is a problem. The red testa seeds, he observedcontain almost twice as much iron as the cream seeds.Valombola*et al*., (2021)[36], in their Bambara groundnut farmer-preferred traits survey in Namibia, reported that majority (45%) of the respondents chose seed colour trait as the preferred selection criteria for planting seeds.The creamcolour was the most selected colour (36%), followed by tan colour(33%). According to Mabhaudhi*et al*., (2013)[48], Bambara groundnut plants which emanate from dark seeded germplasm are believed to tolerate drought more than those from light coloured seeds because of polyphenols that act as antioxidants under water stress conditions.

In this study, fifty percentof the landraces had no eye pattern (plain). This observation is in agreement with what Mohammed *et al*., (2016)[35] observed in their study, where more germplasm from Zambian collectionhad plain eye.The variations in seed eye patterns and seed coat colour displayed by the landraces in this study are useful to differentiate between the germplasm in a program of genetic improvement of Bambara groundnut[35,49].

In this study, The Shannon-Weiner diversity (H') indices for the Bambara groundnut qualitative traits assessed were quite high. This indicates that there are high variations of characters amongst these farmer-held accessions in the Lake Victoria basin. Knowledge of variation of characters is important in crop improvement programs, as plant breeders should know which population is more varied for which characters[27]. The diversity in traits observed among these germplasm could be due to seed exchange across the borders from Tanzania to Migori, and from Uganda to Busia. The diversity in traits could also be explained by the phenotypic plasticity[20]which results from adaptability of accessions to different agro-ecological environments. These factors are crucial and may contribute to significant qualitative traitdiversity by creating or maintaining polymorphism as observed in this study. Therefore, (H') can be useful in identifying the traits that need to be improved by breeders. Even though the diversity of the crop remains largely unexploited[35]in Africa.

Qualitative morphological characters are important in Taxonomy and can be utilized as taxonomic markers in classification. The Cluster analysis revealed the importance of qualitative morphological markers to differentiate and classify the farmer-held accessions in the Lake Victoria Basin.Two major clusters were observed. The accessions with common traits were clustered together, while those with few common traits were clustered apart. The dendrogram, therefore, showed how varied the accessions were for the traits studied. The similarity in most traits amongst some accessions as observed in the M4 and M2 accessions from MigoriCounty, could be due to their adaptability to the same environment. This can be explained by the fact that since most farmers plant the germplasm within their possession year in and year out[29],germplasm recycling could have led to adaptability to the environment. Due to the proximity of MigoriCounty to Tanzania, the two accessions most probably may have originated from Tanzaniathrough seed exchange at the border, hence their close similarity to each other.Massawe*et al*., (2003)[50] observed that landraces were grouped based on their areas of originand that this is an indication of the importance of environmental adaptation on the genetic variation in Bambara groundnut[27].

The relative proximity of Kisumu and BusiaCounties could have led to their germplasm similarities. In Western Kenya, BusiaCounty is the largest Bambara groundnut producer and holds the largest Bambara groundnut accessions type[33]. Due to trading and market demands, the Busiagermplasms most probably found their way to Kisumu County. Cultivation of such ‘alien’ germplasmin same county with unique environmental and edaphic conditions could be leading to the adaptability of thesegermplasms to similar environments, hence the similarity in groupings and clustering. Bambara groundnut is cleistogamous and autogamous[7].Hence, the accessions in the same cluster might have similar genetic make-up[20].However, intense molecular work needs to be carried out to back up and ascertain the real extent of similarity as observed in this research. These results are similar to those of Molosiwa, (2012)[27], who clustered thirty-four (34) morpho-agronomic traits in Botswana and observed diversity by cluster analysis. In his research, the cluster analysis revealed three major clusters. Khan *et* *al*., (2021)[28] also clustered fifteen (15) qualitative traits in Malaysia and observed that fifteen accessions were grouped in five major clusters based on their similarity. These cultivated (*Vignasubterranea* var. subterranea) Kenyan accessions could have originated from some wild varieties (*Vignasubterranea* var. spontanea) in East Africa, or they could have reached the Lake Victoria Basin through seed exchange at the borders of various countries.

V. CONCLUSION

The qualitative phenotypic diversity amongst the farmer-held Bambara groundnut accessions in the Lake Victoria Basin, Kenya has been unraveled. The accessions studied showed high phenotypic variations. The germplasm assessed had a high percentage of oval leaflet shape (50 %), brown pod colour (66.67%), most pod shapes were ending in a point, round on the other side (66.67%), and fifty percent (50%) of the seeds had no eye pattern. The cream was the dominant seed testacolour (50%), whereas 66.67% of the germplasm had no testa pattern (plain). The phenotypic variation of accessions showed a tendency of normal distribution pattern that is an important factor in selection and breeding. Cluster analysis grouped the six germplasms in two major clusters, the Migoriaccessions were grouped, whereas the Kisumu and Busia accessions were also broadly grouped. The (H') indices indicated high levels of diversity amongst all traits assessed, with terminal leaflet shape and seed eye pattern having the highest index of 2.0708, followed by pod texture (2.062). The seed testa pattern had the least index (1.6501).

The diversity observed is crucial for crops to withstand pests and diseases. The wide range of phenotypes observed can assist in adapting this crop to various environments, thereby cushioning it from harsh and erratic climatic changes, as crops with favorable traits survive better than those with poor traits. Henceenough genetic diversity will ensure survival of the Bambara groundnut landraces in a given environment. Knowledge of the phenotypic diversity of these Kenyan accessionscan be employed in breeding programs to develop improved cultivars with stable yields as currently; there are no improved cultivars of this crop in Kenya. This will help boost food productivity and address food and nutrition insecurity which is rampant in Western Kenya, the rest of the Sub- Saharan Africa, and beyond.

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