Tropical Grasslands-Forrajes Tropicales
DOI: 10.17138/TGFT(7)25-34

Research Paper

RETRACTED: Agro-morphological characterization of *Urochloa* grass accessions in Kenya

Caracterización agro-morfológica de accesiones de Urochloa *en Kenia*

DONALD M.G. NJARUI[1], MWANGI GATHERU[1] AND SITA R. GHIMIRE[2]

[1]*Kenya Agricultural and Livestock Research Organization (KALRO), Katumani, Machakos, Kenya.* www.kalro.org
[2]*Biosciences eastern and central Africa – International Livestock Research Institute (BecA-ILRI) Hub, Nairobi, Kenya.* hub.africabiosciences.org

Abstract

Information of existing phenotypic diversity of *Urochloa* grass is important in selection for pasture development. Forty-seven accessions from 8 different *Urochloa* species obtained from the genebank of International Center for Tropical Agriculture in Colombia were characterized using a set of 22 agronomic and morphological characters. Most of the accessions originated from the East African region. The accessions were planted in December 2013 at Katumani, Eastern Kenya. Twelve seedlings of each accession were transplanted in single row plots at a spacing of 10 cm between plants. Agro-morphological data were collected from the middle 10 plants for each accession. Multivariate analyses were applied to cluster the accessions with similar agronomic and morphological traits. Principal component analysis revealed 4 components with eigenvalues greater than 1 with first and second components accounting for 23.8 and 20.2% of variation, respectively. The cluster analysis identified 5 main groups differentiated largely by days to 50% flowering, flowering duration and plant spread. Leafiness, growth habit, culm thickness and stigma color did not show significant difference among the clusters. The results provided useful information on the diversity in agronomy and morphology that exists among accessions but the collection was not sufficiently diverse and a much wider sample of accessions is needed to identify the true extent of variation in this genus. Important variables like dry matter yield and chemical composition of these accessions would need to be assessed before proceeding with any further evaluation in the field.

Keywords: *Brachiaria*, cluster analysis, germplasm, principal component analysis, tropical grass.

Resumen

En Katumani, Kenia Oriental, se caracterizaron 47 accesiones de ocho especies diferentes del género *Brachiaria* (ahora: *Urochloa*) obtenidas del banco de germoplasma del Centro Internacional de Agricultura Tropical (CIAT) en Colombia, utilizando un conjunto de 22 caracteres agronómicos y morfológicos. La mayoría de las accesiones se originaron en África Oriental. Para el efecto fueron trasplantadas 12 plántulas en parcelas de una línea a una distancia de 10 cm entre ellas. Las observaciones se realizaron en 10 plantas y para el análisis de los datos se utilizaron métodos multivariados con el fin de agrupar las accesiones con características agronómicas y morfológicas similares. El análisis de componentes principales (ACP) permitió identificar cuatro componentes con eigenvalores >1, donde el primero y segundo representaron 23.8 y 20.2% de variación, respectivamente. En el análisis de conglomerados fueron identificados cinco grupos principales, diferenciados por las características: días a 50% de floración, duración de floración y despliegue de la planta. La frondosidad, el hábito de crecimiento, el grosor del culmo y el color del estigma no mostraron diferencias significativas entre los grupos. Los resultados proporcionaron información útil sobre la diversidad agronómica y morfológica entre las accesiones, pero el tamaño reducido de la colección no permitió identificar el alcance de la

Correspondence: D.M.G. Njarui, Kenya Agricultural and Livestock Research Organization - Katumani, P.O. Box 340 - 90100, Machakos, Kenya. Email: donaldnjarui@yahoo.com

variación en este género. Variables importantes como el rendimiento de materia seca y la composición química de estas accesiones deben ser evaluadas antes de proceder con trabajos similares en campo.

Palabras clave: Análisis de componentes principales, análisis de conglomerados, *Brachiaria*, germoplasma, gramíneas tropicales.

Introduction

The genus *Brachiaria* consists of more than 100 species with 33 species having been reported in Kenya. Eastern and Central Africa is the center of origin and diversity of the *Brachiaria* grasses (Boonman 1993). However, only a few of the species have been selected for forage production and are widely cultivated in South America, Australia and Southeast Asia. Taxonomically, they are now accepted to belong to the genus *Urochloa* by the major taxonomic databases such as GRIN (2018). The most common and extensively cultivated species for pastures are *U. brizantha* (Hochst. ex A. Rich.) R.D. Webster [syn. *B. brizantha* (Hochst. ex A. Rich.) Stapf], *U. ruziziensis* (R. Germ. & C.M. Evrard) Crins (syn. *B. ruziziensis* R. Germ. & C.M. Evrard), *U. decumbens* (Stapf) R.D. Webster (syn. *B. decumbens* Stapf) and *U. mutica* (Forssk.) T.Q. Nguyen [syn. *B. mutica* (Forssk.) Stapf] (Ndikumana and de Leeuw 1996). From early 1940s to mid1980s, there were several major and minor collection missions by several research institutions targeting *Urochloa* species in Eastern Africa (Keller-Grein et al. 1996). Most of this germplasm is held in genebanks under the International Treaty on Plant Genetic Resources for Food and Agriculture and is used in evaluation and breeding of cultivars.

Despite the diversity of *Urochloa* spp. in Eastern and Central Africa, comparatively little information is available on their agro-morphological characteristics. In Kenya, past evaluations identified and selected Congo Signal grass (*U. ruziziensis*) for commercialization in the Western region (Wandera 1997). However, demand for seed was comparatively low compared with other preferred grasses, e.g. Rhodes grass *(Chloris gayana* Kunth); consequently, seed production was discontinued. Other species, e.g. *U. brizantha*, *U. decumbens* and *U. humidicola* (Rendle) Morrone & Zuloaga [syn. *B. humidicola* (Rendle) Schweick.], were evaluated in small-plot agronomic trials in the 1990s (Ndikumana and de Leeuw 1996) but none has been used commercially in Africa.

In recent years, there has been renewed interest in Kenya to develop high-yielding and nutritious forages to support the growing livestock industry using *Urochloa* species. Grasses in the genus *Urochloa* have advantages over grasses in other genera including adaptation to infertile acid soils and high dry matter yields (Rodrigues et al. 2014). The recent program on pasture development in Kenya commenced with introduction of selected lines, improved cultivars and hybrids from South America and Australia to assess their adaptation and production in different agro-ecological zones. Unfortunately, some of these grasses have shown susceptibility to pests and diseases (Njarui et al. 2016). Consequently, there is a need to explore other germplasm either through collection or acquisition of material maintained by different research institutions and genebanks across the world.

The Kenya Agricultural and Livestock Research Organization (KALRO) obtained a selection of *Urochloa* accessions from the Genetic Resources Program of International Center for Tropical Agriculture (CIAT). To exploit this germplasm for forage, it is important to understand the agro-morphological characteristics and variations that exist among the accessions. Past evaluations of collections of various tropical genera and species have indicated considerable diversity in growth habit (Veasey et al. 2001; van de Wouw et al. 2009). Morphological and agronomic classification methods have been widely used to group accessions with similar characters (Pengelly et al. 1992; van de Wouw et al. 1999a). Successful classification of large numbers of accessions of buffel grass (*Cenchrus ciliaris* L.), guinea grass (*Panicum maximum* Jacq.) and *Indigofera* spp. (Hassen et al. 2006; Jorge et al. 2008; van de Wouw et al. 2008) using cluster and principal component analyses has identified distinct groups. The objective of this study was to characterize the *Urochloa* grass accessions obtained from CIAT and determine the level of diversity in morphological and agronomic traits, which can be exploited for possible integration in different farming systems of Kenya.

Materials and Methods

Site

The experiment was conducted from December 2013 to August 2014 at KALRO - Katumani (37º28' E, 1º58' S;

1,600 masl), Kenya. The climate and soil characteristics have been described by Njarui and Wandera (2004). Mean annual rainfall is 717 mm, with a bimodal pattern; the long rains occur from March to May and the short rains from mid-October to December with peaks in April and November, respectively. There are 2 distinct dry seasons, a short dry spell in January-February and a long dry season from June to mid-October. Evapotranspiration rates are high and exceed the amount of rainfall in all months except November, when total rainfall exceeds evaporation. The mean monthly temperature is 19.6 ºC with March (21 ºC) and July (16.6 ºC) being the warmest and coolest months, respectively. Soils are chromic luvisols (Aore and Gitahi 1991) and are generally low in nitrogen and phosphorus (Okalebo et al. 1992), with a pH of 6.5.

Treatment and design

Individual seeds of 80 *Urochloa* accessions, including one commercial cultivar, were sown in polybags in a greenhouse using a mix of forest soil, sand and manure at a ratio of 3:2:1. At about 4 weeks after seedling emergence, in December 2013, 12 uniform and healthy seedlings from each accession were transplanted in the field. Accessions were randomly allocated in unreplicated single rows without following the order of accession numbers. The spacing between seedlings within rows was 10 cm and the inter-row spacing was 2 m, while the space between different accessions within rows was 1 m. Triple superphosphate (TSP with 46% P_2O_5) fertilizer was applied at a rate of 40 kg P/ha only during planting. The plots were kept weed-free by hand-weeding.

Origin of materials

As no *Urochloa* grass seed collections were available in the Kenyan genebank, KALRO obtained the accessions screened in the experiment from the Genetic Resources Program of CIAT, Colombia. Eighty accessions of *Urochloa* spp. were supplied under the Standard Material Transfer Agreement of FAO. The majority of the accessions supplied had been collected in the Eastern region of Africa, mainly in Ethiopia and Kenya.

Data collection

Data were collected from only 47 accessions comprising 8 species listed in Table 1. The remaining 32 accessions and *U. brizantha* cv. Toledo (CIAT No. 26110) are not listed since they failed to maintain the minimum number of plants required for monitoring due to poor establishment and termite damage, occasioned by an unexpected short dry spell. Twenty-two agro-morphological characters were measured (Table 2), based on their agronomic relevance and expected variation among accessions. These qualitative characters were recorded for 10 plants for each accession as suggested by van de Wouw et al. (1999b) discarding one plant on each end of the row to avoid any border effects. All plants were evaluated once at 50% flowering stage to minimize differences due to stage of growth. The data were collected for a single season in order to minimize differences due to environment of the characterization site as recommended by van de Wouw et al. (1999b).

Data analyses

The correlations among the observed variables were calculated using the Pearson's correlation coefficient. When pairs of variables had a high correlation coefficient ($r \geq 0.7$), one of these variables was omitted to avoid indirect weighting in cluster analysis according to criteria applied by Hassen et al. (2006) and van de Wouw et al. (2009). After standardizing the variables to a mean of 0 and a variance of 1, a principal component analysis was carried out using the program Statistical Analysis System (SAS) software (SAS 2001). Hierarchical cluster analysis was carried out using the complete linkage method according to criteria recommended by van de Wouw et al. (2009). Variations between the groups of accessions for the different characteristics were assessed by one-way analysis of variance considering groups as treatments and individual accessions within a group as replications.

Table 1. *Urochloa* accessions used in the characterization study.

Accession No.[1]	Species	Origin	Location	Latitude (º)	Longitude (º)	Elevation (masl)
26107	*Urochloa. brizantha*	Burundi	Rutana	4.0167 S	30.0833 E	1,220
26129	*U. brizantha*	Burundi	Rutana	3.9667 S	30.15 E	1,170
26133	*U. brizantha*	Burundi	Rutana	4.0167 S	30.0833 E	1,200
26647	*U. brizantha*	Burundi	Karuzi	3.05 S	30.15 E	1,640
16106	*U. brizantha*	Ethiopia	Shoa	8.9833 N	37.3333 E	1,900
16118	*U. brizantha*	Ethiopia	Welega	9.0833 N	35.9 E	1,890
16122	*U. brizantha*	Ethiopia	Welega	9.55 N	35.45 E	1,990
16150	*U. brizantha*	Ethiopia	Sidamo	7.15 N	37.95 E	2,040
16158	*U. brizantha*	Ethiopia	Sidamo	6.8167 N	37.7167 E	1,990
16169	*U. brizantha*	Ethiopia	Harerge	9.4 N	42.0333 E	1,970
16289	*U. brizantha*	Ethiopia	Kaffa	8.1 N	37.4667 E	1,850
16320	*U. brizantha*	Ethiopia	Welega	8.9333 N	35.5333 E	1,640
16324	*U. brizantha*	Ethiopia	Gojjam	10.9667 N	36.4833 E	1,690
16339	*U. brizantha*	Ethiopia	Gonder	12.5167 N	37.0339 E	2,080
36083	*U. humidicola*	Ethiopia	Sidamo	5.86 N	39.1 E	1,790
6130	*U. ruziziensis*	Kenya	Rift Valley	0.6167 N	35.1667 E	2,030
6384	*U. brizantha*	Kenya	Rift Valley	0.0667 S	34.6833 E	1,400
6385	*U. brizantha*	Kenya	Rift Valley	0.6 N	35.5333 E	2,120
6399	*U. brizantha*	Kenya	Rift Valley	-	-	2,130
6426	*U. brizantha*	Kenya	Rift Valley	0.5833 N	35.3667 E	2,300
6684	*U. brizantha*	Kenya	Rift Valley	0.35 N	34.8167 E	1,606
16482	*U. brizantha*	Kenya	Uashin Gishu	0.5333 N	35.0333 E	1,700
16483	*U. brizantha*	Kenya	Nandi	0.35 N	35.05 E	1,900
16514	*Brachiaria jubata*[2]	Kenya	Trans Nzoia	1.1167 N	35.0667 E	1,920
16536	*B. jubata*	Kenya	Trans Nzoia	1.0667 N	34.8833 E	1,800
16539	*B. jubata*	Kenya	Trans Nzoia	0.8833 N	35.9333 E	1,640
16541	*B. jubata*	Kenya	Nandi	0.35 N	35.05 E	1,900
26302	*U. decumbens*	Rwanda	Byumba	1.3333 S	30.3 E	1,410
26353	*B. jubata*	Rwanda	Byumba	1.4667 S	30.2833 E	1,470
6674	*U. brizantha*	Tanzania	Tanga	5.35 S	37.45 E	-
6241	*U. ruziziensis*	Uganda	-	-	-	909
6686	*U. brizantha*	Uganda	East Mengo	1.4333 N	32.0167 E	1,061
6735	*U. brizantha*	Malawi	Central	13.6833 S	33.75 E	1,300
6419	*U. ruziziensis*	Zaire	-	-	-	-
16097	*U. brizantha*	Zimbabwe	-	-	-	-
16903	*U. nigropedata*	Zimbabwe	Murewa	17.7 S	31.8 E	1,360
16906	*U. nigropedata*	Zimbabwe	Mazowe	17.6333 S	30.95 E	1,240
26894	*U. subquadripara*	Togo	Maritime	6.1667 N	1.25 E	10
26886	*U. lata*	Oman	-	17.1667 N	54.5 E	200
660	*U brizantha*	Unknown	-	-	-	-
664	*U. decumbens*	Unknown	-	-	-	-
667	*U. brizantha*	Unknown	-	-	-	-
6369	*U. humidicola*	Unknown	-	-	-	-
6370	*U. decumbens*	Unknown	-	-	-	-
6711	*U. ruziziensis*	Unknown	-	-	-	-
26646	*U. brizantha*	Unknown	-	-	-	-
26991	*U. brizantha*	Unknown	-	-	-	-

[1]CIAT accession numbers.
[2]Species not listed in GRIN (2018); in TPL (2013) recognized as *Brachiaria jubata* (Fig. & De Not.) Stapf.

Table 2. Characters used in the agronomic and morphological study.

Character	Definition	No. of observations	Unit
Date of first flowering[1]	Appearance of first flower	full plot score	day
Date to 50% flowering	Half of plants in plots have flowered	full plot score	day
Date to full flowering[1]	All plants have flowered	full plot score	day
Flowering duration	Days from first flower to full flowering	full plot score	day
Plant height	Average height from ground to flag leaf at 50% flowering	10 plants	cm
Leafiness	An estimate of the amount of leaves (1 = no leaves to 10 = very leafy at full flowering)	full plot score	1–10
Growth habit	Angle of the culm to the ground (1 = prostrate to 5 = erect), taken at 50% flowering	full plot score	1–5
Culm thickness	Average diameter of culm at lowest internode at 50% flowering	10 observations	mm
Rhizomes[1]	Presence of rhizomes (1 = no rhizomes to 10 prolific rhizomes), 2 weeks after harvest	full plot score	1–10
Leaf length	Length from ligule to tip of leaf (second leaf from flag leaf)	10 observations	cm
Leaf width	Width of leaf at widest point (second leaf from flag leaf)	10 observations	mm
Leaf ratio	Leaf length divided by leaf width		
Ligule length[1]	Length of the ligule	10 observations	mm
Leaf hairiness-adaxial[1]	Hairiness of adaxial surface of the leaf (1 = glabrous to 5 = medium dense hairs)	10 observations	1–5
Leaf hairiness-abaxial[1]	Hairiness of abaxial surface of the leaf (1 = glabrous to 5 = medium dense hairs)	10 observations	1–5
Leaf sheath hairiness	Hairiness of the leaf sheath (1 = glabrous to 5 = medium dense hairs)	10 observations	1–5
Inflorescence length[1]	Length of the main rachis from the lowest branch to the top spikelet/bristles	10 observations	cm
Inflorescence width	Width at widest point	10 observations	cm
Inflorescence ratio[1]	Inflorescence length divided by width		
Raceme length[1]	Longest primary branch of inflorescence	10 observations	cm
Stigma color	1 = no purple to 5 = entire stigma purple	full plot score	1–5
Plant spread	Diameter from one edge to the other of the plant	10 observations	cm

[1]Characters excluded from agro-morphological analysis due to high correlation (Pearson's coefficient ≥0.7) with other characters.

Results

The principal component (PC) analysis revealed 4 components with eigenvalues greater than 1 (Table 3). The first PC, which explained 23.8% of the total variation, was strongly and positively associated with agro-morphological characters: leaf width (r = 0.76, P<0.0001), plant height (r = 0.75, P<0.0001), days to 50% flowering (r = 0.74, P<0.0001) and plant spread (r = 0.74, P<0.0001). The second PC, which explained 20.2% of the total variation, was strongly and positively associated with leaf length (r = 0.88, P<0.0001), inflorescence width (r = 0.76, P<0.0001) and leaf ratio (r = 0.68, P<0.0001). The third PC, which explained 14.5% of the total variation, was positively associated with days to 50% flowering (r = 0.56, P<0.0001) and flowering duration (r = 0.68, P<0.0001), while the fourth PC, which explained only 9.9% of the total variation, was strongly and positively associated with culm thickness (r = 0.71, P<0.0001). The first and second PCs are plotted in Figure 1 and described 44% of the variation. They revealed separation of groups across the PC1 axis. Accessions with higher values for PC1 (CIAT 16320, 6674, 6686, 6369, 6130, 26133, 6419, 667 and 660) had a prostrate growth habit, greater plant spread and were taller and late flowering. Accessions with higher values for PC2 had an erect growth habit, large leaf ratio and higher inflorescence width.

Most of the plant characters recorded showed significant (P<0.05) variations between accessions (Table 4). The differences in days to 50% flowering were large and varied from 91 to 194 days, while differences in height were smaller (range 53–86 cm). Differences in plant spread were large (range of 107–226 cm) with plants in Groups IV and V having the largest spread and those in Groups 1 and II the lowest spread. Conversely, differences between groups in leaf width, leaf ratio, leaf sheath hairiness and inflorescence were small, while there were no differences between groups in terms of leafiness, leaf length, growth habit, culm thickness and stigma color.

Table 3. Eigenvector coefficients of 13 characters for the first 4 principal components with eigenvalue, individual and cumulative percentage of the total variance.

Character	Principal Component			
	First	Second	Third	Fourth
Days to 50% flowering	0.422	-0.117	-0.409	-0.106
Flowering duration	0.300	-0.036	-0.496	-0.306
Plant height	0.425	0.237	0.002	0.020
Leafiness	-0.006	0.118	0.254	-0.505
Growth habit	-0.018	0.234	-0.387	0.377
Culm thickness	0.182	0.006	0.265	0.627
Leaf length	0.178	0.546	0.030	0.029
Leaf width	0.432	0.028	0.341	-0.099
Leaf ratio	-0.208	0.419	-0.264	0.157
Leaf sheath hairiness	0.263	-0.284	0.223	0.149
Inflorescence width	0.097	0.467	0.224	-0.117
Stigma color	-0.027	0.290	0.119	-0.120
Plant spread	0.419	-0.053	-0.043	0.137
Eigenvalue	3.094	2.627	1.880	1.286
Individual percentage	23.80	20.21	14.46	9.88
Cumulative percentage	23.80	44.01	58.47	68.35

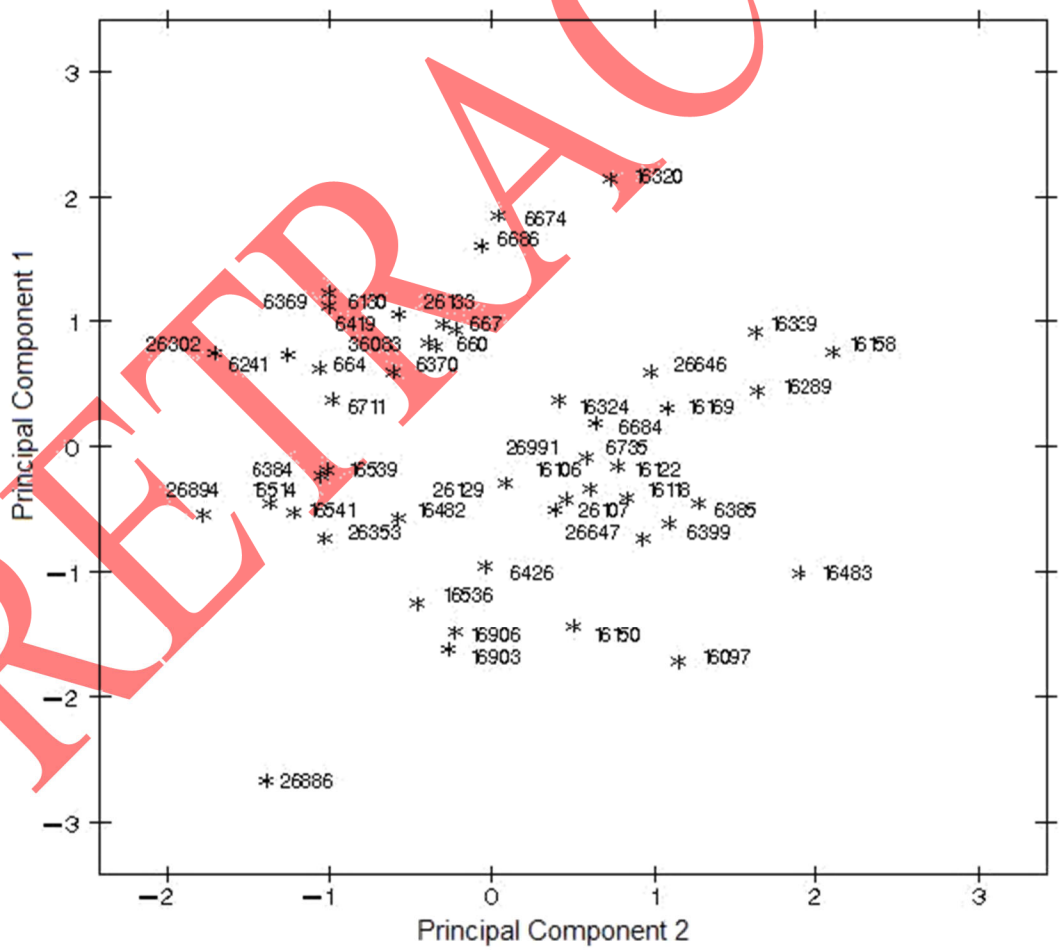

Figure 1. Scatter diagram of 47 *Urochloa* accessions plotted against the first 2 principal components of the correlation matrix explaining 44% of the total variation.

Table 4. Means of agro-morphological characters showing differences among clusters of 47 *Urochloa* accessions.

Character	Cluster group				
	1	II	III	IV	V
Number of accessions included	13	16	11	5	2
Time to 50% flowering (days)	129b[1]	91c	138b	127b	194a
Flowering duration (days)	49.0b	25.1c	59.1b	25.0c	104.0a
Plant height (cm)	68.0b	52.7b	85.6a	69.5ab	70.6ab
Leafiness	6.6a	7.0a	7.2a	6.6a	5.5a
Growth habit	3.7a	3.9a	3.9a	3.2a	6.5a
Culm thickness (cm)	2.9a	3.0a	3.6a	6.4a	2.9a
Leaf length (cm)	20.3a	21.7a	29.0a	16.8a	19.7a
Leaf width (mm)	13.1bc	10.4cd	14.7ab	15.0a	9.9d
Leaf ratio	15.8b	22.2a	21.3a	11.1b	20.6ab
Leaf sheath hairiness	2.3b	1.9b	2.5b	4.3a	1.6b
Inflorescence width (mm)	8.8b	10.2b	13.4a	8.5b	4.5b
Stigma color	3.2a	3.6a	3.9a	2.6a	2.0a
Plant spread (cm)	116c	107c	179b	226a	216a

[1]Within a row, means followed by different letters differ significantly at P<0.05.

Cluster analysis based on agro-morphological characters highlighted 5 main groups as shown in the dendrogram (Figure 2). The first level of separation (Group V vs. others) was mainly on the basis of days to 50% flowering and flowering duration. The 2 accessions classified in Group V, both *U. humidicola* (CIAT 6369 and 36083), were late-flowering (Table 4) and took 194 days to flower. While accession CIAT 36083 originated from Ethiopia, the origin of accession CIAT 6369 is unknown. The next separation (Groups IV and III) occurred due to differences in plant spread, leaf width, leaf ratio, leaf sheath hairiness, inflorescence width and plant height. Accessions in Group IV had greater spread, broader leaves and more hairiness, while accessions in Group III were taller and had greater inflorescence width. The 5 accessions in Group IV were evenly distributed, coming from Zaire, Kenya, Uganda, Rwanda and unknown origin and represented *U. ruziziensis* and *U. decumbens*. The 11 accessions in Group III were all *U. brizantha,* with most accessions from Ethiopia but some of unknown origin. Separation of Groups I and II was mainly on the basis of days to 50% flowering, flowering duration, leaf width and leaf ratio. The majority of accessions in Group II originated from Kenya, Ethiopia and Zimbabwe and represented 4 species: *U. brizantha, U. nigropedata* (Munro ex Ficalho & Hiern) A.M. Torres & C.M. Morton [syn. *B. nigropedata* (Munro ex Ficalho & Hiern) Stapf], *B. jubata* and *U. lata* (Schumach.) C.E. Hubb. [syn. *B. lata* (Schumach.) C.E. Hubb.]. Accessions in Group I were late-flowering and had broader and larger leaves than those in Group II, representing *U. brizantha, U. decumbens, U. ruziziensis, U. subquadripara* (Trin.) R.D. Webster (syn. *B. subquadripara* (Trin.) Hitchc., *B. jubata* and *U. lata,* with 5 of the 13 accessions coming from Kenya.

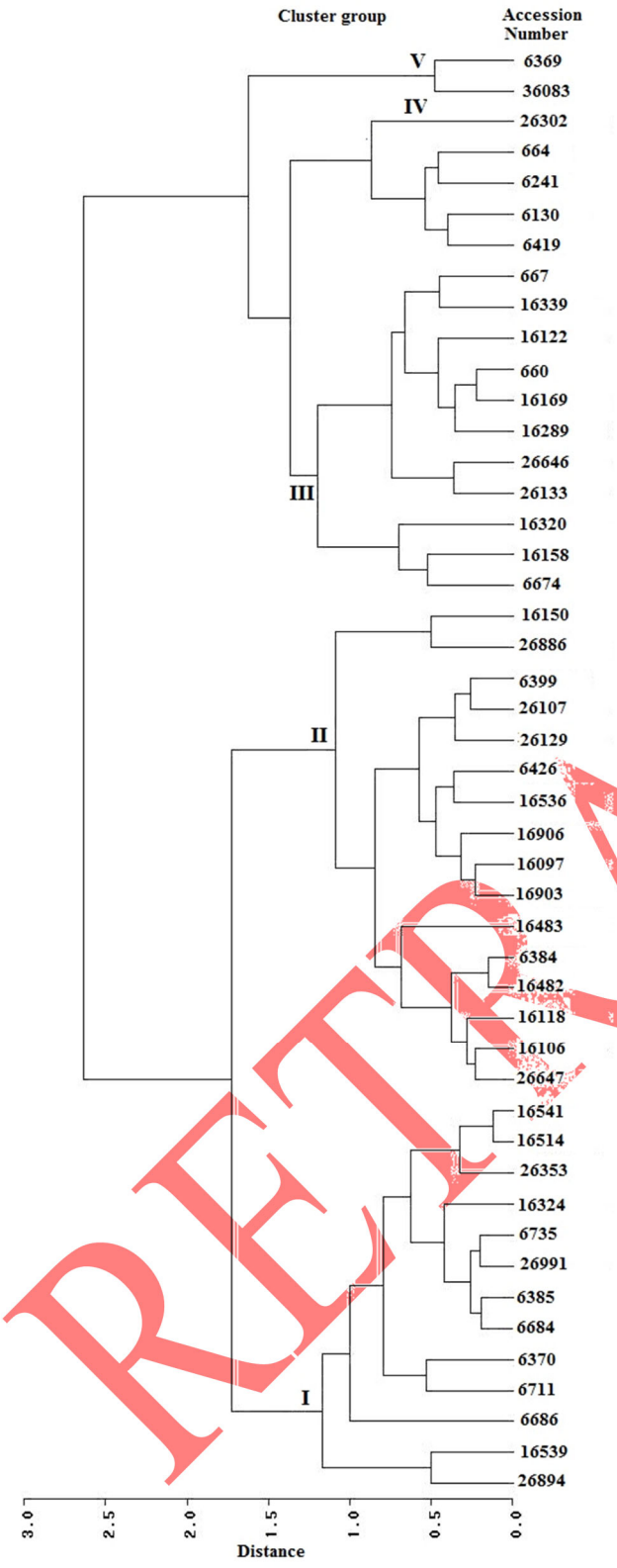

Figure 2. Dendrogram of agro-morphological classification of 47 *Urochloa* accessions obtained from complete clustering on 13 characters. Accession numbers belong to CIAT.

Discussion

Classification using the agro-morphological technique is useful in defining groups based on agronomic characters (Pengelly et al. 1992). In this study, 13 plant characters were selected from a total of 22 morphological and agronomic characters. The principal component and cluster analyses showed existing phenotypic variability among *Urochloa* species. Approximately 60% of the accessions evaluated were *U. brizantha* and the majority of these originated from Eastern Africa, which is regarded as the center of genetic diversity of *Urochloa*. Ethiopia and Kenya accounted for about 51% of the origins of the tested accessions. A good number of accessions were from Burundi, Rwanda and Zimbabwe, while accessions from Uganda, Zaire, Oman and Togo were poorly represented. Our classification into groups was not limited to one country with materials from the same region being classified in different groups indicating the degree of phenotypic diversity within the *Urochloa* genus. The 11 accessions which were collected from Ethiopia were distributed in 4 of the 5 clusters, while 13 accessions from Kenya belonged to 3 clusters. It is possible that different accessions which are phenotypically similar occur in different countries. However, genetically closely related accessions can have very different morphology and therefore different prospective use and agronomic value (van de Wouw et al. 1999a).

Agro-morphological characters were variable in determining composition of the groups with 50% flowering, flowering duration and plant spread being key determinants. These characters are important and form the basis of selection for different environments and forms of utilization. Flowering data are important adaptive characteristics (Hassen et al. 2006), with early flowering ensuring survival and sustainability in areas with a short growing period. On the other hand, accessions CIAT 6369 and 36083 that flowered late would be useful in areas with a long growing season. Those that have a wide spreading habit in cluster IV would be useful as ground cover to reduce soil erosion, while tall accessions which occurred in cluster III would be suitable for cut-and-carry livestock feeding systems.

The variance accounted for by the first and second components for agro-morphological data was 44%, a relatively low percentage of total variation compared with >75% obtained by Hassen et al. (2006) and Veasey et al. (2001). Normally variation of >75% is required to satisfactorily explain the variability expressed between individual accessions (Veasey et al. 2001). It is important

to note that most of the accessions originated from only 8 countries in Africa and from each country only a few accessions were classified, so the material does not reflect the total *Urochloa* phenotypic diversity that exists within the region. Furthermore, even within the countries of origin the accessions were from similar agro-ecological zones. For example, all 13 accessions evaluated from Kenya were collected from within the Rift Valley region. This was a major limitation of our study as the material selected was not sufficiently diverse. There is a need to expand the collection to cover wider agro-ecological zones in addition to exploring germplasm from other countries. Nevertheless, our results provide useful information on the phenotypic diversity among the *Urochloa* accessions tested. This information adds to the pool of knowledge on collections of *Urochloa* species in Africa and would be useful in future evaluations. Attributes like dry matter yield and chemical composition need to be assessed on these accessions before proceeding with any further evaluation in the field.

Acknowledgments

The authors are grateful to Ms. D. Sila and Mr. N. Olonde of KALRO - Katumani, for their assistance in data collection. The seeds of *Urochloa* accessions were donated by the Genetic Resources Program of International Center for Tropical Agriculture (CIAT), Colombia and we are grateful for this support. The study was a collaborative work between Biosciences eastern and central Africa - International Livestock Research Institute (BecA-ILRI) Hub and Kenya Agricultural and Livestock Research Organization (KALRO) and was funded by the Swedish International Development Cooperation Agency.

References

(Note of the editors: All hyperlinks were verified 14 January 2019.)

Aore WW; Gitahi MM. 1991. Site characterization of ACIAR project experimental sites (Machakos and Kitui District). A provisional report. Kenya soil survey. Miscellaneous Paper No. M37.

Boonman G. 1993. East Africa's grasses and fodders: Their ecology and husbandry. Task for vegetation science. Springer, Dordrecht, Netherlands. p. 152–172. doi: 10.1007/978-94-015-8224-7

GRIN (Germplasm Resources Information Network). 2018. GRIN Taxonomy. USDA, Agricultural Research Service, National Plant Germplasm System. goo.gl/hWkiuu

Hassen A; Rethman NFG; Apostolides Z. 2006. Morphological and agronomic characterisation of *Indigofera* species using multivariate analysis. Tropical Grasslands 40:45–59. goo.gl/fpn6BS

Jorge MAB; van de Wouw M; Hanson J; Mohammed J. 2008. Characterisation of a collection of Buffel grass (*Cenchrus ciliaris*). Tropical Grasslands 42:27–39. goo.gl/RAohET

Keller-Grein G; Maass BL; Hanson J. 1996. Natural variation in *Brachiaria* and existing germplasm collections. In: Miles JW; Maass BL; Valle CB do; Kumble V, eds. *Brachiaria*: Biology, agronomy, and improvement. CIAT Publication No. 259. CIAT (Centro Internacional de Agricultura Tropical); EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), Cali, Colombia. p. 16–42. hdl.handle.net/10568/50877

Ndikumana J; de Leeuw PN. 1996. Regional experience with *Brachiaria*: Sub-Saharan Africa. In: Miles JW; Maass BL; Valle CB do; Kumble V, eds. *Brachiaria*: Biology, agronomy, and improvement. CIAT Publication No. 259. CIAT (Centro Internacional de Agricultura Tropical); EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), Cali, Colombia. p. 247–257. hdl.handle.net/10568/49788

Njarui DMG; Wandera FP. 2004. Effect of cutting frequency on productivity of five selected herbaceous legumes and five grasses in semi-arid tropical Kenya. Tropical Grasslands 38:158–166. goo.gl/tiQxNs

Njarui DMG; Gatheru M; Ghimire SR; Mureithi JG. 2016. Effect of season and cutting interval on productivity and nutritive value of *Brachiaria* grass cultivars in semi-arid tropical Kenya. In: Njarui DMG; Gichangi EM; Ghimire SR; Muinga RW, eds. Climate smart *Brachiaria* grasses for improving livestock production in East Africa - Kenya experience. Proceedings of a workshop held in Naivasha, Kenya, 14–15 September 2016. p. 46–61. hdl.handle.net/10568/79797

Okalebo JR; Simpson JR; Probert ME. 1992. Phosphorus status of cropland soils in the semi-arid areas of Machakos and Kitui districts, Kenya. In: Probert ME, ed. A search for strategies for sustainable dryland cropping in semi-arid Eastern Kenya. Proceedings of a symposium held in Nairobi, Kenya, 10–11 December 1990. ACIAR Proceedings No. 41. ACIAR, Canberra, Australia. p. 50–54. goo.gl/i7gYnG

Pengelly BC; Hacker JB; Eagles DA. 1992. The classification of a collection of buffel grasses and related species. Tropical Grasslands 26:1–6. goo.gl/3tzyqm

Rodrigues RC; Sousa TVR; Melo MAA; Araújo JS; Lana RP; Costa CS; Oliveira MO; Parente MOM; Sampaio IBM. 2014. Agronomic, morphogenic and structural characteristics of tropical forage grasses in northeast Brazil. Tropical Grasslands-Forrajes Tropicales 2:214–222. doi: 10.17138/tgft(2)214-222

SAS. 2001. The SAS system for Windows. V8. SAS Institute Inc., Cary, NC, USA.

TPL (The Plant List). 2013. The Plant List Version 1.1. www.theplantlist.org

van de Wouw M; Hanson J; Luethi S. 1999a. Morphological and agronomic characterisation of a collection of Napier grass (*Pennisetum purpureum*) and *P. purpureum* ×

P. glaucum. Tropical Grasslands 33:150–158. goo.gl/QLcvUQ

van de Wouw M; Hanson J; Nokoe S. 1999b. Observation strategies for morphological characterisation of forages. Genetic Resources and Crop Evolution 46:63–71. doi: 10.1023/A:1008627527822

van de Wouw M; Jorge MA; Bierwirth J; Hanson J. 2008. Characterisation of a collection of perennial *Panicum* species. Tropical Grasslands 42:40–53. goo.gl/11tvqG

van de Wouw M; Mohammed J; Jorge MA; Hanson J. 2009. Agro-morphological characterisation of a collection of *Cynodon*. Tropical Grasslands 43:151–161. goo.gl/34rbxc

Veasey EA; Schammass EA; Vencovsky R; Martins PS; Bandel G. 2001. Germplasm characterization of *Sesbania* accessions based on multivariate analysis. Genetic Resources and Crop Evolution 48:79–91. doi: 10.1023/A:1011238320630

Wandera JL. 1997. Forage research and production in western Kenya. In: Rees DJ; Nkonge C; Wandera JL, eds. A review of agricultural practices and constraints in the north Rift Valley Province. Proceedings of a workshop held at Kitale, Kenya, 26–28 September 1995. p. 169–187.

(Received for publication 11 March 2018; accepted 14 December 2018; published 31 January 2019)