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RESEARCH ARTICLE

Urochloa mosambicensis in the Brazilian semi-arid region: morpho-agronomic characterization of accessions under restricted climatic conditions

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Abstract The objective of this study was to morpho-agronomically characterize *Urochloa* sp. accessions from the forage collection of Embrapa Caprinos e Ovinos, aiming to identify the most divergent accessions to support the selection of materials better adapted to cultivation under semi-arid conditions. Fifteen *Urochloa* sp. accessions were used in a randomized block design with three replications and eight plants per plot, with a spacing of 0.5 m between plants and 0.5 m between rows. A uniformization cut (60 days after transplantation) was performed, followed by two subsequent cuts at intervals of 60 days, starting from the uniformization cut. The morphological characterization was initiated 12 days after the uniformization cut. The characterization of the accessions was performed based on 24 quantitative and qualitative morpho-agronomic descriptors of *Brachiaria*. The evaluations of fresh and dry matter productivity were performed following the two subsequent cuts after the uniformization cut. After completing these evaluations, a water deficit tolerance assessment was also conducted. The quantitative descriptors were subjected to analysis of variance, considering the two cuts. The obtained data were analyzed, and ten groups were formed, with the accessions UmCO-11 (2) and UmCO-2 (2) showing the highest genetic divergence. In conclusion, high variability was observed among the evaluated *Urochloa* accessions, which may indicate their potential for incorporation into breeding programs. The identification of genotypes tolerant to water deficit stress is of great value for ensuring productivity and the perenniality of pasture.

Keywords Forage grasses · Dry matter productivity · Genetic divergence · Plant genetic resources

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Introduction

Species of the *Urochloa* genus play an important role in Brazil's economy, occupying extensive pasture areas and accounting for more than 80% of cultivated areas (Jank et al. 2014). These grasses have desirable characteristics, such as high productivity, adaptation to acidic and low-fertility soils, and resistance to spittlebugs (Valle et al. 2010; Simeão et al. 2023).

The proper introduction of these species in semi-arid regions enables diversification in animal feed, thereby enhancing the production of ruminants in the region, such as cattle, goats, and sheep (Abreu et al. 2017). Since the highest production of native caatinga forage biomass occurs during the rainy seasons, there is a reduction in its availability during the dry period due to irregular rainfall in the region, and this adversely affects animal growth, causing weight loss and impacting overall body condition (Paula et al. 2020).

Due to this condition, it is necessary to have alternative forms of feeding available for these animals throughout the year. This requires efforts to adapt other forage grasses with maximization of both forage production and dry matter content and that are also adapted to different soil types and exhibit drought tolerance. Therefore, the development and utilization of *Urochloa* species cultivars in semi-arid regions would certainly contribute to increased animal productivity (Jesus et al. 2020).

Urochloa grasses are mostly of African origin, and it is believed that cultivated representatives of this genus (*Urochloa decumbens*, *U. brizantha*, *U. ruziziensis* and *U. humidicola*) were introduced to Brazil in 1952, with reports of the species *Urochloa mosambicensis* in the state of Pernambuco in northeast Brazil emerging as recently as 1975 (Oliveira 2005). The first research carried out with *U. mosambicensis* was reported in the Brazilian Northeast region by the government initiative of SUDENE, where other forages were also evaluated, such as pangola grass (*Digitaria* spp.), buffel grass (*Cenchrus ciliaris*) and, to a lesser extent, urochloa grass (*U. mosambicensis*) (Viana 1972; Bueno et al. 2022).

Since its introduction, despite the absence of registered cultivars of *U. mosambicensis* in Brazil, the species has been used in semi-arid regions for grazing (Oliveira et al. 1988; Oliveira 1999), hay production (Camurça et al. 2002), and integrated production systems (Voltolini et al. 2010; Drumond et al. 2013). Research has been conducted on *U. mosambicensis* in Brazil, including agronomic characterizations under different levels of phosphorus and nitrogen fertilization (Bezerra et al. 2017, 2019; Gonçalves et al. 2022), potassium fertilization (Vilela et al. 2017), and swine manure application (Cruz et al. 2016; Sá Júnior et al. 2018), structural and productive characterization under different cutting heights and ages (Alves et al. 2015a, b; Bueno et al. 2015; Carvalho et al. 2018; Cruz and Leite 2020), and morphogenic research (Alves et al. 2015a; Bueno et al. 2019).

When introducing new materials adapted to a specific region, especially for animal feed purposes, knowledge of the morphological and agronomic characteristics of forage plants is a determining factor that can ensure efficient and sustainable animal production in pasture areas (Silva et al. 2015). Thus, it is important to describe, differentiate and identify genotypes or accessions of the same species through observations or measurements of these characteristics that can be useful and suitable for use under pasture conditions (Menezes 2011) and for use in genetic breeding programs.

Apomixis can be used in genetic improvement programs to immediately fix a superior genotype identified at any stage of the program (Chaves et al. 2019). As a result of apomixis, the descendants are identical to the parent plant (Hojsgaard and Hörandl 2019), which over time limits the base material for continuing improvement programs for the crop. In this sense, the need to identify sexual plants of *U. mosambicensis* for subsequent recombination is evident, seeking to expand the genetic base of the crop, as well as to recombine superior genotypes to obtain new materials with characteristics of commercial interest. However, before recombination, it is extremely important that potential parents have their morpho-agronomic characteristics well evaluated.

Considering the information above, the objective of this study was to characterize accessions of *Urochloa* spp. from the forage collection of Embrapa Caprinos e Ovinos using morpho-agronomic descriptors, aiming to identify the most divergent accessions for generating lines with potential use under semi-arid conditions, as well as a possible alternative strategy for future stages of a breeding program centered around the species to be carried out at Embrapa.

Material and methods

Location of the experiment

The present study was conducted at the Caatinga Experimental Field, owned by Embrapa Semiárido, in Petrolina, Pernambuco (PE), at 09° 04′ latitude south and 40° 19′ longitude west. This area has an altitude of 376.5 m. The soil in this area is classified as a dystrophic red–yellow Argisol with a sandy texture. The average temperatures, including the minimum average, average and maximum average, of the last 30 years in this region of northeastern Brazil ranged from 18–22, 25–27 and 32–34 °C, respectively, with an average precipitation of 386 mm.

Plant material and field procedure

Eleven accessions of *U. mosambicensis* were used: UmCO-1 (1), UmCO-2 (2), UmCO-4 (1), UmCO-5 (2), UmCO-6 (1), UmCO-7 (1), UmCO-8 (1), UmCO-9 (1), UmCO-10 (2), UmCO-11 (2), and UmCO-13 (2). Additionally, four *Urochloa* accessions from different species not yet commercially exploited were included: UaCO-15 (1) (*U. advena* (Vickery) R.D. Webster), UbCO-16 (1) (*U. brachyura* (Hack. ex Schinz) Stapf), UoCO-18 (1) (*U. oligotricha* (Fig. & De Not.) Henrard.) and UspCO-23 (1) (*Urochloa* sp.). These four accessions were sourced from the forage collection of Embrapa Caprinos e Ovinos.

The seeds were germinated in expanded polystyrene trays filled with commercial substrate, where they were kept for approximately 15 days until the seedlings were established. After that, the seedlings were transferred to the experimental area. The experiment followed a randomized block design with three replications, and each plot contained eight plants distributed in two lines of 2.0 m.

The experimental area was prepared by plowing and harrowing. Pits were dug using a manual digger. The spacing used was 0.5 m between plants and 0.5 m between rows (0.50 m × 0.50 m). Drip irrigation with a flow rate of 2 L h^{-1} was applied three days per week, with each irrigation session lasting approximately 2h/day. Whenever necessary, manual weeding was performed to control weeds.

The chemical analysis of the soil of the experimental area was performed in the 20 to 40 cm layer (Table 1) following the methodology described by Raij et al. (2001). Based on the chemical analysis, basal fertilizer application was carried out according to Cavalcanti (2008).

The study was carried out from October 2019 to July 2020. Sixty days after transplanting, a uniformization cut was performed on the plants at a height of 10 cm from the ground. The evaluation of descriptors started 12 days after the uniformization cut and continued until the seed harvest. In addition to the uniformization cut, two more cuts were performed with a 60-day interval between them after the uniformization cut. The productivity of fresh and dry matter was evaluated during these cuts. After completing the biomass evaluations, irrigation was stopped, and 90 days later, an evaluation of drought tolerance was conducted. Accessions that showed regrowth after this period were considered tolerant of water deficits. This regrowth mechanism is extremely important for evaluating whether the applied management practice favors regrowth, that is, if the plant is able to perpetuate by producing new tillers, ensuring productivity and the perenniality of a more vigorous pasture (Martuscello et al. 2019; Volenec and Nelson 2020; Cruz et al. 2021).

Analyzed variables

The genotypes were characterized based on 24 morpho-agronomic, quantitative, and qualitative descriptors of *Brachiaria* provided by the Ministry of Agriculture, Livestock, and Supply (MAPA) (BRASIL 2001). The quantitative descriptors were (a) plant

Table 1 Results of the soil chemical characteristic analysis in the 20–40 cm layer at the Caatinga Semi-arid Experimental Field of Embrapa, Petrolina, PE, Brazil

Sample identification	Determination												
	C.E	pH	C	P	K	Na	Ca	Mg	Al	H + Al	SB	CTC	V
	mS m^{-1}	-	g kg^{-1}	mg dm^3	$cmol_c$ dm^{-3}								%
20–40 cm	0.61	5.5	0.0	0.92	0.32	0.09	1.7	0.80	0.05	1.0	2.9	3.9	75.2

height (APL), measured in cm from the center of the clump to the flag leaf, 30 days after the uniformization cut, using a graduated ruler; (b) basal tillering intensity (IPB), determined by counting the basal tillers 45 days after the uniformization cut and expressed in tillers/m^2; (c) stem diameter (DC), measured with a digital caliper and expressed in mm; (d) stem internode length (CIC) and leaf blade length (CLF), measured in cm with a graduated ruler on the middle third of the plant; (e) leaf blade length, measured along the central vein from the ligule insertion point to the apex; (f) leaf blade width (LLF), measured using a digital caliper, with values expressed in mm, with the maximum width measured on the middle part of the leaf blade; (g) floral stem length (CHF), defined as the distance from the flag leaf node to the insertion point of the last raceme; (h) floral axis length (CEF), defined as the distance between the insertion points of the first and last racemes; (i) basal raceme length (CRB), measured with a graduated ruler, with values expressed in cm; (j) number of racemes (QR) per inflorescence; (k) number of inflorescences (NI) per plant; (l) fresh matter productivity (PMF); and m) dry matter productivity (PMS).

The measured qualitative descriptors were as follows: (a) growth habit: 1-erect, 3-intermediate, and 5-prostrate; (b) leaf architecture: 1-erect and 2-arched; (c) sheath pilosity: 1-absent or very little, 3-low, 5-medium, 7-high, and 9-very high; (d) sheath pilosity distribution: 1-glabrous, 2-basal, 3-apical, 4-on the margins, and 5-dispersed; (e) blade shape: 1-linear and 2-lanceolate; (f) blade pilosity: 1-absent or very little, 3-low, 5-medium, 7-high, and 9-very high; (d) blade pilosity distribution: 1-glabrous, 2-dorsal side, 3-ventral side, 4-both sides, 5-base, and 6-on the margins; (h) spikelet insertion on the rachis: 1-uniseriate, 2-biseriate, and 3-combined; (i) flowering cycle: 3-early, 5-medium, and 7-late; j) rhizome shape: 1-globose, 3-intermediate, and 5-elongate; and (l) stolons: 1-without stolons and 9-stoloniferous.

Statistical analysis

After collecting the data, variance homogeneity tests were carried out (Bartlett 1937), as well as a test for normality, using the chi-square test (X^2). Thereafter, the data were subjected to an analysis of variance, and the means were grouped using the Scott−Knott test (1974) at a 5% significance level.

For graphical representation of the genetic divergence among the accessions, using a dendrogram, two matrices were generated: the first one for qualitative data, using the nonstandardized average Euclidean distance, and the second one for quantitative data, using the generalized distance of Mahalanobis (1936). After obtaining the combined matrix of qualitative and quantitative data, the clustering of accessions was performed using the unweighted pair group method with arithmetic mean (UPGMA) technique. The cut point of the dendrogram for the formation of groups was determined using the method proposed by Mojena (1977). The cophenetic correlation coefficient (CCC) was also estimated. All analyses were performed using GENES computational software (Version 2021.1.9) (Cruz 2016).

Results and discussion

Analysis of fresh and dry matter productivity

For the analysis of fresh matter productivity (PMF) and dry matter productivity (PMS), the values of the mean squares obtained in the analysis of variance revealed significant differences between the evaluated accessions, indicating the existence of genetic divergence between them (Table 2). This variation between the accessions can be exploited in selection in the species' genetic breeding programs for the development of new materials.

The mean values of fresh and dry matter productivity for the first and second cuts per genotype, according to Scott and Knott (1974) clustering at a 5% level of significance, showed the formation of different groups (Table 3), reinforcing the existence of variation among the accessions.

Considering the fresh matter productivity trait in the first cut, the clustering means generated seven groups, where the average productivity values ranged from 11.233 to 31.026 kg/ha, with accession UmCO-11 (2) standing out with the highest average. In the second cut, the mean values ranged from 4.623 kg/ha to 21.347 kg/ha, resulting in the formation of five groups, with the highest averages observed for the accessions UmCO-13 (2) and UmCO-5 (2).

A reduction in productivity was observed during the second cut compared to the first, which may be associated with the initial fertilization of the area

Table 2 Summary of the analysis of variance results from the randomized block design for fresh matter productivity (PMF) and dry matter productivity (PMS) in kg/ha, evaluated in 15 *Urochloa* grass accessions after the first and second cuts

		Mean square			
		PMF		PMS	
Source of variation	Degrees of freedom	Cut 1	Cut 2	Cut 1	Cut 2
Block	2	877056.09	180299.02	124299.62	379536.2
Accessions	14	101307618.86 **	66738788.46 **	5139087.98 **	4703795.00 **
Residual	28	1012106.04	1113156.99	496589.53	544678.41
Mean		23190.71	12589.64	5567.22	3423
CV (%)		4.34	8.38	12.66	21.56

**significant at the 1% level based on the F test

Table 3 The mean values of fresh matter productivity (PMF) and dry matter productivity (PMS) in kg/ha, evaluated in 15 *Urochloa* grass accessions after the first and second cuts

	PMF		PMS	
Genotypes	Cut 1	Cut 2	Cut 1	Cut 2
UmCO-11 (2)	31.026a	12.443c	8.960a	3.252b
UaCO-15 (1)	28.980b	13.024c	6.416b	2.906b
UmCO-2 (2)	28.771b	14.055c	5.794c	3.109b
UmCO-5 (2)	27.632b	20.858a	6.293b	5.623a
UmCO-8 (1)	26.064c	14.234c	5.469c	3.531b
UbCO-16 (1)	25.987c	12.362c	5.229c	3.698b
UmCO-10 (2)	25.710c	13.027c	5.565c	2.617c
UoCO-18 (1)	24.859c	17.391b	5.529c	3.999b
UmCO-13 (2)	24.064d	21.347a	6.091b	5.939a
UmCO-4 (1)	22.299e	12.820c	4.901c	3.326b
UmCO-6 (1)	18.708f	6.033e	4.739c	1.920c
UspCO-23 (1)	17.708f	8.505d	4.268c	2.527c
UmCO-9 (1)	17.054f	6.856d	4.008d	1.927c
UmCO-1 (1)	16.199f	12.438c	5.116c	4.898a
UmCO-7 (1)	11.233 g	4.623e	3.138d	2.068c

[1]Means followed by the same lowercase letter in a column do not differ significantly from each other according to the Scott–Knott test at a 5% significance level

where the materials had better performance. A similar finding was reported by Favare (2019) when evaluating dry matter productivity in elephant grass (*Pennisetum purpureum* Shum.), a behavior associated with soil fertility decline and, consequently, the lack of nutrient replenishment through fertilization. Sá Junior et al. (2018), when evaluating the phytomass accumulation rate of urochloa grass under different doses of swine manure and cutting heights, observed a behavior similar to that in the present study, where the highest phytomass accumulation rate occurred in the first cycle.

Among the 15 accessions, UmCO-13 (2) and UmCO-5 (2) displayed consistent mean values for both cuts. For the first cut, they yielded 24.064 kg/ha and 27.632 kg/ha, respectively, while for the second cut, the values were 21.347 kg/ha and 20.858 kg/ha, respectively (Table 3). This potential for sustained productivity may be associated with a combination of factors, such as the plant's photosynthetic capacity, leaf area index, height, and light interception, leading to higher net forage accumulation and increased dry matter production (Borges et al. 2011; Anjos and Chaves 2021; Reis et al. 2021). This suggests that these accessions demonstrate superiority in this trait, as they maintained high productivity levels in the two cutting cycles.

Bueno et al. (2015) and Alves (2016), when evaluating the biomass production of different *Urochloa* genotypes, obtained results similar to those in the present study, with the accession UmCO-13 (2) also standing out. Accession UmCO-7 (1) showed the lowest average for both cuts, i.e., 11.233 kg/ha for the first cut and 4.623 kg/ha for the second cut (Table 3). This result may be associated with the fact that the accession exhibited early flowering and a higher number of inflorescences. These characteristic favors higher seed production, indicating likely competition for nutrients where the majority is directed toward the reproductive phase, and consequently, there may be a lower leaf production rate and lower biomass production due to the rapid senescence process of the plant. Similar results were found by Patês (2009) when evaluating the structural characteristics of *Panicum maximum* 'Atlas' under different nitrogen doses.

Regarding fresh matter productivity, in a study conducted by Gobbi et al. (2018), the cultivars Xaraés and MG-4 belonging to the species *U. brizantha* stood out in having the highest annual forage masses during the rainy season, measuring 17.544 and 20.081 kg/ha/year, respectively. Santos et al. (2003) reported values similar to those obtained in the present study for fresh matter productivity, measuring 25 t/ha/35 days for *U. brizantha* 'Marandu'. The *Urochloa* genotypes evaluated in the present work showed good productive performance when compared to the ones mentioned above.

For dry matter productivity (PMS), after the first cut, the mean productivity ranged from 3.138 to 8.960 kg/ha in accessions UmCO-7 (1) and UmCO-11 (2), respectively. After the second cut, the mean PMS ranged from 1.920 kg/ha to 5.623 kg/ha for UmCO-6 (1) and UmCO-13 (2), respectively.

Rodrigues (2004) evaluated the dry matter (DM) production of four cultivars of *U. brizantha* under irrigation and found yields ranging from 5.856 to 6.211 kg/ha of DM under field conditions. Oliveira et al. (2016) evaluated the dry matter production capacity of different forage species and found a mean value of 4.350 kg/ha for *U. mosambicensis* under rainfed conditions. Sá Junior et al. (2018), when evaluating productivity under swine manure fertilization, found that this experimental condition resulted in an accumulation of 3.120 kg/ha of dry matter in urochloa grass at a cutting height of 10 cm.

Melo et al. (2020), Melo et al. (2021), and Rodrigues et al. (2022) obtained values similar to those for the accessions in the present study when evaluating dry matter productivity for *U. brizantha* and *U. ruziziensis* grasses. These results show the productive potential of the species *U. mosambicensis* and other genotypes evaluated in the development of new cultivars.

After the irrigation cutoff, the accessions were observed over a period of 90 days, and the majority showed satisfactory responses, exhibiting regrowth capacity and survival despite the lack of water during the study period. The accessions UmCO-7 (1), UmCO-6 (1), and UmCO-1 (1), however, were more sensitive during the water shortage period and did not survive. Due to drought in the northeastern region, the identification of genotypes tolerant to water deficit stress is of great value for exploration within breeding programs for any forage species. The identification and subsequent utilization of these accessions for advancing breeding programs could be of great potential, especially when the accessions are intended for animal feed in a region where food scarcity is significant.

Analysis of quantitative and qualitative descriptors

Based on the analysis of variance, significant differences were observed among the genotypes for the 11 descriptors studied, indicating genetic divergence among the genotypes (Table 4).

The coefficient of variation in the present study ranged from 3.38 to 15.70 (Table 4). The results obtained in the present study for the coefficient of variation (CV) were within the expected range for most of the variables when compared to those of other research. Similar results were found by Santos et al. (2019) when evaluating the structural characteristics of two cultivars of *U. brizantha* in a greenhouse, where they obtained a coefficient of variation similar to the one found in the present study for leaf blade length (11.64%).

Based on the mean comparison test, four groups were generated for the plant height variable. The genotypes UmCO-5 (2) and UmCO-11 (2) exhibited the highest values of 71 cm and 66 cm, respectively (Table 5).

Pinto et al. (2021), evaluating the green forage productivity of *U. ruziziensis* clones with cutting intervals of 70 days, found an average variation in height of 71.63 cm, where the means were separated into four distinct groups. Melo et al. (2020), when evaluating the height of *U. brizantha* under different irrigation depths, observed an average height of 43 cm at 34 days of growth. Rezende et al. (2011), evaluating *U. brizantha* 'Marandu' subjected to different phosphorus dosages in pots, observed a plant height pattern similar to that in the present study60 days after the uniformization cut.

Regarding the basal tillering intensity, the highest averages were detected in the genotypes UmCO-6 (1) and UmCO-2 (2), with 1032 and 1021 tillers/m^2, respectively. This basal tillering potential was also observed by Bueno et al. (2019) when evaluating different accessions of *U. mosambicensis*. On the other

Table 4 Summary of the analysis of variance results for morpho-agronomic descriptors evaluated in 15 urochloa grass accessions after the uniformization cut

		Mean Square					
		Plant		Stem			Leaf
Source of variation	Degree of freedom	[1]APL	IPB	CIC	DC	CLF	LLF
Block	2	4.81	77,331.75	0.46	5.13	2.53	0.45
Accessions	14	200.54 **	92,257.89 **	4.73 **	11.95 **	16.39 **	3.98 **
Residual	28	7.27	15,102.54	0.15	1.72	2.90	0.60
Mean		53.45	782.51	11.51	15.03	13.58	10.84
CV (%)		5.05	15.70	3.38	8.72	12.54	7.17

		Mean Square				
		Inflorescence				
Source of variation	Degree of freedom	[1]CHF	CEF	CRB	QR	NI
Block	2	57.15	0.09	0.11	0.36	153.89
Accessions	14	25.58 **	3.30 **	1.54 **	1.26 *	9176.99 **
Residual	28	8.41	0.20	0.28	0.48	242.84
Mean		25.42	5.55	3.91	4.69	130.29
CV (%)		11.4	8.07	13.5	14.69	11.96

**significant at a 1% probability based on the F test. APL—plant height, IPB—basal tillering intensity, CIC—stem internode length, DC—stem diameter, CLF—leaf blade length, LLF—leaf blade width, CHF—floral stem length, CEF—floral axis length, CRB—basal raceme length, QR—raceme quantity, NI—number of inflorescences, PS—seed production, CV(%) = coefficient of variation

Table 5 Scott–Knott (1974) test results for the mean data of the descriptors evaluated in 15 urochloa grass accessions

Genotype	Morphoagronomic characteristics[a]										
	APL (cm)	IPB (m^2)	CIC (cm)	DC (mm)	CLF (cm)	LLF (mm)	CHF (cm)	CEF (cm)	CRB (cm)	QR (unit)	NI (unit)
UmCO-5 (2)	71a	694b	13.33a	1.99a	18.25a	9.76b	24.95b	6.19b	3.15b	5a	112d
UmCO-11 (2)	66a	803a	10.57c	1.40c	13.81c	9.96b	23.05b	4.13d	3.02b	4b	105d
UbCO-16 (1)	60b	865a	9.71d	1.58b	12.78c	12.03a	22.04b	4.93c	3.77b	4b	142c
UmCO-9 (1)	59b	450b	13.34a	1.35c	15.15b	11.46a	30.51a	6.59b	5.01a	4b	198b
UaCO-15 (1)	55c	969a	9.93d	1.67b	12.06c	10.50b	21.38b	4.30d	3.80b	5a	46e
UmCO-4 (1)	55c	728b	11.11c	1.62b	13.31c	12.86a	27.72a	5.61b	4.45a	4b	119d
UoCO-18 (1)	54c	896a	9.78d	1.50c	13.39c	12.63a	21.66b	4.36d	3.27b	5a	108d
UmCO-1 (1)	52c	871a	12.31b	1.21c	13.33c	11.50a	26.10a	6.06b	5.31a	4b	197b
UmCO-8 (1)	51c	914a	10.79c	1.70b	18.58a	9.70b	30.08a	7.81a	3.56b	5a	68e
UmCO-2 (2)	51c	1021a	12.07b	1.44c	10.52c	9.16b	27.93a	5.09c	3.78b	4b	148c
UmCO-13 (2)	47d	691b	12.86a	1.30c	14.99b	10.20b	25.51a	6.41b	3.24b	5a	85e
UmCO-7 (1)	45d	601b	10.75c	1.55b	11.88c	10.46b	24.62b	5.28c	4.12a	5b	240a
UmCO-6 (1)	44d	1032a	11.78b	1.24c	11.09c	11.93a	22.51b	4.31d	3.16b	3b	157c
UmCO-10 (2)	44d	624b	11.47c	1.50c	12.40c	10.63b	26.62a	5.93b	4.27a	6a	62e
UspCO-23 (1)	43d	574b	12.80a	1.45c	12.09c	9.80b	26.63a	6.23b	4.66a	5a	166c

[a]Means followed by the same lowercase letter in a column do not differ significantly from each other according to the Scott–Knott test at a 5% significance level

APL—plant height, IPB—basal tillering intensity, CIC—stem internode length, DC—stem diameter, CLF—leaf blade length, LLF—leaf blade width, CHF—floral stem length, CEF—floral axis length, CRB—basal raceme length, QR—raceme quantity, NI—number of inflorescences

hand, the genotypes with the lowest tillering were UmCO-9 (1) and UspCO-23, with 574 and 450 tillers/m^2, respectively. The values obtained in the present study were higher than those found by Rezende et al. (2011), with 796 tillers/m^2 for *U. brizantha* 'Marandu', and Rodrigues et al. (2022), with 263 tillers/m^2 for *U. ruziziensis*. The tillering intensity is directly linked to the regrowth capacity, where its potential depends on leaf emergence, and its establishment over time ensures the plant's life cycle progression in addition to ensuring greater soil protection and determining forage production (Santos et al. 2009; Alves 2016).

In terms of stem characteristics, the internode length ranged from 9.71 to 13.34 cm. The average stem diameter ranged from 1.21 to 1.99 mm, with the genotypes UmCO-1 (1) and UmCO-5 (2) showing the largest values. Stem diameter is extremely important for the development of grasses, and according to Kirchner et al. (2020), as stem diameter increases, the capacity for regrowth also increases, thereby contributing to an increased number of leaves, which will be used for animal feed. On the other hand, an increase in stem diameter can indicate a higher fiber and lignin content, which can lead to lower plant digestibility and decreased animal performance (Nascimento et al. 2023).

The genotypes UmCO-5 (2) and UmCO-8 (1) showed the longest leaf blade lengths, at 18.25 cm and 18.58 cm, respectively, while UmCO-2 (2) had the lowest value of 10.52 cm. For leaf blade width, the clustering of means resulted in two groups, where genotypes UmCO-4 (1), UoCO-18 (1) and UbCO-16 (1) had statistically equal means, ranging from 12.03 to 12.86 cm. According to Migliorini et al. (2012), wider and longer leaf blades are desirable characteristics for forage plants, as they are directly related to forage quality and contain higher nutrient concentrations, which can facilitate the foraging process of animals (Lima and Deminicis 2008; Oliveira et al. 2019). Similar results were found by Assis et al. (2003) for six species of *Urochloa*. These authors reported average leaf blade lengths ranging from 19.14 to 20.87 cm and leaf blade widths ranging from 8.16 to 17.08 mm.

For the descriptors related to inflorescences, the genotypes were separated into five groups based on the number of inflorescence variables, and the UmCO-7 (1) genotype presented the highest average for this characteristic, remaining alone in the first group (Table 5). According to Bruno et al. (2017) and Catuchi et al. (2019), the development of reproductive structures is directly related to seed production, which can be influenced by various genetic and environmental factors.

Regarding floral stem length, two groups were formed, with the genotypes UmCO-13 (2), UmCO-1 (1), UmCO-10 (2), UspCO-23 (1), UmCO-4 (1), UmCO-2 (2), UmCO-8 (1) and UmCO-9 (1) having the highest means. For the floral axis length, four groups were established, with UmCO-8 (1) showing the highest mean. The raceme length ranged from 3.02 cm in UmCO-11 (2) to 5.31 cm in UmCO-1 (1). Regarding the number of racemes, two groups were formed, with the accession UmCO-10 (2) having an average of 6 racemes per inflorescence, while UmCO-6 (1) belonged to group two, showing the lowest average (Table 4). According to Quadros et al. (2010), the longer the raceme is, the larger the seed production compartment, and consequently, the greater the plant's capacity for reproduction.

When evaluating the reproductive characteristics of six species of *Urochloa*, Assis et al. (2003) found similar results, where the floral stem length ranged from 25.67 to 34.15 cm, the floral axis length ranged from 6.05 to 11.07 cm, the raceme length ranged from 3.58 to 8.70 cm, and the number of racemes per inflorescence ranged from 3 to 5.

Regarding the qualitative descriptors, twelve accessions displayed an erect growth habit, while three accessions exhibited intermediate growth. Specifically, the accessions UmCO-2 (2), UmCO-9 (1) and UspCO-23 (1) showed intermediate growth.

All accessions evaluated presented stolons and an intermediate rhizome shape. These structures are modified stems that reproduce asexually, allowing the plant, in the case of grasses, to produce the largest number of tillers, which allows a greater capacity for regrowth and protects the plant during grazing (Rechenthin 1956; Guo et al. 2021).

Because they are underground stems, rhizomes are used by plants to store water and nutrients, which are allocated to plant development (Guo et al. 2021). In addition, they are strategically linked to perennial growth, presenting greater resistance in a period of mild drought (Zhou et al. 2014; Guo et al. 2021).

In general, all accessions presented erect leaves with a lanceolate shape. Regarding hairiness and its distribution on the sheath and leaf blade, great variation was observed between the accessions. The UmCO-2 accession (2) presented high hairiness with a dispersed distribution; this same accession presented high hairiness on the leaf blade distributed on both faces of the leaf. According to Mansoor et al. (2002), hairiness is a characteristic that can play an important role in adapting to drought since it minimizes water loss by transpiration. Moreover, it is also related to the palatability of the leaf to animals (Silva et al. 2009).

In contrast, the accessions UmCO-10 (2), UmCO-8 (1), UmCO-5 (2) and UmCO-1 (1) showed little hairiness on both the sheath and the entire leaf, with a dispersed distribution on the sheath and on both faces of the leaf blade. The UmCO-4 (1) accessions showed little hairiness along and on both sides of the leaf. On the other hand, the accessions UmCO-9 (1) and UspCO-23 (1) presented average hairiness distributed on both faces. Hairiness was absent in the following accessions: UmCO-11 (2), UmCO-7 (1), UmCO-6 (1), UmCO-13 (2), UoCO-18 (1), UmCO-UaCO-15 (1) and UbCO-16 (1).

For the insertion of the spikelet into the rachis, the accessions UmCO-2 (2), UmCO-10 (2) and UmCO-9 presented the combined type, i.e., simultaneous uni- and biseriate insertion, while the other accessions presented the biseriate type.

Regarding the flowering cycle, which was evaluated twelve days after the uniform cut, all patterns (early, intermediate, and late) were recorded, with UmCO-7 (1), UmCO-6 (1) and UmCO-1 (1) showing early flowering. According to Wolabu et al. (2023), this type of behavior may have advantages related to seed production since the collection of these seeds can be carried out earlier.

Additionally, regarding flowering, the accessions UmCO-11 (2), UmCO-4 (1), UmCO-2 (2) and UmCO-10 (2) presented intermediate (medium) flowering, while the remaining accessions presented late flowering. In forages, intermediate to late flowering can influence biomass productivity and consequently nutritional quality (Wolabu et al. 2023). The different behaviors of the accessions for the character in question evidence its potential for exploitation in the breeding program of the species.

Multivariate analyses for the study of genetic divergence among *Urochloa* sp. accessions

According to Sokal and Rohlf (1962), for a good graphical representation of a dendrogram, the cophenetic correlation coefficient (CCC) should be higher than 0.7. Thus, the result obtained in this study (0.91) for this parameter (Fig. 1) indicates a high degree of reliability of the information used in the representation of the accessions, indicating that the obtained dendrogram satisfactorily reproduces the information contained in the dissimilarity matrix and the formed groups.

The dendrogram was obtained from the dissimilarity matrix generated by summing the matrices of qualitative and quantitative traits. Based on the cutoff point determined using the Mojena method (1977), the formation of 10 groups was established (Fig. 1) for the 15 accessions. Group II consisted of the accessions UmCO-7 (1) and UmCO-6 (1); Group VII included accessions UmCO-8 (1) and UmCO-5 (2), and there was a subgroup formed by the accessions UmCO-13 (2), UoCO-18 (1), UaCO-15 (1), and UbCO-16 (1), while the remaining groups consisted of only one genotype each (Fig. 1).

According to Vieira et al. (2008), Barros et al. (2020), and Cordeiro et al. (2021), the formation of groups with only one genotype highlights the variability present in the studied accessions. This feature is of great value for breeders, as it indicates the presence of high contrast among the genotypes, which allows their exploration for a variety of purposes in breeding programs.

Group II, formed by the accessions UmCO-7 (1) and UmCO-6 (1), exhibited unique characteristics, such as early flowering.

Group IX was formed by four different accessions, and the characteristics that contributed the most to the clustering of this group were spikelet insertion into the rachis of the "biseriate" type, late flowering, basal tillering intensity, and high dry matter productivity.

Group X, composed of the accession UmCO-2 (2), was the most divergent. The accession exhibited an intermediate growth habit; late flowering; spikelet insertion into the rachis of the "combined" type, i.e., simultaneous uniseriate and biseriate insertion; high pilosity distributed on both sides of the leaf, which may play an important role in adaptation to drought; high basal tillering intensity; and good soil coverage.

According to Benin et al. (2002), the more distant the groups, the more divergent they are. This divergence facilitates crossing, leading to new recombination events and broadening the variability within the species whenever feasible. These factors do not

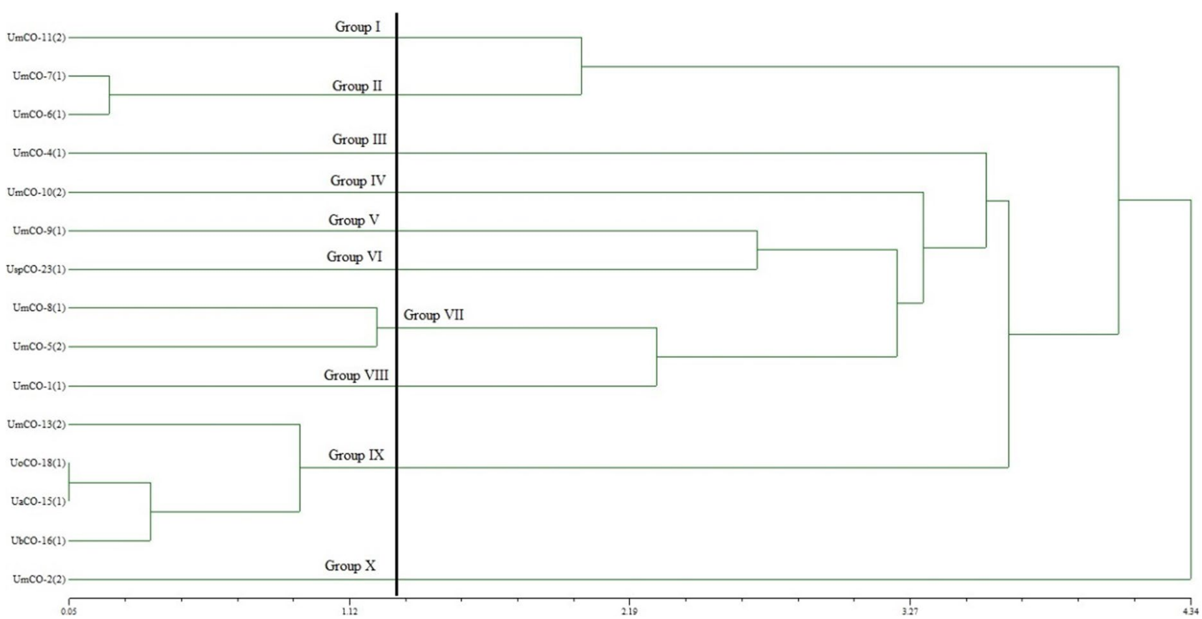

Fig. 1 Representative dendrogram of the genetic diversity among 15 accessions of *Urochloa* spp. obtained by clustering using the unweighted pair group method with arithmetic mean (UPGMA) technique, with CCC = 91%

occur in apomictic plants because the descendants are clones of the maternal plant, representing the narrowing of the genetic base within the species improvement program. The variation pattern observed among the accessions in this study reinforces the existence of genetic divergence among the genotypes. Gonçalves et al. (2011), Assis et al. (2014), and Torres et al. (2015), while working with *Urochloa*, found genetic divergence among the materials, which varied in each study. This corroborates the results of the present study and emphasizes the importance of the wide genetic divergence within the species as well as the significance of characterizing the available *U. mosambicensis* germplasm.

Conclusion

The *U. mosambicensis* accessions characterized showed great variability for most of the descriptors evaluated. Some of the descriptors, such as production, plant height, tillering intensity, and number of inflorescences, as well as accessions that have been identified as possibly tolerant to water stress, may be incorporated into breeding programs with the aim of obtaining new cultivars. Since some of the morphological features are influenced by the environment, this characterization should be repeated for another year or two and be complemented by molecular characterization.

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Author contributions CTVDM, RPA, TLN, LGB and NFM conceived and planned the study and wrote the manuscript; LGB provided the germplasm accessions, which were multiplied by CTVDM for the experiment; CTVDM, RMEB and RPA carried out the phenotyping; CTVDM, NFM and TLN analyzed the data. All the authors have read and approved the final manuscript.

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Declarations

Conflict of interest The authors have not disclosed any competing interests.

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