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Research Paper

Nutritional and biomass evaluation of a *Megathyrsus maximus* collection in a dry tropical climate in Colombia

Evaluación nutricional y de biomasa de una colección de Megathyrsus maximus *en un clima tropical seco en Colombia*

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Abstract

Agronomic and nutritional parameters of a set of 28 accessions of *Megathyrsus maximus* established in Colombia during the rainy season were evaluated to identify accessions with differences in nutritional quality and characterize germplasm of *M. maximus*. ANOVA and multivariate analysis showed differences among accessions. Agronomic variables such as plant height, dry matter yield and green fresh weight were not correlated with nutritional variables. Flowering affected nutritional quality (neutral detergent fiber, acid detergent fiber and relative feed value). Flowering, fiber concentration, digestibility and crude protein concentration had the most influence on forage quality of *M. maximus*. The integral evaluation of biomass and nutritional parameters showed that the set of 28 *M. maximus* accessions contained 2 accessions with high nutritional quality and competitive biomass production. Heterogeneity of the collection in nutritional and agronomic characteristics indicates opportunities for plant breeding to produce additional accessions for improving cattle production in the tropics.

Keywords: Digestibility, grassland, quality, Relative feed value (RFV), yield.

Resumen

En una colección de 28 accesiones de *Megathyrsus maximus* establecida durante periodo de lluvias en trópico colombiano se evaluaron parámetros nutricionales y agronómicos con el objetivo de identificar accesiones con diferente calidad y caracterizar material forrajero de *M. maximus*. Los análisis de varianza y multivariado mostraron diferencias entre accesiones. Variables agronómicas como tales como altura, materia seca y forraje verde no presentaron correlación con las variables nutricionales. La floración afectó la calidad nutricional (fibra detergente neutro, fibra detergente ácido y el valor relativo del alimento). La floración, la concentración de fibra, la digestibilidad y la concentración de proteína cruda fueron los que más influyeron en la calidad del forraje de *M. maximus*. La evaluación integral de biomasa y parámetros nutricionales mostró que el conjunto de 28 accesiones de *M. maximus* había dos materiales promisorios con alta calidad nutricional y producción de biomasa competitiva. La heterogeneidad de la colección en las características nutricionales y agronómicas indica oportunidades para el trabajo en fitomejoramiento de producir accesiones adicionales que mejoren la producción ganadera en los trópicos.

Palabras clave: Calidad, digestibilidad, pastizal, rendimiento, Valor Relativo de forrajes (VRF).

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Introduction

Forages are the main feed for cattle production systems in the tropics (Gerber et al. 2015). Yield and nutritional quality are important variables for understanding genotype-environment-management relationships (Lemaire and Belanger 2020). These parameters can be used for identification of forages that significantly contribute to increased production efficiency in agricultural production systems (Khan et al. 2020) and sustainable cattle intensification (Cardoso et al. 2020; Mwendia et al. 2022).

The eco-efficient use of grasslands as animal feed can contribute to food security and to sustainable meat and milk production. In a livestock production and climate change context, several strategies are promoted for sustainable production, including interventions in feeding and nutrition of ruminants (Bhatta et al. 2017). Nutritional composition and digestibility of forages influence the productivity of grazing animals (Bezabih et al. 2014) and their methane emissions (Barahona-Rosales et al. 2014).

Integration of biomass yield and forage quality is economically important for production (Schaub et al. 2020) and adoption and use of forage by farmers (Keba et al. 2013; Garcia et al. 2020). These characteristics contribute to identifying suitable grassland management practices for adapting to climate change (Perotti et al. 2021) and are of high interest to forage breeders, researchers and cattle producers (Jank et al. 2011; Carvajal-Tapia et al. 2022).

Megathyrsus maximus is a grass commonly used in tropical livestock production systems with outstanding agronomic, nutritional and environmental characteristics under dry tropical conditions (Carvajal-Tapia et al. 2021b). This grass has potential for inclusion in silvopastoral forage systems (Paciullo et al. 2017) and forage mixtures in grassland (Matínez-Mamian et al. 2020).

The present study evaluated agronomic parameters, including plant height, flowering, dry matter yield (DMY) and green fresh weight (GFW) together with nutritional parameters, including gas production (GP), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), organic matter (OM), organic matter digestibility (DOM), metabolizable energy (ME), in vitro dry matter digestibility (IVDMD), non-fiber carbohydrate (NFC), total digestible nutrients (TDN) and relative feeding value (RFV) of 28 accessions of *M. maximus* established in a dry tropical agroecosystem in Colombia. The aim was to determine biomass and nutritional quality of a selection of accessions of *M. maximus* by quantifying a range of variables to identify those accessions with potential for use in plant breeding for enhancing cattle production in the tropics.

Materials and Methods

Climatic characteristics

This study was conducted in a dry tropical forest agroecosystem located in the Patía Valley, Cauca Department, southwestern Colombia, at 625 masl with annual average temperature of 27.9 °C, annual precipitation of 1,414 mm and two rainy seasons per year. Specific environmental conditions for the trial period were on average 27.4 °C, 77 % and 172 mm for temperature, relative humidity and cumulative precipitation, respectively (Figure 1).

Agronomic evaluation

Soils at the experimental site were Mollisols, suborder Ustolls and group Haplustolls. The chemical analysis of samples collected from 0–20 cm depth had the following values: pH=6.26, C ox=18.14 g/kg, total N=0.22 %, organic matter=4.50 %, P=6.3 ppm, Ca=14.58 cmol/kg, Mg=6.91 cmol/kg, K=0.59 cmol/ kg, Na=0.10 cmol/kg, cation exchange capacity=27.10 cmol/kg and B=83 ppm or mg/kg.

A collection of 130 *Megathyrsus maximus* accessions provided by the germplasm bank of the Alliance of Bioversity International and CIAT were planted as tillers in 4 m^2 plots separated by 1m wide pathways in a randomized complete block design with 3 replicates in 2015. In 2017, agronomic data were recorded for 28 accessions selected as displaying above average in green forage weight (GFW), dry matter yield (DMY) and plant height in previous experiments (Table 1).

Agronomic evaluation was carried out in the Patía Valley, Colombia during the rainy season from 24 March to 4 May 2017. A standardization cut at 30 cm above the ground was carried out 23 March 2017. After a regrowth period of 41 days, forage on plots was harvested for evaluation. Variables measured were plant height (cm) (Toledo and Schultze-Kraft 1982) and flowering (%) (estimated flowering percentage of full plot). Using a 1 m^2 quadrat, each plot received a mechanical cut at a height of 30 cm from ground level and the resulting green forage mean was weighed from each of the quadrats. The production of green forage per ha (GFW) of each accession was calculated. Subsamples of about 200 g were taken from each plot,

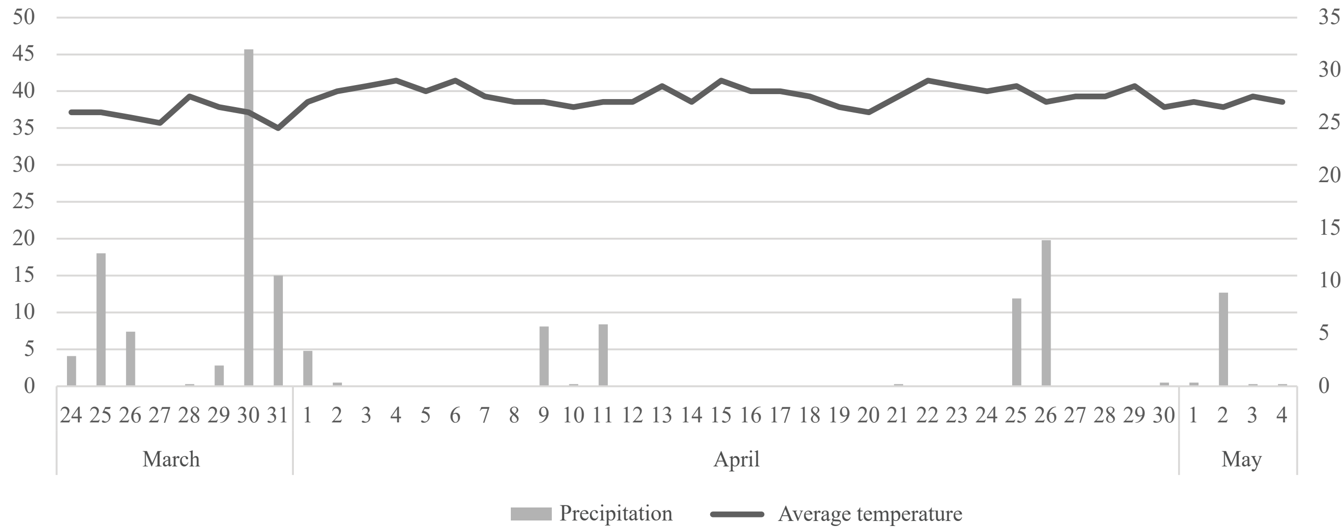

Figure 1. Average temperature and daily precipitation during the experimental period in 2017. Data from the NUTRIFACA meteorological station, Patía Valley of Colombia.

Table 1. CIAT number, origin, and code of other institutions of the evaluated 28 accessions of *Megathyrsus maximus*.

Origin	CIAT and other genebank accession numbers
Kenya	693 (RWS-025, CPI-059903), 6536 (K-741299-303, FAO-01682, FAO-01686), 6900 (K-70, BRA-006351), 6901 (BRA-006360, K-71) and 16004 (KK-15, BRA-007641).
Tanzania	6949 (BRA-005797, K-172), 6955 (K-180, BRA-005851), 6963 (BRA-006653, K-190B), 16011 (BRA-007013, T-3), 16034 (BRA-005029, T-64), 16035 (BRA-007269, T-65), 16038 (BRA-005037, T-69), 16039 (BRA-007293, T-71), 16044 (BRA-007343, T-80), 16058 (T-99) and 16059 (BRA-007471, T-102).
Unknown	673 (ILRI-16553, 3622)[a], 6171[b], 6461 (K-6331), 6497 (K-74895-96), 6836 (G-95, BRA-004839), 6839 (BRA-004863, G-98), 6840 (BRA-004871, G-99), 26723 (CPAC-3273), 26925 (BRA-005576, ORSTOM-K146) and 26944 (BRA-003638, ORSTOM-63).
Commercial	16031 Tanzania (BRA-007218, ILCA-16554, T-58) and 6299 Tobiatá (CPI-089251, ILRI-07160, CNPGC-132/78, K-00187).

[a]Promising accessions in Colombia and Vietnam
[b]Promising accessions in Colombia (Carimagua)

weighed and oven-dried under controlled ventilation at temperatures from 60 to 70 °C until they reached constant weight (48 to 72 hours) to calculate dry matter yield (DMY). The dried subsamples were processed and sent to the laboratory of Animal Nutrition and Rangeland Management in the Tropics and Subtropics of the University of Hohenheim in Stuttgart, Germany for the nutritional evaluation.

Nutritional evaluation

The dried samples were ground in a Retsch SM 100 mill (Retsch GmbH, Haan, Germany) to pass through a 1 mm sieve. Gas production (mL/200 mg DM 24 h) was determined using a completely randomized design with six replicates using the Hohenheim gas test (GP). Based on GP, ruminal degradability of organic matter (g/kg DM) and metabolizable energy (MJ/kg DM) were estimated (Close and Menke 1986). Rumen fluid was collected from 2 cannulated Jersey cows that were fed a diet composed of concentrate mixture (251 g/kg), maize silage (243 g/kg), grass silage (243 g/kg), grass hay (170 g/ kg), rapeseed meal (52 g/kg), barley straw (22 g/kg) and a mineral-amino-acid-vitamin mixture (19 g/kg). The forage:concentrate ratio was 68:32 [Net energy for lactation (NEL)=6.2 MJ/kg DM and crude protein (CP)=134 g/kg DM] as-fed basis. Samples were also analyzed using the Dumas combustion procedure for total N determination (AOAC 2005) and values multiplied by 6.25 to estimate crude protein concentration (CP; method 4.1.2) and crude ash (CA; method 8.1) using the official methods of the Verband Deutscher (VDLUFA 2007). NDF and ADF were determined using the ANKOM fiber analyzer (Van Soest et al. 1991). DOM and ME (Close and Menke 1986) were calculated from GP (g/kg DM), crude protein, ash and crude lipids (EE, ether extract) by the equations:

$$\% \text{ DOM}=14.88 + 0.889 \text{ GP} + 0.045 \text{ CP} + 0.065 \text{ ash; and}$$
$$\text{ME}=1.242 + 0.146 \text{ GP} + 0.007 \text{ CP} + 0.0224 \text{ EE}$$

A value of 16.4 g/kg EE was used for all accessions.

In vitro dry matter digestibility (IVDMD) was determined with the near infrared spectroscopy (NIRS) equipment model Foss 6500 and MINISIS software (IS-2250) version 2.71 as reported by Mazabel et al. (2020) in the Alliance of Bioversity International and CIAT forage and animal nutrition quality laboratory.

Quality indices were calculated based on the nutritional data. Relative feed value (RFV) was calculated and classified on the scale: RFV>151=excellent; 125–151=first quality; 103–124=second quality; 87–102=third quality; and 75–86=fourth quality (FEDNA 2014) using the equation:

$$\text{RFV}=(\text{DDM x DMI})/1.29$$

where:

DDM=digestible dry matter (88.9 - (0.779 x % ADF);

DMI (kg/d)=dry matter intake (% of BW) (120/% NDF); and

BW=body weight (kg).

Total digestible nutrients (TDN) were estimated according to the method of Jayanegara et al. (2019):

$$\text{TDN}=0.479 \text{ NDF} + 0.704 \text{ NFC} + 1.594 \text{ EE} + 0.714 \text{ CP}$$

where:

NDF=neutral detergent fiber; and

NFC (non-fiber carbohydrate)=OM - (NDF + EE + CP).

Statistical analysis

Agronomic variables (plant height, flowering, DMY and GFW) were used for analysis. Nutritional variables were: NDF, ADF, CP, OM, DOM, GP, ME, IVDMD, RFV, NFC and TDN. ANOVA and Tukey's multiple range test were carried out using statistical package SAS version 9.2.1 to determine statistical differences in plant height, flowering, GFW, DMY and GP among the accessions. The multivariate analysis was carried out with software R version 4.1.2 for the variables plant height, flowering, DMY, GFW, NDF, ADF, CP, OM, DOM, ME, IVDMD, NFC, RFV and TDN. Pearson correlation was obtained with ggcorrplot in R (Kassambara 2019) using the Bonferroni test for hypothesis testing on non-zero correlation. To classify the accessions, the data were standardized with Z-score. The multivariate analysis with principal components and clustering was performed using the package FactoMineR (Lê et al. 2008). Based on the variables evaluated, hierarchical clustering was carried out using the agglomerative algorithm of Ward and Euclidean distance. Visualization was performed using the functions fviz_pca_biplot and fviz_cluster (factoextra library). Figures were created using the package 'ggplot2' (Wickham 2016).

Results

Analysis of variance indicated significant difference ($P<0.05$) between accessions in the variables flowering, plant height and GP (Table 2). Accessions 16059, 16031 (Tanzania), 26723, 6497, 6840 and 16035 had the highest GP, which placed them in the first 10 accessions with the highest DOM and ME values. Accessions 673, 6171, 6461, 6497, 6536, 6836, 6839, 6900, 6949, 6955, 16004, 16011, 16058, 16059, 26944 and 6840 displayed full flowering at harvest, while accessions 6963, 26723, 26925, 16035, 6299 Tobiata and 16044 displayed ≤5 % flowering at harvest (Table 2). The commercial variety Tobiata and accession 693 were the tallest but not significantly different from most accessions ($P>0.05$). The analysis of variance showed no significant differences between accessions for dry biomass yield (Table 2).

All accessions contained high concentrations of NDF (range 655–733 g/kg) and OM (range 810–872 g/kg) and IVDMD ranged from 50.7 to 63.7 % with DOM ranging from 44.1 to 55.7 % (Table 3). CP concentration ranged from 45.8 to 108.5 g/kg. Relative feed value of the accessions ranged from 67.2 to 86.6, indicating that forage was in the fourth quality category. TDN values ranged from 43.8 to 47.0 (Table 3).

There was a moderate to high positive correlation between flowering and NDF and ADF concentrations, and a negative correlation with IVDMD and RFV. Structural carbohydrates represented by the concentrations of NDF and ADF were related negatively and moderately to CP, DOM and IVDMD, and positively to OM only for NDF. CP concentration, IVDMD and DOM presented positive relationships with RFV, while RFV was negatively correlated with NDF and ADF (Figure 2).

Principal component analysis (PCA) identified components 1 and 2 representing up to 63.1 % of the variation (Figure 3). Accessions 26723 and 693 in Cluster 1 were tall and high-yielding plus late-flowering (Figure 4). They have low concentrations of ADF and NDF and high concentrations of DOM and ME, with an RFV of 78.1. Cluster 2 grouped 10 accessions that included commercial varieties, characterized by low concentrations of ADF and NDF, high CP concentrations, adequate IVDMD, late flowering, average DMY of 5,196 kg/ha and a high value of RFV (Table 4; Figure 4).

Table 2. Mean values of agronomic characteristics and gas production of 28 accessions of *M. maximus* grown in a Colombian dry tropical agroecosystem.

CIAT accession no.	Height (cm)	Flowering (%)	DMY (kg/ha)	GFW (kg/ha)	GP (mL/mg DM 24 h)
673	120.0 ^{bc}	100 ^{a}	5,997 ^{a}	21,190 ^{ab}	26.10 ^{hij}
693	160.3 ^{a}	33.3 ^{cd}	8,720 ^{a}	32,733 ^{ab}	29.75^{cdef}
6171	136.0 ^{abc}	100 ^{a}	8,198 ^{a}	25,933 ^{ab}	27.26 ^{efghi}
6299 Tobiata	160.7 ^{a}	0 ^{d}	4,856 ^{a}	18,627 ^{ab}	26.50 ^{ghi}
6461	144.0 ^{abc}	100 ^{a}	6,594 ^{a}	22,680 ^{ab}	29.17 ^{defg}
6497	131.5 ^{abc}	100 ^{a}	5,742 ^{a}	19,980 ^{ab}	30.83 ^{abcd}
6536	130.7 ^{abc}	100 ^{a}	6,553 ^{a}	23,613 ^{ab}	29.20 ^{defg}
6836	142.0 ^{abc}	100 ^{a}	6,496 ^{a}	26,773 ^{ab}	26.00 ^{hij}
6839	139.7 ^{abc}	100 ^{a}	6,047 ^{a}	25,027 ^{ab}	28.20 ^{defgh}
6840	148.3 ^{ab}	93.3^{abc}	6,808 ^{a}	25,393 ^{ab}	30.30 ^{abcd}
6900	141.3 ^{abc}	100^{a}	5,312 ^{a}	21,107 ^{ab}	23.70 ^{ijkl}
6901	147.0 ^{ab}	50.0 ^{abc}	4,948 ^{a}	18,193 ^{ab}	24.90 ^{ijk}
6949	123.7 ^{abc}	100 ^{a}	7,375 ^{a}	26,800 ^{ab}	24.70 ^{ijkl}
6955	138.0 ^{abc}	100 ^{a}	5,998 ^{a}	19,653 ^{ab}	26.30 ^{hij}
6963	157.3 ^{ab}	5.0 ^{d}	6,645 ^{a}	28,593 ^{ab}	22.10 ^{l}
16004	135.3 ^{abc}	100 ^{a}	8,622 ^{a}	30,177 ^{ab}	26.80 ^{ghi}
16011	143.3 ^{abc}	100 ^{a}	6,099 ^{a}	23,760 ^{ab}	22.50 ^{kl}
16031 Tanzania	133.3 ^{abc}	50.0 ^{abc}	4,028 ^{a}	17,960 ^{ab}	32.60 ^{ab}
16034	145.7 ^{ab}	30.0 ^{cd}	4,134 ^{a}	16,543 ^{ab}	25.80 ^{hij}
16035	157.0 ^{ab}	0 ^{d}	5,666 ^{a}	20,067 ^{ab}	30.30 ^{abcd}
16038	152.0 ^{ab}	33.3 ^{cd}	7,098 ^{a}	22,267 ^{ab}	29.86 ^{bcde}
16039	147.3 ^{ab}	35.0 ^{abc}	4,319 ^{a}	16,013 ^{ab}	27.20 ^{efghi}
16044	141.3 ^{abc}	0 ^{d}	6,123 ^{a}	21,573 ^{ab}	26.20 ^{l}
16058	142.3 ^{abc}	100 ^{a}	7,041 ^{a}	21,023 ^{ab}	25.80 ^{hij}
16059	128.7 ^{abc}	100 ^{a}	6,069 ^{a}	20,467 ^{ab}	32.80 ^{a}
26723	154.7 ^{ab}	2.0 ^{d}	11,056 ^{a}	46,080 ^{a}	32.10 ^{abc}
26925	106.0 ^{c}	1.0 ^{d}	4,145 ^{a}	15,093 ^{ab}	29.58 ^{cdef}
26944	136.0 ^{abc}	100 ^{a}	4,279 ^{a}	15,520 ^{ab}	27.06 ^{fghi}
Means	141.95	65.06	6,255	22,994	27,636
Root MSE	11.78	20.08	2.41	8.8	1,273
CV	8.35	30.86	38.68	38.29	4.6
Pr > F	0.0001	<0.0001	0.2116	0.1162	<0.0001

GP=gas production with Hohenheim gas test; DMY=dry matter yield; GFW=green forage weight.
Values within columns followed by different letters are significantly different according to the Tukey HSD (honestly significant difference) test (P<0.005).

Table 3. Nutritional characteristics of 28 accessions of *M. maximus* grown in a Colombian dry tropical agroecosystem.

CIAT accession no.	NDF (g/kg)	ADF (g/kg)	CP (g/kg)	OM (%)	DOM (MJ/kg)	ME (%)	IVDMD (%)	NFC (%)	RFV	TDN (%)
673	710	431	63.2	856	47.0	6.1	50.9	6.6	72.5	45.8
693	683	385	75.0	838	51.4	6.7	57.9	6.3	80.3	45.1
6171	724	439	67.8	864	47.9	6.4	53.0	5.7	70.3	46.1
6299 Tobiata	684	397	74.9	824	50.2	6.2	56.3	4.8	78.9	44.1
6461	686	389	73.0	839	50.8	6.6	58.4	6.4	79.5	45.2
6497	716	424	60.0	855	50.7	6.7	58.8	6.3	72.6	45.6
6536	711	418	62.1	867	49.4	6.5	53.8	7.8	73.7	46.6
6836	724	442	59.4	861	46.5	6.1	50.7	6.1	70.0	45.8
6839	673	381	86.7	843	51.3	6.5	58.6	6.7	81.9	45.8
6840	709	413	69.7	872	50.5	6.7	52.2	7.7	74.4	47.0
6900	719	433	68.1	851	45.3	5.8	52.1	4.7	71.4	45.2
6901	719	431	71.8	840	46.8	6.0	53.3	3.3	71.6	44.5
6949	733	462	45.8	864	44.1	5.8	53.9	6.9	67.2	45.8
6955	727	446	66.9	864	47.3	6.2	54.5	5.5	69.3	46.0
6963	690	393	69.5	838	44.9	5.6	56.1	6.2	78.6	45.0
16004	702	414	73.9	856	48.4	6.3	57.8	6.3	75.1	46.0
16011	725	428	61.6	837	44.6	5.6	51.9	3.5	71.3	44.2
16031 Tanzania	675	370	108.5	831	55.7	7.3	60.8	3.1	82.9	44.9
16034	670	375	76.3	833	48.8	6.1	59.7	7.0	82.9	45.1
16035	682	369	88.7	858	51.3	6.8	63.7	7.1	82.1	46.6
16038	714	395	72.2	868	49.8	6.7	57.2	6.5	75.7	46.6
16039	690	404	74.4	847	48.9	6.3	58.7	6.6	77.5	45.6
16044	680	369	88.7	846	49.0	6.3	60.9	6.1	82.3	45.8
16058	693	401	84.4	830	49.3	6.2	52.0	3.6	77.4	44.4
16059	698	416	76.7	861	53.4	7.1	57.5	7.0	75.3	46.5
26723	697	411	70.2	841	53.3	7.0	58.7	5.8	75.9	45.1
26925	654	359	76.6	810	53.2	6.7	59.7	6.2	86.6	43.8
26944	714	427	81.0	854	49.0	6.3	54.3	4.3	72.5	45.6

NDF=neutral detergent fiber; ADF=acid detergent fiber; CP=crude protein; OM=organic matter; DOM=organic matter digestibility; ME=metabolizable energy; IVDMD=in vitro dry matter digestibility; NFC=non-fiber carbohydrate; RFV=relative feed value; and TDN=total digestible nutrients.

Table 4. Mean characteristics for the three clusters identified in the *M. maximus* collection.

Cluster	Plant height (cm)	Flowering (%)	DMY (kg/ha)	GFW (kg/ha)	NDF (g/kg)	ADF (g/kg)	CP (g/kg)	OM (g/kg)	DOM (%)	ME (MJ/kg)	IVDMD (%)	NFC (%)	RFV	TDN (%)
1	157.5	17.6	9,888	39,407	690	398	72.6	839	52.3	6.8	58.3	6.1	78.1	45.1
2	144.8	20.4	5,196	19,493	686	386	80.2	839	49.9	6.4	58.6	5.7	79.9	45.1
3	136.3	99.5	6,452	23,069	710	423	68.8	855	48.5	6.3	54.4	5.9	73.4	45.7

DMY=dry matter yield; GFW=green forage weight; NDF=neutral detergent fiber; ADF=acid detergent fiber; CP=crude protein; OM=organic matter; DOM=organic matter digestibility; ME=metabolizable energy; IVDMD=in vitro dry matter digestibility; NFC=non-fiber carbohydrate; RFV=relative feed value; TDN=total digestible nutrients.

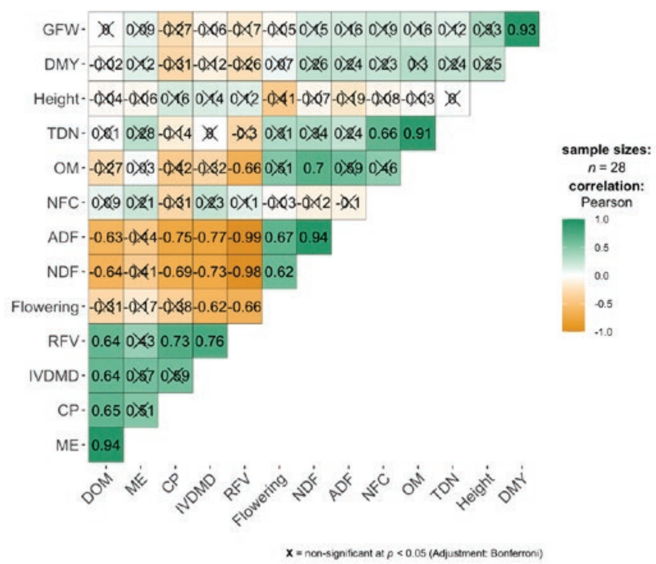

Figure 2. Pearson correlation coefficients among agronomic, nutritional, and quality index variables in a collection of *M. maximus* established in the tropics of Colombia.

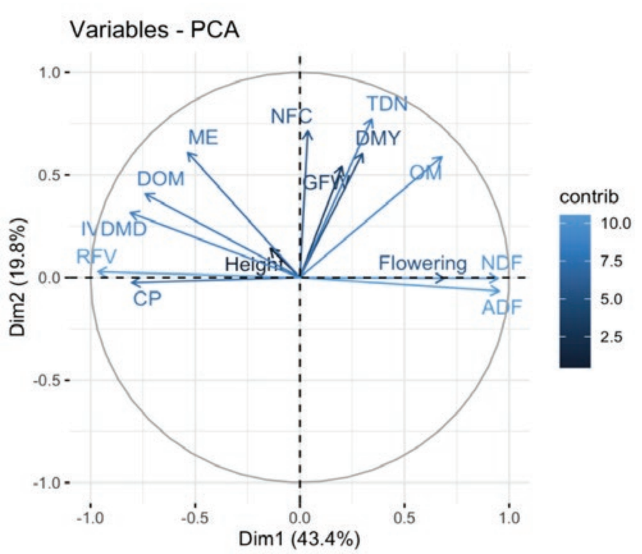

Figure 3. Biplot PCA of agronomic, nutritional, and quality variables in the classification of *M. maximus* accessions established in the Colombian tropics. DMY=dry matter yield; GFW=green forage weight; NDF=neutral detergent fiber; ADF=acid detergent fiber; CP=crude protein; OM=organic matter; DOM=organic matter digestibility; ME=metabolizable energy; IVDMD=in vitro dry matter digestibility; NFC=non-fiber carbohydrate; RFV=relative feed value; and TDN=total digestible nutrients.

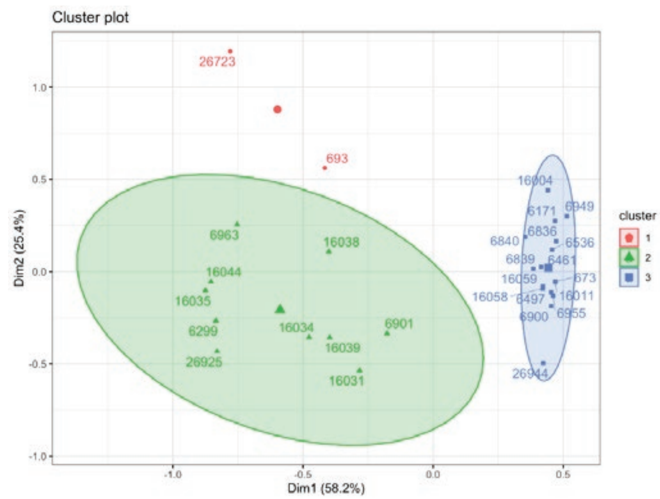

Figure 4. Cluster analysis based on principal components of a set of accessions of *M. maximus* established in the Colombian tropics.

Discussion

Yield, quality and cutting interval of tropical grasses (Mwendia et al. 2022) are fundamental parameters for evaluating the performance of forage accessions for sustainable intensification of cattle production. Results from the evaluation suggested good agronomic adaptation for Accessions 6497, 6840, 16031 (Tanzania), 16035, 16059 and 26723 with adequate DMY and good forage energy value.

The flowering composition of grasslands is modulated by their phenological stage and rainfall (Ferner et al. 2015). In the Patía Valley, flowering is not seasonal and occurs from 40 to 60 days after grazing depending on climatic conditions, being faster in dry periods than in rainy periods (Carvajal-Tapia et al. 2021a). The relationships among the variables and their distribution demonstrate the negative influence of structural carbohydrates and flowering on nutritional quality. Flowering was positively correlated with NDF and ADF concentrations and negatively associated with IVDMD and RFV, reducing grass nutritional value (Seepaul et al. 2016), possibly by reduction in metabolism (Costa et al. 2017) and association with physiological aspects related to the maturation process of forage (Vranić et al. 2009). Accessions with early flowering had a lower index of RFV, similar to that found in *Bulbous barley* (Uzun 2010). This suggests that late-flowering accessions have higher quality than earlier-flowering accessions after 41 days of regrowth. Twelve of the 28 accessions studied were late flowering (Clusters 1 and 2) and 16 accessions were early flowering (Cluster 3). RFV is an indicator of forage quality and is related to digestibility parameters (IVDMD) (Akdeniz et al. 2019) and fiber concentration (Escobar et al. 2020) and is obviously related to stage of maturity (Jeranyama and Garcia 2004; Seydosoglu and Bengisu 2019), the percentage of flowering at harvest and fodder intake. The range observed for RFV (67.2–86.6) shows values higher than those reported by Keba et al. (2013) and for most tropical grasses (Mwendia et al. 2017) and are similar to those reported for temperate Festuca species (Akdeniz et al. 2019). This indicates that *M. maximus*, under the edaphoclimatic conditions of the Patía Valley agroecosystem, is an outstanding species for its quality indices.

Plant height has high heritability and is a good in situ indicator of biomass components (green fresh weight and dry matter yield) of *M. maximus* (Carvajal-Tapia et al. 2022). This is a morphological characteristic associated with tolerance of shade (Malaviya et al. 2020), which is related to grass adaptation and growth under silvopastoral arrangements or grass-legume associations. Plant height ranged from 106.0 to 160.7 cm, similar to those presented by Malaviya et al. (2020) (94.3–153.3 cm), which suggests that the set of accessions evaluated have adequate yield for use in silvopastoral systems. Forage yield is important for farmers and Accessions 693 and 26723 were identified as promising by Carvajal-Tapia et al. (2022), during evaluations over 2 years in different harvests under contrasting rainfall conditions. In addition to their high production, these accessions have adequate nutritional quality with low values of NDF and ADF and high IVDMD, ME and RFV. A similar result was reported by Carvajal-Tapia et al. (2021a), from the nutritional classification of 129 accessions of *M. maximus*.

CP concentration had a positive correlation with RFV and a negative correlation with NDF and ADF, similar to results from other research on tropical forages (Musco et al. 2016), perennial temperate grasses (Uzun 2010) and legumes (Barahona-Rosales 1999). Protein and fiber concentrations are important for reducing enteric emissions (Barahona-Rosales and Sánchez-Pinzón 2005; Rivera-Herrera et al. 2017). Greater metabolizable energy availability from forage (Pell and Schofield 1993), higher digestibility and superior quality are characteristics associated with greater feed efficiency (Akdeniz et al. 2019) and late or limited flowering (Espinoza-Canales et al. 2017). Therefore, accessions of Clusters 1 and 2 can be considered as having potential for improving animal diets and meeting ruminant dietary requirements. Accessions CIAT 693, 6299, 16031, 16034, 16038 and 16044 from Clusters 1 and 2 are accessions were classified as promising for productive, nutritional and environmental parameters (Carvajal-Tapia et al. 2021b).

Commercial varieties such as Tanzania and Tobiata grouped in Cluster 2 and showed similar nutritional quality to but different yields from those reported by Villegas et al. (2020) and Carvajal-Tapia et al. (2021a), when evaluated under greenhouse and field conditions. This indicates that edaphoclimatic conditions have more influence on agronomic characters than on nutritional characters in this species. Clusters 1 and 2 included *M. maximus* accessions with promising nutritional quality under tropical dry forest edaphoclimatic conditions, while Cluster 3 included accessions with high NDF and ADF contents and early flowering.

Conclusions

Flowering, fiber concentrations, digestibility and crude protein concentrations are variables that have marked influence on the classification of *M. maximus* accessions evaluated, including commercial varieties with high nutritional quality (693 and 26723) and biomass yields (>4,000 kg/ha). Accessions with low quality and high average DMY of 6,452 kg/ha were also identified. Heterogeneity in nutritional and agronomic characters will facilitate their use in plant-breeding to develop elite genotypes that promote development of eco-efficient livestock production systems. Among the agronomic variables, flowering behavior is equal to or more important than forage production because of its influence on nutritional quality. Researchers are encouraged to study the physiological behavior of accessions under tropical environmental conditions during grass evaluation.

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