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Classification of Megathyrsus Maximus Accessions Grown in the Colombian Dry Tropical Forest by Nutritional Assessment During Contrasting Seasons

Juliana Isabel Carvajal-Tapia [1]*, Johanna Mazabel [2] and Nelson Jose Vivas-Quila [3]

[1] National Open and Distance University, CEAD, Popayán, Colombia, [2] Alliance Bioversity International and CIAT, Cali, Colombia, [3] Agricultural Nutrition Research Group, NUTRIFACA, School of Agricultural Sciences, University of Cauca, Popayán, Colombia

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***Correspondence:**
Juliana Isabel Carvajal-Tapia
jicarvajal@unicauca.edu.co;
juliana.carvajal@unad.edu.co

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The diversity and use of tropical forages for cattle feeding are the protagonists in livestock systems. The production and nutritional quality of forages represent a strategy of continuous research in animal feeding to help mitigate the environmental impact generated by tropical livestock. The objective of this study was to classify the nutritional behavior in contrasting seasons and the relationship with agronomic traits of a collection of 129 CIAT (Centro Internacional de Agricultura Tropical) accessions of *Megathyrsus Maximus* established in the Colombian dry tropics. By means of the near-infrared reflectance spectroscopy (NIRS) technique, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and *in vitro* dry matter digestibility (IVDMD) were determined under rainy and dry seasons as fixed effects. We measured plant height, dry matter biomass (DMB) and flowering in field. Aspects such as plant height and DMB did not show correlation with nutritional aspects, whereas flowering was correlated with the content of structural carbohydrates. Despite genotype and precipitation affecting nutritional value, there is relative nutritional steadiness in NDF, ADF, and IVDMD between seasons for some accessions. According to the cluster analysis carried out for each season, it was evidenced that from the total collection, 51.2% of the accessions during the dry season and 19.4% of the accessions during the rainy season were classified with a better nutritional profile, thus, showing a higher number of materials with better nutritional behavior in the dry season. Both the genotypic characteristics of *M. maximus* and environmental conditions during contrasting seasons are factors that might influence the variability of the nutritional content, productive parameters, and flowering. Additionally, fodder material classification under Hotelling's T-squared test and Nutritional Classification Index suggests accessions that might be promising for resilient nutritional quality and adequate DMB, which proves that *M. maximus* could become an alternative for animal feeding and sustainable livestock production during critical dry periods in tropical agroecosystems.

Keywords: forages, grassland, Guinea grass, livestock, *Panicum*

INTRODUCTION

The expansion of the agricultural frontier with crops and pastures in tropical regions of developing countries for food production requires implementing production strategies with an eco-efficient focus to sustainably meet the increasing demand for food (Rao, 2013).

The major part of livestock activity in intertropical regions is carried out under grazing systems and mixed model systems (concentrated pastures), (Gerber et al., 2015). Food for these livestock systems based on pastures is developed through the production of forages, which depends on the rainfall pattern (Castañeda et al., 2015; Gándara et al., 2017; Marcillo et al., 2021), which is influenced by the consequences of climate change. The instability in forage production brings along with it an increase in production costs because of the use of supplements (concentrates), (Morales-Vallecilla and Ortiz-Grisales, 2018) and nutritional variables that influence productivity (Cooke et al., 2020), thus, compromising both cattle feeding efficiency and the sustainable management of herds (Paul et al., 2020).

The diversity and use of tropical forages for livestock feeding are protagonists in tropical livestock systems. Characteristics such as biomass yield and nutritional quality depend on genetics, environment, and some other factors (Paul et al., 2020). Investigating and evaluating these characteristics will contribute to the development of forages adapted to the specific edaphoclimatic conditions of the tropics and identifying genotypes capable of producing "more with less," which, according to Rao (2013), is important for advancing toward an eco-efficient livestock system.

Megathyrsus maximus–Panicum maximum (Cook and Schultze-Kraft, 2015) is an African species that has been widely distributed in the warm areas of Colombia. Under edaphoclimatic conditions of the Colombian dry tropical forest, the response in terms of production is adequate during low-precipitation periods. Also, this grass has short recovery periods, tolerance of shade and moderate drought periods, tolerance of short flooding periods (Morales-Velasco et al., 2016; Matínez-Mamian et al., 2020), and an adequate response in association with forage legumes (Matínez-Mamian et al., 2020) and with silvopastoral systems (Barragán-Hernández and Cajas-Girón, 2019). This grass is promising for environmental management of cattle because of its potential for biological nitrification inhibition (IBN), (Carvajal-Tapia et al., 2021) and is outstanding for its nutritive value, perenniality, and adaptive potential, and for showing diversity among cultivars in terms of yield, forage quality, and response to nutrient fertilization (Benabderrahim and Elfalleh, 2021).

The nutritional quality of *M. maximus* in terms of protein and fiber content, and digestibility, has a wide range of values generated by different edaphoclimatic, genotypic, and management conditions. The attributes of adaptation to edaphoclimatic limitations, forage quality, and seed production facilitate the development of superior cultivars in current grass breeding activities (Rao, 2013). However, identifying the nutritional behavior of the species in a potential livestock area can help to find a versatile feeding alternative for the establishment and development of eco-efficient livestock production or to select material with improved fodder quality (Ramakrishnan et al., 2014).

The nutritional quality and association with the productive parameters of a broad range of accessions of *M. maximus* in Colombian tropical regions have not been described in detail or correlated with climatic factors. This is a relevant aspect in the identification of resilient forage species, particularly for the agricultural sector that faces the consequences of climate change. Therefore, we propose the hypothesis that the rainfall pattern that determines two contrasting seasons (rainy and dry) in tropical regions influences not only the agronomic behavior of the collection of *M. maximus* but also the nutritional composition and at the same time can be related to the productive variables of forages.

NIRS (near-infrared reflectance spectroscopy) is a fast and accurate technique with an eco-friendly technology to diagnose the nutritional quality of tropical forages (International Organization for Standardization ISO 12099:2017., 2017; Parrini et al., 2018; Mazabel et al., 2020). Since 2015, the CIAT forages and animal nutrition quality laboratory has worked on the development of NIRS predictive models, in particular, for neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), and *in vitro* dry matter digestibility (IVDMD) for tropical forages.

With the purpose of helping to identify promising forage crops for tropical areas and to classify potential germplasm for smallholder farmers or plant breeding programs, the object of this study was to classify the vegetative material of *M. maximus* established in the Colombian dry tropics according to nutritional behavior using NIRS methodology during contrasting seasons and the relationship with plant height, forage production, and flowering with nutritional quality.

MATERIALS AND METHODS

Location

The experiment was conducted in a tropical dry forest agroecosystem in the Patía Valley, which is located in the department of Cauca in southwestern Colombia, with an average temperature of 27.9°C and bimodal cycle with average annual precipitation of 1,414 mm (**Figure 1**). To guarantee the process of establishing experimental plots, we used water irrigation and mechanical weed control.

The local soil is a medium-fertility Mollisol. Chemical analysis in the 0-to 20-cm layer showed pH of 6.26, organic matter content of 4.50%, phosphorus content of 6.3 ppm, and calcium, magnesium, and potassium content of 14.58, 6.91, and 0.59 cmol/kg, respectively. 1 year after establishment of the experimental plots, we applied fertilizer only once at a rate of 150 kg N/ha and 95 kg P/ha.

Experimental Design in Fields

For the agronomic and nutritional evaluation in December of 2015, 129 accessions of *M. maximus*, including commercial varieties provided by the germplasm bank of the International Center for Tropical Agriculture (CIAT) and two improved

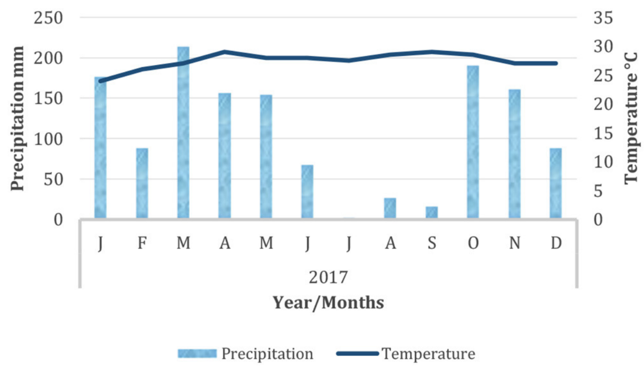


FIGURE 1 | Average temperature values and rainfall accumulation during experiments in field trials. Coordinates: N: 1°59′13″; W: 77°5′57′′, Patía Valley. Source: NUTRIFACA Weather Station, 2016–2018.

TABLE 1 | Centro internacional de agricultura tropical (CIAT) accession numbers and origin of evaluated *Megathyrsus maximus* and commercial cultivars.

Origin	CIAT accessions
Kenya	622, 688, 691, 692, 693, 6,526, 6,536, 6,571, 6,890, 6,891, 6,893, 6,897, 6,898, 6,900, 6,901, 6,903, 6,906, 6,912, 6,915, 6,918, 6,923, 6,981, 6,982, 6,983, 6,984, 6,986, 6,990, 6,996, 16,003, 16,004 y 16,005
Tanzania	6,927, 6,928, 6,929, 6,944, 6,945, 6,948, 6,949, 6,951, 6,954, 6,955, 6,960, 6,963, 6,967, 6,968, 6,969, 6,975, 16,011, 16,017, 16,018, 16,019, 16,021, 16,023, 16,025, 16,027, 16,028, 16,034, 16,035, 16,036, 16,038, 16,039, 16,041, 16,044, 16,046, 16,048, 16,049, 16,051, 16,054, 16,055, 16,057, 16,058, 16,059, 16,060, 16,061, 16,062, 16,064, 16,065, 16,068, 16,069 y 16,071
Unknown	673, 685, 6,094, 6,095, 6,171, 6,175, 6,461, 6,497, 6,500, 6,501, 6,525, 6,658, 6,784, 6,787, 6,796, 6,799, 6,805, 6,831, 6,836, 6,837, 6,839, 6,840, 6,842, 6,843, 6,855, 6,857, 6,864, 6,866, 6,868, 26,723, 26,906, 26,911, 26,917, 26,923, 26,924, 26,925, 26,936, 26,937, 26,939, 26,942, 26,944 y 26,947
Ivory Coast	6,872
Rwanda	26,360
Commercial	6,962 Mombasa, 6,826 Coloniao, 16,031 Tanzania, 6,299 Tobiatá, 26,900 Vencedor y Massai

Urochloa species (*U. brizantha* cv. Toledo and hybrid cv. Cayman) as controls (**Table 1**), were established in plots using a randomized complete block design with three replications. The experimental units (plots) measured 4 m^2, and the plants had 10–12 tillers. The distance between plots was 1 m, and the distance between blocks was 2 m (**Figure 2**).

To determine the number of regrowing days and provide homogeneous conditions for all accessions, a standardization cut was applied. It was a mechanical cutting of plots at a residual height of 30 cm above the soil. Seasonal conditions in the field area and harvesting age are shown in **Table 2**.

We measured (a) plant height according to the methodology of Toledo and Schultze-Kraft (1982) and (b) flowering (FW). We used observations and calculated the percentage of flowering present in the experimental plot in a range of 0–100% at the time of evaluation. For dry matter biomass (DMB), we estimated the availability of green forage (GF) after cutting at the height of 30 cm from the ground and measuring the weight per plot in the field. Out of all the GF, we weighed subsamples of ∼200 g. These were dried in an oven with controlled ventilation at a temperature of 60°C (140°F) until reaching constant weight (48 to 72 h). With the final weight of the subsamples, we estimated dry matter.

Near-Infrared Reflectance Spectroscopy Testing in the Laboratory

The subsamples obtained in the field to determine DMB were analyzed in the CIAT forages and animal nutrition quality laboratory, where they were pulverized using a Retsch SM 100 (Retsch GmbH, Haan, Germany) with a 1-mm bottom screen. For NIRS processing, we used a Foss 6,500 model and ISIS software (IS-2,250) version 2.71 (FOSS and Infrasoft International, USA, 2005). For each sample, duplicates of the spectra were taken in separate quartz cells of 3.5-cm internal diameter and 1-cm thick. The wavelength range was from 400 to 2,500 nm.

The values obtained through wet chemistry were used to build chemo metric models (Mazabel et al., 2020) and generate predictive equations in NIRS. Chemical analyses were performed in duplicate for each accession in both seasons (rainy and dry) under the guidelines of the 21st edition of the Official Methods of Analysis of (AOAC International, 2002). Crude protein content was determined using the FOSS Kjeltec^{TM} 8,100 (Foss Company, HillerØed, Denmark). An ANKOM 2,000 fiber analyzer (ANKOM Technology Corporation, Macedon, NY, USA) was used for NDF and ADF (Van Soest et al., 1991) and for IVDMD (Tilley and Terry, 1963).

The results of the reference chemical analysis and the spectral signals of each sample were processed using Win ISI software version 4.0. Then, the results were incorporated in equations generated at the CIAT forages and animal nutrition quality laboratory, as follows: R^2 of 0.93, 0.98, 0.85, and 0.98 and standard error for cross validation (SECV) of 2.11, 1.22, 2.78, and 0.61 for NDF, ADF, IVDMD, and CP, respectively (Molano et al., 2016). This increases the action range and accuracy of the model.

Data Analysis

Descriptive statistics and Pearson correlation coefficient for every season were obtained with SAS Statistical Software (Statistical Analysis System) version 9.4 (2018) (SAS, 2016). Figure of correlation was obtained with package corrplot in R (Wei and Simko, 2017). Cluster analysis was used, and principal components were calculated using the library "FactoMineR" and package "Factoextra" (Kassambara and Mundt, 2020) with the variables NDF, ADF, CP, and IVDMD for every season. Figures were created in R using the package "ggplot2" (Wickham, 2016). Wilcoxon sum rank test was used to compare differences between means in terms of the season for each of the variables in R version 4.0.3 (R Core Team, 2020).

To find a classification index for the fodder material according to nutritional content, multicriteria weighted indices were adapted (Contreras et al., 2004). To obtain a level

FIGURE 2 | Aerial view of the field experimental design. R, replications.

TABLE 2 | Seasonal conditions and plant harvesting parameters for agronomy and nutritional evaluation in the Patía Valley, Cauca, Colombia.

Season	Plant harvesting parameter		Period of evaluation from	Temperature (°C)			Humidity average %	Total precipitation (mm)
	Regrowing	Average height (cm)		Minimum	Maximum	Average	Average	
Rainy	6 weeks or 41 days	130.7	March 24 to May 4, 2017	21.5	31.8	26.7	77	172.1
Dry	8 weeks or 55 days	55.2	June 30 to August 24, 2017	19.6	36.1	27.8	61.7	22.8

of classification, a value was assigned to each variable considering the relative importance with regard to nutritional assessment of CP, NDF, ADF, and IVDMD in consumption, use, and rumen degradability-diet composition (Van Soest, 1982; Barahona-Rosales and Sánchez-Pinzón, 2005). The Nutritional Classification Index was calculated as follows:

NCI = (IVDMD R *8 + IVDMD D *7 + CP R *6 + CP D *5 + NDF R*4 + NDF D *3 + ADF R*2 + ADF D *1)/8,

where NCI is the Nutritional Classification Index, IVDMD R is the *in vitro* dry matter digestibility rainy season, IVDMD D is the IVDMD dry season, CP R, is the crude protein rainy season, CP D is the CP dry season, NDF R is the neutral detergent fiber rainy season, NDF D is the NDF dry season, ADF R is the acid detergent fiber rainy season, and ADF D is the ADF dry season.

To select accessions without significant changes in nutritional composition in the evaluation from one season to the next, the Hotelling T-squared test was performed using the Hotelling library and package corpcor in R (Schafer et al., 2017).

RESULTS

The contrasting seasons present in the Colombian dry tropics might explain the differences found in this research regarding the agronomic and nutritional behavior of *M. maximus*. Flowering, plant height, BDM, and CP decreased during the dry season compared with the rainy season at 64.8, 57.8, 43.1, and 27.7%, respectively (**Table 3**). Low precipitation, the lowest relative humidity, and the highest temperature (**Table 2**) were determining factors for the changes observed mainly in the agronomic variables. The average NDF, ADF, and IVDMD contents of the *M. maximus* collection differ from 1 to 2% from one season to the other. The Wilcoxon test for comparison of means indicates statistical differences when the accessions are under different rainfall conditions (**Table 3**).

Commercial cultivars of *M. maximus* show a similar nutritional behavior as the rest of the studied collection. During the dry season, NDF content increased slightly except in

TABLE 3 | Descriptive statistics and significance between seasons of the nutritional composition and agronomic traits of a collection of *Megathyrsus maximus* in Colombian dry tropical.

Variable	Season	$\bar{x}$	Median	SD	Minimum	Maximum	*p*-value
NDF (%)	Rainy	66.5	66.5	1.47	63.2	70.7	0.00118
	Dry	67.2	67.1	2.17	62.1	74.0	
ADF (%)	Rainy	39.2	39.0	1.48	35.3	42.6	0.00000
	Dry	38.3	38.2	1.54	34.7	44.0	
CP (%)	Rainy	10.1	10.1	0.95	7.6	13.9	0.00000
	Dry	7.3	7.3	0.98	4.9	10.5	
IVDMD (%)	Rainy	57.9	58.0	2.13	52.3	62.6	0.00126
	Dry	59	59.2	2.78	50.0	65.3	
Height (cm)	Rainy	130.7	132.7	19.27	74	163.3	0.00000
	Dry	55.2	55.0	7.87	35	76.7	
Biomass (t/ha)	Rainy	5.8	5.6	1.42	2.5	9.5	0.00000
	Dry	3.3	3.2	0.79	1.6	5.3	
Flowering (%)	Rainy	76.2	100	34.19	34.1	100	0.00000
	Dry	26.8	20	25.78	0	100	

NDF, neutral detergent fiber; ADF, acid detergent fiber; CP, crude protein; IVDDM, in vitro digestibility of dry matter.

Mombasa, Massai, and Coloniao. In contrast, ADF content decreased, except in Tanzania. Tanzania shows higher CP content and the lowest NDF y ADF content during the rainy season. Mombasa and Coloniao stand out for featuring the lowest NDF and ADF content during the dry season. Vencedor and Coloniao showed high IVDMD during the rainy season and Mombasa in the dry season (**Figure 3**).

Analysis using Pearson's correlation coefficient shows that different degrees of associativity exist, highlighting values highly significant and superior ($r \geq 0.3$). Among the agronomic measurements, plant height is directly related to DMB in a positive manner ($r = 0.41$ and 0.48, rainy and dry season, respectively), whereas with flowering, it is related in a negative manner in the rainy season ($r = 0.39$). This could be interpreted as a high forage yield being estimated for the tall accessions in the rainy season during 42 days, and not presenting flowering or having low flowering upon finalizing the cutting period.

The positive relationship existing between flowering and structural carbohydrate content is evidenced in the two seasons. This suggests that physiological traits such as flowering could have a stronger relationship with the nutritional parameters in the *M. maximus* collection under the edaphoclimatic conditions of the Colombian dry tropical forest. Likewise, in **Figure 4**, a higher degree of associativity is noted among the traits estimated in the nutritional evaluation.

In both seasons, the structural carbohydrate content of *M. maximus* influenced CP content in a negative manner. The correlation is higher for ADF content.

In the rainy season, ADF ($r = 0.65$) shows a moderate and negative correlation with IVDMD, higher than when we refer to NDF ($r = 0.49$). NDF and ADF have an evident positive correlation, resulting from the use of NDF content in the ADF calculation (**Figure 4**).

For the cluster analysis, three clusters (Cl) were defined (**Table 4** and **Figure 5**) considering the degree of resemblance in specific characteristics of the accessions for each cluster. For both seasons, the best nutritional composition corresponds to accessions of Cl 1; some accessions and material of genus *Urochloa* have lower NDF and ADF and higher CP and IVDMD, contrary to what Cl3 shows, with accessions having lower nutritional *content* with higher NDF and ADF and lower CP. Cl2 materials are characterized by having an intermediate composition between Cl1 and Cl3 (**Tables 4**, **5**). In dry and rainy seasons, 51.2 and 19.4% of the collection, respectively, stands out for its nutritional profile. Therefore, a higher number of accessions have a great nutritional profile during the dry season in the tropics and are available for further study.

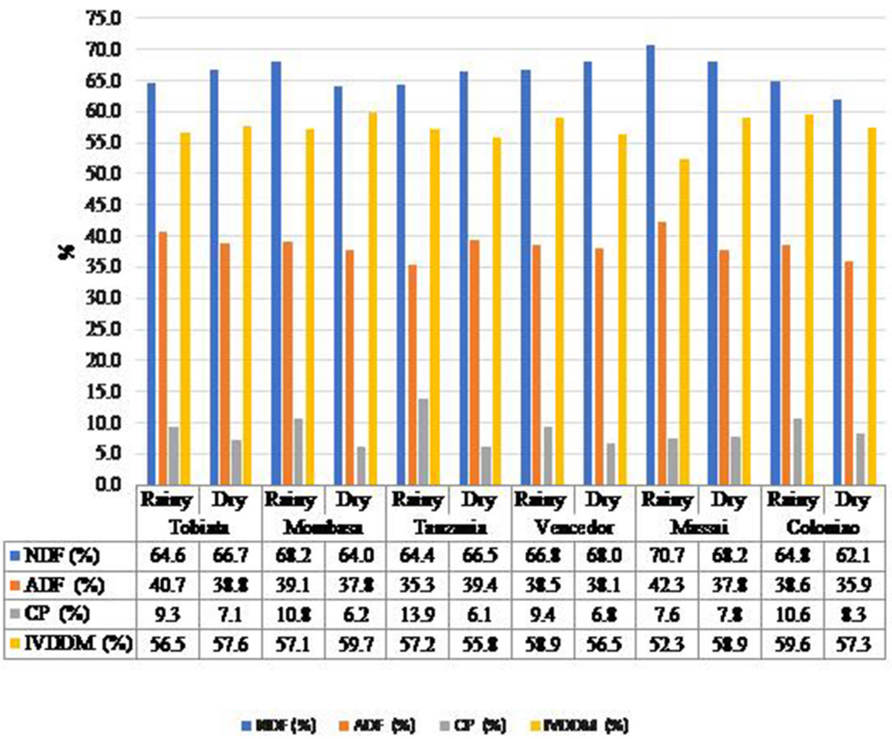
The distribution of the clusters (**Figure 5**) shows the description of the correlations and the different nutritional behavior from *Megathyrsus* and *Urochloa* species, during both seasons. Also, during the rainy season, the response of Tanzania stands out.

In each season, the following accessions stand out for being part of the 41.9% of the collection with DMB above average at 5.9 and 3.4 t/ha in the rainy and dry season, respectively, and being classified in the cluster with the best nutritional profile (Cl).

In the rainy season, accessions CIAT 6,501, 6,842, 6,868, 16,004, 16,023, 16,048, 16,062, 16,071, and 26,723 stand out; in the dry season, accessions CIAT 693, 6,171, 6,497, 6,658, 6,836, 6,891, 6,898, 6,903, 16,005, 16,011, 16,025, 16,027, 16,034, 16,035, 16,036, 16,038, 16,039, 16,044, 16,049, 16,058, 16,059, 26,936, 26,937 and Massai stand out.

For the NCI, the highest indices correspond to accessions 685 (199.05) and 6,864 (197.30), belonging to Cl1 in both seasons. Accession CIAT 26,911 had one of the highest values for NDF, also standing out for its value in NCI (198.91).

On the other hand, Hotelling's multivariate T-squared test showed that accessions 6,968, 26,360, and 26,947 did not feature



	Rainy Tobiata	Dry Tobiata	Rainy Mombasa	Dry Mombasa	Rainy Tanzania	Dry Tanzania	Rainy Vencedor	Dry Vencedor	Rainy Massai	Dry Massai	Rainy Colonião	Dry Colonião
NDF (%)	64.6	66.7	68.2	64.0	64.4	66.5	66.8	68.0	70.7	68.2	64.8	62.1
ADF (%)	40.7	38.8	39.1	37.8	35.3	39.4	38.5	38.1	42.3	37.8	38.6	35.9
CP (%)	9.3	7.1	10.8	6.2	13.9	6.1	9.4	6.8	7.6	7.8	10.6	8.3
IVDDM (%)	56.5	57.6	57.1	59.7	57.2	55.8	58.9	56.5	52.3	58.9	59.6	57.3

FIGURE 3 | Comparative analysis between commercial cultivars of *Megathyrsus maximus* in terms of CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVDMD, *in vitro* dry matter digestibility.

significant changes from the rainy to dry season in NDF, ADF, CP, and IVDMD, and their NCI surpassed 189.94.

Discussion

Edaphoclimatic stress factors are abiotic indicators that become important in the search for forage material adapted for intensive production in a sustainable manner (Rao, 2013). In the Patía Valley region, a representative dry tropical agroecosystem, the evaluations set up in this research during contrasting seasons allowed us to compare the agronomic and nutritional behavior of a collection of *M. maximus*, helping to identify physiological mechanisms and the association of flowering with nutritional traits, which contributes to the selection of interesting traits. This provides tools so that breeding programs can broaden their research when seeking forage material resilient to climate change.

Plant height, flowering, DMB and crude protein of the collection were higher during the rainy season, contrasting with stress, growth, and production limitations during the dry season (Hare et al., 2015), which indicates that the water supply favors agronomic characteristics and protein content (Larsen et al., 2021). Weather characteristics have an effect on agronomic and nutritional parameters for *M. maximus* (Machado, 2013; Lemos et al., 2017; Maranhão et al., 2021; Marcillo et al., 2021).

Productive Measurements and Flowering

The mean values for plant height and DMB reached by the *M. maximus* germplasm were similar and superior to those registered in other tropical regions (Machado, 2013; Benabderrahim and Elfalleh, 2021), with fertilization (Braz et al., 2017) or higher rainfall (Macedo et al., 2017).

Studies with commercial varieties suggest that, at 70-to 90-cm height, a higher quantity of biomass is generated with adequate grassland recovery for the next grazing (Soares Filho et al., 2015; Carvalho et al., 2017). In the rainy season, the entire collection reached the mínimum value of the range; whereas, in the dry season, this was obtained only by accessions 16,035, 691, 6,982, 6,960, and 6,915 (**Supplementary Material**). For DMB, an important variable for adoption processes by farmers in tropical countries (Mwendia et al., 2019), the mean and maximum values (5.8 and 9.5 t/ha, respectively) of the collection during the rainy season were similar to those reported in previous studies in the same zone with commercial cultivars (6.3 and 9.8 t/ha, every 45 days) (Vivas-Quila et al., 2015). In spite of the dry season, the average and maximum values of DMB declined notably (3.3 and 5.3 t/ha, respectively). The values obtained were also higher than those obtained with naturalized species in the Patía Valley region, and in different tropical regions such as Brazil (Macedo et al., 2017) and Cuba (Machado, 2013). These values were improved only in Thailand with nitrogen fertilization (Hare et al., 2015). In addition, the positive correlation between plant height and DMB (**Figure 4**) might indicate that the evaluated collection presents adequate DMB yield under the edaphoclimatic conditions of the Patía Valley.

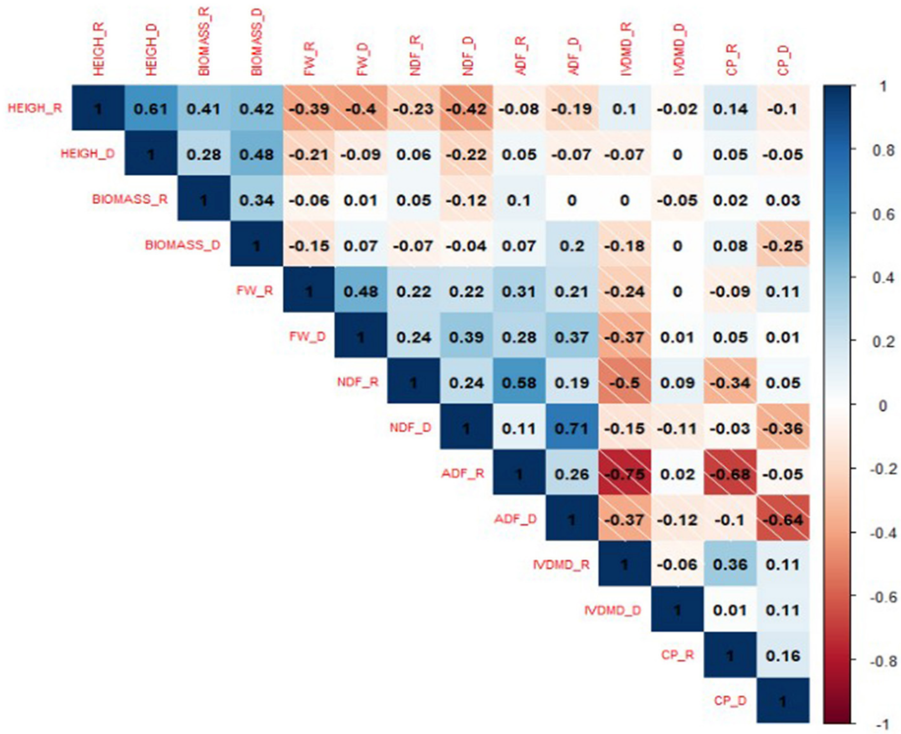


FIGURE 4 | Correlograms with Pearson coefficient to visualize correlation among agronomic and nutritional variables of the *Megathyrsus maximus* collection in the Patía Valley of Colombia. BIOMASS_R, biomassa dry matter in rainy season; BIOMASS_D, biomassa dry matter in dry season; Heigh_R, in rainy season; Heigh_D, in dry season; FW_R, flowering in rainy season; FW_D, flowering in dry season; NDF_R, neutral detergent fiber in rainy season; NDF_D, neutral detergent fiber in dry season; ADF_R, acid detergent fiber in rainy season; ADF_D, acid detergent fiber in dry season; CP_R, crude protein in rainy season; CP_R, in dry season; IVDMD_R, *in vitro* dry matter digestibility in rainy season; IVDMD_D, *in vitro* dry matter digestibility in dry season.

TABLE 4 | Nutritional behavior per cluster in a *Megathyrsus maximus* collection during rainy and dry seasons in Colombian dry tropical forests.

Cluster	Number of accessions		NDF (%)		ADF (%)		CP (%)		IVDMD (%)	
	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
1	25	66	64.7 ± 1.6c	65.9 ± 1.7c	37.0 ± 1.4c	37.2 ± 1.1c	11.4 ± 0.7a	8.0 ± 0.8a	59.9 ± 1.7a	60.2 ± 2.0a
2	55	30	66.6 ± 1.3b	67.4 ± 1.8b	38.6 ± 0.7b	38.6 ± 1.0b	10.0 ± 0.7b	7.1 ± 0.6b	59.0 ± 1.0b	55.9 ± 1.9c
3	51	35	67.4 ± 1.1a	69.5 ± 1.9a	40.6 ± 0.8a	40.2 ± 1.3a	9.5 ± 06c	6.4 ± 0.6c	55.8 ± 1.3c	60.0 ± 1.9b

Note. NDF, neutral detergent fiber; ADF, acid detergent fiber; CP, crude protein; IVDDM, in vitro digestibility of dry matter. Different letters denote statistical differences according to analysis of variance and Tukey HSD test (α = 0.05).

Megathyrsus maximus is usually described as drought resistant (Rodríguez et al., 2017) with adaptation to varied edaphoclimatic conditions because of its clumps and strong root system (Kissmann and Groth, 1995; Benabderrahim and Elfalleh, 2021). However, it expresses its productive potential during the rainy season. Under the edaphoclimatic conditions of the Patía Valley and during the rainy period, it is possible to consider a recovery period of about 35 days, and it is advised to consider irrigation during the dry season to reach the potential of the species.

Flowering is a determining variable for plant breeding technology adoption processes. It is related to forage yield (Casler et al., 2018; Casler, 2019). Flowering determines nutritional composition (Gusha et al., 2019), specifically in this research with NDF and ADF content and persistency in the field. Light intensity might also affect flowering (Tavares de Castro and Carvalho, 2000). During the dry season, no flowering occurred, or it was lower than 10% for accessions: 622, 688, 693, 6,094, 6,175, 6,299 Tobiatá, 6,497, 6,500, 6,525, 6,658, 6,796, 6,837, 6,857, 6,868, 6,897, 6,901, 6,906, 6,918, 6,923, 6,927, 6,928, 6,948, 6,962, 6,963, 6,968, 16,003, 16,017, 16,023, 16,027, 16,028, 16,034, 16,035, 16,036, 16,038, 16,039, 16,048, 16,049, 16,051, 16,055, 16,061, 16,062, 16,069, 16,071, 26,360, 26,900 vencedor, 26,906, 26,923, 26,924, 26,925, 26,937, and 26,939 (39.5% of the collection), and during the rainy season for accessions 6,299 Tobiatá, 6,962 Mambasa, 6,963, 16,027, 16,028, 16,035, 16,044, 16,051, 16,061, 16,069, 16,071, 26,723, and 26,925.

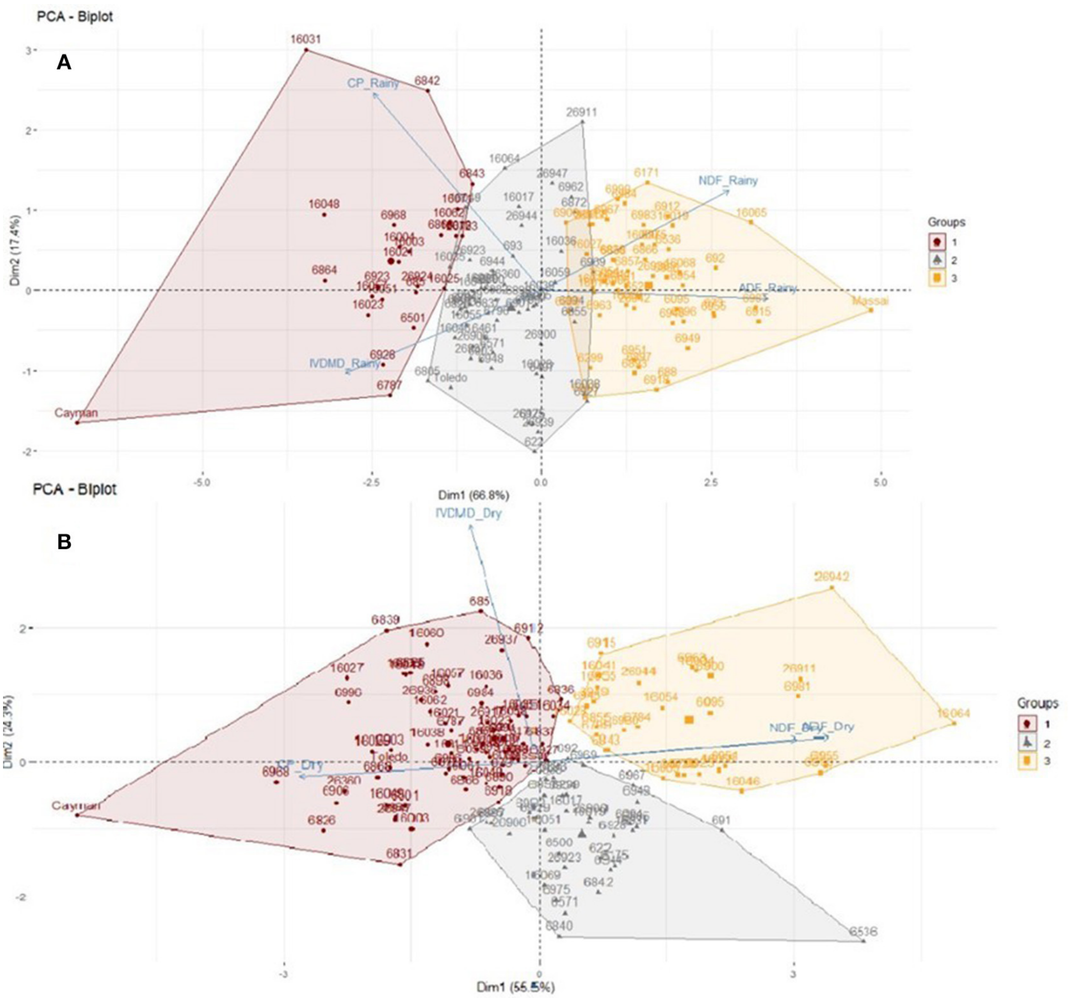


FIGURE 5 | Cluster analysis based on principal components of the germplasm collection of *Megathyrsus maximus*. Cumulative variance accounts for 86 and 80% for the rainy and dry season, respectively. ADF, acid detergent fiber; CP, crude protein; IVDMD, *in vitro* dry matter digestibility; NDF, neutral detergent fiber. **(A)** Rainy season. **(B)** Dry season.

Flowering was the variable that declined the most when it was evaluated in the dry season vis-à-vis the rainy season. Lower flowering in germplasm during the dry season despite better light conditions in the tropics could be associated with hydric stress (Wilson and Ng, 1975) and high evaporation, with the possibility that this could generate a negative hydric balance for forage production and the production process of grasses (Rao, 2013). According to (Atencio Solano et al., 2018) , there is an evident effect of the dry season on vegetative development, which influences flowering of the species. This matches the negative correlation between flowering and plant height in the rainy season ($r = 0.39$).

Nutritional Composition

Factors such as management, regrowth age, fertilization, cut height, phonological aspects, growth under shade, and season might have a significant effect on the nutritional value of forages (Van Soest, 1982; Velásquez et al., 2010; Santiago-Hernández et al., 2016; de Vasconcelos et al., 2019; Schnellmann et al., 2020; Tesk et al., 2020), which affects digestibility in animals (Valente et al., 2010). Variability in structural carbohydrates (NDF, ADF) in the *M. maximus* collection might be influenced by characteristics related to the accessions' own physiological and metabolic aspects such as the conversion efficiency of nitrogen and flowering rate (dos Costa et al., 2017), which might generate a wide range of available accessions and could be used in plant breeding programs (Deo et al., 2020) to produce or select materials with the best IVDMD (Barahona-Rosales and Sánchez-Pinzón, 2005).

The protein content decline during low precipitation periods, similar to that found by Larsen et al. (2021), might be caused by the lack of production of new leaves and tillers. Also, the senescent material decreases cellular content, in particular, protein (Vargas Junior et al., 2013). *M. maximus* shows a higher protein content during the rainy season and under shady

TABLE 5 | Grouping of the *M. maximus* collection by nutritional behavior in rainy and dry seasons of the Patía Valley, Cauca, Colombia.

Season	Cluster 1
Rainy	685, 6,501, 6,787, 6842, 6,843, 6,864, 6,868, 6923, 6,928, 6,968, 16,003, 16,004, 16,018, 16,021, 16,023, 16,025, 16,031, 16,048, 16,051, 16,057, 16,062, 16,071, 26,723, 26,924 and Urochloa hibrido cv Cayman
Dry	673, 685, 688, 693, 6,171, 6,461, 6,497, 6,501, 6525, 6,658, 6,787, 6,826, 6,831, 6,836, 6,837, 6,839, 6,864, 6,866, 6,868, 6,872, 6,890, 6,891, 6,898, 6903, 6,906, 6,912, 6,918, 6,927, 6,962, 6,968, 6,983, 6,984, 6,986, 6996, 16,003, 16,005, 16,011, 16,018, 16,021, 16,023, 16,025, 16,027, 16,034, 16,035, 16,036, 16,038, 16,039, 16,044, 16,048, 16,049, 16,057, 16,058, 16,059, 16,060, 16,061, 16,062, 16,071, 26,360, 26,917, 26,924, 26,936, 26,937, 26,947, Massai, Urochloa brizantha cv toledo and Urochloa hibrido cv Cayman
	Cluster 2
Rainy	622, 693, 6,094, 6,175, 6461, 6,497, 6,500, 6,571, 6,784, 6,796, 6,799, 6,805, 6,826, 6,831, 6,837, 6,839, 6,855, 6,872, 6,890, 6,901, 6,903, 6,927, 6,929, 6,944, 6,948, 6,960, 6,962, 6,969, 6,982, 16,005, 16,017, 16,028, 16,034, 16,035, 16,036, 16,038, 16,039, 16,044, 16,046, 16,049, 16,055, 16,059, 16,061, 16,064, 26,360, 26,900, 26,906, 26,911, 26,923, 26,925, 26,937, 26,939, 26,944, 26,947 and *Urochloa brizantha* cv toledo
Dry	622, 691, 692, 6,094, 6,175, 6,299, 6,500, 6,536, 6,571, 6,805, 6,840, 6,842, 6,857, 6,893, 6,897, 6,901, 6,928, 6,929, 6,944, 6,948, 6,954, 6,967, 6,969, 6,975, 6,982, 16,017, 16,019, 16,031, 16,051, 16,069, 26,900, 26,906, 26,923, 26,925 and 26,939
	Cluster 3
Rainy	673, 688, 691, 692, 6,095, 6,171, 6,299, 6,525, 6,536, 6,658, 6,836, 6,840, 6,857, 6,866, 6,891, 6,893, 6,897, 6,898, 6,900, 6,906, 6,912, 6,915, 6,918, 6,945, 6,949, 6,951, 6,954, 6,955, 6,963, 6,967, 6,975, 6,981, 6,983, 6,984, 6,986, 6,990, 6,996, 16,011, 16,019, 16,027, 16,041, 16,054, 16,058, 16,060, 16,065, 16,068, 16,069, 26,917, 26,936, 26,942 and Massai
Dry	6,095, 6,784, 6,796, 6,799, 6,843, 6,855, 6,900, 6,915, 6,923, 6,945, 6,949, 6,951, 6,955, 6,960, 6,963, 6,981, 6,990, 16,004, 16,028, 16,041, 16,046, 16,054, 16,055, 16,064, 16,065, 16,068, 26,723, 26,911, 26,942 and 26,944

conditions (Dele et al., 2017; Barragán-Hernández and Cajas-Girón, 2019). In contrast, other authors argue that higher values for protein can be found during the dry season (Rodríguez et al., 2017).

The preservation of beef cattle is an important goal in the Patía Valley region, where animals lose weight and mortality increases because of the lack of water and good-quality feed. Considering the challenging hydric conditions of the tropical zone during the dry season, the average protein content of 7.3% and the maximum of 10.5% in *M. maximus* stand out. These nutritional values contribute to preserving rumen functionality. A relevant consideration to keep a functional rumen in bovines is the minimum required nitrogen amount equivalent to 8% of CP (Gaviria et al., 2015). Also, considering that in this region most of the plants for a complementary diet are grasses, fodder legumes, and other plants rich in protein, the contribution of *M. maximus* could be ideal to avoid a loss of rumen functionality and to support livestock production during the dry season.

A high negative correlation exists between structural carbohydrate content and digestibility (Jung et al., 1997) in the *M. maximus* collection in the rainy season. This might have incremented IVDMD by 1.86% during the dry season. Therefore, the results of this parameter highlight the potential of this species as an alternative during low-precipitation periods, for both biomass production (Morales-Velasco et al., 2016) and steady relative quality.

During the dry season, Tobiatá, Mombasa, Tanzania, Vencedor, Massai, and Coloniao had protein content of 7.09, 6.24, 6.13, 6.72, 7.82, and 8.30%, respectively. These values were higher than those found in commercial cultivars in important tropical livestock areas (dos Costa et al., 2017; Silva et al., 2017; da Silva et al., 2018). However, in the same research location where this experiment took place, and with a similar number of regrowing days and average height in Massai, Ruiz et al. (2015) showed 14.20% CP. This could possibly be due to fertilization at establishment and evaluation during the rainy season.

In tropical regions of Colombia, productive differences exist between commercial cultivars and genotypes of the evaluated collection in this research, which could be associated with aspects inherent to morphology (Patiño-Pardo et al., 2018) and nutritional profile. These are advantageous characteristics in terms of adaptation to different livestock systems.

Some studies suggest that *in vitro* and *in vivo* digestibility of organic matter increases with the rainy season (Vargas Junior et al., 2013; Silva et al., 2017), and others show that water stress did not significantly affect organic matter digestibility (OMD), (Fariaszewska et al., 2020). The findings in this research suggested that ADF decreased similar to that reported by Larsen et al. (2021) and IVDMD increased slightly during the dry season vis-à-vis the rainy season. This condition might be related to the average height of germplasm of 130.7 vs. 55.2 cm during the rainy and dry seasons, respectively. Therefore, growth in height could result from a decrease in leaf material and the respective digestibility (Kalmbacher et al., 1980), and drought stress might delay maturity, which can improve the OMD of forages (Fariaszewska et al., 2020). The correlations found in the *M. maximus* collection were similar to those reported by Stabile et al. (2010) with commercial cultivars.

The classification of the accessions under multivariate tests (by cluster analysis and Hotelling's *T*-squared test) and NCI shows that the genotypic and physical characteristics specific to each accession (not included in this study) as well as morphological aspects (Santos et al., 2010), leaf-to-stem ratio (Homen et al., 2010), and maturity or metabolism rate (dos Costa et al., 2017) may have influenced the classification of materials with a low or high nutritional profile.

This classification shows that some accessions respond to prolonged tropical dry periods and possibly show promise for resilient nutritional quality with adequate DMB. In addition, *M. maximus* outperforms other forage species used for grazing under semiarid or dry tropical conditions (Coêlho et al., 2018). For a diversity of agronomic parameters and nutritional composition related to genetic aspects, *M. maximus* shows promise for breeding programs.

Agronomic and nutritional analysis, in general terms, allows us to learn about a large group of *Megathyrsus maximus* accessions as potential options for the establishment and management of productive and efficient cattle raising under the agro ecological conditions of the Patía Valley, thus, contributing to the agricultural development of the region and the quality of life of its producers.

The *M. maximus* collection contains several materials that stand out for their nutritional value (CP, NDF, ADF, and IVDMD), which, although they did not show a relationship with DMB, have sufficient productive yield. They also have adaptation potential for drought or low-rainfall conditions in tropical regions. Therefore, they represent a suitable option for sustainable livestock systems. Furthermore, they help subsequent plant breeding programs to contribute to finding alternative materials to maintain adequate feeding efficiency for cattle and mitigate the effects of climate change.

Both the genotypic characteristics of *M. maximus* and environmental conditions during contrasting seasons are factors that might influence the variability of nutritional content, productive parameters, and flowering of the evaluated germplasm. This allows a classification of forage material according to specific or preferential criteria of farmers and plant breeders.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JC-T carried out the experimental work, statistical analyses, wrote the manuscript, the original draft, and the methodology. JM performed the experiment based on NIRS Technology. NV-Q handled the supervision, the project administration, the acquisition of funds, helped on the conceptualization, validation, and the writing of the original draft. All authors contributed to the analysis and interpretation of data.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.684747/full#supplementary-material

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