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PLANT BREEDING

Correlation of shear strength and physicochemical properties as a criterion for the selection of accessions of *Paspalum* grasses

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ABSTRACT. The present study aimed to evaluate the application of shear strength and its correlations with leaf blade morphological and chemical variables as a tool capable of detecting differences between species and accessions of the genus *Paspalum* in the early stages of a forage plant breeding programme. A total of 13 *Paspalum* accessions from two species (*Paspalum atratum* and *Paspalum regnellii*) were subjected to analyses of shear strength, which also analysed the neutral detergent fibre, acid detergent fibre, lignin, and digestibility. Morphological measurements were also performed to standardize the shear strength per unit of leaf tissue. The experimental design consisted of complete randomized blocks, with four replications and eight cuts performed over 2 years. Shear strength was evaluated for its potential usefulness for detecting differences between accessions of the same species and the correlations of accessions. It was possible to use the shear strength measured with the texturometer to detect differences between species and accessions of the *Paspalum* genus. The results showed significant correlations of shear strength and neutral detergent fibre (r = 0.49), and negative correlations were found between digestibility and shear strength (r = -0.55). These correlations were maintained when the strength variables were standardized according to the morphological variables. Thus, shear strength can be used in the initial stages of the selection of species of the genus *Paspalum*.

Keywords: indirect selection; morphophysiology; forage plant.

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Introduction

The low diversity of species and cultivars of forage plants in Brazil generates great vulnerability in pasture animal production systems. The risks associated with this situation tend to worsen with global climate change, which will cause changes in rainfall regimes in addition to an increase in temperature and the incidence of pests and diseases (Valle, Barrios, Jank, & Santos, 2014).

Grasses native to Brazil with forage potential have emerged as alternative solutions to this problem. In addition to presenting the largest number of species with forage potential and playing a relevant role in soil conservation, especially in coastal areas, the species of the genus *Paspalum* are the most well studied and promising for launching commercial cultivars adaptable to different climatic conditions (Valls & Pozzobon, 1987).

The selection of programmes for launching new varieties of fodder plants that have good agronomic performance allied to satisfactory chemical parameters has been based on assessments of a large number of collections and accessions, requiring substantial time and investments. In this context, there is a need to apply alternative techniques to reduce the costs related to the quality description of forage grasses in the initial stages of selection, among which the shear strength can be highlighted (Hugles et al., 2000; Herrero, Valle, Hughes, Sabatel, & Jessop, 2001).

Shear strength (SS) is defined as the force required to tear a leaf blade when applied at 90° on the leaf surface. The resistance to shear is influenced by morphology (which is related to chemical composition), especially the cell wall, due to the presence of lignin and cellulose, which are common in tropical species (Wilson, 1997).

Thus, it can be inferred that the higher the shear strength (SS) value, the higher the values for neutral detergent fibre (NDF), acid detergent fibre (ADF), and cellulose, and the lower the digestibility. Compared to traditional protocols, SS presents itself as a less expensive, faster, simpler technique and, as long as it has a correlation with physical-chemical characteristics and digestibility, it can be used for the initial identification of accessions with the potential for advanced assessments.

The present study aimed to evaluate the application of shear strength and its correlations with leaf blade morphological and chemical variables as a tool capable of detecting differences between species and accessions of the genus *Paspalum* in the early stages of a forage plant breeding programme.

Material and methods

The experiment was conducted at the Faculty of Veterinary Medicine and Animal Science (FMVZ/UNESP), Botucatu campus, in the foraging sector of the Lageado experimental farm. The site is located at a latitude of 22°51'01” south and a longitude of 48°25'27” west longitude and has an elevation of 800 metres. According to the Köeppen classification, the predominant climate in the region is of the Cwa type, which is characterized by the tropical climate of areas at elevation, with dry winters and hot and rainy summers (Cunha & Martins, 2009).

The soil of the area is classified as Latosol Red dystrophic (Santos et al., 2018), with 630, 90 and 280 g kg^{-1} of clay, silt, and sand, respectively. The chemical composition of the soil in the 0-20 cm deep layer before the installation of the experiment is described in Table 1. The nutrient contents were corrected in relation to the requirements of forage grasses.

Table 1. Chemical attributes of the soil in the 0-20 cm layer of the experimental area before the implementation of the experiment.

pH	MO	P	H + Al	K	Ca	Mg	SB	CTC	V
$CaCl_2$	g dm^{-3}	mg dm^{-3}	----------------------	----------------------	mmol$_c$ dm^{-3}	----------------------	----------------------		--- % ---
4.7	46.5	8.2	45.7	0.8	21.4	11.2	33.4	79.1	42.2

MO: organic matter; P: phosphorus; H + Al: potential acidity; K: potassium; Ca: calcium; Mg: magnesium; SB: sum of exchangeable bases; CTC: cation exchange capacity; V: base saturation.

Thirteen accessions of two species of grass of the genus *Paspalum* were evaluated from the *Paspalum* germplasm bank (BGP) of Embrapa in São Carlos, São Paulo State, Brazil. The two species assessed (*P. atratum* and *P. regnellii*) are those with the highest number of individuals with potential for release as new cultivars.

Each experimental plot (represented by access) was formed by 5 plants (one plant per pit); each pit was 0.20 cm deep and spaced 0.50 m apart, making a line 2.0 m long and 0.5 m wide on each side, occupying a useful area of 2.0 m^2. The distance between the plots was 2.5 metres.

The experimental design used was complete randomized blocks with 4 replications. The experiment was conducted for two years with evaluations performed in the periods with the greatest rainfall (i.e., summer).

The plants were standardized by cutting the three central clumps of the plot 10 cm from the ground. The samples (approximately 300 g) were packed in paper bags duly identified to determine the chemical composition. From the rest of the material collected in the field, 10 tillers were chosen, and from these, 10 fully expanded leaf blades were selected. Because they are accessions (new materials), it has already been observed that the ontogenetic leaf patterns (senescent, senescence, expanded, and expanding periods and the sequence in which leaves appear) differ from the known patterns for other forage species.

The leaf area (LA) (cm^2) was individually evaluated in an LI-300 leaf area meter (LI-COR, Lincoln, Nebraska, USA). After this evaluation, the shear strength (kg) of the leaves was assessed. This characteristic was measured in the middle portion of the leaf blade using a texturometer (TA.XT2i Plus Texture Analyzer) equipped with a roller device for traction and tear testing.

The linear density (weight per leaf blade length) (LD) is expressed in g/cm and was obtained by dividing weight (g) by length (cm) according to the following equation:

$$LD = ((\frac{\text{weight}}{\text{length}}) \times 100)$$

The density of the leaf area (weight per unit leaf area) (DLF) is expressed in g cm^{-2} and was obtained by dividing weight (g) by leaf area (cm^2) according to the following equation:

$$DLF = ((\frac{\text{weight}}{\text{leaf arear}}) \times 100)$$

The raw data of the shear strength were standardized according to ratios with the leaf width, length, weight, linear density and area, generating the following calculated variables: strength/width (kg cm^{-1}), strength/linear density (kg g^{-1} cm^{-1}) (SS/LD) and area/strength/density (kg g^{-1} cm^{-2}) (SS/DLF). This standardization between the morphological characteristics and the physical characteristics is necessary for the comparison of the differences in resistance between the samples (Hughes et al., 2000).

The following chemical constituents in leaf blades were analysed: neutral detergent fibre (Goering & van Soest, 1970), acid detergent fibre (AOAC, 1995) and lignin (Goering & van Soest, 1970).

The digestibility in vitro (IVDMD) was determined with an artificial rumen fermenter (DaisyII) (Mabjeesh, Cohen, & Arieli, 2000). The inoculum used was obtained from a nonlactating fistulated cow kept in a pasture of *Urochloa decumbens*. The collection of ruminal fluid was approved by the ethics board for animal use protocols (CEUA 0165/2017).

The data were tested for normal distributions using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC) and a Shapiro-Wilk test (W). The accessions were considered the experimental units. For the descriptive statistics, the MEANS procedure (SAS Inst. Inc., Cary, NC) was used. The data were analysed using the MIXED procedure (SAS Inst. Inc.,) with the Satterthwaite command to adjust the denominator degrees of freedom (DDF) for fixed effect tests. The model of the shear strength parameters, morphological and physiological characteristics and chemical composition included the effect of the ACE's being cut and the resulting interactions. The random variable is the year, which represents the accession year in this model. The results are reported as the mean of the least squares (LSMEANS) and separated using LSD according to the observed effect. The CORR procedure (SAS Inst.) was used to perform Pearson's correlation on the chemical, morphological and physical data. The partial command was used so that observations with missing values were excluded from the analysis. For all the analyses, the results were considered significant if $p \leq 0.05$, and trends were discussed if $p > 0.05$ and $p \leq 0.10$.

Because of the high variability in the characteristics between the two species, multivariate statistics were used to facilitate the visualization of the relationships between the variables and the similarities between individuals of the species. This method of displaying data facilitates interpretation. Considering the average data by treatments, data analysis was performed using cluster analysis (CA) and principal component analysis (PCA). In the cluster analysis, to find groups of genotypes, the hierarchical cluster method was used. This method begins with a symmetric similarity matrix, which contains the proximity measurements between n individuals (genotypes) obtained from the Euclidean distance between points.

Initially, the first similarity matrix was calculated, and then the individuals with the lowest observed distances were grouped. Then, the averages of the groups were calculated, and the statistical procedure was performed. At each step, form or If a new grouping level was formed, as shown in the dendrogram.

After the formation of k groups, a confirmatory analysis was carried out using multivariate variance analysis (MANOVA) followed by an F test (n, k; $p \leq 0.01$) to test the null hypothesis (H_0: homogeneity of the groups). Upon rejecting the H_0, Hotelling's T^2 multivariate test ($p \leq 0.01$) was applied to check if there were pairwise (e) differences between the mean vectors (centroids) of the k groups formed.

Principal component analysis (PCA) was also carried out as a complement to the cluster analysis (CA) to better understand the relationships between the variables and the genotype groups created. The PCA allowed the greatest amount of original information contained in p variables (p = 13 in this study) to be condensed into two latent orthogonal axes (i.e., main components), which are linear combinations of the original variables and are created with the two largest eigenvalues of the data covariance matrix (Hair, Black, Babin, Anderson, & Tatham, 2009).

In this way, the initial set of variables was characterized by two new latent axes, which made it possible to locate the variables on a plane (ordering the genotypes along the main components). The adequacy of this analysis is verified by the amount of information related to the original variables explained by the main components, which have relatively high eigenvalues (Kaiser, 1958).

Results and discussion

There were no marked differences in the values of the climatic variables between the experimental period and the historical average (Table 2).

Table 2. Precipitation and maximum and minimum temperatures during the study period as well as long-term averages from 1968 to 2018 in the municipality of Botucatu, state of São Paulo, Brazil.

Climatic characteristics	Month				
	October	November	December	January	February
			2016–2017		
Monthly rainfall, mm	162.8	145.8	184.9	359.2	140.7
Temp., average max., °C	27.8	28.1	29.3	28.6	30.3
Temp., average min., °C	16.2	17.1	18.8	19.5	20.1
			2017–2018		
Monthly rainfall, mm	151.1	213.6	154.4	267.2	88.1
Temp., average max., °C	28.0	27.5	28.4	28.0	27.7
Temp., average min., °C	17.2	16.8	19.2	18.8	18.3
			Long-term average (50 years)		
Monthly rainfall, mm	133	133.8	185	224	141
Temp., average max., °C	27.2	27.7	27.2	28.1	28.0
Temp., average min., °C	15.1	16.2	16.4	17.1	19.0

mm: millimeter; max: maximum; min: minimum; temp: temperature.

Precipitation and temperature conditions did not limit the development of the studied species (Silveira & Perez, 2014). The accessions of *P. atratum* are more adapted to flooded regions with rainfall above 1,600 mm; however, the development of this species is not compromised in regions with short dry periods (Leite & Fernandes, 1999).

The cluster analysis (based on the hierarchical method) made it possible to separate the 13 accessions into two groups. The threshold points used in the definition of the groups were at vertical distances of 5.10 and 15, as shown in the dendrogram in Figure 1.

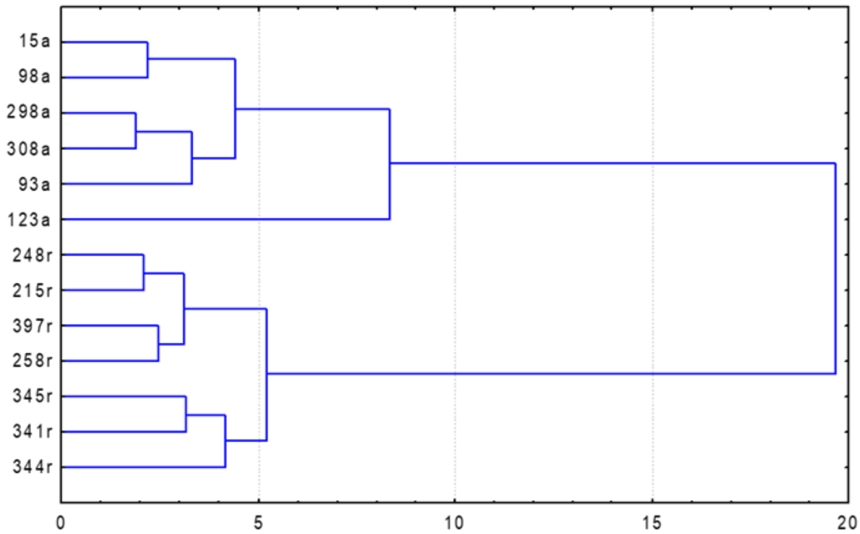

Figure 1. Dendrogram showing the group structure of 13 *Paspalum* accessions.

The dendrogram shows the division of the two species (*P. atratum* and *P. regnellii*), with only accession 123 showing patterns different than those of the remaining species; this result persisted throughout the evaluations conducted in this work.

Significant differences ($p < 0.0001$) were found between the species and accessions studied, although there were no year and accession interactions ($p < 0.05$) for the morphophysiological characteristics. The mean values of the morphophysiological parameters of the 13 *Paspalum* accessions over two years are shown in Table 3.

The accessions of *P. atratum* had longer leaves than those of *P. regnellii* ($p < 0.0001$), with the exception of accession BGP 123, for which larger leaves are present in the accessions of *P. regnellii*. Accession BGP 341 showed the highest values for the leaf length variable ($p < 0.0001$).

The highest values of density per leaf area (g cm^{-2}) are present in *P. atratum* ($p < 0.0001$), while there were no differences in the weight (g), area (cm^2) or linear density (g cm^{-1}) of the leaf blades between the studied species.

Accession BGP 123 showed morphophysiological patterns different from those of the other accessions of *P. atratum*, except for the density per leaf area, for which BGP 123 presented values statistically equal to those of the other species.

Table 3. Morphophysiological characteristics of leaf blades from 13 *Paspalum* accessions.

Species	BGP accession	Length (cm)	Mean width (cm)	Weight (g)	LA (cm^2)	LD ($g\ cm^{-1}$)	DLF ($g\ cm^{-2}$)
P. atratum	15	60.9 a	1.9 d	2.8 a	86.4 a	4.7 a	3.8 a
	98	59.2 ab	2.1 d	2.6 a	78.8 abc	4.7 a	3.9 a
	298	58.8 ab	1.7 e	2.2 b	69.1 bcd	3.6 d	3.3 a
	93	56.7 ab	2.1 d	2.6 a	71.5 abcd	4.7 a	3.8 a
	308	54.2 b	2.0 d	2.3 b	66.6 cd	3.6 d	3.6 a
	123	46.9 cd	1.4 f	1.3 f	39.8 e	2.8 e	3.5 a
P. regnellii	248	50.1 c	2.5 c	2.0 bcd	81.4 abc	3.8 cd	2.5 b
	345	44.9 d	2.4 c	1.8 cde	75.3 abcd	3.9 cd	2.5 b
	341	44.8 d	2.6 a	2.1 bc	79.7 abc	4.4 ab	2.7 b
	397	44.4 d	2.7 b	1.9 bcd	84.8 ab	4.3 abc	2.6 b
	215	44.0 d	2.5 c	1.8 cde	72.3 abcd	4.0 bcd	2.5 b
	258	41.0 de	2.5 c	1.5 ef	71.2 abcd	3.6 d	2.2 b
	344	38.2 e	2.5 c	1.6 def	62.5 d	4.2 abc	2.7 b
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EPM		2.03	0.05	0.12	4.83	0.15	0.23

The averages in the columns followed by the same letters do not differ statistically according to a 5% SNK test. BGP: *Paspalum* germplasm bank; LA: leaf area; LD: linear density; DLF: density per leaf area; EPM: average standard error.

The average values found for the variables length and width in both species are higher than those verified by Lucena, Catian, and Lempp (2017), who, studying the leaf blade morphophysiology of eight species of *Paspalum*, obtained average values for width of 1.39 and 1.37 for length of 27.45 and 22.92 for *P. atratum* and *P. regnellii* respectively. And ste result reflects mainly results mainly reflect the cuts range from differences in leaf blades and soil and weather conditions of the study regions.

For the leaf area variable, the results are lower than those found by Lucena et al. (2017), who obtained values of 109.56 for *P. atratum* accessions and 98.29 for *P. regnellii* accessions. Costa and Paulino (1998), evaluating accessions of *P. atratum* at different cutting ages, stated that the leaf area is directly proportional to the age of the cuts. In this way, the lowest values obtained for this variable are directly linked to younger cutting ages, which were 28 days for this study and 35 days for Lucena et al. (2017).

The accessions of *P. regnellii* showed relatively wide leaves. This morphological characteristic is directly associated with the amount of chlorophyll parenchyma that makes up the mesophyll, which is an important characteristic from a qualitative point of view, because it is associated with nutritious and digestible tissue (Akin, 1979).

Longer leaves tended to be narrower and had a higher density per leaf area. Morphologically, the density per leaf area was the characteristic that best differentiated the species, which was the result of the association of the leaf area with weight. This parameter is of particular interest in studies of shear resistance, as it can influence the resistance to harvest, degradation, and consumption (Hughes et al., 2000).

The chemical composition and digestibility of the 13 accessions are shown in Table 4. No interactions ($p < 0.05$) between the chemical composition and digestibility of the accessions (by year) were identified. The accessions of *P. regnellii* had higher levels of NDF ($p < 0.0001$) and lower digestibility ($p < 0.01$).

The values of ADF and lignin were not distinguishable between the studied *Paspalum* species and among the accessions, while NDF and IVDMS could be discriminated between the studied species, except for BGP accession 123.

The *P. regnellii* accessions that showed higher concentrations of NDF showed lower levels of digestibility. This relationship has been extensively analysed by numerous studies (Minson, 1982; Wilson, Brown, & Windham, 1983; Weiss, 1994; Hughes et al., 2000; Queiroz, Gomide, & Maria, 2000). In this study, digestibility showed negative correlations with NDF, ADF and lignin ($r = -0.78$, $r = -0.70$, $r = -0.40$, respectively). Tropical grasses, when well managed and at the optimum point of management, present 50% digestibility and NDF levels between 60 and 75%, on average (Euclides, 1995).

Neutral detergent fibre is an essential component of the diet of ruminants and is necessary to obtain the maximum dry matter intake and energy, stimulating chewing activity and saliva secretion. On the other hand, NDF represents, in part, the fraction of carbohydrates in foods with slow and variable digestion, and when included above certain limits defined by the potential of animal production, it can limit both food consumption and performance (Mertens, 1997).

Table 4. Chemical composition of the leaf blades of 13 *Paspalum* accessions.

Species	BGP accession	NDF	ADF	Lignin	IVDMS
			(% MS)		(%)
P. atratum	15	69.1 d	35.5 b	4.68 b	56.02 c
	98	67.7 d	36.4 ab	4.68 b	56.24 c
	298	68.4 d	36.5 ab	5.29 ab	58.51 b
	93	69.1 d	36.0 ab	5.42 ab	60.48 a
	308	68.5 d	36.0 ab	4.85 b	57.48 bc
	123	72.1 bc	36.4 ab	5.04 ab	55.33 d
P. regnellii	248	72.3 bc	36.4 ab	5.44 ab	55.18 d
	345	75.1 a	38.1 a	6.45 a	53.20 f
	341	71.5 c	36.6 ab	6.11 ab	55.45 d
	397	74.2 ab	38.2 a	5.50 ab	54.20 e
	215	74.9 a	37.5 ab	5.51 ab	54.57 e
	258	73.5 abc	37.3 ab	5.33 ab	54.80 e
	344	71.0 c	35.3 b	5.42 ab	55.91 d
P		<0.0001	<0.0001	<0.001	<0.01
EPM		1.00	1.02	0.55	1.14

The means in the columns followed by the same letters do not differ statistically according to a 5% SNK test. BGP: *Paspalum* germplasm bank; NDF: neutral detergent fibre; ADF: acid detergent fibre; IVDMS: In vitro dry matter digestibility; EPM: average standard error.

Leite, Silveira, Fernandes, and Gomes (2001), evaluating NDF, ADF, lignin and digestible *P. atratum* at 28 days in Gleysol haplic soil in Brasilia, obtained the following values, all of which are below those observed in the present study: 61.2, 34, 4.6, and 61.5%, respectively. These results are mainly attributed to the difference in precipitation between the study areas (857 mm in Brasília), considering that this species of *Paspalum* grows better in hydromorphic areas.

For species of *P. regnellii,* Batista, Meirelles, and Godoy (2005), evaluating the nutritional quality of *Paspalum* in the central region of the state of São Paulo under edaphic conditions and cut intervals similar to those used in the present study, obtained values of 77.19% for NDF, 39.84% for ADF, and 59.79% for digestibility. These values are higher than those observed in the present study; lower digestibility, even with higher fibre contents, may be associated mainly with morphophysiological characteristics, with denser leaf blades having greater resistance to rumen degradation (Hughes et al., 2000). According to Paciullo (2002), anatomical studies, mainly of leaf blades, provide complementary information on the quality of forages, since chemical analysis and digestibility do not always explain all the variations in the study of forage grasses.

The density per leaf area is highly related to the ease with which leaf blades can be reduced during digestion in the rumen and may influence the rate of degradation and fermentation (Wilson, 1994). It should also be noted that lower shear strength values may indicate greater acceptability by animals; on the other hand, they may be associated with leaf blade susceptibility to attack by pests and diseases (Hughes et al., 2000).

The shear strength values of the 13 accessions are shown in Table 5. There were no accession and year interactions ($p < 0.05$) for any of the characteristics studied.

Table 5. Shear strength parameters of 13 *Paspalum* accessions.

Species	BGP accession	Shearing strength (kg)	Shearing strength/leaf width (kg cm^{-1})	Shearing strength/linear density (kg cm^{-1})	Shearing strength/area density (kg cm^{-2})
P. atratum	15	0.99 d	0.50 abc	21.67 fg	30.41 c
	98	0.94 de	0.42 de	19.27 g	25.89 c
	298	0.91 e	0.47 cd	22.95 ef	27.65 c
	93	0.95 de	0.44 cde	19.0 g	27.02 c
	308	0.91 e	0.42 de	20.35 fg	28.91 c
	123	0.83 f	0.56 a	25.47 de	24.18 c
P. regnellii	248	1.09 bc	0.49 abcd	31.76 b	51.23 b
	345	1.06 c	0.46 cde	28.08 cd	48.28 b
	341	1.04 c	0.39 e	25.51 de	45.51 b
	397	1.20 a	0.56 a	35.03 a	66.09 a
	215	1.14 b	0.49 abcd	30.00 bc	50.44 b
	258	1.14 b	0.55 ab	36.32 a	64.41 a
	344	1.07 c	0.47 bcd	27.99 cd	44.53 b
P		<0.0001	<0.0001	<0.0001	<0.0001
EPM**		0.20	0.02	1.45	3.19

The averages in the columns followed by the same letters do not differ statistically according to a 5% SNK test. BGP: *Paspalum* germplasm bank; EPM: average standard error.

The shear strength differed between the studied species, and it was possible to detect differences between accessions of the same species ($p < 0.0001$). It was possible to differentiate shear strength by leaf area between species, but this variable could not be used to discriminate accessions of the same species ($p < 0.0001$). Shear strength/width and shear strength/linear density were not good discriminators of the species. The accessions that had less resistance to shear, i.e., those belonging to *P. atratum*, were also those that presented a lower density per leaf area and NDF and showed greater digestibility (again, with the exception of BGP 123).

Negative correlations were found between digestibility and shear strength (r = -0.55). However, positive and strong correlations were found between shear strength and NDF (r = 0.49). These correlations were maintained when the strength parameters were standardized considering the morphological parameters, showing positive and strong correlations for linear density (r = 0.52) and density per leaf area (r = 0.56); the correlations were lost when the shear resistance was standardized by leaf width (r = 0.27).

Accession BGP 123, belonging to *P. atratum*, which differed morphologically from the other accessions of this species when the shear strength values were recalculated by density per leaf area (Table 5), was again included in the *P. atratum* species. The patterns of the ste values can be explained by McClelland and Spielrein (1957) and Prince (1961), who stated that the intrinsic differences in length and weight of leaves between species could be explained by the expression of the shear strength measurements based on the density per leaf area (g cm^{-2}).

When standardized by unit, the leaf tissue density and linear density of the leaf area were highly correlated with the NDF results; this finding is in accordance with the works of McClelland and Spielrein (1957), Prince (1961), and Herrero et al. (2001), which state that NDF can be correlated to strength parameters and can be a good parameter for the selection of accessions. There is a clear possibility for correlating the NDF with the standardized parameters per unit of leaf tissue, shear strength by linear density and leaf area.

The results of the principal component analysis (Figure 2), which supplemented the other analyses, made it possible to better understand the relationships between the variables studied and the accessions. Figure 2 shows the projection of the 14 variables (length, mean width, weight, LA, LD, DLF, NDF, ADF, lignin, IVDMD, shearing strength, shearing strength/leaf width, shearing strength/linear density, and shearing strength/area density) of the 13 accessions to a two-dimensional plane formed by the first and second principal components (Factor 1 and Factor 2), with 78 and 11% of the total variance explained.

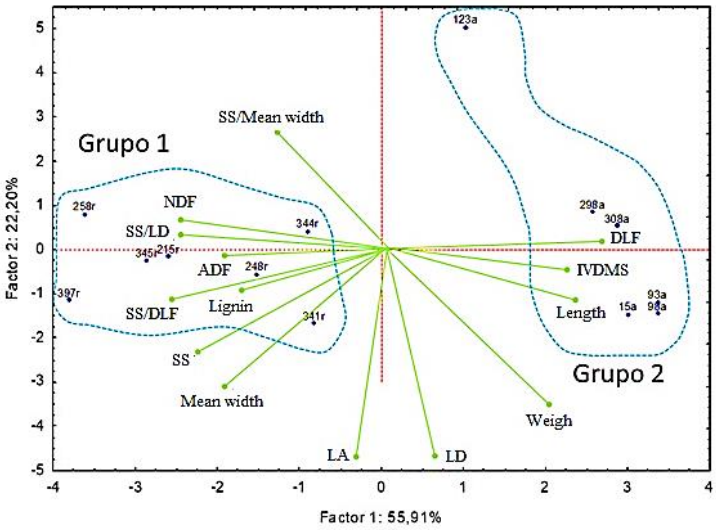

Figure 2. Projection of 13 accessions, 14 variables in the plane formed by the first two principal component analysis and the representation of the two groups generated in the cluster analysis.

Length, ADF, lignin, IVDMD, shear strength, and shear strength/density per leaf area had strong contributions to Factor I. The accessions were divided into two groups, which were negatively correlated, and this division reflects the species to which the accessions belong, except for accession BGP 123. Mean width, leaf area (LA), NDF, ADF, lignin, shear strength, shearing strength/leaf width, shearing strength/linear density, and shearing strength/density per leaf area were negatively correlated with length, mean weight, linear density (LD), density per leaf area (DLF), and IVDMD.

The possibility of using shear strength as a quality indicator in accessions of the *Paspalum* genus was confirmed, considering that the correlations between shear strength and NDF are strong and that there was also a negative correlation of shear strength and digestibility. Therefore, shear strength provides a fast, inexpensive and reproducible method that is ideal for the initial stages of forage grasses selection.

Conclusion

It was possible to use the shear strength measured with the texturometer to detect differences between species and accessions of the *Paspalum* genus. There was a positive correlation of the shear strength and NDF content and a negative correlation of the shear strength and digestibility and morphological characteristics, showing that this technique has the potential to be used as a selection tool in the initial stages of breeding programmes of this kind, which aim to produce better quality forage materials.

References

Akin, D. E. (1979). Microscopic evaluation of forage digestion by rumen microorganisms-a review. *Journal of Animal Science*, *48*(3), 701-710. DOI: https://doi.org/10.2527/jas1979.483701x

AOAC (1995). *Official Method 991.14 for Coliform and Escherichia coli counts in foods, Official methods of analysis*. Washington, DC: AOAC.

Batista, L., Meirelles, P. D. L., & Godoy, R. (2005). Produção e qualidade da forragem em acessos selecionados de "*Paspalum*" na região Central do Estado de São Paulo. In *Reunião Anual da Sociedade Brasileira de Zootecnia*: *A Produção animal e o foco no agronegócio* (p. 1-6). Goiânia, GO: SBZ.

Costa, N. D. L., & Paulino, V. T. (1998). Produção de forragem e composição mineral de *Paspalum atratum* BRA-9610 em diferentes idades de corte. In *Reunião Anual da Sociedade Brasileira de Zootecnia* (p. 336-338). Botucatu, SP: SBZ.

Cunha, A. R., & Martins, D. (2009). Classificação climática para os municípios de Botucatu e São Manuel, SP. *Irriga, 14*(1), 1-11. DOI: https://doi.org/10.15809/irriga.2009v14n1p1-11

Euclides, V.P.B. (1995). Valor alimentício de espécies forrageiras do gênero Panicum. In A. M. Peixoto, J. C. Moura, & V. P. Faria (Eds.), *Simpósio sobre manejo da pastagem* (p. 245-274). Piracicaba, SP: Fealq.

Goering, H. K., & Van Soest, P. J. (1970). *Forage fiber analyses: apparatus, reagents, procedures, and some applications*. Washington, DC: USDA.

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2009). *Análise multivariada de dados*. (6. ed.). Porto Alegre, RS: Bookman.

Herrero, M., Valle, C. B., Hughes, N. R. G., Sabatel, V. O, & Jessop, N. S. (2001). Measurements of physical strength and their relationship to the chemical composition of four species of *Brachiaria*. *Animal Feed Science and Technology*, *92*(3-4), 149-158. DOI: https://doi.org/10.1016/S0377-8401(01)00261-9

Hughes, N. R. G., Valle, C. B., Sabatel, V. O., Boock, J., Jessop, N. S., & Herrero, M. (2000). Shearing strength as an additional selection criterion for quality in *Brachiaria* pasture ecotypes. *The Journal of Agricultural Science*, *135*(2), 123-130. DOI: https://doi.org/10.1017/S0021859699008084

Kaiser, H. F. (1958). The varimax criterion for analytic rotation in factor analysis. *Psychometrika*, *23*(3), 187-200. DOI: https://doi.org/10.1007/BF02289233

Leite, G. G., & Fernandes, F. D. (1999). *Qualidade da forragem do capim Paspalum atratum cv. Pojuca*. Brasília, DF: Embrapa Cerrados.

Leite, G. G., Silveira, L. F., Fernandes, F. D., & Gomes, A. C. (2001). *Crescimento e composição química do capim Paspalum atratum cv pojuca* (Boletim de Pesquisa e Desenvolvimento). Brasília, DF: Embrapa Cerrados.

Lucena, K. C., Catian, G., & Lempp, B. (2017). Características morfológicas e químicas de lâminas foliares de *Paspalum* spp. *Revista de Biologia Neotropical/Journal of Neotropical Biology*, *14*(1), 1-10. DOI: https://doi.org/10.5216/rbn.v1i1.43247

Mabjeesh, S. J., Cohen, M., & Arieli, A. (2000). In vitro methods for measuring the dry matter digestibility of ruminant feedstuffs: comparison of methods and inoculum source. *Journal of Dairy Science*, *83*(10), 2289-2294. DOI: https://doi.org/10.3168/jds.S0022-0302(00)75115-0

McClelland, J. H., & Spielrein, R. E. (1957). An investigation of the ultimate bending strength of some common pasture plants. *Journal of Agricultural Engineering Research, 2*, 288-292.

Mertens, D. R. (1997). Creating a system for meeting the fiber requirements of dairy cows. *Journal of Dairy Science*, *80*(7), 1463-1481. DOI: https://doi.org/10.3168/jds.S0022-0302(97)76075-2

Minson, D. J. (1982). Effect of chemical composition on feed digestibility and metabolisable energy. *Nutrition Abstracts and Reviews*, *52*, 591-615.

Paciullo, D. S. C. (2002). Características anatômicas relacionadas ao valor nutritivo de gramíneas forrageiras. *Ciência Rural*, *32*, 357-364.

Prince, R. P. (1961). Measurement of ultimate strength of forage stalks. *American Society of Agricultural Engineers*, *4*(2), 208–209. DOI: https://doi.org/10.13031/2013.41054

Queiroz, D. S., Gomide, J. A., & Maria, J. (2000). Avaliação da folha e do colmo de topo e base de perfilhos de três gramíneas forrageiras: 2. Anatomia. *Revista Brasileira de Zootecnia*, *29*(1), 61-68. DOI: https://doi.org/10.1590/S1516-35982000000100008

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., ... Cunha, T. J. F. (2018). *Sistema brasileiro de classificação de solos*. Brasília, DF: Embrapa.

Silveira, M. C. T., & Perez, N. B. (2014). *Informações sobre plantas forrageiras C4 para cultivo em condições de deficiência de drenagem e tolerância a frio*. Bagé, RS: Embrapa Pecuária Sul. (Documentos, INFOTECA-E).

Valle, C. D., Barrios, S. C. L., Jank, L., & Santos, M. F. (2014). Melhoramento de plantas forrageiras para uma pecuária de baixa emissão de carbono. In B. C. e Pedreira, D. H. Pereira, D. S. Pina, R. A. Carnevalli, & L. B. Lopes (Eds.), *Intensificação da produção animal em pastagens: Anais do 1º Simpósio de Pecuária Integrada Embrapa* (p. 109-139). Brasília, DF: Embrapa.

Valls, J. F. M., & Pozzobon, M. T. (1987). Variação apresentada pelos principais grupos taxonômicos de Paspalum com interesse forrageiro no Brasil. In Y. H. Savidan, P. B. Alcântara, J. F. M. Valls, C. Quarín, & A. R. P. Almeida (Eds.), *Anais do Encontro Internacional sobre Melhoramento Genético de Paspalum* (p. 15-21). Nova Odessa, SP: Instituto de Zootecnia, SAPF-DNAP-IZ, CNPGC-Embrapa, Orstom e Procisur.

Weiss, W. P. (1994). Estimation of digestibility of forages by laboratory methods. In G. C. Fahey Jr. (Ed.), *Forage quality, evaluation, and utilization* (p. 644-681). Madison, US: ASA, CSSA, SSSA Books. DOI: https://doi.org/10.2134/1994.foragequality.c16

Wilson, J. R. (1994). Cell wall characteristics in relation to forage digestion by ruminants. *The Journal of Agricultural Science*, *122*(2), 173-182. DOI: https://doi.org/10.1017/S0021859600087347

Wilson, J. R. (1997). Structural and anatomical traits of forages influencing their nutritive value for ruminants. In *Simpósio internacional sobre produção animal em pastejo* (p. 173-208). Viçosa, MG: UFV.

Wilson, J. R., Brown, R. H., & Windham, W. R. (1983). Influence of leaf anatomy on the dry matter digestibility of C3, C4, and C3/C4 intermediate types of *Panicum* species 1. *Crop Science*, *23*(1), 141-146. DOI: https://doi.org/10.2135/cropsci1983.0011183X002300010041x