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Original Article

Selection of *Paspalum* accessions for use in poorly drained soils

Seleção de acessos de *Paspalum* para uso em solos mal drenados

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Abstract

Excess soil water can result from inadequate drainage, seasonal groundwater fluctuations, and extreme rainfall events. Diversifying forage species is a key strategy for mitigating these challenges. This study aimed to evaluate *Paspalum* germplasm collected from different regions of Brazil and identify accessions with potential for use in poorly drained environments. A total of twenty-three *Paspalum* accessions were assessed under two water regimes (flooded and non-flooded), alongside *Urochloa brizantha* cv. Marandu, in a randomized block design with a 24 × 2 factorial arrangement and three replications. The experiment was conducted in a greenhouse using potted plants. The evaluated traits were dry mass of leaves, stems, dead material, aerial biomass, roots, the ratio of dead material dry mass to aerial biomass, leaf area, number of tillers, and leaf elongation. Data were subjected to analysis of variance and a means comparison test at a 5% significance level, followed by biplot analysis. All genotypes were affected by flooding; however, BGP238, BGP112, and BGP410 exhibited superior performance in the assessed growth and biomass production traits compared to *U. brizantha* cv. Marandu under both flooded and non-flooded conditions. These genotypes can advance in plant breeding studies.

Keywords: excess water, germoplasm, flooding, Brachiaria, genetic resources, summer forage, plant breeding.

Resumo

O excesso de água no solo pode resultar de drenagem inadequada, flutuações sazonais do lençol freático e eventos extremos de precipitação. A diversificação de espécies forrageiras é uma estratégia fundamental para mitigar esses desafios. Este estudo teve como objetivo avaliar germoplasma de *Paspalum* coletado em diferentes regiões do Brasil e identificar acessos com potencial para uso em ambientes com drenagem deficiente. Foram avaliados vinte e três acessos de *Paspalum* sob dois regimes hídricos (alagado e não alagado), juntamente com *Urochloa brizantha* cv. Marandu, em um delineamento em blocos casualizados, com arranjo fatorial 24 × 2 e três repetições. O experimento foi conduzido em casa de vegetação, utilizando plantas cultivadas em vasos. Foram avaliados: massa seca de folhas, colmos, material morto, biomassa aérea e raízes, a relação entre a massa seca do material morto e a biomassa aérea, área foliar, número de perfilhos e alongamento foliar. Os dados foram submetidos à análise de variância e ao teste de comparação de médias a 5% de significância, seguido de análise biplot. Todos os genótipos foram afetados pelo alagamento; no entanto, o BGP238, o BGP112 e o BGP410 apresentaram desempenho superior nos indicadores de crescimento e produção de biomassa avaliados, quando comparados à *U. brizantha* cv. Marandu, tanto sob condições de alagamento quanto sem alagamento. Esses genótipos podem avançar em estudos de melhoramento de plantas.

Palavras-chave: excesso de água, germoplasma, alagamento, Brachiaria, recursos genéticos, forrageiras de verão, melhoramento de plantas.

1. Introduction

The *Urochloa brizantha* cv. Marandu is widely used as forage grass in Brazil (Omote et al., 2021). Despite its high acceptance among farmers, *U. brizantha* cv. Marandu is not resistant to waterlogging conditions (Caetano and Dias-Filho, 2008; Ribeiro-Júnior et al., 2017) and does not thrive in typical conditions found in certain regions in the Central-West and North of Brazil, where seasonal water stress can occur due to excess water caused by soil and climate factors (Dias-Filho, 2011). The breeding of forage grass cultivars resistant to waterlogging conditions may contribute to reducing vulnerability of pasture-based animal production systems in these areas.

Stress imposed on plants depends on duration, depth and frequency of waterlogging conditions. Additionally, plants responses to this stress may be related to increase on internal aeration or to a higher tolerance to anoxia and recovery after stress period (Colmer and Voesenek, 2009).

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Dias-Filho and Lopes (2012) suggest that screening accessions for use under waterlogging conditions should consider traits such as biomass production (aerial parts and roots), leaf elongation rate, gas exchange rates (photosynthetic rate and stomatal conductance), and leaf chlorophyll content (SPAD). Besides that, traits like alcoholic dehydrogenase activity, minerals and amide concentrations in leaves, and soluble sugars level in roots may be evaluated.

Most species of *Paspalum* are native from South America and have been used for grazing and as turfgrass in Brazil and other countries. There are cultivars of *Paspalum atratum*, *P. notatum*, and *P. vaginatum* registered in the International Union for the Protection of New Varieties of Plants - UPOV (Omote et al., 2021). Besides that, some species of *Paspalum* have been reported as resistant to waterlogging conditions (Loreti and Oesterheld, 1996; Penteado and Macedo, 2000; Ramos et al., 2002; Hare et al., 2004; Coelho-Souza et al., 2011; Beloni et al., 2017).

Accessions conserved in the Germplasm Bank of Embrapa Livestock Southeast were collected from different climate and soil conditions, including places characterized by the occurrence of waterlogging conditions (AV-Consultas, 2021). Some of these accessions have shown adaptive strategies to stress due to excess water in greenhouse experiments (Matta et al., 2013; Beloni et al., 2017).

The aim of this experiment was to identify accessions of *Paspalum* from the Germplasm Bank of Embrapa Livestock Southeast promising for use in poorly drained soils.

2. Material and Methods

The experiment was conducted in a greenhouse at Embrapa Livestock Southeast in São Carlos, São Paulo State, Brazil (21°55’00” S and 47°48’00” W), at an altitude of 700 m. The temperature and relative humidity inside the greenhouse were: 25.3 ± 7 and 84.7 ± 20, respectively.

The experimental design was a randomized complete block with a 24x2 factorial arrangement (24 genotypes and two water conditions) and three replicates. Twenty-three accessions of *Paspalum* were previously selected based on their potential for use as forage in animal production systems in Brazil (Table 1). *U. brizantha* cv. Marandu was used as a negative control and *P. regnellii* BRS Guará (BGP215) was included as a positive control.

Water conditions were: (i) control (irrigated plants maintained at 80% of the pots’ water holding capacity by daily irrigation based on evaporation measurements taken with a Piché evaporimeter); (ii) waterlogging (a 3 cm water layer above the soil surface was maintained by daily irrigation). The treatments were applied for 14 days following plant establishment (adaptation to the experimental environment). As this study represents an initial screening of accessions, the 14-day period allows for an efficient evaluation without the need to advance all accessions to field trials, optimizing resources and focusing on the most promising materials. This approach aligns with methodologies previously described in the literature, such as the protocol outlined by Dias-Filho and Carvalho (2000).

Seeds of twenty-three accessions of *Paspalum* (Table 1) were obtained from the *Paspalum* Germplasm Bank at Embrapa Livestock Southeast and sown in trays filled with commercial substrate (Plantmax®). For *U. brizantha* cv. Marandu, commercially available seeds were used. Each pot contained a single plant, which was transplanted into 2 L pots when it had approximately three fully expanded leaves. A tube was installed at the bottom of the pots to control of water drainage.

Pots were filled with soil characterized by the following physiochemical properties: pH H_2O 5.7; Ph CaCl2 5.0; OM 20 g dm^{-3}; P 5 mg dm^{-3}; K 0.9 mmolc dm^{-3}; Ca 18 mmolc dm^{-3}; Mg 9 mmolc dm^{-3}; H+Al 25 mmolc dm^{-3}; Al 0 mmolc dm^{-3}; CTC 53 mmolc dm^{-3}; S 28 mmolc dm^{-3}; V 53%; Ca+Mg/K 29; S.SO4 10 mg dm^{-3}. Soil fertilization followed Malavolta (1980) recommendations, with 0.55 g urea, 1.83 g single superphosphate, and 0.21 g potassium chloride per pot.

The number of tillers per pot and the leaf elongation rate were evaluated twice weekly from the beginning of the water treatment application until the end of the experiment, resulting in a total of five measurements. For leaf elongation rate determination, a single tiller per pot was monitored. The rate was calculated as the increase in leaf length per tiller between consecutive measurements divided by the number of days (cm tiller^{-1} day^{-1}).

At the end of the experiment, after 14 days, plants were harvested, and the aerial biomass was separated into leaves, stems, and dead material. Leaf area (cm^2) was measured before drying using a LI-COR Model LI-3100 leaf area meter. Roots were washed to remove soil residues using tap water and sieves. Afterward, all plant material was dried in a forced-air oven at 65 °C for 72 hours and then weighed. The specific leaf area (cm^2 g^{-1}), aerial biomass, and the proportion of leaves, stems, dead material, and roots were calculated. Aerial dry biomass was determined as the sum of leaf, stem, and dead material dry mass.

The experimental model was represented by the Equation 1:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{(j)k} + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (1)$$

where y_{ijk} represents the observed response of the i-th genotype in the k-th block within the j-th treatment, μ is the overall mean, α_i is the effect of the i-th genotype, β_j is the effect of the j-th treatment, $\gamma_{(j)k}$ is the effect of the k-th block within the j-th treatment, $(\alpha\beta)_{ij}$ is the interaction between the i-th genotype and the j-th treatment, and ε_{ijk} represents the residual effect for y_{ijk}. We assumed that the errors were independent and identically distributed, in other words, $\varepsilon_{ijk} \sim N(0, \sigma 2)$ for i = 1,..., 24, j = 1, 2, and k = 1, 2, 3 with cov(ε_{ijk} , $\varepsilon_{i'j'k'}$) = 0.

For all phenotypic traits evaluated, we tested the hypotheses using analysis of variance (ANOVA), followed by the Scott-Knott test at a 5% significance level. Additionally, a biplot analysis was performed to evaluate the genotype × environment interaction, and principal component analysis (PCA) was used to assess interrelationships among phenotypic traits. Statistical analyses were conducted using R software (ver. 4.3.1).

Table 1. Accessions of *Paspalum* evaluated for their tolerance to waterlogging stress: local code, scientific name, colletor code, collection location, and botanical group.

Local code (BGP)	Scientific name	Collector Code	Collection location	Botanical group
3	*Paspalum notatum* Flüggé	Ip 6915	Pensacola – USA	Notata
112	*Paspalum regnellii* Mez	VDBdSv 10073	Praia Grande - SC - Brazil	Virgata
169	*Paspalum virgatum* L.	VQFdSv 11855	Itaquiraí – MS - Brazil	Virgata
173	*Paspalum plenum* Chase	VQFdSv 11894	Aral Moreira – MS - Brazil	Quadrifaria
215	*Paspalum regnellii* Mez BRS Guará	Lr 2	Itirapina - SP - Brazil	Virgata
219	*Paspalum umbrosum* Trin.	VTsCr 14193	Bento Gonçalves – RS - Brazil	Paniculata
229	*Paspalum quarinii* Morrone and Zuloaga	VTsDp 14220	S. M. das Missões – RS - Brazil	Quadrifaria
234	*Paspalum dilatatum* Poir. biotipo uruguaiana	VTsDp 14251	Uruguaiana – RS - Brazil	Dilatata
238	*Paspalum urvillei* Steud. x *P. dilatatum* Poir.	VTsZi 14285	Xangri-lá - RS - Brazil	Dilatata
248	*Paspalum regnellii* Mez	VTsRcRm 14424	Capão Alto – SC - Brazil	Virgata
252	*Paspalum plenum* Chase	VQFdSv 11894	São Carlos - SP - Brazil	Virgata
253	*Paspalum quarinii* Morrone and Zuloaga	Lr s/no.	Goiânia - GO - Brazil	Quadrifaria
255	*Paspalum conspersum* Schrader	Lr s/no.	Goiânia - GO - Brazil	Virgata
267	*Paspalum lenticulare* Kunth	VRcMmSv 14507	Paranaíba -MS - Brazil	Plicatula
289	*Paspalum malacophyllum* Trin.	VRcMmSv 14582	Aral Moreira – MS - Brazil	Malacophylla
293	*Paspalum malacophyllum* Trin.	VRcMmSv 14606	Japorã – MS - Brazil	Malacophylla
294	*Paspalum notatum* Flüggé	VRcMmSv 14613	Itaquiraí – MS - Brazil	Notata
295	*Paspalum notatum* Flüggé	VRcMmSv 14614	Itaquiraí -MS - Brazil	Notata
308	*Paspalum atratum* Swallen	V 14525	Terenos -MS - Brazil	Plicatula
365	*Paspalum conspersum* Schrader		Origem desconhecida	Virgata
397	*Paspalum regnellii* Mez		Origem desconhecida	Virgata
402	*Paspalum regnellii* Mez		Origem desconhecida	Virgata
410	*Paspalum plenum* Chase		Origem desconhecida	Quadrifaria

Bd = I. I. Boldrini; Cr = C. M. Castro; D = M. Dall'Agnol; Dp = Dario Palmieri; Fd = M. S. França Dantas; Ip = Inst. nº, IAPAR; Lr = L. A. R. Batista; Mm = M. D. Moraes; Q = C. L. Quarin; Rc = Regina Célia de Oliveira; Rm = R. Miz; Sv = Glocimar Pereira da Silva; Ts = T. Souza-Chies; V = José Francisco Montenegro Valls; Zi = F. Zilio.

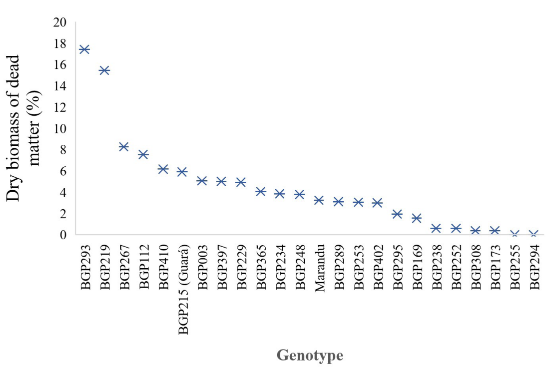

Figure 1. Percentage of dead material for the evaluated genotypes under flooded conditions.

3. Results

The genotype × treatment interaction was observed only for the evaluation of the percentage of dead material, which showed a different response to water conditions among genotypes (Table 2). However, a genotype effect was observed for all evaluated accessions, and the water condition treatments affected leaf dry biomass, aerial dry biomass, dead material dry biomass, root dry biomass, leaf area, number of tillers, and leaf elongation rate.

There was no significant difference between the genotypes under control conditions regarding the percentage of dead material. However, the genotypes BGP293 (17.4%) and BGP219 (15.4%) exhibited a higher percentage of dead material compared to the others, with an average percentage of 3.4% (Figure 1). *U. brizantha* cv.

Marandu and *P. regnellii* cv. Guará exhibited 3.2% and 5.9%, respectively. The genotypes BGP293 and BGP219 also showed lower dry biomass of aerial parts (Table 3), suggesting that the high percentage of dead material was related to the negative effects of flooding conditions rather than a natural senescence process.

Leaf, aerial part and root dry biomass, leaf area, and the number of tillers were higher in plants under control conditions compared to those under waterlogged conditions (Table 4), indicating a negative effect of water stress on plant development. Additionally, plants under waterlogged conditions exhibited a higher dry biomass of dead material. No differences were observed between control and waterlogged conditions for leaf elongation rate and stem dry biomass.

The genotypes exhibited significant differences for the evaluated traits, with some *Paspalum* accessions outperforming *U. brizantha* cv. Marandu under both water conditions. Table 3 presents the means for both control and waterlogging conditions, with highlighted cells indicating better performance compared to *U. brizantha* cv. Marandu.

Genotype BGP238 showed superior performance to *U. brizantha* cv. Marandu in six out of eight traits, with no differences observed between the two for dry biomass of dead material and leaf elongation rate. Additionally, BGP238 exhibited the highest absolute values for root and stem dry biomass, leaf area, and tiller number among all genotypes. Genotypes BGP112, *P. regnellii* cv. Guará (BGP215), BGP267, and BGP410 performed similarly or better than *U. brizantha* cv. Marandu in five of the eight traits. Genotype BGP219 exhibited low dry biomass in aerial parts, coupled with a high amount of dead material biomass, but, on the positive side, it also had one of the highest tiller counts.

A biplot analysis was conducted to assess the genotypes' responses under both treatments. For most traits, the linear dispersion of the data points suggests no interaction between genotypes and water treatments, confirming the findings from the analysis of variance. This analysis allowed us to identify the genotypes that excelled under both water conditions and how they performed (Figure 2).

4. Discussion

The negative effects of waterlogged conditions on leaf and root dry biomass, leaf area, and the number of tillers align with previous studies, which have reported similar findings (Mattos et al., 2005b). The increase in the dry biomass of dead material under waterlogged conditions observed here is consistent with findings in *U. decumbens* and *U. brizantha* cv. Marandu (Mattos et al., 2005a). The senescence response might be related to limitations in root function due to hypoxia or anoxia in the soil (Thomson and Greenway, 1991), or it may reflect the mobilization of nutrients from older to younger leaves, triggering premature senescence (Trought and Drew, 1980).

The effect that contrasted with previous studies was that waterlogged conditions did not affect leaf elongation rates in this experiment. A reduction in leaf elongation rates was expected in *U. mutica*, *U. humidicola*, *U. decumbens* cv. Basilisk, and *U. brizantha* cv. Marandu under waterlogging, as reported by Mattos et al. (2005b) and Dias-Filho and Carvalho (2000). Environmental conditions in the experiment, such as nutrient availability or soil properties compared to previous studies, may have influenced the response.

In Table 5 it is possible to identify genotypes with superior performance in both control and flooded conditions, based on the biplot analysis. Genotypes on the upper right quadrant in the biplot analysis of leaf dry biomass, stem dry biomass, dry biomass of aerial parts, roots dry biomass, leaf area, number of tillers, and leaf elongation rate, and genotypes on the lower left quadrant for dry biomass of dead material were considered to have a better performance for that descriptor compared to the mean of all genotypes. Although stem growth is not desirable in forage species and their management, genotypes with higher stem dry biomass were considered favorable in this analysis, as the experiment aimed to assess plant responses to stress.

Based on Table 5, the genotype BGP238 had a better performance than the mean of all genotypes for all descriptors, except leaf elongation rate. Genotypes BGP112, BGP169, BGP173, BGP308, BGP397, BGP402 and

Table 2. Analysis of variance (ANOVA) of leaf dry biomass, stem dry biomass, dry biomass of dead material, dry biomass of aerial parts, percentage dead material, roots dry biomass, leaf area, number of tillers, leaf elongation rate.

	Causes of variation		
Item	**Genotype**	**Treatment**	**Genotype x Treatment**
Leaf dry biomass, g pot^{-1}	**	**	
Stem dry biomass, g pot^{-1}	**		
Dry biomass of dead material, g pot^{-1}	**	*	
Dry biomass of aerial parts, g pot^{-1}	**	*	
Percentage dead material, %	**	**	*
Roots dry biomass, g pot^{-1}	**	**	
Leaf area, cm^2 pot^{-1}	**	**	
Number of tillers, units pot^{-1}	**	**	
Leaf elongation rate, cm tiller^{-1} pot^{-1}	**		

*p < 0.05; **p < 0.01.

Table 3. Effect of genotype over leaf dry biomass, stem dry biomass, dry biomass of dead material, dry biomass of aerial parts, roots dry biomass, leaf area, number of tillers, and leaf elongation rate.

Genotype	Leaf dry biomass (g pot^{-1})		Stem dry biomass (g pot^{-1})		Dry biomass of dead material (g pot^{-1})		Dry biomass of aerial parts (g pot^{-1})		Roots dry biomass (g pot^{-1})		Leaf area (cm^2 pot^{-1})		Number of tillers (unit pot^{-1})		Leaf elongation rate (cm tiller^{-1} day^{-1})	
BGP003	1.800	c	2.100	b	0.15	b	4.050	b	7.950	b	434.40	c	15.30	b	1.23	b
BGP112	2.950	b	4.583	a	0.38	a	7.917	a	19.400	a	555.00	b	11.20	c	1.26	b
BGP169	3.217	b	3.433	a	0.12	b	6.767	a	6.782	b	458.16	c	10.00	d	1.86	a
BGP173	3.417	b	3.750	a	0.02	b	7.183	a	5.950	b	447.92	c	8.80	d	2.09	a
BGP215 (Guará)	3.000	b	2.817	b	0.20	b	6.017	a	15.550	a	520.99	b	9.70	d	2.00	a
BGP219	1.667	c	2.583	b	0.38	a	4.633	b	6.600	b	447.48	c	21.50	a	0.92	b
BGP229	1.833	c	1.433	b	0.10	b	3.367	b	3.717	b	358.61	c	18.30	b	1.20	b
BGP234	2.033	c	3.933	a	0.43	a	6.400	a	8.017	b	553.00	b	21.80	a	1.07	b
BGP238	3.050	b	4.683	a	0.08	b	7.817	a	23.350	a	847.16	a	22.00	a	0.93	b
BGP248	3.117	b	2.800	b	0.27	a	6.183	a	9.217	b	514.29	b	8.30	d	1.90	a
BGP252	2.933	b	2.933	b	0.02	b	5.883	a	7.567	b	348.99	c	6.00	d	2.04	a
BGP253	2.050	c	1.917	b	0.13	b	4.100	b	8.233	b	335.66	c	10.70	c	1.16	b
BGP255	2.267	c	2.817	b	0.00	b	5.083	b	6.783	b	343.50	c	8.50	d	1.80	a
BGP267	5.167	a	1.933	b	0.50	a	7.600	a	18.900	a	605.48	b	13.80	c	1.13	b
BGP289	1.517	c	1.465	b	0.05	b	3.032	b	7.000	b	339.74	c	11.30	c	1.79	a
BGP293	1.700	c	1.867	b	0.28	a	3.850	b	5.983	b	440.35	c	12.00	c	1.72	a
BGP294	1.667	c	2.650	b	0.00	b	4.317	b	5.883	b	368.61	c	15.80	b	1.05	b
BGP295	1.950	c	2.000	b	0.13	b	4.083	b	4.767	b	457.59	c	11.80	c	0.69	b
BGP308	4.717	a	3.000	b	0.03	b	7.750	a	8.867	b	750.41	a	14.40	c	1.41	b
BGP365	2.750	b	2.617	b	0.18	b	5.550	b	9.183	b	409.88	c	12.20	c	1.59	a
BGP397	2.933	b	4.550	a	0.27	a	7.750	a	10.700	b	549.63	b	10.20	d	1.70	a
BGP402	2.367	c	3.450	a	0.28	a	6.100	a	12.300	b	542.87	b	10.00	d	1.78	a
BGP410	4.433	a	3.283	a	0.33	a	8.050	a	17.450	a	380.11	c	8.00	d	2.43	a
Marandu	2.650	b	1.867	b	0.13	b	4.650	b	7.733	b	395.86	c	8.30	d	1.57	a

Means of two water conditions (control and waterlogging conditions) and three replicates are presented. Values followed by the same lowercase letter in a colunm do not differ by the Scott Knott test considering a significance level of 5%. Highlighted cells indicate a better performance than U. brizantha cv. Marandu.

Table 4. Effect of water treatment condition (control and waterlogging) over leaf dry biomass, dry biomass of dead material, roots dry biomass, leaf area and number of tillers.

Item	Treatments			
	Control		Waterlogging	
Leaf dry biomass, g pot^{-1}	3,034	a	2,3972	b
Dry biomass of dead material, g pot^{-1}	0.1486	b	0.225	a
Dry biomass of aerial parts, g pot^{-1}	5,8805	a	5,6304	b
Roots dry biomass, g pot^{-1}	11,6374	a	8,18611	b
Leaf area, cm^2 pot^{-1}	541,0389	a	409,3935	b
Number of tillers, units pot^{-1}	13,6478	a	11,2816	b

Means of 24 genotypes and three replicates are presented. Values followed by the same lowercase letter in a row do not differ by the Scott Knott test considering a significance level of 5%.

BGP410 had a better performance in five of the descriptors evaluated, and were better than *P. regnellii* cv. BRS Guará, used as positive control in the present experiment because of its tolerance to waterlogging conditions (Matta et al., 2013). All these genotypes were placed in the upper right quadrant in the biplot analysis of dry biomass of aerial parts. Pezzopane et al. (2017) observed that the BGP112 and BGP238 under waterlogged conditions exhibited higher aboveground biomass compared to the control treatment, a finding also reported by Santos et al. (2021).

Among the highlighted genotypes, BGP112, BGP238, BGP410 showed high root dry biomass on both conditions. The allocation of dry biomass to the root system is one of the strategies plants use to survive waterlogging conditions and is generally observed in plants tolerant to this stress (Armstrong et al., 1994; Liao and Lin, 2001).

The genotypes BGP238, BGP112 and BGP410 seem to be promising for use in areas with risk of occurrence

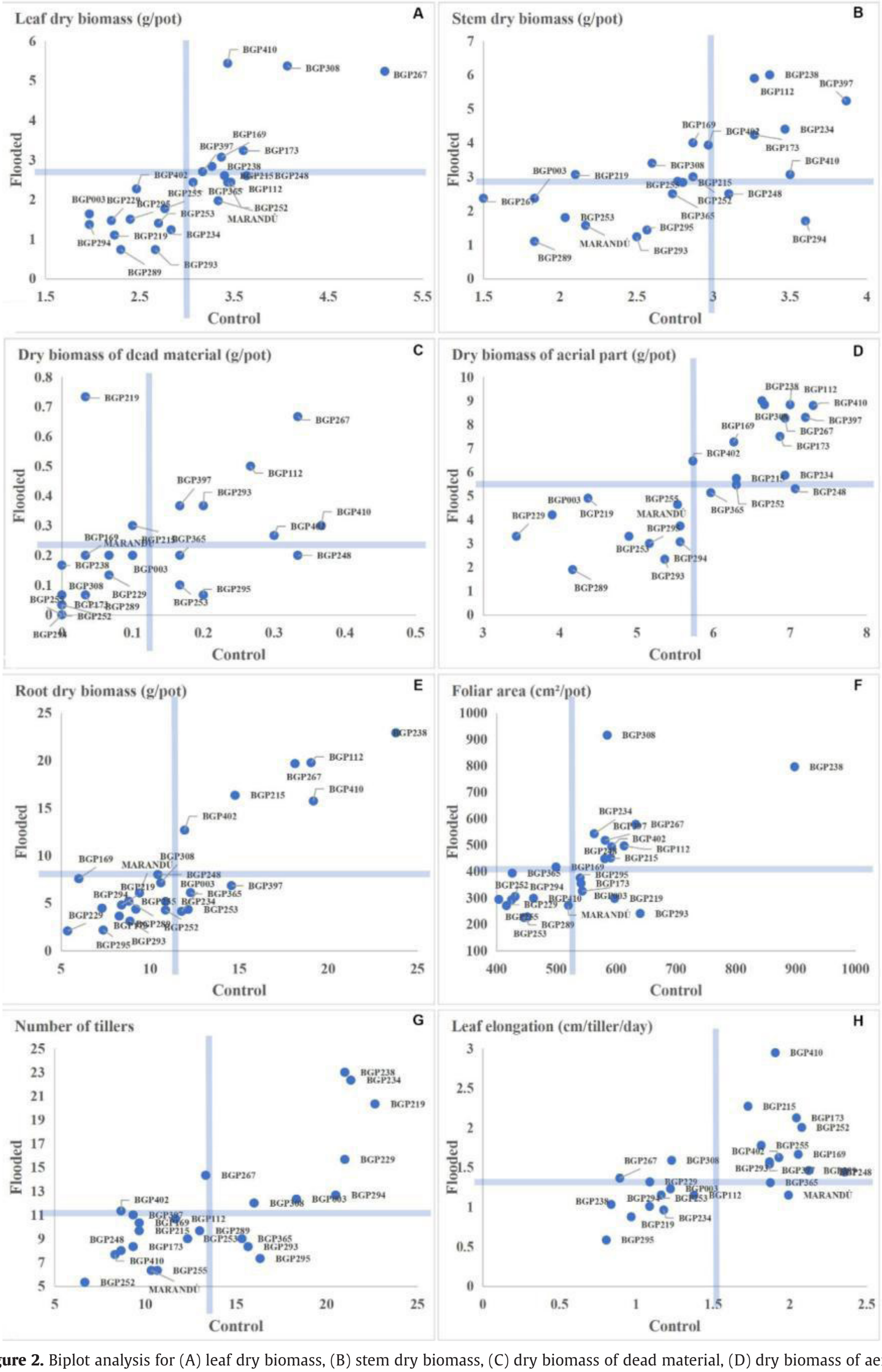

Figure 2. Biplot analysis for (A) leaf dry biomass, (B) stem dry biomass, (C) dry biomass of dead material, (D) dry biomass of aerial parts, (E) roots dry biomass, (F) leaf area, (G) number of tillers, and (H) leaf elongation rate.

Table 5. Genotypes classification based on the number of descriptors with a better performance in the biplot analisys.

Genotype	Leaf dry mass	Stem dry mass	Dry mass of dead material	Dry mass of aerial parts	Roots dry mass	Leaf area	Number of tillers	Leaf elongation rate	Number of descriptors with a better performance
BGP003			X				X		2
BGP112	X	X		X	X	X			5
BGP169	X	X	X	X				X	5
BGP173	X	X	X	X				X	5
BGP215 (Guará)	X			X	X	X			4
BGP219							X		1
BGP229			X				X		2
BGP234		X		X		X	X		4
BGP238	X	X	X	X	X	X	X		7
BGP248	X					X		X	3
BGP252	X	X	X					X	4
BGP253									0
BGP255			X					X	2
BGP267	X			X	X	X			4
BGP289			X						1
BGP293									0
BGP294			X				X		2
BGP295									0
BGP308	X		X	X		X	X		5
BGP365	X							X	2
BGP397	X	X		X		X		X	5
BGP402		X		X	X	X		X	5
BGP410	X	X		X	X			X	5

Genotypes on the upper right quadrant in the biplot analysis of leaf dry biomass, stem dry biomass, dry biomass of aerial parts, roots dry biomass, leaf area, number of tillers, and leaf elongation rate, and genotypes on the lower left quadrant for dry biomass of dead material were considered to have a better performance for that descriptor than the mean of all genotypes.

of seasonal waterlogging conditions. They had a better performance than the mean of all genotypes in both control and waterlogging conditions, as shown by the biplot analysis (Table 5, Figure 2) and achieved statistically superior results compared to *U. brizantha* cv. Marandu (Table 3). Santos et al. (2021) also pointed out that the BGP112 is promising for use in poorly drained soils.

Accession BGP238 is a natural hybrid between the species *P. urvillei* and *P. dilatatum* collected in Xangri-lá, Rio Grande do Sul, near the coast. According to Zuloaga and Morrone (2005), *P. urvillei* is native from Bolivia, Brazil, Chile, Paraguay, Argentina and Uruguay. It is considered a weed of several cultures, it has a natural occurrence on roadsides, estuaries, and low fields. *P. dilatatum*, on the other hand, can be found in fields, along roadsides, mainly in fertile areas.

According to the same authors, *Paspalum regnellii* has a natural occurrence from the center of Brazil to the south, northeast of Argentina and east of Paraguay. It is often found in forest edges, disturbed environments, in places with clayey and humid soils. Therefore, it is also possible to assume that this species has tolerance to waterlogging due to its adaptation to the region of natural occurrence, hence the best results in this work for accessions BGP112, 397 and 402.

BGP410 corresponds to *Paspalum plenum*, a species described by Zuloaga and Morrone (2005) as being distributed from Mexico to Brazil, Paraguay, and northern Argentina. Its occurrence is typically found in lowlands, riverbanks, road margins, and along canals and ditches. Therefore, this species may have a natural adaptation to temporary waterlogging conditions.

In summary, this study demonstrates that waterlogging has a negative effect on the development of all genotypes evaluated. The genotypes BGP238 (*Paspalum urvillei* Steud. x *Paspalum dilatatum* Poir.), BGP112 (*Paspalum regnellii*), and BGP410 (*Paspalum plenum*) showed promise for use in areas at risk of seasonal waterlogging conditions and should be further evaluated under field conditions.

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References

ARMSTRONG, W., BRÄNDLE, R. and JACKSON, M., 1994. Mechanisms of flood tolerance in plants. *Acta Botanica Neerlandica*, vol. 43, no. 4, pp. 307-358. http://doi.org/10.1111/j.1438-8677.1994.tb00756.x.

BELONI, T., PEZZOPANE, C.G., ROVADOSCKI, G.A., FÁVERO, A.P., DIAS-FILHO, M.B. and SANTOS, P.M., 2017. Morphological and physiological responses and the recovery ability of *Paspalum* accessions to water deficit and waterlogging. *Grass and Forage Science*, vol. 72, no. 4, pp. 840-850. http://doi.org/10.1111/gfs.12281.

CAETANO, L.P.S. and DIAS-FILHO, M.B., 2008. Responses of six *Brachiaria* spp. accessions to root zone flooding. *Revista Brasileira de Zootecnia*, vol. 37, no. 5, pp. 795-801. http://doi.org/10.1590/S1516-35982008000500003.

COELHO-SOUZA, S.A., GUIMARÃES, J.R.D., MIRANDA, M.R., POIRIER, H., MAURO, J.B.N., LUCOTTE, M. and MERGLER, D., 2011. Mercury and flooding cycles in the Tapajós river basin, Brazilian Amazon: the role of periphyton of a floating macrophyte (*Paspalum repens*). *The Science of the Total Environment*, vol. 409, no. 14, pp. 2746-2753. http://doi.org/10.1016/j.scitotenv.2011.03.028. PMid:21536317.

COLMER, T.D. and VOESENEK, L.A.C.J., 2009. Flooding tolerance: suites of plant traits in variable environments. *Functional Plant Biology*, vol. 36, no. 8, pp. 665-681. http://doi.org/10.1071/FP09144. PMid:32688679.

DIAS-FILHO, M.B., 2011. *Degradação de pastagens: processos, causas e estratégias de recuperação.* 4. ed. Belém: Editora do Autor, 204 p.

DIAS-FILHO, M.B. and CARVALHO, C.J.R., 2000. Physiological and morphological responces of *Brachiaria* spp. to flooding. *Pesquisa Agropecuária Brasileira*, vol. 35, no. 10, pp. 1959-1966. http://doi.org/10.1590/S0100-204X2000001000006.

DIAS-FILHO, M.B. and LOPES, M.J. S., 2012. *Triagem de forrageiras para tolerância ao excesso de água no solo.* 1. ed. Belém: Embrapa Amazônia Oriental, 29 p. Documentos, no. 381.

HARE, M., SAENGKHAM, M., TATSAPONG, P., WONGPICHET, K. and TUDSRI, S., 2004. Waterlogging tolerance of some tropical pasture grasses. *Tropical Grasslands*, vol. 38, pp. 227-233.

LIAO, C.T. and LIN, C.H., 2001. Physiological adaptation of crop plants to flooding stress. *Proceedings of the National Science Council Republic of China*, vol. 25, no. 3, pp. 148-157. PMid:11480770.

LORETI, J. and OESTERHELD, M., 1996. Intraspecific variation in the resistance to flooding and drought in populations of Paspalum dilatatum from different topographic positions. *Oecologia*, vol. 108, no. 2, pp. 279-284. http://doi.org/10.1007/BF00334652. PMid:28307840.

MALAVOLTA, E., 1980. *Elementos de nutrição mineral das plantas*. 1. ed. São Paulo: Agronômica Ceres, 251 p.

MATTA, F.P., COSTA, A.C.S., MAGRINI, V., GRACIANO, C., MARQUES, G., FERREIRA, R. and SHIRATA, D., 2013. Avaliação da tolerância ao encharcamento e alagamento de *Paspalum regnellii*. In: *Anais do Congresso Brazileiro de Melhoramento de Plantas*, 2013, Uberlândia, Brazil. São Carlos: Embrapa Pecuária Sudeste, 4 p.

MATTOS, J.L.S., GOMIDE, J.A., MARTINEZ, Y. and HUAMAN, C.A., 2005a. Effect of water deficit and flooding on the growth of *Brachiaria* species in the field. *Revista Brasileira de Zootecnia*, vol. 34, no. 3, pp. 755-764. http://doi.org/10.1590/S1516-35982005000300006.

MATTOS, J.L.S., GOMIDE, J.A., MARTINEZ, Y. and HUAMAN, C.A., 2005b. Effect of flooding on the growth of *Brachiaria* species in greenhouse. *Revista Brasileira de Zootecnia*, vol. 34, pp. 765-773. http://doi.org/10.1590/S1516-35982005000300007.

OMOTE, H., CASTRO, L.M., GRACIANO, V.A., SANTOS, R.C.D., SOUZA, J.D.F.D., VAZ, A.P.A., ARAÚJO, A.R.D., SALMAN, A.K.D., BUENO, L.G., KÖPP, M.M., ANTÔNIO, R.P., EUCLIDES, V.P.B., GUARDA, V.D.A. and SANTOS, P.M., 2021. *Monitoramento tecnológico de cultivares de forrageiras no Brasil*. São Carlos: Embrapa Pecuária Sudeste, 34 p.

PENTEADO, M.I.O. and MACEDO, M.C.M., 2000. Evaluation of forage species under savanna poor soil drainage conditions. *Revista Brasileira de Zootecnia*, vol. 29, pp. 1616-1622. http://doi.org/10.1590/S1516-35982000000600004.

PEZZOPANE, C.D.G., LIMA, A.G., DA-CRUZ, P.G., BELONI, T., FÁVERO, A.P. and SANTOS, P.M., 2017. Evaluation and strategies of tolerance to water stress in *Paspalum germplasm. Tropical Grasslands-Forrajes Tropicales*, vol. 5, no. 3, pp. 153-162. http://doi.org/10.17138/TGFT(5)153-162.

RAMOS, A.K.B., LEITE, G.G., FERNANDES, F.D. and VILELA, L., 2002. *Uso e manejo de pastagens de capim pojuca: origem, adaptação e características gerais.* 1. ed. Planaltina: Embrapa Cerrados, 7 p. Circular Técnica, no. 21.

RIBEIRO-JÚNIOR, N.G., FAGUNDES, O.S., BENEVENUTI, A.S., YAMASHITA, O.M., ROSSI, A.A.B., CARVALHO, M.A.C. and SILVA, I.V., 2017. Tropical forages: morphoanatomy of plants grown in areas with the death of pasture syndrome. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 77, no. 4, pp. 868-875. http://doi.org/10.1590/1519-6984.05116. PMid:28492803.

SANTOS, P.M., MATTA, F. P., CAVALLARI, M.M. and PEZZOPANE, J.R.M., 2021. *Selection of Paspalum accessions for use in poorly drained soils.* 1. ed. São Carlos: Embrapa Pecuária Sudeste, 18 p. Boletim de Pesquisa e Desenvolvimento, no. 51.

SISTEMA ALELOVEGETAL CONSULTAS – AV-CONSULTAS, 2021 [viewed 14 May 2023]. *Empresa Brasileira de Pesquisa Agropecuária* [online]. Available from: https://av.cenargen.embrapa.br/avconsulta/Passaporte/busca.do

THOMSON, C.J. and GREENWAY, H., 1991. Metabolic evidence for stelar anoxia in maize roots exposed to low O(2) concentrations. *Plant Physiology*, vol. 96, no. 4, pp. 1294-1301. http://doi.org/10.1104/pp.96.4.1294. PMid:16668333.

TROUGHT, M.C.T. and DREW, M.C., 1980. The development of waterlogging damage in wheat seedlings (*Triticum aestivum* L.). *Plant and Soil*, vol. 56, no. 2, pp. 187-199. http://doi.org/10.1007/BF02205847.

ZULOAGA, F.O. and MORRONE, O., 2005. Revisión de las especies de *Paspalum* para América del Sur Austral (Argentina, Bolivia, sur de Brazil, Chile, Paraguay y Uruguay). *Monographs in Systematic Botany from the Missouri Botanical Garden*, vol. 102, pp. 1-297.