p-ISSN 2615-787X e-ISSN 2615-790X
Accredited by Directorate General of Strengthening for Research and Development No: 30/E/KPT/2018

Tropical Animal Science Journal, September 2022, 45(3):308-318
DOI: https://doi.org/10.5398/tasj.2022.45.3.308
Available online at http://journal.ipb.ac.id/index.php/tasj

Production Potential and Quality of *Panicum maximum* Cultivars Established in a Semi-Arid Environment

M. de G. Pereira*, G. dos S. Difante, L. C. V. Ítavo, J. G. Rodrigues, A. L. C. Gurgel, A. M. Dias, C. C. B. F. Ítavo, E. L. de L. Veras, A. B. G. da Costa, & G. O. de A. Monteiro
Faculty of Veterinary Medicine and Animal Science, Federal University of Mato Grosso do Sul
Avenida Senador Filinto Müller 2.443, Campo Grande, 79074-460, MS, Brazil
*Corresponding author: marislayne@outlook.com
(Received 26-06-2021; Revised 24-08-2021; Accepted 27-10-2021)

ABSTRACT

This study was conducted to examine the forage production potential and quality of *Panicum maximum* cultivars in a semi-arid environment, in four different periods. Six cultivars were evaluated: Aruana, Massai, Mombasa, BRS Tamani, Tanzania, and BRS Zuri. The experiment was laid out in a randomized-block design with four replicates, and assessments took place in four different periods (establishment, dry season, transition, and rainy season). Forage accumulation rate (FAR), chemical composition, digestibility, and *in vitro* rumen degradation kinetics were evaluated. There was an interaction effect between cultivars and evaluation periods for all variables, except dry matter (DM) content. The highest FAR occurred in cvs. BRS Tamani (47.0 kg DM/ha/day) and BRS Zuri (86.9 kg DM/ha/day) in the establishment and rainy periods, respectively, while cv. Aruana showed the lowest FAR (14.5 kg DM/ha/day). The highest crude protein contents were found in cv. BRS Tamani in the transition period; cv. BRS Zuri in the dry season; and cv. Tanzania in the rainy season (128.2, 116.7, and 95.0 g/kg DM, respectively). Cultivar Aruana showed the highest average *in vitro* dry matter digestibility (810.0 g/kg DM). Cultivars Aruana and Zuri exhibited the highest means of the total *in vitro* gas production (23.59 and 20.24 mL/100 mg DM, respectively). Cultivars BRS Tamani and BRS Zuri had the best response in terms of forage accumulation and nutritional value. The quality of cv. Massai remained constant throughout the year. All *Panicum maximum* cultivars evaluated here have the potential for use in animal production systems in a semi-arid environment.

Keywords: chemical composition; forage accumulation; in vitro digestibility; in vitro gas production; Megathyrsus maximus; water deficit

INTRODUCTION

Among the many existing ruminant-production models, animals raised on pasture stand out as the most practical and economic systems (Porto *et al.*, 2017). However, in semi-arid environments, this activity is strongly affected by long periods of drought that compromise animal husbandry on pasture (Oliveira *et al.*, 2017). Irregular rainfall distribution can lead to changes in forage plant growth (Magalhães *et al.*, 2012). Nonetheless, forage cultivars have the adaptive capacity, even in adverse situations—a trait may render them suitable to intensify systems with sustainability in other regions (Campos *et al.*, 2016).

The use of forage species with high production potential and nutritional quality is an important tool that provides sustainability to production systems (Braz *et al.*, 2017), as animal performance is directly affected by forage quantity and quality (Cleland *et al.*, 2018). Therefore, the search for high-yielding tropical forage crops of high nutritional value that can adapt to semi-arid regions' climatic conditions has become a fundamental premise for the success of pasture-based animal production systems.

The *Panicum maximum* species emerges as an alternative for use in semi-arid environments due to its high nutritional quality and forage production capacity and adaptability to different soil-climatic conditions (Veras *et al.*, 2020). In this respect, several studies have been carried out in recent years with this species in semi-arid environments (Njarui *et al.*, 2015; Oliveira *et al.*, 2018; Oliveira *et al.*, 2019; Veras *et al.*, 2020). However, there is still little information about the potential of more forage cultivars as alternatives for forage production in the semi-arid region, as well as the understanding of their responses to the environment. These processes can affect their nutritional values and the consequences of using these grasses on the kinetics of *in vitro* rumen degradation in different periods. Therefore, the present study was undertaken to evaluate the production potential of *P. maximum* cultivars in a semi-arid environment based on their forage accumulation rate, chemical

composition, digestibility, and kinetics of *in vitro* rumen degradation in four periods (establishment, dry season, transition, and rainy season).

MATERIALS AND METHODS

Location

The experiment was carried out at the Federal University of Rio Grande do Norte (UFRN), Macaíba Campus, Brazil (5°53'35.12" S, 35°21'47.03" W, 11 m above sea level). The experimental period was from April 10, 2016, to April 1, 2017. The climate in the region is classified as a dry sub-humid type, with water surplus occurring between May and August (Thornthwaite, 1948). To monitor the daily precipitation, a rain gauge was installed in the area, whereas temperature and evapotranspiration data were obtained from the National Institute of Meteorology database. The water balance was calculated by the Thornthwaite & Mather method (1955), adopting a soil water-holding capacity of 25 mm (Figure 1).

The soil in the experimental area belongs to the Arenosol class (FAO, 2014). Fertilization and soil correction was carried out based on the result of soil analysis (Table 1). For correction and time-of-planting fertilization, 500 kg/ha limestone, 164 kg/ha potassium chloride, 105 kg/ha single superphosphate, and 100 kg/ha/year nitrogen (as ammonium sulfate) were applied on two occasions: 45 days after planting and after the establishment period.

Experimental Design

The treatments consisted of six *Panicum maximum* cultivars, namely, Aruana, Massai, Mombasa, BRS Tamani, Tanzania, and BRS Zuri. The experiment was laid out as a split-plot arrangement in a randomized-block design with six treatments (cultivars) and four replicates. The cultivars represented the plot and the periods of the subplot. The blocks were composed of six plots with a total area of 4.0 m^2, a usable area of 1.3 m^2, and a bordering area of 0.70 m^2. The blocks were spaced 2.0 m apart and the plots 1.0 m apart, totaling 24 plots in a 375-m^2 area. Sowing was carried out as described by Rodrigues *et al.* (2021).

Harvesting and Processing of Samples

The forage was harvested when its canopy intercepted on average 90% of the incident light, with the first cut taking place 110 days after sowing (establishment period), then at 84 days of regrowth after the first cut (dry season); at 111 days of regrowth after the second cut (transition period); and at 51 days of regrowth after the third cut (rainy season). All forage contained in an area of 1.0 m^2 of each plot was collected by cutting the grass at 15 cm from ground level. The sample was

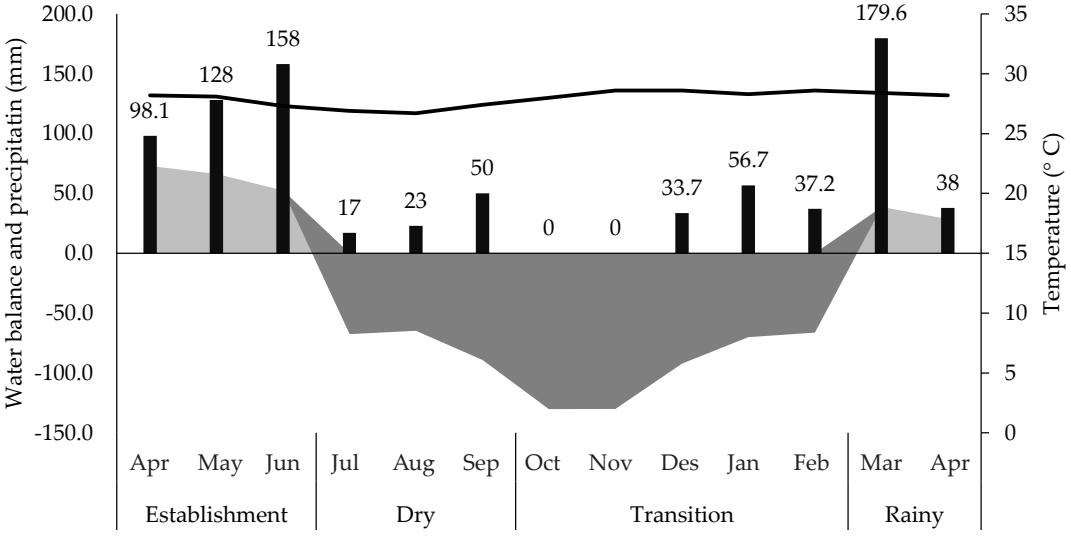

Figure 1. Water balance, precipitation, and average temperature from April 2016 to April 2017 in Macaíba, Rio Grande do Norte, Brazil. = surplus; = deficit; = precipitation; = temperature.

Table 1. Chemical characteristics of the soil in the experimental area in the 0-20 and 20-40 cm deep layers

Layer (cm)	Chemical characteristics												
	P	K	Na	pH	Ca	Mg	Al	H+Al	CEC	BS (%)	Particle size (%)		
	-- mg/dm^3 --				------- cmol$_c$/dm^3 -------						Sand	Silt	Clay
0-20	18	63	20	6.6	3.1	0.2	0.0	1.2	4.4	72.0	84.6	4.0	11.4
20-40	8	49	13	5.6	0.9	0.1	0.0	1.1	2.2	49.6	85.2	2.0	12.8

Note: Source= Soil Laboratory of the Agricultural Research Corporation of Rio Grande do Norte. pH= pH in water (1:2.5). Chemical characteristics: CEC= cation-exchange capacity at pH 7.0 [BS+(H+Al)]; BS= base saturation [(BS/CEC) * 100]; P= phosphorus; K= Potassium; Na= Sodium; Ca= calcium; Mg= magnesium; Al= Aluminum; H+Al= hydrogen + aluminum.

weighed and a sub-sample was taken for the separation of morphological components. Forage accumulation rate (FAR) was calculated by dividing the weight of collected forage mass by the duration of each period. The leaf blades were weighed, dried, and ground to 1 mm and sent for laboratory analysis, using two replicates of each plot.

Laboratory Analysis

Analyses were performed at the Laboratory of Applied Nutrition at the Faculty of Veterinary Medicine and Animal Science, Federal University of Mato Grosso do Sul (UFMS). To determine the organic matter (OM) content of the samples, the dry matter (DM) and ash contents were measured according to methods 930.15 and 942.05 of the Association of Official Analysis Chemists International (AOAC, 2000), respectively. The nitrogen content was quantified by method 976.05 (AOAC, 2000), where the constant factor of 6.25 was applied to convert the total nitrogen content into crude protein (CP). The neutral (NDF) and acid (ADF) detergent fiber contents were determined following the method proposed by Van Soest & Robertson (1985). Protodioscin was extracted and quantified following the method proposed by Ganzera *et al.* (2001).

In vitro digestibility was assessed following the method proposed by Tilley & Terry (1963) with modifications and adapted to the Ankom Daisy System (Ankom Technology Corp., Macedon, NY, USA), as described by Holden (1999). The procedure consisted of incubating 0.5-g samples of plant material in synthetic polypropylene fabric bags (5×5 cm, 100 μm) for 48 h in the first stage, followed by an additional 24-h incubation after the addition of 40 mL HCl (6N) and 8 g pepsin. The samples were incubated in jars with a Bunsen valve, containing 1.600 mL of buffer solution type A (per L): 10.0 g KH_2PO_4, 0.5 g $MgSO_47H_2O$, 0.5 g NaCl, 0.1 g $CaCl_22H_2O$, and 0.5 g urea; buffer solution type B (per 100 mL): 15.0 g Na_2CO_3, 1.0 g $Na_2S_9H_2O$ (at the B:A ratio of 1:5, to reach a final pH value of 6.8); and 400 mL of sheep rumen inoculum. At the end of the incubation period, the bags were washed, dried (55 °C/24 h), weighed, and corrected, using blank bags, for bacterial contamination (Holden, 1999).

To determine the *in vitro* digestibility of dry matter (IVD_{DM}), organic matter (IVD_{OM}), crude protein (IVD_{CP}), neutral detergent fiber (IVD_{NDF}), and acid detergent fiber (IVD_{ADF}), we followed the same procedures for composition analysis mentioned above and calculated the difference between the nutrients contained in the vegetable sample and the nutrients present in the residue.

Cumulative in vitro gas production was analyzed using the ANKOM® RF Gas Production system (Ankom Technology Corp., Macedon, NY, USA). Twenty-four bottles equipped with pressure sensors connected wirelessly to a computer were used. The samples were incubated in triplicate for 48 h. Each bottle (310 mL) was filled with 0.5000±0.0005 g of plant material and 100 mL of buffer solution composed of solutions A and B mentioned above. The mixture was preheated to 39 °C to receive 25 mL of inoculum, which was obtained by mixing rumen fluids collected from three sheep. Before the pressure sensor was attached to the bottles, CO_2 was purged into them to provide an anaerobic environment. Three bottles containing solutions A and B and rumen fluid were incubated to correct bacterial growth. Data were recorded every 5 min and processed at the end for cumulative gas production in mL of gas/100 mg of incubated DM. To determine the gas production kinetic parameters, the two-compartment logistic model proposed by Schofield *et al.* (1994) was used:

$$Y = A/(1+exp^{(2-4*B*(Lag-t))}) + D/(1+exp^{(2-4*E*(Lag-t))})$$

where Y is the cumulative gas production at time t (mL/100 mg DM); A and D represent the volume of gas produced by the degradation of non-fibrous carbohydrates (NFC) and soluble compounds, and fibrous carbohydrates, respectively; B and E are the rates of degradation of NFC and soluble compounds, and fibrous carbohydrates, respectively; and Lag is the time (h) the bacteria take to colonize the particle.

Statistical Analysis

Results were subjected to analysis of variance. When significant by the F test, the effects of the sources of variation and interactions were compared by Tukey's test at 5% significance. For the nutritional value and digestibility of the morphological components, the following statistical model was used:

$$Y_{ijk} = \mu + C_i + P_j + B_k + CP_{ij} + \varepsilon_{ijk},$$

where Y_{ijk} was observed value of cultivar i in period j and block k; μ was overall mean effect; C_i was effect of cultivar i; P_j was effect of period j; B_k was effect of block k; CP_{ij} was interaction effect between cultivar i and period j; and ε_{ijk} was random error effect.

The cumulative *in vitro* gas production parameters were estimated by the Gauss-Newton method, using SAEG software (System for Statistical and Genetic Analysis; UFV, 1997). Means were subjected to analysis of variance, and when significant by the F test, they were analyzed by Tukey's test at a significance level of 5%. Finally, correlations were obtained by Pearson correlation analysis and the t-test, considering significance at $p \leq 0.05$.

RESULTS

Forage Accumulation Rate

There was a significant interaction effect ($p<0.0001$) between cultivars and evaluation periods for FAR. The lowest FAR was observed in cv. Aruana in the dry season and the transition period. The highest FAR, in turn, were shown by cv. Zuri during the rainy season and in cv. Tamani during the establishment period (Table 2).

Chemical Composition

There was no significant interaction effect between cultivars and periods for DM content. The highest average DM content was found in cv. Aruana (444.2 g/

kg), and the lowest in cvs. Mombasa (345.0 g/kg) and Tanzania (340.0 g/kg) (Figure 2A).

The cultivars showed similar average DM contents (412.3 g/kg) in the establishment, dry, and transition periods. The lowest average DM content (286.0 g/kg) was observed during the rainy season (Figure 2B).

There was an interaction effect between cultivars and periods for the OM (p<0.001), CP (p<0.001), NDF (p=0.0179), ADF (p<0.001), and protodioscin (p<0.001) contents (Table 3). The highest average OM contents were observed in cvs. Massai (925.5 g/kg DM), Mombasa (924.2 g/kg of DM), and Tamani (918.0 g/kg DM) in the establishment period; cvs. Mombasa and Tamani in the dry season (914.2 and 914.0 g/kg DM, respectively); cv. Tanzania (922.5 g/kg DM) in the transition period; and cvs. Aruana, Massai, Mombasa, and Zuri in the rainy season. In contrast, the lowest OM contents were detected in cvs. Tamani and Zuri in the transition period (901.2 and 908.8 g/kg DM, respectively). The highest average CP contents were observed in cv. Zuri in the dry season and cv. Tamani in the transition period (116.7 and 128.2 g/kg DM, respectively). The lowest CP means, in turn, were found in cvs. Massai and Zuri in the establishment period (66.2 and 64.7 g/kg DM, respectively) (Table 3).

The highest NDF contents were observed in cv. Zuri in the establishment period (827.5 g/kg DM) and cvs. Massai, Mombasa, Tamani, and Tanzania during the rainy season (766.0, 746.5, 762.0, and 750.7 g/kg DM, respectively). The lowest NDF contents, in turn, were detected in cv. Aruana (644.5 g/kg DM). As regards ADF, the highest contents were observed in cv. Tamani in its establishment; cv. Tanzania in the dry season; and cv. Mombasa in the transition period (623.5, 503.2 and 694.7 g/kg DM, respectively). The transition period concentrated the lowest ADF means, especially for cv. Aruana (380.0 g/kg DM). The highest protodioscin content was detected in cv. Aruana during the transition period (1.14 g/kg DM). In the same period, the lowest mean for this variable was observed in cv. Tamani (0.93 g/kg DM) (Table 3).

In Vitro Digestibility

There were significant interaction effects between cultivars and periods for IVD_{DM} (p<0.001), IVD_{OM} (p<0.001), IVD_{CP} (p<0.001), IVD_{NDF} (p<0.001), and IVD_{ADF} (p<0.001) (Table 4). The highest IVD_{DM} occurred during the transition and rainy periods in cv. Aruana (826.0 and 810.0 g/kg DM, respectively). During the establishment period, cv. Zuri exhibited the lowest IVD_{DM} (633.0 g/kg of DM). Cultivar Massai showed a similar response for IVD_{OM} (717.5 g/kg DM), which, in the establishment period, was similar to the mean IVD_{OM} of cv. Aruana in the transition and rainy periods (810.0 and 798.0 g/kg DM, respectively) (Table 4).

The highest IVD_{CP} was found in cv. Zuri during the dry season (928.5 g/kg DM), cv. Aruana in the transition period (912.0 g/kg DM), and cv. Tamani in the rainy season (827.5 g/kg DM). The lowest IVD_{CP} was detected in cv. Mombasa in the rainy season (771.5 g/kg DM) and cv. Tanzania in the establishment period (756.0 g/

Table 2. Forage accumulation rate (FAR, kg DM/ha/day) of *Panicum maximum* cultivars grown in a semi-arid environment

Periods	Cultivars						SEM	P-value
	Aruana	Massai	Mombasa	Tamani	Tanzania	Zuri		
Establishment	27.9 ^{bA}	27.0 ^{bC}	27.4 ^{bC}	47.0 ^{aA}	33.5 ^{abBC}	24.7 ^{bB}	3.4	0.007
Dry	13.4 ^{bB}	47.3 ^{aB}	44.4 ^{aB}	31.0 ^{abB}	46.1 ^{aAB}	34.8 ^{aB}	5.2	<0.001
Transition	14.5 ^{aB}	24.1 ^{aC}	29.8 ^{aC}	20.7 ^{aB}	30.2 ^{aC}	25.8 ^{aB}	2.4	0.1
Rainy	36.2 ^{dA}	81.6 ^{abA}	63.8 ^{bcA}	53.4 ^{cdA}	58.5 ^{cA}	86.9 ^{aA}	7.6	<0.001
SEM	5.5	13.5	8.4	7.4	6.5	14.8		
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		

Note: Means with different lowercase superscripts in the same row and uppercase superscripts in the same column differ significantly (p<0.05). Establishment period (110 days), dry season (84 days), transition period (111 days), and rainy season (51 days). SEM= standard error of the mean.

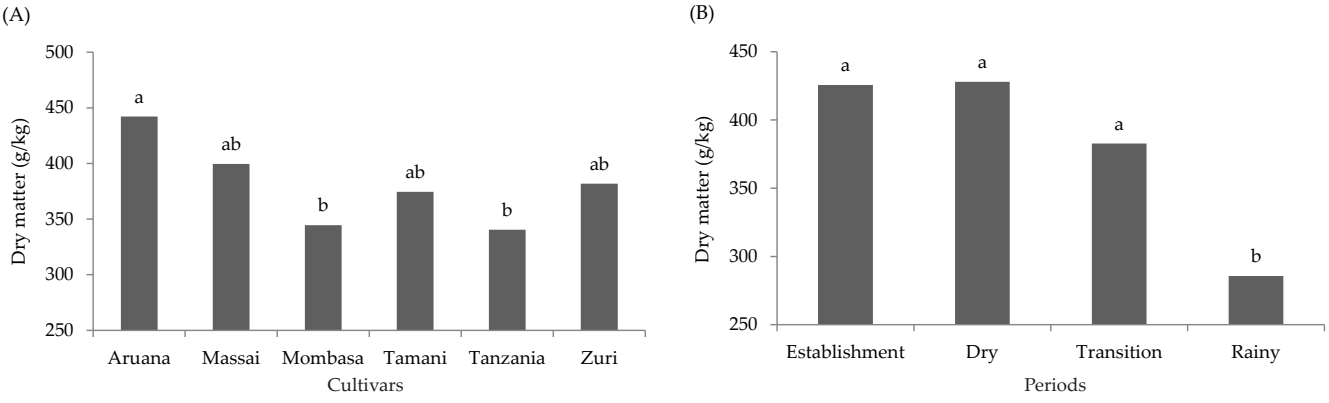

Figure 2. Dry matter content of several *Panicum maximum* cultivars grown in a semi-arid environment. ^{a,b}Distinct lowercase letters differ (p<0.05) according to Tukey's test.

Table 3. Mean contents of organic matter, crude protein, neutral detergent fiber, acid detergent fiber, and protodioscin in *Panicum maximum* cultivars grown in a semi-arid environment

Period	Cultivar						SEM	p-value
	Aruana	Massai	Mombasa	Tamani	Tanzania	Zuri		
	Organic matter (g/kg DM)							
Establishment	921.0 ^{aAB}	925.5 ^{aA}	924.2 ^{aA}	918.0 ^{aA}	919.2 ^{aAB}	865.2 ^{bC}	9.4	<0.001
Dry	917.5 ^{aAB}	911.0 ^{aB}	914.2 ^{aA}	914.0 ^{aA}	909.0 ^{aB}	842.7 ^{bD}	11.8	<0.001
Transition	909.7 ^{abB}	912.0 ^{abB}	913.7 ^{abA}	901.2 ^{bB}	922.5 ^{aA}	908.8 ^{bB}	2.8	<0.001
Rainy	922.5 ^{aA}	928.2 ^{aA}	923.2 ^{aA}	852.0 ^{bC}	917.7 ^{aAB}	921.0 ^{aA}	11.8	<0.001
SEM	2.8	4.4	2.8	15.2	2.8	18.3		
p-value	0.031	<0.001	0.033	<0.001	0.028	<0.001		
	Crude protein (g/kg DM)							
Establishment	80.2 ^{bC}	66.2 ^{cC}	62.5 ^{cB}	93.0 ^{aC}	77.2 ^{bB}	64.7 ^{cC}	4.7	<0.001
Dry	94.0 ^{bB}	101.5 ^{bA}	82.2 ^{cA}	115.0 ^{aB}	75.2 ^{cB}	116.7 ^{aA}	6.8	<0.001
Transition	115.0 ^{bA}	84.2 ^{cB}	66.0 ^{dB}	128.2 ^{aA}	87.0 ^{cA}	115.5 ^{bA}	9.7	<0.001
Rainy	79.7 ^{bC}	61.5 ^{dC}	64.0 ^{dB}	88.5 ^{abC}	95.0 ^{aA}	74.0 ^{cB}	5.4	<0.001
SEM	8.2	9.1	4.5	9.3	4.5	13.6		
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
	Neutral detergent fiber (g/kg DM)							
Establishment	778.7 ^{bA}	762.0 ^{bA}	770.7 ^{bA}	773.7 ^{bA}	789.0 ^{abA}	827.5 ^{aA}	9.5	0.002
Dry	694.2 ^{abB}	724.0 ^{aAB}	700.5 ^{abB}	674.0 ^{bB}	719.5 ^{abB}	729.7 ^{aB}	8.7	0.007
Transition	644.5 ^{cC}	703.2 ^{abB}	690.5 ^{abcB}	669.2 ^{bcB}	717.7 ^{aB}	735.2 ^{aB}	13.4	<0.001
Rainy	731.5 ^{aB}	766.0 ^{aA}	746.5 ^{aA}	762.0 ^{aA}	750.7 ^{aA}	768.2 ^{aB}	5.7	0.187
SEM	28.4	15.2	18.9	27.9	16.7	22.4		
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
	Acid detergent fiber (g/kg DM)							
Establishment	450.0 ^{dA}	466.2 ^{cdB}	612.5 ^{abB}	623.5 ^{aA}	511.0 ^{cA}	567.5 ^{bA}	30.2	<0.001
Dry	417.5 ^{bAB}	474.0 ^{aAB}	491.2 ^{aC}	496.5 ^{aBC}	503.2 ^{aA}	503.5 ^{aB}	13.4	<0.001
Transition	380.0 ^{cB}	463.5 ^{bB}	694.7 ^{aA}	476.0 ^{bB}	475.0 ^{bA}	517.0 ^{bB}	42.9	<0.001
Rainy	436.2 ^{cA}	521.0 ^{abA}	534.7 ^{aC}	543.7 ^{aB}	466.7 ^{bcA}	551.0 ^{aAB}	19	<0.001
SEM	15.2	13.5	44.8	32.7	10.7	14.8		
p-value	0.002	0.009	<0.001	<0.001	0.054	0.003		
	Protodioscin (g/kg DM)							
Establishment	1.01 ^{aB}	0.94 ^{cB}	0.96 ^{bA}	0.94 ^{cBC}	0.96 ^{bA}	0.96 ^{bA}	0,01	<0.001
Dry	1.02 ^{aB}	0.95 Cab	0.95 ^{cA}	0.96 ^{bcA}	0.95 ^{cAB}	0.97 ^{bA}	0,01	<0.001
Transition	1.14 ^{aA}	0.94 ^{cB}	0.95 ^{bcA}	0.93 ^{cC}	0.95 ^{bcAB}	0.96 ^{bA}	0,03	<0.001
Rainy	0.95 ^{abC}	0.96 ^{aA}	0.95 ^{abA}	0.95 ^{abAB}	0.94 ^{bcB}	0.92 ^{cB}	0,01	<0.001
SEM	0.04	0,01	0,01	0,01	0,01	0,01		
p-value	<0.001	<0.001	0.259	<0.001	<0.001	<0.001		

Note: Means with different lowercase superscripts in the same row and uppercase superscripts in the same column differ significantly (p<0.05). Establishment period (110 days), dry season (84 days), transition period (111 days), and rainy season (51 days). SEM= standard error of the mean.

kg DM). Cultivar Massai had the highest IVD_{NDF}, which remained constant throughout the establishment, transition, and rainy periods (698.0, 681.0, and 701.5 g/kg DM, respectively) and declined only in the dry season (644.0 g/kg DM). The lowest IVD_{NDF} means were detected in cv. Mombasa during the establishment period (602.0 g/kg DM). As for IVD_{ADF}, the highest means were found in cvs. Massai in the transition period (766.0 g/kg DM) and Tamani in the establishment period (641.5 g/kg DM). The lowest IVD_{ADF} mean was recorded in cv. Aruana during the transition period (484.0 g/kg DM) (Table 4).

In Vitro Degradation Kinetics

There was a significant interaction effect between cultivars and evaluation periods for the parameters of cumulative gas production (Y) (p<0.001), the volume of gas produced by the degradation of NFC and soluble compounds (A) (p<0.001), rate of degradation of NFC and soluble compounds (B) (p<0.001), time taken by the bacteria to colonize the particle (Lag) (p<0.001), the volume of gas produced by the degradation of fibrous carbohydrates (D) (p<0.001), and rate of degradation of fibrous carbohydrates (E) (p<0.001) (Table 5).

Cumulative gas production was the highest in cv. Zuri (20.24 mL/100 mg DM) during its establishment period, cvs. Massai and Tanzania in the dry season, and cv. Aruana in the transition and rainy periods. The lowest mean for Y occurred in cv. Massai in the rainy season (11.27 mL/100 mg DM).

The highest means of gas produced (mL) by the degradation of NFC and soluble compounds (A) were observed in cvs. Mombasa, Tamani, and Zuri in the establishment period; cvs. Massai and Tanzania in the

Table 4. *In vitro* digestibility of dry matter, organic matter, crude protein, neutral detergent fiber, and acid detergent fiber of the leaf blade of *Panicum maximum* cultivars grown in a semi-arid environment

Period	Cultivar						SEM	p-value
	Aruana	Massai	Mombasa	Tamani	Tanzania	Zuri		
	In vitro digestibility of dry matter (g/DM)							
Establishment	744.5 ^{aC}	724.0 ^{aAB}	661.0 ^{cC}	680.5 ^{bcC}	684.5 ^{bB}	633.0 ^{dD}	16.6	<0.001
Dry	766.0 ^{aB}	717.5 ^{bB}	702.0 ^{bB}	708.5 ^{Bb}	713.0 ^{bA}	707.5 ^{bB}	9.6	<0.001
Transition	826.0 ^{aA}	742.0 ^{bA}	728.0 ^{bA}	742.0 ^{bA}	726.0 ^{bA}	735.5 ^{bA}	15.5	<0.001
Rainy	810.0 ^{aA}	736.5 ^{bAB}	694.5 ^{dB}	709.5 ^{cdB}	717.0 ^{bcA}	687.5 ^{dC}	18.3	<0.001
SEM	18.9	5.6	13.8	12.6	9	21.7		
p-value	<0.001	0.009	<0.001	<0.001	<0.001	<0.001		
	In vitro digestibility of organic matter (g/kg DM)							
Establishment	727.5 ^{aB}	717.5 ^{aA}	638.0 ^{bC}	637.0 ^{bC}	654.0 ^{bB}	569.5 ^{cC}	23.8	<0.001
Dry	736.0 ^{aB}	701.5 ^{bA}	675.5 ^{bcB}	680.5 ^{bcB}	674.5 ^{bcAB}	650.0 ^{cB}	12	<0.001
Transition	810.0 ^{aA}	717.0 ^{bA}	724.0 ^{bA}	711.5 ^{bA}	697.0 ^{bA}	711.5 ^{bA}	16.7	<0.001
Rainy	798.0 ^{aA}	713.0 ^{bA}	675.5 ^{cB}	641.0 ^{dC}	688.5 ^{bcA}	650.0 ^{cdB}	23.3	<0.001
SEM	21.1	3.7	17.6	17.6	9.4	29.1		
p-value	<0.001	0.396	<0.001	<0.001	0.002	<0.001		
	In vitro digestibility of crude protein (g/kg DM)							
Establishment	825.5 ^{abC}	752.0 ^{cB}	793.0 ^{bcBC}	767.0 ^{cB}	756.0 ^{cC}	869.0 ^{aB}	18.8	<0.001
Dry	886.0 ^{abAB}	847.5 ^{bA}	869.5 ^{bA}	849.0 ^{bA}	780.0 ^{cBC}	928.5 ^{aA}	20.1	<0.001
Transition	912.0 ^{aA}	832.5 ^{bA}	825.5 ^{bAB}	867.5 ^{abA}	826.0 ^{bA}	865.0 ^{abB}	13.8	<0.001
Rainy	861.0 ^{aBC}	775.0 ^{bcB}	771.5 ^{cC}	827.5 ^{aA}	821.5 ^{abAB}	816.5 ^{abcC}	13.9	<0.001
SEM	18.4	22.8	23.3	21.8	16.8	22.9		
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
	In vitro digestibility of neutral detergent fiber (g/kg DM)							
Establishment	624.0 ^{bcA}	698.0 ^{aA}	602.0 ^{cB}	639.5 ^{bB}	645.5 ^{bA}	612.0 ^{bcC}	13.9	<0.001
Dry	640.5 ^{abA}	644.0 ^{abB}	623.0 ^{bAB}	624.5 ^{abB}	610.0 ^{bB}	659.5 ^{aAB}	7.3	0.004
Transition	631.0 ^{cA}	681.0 ^{aA}	644.5 ^{bcA}	671.5 ^{abA}	638.5 ^{bcAB}	688.5 ^{aA}	9.9	<0.001
Rainy	648.0 ^{cA}	701.5 ^{aA}	641.5 ^{cA}	696.5 ^{abA}	663.5 ^{bcA}	647.0 ^{cB}	10.8	<0.001
SEM	5.3	13.2	9.8	16.1	11.1	15.8		
p-value	0.202	<0.001	0.004	<0.001	0.001	<0.001		
	In vitro digestibility of acid detergent fiber (g/kg DM)							
Establishment	500.5 ^{cBC}	636.0 ^{aC}	582.5 ^{bBC}	641.5 ^{aA}	578.0 ^{bAB}	591.5 ^{bB}	20.8	<0.001
Dry	529.0 ^{cB}	632.0 ^{aD}	566.0 ^{bcC}	606.0 ^{aB}	558.0 ^{bcB}	621.0 ^{aB}	16.5	<0.001
Transition	484.0 ^{dC}	766.0 ^{aA}	684.5 ^{bA}	608.5 ^{cB}	573.0 ^{cB}	665.0 ^{bA}	39.9	<0.001
Rainy	646.0 ^{abcA}	675.0 ^{aB}	608.0 ^{dB}	658.5 ^{abA}	610.5 ^{cdA}	622.5 ^{bcdB}	11.2	<0.001
SEM	36.6	31.1	26.2	12.8	11.1	15.1		
p-value	<0.001	<0.001	<0.001	<0.001	0.002	<0.001		

Note: Means with different lowercase superscripts in the same row and uppercase superscripts in the same column differ significantly ($p<0.05$). Establishment period (110 days), dry season (84 days), transition period (111 days), and rainy season (51 days). SEM= standard error of the mean.

dry season; and cv. Aruana in the transition period. Parameter A was lowest in cv. Massai during the rainy season (1.05 mL/100 mg DM). As for the degradation rate of NFC and soluble compounds (B), the highest mean was detected in cv. Tanzania in the establishment period; cvs. Mombasa and Tamani in the dry season; cv. Mombasa in the transition period; and cv. Tamani in the rainy season. The lowest means of parameter B was found in cvs. Mombasa and Tamani in the establishment period**.**

Lag time was the longest in cvs. Mombasa and Tamani in the establishment period (3.4330 and 3.1790 h, respectively); cvs. Aruana, Tanzania, and Zuri in the transition period (0.2740, 0.5420, and 0.1550 h, respectively); and cvs. Massai and Mombasa in the rainy season (3.3675 and 2.7495 h, respectively). The shortest lag time was shown by cv. Tamani during the rainy season (0.4940 h).

The volume of gas (mL) produced by fibrous carbohydrates (D) degradation was the largest in cv. Zuri during the establishment period (16.65 mL/100 mg DM); cvs. Massai and Tanzania in the dry season (13.63 and 14 .61 mL/100 mg DM, respectively); cvs. Massai, Mombasa, and Tanzania in the transition period (13.63 and 14.61 mL/100 mg DM, respectively); and cv. Aruana in the rainy season (17.54 mL/100 mg DM). The lowest means of parameter D, in turn, were found in cv. Tamani in the establishment period and cv. Massai in the rainy season (10.45 and 10.23, respectively). Regarding the degradation rate of fibrous carbohydrates (E), the highest means were found in cvs. Aruana, Massai, and Tanzania in the establishment period; cvs. Tamani, Tanzania, and Zuri in the dry season; cvs.

Table 5. Variables of *in vitro* degradation kinetics of the leaf blade of *Panicum maximum* cultivars grown in a semi-arid environment

Variables	Cultivar						SEM	p-value
	Aruana	Massai	Mombasa	Tamani	Tanzania	Zuri		
	Establishment							
Y (mL/100 mg DM)	18.33 ^{abB}	18.09 ^{abB}	17.68 ^{abA}	16.43 ^{bAB}	18.52 ^{abB}	20.24 ^{aA}	0.51	<0.001
A (mL/100 mg DM)	5.01 ^{aB}	3.86 ^{aB}	5.46 ^{aA}	5.97 ^{aA}	3.34 ^{aB}	3.60 ^{aA}	0.44	0.023
B (/h)	0.8421 ^{abA}	0.8420 ^{abA}	0.4084 ^{cB}	0.3885 ^{cB}	0.9870 ^{aA}	0.4765 ^{bA}	0.11	<0.001
Lag (h)	0.6992 ^{bA}	0.7027 ^{bB}	3.4330 ^{aA}	3.1790 ^{aA}	0.8945 ^{bA}	0.5721 ^{bA}	0.55	<0.001
D (mL/100 mg DM)	13.32 ^{bcB}	14.23 ^{bcA}	12.22 ^{cdA}	10.45 ^{dB}	15.18 ^{abA}	16.65 ^{aA}	0.9	<0.001
E (/h)	0.0327 ^{aA}	0.0300 ^{aA}	0.0200 ^{bB}	0.0285 ^{abB}	0.0330 ^{aA}	0.0285 ^{abA}	0.002	<0.001
R^2	0.99	0.99	0.99	0.99	0.99	0.99		
	Dry							
Y (mL/100 mg DM)	16.93 ^{bB}	22.13 ^{aA}	11.79 ^{cB}	13.31 ^{cC}	21.27 ^{aA}	13.69 ^{cC}	1.78	<0.001
A (mL/100 mg DM)	7.25 ^{aAB}	8.50 ^{aA}	2.01 ^{bB}	2.00 ^{bB}	6.66 ^{aA}	2.62 ^{bA}	1.2	<0.001
B (/h)	0.2918 ^{bB}	0.3445 ^{bB}	0.9855 ^{aA}	0.9865 ^{aA}	0.5750 ^{abB}	0.4660 ^{bA}	0.13	<0.001
Lag (h)	0.2348 ^{bA}	1.8330 ^{aB}	1.0150 ^{abB}	1.9450 ^{aAB}	0.7855 ^{abA}	0.5010 ^{abA}	0.29	0.005
D (mL/100 mg DM)	9.67 ^{bC}	13.63 ^{aA}	9.78 ^{bB}	11.31 ^{bB}	14.61 ^{aA}	11.07 ^{bB}	0.83	<0.001
E (/h)	0.0321 ^{abA}	0.0240 ^{bA}	0.0325 ^{abA}	0.0385 ^{aA}	0.0340 ^{aA}	0.0340 ^{aA}	0.002	<0.001
R^2	0.99	0.99	0.98	0.98	0.99	0.99		
	Transition							
Y (mL/100 mg DM)	22.50 ^{aA}	18.73 ^{bB}	15.85 ^{cA}	15.27 ^{cBC}	19.13 ^{bAB}	16.01 ^{cBC}	1.13	<0.001
A (mL/100 mg DM)	9.46 ^{aA}	5.72 ^{bB}	2.76 ^{cB}	4.59 ^{bcA}	5.77 ^{bAB}	3.43 ^{bcA}	0.97	<0.001
B (/h)	0.3235 ^{bcB}	0.5460 ^{bcAB}	0.9850 ^{aA}	0.6080 ^{abcAB}	0.6895 ^{abAB}	0.2265 ^{bA}	0.11	<0.001
Lag (h)	0.2740 ^{aA}	0.6105 ^{aB}	1.1700 ^{aB}	0.7535 ^{aBC}	0.5420 ^{aA}	0.1550 ^{aA}	0.15	0.353
D (mL/100 mg DM)	13.03 ^{aB}	13.01 ^{aA}	13.09 ^{aA}	10.68 ^{bB}	13.36 ^{aA}	12.58 ^{abB}	0.4	0.012
E (/h)	0.0327 ^{aA}	0.0280 ^{aA}	0.0365 ^{aA}	0.0360 ^{aAB}	0.0345 ^{aA}	0.0315 ^{aA}	0.001	0.060
R^2	0.99	0.99	0.99	0.98	0.99	0.99		
	Rainy							
Y (mL/100 mg DM)	24.68 ^{aA}	11.27 ^{dC}	17.90 ^{bcA}	18.46 ^{bcA}	19.80 ^{bAB}	16.61 ^{cB}	1.78	<0.001
A (mL/100 mg DM)	7.14 ^{aAB}	1.05 ^{dC}	6.65 ^{abA}	4.19 ^{bcAB}	4.77 ^{abcAB}	3.54 ^{cdA}	0.9	0.001
B (/h)	0.7286 ^{abA}	0.5245 ^{bAB}	0.5195 ^{bB}	0.9865 ^{aA}	0.9600 ^{aAB}	0.5085 ^{bA}	0.09	<0.001
Lag (h)	0.6873 ^{bA}	3.3675 ^{aA}	2.7495 ^{aA}	0.4940 ^{bC}	0.5530 ^{bA}	1.1360 ^{bA}	0.51	<0.001
D (mL/100 mg DM)	17.54 ^{aA}	10.23 ^{dB}	11.25 ^{cdAB}	14.26 ^{bA}	15.03 ^{bA}	13.07 ^{bcB}	1.08	<0.001
E (/h)	0.0330 ^{aA}	0.0235 ^{bcA}	0.0165 ^{cB}	0.0385 ^{aA}	0.0335 ^{aA}	0.0320 ^{abA}	0.003	<0.001
R^2	0.99	0.99	0.98	0.99	0.99	0.99		

Note: Means with different lowercase superscripts in the same row and uppercase superscripts in the same column differ significantly ($p<0.05$). Establishment period (110 days), dry season (84 days), transition period (111 days), and rainy season (51 days). Y= cumulative gas production at time t (extent of degradation); A= volume of gas (mL) produced by the degradation of non-fibrous carbohydrates and soluble compounds; B= degradation rate of non-fibrous carbohydrates and soluble compounds (/h); Lag= time taken by the bacteria to colonize particle (h); D= volume of gas (mL) produced by the degradation of fibrous carbohydrates; E= fibrous carbohydrate degradation rate (/h); R^2= coefficient of determination; SEM= standard error of the mean.

Aruana, Massai, Mombasa, Tanzania, and Zuri in the transition period; and cvs. Aruana, Tamani, and Tanzania in the rainy season. Cultivar Mombasa exhibited the lowest E.

Correlation Analysis

Correlation analysis was performed between FAR, chemical composition, *in vitro* digestibility, and ruminal degradation kinetic parameters (Table 6). The analysis revealed high positive correlations between IVD_{DM} and IVD_{OM}; IVD_{DM} and A; and Y and D.

Moderate positive correlations were found for CP content with IVD_{CP}; protodioscin content with IVD_{DM} and A; and A with IVD_{OM} and Y. Moderate negative correlations were observed for FAR with DM; CP with NDF; NDF with IVD_{DM} and IVD_{OM}; and Lag time with IVD_{DM} and A (Table 6).

DISCUSSION

Forage Accumulation Rate

The evaluation periods influenced the FAR of the *Panicum maximum* cultivars. The periods of higher rainfall (Figure 1) favored forage accumulation (Table 2). This is explained by the rainfall and temperature conditions in that period, which were optimal for developing new plant tissues (Echeverria *et al.*, 2016). In cv. Aruana, the FAR means were low throughout the year and had a sharper decrease in the dry season (62.9%), which indicates a greater sensitivity of that cultivar to the soil-climatic characteristics of the region and low potential for production and use in farming systems in the semi-arid environment. Emerenciano *et al.* (2013) evaluated the production of tropical forage crops in semi-arid conditions similar to those of the present study and obtained

Table 6. Pearson correlation (R) between chemical composition, *in vitro* digestibility, forage accumulation, and *in vitro* degradation kinetic variables of *Panicum maximum* cultivars grown in a semi-arid environment

	FAR	DM	OM	CP	NDF	ADF	PROT	IVD_{DM}	IVD_{OM}	IVD_{CP}	IVD_{NDF}	A	*Lag*	D
DM	-0.52*	-												
OM	-0.52_{ns}	-0.03_{ns}	-											
CP	-0.33*	0.20_{ns}	-0.33*	-										
NDF	0.38*	-0.19_{ns}	-0.06_{ns}	-0.54*	-									
ADF	0.38*	-0.27*	-0.09_{ns}	-0.39*	0.41*	-								
PROT	-0.35*	0.26*	-0.01_{ns}	0.27*	-0.33*	-0.44*	-							
IVD_{DM}	-0.33*	0.06_{ns}	0.20_{ns}	0.35*	-0.57*	-0.61*	0.54*	-						
IVD_{OM}	-0.32*	0.05_{ns}	0.05*	0.24*	-0.56*	-0.55*	0.48*	0.95*	-					
IVD_{CP}	-0.34*	0.25*	0.25*	0.62*	-0.45*	-0.45*	0.44*	0.38*	0.25*	-				
IVD_{NDF}	0.10_{ns}	-0.22*	-0.22_{ns}	0.14_{ns}	0.01_{ns}	0.01_{ns}	-0.21*	0.22*	0.20_{ns}	-0.12_{ns}	-			
A	-0.43*	0.07_{ns}	0.07_{ns}	0.27*	-0.34*	-0.34*	0.53*	0.71*	0.62*	0.28*	-0.02_{ns}	-		
Lag	0.33*	0.06_{ns}	0.06*	-0.25*	0.13_{ns}	0.13*	-0.35*	-0.57*	-0.47*	-0.49*	-0.25*	-0.65*	-	
D	0.16_{ns}	-0.13_{ns}	-0.13_{ns}	-0.26*	0.38*	0.14_{ns}	-0.16_{ns}	-0.05_{ns}	-0.04_{ns}	-0.16_{ns}	-0.05_{ns}	0.15_{ns}	-0.08_{ns}	-
Y	-0.11_{ns}	-0.04_{ns}	-0.04_{ns}	-0.08_{ns}	0.15_{ns}	0.15*	0.01_{ns}	0.26*	-0.05*	-0.04_{ns}	-0.01_{ns}	0.63*	-0.37*	0.82*

Note: *Significant by t test at 5%. ns= not significant. FAR= forage accumulation rate; DM= dry matter; OM= organic matter; CP= crude protein; NDF= neutral detergent fiber; PROT= protodioscin; IVD_{DM}= *in vitro* digestibility of dry matter ; IVD_{OM}= *in vitro* digestibility of organic matter; IVD_{NDF}= *in vitro* digestibility of neutral detergent fiber; A= gas volume (mL) produced by the degradation of non-fibrous carbohydrates and soluble compounds; Lag= Bacteria colonization time (h); D = gas volume (mL) produced by the degradation of fibrous carbohydrates and soluble compounds; Y = total gas volume at time t (extent of degradation).

lower yields in cv. Aruana when compared with other cultivars of the genera *Panicum* and *Brachiaria*.

Cultivars Zuri and Tamani exhibited high production potential during the rainy season and their establishment period, respectively (Table 2). This finding suggests a high potential for using these cultivars as forage alternatives for pasture-based production systems in semi-arid regions.

Chemical Composition

Both the chemical composition and the digestibility of a forage crop can vary according to chemical, physical, and structural factors inherent to the plant as well as environmental factors, especially the soil-climatic conditions of the region (Lopes *et al.,* 2017). In the present study, the different evaluation periods influenced the composition of the studied cultivars. Dry matter content was the highest in cv. Aruana, likely due to the physiological maturity of the plant (Silva *et al.,* 2014), as evidenced by the early flowering process in that cultivar. The high water availability may have influenced the lowest DM content found during the rainy season in that period, which contributed to the rapid increase in FAR, and the short harvesting interval, which provided plant material of less age and with less DM content (Garcez *et al.,* 2016). According to the correlation analysis performed in the present study, FAR and DM contents were inversely correlated (Table 6).

The low levels of chemical components such as CP and protodioscin observed in the establishment period and in the rainy season may be related to the high accumulation of forage and consequent increase in forage yield, which, according to Viciedo *et al.* (2019), affect nutrient contents in the plant. Campos *et al.* (2016) stated that forage quality losses are not only related to low production in dry periods, as this phenomenon also occurs in rainy periods.

The NDF contents (Table 3) exceeded the range of 55 to 60%, which can have a negative impact on voluntary forage intake (Geron *et al.,* 2013). Likewise, the ADF contents also exceeded 40% of the plant composition, considered the threshold value above which forage digestibility is compromised (Van Soest, 1994). Increases in the level of fibrous components—NDF and ADF—occur simultaneously with a decrease in CP content due to the decrease in potentially digestible components caused by the advance of plant maturity (Rodrigues *et al.,* 2014).

The content of protodioscin—the main saponin associated with intoxication and used as an indicator of photosensitization in animals (Lelis *et al.,* 2018)—in the cultivars was low when compared with those described in studies with cultivars of the genus *Brachiaria* (Faccin *et al.,* 2014; Porto *et al.,* 2013; Leal *et al.,* 2016, 2020). In *Brachiaria* spp., Melo *et al.* (2018) found that protodioscin levels between 3 and 13 g/kg DM caused intoxication in lactating lambs. Nonetheless, the values found in the current experiment (0.93 to 1.43 g/kg of DM) are lower than those reported in the abovementioned studies. Thus, *Panicum maximum* cultivars may be indicated as an alternative to the use of forages of the genus *Brachiaria* also in small-ruminant production systems.

In research with *Panicum maximum* in a Brazilian semiarid environment, Emerenciano Neto *et al.* (2020) found mean concentrations of CP (97.2 g/kg of DM), NDF (757 g/kg of DM) slightly higher than the means of this study (87 and 734.5 g/kg of DM, respectively). In the semi-arid region of Ethiopia, Keba *et al.* (2013) found concentrations of CP (66.8 g/kg of DM) and FDA

(480 g/kg of DM) lower than those found in this study, while the concentrations of NDF (766.2 g/kg of DM) was higher. Similar concentrations of CP and lower concentrations of NDF and ADF (95.7, 570 and 371 g/kg of DM, respectively) were found in studies by Omotoso *et al.* (2020) in the Savanna Zone Nigeria. It was possible to observe that, in general, *Panicum maximum* cultivars cultivated in environments with less restrictive climatic conditions present a higher forage quality (Tontini *et al.*, 2021; Pereira *et al.*, 2021).

Over the studied periods, cvs. Aruana and Mombasa showed losses in yield and quality, respectively. These losses were possibly because they are demanding soil fertility and water availability; these cultivars were affected by the soil-climatic conditions of the region where they were grown. However, these cultivars can be used in semi-arid environments depending on the objective of the production system.

In Vitro Digestibility and Degradation Kinetics

Cultivar Aruana exhibited the highest IVD_{DM} during the transition and rainy periods (Table 4). The highest cumulative gas production (Y) means in this cultivar also occurred in the same periods (Table 6), indicating high quality with no water stress. The good fiber quality of cv. Aruana, as represented by low ADF contents, contributed to the higher digestibility and larger gas volumes (degradation) seen in these two periods. As the ADF content of the cultivars increased, IVD_{DM} decreased (Table 4) since digestibility is strongly influenced by the ADF content of plants (Van Soest, 1994). Studying the species in southwest Asia, Hayashi *et al.* (2021) found lower levels of IVD_{MD} (353.5 g/kg DM), as well as smaller concentrations of DM (266.5 g/kg DM) and OM (858.5 g/kg DM) and higher levels of CP (107 g/kg DM), NDF (767 g/kg DM), and ADF (541.5 g/kg DM).

Cultivar Massai showed the highest IVD_{NDF} means during the establishment, transition, and rainy periods, with practically constant results (Table 4). On the other hand, in the dry season, when digestibility was slightly affected, this cultivar exhibited the highest means of cumulative gas production and parameters A and D (Table 5), suggesting little change in its fiber quality in response to the availability of rainfall. This fact indicates high quality and sustainability potential in this forage grass for semi-arid regions.

Cultivar Zuri had losses in IVD_{DM} during its establishment period, which may be related to its low CP and high fiber contents. However, cumulative gas production (Y) in the same period was greater in this cultivar than in the others. Most of it was associated with the volume of gas produced by fibrous carbohydrates (D) degradation resulting from the high NDF values seen in that period. Despite the digestibility losses (Table 4) and the lower average FAR (Table 2) seen in the establishment period, the large amount of fiber was likely sufficient to meet the requirements for microbial growth to maintain the degradation potential in the rumen fluid (Mccann *et al.*, 2014).

The IVD_{CP} was higher than 70% in all cultivars and periods, suggesting high protein quality in the evaluated cultivars. The highest IVD_{CP} was also associated with the highest means of the volume of gas produced by the degradation of NFC and soluble compounds (A), likely due to the greater presence of cellular content relative to the cell wall of the grasses.

The increase in fibrous fractions (NDF and ADF) had a negative impact on the *in vitro* digestibility of DM, OM, and CP and a positive effect on gas production. This was due to the larger volume of gas that originated from the fibrous fraction, which constitutes the largest share of the total gas volume in *Panicum maximum* cultivars.

Because of its high NDF levels, cv. Mombasa had a reduction in IVD_{NDF} and IVD_{CP}. This result may be related to the direct relationship between fiber quantity and quality, the amount of CP, and digestibility (Santos *et al.*, 2020) since higher fiber and lower CP contents in a forage plant imply lower digestibility indices (Habermann *et al.*, 2019).

Correlation Analysis

The correlation coefficients found in this study (Table 6) help us to understand the climate-plant-animal relationships. Among the significant coefficients found, negative correlations were detected between the fibrous fractions and CP, IVD_{DM}, IVD_{OM}, and IVD_{CP}. This fact may be related to the physiological maturation events in forage plants since increases in cell wall thickness, and tissue lignification (Valente *et al.*, 2010) induce a decrease in the concentration of potentially degradable components (Rodrigues *et al.*, 2014). Increasing levels of fibrous fractions in a plant imply a reduction in its digestible nutrient content and cause changes in the metabolism of the rumen microbiome and in DM intake by the animal (Garcez *et al.*, 2016).

Information on the nutritional composition of forage plants is essential for balancing diets, maintaining animal health, and system production levels (Ki *et al.*, 2017). The present findings reinforce the importance of studies examining the potential of forage plants that are more productive in and adapted to the semi-arid environment to elucidate the environmental influence on the growth and development of these plants as well as identify the times when there can be a balance between forage accumulation and forage quality. With this information, management strategies can be devised to maximize the use of forages in animal production systems in semi-arid regions.

CONCLUSION

Cultivars BRS Tamani and BRS Zuri had the highest forage yield coupled with the highest nutritional values, even in the periods of seasonal forage production in the semi-arid environment. Cultivar Massai maintained its fiber quality throughout the year. The semi-arid conditions impaired forage accumulation in cv. Aruana and forage quality in cv. Mombasa, which may limit their recommendation for these environments without irrigation. However, these five *Panicum maximum* cultivars have the potential for establishment and can be

indicated as alternatives for use in animal production systems in semi-arid environments.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organization related to the material discussed in the manuscript.

ACKNOWLEDGEMENT

The authors thank CAPES (Coordination for the Improvement of Higher Education Personnel, Brazil; Finance Code 001) for the fellowship grant awarded to the first author; the National Council for Scientific and Technological Development (CNPq); and the Federal University of Rio Grande do Norte. This study was supported by the Federal University of Mato Grosso do Sul.

REFERENCES

AOAC. 2000. Official Methods of Analysis. 17th Edition. Washington, DC., USA.

Braz, T. G. S., J. A. Martuscello, L. Jank, D. M. Fonseca, M. D. V. Resende, & A. B. Evaristo. 2017. Genotypic value in hybrid progenies of *Panicum maximum* Jacq. Ciênc. Rural. 47:1–6. https://doi.org/10.1590/0103-8478cr20160599

Campos, F. P., D. R. O. Nicácio, P. Sarmento, M. C. P. Cruz, T. M., Santos, A. F. G. Faria, M. E. Ferreira, M. R. G. Conceição, & C. G. Lima. 2016. Chemical composition and *in vitro* ruminal digestibility of hand-plucked samples of *Xaraes palisade* grass fertilized with incremental levels of nitrogen. Anim. Feed Sci. Technol. 215:1–12. https://doi.org/10.1016/j.anifeedsci.2015.12.013

Cleland, J. D., E. Johnson, P. C. H. Morel, P. R. Kenyon, & M. R. Waterland. 2018. Mid-infrared reflectance spectroscopy as a tool for forage feed composition prediction. Anim. Feed Sci. Technol. 241:102–111. https://doi.org/10.1016/j.anifeedsci.2018.04.022

Echeverria, J. R., V. P. B. Euclides, A. F. Sbrissia, D. B. Montagner, R. A. Barbosa, & N. N. Nantes. 2016. Acúmulo de forragem e valor nutritivo do híbrido de Urochloa "BRS RB331 Ipyporã" sob pastejo intermitente. Pesqui. Agropecu. Bras. 51:880–889. https://doi.org/10.1590/S0100-204X2016000700011

Emerenciano Neto, J. V., G. S. Difante, Â. M. Q. Lana, H. R. Medeiros, E. M. Aguiar, D. B. Montagner, & J. S. Souza. 2018. Forage quality and performance of sheep in Massai grass pastures managed at pre-grazing canopy heights. S. Afr. J. Anim. Sci. 48:1073-1081. https://doi.org/10.4314/sajas.v48i6.10

Emerenciano Neto, J. V., G. S. Difante, H. R. Medeiros, E. M. Aguiar, L. S. Fernandes, T. F. M. Trindade, M. G. Bezerra, H. C. B. Oliveira, & R. C. P. Galvão. 2020. Cultivated pastures affect nutrient intake and feeding behavior of sheep. Trop. Anim. Sci. J. 43:117–124. https://doi.org/10.5398/tasj.2020.43.2.117

Faccin, T. C., F. Riet-Correa, F. S. Rodrigues, A. C. Santos, G. K. A. Melo, J. A. Silva, R. Ferreira, C. C. B. F. Ítavo, **& R. A. A. Lemos.** 2014. Poisoning by *Brachiaria brizantha* in flocks of naïve and experienced sheep. Toxicon. 82:1–8. https://doi.org/10.1016/j.toxicon.2014.02.008

FAO. 2014. World Reference Base for Soil Resources. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps.

Ganzera, M., E. Bedir, & I. A. Khan. 2001. Determination of steroidal saponins in *Tribulus terrestris* by reversed-phase high-performance liquid chromatography and evaporative light scattering detection. J. Pharm. Sci. 90:1752–1758. https://doi.org/10.1002/jps.1124

Garcez, B. S., A. A. Alves, D. L. C. Araújo, M. S. B. Lacerda, L. G. C. Sousa, & L. F. Carvalho. 2016. Degradabilidade ruminal do capim colonião (*Panicum maximum* Jacq. cv. Colonião) em três idades pós-rebrota. Acta Vet. Bras. 10:130–134. https://doi.org/10.21708/avb.2016.10.2.5513

Geron, L. J. V., A. A. Mexia, R. L. Cristo, J. Garcia, L. S. Cabral, R. J. Trautmann, O. S. Martins, & L. M. Zeoula. 2013. Consumo, digestibilidade dos nutrientes e características ruminais de cordeiros alimentados com níveis crescentes de concentrado em ambiente tropical no Vale do Alto Guaporé - MT. Semin. Ciênc. Agrár. 34:2497–2510. https://doi.org/10.5433/1679-0359.2013v34n5p2497

Habermann, E., E. A. D. Oliveira, D. R. Contin, G. Delvecchio, O. Viciedo, M. A. Moraes, R. M. Prado, K. A. P. Costa, M. R. Braga, & C. A. Martinez. 2019. Warming and water deficit impact leaf photosynthesis and decrease forage quality and digestibility of a C4 tropical grass. Physiol. Plant. 165:383–402. https://doi.org/10.1111/ppl.12891

Hayashi, Y., E. Takeya, Y. Ikeno, H. Kumagai, E. M. Cruz, N. P. Garcia, D. L. Aquino, & T. Fujihara. 2021. Periodic changes in chemical composition and *in vitro* digestibility of locally available Gramineae feed resources in the Philippines. Trop. Anim. Health Prod. 53:123. https://doi.org/10.1007/s11250-021-02572-y

Holden, L. A. 1999. Comparison of methods of *in vitro* dry matter digestibility for ten feeds. J. Dairy Sci. 82:1791–1794. https://doi.org/10.3168/jds.S0022-0302(99)75409-3

Keba, H. T., I. C. Madakadze, A. Angassa, & A. Hassen. 2013. Nutritive value of grasses in semi-arid rangelands of Ethiopia: Local experience based herbage preference evaluation versus laboratory analysis. Asian-Australas. J. Anim. Sci.26:366-377. https://doi.org/10.5713/ajas.2012.12551

Ki, K. S., S. B. Park, D. H. Lim, & S. Seo. 2017. Evaluation of the nutritional value of locally produced forage in Korea using chemical analysis and *in vitro* ruminal fermentation. Asian-Australas. J. Anim. Sci.30:355. https://doi.org/10.5713/ajas.16.0626

Leal, E. S., L. C. V. Ítavo, **C. B. Valle, C. C. B. F.** Ítavo, **A. M. Dias, M. Barbosa-Ferreira, C. M. Soares, G. K. A. Melo, & V. B. N. Ferreira.** 2016. Anti-nutritional potential of protodioscin and kinetics of degradation in *Urochloa* grasses. Semin. Ciênc. Agrár. 37:2247–2258. https://doi.org/10.5433/1679-0359.2016v37n4p2247

Leal, E. S., L. C. V. Ítavo, **C. B. Valle, C. C. B. F.** Ítavo, **A. M. Dias, G. S. Difante, M. Barbosa-Ferreira, L. M. Nonato, G. K. A. Melo, & A. L. C. Gurgel.** 2020. Influence of protodioscin content on digestibility and *in vitro* degradation kinetics in *Urochloa brizantha* cultivars. Crop Pasture Sci. 71:278–284. https://doi.org/10.1071/CP18357

Lelis, D. L., L. N. Rennó, M. L. Chizzotti, C. E. R. Pereira, J. C. P. Silva, L. G. T. Moreira, F. B. P. Carvalho, & F. H. M. Chizzotti. 2018. Photosensitization in naïve sheep grazing signal grass (*Brachiaria decumbens*) under full sunlight or a silvopastoral system. Small Rumin. Res. 169:24–28. https://doi.org/10.1016/j.smallrumres.2018.08.018

Lopes, C. M., D. S. C. Paciullo, S. A. C. Araújo, C. A. M. Gomide, M. J. F. Morenz, & S. D. J. Villela. 2017. Massa de forragem, composição morfológica e valor nutritivo de capim-braquiária submetido a níveis de sombreamento e fertilização. Arq. Bras. Med. Vet. Zootec. 69:225–223. https://doi.org/10.1590/1678-4162-9201

Magalhães, J. A., M. S. S. Carneiro, A. C. Andrade, E. S. Pereira, J. S. Souto, M. S. C. Pinto, B. H. N. Rodrigues, N. L. Costa, & W. J. E. M. Filho. 2012. Eficiência do nitrogênio,

produtividade e composição do capim-andropogon sob irrigação e adubação. Arch. Zootec. 61:577–588. https://doi.org/10.21071/az.v61i236.2213

Mccann, J. C., T. A. Wickersham, & J. J. Loor. 2014. High-throughput methods redefine the rumen microbiome and its relationship with nutrition and metabolism. Bioinform. Biol. Insights. 8:109–125. https://doi.org/10.4137/BBI.S15389

Melo, G. K. A., C. C. B. F. Ítavo, J. A. Silva, K. L. S. Monteiro, T. C. Faccin, R. C. Pupin, R. F. Heckler, L. C. V. Ítavo, P. C. G. Silva, P. V. Leal, & R. A. A. Lemos. 2018. Poisoning by *Brachiaria* spp. in suckling lambs supplemented and unsupplemented in a creep-feeding system. Small Rumin. Res. 158:30–34. https://doi.org/10.1016/j.smallrumres.2017.11.014

Njarui, D. M. G., M. Gatheru, D. M. Mwangi, & G. A. Keya. 2015. Persistence and productivity of selected Guinea grass ecotypes in semiarid tropical Kenya. Grassl. Sci. 61:142–152. https://doi.org/10.1111/grs.12092

Oliveira, J. S., J. V. Emerenciano Neto, G. S. Difante, F. N. Lista, R. S. Santos, J. D. V. Bezerra, B. R. S. Bonfim, L. B. S. Milhomens, & J. S. M. Ribeiro. 2019. Structural and productive features of *Panicum* cultivars submitted to different rest periods in the irrigated semiarid region of Brazil. Biosci. J. 35:682–690. https://doi.org/10.14393/BJ-v35n3a2019-36402

Oliveira, L. B., E. M. Santos, L. P. Felix, R. M. A. Pinho, A. J. S. Macêdo, A. M. Zanine, A. M. R. Rufino, D. M. Pereira, & J. P. Alves. 2018. Evaluation of spontaneous species in the implementation of a *Panicum maximum* cv. Aruana pasture in the semi-arid region. Int. J. Agric. Biol. 20:1825–1832.

Oliveira, V. S., J. A. S. Morais, E. N. Muniz, J. L. Fagundes, I. G. S. Lima, J. S. C. Santana, & C. B. Santos. 2017. Cinética ruminal de forrageiras tropicais submetidas ou não a sistema de irrigação. Bol. Ind. Anim. 74:195–204. https://doi.org/10.17523/bia.v74n3p195

Omotoso, O. B., O. A. Olatunji, O. O. Obameso, A. Odunofoye, A. N. Fajesmisin, J. A. Alokan. 2020. Nutritional value and acceptability of some selected forages in the derived Savanna zone of Nigeria as ruminant feed. J. Rangel. Sci. 10:426–433.

Pereira, M., R. G, Almeida, M. C. M. Macedo, V. A. C. Santos, É. L. **Gamarra, J. Castro-Montoya, B. Lempp, & M. G. Morais.** 2021. Anatomical and nutritional characteristics of *Megathyrsus maximus* genotypes under a silvopastoral system. Tropical Grasslands-Forrajes Tropicales 9:159–170. https://doi.org/10.17138/tgft(9)159-170

Porto, E. M. V., D. D. Alves, C. M. T. Vitor, M. F. Silva, C. G. Magalhães, A. M. S. S. David, V. M. Gomes, & C. J. A. Brant. 2017. Produção de biomassa de cultivares do capim-buffel submetidos à adubação nitrogenada. Revista Unimontes Cientifica 19:122–129.

Porto, M. R., K. C. Saturnino, E. M. M. Lima, S. T. Lee, R. A. A. Lemos, C. Marcolongo-Pereira, F. Riet-Correa, & M. B. Castro. 2013. Avaliação da exposição solar na intoxicação experimental por *Brachiaria decumbens* em ovinos. Pesqui. Vet. Bras. 19:122–129. https://doi.org/10.1590/S0100-736X2013000800011

Rodrigues, J. G., G. S. Difante, A. L. C. Gurgel, E. L. L. Veras, A. B. G. Costa, M. G. Pereira, J. V. Emerenciano Neto, & C. M. Costa. 2021. Establishment of *Brachiaria* cultivars in the soil-climatic conditions of the Brazilian semi-arid region. Acta Sci. Anim. Sci. 43:1–10. https://doi.org/10.4025/actascianimsci.v43i1.51802

Rodrigues, R. C., T. V. R. Sousa, M. A. A. Melo, J. S. Araújo, R. P. Lana, C. S. Costa, M. E. Oliveira, M. O. M. Parente, & I. B. M. Sampaio. 2014. Agronomic, morphogenic and structural characteristics of tropical forage grasses in northeast Brazil. Trop. Grassl.-Forrajes Trop. 2:214–222. https://doi.org/10.17138/TGFT(2)214-222

Santos, A. R. M., L. V. Barros, M. L. C. Abreu, & B. C. Pedreira. 2020. *In vitro* ruminal fermentation parameters and methane production of Marandu palisadegrass (*Urochloa brizantha*) in a silvopastoral system associated with levels of protein supplementation. Grass. Forage. Sci. 75:339–350. https://doi.org/10.1111/gfs.12476

Schofield, P., R. E. Pitt, & A. N. Pell. 1994. Kinetics of fiber digestion from *in vitro* gas production. J. Anim. Sci. 72:2980–2991. https://doi.org/10.2527/1994.72112980x

Silva, D. C., A. A. Alves, M. S. B. Lacerda, M. A. M. Filho, M. E. Oliveira, & E. A. Lafayette. 2014. Valor nutritivo do capim-andropogon em quatro idades de rebrota em período chuvoso. Acta Sci. Anim. Sci. 15:626–636. https://doi.org/10.1590/S1519-99402014000300004

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. Cornell University Press: Cornell, 2nd Ed. https://doi.org/10.7591/9781501732355

Van Soest, P. J., & J. B. Robertson. 1985. Analysis of Forages and Fibrous Foods. Cornell University Press: Ithaca, N.Y.

Veras, E. L. L., G. S. Difante, A. L. C. Gurgel., A. B. G. Costa, J. G. Rodrigues, C. M. Costa, J. V. Emerenciano Neto, M. G. Pereira, & P. R. Costa. 2020. Tillering and structural characteristics of *Panicum* cultivars in the Brazilian semiarid region. Sustainability 12: 3849. https://doi.org/10.3390/su12093849