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Nutritional value and fermentability of sorghum silages grown in the Amazon biome

Juliana Maria Silva de Souza[1] | **Arthur Behling Neto**[2] | **Maria Antônia Bortolucci da Rosa**[1] | **Flávio Dessaune Tardin**[3] | **Rosemary Lais Galati**[4] | **Carla Silva Chaves**[1] | **Dalton Henrique Pereira**[2]

[1]Programa de Pós-Graduação em Zootecnia, Universidade Federal de Mato Grosso, Sinop, MT, Brazil

[2]Instituto de Ciências Agrárias e Ambientais, Universidade Federal de Mato Grosso, Sinop, MT, Brazil

[3]Empresa Brasileira de Pesquisa Agropecuária, Embrapa Milho e Sorgo, Sete Lagoas, MG, Brazil

[4]Faculdade de Agronomia e Zootecnia, Universidade Federal de Mato Grosso, Cuiabá, MT, Brazil

Correspondence
Dalton Henrique Pereira, Instituto de Ciências Agrárias e Ambientais, Universidade Federal de Mato Grosso, Sinop, MT, Brazil.
Email: dalton.pereira@ufmt.br

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Abstract

In recent years, agricultural production systems have intensified, making it necessary to improve the food supplied to animals, where sorghum silage is one of the most commonly used roughages. The sorghum genotypes present significant differences in dry matter losses, fermentative profiles and nutritional values, allowing the identification of materials with high potential for producing high-quality silages that meet the dietary demands of ruminants and are recommended for use. Therefore, this work aimed to evaluate silages from 15 sorghum genotypes for different purposes to identify materials that could be recommended for silage production in the Amazon biome. The experiment was carried out in Sinop/MT to evaluate the fermentative characteristics and chemical composition of the sorghum silages. Fifteen sorghum genotypes, 15F30005, 15F30006, CMSXS 5027, 5030, 5043, 5045, 201934B008, CMSXS 7501, BRS 658, BRS 659, Volumax, BRS 511, BRS Ponta Negra, BRS 716 and AGRI-002E, were ensiled in experimental silos with six replications per treatment. For the content of NH_3-N, BRS 658 and BRS 659 had the lowest average, 29.9 g NH_3-N/kg total *N*. The highest average dry matter content was from BRS 658, BRS 659, AGRI-002E and BRS 716, at 295.0 g/kg. The highest average crude protein content of 78.1 g/kg dry matter (DM) was obtained from BRS658 and BRS 659. For lignin, BRS 659, Volumax, Ponta Negra, 15F30006, CMSXS 5027 and CMSXS 5030 had the lowest average value, 49.5 g/kg DM. All the genotypes evaluated presented characteristics suitable for ensiling. The materials with the highest nutritional value were the commercial varieties BRS 658, BRS 659 and Ponta Negra. The experimental varieties 15F30005, CMSXS 5027 and CMSXS 5030 demonstrated similar nutritional values to the commercial varieties, making them promising candidates for future release, commercialization and use in animal feed silage.

KEYWORDS
chemical composition, ensiling, fermentation, *Sorghum bicolor*

1 | INTRODUCTION

Ensiling forage crops is a conservation strategy used to address the scarcity of feed for ruminant animals, particularly during periods of water shortage, or to provide autonomy within various production systems (Bernardes et al., 2018). In recent years, Brazil has been increasingly affected by climatic phenomena such as El Niño, which disrupt normal rainfall patterns and extend drought periods (Rojas et al., 2014). This issue has been exacerbated in the Amazon biome, where studies predict a significant temperature rise of 1.12°C (Braga & Laurini, 2024). Additionally, Mu and Jones (2022) reported that rainfall patterns in the Brazilian Legal Amazon are highly variable, with no consistent trends across the region. Since most beef and dairy farms in the Amazon rely on pasture-based systems, they experience a pasture deficit lasting 4–6 months each year. As a result, forage conservation has become a crucial strategy for increasing stocking rates and improving animal performance during the dry season (Daniel et al., 2019). This helps mitigate the effects of fluctuations in forage availability and nutritional value for pasture-raised animals, thereby providing greater autonomy to production systems (Stella et al., 2016).

Various forages can be ensiled if the factors associated with fermentative capacity are adequate (Borreani et al., 2018a). The crops most commonly used for silage production are corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) (Argenta et al., 2014). However, despite corn being the most important crop for agricultural production, it is more sensitive to water deficit than other grasses (Abbade, 2020).

In this scenario, sorghum silage becomes attractive because it presents advantages such as high biomass production and efficient water use, in addition to having greater tolerance to water deficit and resistance to soils with low fertility, characteristics that confer adaptability to cultivation in arid and semiarid regions (Schlegel et al., 2018). In addition, it is essential to evaluate the genotypes available on the market and those in the development and launch phases, seeking to achieve a balance between productivity and nutritional value, with a focus on ruminant nutrition (Sher et al., 2017).

However, there are no reports in the literature on the use of new sorghum cultivars for silage grown in the Amazon biome. This study aimed to evaluate the losses, fermentation profile and nutritional value of silage from 15 commercial and experimental sorghum genotypes for different purposes. With the results obtained, experimental materials that have the potential to be made available on the market and can be recommended for silage production in the Amazon biome should be selected.

2 | MATERIALS AND METHODS

2.1 | Location and conduct of the experiment

Planting and ensiling were carried out in the experimental area of Embrapa Agrossilvipastoril, Sinop, MT, Brazil (latitude 11°51′ S, longitude 55°35′ W and average altitude of 384 m). Laboratory analyses were carried out at the Laboratório de Nutrição Animal e Forragicultura da Universidade Federal de Mato Grosso, Campus Universitário de Sinop, Mato Grosso, Brazil.

The experimental area, located in the Amazon biome, has soil classified according to Santos et al. (2013) as a typical Dystrophic Red Yellow Oxisol, moderate A, very clayey texture and flat relief (Viana et al., 2015). The climate of the region, according to the Köppen climate classification, is Am (monsoon tropical), with an average annual air temperature of 25°C, an average minimum temperature of 18°C and an average maximum temperature of 33°C, with an average annual relative humidity of 83°C. The average yearly accumulated precipitation is 2250 mm (Alvares et al., 2013).

The accumulated precipitation data for the period during which the experiment was conducted were collected at an automatic station installed on the premises of Embrapa Agrossilvopastoril (Figure 1).

Sowing was carried out on 11/20/2019 and harvests between February 29, 2020 and April 24, 2020, totaling a cycle that varied from 101–103 days for BRS 658, BRS 659, Volumax, Ponta Negra, 15F30005 and 15F30006; 113 days for BRS 511, CMSXS 5027 and CMSXS 5030; 140 days for CMSXS 5043, CMSXS 5045 and 2019B008; and 156 days for AGRI002-E, BRS 716 and CMSXS 7501. The variation in harvest date occurred as a function of the time to reach the ensiling point when half of the panicles presented grains at the milky-pasty point, and this point varied depending on the type of sorghum.

2.2 | Genotype and silage fermentation profile

Fifteen sorghum genotypes of different types were evaluated, including commercial and experimental materials developed by Embrapa Milho e Sorgo, separated by the purpose of use, namely, forage; the genotypes BRS 658, BRS 659, Volumax, BRS Ponta Negra, 15F30005 and 15F30006; saccharine, BRS 511, CMSXS 5027, CMSXS 5030, CMSXS 5043 and CMSXS 5045; and biomass, BRS 716, AGRI-002E, 201934B0008 and CMSXS 7501 (*brown midrib, BMR).*

The experimental field was divided into 45 plots, with three replications per genotype. In the field, there were three plots per treatment, each consisting of two 5-m rows spaced 0.70 m apart, totaling 7 m^2. The cutting was carried out manually at 20 cm above ground level. At the time of cutting, 30 whole representative plants with a chopping length of approximately 2 cm were selected from each plot and chopped in a stationary forage harvester. After chopping, the material was homogenized, separated by approximately 4.5 kg and ensiled in experimental silos.

The experimental silos consisted of commercial plastic buckets with a volume of 7.8 dm^3 and a self-sealing lid. The lids were modified by inserting a Bunsen-type valve with a small fissure on the side and an epoxy-sealed end to release the gases produced inside the silo.

To measure the loss of effluents, nonwoven fabric (NWF) bags containing approximately 1.2 kg of dry sand were placed at the bottom of the experimental silos in a forced air ventilation oven (55°C for 48 h) with a shadow cutout of the same diameter as the bucket to separate the silage from the effluent. A small cutout was placed at the

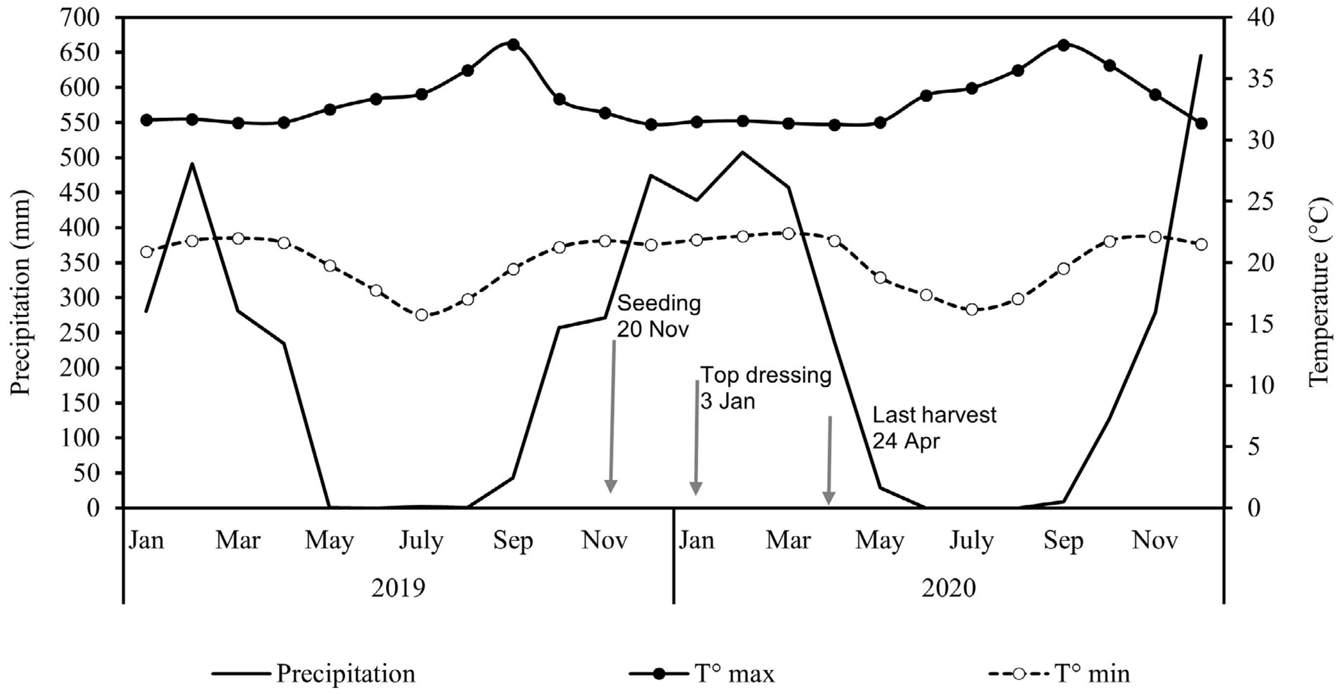

FIGURE 1 Rainfall, minimum, average and maximum temperature during the experiment for Sinop/MT. *Source*: Embrapa Agrossilvipastoril weather station (2020).

top to prevent valve obstruction. Before ensiling, the components were weighed to serve as a tare weight, which was later used to calculate losses.

Two silos were used per plot (3 field plots per cultivar), totaling 6 silos per genotype and a total of 90 experimental silos. The silos, all of which were identified, were compacted with a wooden plunger until they reached an average density of 550 kg/m^3. After that, the silos were closed and sealed with adhesive tape on the lid to prevent air from entering, and the process lasted at least 163 days. The chemical composition of the forage used to produce silage was analyzed by Rosa et al. (2022) and is described in Table 1.

Upon opening, the closed silos were weighed to estimate the loss due to gases, and subsequently, the silo + sand + cover set was weighed to estimate the loss due to effluents (Jobim et al., 2007).

Samples were collected from the geometric center of the experimental silo, which was homogenized, and two subsamples were taken for fresh analysis and drying. Approximately, 700 g of the sample was placed in paper bags to obtain the air-dried sample (ADS) content of the material (AOAC, 1990). After drying, the samples were ground in a Willey-type stationary mill with a 1 and 2 mm mesh sieve to carry out chemical analyses.

To measure the pH, fresh material was used according to the methodology of Kung Jr. (1996), where 25 g of fresh silage was processed in a blender for 1 min with 225 mL of distilled water, and then two readings were taken on a bench pH meter (model PG2000—Gehaka). To measure titratable acidity, the methodology of Silva and Queiroz (2006) was used, where 9 g of fresh silage and 60 mL of distilled water were added to a 250 mL beaker with a bench pH meter (model PG2000—Gehaka) attached and then titrated with a 0.1 N NaOH solution with slow and frequent stirring until the pH of the material reached 7. The NH_3-N content was determined as described by Chaney and Marbach (1962), and an enzyme-linked immunosorbent assay (ELISA) equipped with an Abs620 filter was used for reading.

2.3 | Chemical composition of silage

The assessment of the physically effective neutral detergent fiber (peNDF) was carried out via the method described by Mari and Nussio (2022) with a *Penn State Particle Size Separator* composed of four sieves, 19, 8, 4 mm, and deep. The *aW* or water activity was determined via the methodology described by Mari (2003). The oven-dried sample (ODS) values were obtained according to method 934.01 (AOAC, 1990). The ASH contents were determined according to method 924.05 (AOAC, 1990).

Regarding the nitrogen fraction in the material, method 920.87 was used (AOAC, 1990) to determine the crude protein (CP) content according to the protocol described by Detmann et al. (2012). Ethereal extract (EE) was measured via the INCT-CA G-005/1 method, as described by Detmann et al. (2012).

Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were determined through sequential extraction via the INCT-CA F-002/1 and INCT-CA F-004/1 methods, respectively, adapted to autoclave and NWF bags weighing 100 g/m^2 according to the procedures described by Detmann et al. (2012), using the solutions described by Van Soest (1994) with a thermostable α-amylase enzyme.

TABLE 1 Chemical composition of the preensiling forage of the 15 sorghum genotypes cultivated in the first harvest in Sinop, MT, Brazil (Rosa et al., 2022).

Genotype	DM^a	ASH^b	EE^b	CP^b	ADFap^b	NDFap^b	iNDF^b	Lig^b	NFC^b	TDN^b	WSC^b	BC^b	FC
BRS 658	296.1	38.4	24.5	70.5	310.7	525.7	304.5	52.7	340.9	582.4	174.7	35.8	72.89
BRS 659	296.7	43.4	23.0	71.3	285.8	484.6	231.5	49.1	381.0	590.5	205.8	29.1	86.35
Volumax	242.3	54.8	21.1	61.9	349.4	592.4	247.4	44.4	269.7	571.5	181.9	34.3	67.01
BRS Ponta Negra	200.9	39.1	23.5	63.2	342.8	564.5	311.3	53.1	309.7	575.9	126.3	22.4	65.10
15F30005	265.3	42.2	19.1	68.2	328.9	543.5	294.1	51.9	327.0	575.4	178.3	30.8	78.10
15F30006	262.1	45.1	24.1	68.9	287.3	495.7	286.2	42.7	366.3	604.1	228.5	29.3	82.87
BRS 511	197.8	44.9	26.8	57.8	235.4	424.5	283.3	34.2	446.0	651.9	387.8	16.2	195.06
CMSXS 5027	205.9	46.4	24.8	54.2	273.5	456.1	260.4	41.8	418.5	622.6	286.2	24.8	113.65
CMSXS 5030	214.2	41.2	16.0	51.1	257.6	426.7	271.7	42.6	465.1	643.4	395.6	23.8	155.36
CMSXS 5043	241.7	37.1	12.9	46.5	409.1	666.9	372.8	61.4	236.6	530.7	208.2	29.3	80.90
CMSXS 5045	244.4	32.7	13.3	35.2	426.1	692.0	378.3	69.1	226.8	521.0	219.4	28.7	87.72
201934B0008	266.6	41.1	15.4	42.8	436.5	694.8	452.9	78.9	205.9	501.2	138.0	42.1	52.88
AGRI-002E	308.5	33.4	16.0	54.5	424.0	684.6	385.7	72.6	211.5	514.1	175.1	29.1	72.41
BRS 716	289.4	27.5	16.0	39.8	450.5	698.7	430.3	80.6	219.8	513.6	153.7	26.9	74.61
CMSXS 7501*	242.6	37.4	18.8	52.1	409.1	627.6	436.7	51.9	264.0	560.0	153.0	25.8	71.21

Abbreviations: ADFap, acid detergent insoluble fiber corrected for ash and protein; ASH, ash; BC, buffer capacity; CP, crude protein; DM, dry matter; EE, ethereal extract; FC, fermentation coefficient; iNDF, indigestible neutral detergent fiber; Lig, lignin; NDFap, neutral detergent insoluble fiber corrected for ash and protein; NFC, nonfibrous carbohydrates; TDN, total digestible nutrients; WSC, water-soluble carbohydrates.

[a] g/kg.

[b] g/kg DM.

*Material with the *BMR* gene.

With the NDF and ADF residues, ASH (INCT-CA N-004/1) and CP (INCT-CA N-004/1) analyses were carried out to estimate neutral detergent fiber corrected for ash and protein (NDFap) and ADF corrected for ash and protein (ADFap) (Detmann et al., 2012). For lignin, the methodology described by the method for determining lignin in acid detergent in the Daisy^{II} incubator was used (Ankom Technology, 2022). The indigestible neutral detergent insoluble fiber (iNDF) content was determined according to the methods of Valente et al. (2011).

The water-soluble carbohydrate (WSC) content was determined according to the methodology described by Silva and De Queiroz (2006) with adaptations to the dilution, which was 400 mL for sweet sorghum and 200 mL for other sorghum types. The concentration of nonfibrous carbohydrates (NFC) was obtained via formula number 10, as described by Detmann et al. (2012). The determination of total digestible nutrients (TDN) was carried out via the equation described by the NRC (2001).

2.4 | Experimental design and statistical analyses

The experimental design used was completely randomized (DCR), with 15 treatments (genotypes) and six replications (experimental silos). The data were subjected to analysis of variance, and the means of the genotypes for the different characteristics were compared via the Scott–Knott test, adopting a probability level of 5%, via the GENES statistical program (Cruz, 2013).

3 | RESULTS

3.1 | Silage fermentation profile

The variables related to losses and the fermentative profile, namely, gas loss, effluent loss, pH, titratable acidity, water activity, NH_3-N/total N and WSC, differed between the genotypes ($p < 0.05$) (Table 2).

Greater gas losses were observed for the BRS 511 and CMSXS 5030 genotypes ($p < 0.01$), with an average loss of 141.38 g/kg. For effluent losses, the materials BRS Ponta Negra, BRS 511, CMSXS 5027 and CMSXS 5030 presented the highest average, 57.80 kg/t green material ($p < 0.01$).

With respect to pH (Table 2), the materials with the lowest pH values were BRS Ponta Negra, BRS 511, CMSXS 5030, CMSXS 5043 and CMSXS 7501, with an average of 3.73 ($p < 0.01$). In terms of titratable acidity, the volatile acid contents of the cultivars Volumax, BRS 511, CMSXS 5027, CMSXS 5030, CMSXS 5043 and 201934B008 presented the highest average value of 20.58 mL ($p < 0.01$).

The *aW* presented the highest values in BRS Ponta Negra, CMSXS 5030 and CMSXS 7501, with an average of 0.9839 ($p < 0.05$). With respect to the N-NH_3/total N content, the cultivars BRS 658 and BRS 659 comprised the group with the lowest average N-NH_3/total N content, 29.9 g N-NH_3/kg TN ($p < 0.01$). For residual soluble carbohydrates (RSC) ($p < 0.01$), the highest average was 151.6 g/kg dry matter (DM) for saccharine CMSXS 5027 and CMSXS 5030.

TABLE 2 Losses and fermentation profiles of silages of 15 sorghum genotypes grown during the first harvest in Sinop/MT, Brazil.

Genotype	GL	EL	pH	TA*	*aW*	NH_3-N/TN	RSC
BRS 658	22.75f	10.78c	3.88 to	18.40b	0.970b	29.81f	70.80d
BRS 659	22.75 f	10.78 c	3.88 a	18.40 b	0.970 b	29.81 f	70.80 d
Volumax	28.94 f	10.39 c	3.95 a	16.54 b	0.970 b	30.09 f	90.08 c
BRS Ponta Negra	45.98 e	33.72 b	3.92 a	19.91 a	0.970 b	34.24 e	61.17 d
15F30005	64.23 d	59.12 a	3.73 c	16.27 b	0.987 a	36.24 d	72.40 d
15F30006	27.33 f	33.74 b	3.83 b	17.52 b	0.970 b	33.90 e	76.38 d
BRS 511	25.89 f	29.77 b	3.83 b	18.53 b	0.975 b	33.09 e	75.58 d
CMSXS 5027	144.16 a	58.46 a	3.74 c	21.55 a	0.976 b	34.45 e	111.08 b
CMSXS 5030	109.42 b	56.42 a	3.81 b	20.43 a	0.973 b	37.13 d	152.28 a
CMSXS 5043	138.60 a	57.19 a	3.76 c	21.05 a	0.984 a	35.52 d	151.00 a
CMSXS 5045	106.70 b	39.97 b	3.74 c	20.93 a	0.972 b	45.65 b	86.26 c
201934B008	111.53 b	29.99 b	3.79 b	18.38 b	0.966 b	48.41 a	106.10 b
AGRI-002E	81.12 c	28.06 b	3.78 b	19.64 a	0.973 b	48.85 a	43.54 e
BRS 716	69.80 d	18.62 c	3.79 b	17.63 b	0.968 b	36.87 d	37.22 e
CMSXS 7501**	64.57 d	34.23 b	3.78 b	17.60 b	0.970 b	42.31 c	67.45 d
P value	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01
SEM	0.38	3.30	0.02	0.77	0.0042	0.10	0.49

Abbreviations: aW, water activity; EL, effluent loss in kg/t green material; GL, gas loss in g/kg; N-NH_3/NT, g/kg of NH_3-N in relation to total N; RSC, residual soluble carbohydrates in g/kg DM; SEM, standard error of the mean; TA, titratable acidity.

*Amount of 0.1 N NaOH needed to increase the pH of the material to 7.0.

**Material with the BMR gene. Means followed by the same letter in the same column do not differ significantly according to the Scott–Knott test ($p < 0.05$).

3.2 | Chemical composition of silage

The variables related to nutritional value, namely, DM, ASH, CP, EE, NDF, ADF, lignin, iNDF, peNDF, NFC and TDN, differed between the genotypes (Table 3).

The genotypes BRS 658, BRS 659, AGRI-002E and BRS 716 presented relatively high DM levels, with an average of 295.0 g/kg ($p < 0.01$). Volumax had the highest content among the ASH genotypes, at 55.8 g/kg DM ($p < 0.01$). The CP content was greater for the forage genotypes BRS 658 and BRS 659, at 78.1 g/kg DM ($p < 0.01$). The crude fat content was greater for 15F30005, at 42.18 g/kg DM ($p < 0.01$).

The NDFap for the BRS 659 and CMSXS 5027 genotypes had a lower average of 389.4 g/kg DM ($p < 0.01$). For ADFap, BRS 658, BRS 659, 15F30006 and CMSXS 5027 made up the group with the lowest average of 280.3 g/kg DM ($p < 0.01$). For iNDF, BRS 658, BRS 659, Volumax, 15F30005, BRS 511 and CMSXS 5027 had lower averages of 294.8 g/kg DM ($p < 0.01$). For peNDF, the lowest averages were observed for BRS 658, BRS 659, 15F30005, 15F30006 and CMSXS 5027, at 390.78 g/kg DM ($p < 0.01$).

In terms of NFC content, BRS 658, BRS 659, BRS Ponta Negra, 15F30005 and 15F30006, BRS 511, CMSXS 5027, CMSXS 5030 and CMSXS 5045 presented greater averages of 556.94 g/kg DM ($p < 0.01$). For TDN estimation, the highest average was from BRS 659, BRS Ponta Negra and 15F30005, at 674.21 g/kg DM ($p < 0.01$).

4 | DISCUSSION

The material with the greatest gas loss was saccharine, and it can be inferred that there was epiphytic yeast in the ensiled mass, with acetic and alcoholic fermentation, which commonly occurs in sugarcane silages, in which sugars are fermented with ethanol and CO_2, leading to the loss of DM (McDonald et al., 1991). Materials that have succulent stalks, such as saccharine and BRS Ponta Negra, can generate high levels of effluent loss, as they present, at the time of ensiling, a DM content lower than that recommended by Muck and Pitt (1993) and McDonald et al. (1991). Furthermore, Borreani et al. (2018b) highlighted that losses in the form of gases and effluents should not exceed 4% and 0.5%, respectively. However, as previously stated, fermentative losses for some cultivars in the present study were greater than those recommended. Effluent losses are detrimental to the nutritional value of silage, as they favor losses due to the leaching of nutrients produced during the process.

Soluble carbohydrates are the main substrates for lactic acid fermentation, decreasing the pH. Owing to the different concentrations of RSC for the different cultivars, variation in the pH values of the silages was observed. However, despite the variations, all the cultivars evaluated presented an ideal pH value, below 4.2, which classifies the silages of all the genotypes as having a good fermentation profile for the pH parameter (McDonald et al., 1991).

Microorganisms are generally fundamental to the silage fermentation process, and their activity is largely affected by aW (Jobim

TABLE 3 Chemical composition of silages from 15 sorghum genotypes grown during the first harvest in the Sinop/MT treatment in 2020.

Genotype	DM[a]	ASH[b]	CP[b]	EE[b]	NDFap[b]	ADFap[b]	Lig[b]	iNDF[b]	peNDF[b]	NFC[b]	TDN[b]
BRS 658	300.27 a	39.65 c	78.16 a	26.58 c	422.43 b	289.13 d	55.95 c	300.44 d	395.31 d	554.77 a	653.15 b
BRS 659	294.03 a	46.73 b	78.08 a	30.33 b	391.63 c	254.97 d	44.85 d	291.59 d	367.84 d	571.58 a	679.67 a
Volumax	236.87 d	55.77 a	67.72 b	31.37 b	464.67 b	309.84 c	47.43 d	297.94 d	444.37 c	498.60 b	646.42 b
BRS Ponta Negra	204.49 e	35.46 d	62.87 c	27.35 c	447.40 b	343.01 c	50.78 d	349.75 c	441.61 c	572.83 a	671.70 a
15F30005	262.84 b	40.10 c	67.34 b	42.18 a	424.89 b	305.93 c	55.79 c	284.19 d	393.85 d	538.10 a	671.25 a
15F30006	264.79 b	46.17 b	68.34 b	29.38 b	428.60 b	293.26 d	52.70 d	314.64 c	405.75 d	553.28 a	659.92 b
BRS 511	185.87 f	48.05 b	66.76 b	28.17 c	416.40 b	320.41 c	54.14 c	305.57 d	415.18 c	554.58 a	650.20 b
CMSXS 5027	200.57 e	46.82 b	62.34 c	18.57 e	387.14 c	284.08 d	49.27 d	289.03 d	391.14 d	580.27 a	656.97 b
CMSXS 5030	201.32 e	46.09 b	63.98 c	18.57 e	445.76 b	311.26 c	51.82 d	318.92 c	435.68 c	549.47 a	644.50 b
CMSXS 5043	248.50 c	31.33 e	51.40 e	18.92 e	560.78 a	412.68 a	67.86 b	391.83 b	550.37 a	481.42 b	611.60 c
CMSXS 5045	266.48 b	32.82 e	47.58 e	21.05 e	534.20 a	358.75 b	60.80 c	432.24 a	506.80 b	537.60 a	645.97 b
201934B008	274.83 b	36.16 d	46.79 e	24.37 d	604.76 a	429.98 a	84.44 a	431.29 a	558.42 a	438.42 c	582.33 d
AGRI-002E	296.86 a	35.68 d	63.03 c	29.45 b	557.94 a	392.89 a	69.03 b	453.95 a	502.47 b	429.60 c	608.47 c
BRS 716	289.00 a	33.84 e	55.55 d	24.13 d	574.01 a	408.12 a	77.42 a	469.49 a	524.33 b	473.43 b	603.22 c
CMSXS 7501*	234.61 d	40.81 c	56.99 d	22.98 d	555.70 a	375.51 b	62.11 c	446.18 a	515.93 b	494.40 b	619.00 c
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM	0.38	0.11	0.15	0.09	1.56	1.21	0.33	1.27	1.38	1.67	0.80

Abbreviations: ASH, ash; CP, crude protein; DM, dry matter content; EE, ethereal extract; iNDF, indigestible neutral detergent fiber; Lig, lignin; NDF, acid detergent insoluble fiber corrected for ash and protein; NDFap, neutral detergent insoluble fiber corrected for ash and protein; NFC, nonfibrous carbohydrates; peNDF, physically effective neutral detergent fiber; SEM, standard error of the mean; TDN, total digestible nutrients.

[a] g/kg.

[b] g/kg DM.

*Materials with the *BMR* gene. Means followed by the same letter in the same column do not differ significantly according to the Scott–Knott test ($p < 0.05$).

et al., 2007). According to McDonald et al. (1991), the genus *Clostridium* is inhibited when the aW is less than 0.94; lactic acid bacteria exhibit greater resistance. This variable was greater than the reference value for all the cultivars evaluated, especially for BRS Ponta Negra, CMSXS 5030 and CMSXS 751, in which the first two have succulent stalks and a lower DM value; thus, under conditions in which the properties of the silage are not correctly determined, the development and proliferation of undesirable microorganisms in the silages of all the cultivars may have occurred.

The g NH_3-N/kg TN indicates the amount of protein degraded during the fermentation phase, and in the present study, all materials presented values below the maximum recommended concentration, which is 100 to 120 g NH_3-N/kg TN (Kung et al., 2018), indicating an adequate fermentation profile and good-quality silage.

In terms of nutritional value, the dry matter content of silage is one of the most important parameters for successful fermentation. Kung et al. (2018) reported that DM levels below 250 g/kg in sorghum silage could prevent a rapid decline in pH and allow the development of undesirable microorganisms, such as those of the genus *Clostridium*. Although some cultivars presented silage DM contents below the recommended range, the silages presented pH and NH_3-N values within those expected for good-quality silage.

The increase in ASH in comparison with forage may be related to possible soil contamination during ensiling (Rodrigues et al., 2015), and the values should be close to those of forage before ensiling, as occurred in this study.

Sorghum CP levels depend on several factors, including the agronomic behavior of the genotype, maturity stage and edaphoclimatic conditions of the agricultural area (Costa et al., 2016). Good-quality silage must have a CP content that meets the protein demand of the ruminants. The genotypes presented a minimum level of CP (BRS 658 and BRS 659), above 70 g/kg DM (Van Soest, 1965) and close to 80 g/kg DM (Lazzarini et al., 2009) to meet the nitrogen needs of the ruminal flora and allow the rumen to function properly. The genotypes with the highest levels of CP were those specifically developed for fodder and intended for use in animal feed. In contrast, the materials with the lowest CP content were derived from the biomass and biomass saccharin groups, likely because of their larger size and lower proportion of panicles (Behling, 2017).

However, in the scenario of using these silages evaluated in this study as a basal source of roughage in the diet, all of them can be used, and based on the expected animal performance, it is necessary to use nitrogen supplementation to intake and digest nutrients in the diet because there is a concomitant positive response to nitrogen supplementation on animal performance even with forages of medium to high quality (Detmann et al., 2014).

Fibrous portions are important components for defining the nutritional value of silage. Accordingly, Van Soest (1994) reported that

NDF concentrations between 550 and 600 g/kg DM are desirable. In this way, the values found for the silages of all the materials evaluated in this work were within the indicated range, showing potential for use in animal feed.

The value obtained for NDF from the silages of all the genotypes was lower than that obtained for the preensiling forage, and this difference can be explained by the possible occurrence of acid hydrolysis caused by the prolonged period of the fermentation process, which exceeded 160 days. ADF is inversely proportional to digestibility; similarly, the lower the ADF content is, the greater the digestibility of the dry mass of the food (forage) by the animal, resulting in greater voluntary consumption. Among the cell wall components, lignin is the most recognized for limiting the digestion of fibrous polysaccharides in the rumen (Van Soest, 1994).

The digestion of forage fiber is slow, and it is only partially digested by ruminants, mainly because it contains high amounts of lignin, which forms an extremely strong wall that is very resistant to attack by rumen microorganisms, so a relatively high concentration of lignin limits the energy value of the forage (Moore et al., 2020). This compound does not change in level during the ensiling process, and the evaluation of this compound is highly important for selecting genotypes that contain low levels of lignin. In this sense, standard biomass genotypes naturally have relatively high lignin levels, as lignin is the component responsible for providing support for the plant.

Compared with normal plants, plants with the *BMR gene* show a 5% to 50% reduction in lignin concentration; this mutation leads to a reduction of 10 g/kg DM for millet, 12 g/kg DM for sorghum and 20 g/kg DM for maize (Moore et al., 2020). These results confirm the function of this gene in reducing lignin content. Therefore, it is estimated that the digestibility of this material and, consequently, animal performance will be superior when it is used in animal feed compared with the other biomass materials evaluated in this study.

In terms of lignin content, a comparison of the proportion of this component in the BMR CMSXS 7501 material with that of BRS 716, which is the standard material, revealed a reduction of approximately 20% in lignin. In addition, this material had the same lignin content as the fodder crop 15F30005 and the sugar crops BRS 511 and CMSXS 5045, showing potential for use in animal feed.

As the iNDF includes the portion of the undigested plant cell wall throughout the gastrointestinal tract (Sniffen et al., 1992), the group that presented the highest average was composed of genotypes that presented a relatively high lignin content. Furthermore, all the silages had peNDF values higher than those recommended and could be used in the formulation of diets for cattle. A more recent meta-analysis (Khorrami et al., 2021) revealed that the ratio of peNDF measured using the 8-mm sieve of the *Penn State Particle Separator* should range between 150 and 180 g/kg DM to prevent a rumen pH less than 5.8 with diets containing between 20% and 25% starch. For Brazilian conditions, Lanna et al. (2005) recommend a minimum of 150 g/kg DM of peNDF, and Zebeli et al. (2012) recommend that a minimum of 148 to 196 g/kg of peNDF must have a particle size greater than 8 mm.

Even though biomass materials have high levels of cellulose and lignin, further studies are needed to assess the possibility of using these materials in animal feed under specific management practices. In production systems where the silage used has high-performance objectives, such as weight gain or high-yielding dairy cows, forage is the material of choice, as it is more similar in composition to corn silage, with a better CP content and higher quality fiber, which is essential to ensure good production and adequate fat content in milk.

However, in systems that require a high quantity of roughage, the use of biomass materials is recommended since the green material and DM production of these materials average 89.14 and 24.80 Mg/ha, respectively (Rosa et al., 2022). Compared with forage crops, which averaged 57.11 and 14.67 Mg/ha, MV production and DM production increased by approximately 36% and 41%, respectively, with similar values for losses during the ensiling process and the cost of setting up and running the crop, which will reduce the production cost per Mg of silage.

For example, in feedlot systems for finishing, where the main objective of using silage is only to provide a minimum of peNDF in the diet, the use of biomass material is recommended, as this leads to a reduction in the cost of production per t/ha and, consequently, in the cost of the final diet. As a result, further studies are needed to assess the possibility of using these materials in animal feed under specific management practices.

Another alternative for using silage from biomass materials would be in animal maintenance systems during the rearing phase, in which animals are removed from pasture and placed in confinement systems during the dry–rainy transition period owing to the high need for roughage. In addition, owing to the greater mass production of biomass materials, there is also the possibility of using them in extensive systems where there is little financial support, guaranteeing a greater supply of roughage for the animals during the period when pasture is scarce.

With an emphasis on a vision of the future for the launch of the studied genotypes, aiming to combine productivity and forage quality, the genotype 15F30005, with a DM production of 21.79 t/ha (Rosa et al., 2022), a forage purpose and a similar pattern to biomass but with high quality, showed promise in the prelaunch line. In this sense, this genotype has great potential to be launched commercially soon, and the information contained in this work is the first to demonstrate its potential for fermentability and quality in the form of silage.

5 | CONCLUSION

All 15 sorghum genotypes are capable of being used as hybrids for silage production because they present adequate fermentability and nutritional characteristics. In terms of nutritional value, the best materials are the commercial forages BRS 658, BRS 659 and BRS Ponta Negra and the experimental forage genotypes 15F30005 and saccharines CMSXS 5027 and CMSXS 5030, highlighting their potential for launching, commercializing and using silage in animal feed.

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ORCID

Dalton Henrique Pereira https://orcid.org/0000-0002-3128-1103

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