

Article

Productivity, Fermentation Parameters, and Chemical Composition of Silages from Biomass Sorghum Hybrids in Ratoon Crop

Yara América da Silva ¹, Marco Antonio Previdelli Orrico Junior ^{1,*} , Marciana Retore ² , Gessi Ceccon ² ,
Isabele Paola de Oliveira Amaral ¹ , Ana Carolina Amorim Orrico ¹ , Giuliano Reis Pereira Muglia ¹ 
and Tatiane Fernandes ³ 

¹ College of Agricultural Science, Federal University of Grande Dourados, Dourados 79804-970, MS, Brazil; yaraamerica603@gmail.com (Y.A.d.S.); isabelep.oliveira@gmail.com (I.P.d.O.A.); anaorrico@ufgd.edu.br (A.C.A.O.); gmuglia12@gmail.com (G.R.P.M.)

² Brazilian Agricultural Research Corporation-Embrapa Agropecuária Oeste, Dourados 79804-970, MS, Brazil; marciana.retore@embrapa.br (M.R.); gessi.cecon@embrapa.br (G.C.)

³ Department of Dairy Science, Virginia Tech, Blacksburg, VA 24061-0315, USA; fernandest@vt.edu

* Correspondence: marcojunior@ufgd.edu.br; Tel.: +55-67-98116-0711

Abstract

Biomass sorghum stands out for its high dry matter yield and ratooning ability, enabling additional harvests and silage production. This study evaluated the productive potential and fermentation quality of silages from ratoon biomass sorghum hybrids. A 5 × 2 factorial randomized block design was used, with five hybrids (CMSXS5039, CMSXS5044, CMSXS7102, CMSXS7103, and BRS 716) grown in two municipalities of Mato Grosso do Sul, Brazil (Dourados and Jateí). Dry matter production (DMP) did not differ ($p > 0.05$) among the hybrids within each municipality; however, overall yield was higher in Jateí, averaging 12 t DM/ha. In Dourados, CMSXS5039 and CMSXS5044 showed the highest lactic acid concentrations (46.71 and 59.73 g/kg DM), whereas in Jateí, CMSXS7102, CMSXS7103, and BRS 716 stood out (45.70, 44.78, and 40.77 g/kg DM, respectively), among the sites, Jateí had the greater lactic acid production (49.95 g/kg DM). Aerobic stability (AS) averaged 28.5 h, with higher values in Dourados ($p < 0.05$), about 16 h longer than in Jateí. BRS 716 and CMSXS5044 presented the highest crude protein contents (115.17 and 118.33 g/kg DM). CMSXS5039 grown in Jateí had the lowest neutral detergent fiber and the highest starch and non-fiber carbohydrate values. Biomass sorghum hybrids exhibited good yield potential and good silage quality even under low rainfall conditions, with CMSXS5039 best suited for more energetic diets and BRS 716 and CMSXS5044 for more proteic diets.

Keywords: agronomic characteristics; ensiling; forage conservation; *Sorghum bicolor*



Academic Editors: Siran Wang, Lin Sun, Lei Chen and Jie Bai

Received: 23 August 2025

Revised: 12 September 2025

Accepted: 15 September 2025

Published: 18 September 2025

Citation: Silva, Y.A.d.; Orrico Junior, M.A.P.; Retore, M.; Ceccon, G.; Amaral, I.P.d.O.; Orrico, A.C.A.; Muglia, G.R.P.; Fernandes, T.

Productivity, Fermentation Parameters, and Chemical Composition of Silages from Biomass Sorghum Hybrids in Ratoon Crop.

Fermentation **2025**, *11*, 540.

<https://doi.org/10.3390/fermentation11090540>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) has stood out as a promising versatile crop in agricultural production given its adaptability to different climate and soil conditions, in addition to its efficient water use [1,2]. Among the several sorghum types, biomass sorghum has received special attention in the agricultural and livestock sector, particularly for silage production [3,4].

The choice of biomass sorghum for silage production is justified by its superior agronomic characteristics such as high biomass productivity, good nutritive value, and resistance to pests and diseases [5,6]. Furthermore, biomass sorghum has excellent capacity to

adapt to more arid environments or seasons, which makes it a viable choice for regions where other forage crops (such as corn) lack satisfactory performance [7] according to the Agricultural Climate Risk Zoning.

A notable advantage of biomass sorghum is its capacity to ratoon after cutting, enabling two consecutive harvests within the same growing season [8]. Although the second harvest typically yields less biomass than the first, the combined production from both cuts can substantially increase total sorghum output per unit area, thereby reducing the cost per ton of biomass produced [8,9].

However, ratoon sorghum often exhibits marked differences in chemical composition compared with the first cut. Several studies have reported that ratooning tends to have lower dry matter concentrations and reduced levels of water-soluble carbohydrates, along with potential changes in fiber composition and lignification patterns [9]. These compositional shifts can impair the ensiling process by limiting the availability of fermentable substrates for lactic acid bacteria, potentially leading to slower pH decline, suboptimal fermentation profiles, and reduced aerobic stability (AS) of the resulting silage [10].

Given these constraints, there is a pressing need for breeding programs aimed at developing biomass sorghum hybrids that combine high ratoon yield with favorable chemical characteristics to support efficient fermentation and stable silage quality [11].

In face of that, the present research had the following hypotheses: (i) biomass sorghum hybrids sustain satisfactory ratoon yield, justifying an additional harvest; (ii) the silages of new hybrids CMSXS5039, CMSXS5044, CMSXS7102, and CMSXS7103 (in pre-launch phase) have superior nutritive value over silages produced from BRS 716 (commercial hybrid). Therefore, the present study aimed to assess the productive potential and fermentation quality of silages from ratoon biomass sorghum hybrids so as to identify which of those are the most promising for silage production.

2. Materials and Methods

The trial was simultaneously conducted in two regions of the state of Mato Grosso do Sul, Brazil. The first region was a farm located in the municipality of Jateí (22°26'57" S, 54°20'11" W, and 396 m above sea level), which has dystroferric Red Yellow Latosol—LVAd soil type according to the Brazilian Soil Classification System—SiBCS Ref. [12], equivalent to Typic Hapludox in the Soil Taxonomy Ref. [13], with 12% clay.

The second region was the experimental area of Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária—EMBRAPA) located in the municipality of Dourados (22°16'44" S, 54°49'10" W, and 430 m above sea level), which has eutrophic Red Latosol—Lve soil type according to the SiBCS Ref. [12], equivalent to Rhodic Eutrudox in the Soil Taxonomy Ref. [13], with 75% clay. The climate in both sites is Cwa (humid mesothermic, with wet summers) according to the Köppen classification [14]. Figure 1 shows the rain regime throughout the experimental period and the historical rainfall.

The experiment adopted a 5 × 2 factorial randomized block design comprising five biomass sorghum hybrids (CMSXS5039, CMSXS5044, CMSXS7102, CMSXS7103, and BRS 716) sowed in two distinct regions of the state of Mato Grosso do Sul, Brazil (Dourados and Jateí). Variation in soil fertility in the area was the blocking factor.

The soil analysis of the experimental area in Jateí had the following result: sand: 848 g/kg; silt: 32 g/kg; clay: 120 g/kg; pH CaCl₂: 4.7; Al³⁺: 0.07 cmolc/dm³; Ca²⁺: 0.76 cmolc/dm³; Mg²⁺: 0.38 cmolc/dm³; H⁺ + Al³⁺: 2.93 cmolc/dm³; K⁺: 0.80 cmolc/dm³; P (Mehlich): 35.6 mg/dm³; sum of bases: 1.94 (cmolc/dm³); cation exchange capacity: 4.87 cmolc/dm³; base saturation: 39.84%; and organic matter: 13.76 g/kg.

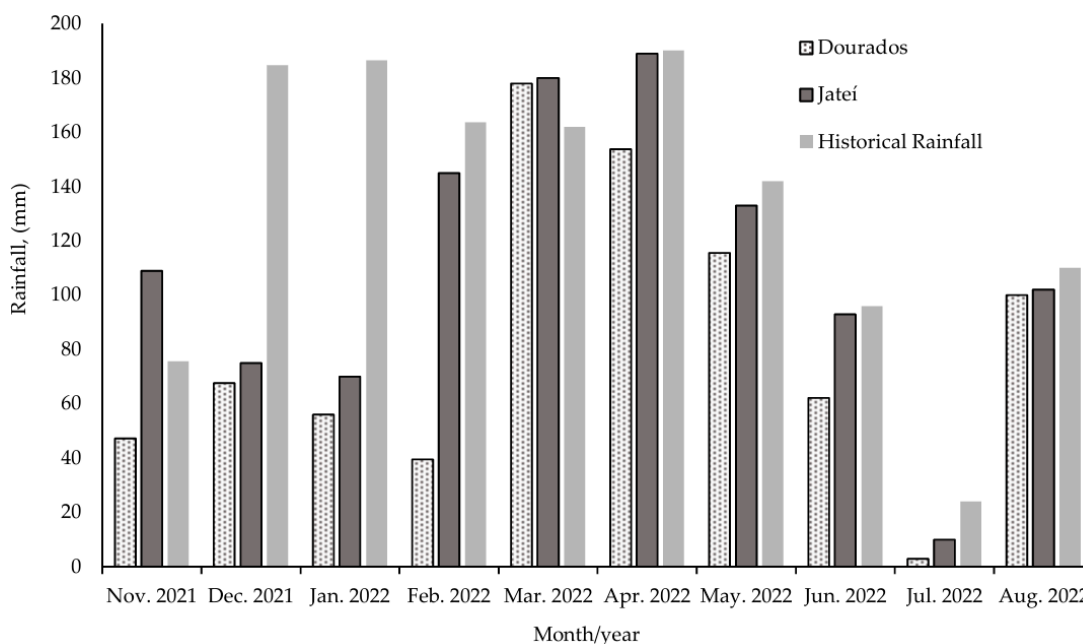


Figure 1. Rainfall (mm) recorded in Dourados and Jateí throughout the experimental period, and historical rainfall of the region (2002–2022).

The soil analysis of the experimental area in Dourados had the following result: sand: 205 g/kg; silt: 158 g/kg; clay: 637 g/kg; pH CaCl₂: 4.9; Al³⁺: 0.07 cmolc/dm³; Ca²⁺: 3.10 cmolc/dm³; Mg²⁺: 1.36 cmolc/dm³; H⁺ + Al³⁺: 4.15 cmolc/dm³; K⁺: 0.64 cmolc/dm³; P (Mehlich): 9.30 mg/dm³; sum of bases: 5.10 cmolc/dm³; cation exchange capacity: 9.25 cmolc/dm³; base saturation: 55.14%; and organic matter: 27.89 g/kg. All physical and chemical soil analyses were carried out according to the methodology described by Ref. [15]

The hybrids were sown in the municipalities of Jateí and Dourados on 5 and 23 November 2021, respectively, using a SHM 1517 seed drill (Semeato Inc., Passo Fundo, RS, Brazil) with a row spacing of 45 cm. Fertilization was applied following recommendations based on soil chemical analysis and according to Ref. [16]. At planting, 300 kg/ha of fertilizer with an 8-20-20 (N-P-K) formula was applied. Subsequently, 20 days after plant emergence, a topdressing fertilization was carried out with 140 kg/ha of nitrogen in the form of ammonium sulfate. Sorghum density was set at 100,000 plants/ha, with an allowable margin of error of ±2.5%. Each experimental plot was composed of seven, 8 m rows. Six experimental plots were sowed per treatment.

The first sorghum harvest took place on 6 March 2022 in Jateí and on 12 April 2022 in Dourados. Fourteen days after cutting, top dressing at 140 kg/ha N, in the form of ammonium sulfate, was applied. The second harvest, after ratoon of the hybrids, took place on 19 July 2022 in Jateí and on 24 August 2022 in Dourados (Figure 2).

In order to assess the productive characteristics of the hybrids, a sample of 2 linear meters was collected from one of the central rows in each plot for morphological separation and determination of dry matter (DM) values of each plant part. The sorghum plants were split into leaf, stem with sheath, and panicle. Plant height was measured with a measuring tape and the stem diameter, with digital calipers. Forage yield per hectare was estimated by multiplying the total plant weight harvested in each plot by its respective content of DM. The results were expressed in tons of DM per hectare (t DM/ha).

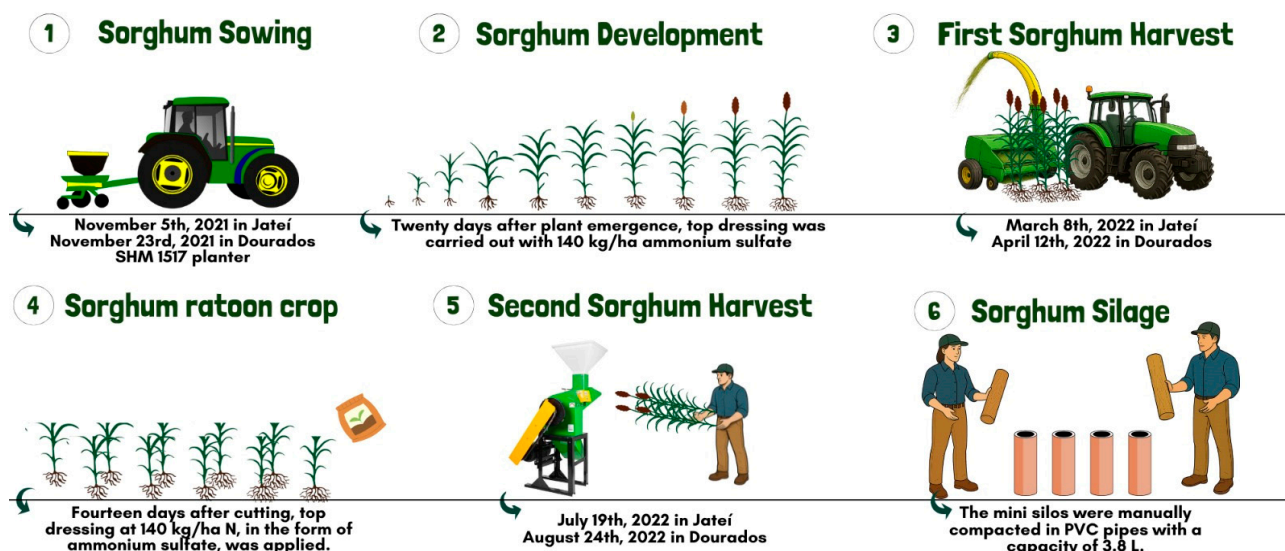


Figure 2. Representation of the production and harvest steps of the different biomass sorghum hybrids assessed in the municipalities of Jateí and Dourados, MS, Brazil.

For silage production, a sample of the central plants from each experimental plot was processed using a stationary forage grinder (JF, model 5D), which chopped the material to an average particle length of 1.5 cm. The material from each plot was homogenized and used to fill the experimental silos. During filling, forage samples from each treatment were collected and frozen at $-18\text{ }^{\circ}\text{C}$ for later analysis of chemical composition, pH, and buffer capacity. The ground forage mass was ensiled in laboratory experimental silos built using PVC pipes (10 cm diameter and 50 cm height) with useful volume of 3.8 L. The material was manually compacted using wood rods to achieve mean density of 270 kg DM/m^3 . At the bottom of each experimental silo, 300 g sand was placed for effluent drainage, separated from the forage by a thin piece of fabric mesh. After filling, the experimental silos were sealed with double-faced (black and white) plastic film and adhesive tape and stored in the laboratory at room temperature.

To calculate fermentation losses, all silo components (silo, sand, and fabric), as well as the ensiled TMR mass, were weighed before and after ensiling. Dry matter recovery (g/kg of ensiled DM), gas losses (g/kg of ensiled DM), and effluent losses (g/kg of ensiled forage) were calculated according to the equations proposed by Ref. [17]. Dry matter recovery was calculated using the following formula:

$$\text{DMR} = 100 - \left(\frac{\text{DMI} - \text{DMF}}{\text{DMI}} \times 100 \right)$$

where DMR = dry matter recovery (% of initial DM mass); DMI = initial DM mass (kg of DM placed in the silos); and DMF = final DM mass (kg of DM removed from the silos).

Gas losses were calculated using the following formula:

$$\text{GL} = \frac{\text{SWI} - \text{SWF}}{\text{DMI}} \times 100$$

where GL = gas loss during storage (% of initial DM mass); SWI = weight of the sealed silo at the beginning (kg); SWF = weight of the sealed silo at the time of opening (kg); and DMI = initial DM mass (kg of DM placed in the silos).

Effluent losses were calculated using the following formula:

$$\text{EP} = \frac{\text{SWF} - \text{SWI}}{\text{DMI}} \times 1000$$

where EP = effluent production (kg/t of DM); SWF = final weight of the set (silo + sand + fabric) in kg; SWI = initial weight of the set (silo + sand + fabric) in kg; and DMI = initial DM mass (kg of DM placed in the silos).

The silos were then opened and the material inside them was removed and homogenized for sample collection. The samples of each of the silages produced were sent to a partner laboratory for chemical composition analysis. Another portion of the samples was frozen for later pH analysis.

The chemical composition of both silage and fresh forage samples was determined using a Foss 5000 Transport near-infrared reflectance spectrophotometer (NIRS; Eden Prairie, MN, USA) with calibrations (WinISI version 4.6.11, FOSS Analytical A/S, Hillerød, Denmark) provided by the Dairy One Forage Laboratory (Ithaca, NY, USA). The analyses included determination of dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), ether extract (EE), soluble carbohydrates (SC), non-fiber carbohydrates (NFC), and starch. Model performance was verified through cross-validation and, when applicable, external validation, considering the coefficient of determination (R^2), standard error of validation (SEV), and residual predictive deviation (RPD), with minimum acceptance criteria of $R^2 \geq 0.90$ and $RPD \geq 3.0$.

A portion of the frozen samples was processed to obtain an aqueous extract, which was used to determine pH (in fresh forage and silage), buffering capacity (only in fresh forage), and organic acids (only in silage). For extract preparation, 25 g of forage were diluted in 225 mL of distilled water and manually homogenized for approximately 20 min. The pH of the extract was measured using a digital potentiometer (mPA210, MS Tecnopon), and buffering capacity was determined according to the method described by Ref. [18]. Acetic acid and butyric acid concentrations were quantified using a gas chromatograph with a mass spectrometry detector (GCMS QP 2010 Plus, Shimadzu, Kyoto, Japan) equipped with a capillary column (Stabilwax, Restek, Bellefonte, PA, USA; 60 m \times 0.25 mm ID, 0.25 μ m polyethylene cross-bond carbowax glycol). Lactic acid concentration was determined by the colorimetric method described by Ref. [19].

Aerobic stability was determined in all silages after the silos were opened. Samples (2 ± 0.005 kg) of each replicate of each treatment were freely placed in clean experimental silos. Temperature sensors were placed in the geometric center of the silages and a double layer of gauze was placed on top of each experimental silo to prevent drying and contamination while allowing for air penetration. Room temperature, as well as the temperature of each silage, was recorded every minute using a datalogger (RC-4, Elitech[®], San Jose, CA, USA). Aerobic stability was defined as the number of hours the silage remained stable before rising by more than 2 °C above the ambient temperature [10].

The data were analyzed using the statistical program Sisvar 5.8 (Build 92). When the interaction of factors was significant ($\alpha \leq 0.05$), the factors were analyzed separately. In the case of non-significant interaction, the factors were analyzed by principal component analysis. The means were compared by Scott-Knott test at 5% level of significance. The data were analyzed according to the following model:

$$Y_{ijk} = \mu + \beta_k + S_i + SA_j + S * SA_{ij} + \varepsilon_{ijk},$$

where Y_{ijk} = dependent variable, μ = overall average, β_k = block effect (random effect; $k = 1, 2, 3, 4, 5,$ and 6), S_i = effect of different hybrids (fixed effect; $i = \text{CMSXS5039, CMSXS5044, CMSXS7102, CMSXS7103, and BRS 716}$), SA_j = site effect (fixed effect; $j = \text{Dourados and Jatef}$), $S * SA_{ij}$ = effect of the interaction between hybrids and sites, and ε_{ijk} = random error associated with each observation.

3. Results

3.1. Productivity and Morphological Characteristics of the Biomass Sorghum Hybrids

No significant difference was observed for DM production (DMP) among the biomass sorghum hybrids. However, significant difference was found in DMP between the production sites, with Jateí having higher productions (Table 1).

Table 1. Agronomic characteristics and chemical composition of different biomass sorghum hybrids assessed in ratoon crops in the municipalities of Jateí and Dourados, MS, Brazil, 2022.

Parameters	(H)					(S)		SEM	p-Value		
	H5039	H5044	H7102	H7103	H716	Jateí	Dourados		H	S	H × S
Agronomic characteristics											
DMP, t/ha	7.49	8.04	7.74	7.26	8.38	12.55	3.00	0.20	0.85	<0.01	0.708
HS, m	1.80 a	1.46 b	1.92 a	1.87 a	1.81 a	2.44	1.10	0.08	<0.01	<0.01	0.069
SD, mm	12.41 a	11.03 b	9.77 c	9.56 c	10.71 b	12.39	9.00	0.51	<0.01	<0.01	0.449
Stem, %	47.06	47.49	45.71	47.30	47.16	43.02	50.87	0.32	0.81	<0.01	0.181
Leaf, %	22.74 b	28.80 a	19.97 b	21.93 b	23.55 b	16.06	30.73	1.47	0.02	<0.01	0.227
Panicle, %	30.20	23.71	34.32	30.77	29.29	40.92	18.40	4.03	<0.01	<0.01	<0.01
Chemical composition											
DM (g/kg FM)	320.04 b	314.23 b	356.18 a	370.44 a	324.52 b	397.26	264.11	10.21	<0.01	<0.01	0.054
CP (g/kg DM)	112.25 b	120.01 a	95.00 c	105.5 b	118.25 a	121.90	94.10	1.99	<0.01	<0.01	0.078
SC (g/kg DM)	68.25 b	73.50 b	45.75 c	62.00 b	92.00 a	75.10	57.50	9.75	0.04	0.07	0.128
ST (g/kg DM)	125.25 a	52.25 c	97 b	101.25 b	70.5 c	125.90	52.60	7.36	<0.01	<0.01	0.547
EE (g/kg DM)	23.750	27.50	21.50	22.75	27.25	30.90	18.20	1.93	0.18	<0.01	0.216
NFC (g/kg DM)	242.75	193.50	181.00	199.50	204.75	246.40	162.20	13.36	0.07	<0.01	0.402
NDF (g/kg DM)	594.25 b	642.02 a	669.75 a	648.25 a	622.75 b	577.00	693.80	12.03	0.01	<0.01	0.677

H = Hybrid; S = Site; H5039 = CMSXS5039; H5044 = CMSXS5044; H7102 = CMSX7102; H7103 = CMSXS7103; H716 = BRS716; HS = Plant height in meters; SD = Steam diameter in millimeters; DMP = total dry matter production; DM = dry matter; FM = fresh matter; CP = crude protein; NDF = neutral detergent fiber; ST = Starch; EE = ether extract; NFC = non-fiber carbohydrate; SC = soluble carbohydrate. SEM = standard error of the mean. Means followed by different letters differ according to Scott-Knott test at 5% probability.

Hybrid CMSXS5044 had the shortest mean height (1.46 m) and highest leaf proportion (28.8%) when compared with the other hybrids assessed. The sites also significantly impacted ($p < 0.01$) plant height and leaf proportion, with the plants grown in Jateí being taller (2.44 m) and having higher leaf proportion (30.73%). Stem diameter (SD) was influenced both by the hybrids and the sites ($p < 0.01$), with the largest SD found for CMSXS5039 and the largest mean SD found in the plants grown in Jateí.

A significant interaction ($p < 0.01$) was observed between the hybrids and sites regarding panicle proportion (Table 1 and Figure 3). Hybrids CMSXS5039 and CMSXS7102 stood out for having the highest panicle proportions ($p < 0.01$) when grown in Jateí.

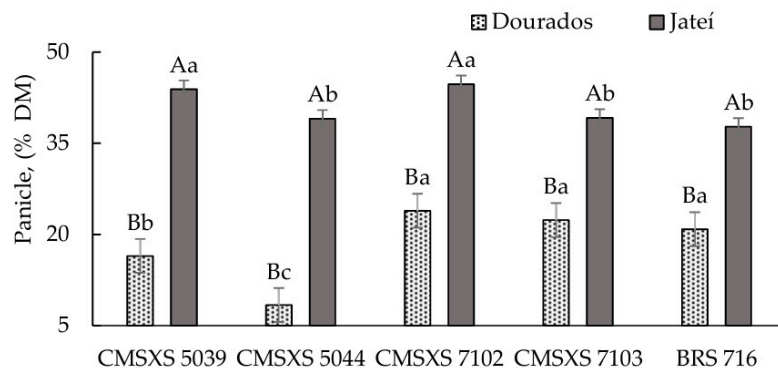


Figure 3. Panicle percentage in different biomass sorghum hybrids assessed in ratoon crops in the municipalities of Jateí and Dourados, MS, Brazil, 2022. Means followed by different letters differ according to Scott-Knott test at 5% probability. Capital letters compare sites and small letters compare hybrids.

Concerning chemical composition (Table 1), hybrids CMSXS7103 and CMSXS7102 had the highest DM values at 356.18 g/kg fresh matter (FM) and 370.44 g/kg FM, respectively, 15.17% higher than hybrid CMSXS5044, which had the lowest DM content (314.23 g/kg FM).

The values of CP, NDF, SC, and starch were influenced by both the hybrids and sites. Hybrid BRS 716 had the highest CP content, followed by hybrids CMSXS5039, CMSXS5044, CMSXS7103, and CMSXS7102, in that order. Hybrids BRS 716 and CMSXS5044 had the lowest starch values but stood out with the highest SC values. Hybrids CMSXS7102, CMSXS7103, and CMSXS5044 had the highest NDF values, whereas hybrids CMSXS5039 and BRS 716 had the lowest NDF values. On average, the plants grown in Jateí had the highest values of CP, starch, and SC and the lowest NDF values when compared with those grown in Dourados.

3.2. Fermentation Parameters and Chemical Composition of Silages from Different Biomass Sorghum Hybrids

A significant interaction ($p < 0.05$) was observed for EP between the hybrids and growth sites (Table 2 and Figure 4). Hybrids CMSXS5039 and CMSXS5044 grown in Dourados had the highest EP values ($p < 0.05$). However, no significant differences were observed for EP among silages produced with the different hybrids in Jateí. DMR was influenced exclusively by the hybrids, with CMSXS7102 having the lowest values (840.28 g/kg DM), approximately 3.56% lower than the average of the other hybrids. No differences ($p > 0.05$) were observed between hybrids and growth sites regarding GL. The average GL value found was 28.49 g/kg DM among the treatments (Table 2).

Table 2. Fermentation parameters and chemical composition of silages of different biomass sorghum hybrids assessed in ratoon crops in the municipalities of Jateí and Dourados, MS, Brazil, 2022.

Parameters	(H)					(S)		SEM	p-Value		
	H5039	H5044	H7102	H7103	H716	Jateí	Dourados		H	S	H × S
EP (kg/t DM)	59.66	51.75	46.13	44.06	41.23	4.39	92.74	4.62	<0.01	<0.01	0.022
DMR (g/kg DM)	858.74 a	871.33 a	840.28 b	860.96 a	860.73 a	859.64	857.18	4.31	0.04	0.688	0.136
GL (g/kg DM)	25.57	38.23	24.53	23.35	30.78	26.07	30.92	0.55	0.06	0.173	0.073
pH	3.84 b	3.82 b	3.91 a	3.80 c	3.77 c	3.91	3.74	0.07	<0.01	<0.01	0.065
Lac. Ac. (g/kg DM)	46.71	59.73	45.7	44.78	40.77	49.95	45.13	0.56	0.02	0.181	<0.01
Ace. Ac. (g/kg DM)	12.39	12.28	19.14	15.48	12.37	12.21	16.46	0.18	<0.01	0.01	<0.01
But. Ac. (g/kg DM)	1.40 a	0.43 c	1.29 b	1.44 a	0.88 b	1.04	1.14	0.02	<0.01	0.433	0.21
NH ₃ -N (g/kg TN)	9.48 a	5.01 c	9.47 a	7.92 a	6.71 b	9.12	6.47	0.08	<0.01	<0.01	0.31
AS (h)	25.55	31.98	28.29	28.9	27.75	20.78	36.71	3.61	0.51	<0.01	0.341
DM (g/kg FM)	301.00	307.92	351.08	340.34	311.42	399.6	245.1	9.79	<0.01	<0.01	<0.01
CP (g/kg DM)	113.50 b	118.33 a	109.75 c	110.58 c	115.17 a	128.57	98.37	2.98	0.04	<0.01	0.074
EE (g/kg DM)	38.25 b	46.5 a	38.17 b	37.25 b	36.58 b	44.76	32.2	1.86	0.05	<0.01	0.516
Starch (g/kg DM)	131.5	64.00	112.17	102	59.67	144.67	43.07	7.84	<0.01	<0.01	<0.01
NFC (g/kg DM)	279.83	228.5	235.33	241.5	229.58	270.43	215.47	1.85	<0.01	<0.01	<0.01
NDF (g/kg DM)	537.83	577.92	585.83	578.33	589.58	531.93	615.87	9.27	<0.01	<0.01	<0.01

H = Hybrid; S = Site; H5039 = CMSXS5039; H5044 = CMSXS5044; H7102 = CMSXS7102; H7103 = CMSXS7103; H716 = BRS716; EP = effluent production; DMR = dry matter recovery; GL = gas loss; pH = potential of hydrogen; Lac. Ac. = lactic acid; Ace. Ac. = acetic acid; But. Ac. = butyric acid; NH₃-N = ammoniacal nitrogen; AS = aerobic stability; DM = dry matter; FM = fresh matter; TN = total nitrogen; EE = ether extract; NFC = non-fiber carbohydrate; NDF = neutral detergent fiber; SEM = standard error of the mean. Means followed by different letters differ according to Scott-Knott test at 5% probability.

Hybrids CMSXS7103 and BRS 716 had the lowest ($p < 0.05$) pH values (3.80 and 3.77, respectively) while CMSXS7102 had the highest pH (3.91). Lactic acid values showed a significant interaction ($p < 0.05$) between the hybrids and sites. The silages produced by hybrids CMSXS5039 and CMSXS5044 in Dourados had the highest values of lactic acid (46.71 and 59.73 g/kg DM), whereas in Jateí, hybrids CMSXS7102, CMSXS7103, and BRS 716 produced silages with the highest lactic acid values (45.70, 44.78, and 40.77 g/kg DM, respectively).

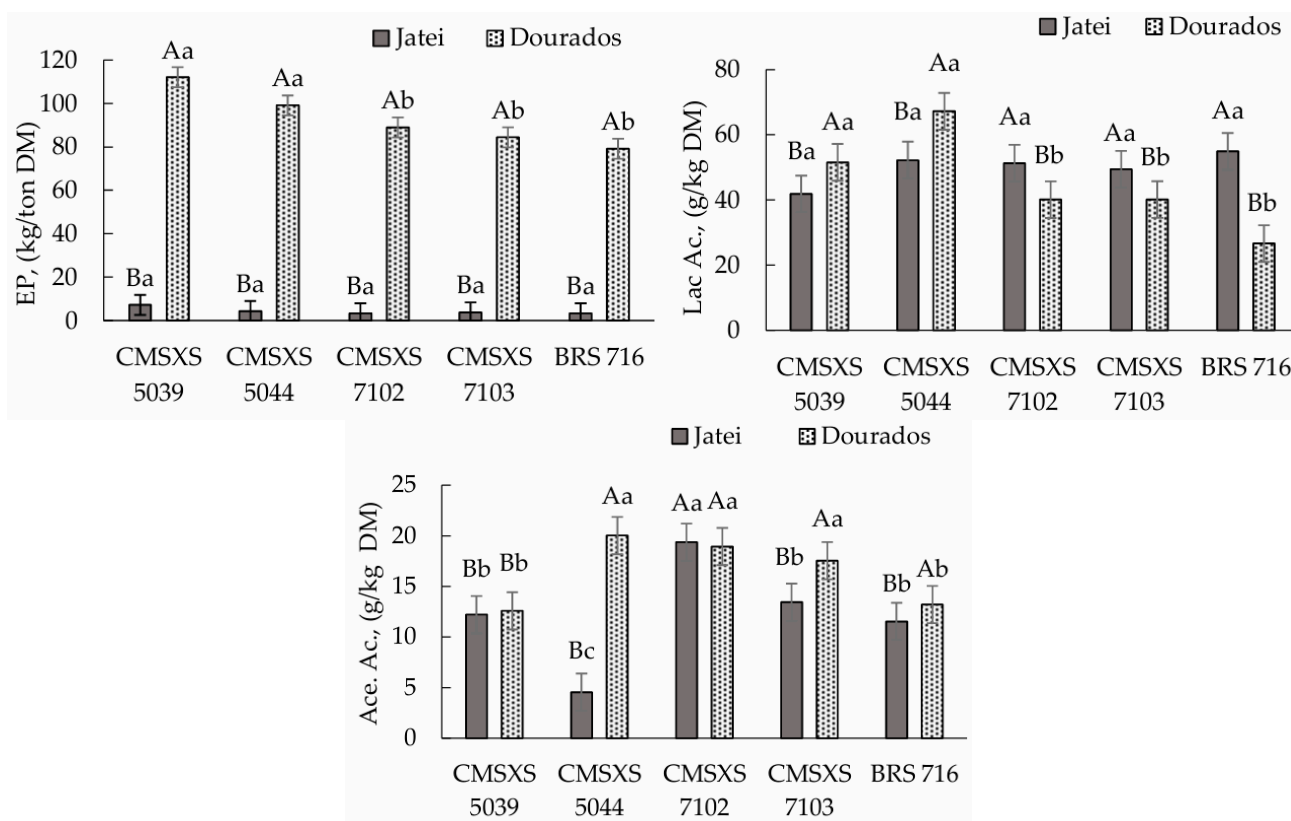


Figure 4. Effluent production (EP), lactic acid (Lac. Ac.) and acetic acid (Ace. Ac.) values of silages from different biomass sorghum hybrids assessed in ratoon crops in the municipalities of Jateí and Dourados, MS, Brazil, 2022. Means followed by different letters differ according to Scott-Knott test at 5% probability. Capital letters compare sites and small letters compare hybrids.

Overall, the hybrids grown in Dourados had the highest acetic acid values, except for CMSXS5039 and CMSXS7102, which had similar values in both sites. The highest acetic acid values were found in hybrids CMSXS7102 (Dourados and Jateí), CMSXS7103 (Dourados), and CMSXS5044 (Dourados), at an average of 18.95 g/kg DM. On the other hand, the lowest acetic acid production was found for hybrid CMSXS5044 grown in Jateí, at an average of 4.55 g/kg DM (Figure 4).

The lowest butyric acid and ammoniacal nitrogen (NH₃-N) values were found in hybrid CMSXS5044 (0.43 g/kg DM and 5.01 g/kg total nitrogen, respectively), with no significant difference between the sites (Table 2). No statistical difference was found in AS among the hybrids tested. However, the silages produced in Dourados had higher ($p < 0.05$) AS at 16 h longer on average when compared with those from Jateí.

Hybrids CMSXS7102 and CMSXS7103 had the highest DM values, while BRS 716 had the lowest DM content in Jateí. In Dourados, hybrid CMSXS5039 and CMSXS5044 had the lowest ($p < 0.05$) DM content (Figure 5). Overall, all hybrids grown in Dourados had lower DM values when compared with Jateí.

Crude protein also significantly varied ($p < 0.05$) among the hybrids tested. Hybrids BRS 716 and CMSXS5044 had the highest CP values at 115.17 g/kg DM and 118.33 g/kg DM, respectively. Hybrids CMSXS7102 and CMSXS7103, meanwhile, had the lowest CP values, approximately 7.25% lower than the highest values observed.

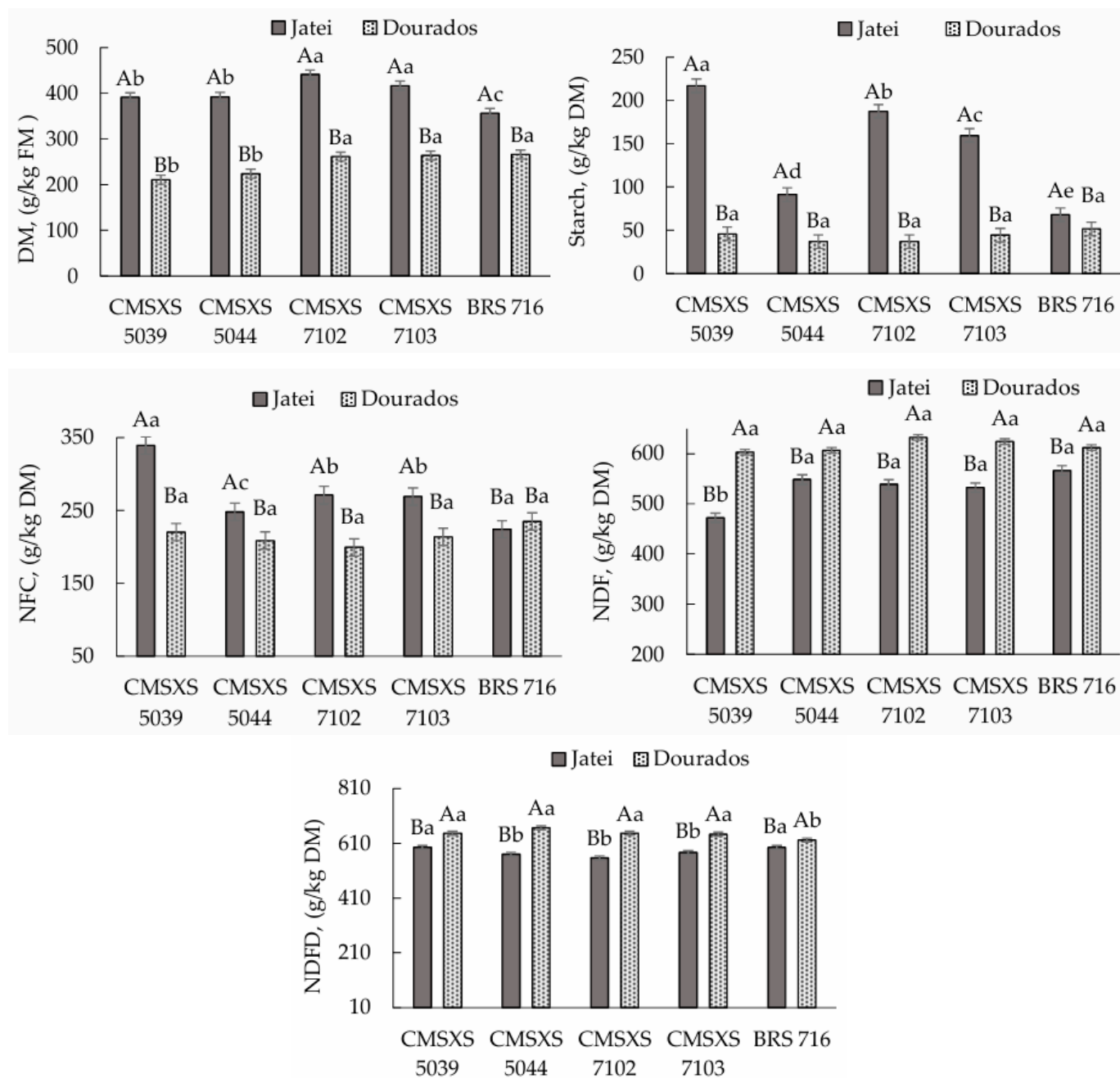


Figure 5. Contents of dry matter (DM), starch, non-fiber carbohydrates (NFC), neutral detergent fiber (NDF), and NDF digestibility (NDFD) of silages from different sorghum biomass hybrids assessed in regrowth in the municipalities of Jateí and Dourados, MS, Brazil. FM = fresh matter. Means followed by different letters differ according to Scott-Knott test at 5% probability. Capital letters compare sites and small letters compare hybrids.

Overall, the silages produced in Jateí had the lowest NDF values, with hybrid CM-SXS5039 having the lowest NDF content among all treatments studied (537.83 g/kg DM). Ether extract content was higher only for hybrid CMSXS5044 (46.5 g/kg DM). No significant difference ($p > 0.05$) was found for starch or NFC values among the hybrids grown in Dourados. However, in Jateí, the silages produced from hybrid CMSXS5039 had the highest starch and NFC values.

4. Discussion

4.1. Productivity and Morphological Characteristics of the Biomass Sorghum Hybrids

The hybrid grown in Jateí achieved an average yield of 12.0 ± 2.3 t DM/ha, which can be considered high for the season. In contrast, the reduced rainfall in Dourados resulted in yields of only 3.0 ± 1.5 t DM/ha, indicating that, despite the recognized tolerance of sorghum hybrids to water stress, adequate minimum temperatures and soil moisture remain essential to achieve harvestable yields. In a study conducted by Ref. [20] evaluating four sorghum cultivars (SHS 400, 1G220, BRS 310, and 0992045) in semi-arid regions of Brazil, grain yields ranged from 1.7 to 5.1 t/ha. The authors reported a strong positive relationship between water availability and grain yield, with the highest productivity observed in areas where total precipitation during the crop cycle reached up to 519 mm.

According to Ref. [21], sorghum requires between 450 and 550 mm of water throughout its growth cycle, with optimal yields occurring when cumulative rainfall exceeds 500 mm. In the present study, the period from April to August—corresponding to the sorghum ratoon phase—recorded cumulative precipitation of approximately 430 mm in Dourados and 527 mm in Jateí, compared with a regional historical average of 562 mm for the same period (Figure 1—data from 2002 to 2022). These less favorable climatic conditions, particularly in Dourados, likely reduced yield potential and help explain the lower biomass production observed in this municipality.

Therefore, producers intending to use sorghum ratoon as a strategy to increase silage availability should consider anticipating planting to coincide with the onset of the rainy season, ensuring that ratoon occurs under still favorable temperature and precipitation conditions. Alternatively, harvesting at a lower DM content (below 33% DM) may also be an option to minimize yield losses.

Although they exhibited the same biomass productions, the tested biomass sorghum hybrids had different heights and leaf proportions. This suggests that while certain morphological parameters may be more stable, others, such as height and leaf proportion, are highly sensitive both to the genetic material and to the environment [22]. Hybrid CMSXS5044, which had the lowest height and highest leaf proportion, can be particularly advantageous in contexts where leaf biomass is preferred. On the other hand, plants grown in Jateí exhibited greater height and lowest leaf proportions, indicating that the climatic or edaphic conditions at this site are more favorable for vegetative growth.

Compared to other sorghum types, biomass sorghum has a longer vegetative cycle, which, combined with its greater plant height, generally results in higher productivity [2,11]. However, the total biomass per area is not influenced only by height Ref. [23], but also by stem diameter, number of shoots, population density, and photosynthesis efficiency of the plants [24]. That means a taller plant does not necessarily result in higher biomass production, thus explaining why in the present experiment hybrids of such different heights produced similar amounts of biomass.

A study by Ref. [11] showed that biomass sorghum varieties have an important correlation between plant height and fiber content in the plant. That is because very tall plants require a higher proportion of fiber for support so as to prevent losses due to lodging. However, Ref [2] did not find a significant correlation between the height of biomass sorghum hybrids and their fiber values. Such results suggest other factors such as hybrid genetics, growth conditions, and maturity stage may also impact the fiber content of biomass sorghum.

In the context of the present experiment, the plants grown in Dourados had significantly lower nutrient values than those grown in Jateí. An example of that difference is in starch values, where the plants from Jateí, which had higher proportions of panicles, also had the highest starch values.

According to Ref. [25], under stress conditions, plants tend to reduce the synthesis of sugars and proteins, decrease growth, store phenolic compounds, and increase tissue lignification, which may compromise forage nutritive value. That finding suggests the water stress in Dourados not only impacted the production of biomass sorghum hybrids but also compromised the nutritive value of the material produced.

Hybrids CMSXS5044 and BRS 716 stood out for their high CP values, attributed to the higher leaf proportions at harvest, a desirable characteristic to improve the nutritional value of the silage, particularly in diets of high-performance ruminants. Overall, the mean CP values of the hybrids were much higher than those commonly observed in the literature for biomass sorghum during the main harvest.

The study by Ref. [11] found CP values between 39 and 54 g/kg DM for biomass sorghum hybrids, which are much lower than the ones in the present experiment. It is likely that the low stature of the plants during ratoon contributed to the plants having lower fiber proportions and, consequently, higher protein values. In the experiment by Ref. [11], height ranged from 4 to 5.5 m and NDF values were approximately 700 g/kg DM.

4.2. Fermentation and Nutritional Parameters of Silages from Biomass Sorghum Hybrids

Effluent production during ensiling may be impacted by several factors that affect both its biomass accumulation and nutritive value. According to the literature, the main factors impacting EP are the DM content in the forage, the type of forage, compaction, particle size, the use of additives, pre-ensiling management, silo type, and climate conditions [26]. In the present experiment, DM content was the only factor that varied among the tested treatments and, therefore, had the greatest impact in the productions observed.

According to Ref. [26], forages with low DM content (below 30%) have more free water, which contributes to increasing effluent production and the loss of essential nutrients via leaching. That suggests the higher water content in the plants harvested in Dourados favored effluent generation Ref. [26], thus pointing to the need for using dry additives to adjust moisture and control effluent losses.

In contrast, the minimum GL values observed and the lack of significance among treatments (hybrids or site) are an indication of the efficiency of the fermentation process. According to Ref. [27], low GL in silages indicates lower DM losses during the fermentation process since gases are byproducts of microbial fermentation. Excess GL may indicate undesired fermentation and, consequently, significant losses of energy and nutrients [28]. Therefore, fermentation that produces less gas is more efficient and better preserves the quality of ensiled forage, which will often have higher lactic acid concentration in relation to other fatty acids [27].

In this study, the biomass sorghum silages obtained from ratoon crops showed lactic acid concentrations lower than those reported by Ref. [29] for the same hybrids in the main harvest. Nevertheless, the silages maintained a satisfactory fermentation profile Ref. [10], suggesting that the lactic acid produced was sufficient to ensure preservation and stability during storage.

Lactic acid plays a central role in silage quality, as it rapidly reduces the pH of the ensiled mass, creating an unfavorable environment for undesirable microorganisms such as *Clostridium* spp., which are associated with dry matter losses Ref. [27] and with undesirable fermentations, particularly butyric fermentation [10]. Moreover, once ingested by ruminants, lactic acid is converted into propionic acid, representing an important metabolic pathway for energy supply [10].

In general, acetic acid productions were low Ref. [10], particularly in the silages produced in Jateí, which suggests a prevalence of homofermentation (lactic acid only) over heterofermentation (lactic acid and other products, such as acetic acid) [30–32]. Studies

have shown that sorghum undergoes significant changes in chemical composition during ratoon Ref. [9], which may result in changes in the fermentation profile of the silages.

A study by Ref. [33] reported that sorghum silages from ratoon had lower acetic acid (26 g/kg DM) when compared with sorghum silages from the main harvest (41 g/kg DM). The authors found that sorghum plants were less productive in ratoon, besides having lower nutrient values and higher lignin concentration. The same likely happened in the present experiment, where the lower nutrient availability in the sorghum plants during ratoon may have favored the growth of strains better adapted to the environmental conditions (homofermentative strains in this case).

Acetic acid is essential for the AS of the silage as it inhibits the growth of yeasts and filamentous fungi responsible for spoilage when the silage is exposed to air [27,34]. To ensure greater AS, acetic acid levels between 15 and 30 g/kg DM are considered ideal [27]. Levels below 15 g/kg DM may not provide sufficient protection, whereas levels above 30 g/kg DM must be monitored as they may compromise silage palatability. This explains why, overall, the silages of the tested hybrids had low AS values (between 20 and 37 h). Nevertheless, the highest AS values were observed for the silages with the highest acetic acid values (silages produced in Dourados).

In order to attempt to solve the low AS issue in sorghum silages during ratoon, the use of heterofermentative inoculants, such as *Letilactobacillus buchneri*, would be recommended. That microorganism favors acetic acid production, thus extending silage AS and reducing losses after opening [10].

Under ideal conditions, butyric acid concentrations should remain below 5 g/kg DM, whereas values above 10 g/kg DM indicate inadequate fermentation [27]. Similarly, NH₃-N levels below 10 g/kg TN reflect good protein preservation, while values exceeding this threshold suggest excessive proteolysis and reduced silage quality [27]. In the present study, both parameters remained within the recommended ranges, confirming the efficiency of the fermentation process. Among the hybrids evaluated, CMSXS 5044 stood out with a low butyric acid concentration (0.43 g/kg DM)—slightly higher than the average reported by Ref. [29] for the first cut, yet still consistent with high-quality silage standards. These results highlight the strong ensiling potential of biomass sorghum ratoon, reinforcing its value as a strategic forage alternative in systems aiming for multiple harvests within a single growing season.

Hybrids such as BRS 716 and CMSXS5044, which had the highest CP values, are advantageous because protein is a crucial component in ruminant diets, especially during the growth phase and milk production. The CP content is directly related to silage nutritional value as quality protein is essential for good animal performance [35]. On the other hand, hybrids CMSXS7102 and CMSXS7103 had CP values about 7.25% lower than the highest values found, which may limit their use in diets that require greater protein supply.

In contrast, hybrid CMSXS5039 had the highest NFC and starch values, which makes it interesting as those components are highly fermentable by ruminants and, therefore, may provide more energy than the other hybrids. Moreover, CMSXS5039 had the lowest NDF values among all hybrids tested, which suggests greater digestibility and, consequently, greater dietary efficiency of ruminants.

Therefore, from a nutritional standpoint, the choice of sorghum cultivar for ensiling will depend on the production system and the nutritional needs of the herd. Hybrid CMSXS5039, with greater digestibility and energetic value, is more indicated to systems that seek high dietary efficiency. Hybrids such as BRS 716 and CMSXS5044, with higher CP values, are more appropriate for diets that require greater protein supply. Those variations highlight the importance of selecting the hybrid according to the specific requirements of production and local growth conditions [11].

5. Conclusions

Biomass sorghum hybrids demonstrated high dry matter yield potential even under low-rainfall conditions. All evaluated hybrids produced silages with satisfactory fermentation quality, with reduced aerobic stability being the only limitation, which could be mitigated by the use of heterofermentative inoculants. In terms of chemical composition, CMSXS5039 stood out as the most suitable hybrid for diets targeting higher energy supply, given its superior starch and non-fiber carbohydrate contents, while BRS 716 and CMSXS5044 proved more appropriate for diets demanding higher protein levels due to their elevated crude protein concentrations.

Author Contributions: Conceptualization, Y.A.d.S., M.R., G.C. and M.A.P.O.J.; methodology, M.R. and G.C.; validation, A.C.A.O. and T.F.; formal analysis, I.P.d.O.A.; investigation, Y.A.d.S. and M.R.; resources, M.A.P.O.J. and G.C.; data curation, A.C.A.O.; writing—original draft, Y.A.d.S., I.P.d.O.A., and G.R.P.M.; writing—review and editing, M.A.P.O.J., M.R., G.C. and T.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Coordination for the Improvement of Higher Education Personnel (CAPES; Brasília, DF, Brazil—n°0001) and the Development of Education, Science and Technology (FUNDECT; Mato Grosso do Sul, MS, Brazil TO: 118/2024 SIAFIC: 813).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: We gratefully acknowledge the support provided by Embrapa Agropecuária Oeste—CPAO, the Federal University of Grande Dourados (UFGD), and the SISPEC network (Network of Smart and Sustainable Livestock Systems, funded by CYTED, ref. 125RT0167), which were essential for the development and execution of this work. We also sincerely thank Latina Seeds for the generous donation of seeds used in the experimental trials.

Conflicts of Interest: Embrapa is a non-profit public institution under the Ministry of Agriculture and Livestock of Brazil. Its work focuses on the development of technologies and knowledge for agriculture and livestock, with an emphasis on sustainability and food security. Dr. Marciana Retore and Dr. Gessi Ceccon are affiliated with Embrapa, which operates on a non-profit basis. Therefore, the authors state that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Orrico Junior, M.A.P.; Retore, M.; Manarelli, D.M.; De Souza, F.B.; Ledesma, L.L.M.; Orrico, A.C.A. Forage Potential and Silage Quality of Four Varieties of Saccharine Sorghum. *Pesqui. Agropecu. Bras.* **2015**, *50*, 1201–1207. [[CrossRef](#)]
2. Castro, M.; Bruzi, A.T.; Nunes, J.A.R.; Parrella, R.A.C.; Lombardi, G.M.R.; Albuquerque, C.J.; Lopes, M. Agronomic and Energetic Potential of Biomass Sorghum Genotypes. *Am. J. Plant Sci.* **2015**, *6*, 1862–1873. [[CrossRef](#)]
3. De Queiroz, F.E.; Rocha, V.R.; Monção, F.P.; Rigueira, J.P.S.; Parrella, R.A.d.C.; Rufino, L.D.d.A.; Santos, A.S.d.; Cordeiro, M.W.S. Effect of Row Spacing and Maturity at Harvest on the Fermentative Profile, Aerobic Stability, and Nutritional Characteristics of Biomass Sorghum (BRS 716) Silage in the Semiarid Region of Brazil. *Rev. Bras. Zootec.* **2021**, *50*, e20200254. [[CrossRef](#)]
4. Manarelli, D.M.; Orrico, M.A.P.; Retore, M.; de Vargas, F.M.; da Silva, M.S.J.; Orrico, A.C.A.; Borquis, R.R.A.; Crone, C.; de Oliveira Neves, F. Productive Performance and Quantitative Carcass Traits of Lambs Fed Saccharine Sorghum Silage. *Pesqui. Agropecu. Bras.* **2019**, *54*, e00577. [[CrossRef](#)]
5. Ra, K.; Shiotsu, F.; Abe, J.; Morita, S. Biomass Yield and Nitrogen Use Efficiency of Cellulosic Energy Crops for Ethanol Production. *Biomass Bioenergy* **2012**, *37*, 330–334. [[CrossRef](#)]
6. Souza, Í.D.A.d.S.; Rocha Júnior, V.R.; Monção, F.P.; Parrella, R.A.d.C.; Cordeiro, M.W.S.; Carvalho, C.d.C.S.; Rigueira, J.P.S.; Aspiazú, I.; Silva, F.V.; Delvaux Júnior, N.d.A. Yield and Nutritional Value of Biomass Sorghum (BRS 716) Managed in Different Row Spacing and Maturity at Harvest in the Semiarid Region of Brazil. *Semin. Agrar.* **2021**, *42*, 3463–3484. [[CrossRef](#)]

7. Peerzada, A.M.; Ali, H.H.; Chauhan, B.S. Weed Management in Sorghum [*Sorghum bicolor* (L.) Moench] Using Crop Competition: A Review. *Crop Prot.* **2017**, *95*, 74–80. [[CrossRef](#)]
8. Lestari, E.; Dewi, I.S.; Yunita, R.; Nur, A. Evaluation of Ratooning Ability in Several Sweet Sorghum (*Sorghum bicolor* [L.] Moench) Mutant Lines. *AIP Conf. Proc.* **2022**, *2462*, 050003. [[CrossRef](#)]
9. Zhou, Y.; Huang, J.; Li, Z.; Wu, Y.; Zhang, J.; Zhang, Y. Yield and Quality in Main and Ratoon Crops of Grain Sorghum under Different Nitrogen Rates and Planting Densities. *Front. Plant Sci.* **2022**, *12*, 778663. [[CrossRef](#)]
10. Kung, L., Jr.; Shaver, R.D.; Grant, R.J.; Schmidt, R.J. Silage Review: Interpretation of Chemical, Microbial, and Organoleptic Components of Silages. *J. Dairy Sci.* **2018**, *101*, 4020–4033. [[CrossRef](#)] [[PubMed](#)]
11. Rosa, M.A.B.; Tardin, F.D.; Souza, J.M.d.S.; Santos, J.A.P.; Macedo, T.d.F.; Santos, J.; de Freitas, M.H.; Todescato, F.; Parrella, R.A.d.C.; Figueiredo, J.E.F.; et al. Characterization of Forage, Sweet and Biomass Sorghum for Agronomic Performance and Ensilability. *Rev. Bras. Milho e Sorgo* **2022**, *21*, 1–22. [[CrossRef](#)]
12. Santos, H.G.; Jacomine, P.K.; Anjos, L.H.C.; Oliveira, V.A.; Lumberras, J.F.; Coelho, M.R.; Almeida, J.A.; Araújo Filho, J.C.; Oliveira, J.B.; Cunha, T.J.F. *Sistema Brasileiro de Classificação de Solos*, 5th ed.; Embrapa: Brasília, Brazil, 2018; p. 356.
13. Soil Survey. *Keys to Soil Taxonomy*, 12th ed.; USDA—Natural Resources Conservation Service: Washington, DC, USA, 2014.
14. Fietz, C.R.; Fisch, G.F. O Clima Da Região de Dourados, MS. *Embrapa Agropecuária Oeste* **2008**, *92*, 32.
15. Silva, F.C. *Manual de Análises Químicas de Solos, Plantas e Fertilizantes*, 2nd ed.; Silva, F.C., Ed.; Embrapa Informação Tecnológica: Brasília, Brazil, 2009; ISBN 978-85-7383-430-7.
16. Borém, A.; Pimentel, L.; Parrella, R. *Sorgo: Do Plantio a Colheita*, 1st ed.; UFV: Vicosa, Brazil, 2014.
17. Jobim, C.C.; Nussio, L.G.; Reis, R.A.; Schmidt, P. Avanços Metodológicos Na Avaliação Da Qualidade Da Forragem Conservada Methodological Advances in Evaluation. *Rev. Bras. Zootec.* **2007**, *36*, 101–119. [[CrossRef](#)]
18. Playne, M.J.; Mc Donald, P.T. The Buffering Constituents of Herbage and of Silage. *J. Sci. Food Agric.* **1966**, *17*, 264–268. [[CrossRef](#)]
19. Pryce, J.D. A Modification of Barker-Summerson Method for the Determination of Lactic Acid. *Analyst* **1969**, *94*, 1151–1152. [[CrossRef](#)] [[PubMed](#)]
20. Von Pinho, R.G.V.; Vasconcelos, R.C. *Cultura Do Sorgo*, 1st ed.; UFLA: Lavras, Brazil, 2002.
21. Ferraz-Almeida, R.; Albuquerque, C.J.B.; Camargo, R.; Lemes, E.M.; Soares de Faria, R.; Quintão Lana, R.M. Sorghum–Grass Intercropping Systems under Varying Planting Densities in a Semi-Arid Region: Focusing on Soil Carbon and Grain Yield in the Conservation Systems. *Agriculture* **2022**, *12*, 1762. [[CrossRef](#)]
22. Oliveira, I.C.M.; Guilhen, J.H.S.; Ribeiro, P.C.d.O.; Gezan, S.A.; Schaffert, R.E.; Simeone, M.L.F.; Damasceno, C.M.B.; Carneiro, J.E.d.S.; Carneiro, P.C.S.; Parrella, R.A.d.C.; et al. Genotype-by-Environment Interaction and Yield Stability Analysis of Biomass Sorghum Hybrids Using Factor Analytic Models and Environmental Covariates. *Field Crops Res.* **2020**, *257*, 107929. [[CrossRef](#)]
23. Li, Y.; Li, C.; Cheng, Q.; Duan, F.; Zhai, W.; Li, Z.; Mao, B.; Ding, F.; Kuang, X.; Chen, Z. Estimating Maize Crop Height and Aboveground Biomass Using Multi-Source Unmanned Aerial Vehicle Remote Sensing and Optuna-Optimized Ensemble Learning Algorithms. *Remote Sens.* **2024**, *16*, 3176. [[CrossRef](#)]
24. Shah, A.N.; Tanveer, M.; Abbas, A.; Yildirim, M.; Shah, A.A.; Ahmad, M.I.; Wang, Z.; Sun, W.; Song, Y. Combating Dual Challenges in Maize Under High Planting Density: Stem Lodging and Kernel Abortion. *Front. Plant Sci.* **2021**, *12*, 1–19. [[CrossRef](#)]
25. Bibi, A.; Sadaqat, H.A.; Tahir, M.H.N.; Fatima Usman, B.; Ali, M. Genetic Analysis of Forage Quality Traits in Sorghum–Sudangrass Hybrids under Water Stress. *J. Anim. Plant Sci.* **2012**, *22*, 1092–1100.
26. Gebrehanna, M.M.; Gordon, R.J.; Madani, A.; VanderZaag, A.C.; Wood, J.D. Silage Effluent Management: A Review. *J. Environ. Manag.* **2014**, *143*, 113–122. [[CrossRef](#)] [[PubMed](#)]
27. Borreani, G.; Tabacco, E.; Schmidt, R.J.; Holmes, B.J.; Muck, R.E. Silage Review: Factors Affecting Dry Matter and Quality Losses in Silages. *J. Dairy Sci.* **2018**, *101*, 3952–3979. [[CrossRef](#)]
28. Kung, L.; Williams, P.; Schmidt, R.J.; Hu, W. A Blend of Essential Plant Oils Used as an Additive to Alter Silage Fermentation or Used as a Feed Additive for Lactating Dairy Cows. *J. Dairy Sci.* **2008**, *91*, 4793–4800. [[CrossRef](#)] [[PubMed](#)]
29. Silva, Y.A.; Orrico Junior, M.A.P.; Retore, M.; Ceccon, G.; Fernandes, T.; Orrico, A.C.A. Chemical Composition, Fermentation Parameters and Losses of Silages from Different Hybrids of Biomass Sorghum. *Grass Forage Sci.* **2025**, *80*, e12706. [[CrossRef](#)]
30. Alves, J.P.; Galeano Jara, E.S.; Orrico Junior, M.A.P.; Fernandes, T.; Retore, M.; Silva, M.S.J.; Orrico, A.C.A.; Lopes, L.S. The Influence of Plant Age and Microbes-Enzymatic Additives on Fermentation of Total Mixed Ration Silages of Capiçú Grass (*Pennisetum Purpureum*, Schum). *Trop. Anim. Sci. J.* **2022**, *45*, 56–63. [[CrossRef](#)]
31. Muck, R.E. Silage Microbiology and Its Control through Additives. *Rev. Bras. Zootec.* **2010**, *39*, 183–191. [[CrossRef](#)]
32. Orrico Junior, M.A.P.; Vendramini, J.M.B.; Erickson, J.; Moriel, P.; Silveira, M.L.A.; Aguiar, A.D.; Sanchez, J.M.D.; Silva, W.L.; Silva, H.M. Nutritive Value and Fermentation Characteristics of Silages Produced from Different Sweet Sorghum Plant Components with or without Microbial Inoculation. *Appl. Anim. Sci.* **2020**, *36*, 777–783. [[CrossRef](#)]
33. McCormick, M.E.; Morris, D.R.; Ackerson, B.A.; Blouin, D.C. Ratoon Cropping Forage Sorghum for Silage: Yield, Fermentation, and Nutrition. *Agron. J.* **1995**, *87*, 952–957. [[CrossRef](#)]

-
34. Wilkinson, J.M.; Rinne, M. Highlights of Progress in Silage Conservation and Future Perspectives. *Grass Forage Sci.* **2018**, *73*, 40–52. [[CrossRef](#)]
 35. NRC. *Nutrient Requirements of Dairy Cattle*, 8th ed.; National Academy Press: Washington, DC, USA, 2021.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.