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Digestive kinetics of sorghum silages grown in the Amazon Biome

Cinética digestiva de silagens de sorgo cultivadas no Bioma Amazônico

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ABSTRACT
The objective of this work was to evaluate the digestibility and kinetic parameters of silages of commercial and experimental sorghum genotypes grown in a crop in amazon biome to identify materials that present the best performance. The experiment was carried out in Sinop/MT with silages from 15 genotypes to evaluate gas production and *in vitro digestibility* and energy estimation, including BRS 658, BRS 659, Volumax, BRS Ponta Negra, 15F30005, 15F30006, BRS 511, CMSXS 5027, 5030, 5043, 5045, BRS 716, AGRI-002E, 201934B008 and CMSXS 7501. Gas production, pH, ammonia-N, and *in vitro* digestibility analyses were carried out, in addition to energy estimation using equations. The silages of materials with the highest gas production and digestibility were forage because they have a greater amount of digestible carbohydrates. On the other hand, the biomass and saccharine standard biomass presented lower performance because they have a higher concentration of lignin and structural carbohydrates in their composition.

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For pH and ammonium-N, there was no difference between treatments. The greatest digestibility and energy potential come from the genotypes BRS 658, BRS 659 Volumax, 15F30006, CMSXS 5027, and CMSXS 5030, making the last three capable of commercial launch and use in the production of silage in animal feed.

Keywords: digestibility, silage, fermentation, *in vitro*, *Sorghum bicolor*.

RESUMO
O objetivo deste trabalho foi avaliar a digestibilidade e os parâmetros cinéticos de silagens de genótipos comerciais e experimentais de sorgo cultivados em cultura no bioma amazônico para identificar materiais que apresentem o melhor desempenho. O experimento foi realizado em Sinop/MT com silagens de 15 genótipos para avaliar a produção de gases e a digestibilidade in vitro e estimativa energética, incluindo BRS 658, BRS 659, Volumax, BRS Ponta Negra, 15F30005, 15F30006, BRS 511, CMSXS 5027, 5030, 5043, 5045, BRS 716, AGRI-002E, 201934B008 e CMSXS 7501. Foram realizadas análises de produção de gás, pH, amônia-N e digestibilidade in vitro, além de estimativa de energia utilizando equações. As silagens de materiais com maior produção de gás e digestibilidade eram forrageiras porque têm maior quantidade de carboidratos digestíveis. Por outro lado, a biomassa padrão de biomassa e sacarina apresentou menor desempenho porque têm maior concentração de lignina e carboidratos estruturais em sua composição. Para o pH e o amônio-N não houve diferença entre os tratamentos. A maior digestibilidade e potencial energético provêm dos genótipos BRS 658, BRS 659 Volumax, 15F30006, CMSXS 5027 e CMSXS 5030, tornando os três últimos capazes de lançamento comercial e utilização na produção de silagem em rações para animais.

Palavras-chave: digestibilidade, silagem, fermentação, in vitro, Sorghum bicolor.

1 INTRODUCTION

Silage is the main bulky feed used to feed beef cattle in Brazil, especially in dry conditions where there is no food availability. Brazil has been affected by climate phenomena such as El Niño, which causes variations in normal precipitation patterns, leading to longer periods of drought and more frequent summers (Rojas et al., 2014).

Given climate change, water resources become more limited, especially in summer conditions (Kim and Jehanzaib, 2020). This leads to water stress in crops, which affects the quality and quantity of forage produced, where the duration and intensity of water stress determines crop survival (Bahrani et al., 2010).

Corn is the crop most used in silage production, however it has a high water requirement (Al-Kaisi and Yin, 2003), so due to the environmental changes mentioned

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above, it becomes necessary to use forages more adapted to these conditions. In these conditions, sorghum stands out over corn, as it has greater resistance to water deficit and drought. Furthermore, sorghum silage has high quality, as sorghum has adequate levels of dry matter, soluble carbohydrates and buffering capacity, which which guarantees adequate fermentation inside the silo, ease of planting, harvesting, compacting and storage (Moraes et al., 2013). Where in Brazil, sorghum silage is the most widely used roughage in the diet of confined cattle (Pinto and Millen, 2018). In which, sorghum (Sorghum bicolor (L.) Moench) has a minimum green mass production of 40 tons ha-1 (Pires et al., 2010).

Sorghum is classified according to its suitability and agronomic characteristics, being divided into grain, saccharine, forage, biomass, and broom (Rodrigues et al., 2014).Forage sorghum is the most used for silage production, as it is the most adapted to the process due to its agricultural suitability. However, sweet sorghum and biomass are being studied regarding their viability to be exploited for silage production, as the first has a high concentration of soluble carbohydrates, and the second has high biomass production per hectare (ha)(Rodrigues et al., 2014).

Knowing the chemical composition of the material that will be ensiled is extremely important, but one must also know the digestibility of the food to formulate diets with greater precision. The digestibility coefficient is used to determine the nutritional and energy value of the food. This value is obtained by evaluating the digestibility of the food and indicates the percentage of the nutrient that is potentially used by the animal (Van Soest, 1994).

In situ and *in vitro* methods are being used more frequently, as they are faster, use a smaller number of animals, smaller sample quantities for evaluation, food costs, and use of labor, in addition to the possibility of evaluating more than one treatment per incubation (KRIEG et al., 2017).

Given the above, the objective of this work was to evaluate the digestibility and production of gases *in vitro* and to estimate the energy value of silages of commercial and experimental sorghum genotypes grown in a harvest in northern Mato Grosso to identify the materials that present the highest performance.

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2 MATERIALS AND METHODS

2.1 LOCATION AND CONDUCT OF THE EXPERIMENT

The planting and ensiling of the experiment were carried out in the experimental area of Embrapa Agrossilvopastoril, located in the municipality of Sinop, Mato Grosso, 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, Sinop University Campus, Mato Grosso.

The planting area is located in the Amazon Biome, with 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 region's climate according to the Köppen climate classification is Am (monsoon tropical), with an average annual air temperature of 25°C, an average annual relative humidity of 83%, and an average annual accumulated precipitation of 2,250 mm (ALVARES et al., 2013).

2.2 GENOTYPES AND CHARACTERISTICS EVALUATED

Fifteen sorghum genotypes of different types were evaluated, including commercial and experimental materials, the latter being developed by Embrapa Milho e Sorgo. The materials evaluated were as follows: forage – BRS 658, BRS 659, Volumax, BRS Ponta Negra, 15F30005 and 15F30006; saccharides – BRS 511, CMSXS 5027, CMSXS 5030, CMSXS 5043 and CMSXS 5045; and biomass – BRS 716, AGRI-002E, 201934B0008 and CMSXS 7501 (BMR).

The field had three plots per treatment, where the useful plots consisted of two rows of five meters and a spacing of 0.70 m, totaling 7 $m^{2.}$ The cut was carried out manually at 20 cm above ground level, at a time when the grains in the middle part of the panicle were in the milky/pasty stage. At the time of cutting, 30 whole representative plants were selected from each plot and chopped in a stationary forage harvester, with a particle size of approximately 2 cm. The processing of samples after cutting, ensiling, and opening the silos is described by (SOUZA, 2021). After opening the silos, the chemical-bromatological composition of the silages was analyzed, as shown in Table 1.

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2.3 OBTAINING SAMPLES

To obtain the samples used in the experimental evaluations, composite sampling was carried out. Due to the high number of samples (15 treatments and 6 experimental silos per treatment), there was a need to create composite samples to make the experiment possible. The already ground samples from each experimental silo were separated according to the treatments, homogenized, and weighed to 25 g from each of the silos into a plastic pot with a lid for storage. After weighing, the sample obtained was homogenized and used for analysis.

2.4 IN VITRO ASSAY

The rumen fluid was obtained through collection from two Holstein x Nelore crossbred male cattle, castrated, and cannulated in the rumen, with an average of 800 kg of body weight. Collection was carried out on the day of incubation before feeding the animals and was carried out in the four quadrants of the rumen, removing the solid+liquid fraction, which was manually filtered through nonwoven fabric to separate only the liquid fraction, placed in thermos bottles preheated to 39 ± 0.5°C until the container filled its capacity, with the samples immediately transferred to the laboratory, where the incubations were carried out.

The animals were maintained on a diet with a roughage:concentrate ratio of 70:30, consisting of BRS 716 sorghum silage as a source of roughage (Table 2) and commercial concentrated feed without added additives from Fortuna Nutrição Animal, Nova Canaã do Norte, MT, provided twice a day (07:30 h and 13:30 h). A daily total of 35 kg of silage, 1.6 kg of concentrate, and 0.4 kg of soybean were provided to the two animals.

The buffer solution was prepared 24 hours before each incubation following the methodology proposed by McDougall, (1948), adding the reducing solution proposed by (FUKUSHIMA; WEIMER; KUNZ, 2003), in a ratio of 44.93

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Table 1- Chemical-bromatological composition of silages from 15 sorghum genotypes grown in the first harvest in Sinop/MT.

Genotype	MS [1]	ASH[2]	BP[2]	EE[2]	NDFap [2]	ADFap [2]	Lig[2]	NDFi [2]	NFC[2]	RSC[2]	NDT [2]
BRS 658	300.27	39.65	78.16	26.58	422.43	289.13	55.95	300.44	554.77	70.80	653.15
BRS 659	294.03	46.73	78.08	30.33	391.63	254.97	44.85	291.59	571.58	90.08	679.67
Volumax	236.87	55.77	67.72	31.37	464.67	309.84	47.43	297.94	498.60	61.17	646.42
BRS Ponta Negra	204.49	35.46	62.87	27.35	447.40	343.01	50.78	349.75	572.83	72.40	671.70
15F30005	262.84	40.10	67.34	42.18	424.89	305.93	55.79	284.19	538.10	76.38	671.25
15F30006	264.79	46.17	68.34	29.38	428.60	293.26	52.70	314.64	553.28	75.58	659.92
BRS 511	185.87	48.05	66.76	28.17	416.40	320.41	54.14	305.57	554.58	111.08	650.20
CMSXS 5027	200.57	46.82	62.34	18.57	387.14	284.08	49.27	289.03	580.27	152.28	656.97
CMSXS 5030	201.32	46.09	63.98	18.57	445.76	311.26	51.82	318.92	549.47	151.00	644.50
CMSXS 5043	248.50	31.33	51.40	18.92	560.78	412.68	67.86	391.83	481.42	86.26	611.60
CMSXS 5045	266.48	32.82	47.58	21.05	534.20	358.75	60.80	432.24	537.60	106.10	645.97
201934B008	274.83	36.16	46.79	24.37	604.76	429.98	84.44	431.29	438.42	43.54	582.33
AGRI-002E	296.86	35.68	63.03	29.45	557.94	392.89	69.03	453.95	429.60	37.22	608.47
BRS 716	289.00	33.84	55.55	24.13	574.01	408.12	77.42	469.49	473.43	67.45	603.22
CMSXS 7501*	234.61	40.81	56.99	22.98	555.70	375.51	62.11	446.18	494.40	50.30	619.00

Source: Adapted from Souza (2021). Were DM: dry matter content; ASH: ash; EE: ethereal extract; CP: crude protein; NDF: neutral detergent insoluble fiber corrected for ash and protein; ADF: acid detergent insoluble fiber corrected for ash and protein; Lig: lignin; $NDF_{i:}$ indigestible neutral detergent fiber; NFC: nonfibrous carbohydrates; RSC: residual soluble carbohydrates; TDN: total digestible nutrients. [1] g $kg^{-1;}$ [2] g kg^{-1} DM; [3] g kg^{-1} total nitrogen. *Material with *BMR* gene.

mL per liter of buffer solution (Table 2) and 1.25 mL of buffer solution, 1% resazurin for each liter of fermentation solution. The solution was bubbled with CO_2 until saturation and remained in an oven at a temperature of 39°C until incubation.

Table 2- Profile and bromatological composition of BRS 716 sorghum silage and concentrate supplied to animals as a source of roughage.

Variable	Silage	Focused
pH	3.98	-
N-NH_3 [1]	38.13	-
MS [1]	299.35	-
ASH[2]	36.52	-
BP[2]	47.81	78.00
EE[2]	22.25	-
NDF[2]	736.20	-
ADF[2]	422.35	-
Lignin [2]	79.81	-
TDN	-	160.00

Where DM: dry matter content; ASH: ash; CP: crude protein; EE: ethereal extract; NDF: neutral detergent insoluble fiber; FDA: acid detergent insoluble fiber; Lig: lignin; TDN: total digestible nutrients. [1] g.$kg^{-1;}$ [2] g kg^{-1} DM. Source: Authors.

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Glass penicillin vials (125 mL) were used. The day before incubation, 0.5000 ± 0.0003 g of sample processed through a 1 mm sieve was added to the appropriate bottles, which were taken to an oven at 39°C. On the day of incubation, 50 mL of fermentation liquid (consisting of 40 mL of buffer solution and 10 mL of ruminal liquid) was added, and the *headspace* of the bottles was maintained with CO_2 insertion. After that, they were closed with rubber caps and sealed with aluminum seals.

The flasks were placed in a water bath for 96 h at 39±0.5°C, and the pressure of the gas produced was recorded to determine the kinetics of gas production (PG). BP measurements were taken at periods of 2, 4, 6, 8, 10, 12, 24, 48, 72, and 96 hours using a commercial pressure measuring device (psi) (model Druck DPI 705) connected *to* a three-way valve, where one port was connected to the transducer, the other to a needle (size 20 x 0.55 mm) and the last was free to remove gases from inside the bottles after readings.

The pressure data (psi*)* produced during the incubations were converted into gas volume (mL) using the regression equation:

$$Volume\ (mL) = 5{,}1592 * pressure\ (PSI) - 0{,}0781\ (R^2 = 0{,}9987)$$

The equation was obtained by injecting a known volume of gas into sealed bottles containing 50 mL of distilled water (simulating the contents of the incubated bottles), where after the air injection, the pressure was measured.

Within 24 hours, two random bottles from each treatment and blanks were removed, immediately opened, and placed in an ice bath to stop fermentation. Subsequently, the contents of each vial were filtered under vacuum through a Gooch crucible number 1.

$_3$ content was also analyzed using the Kjeldahl distillation method (INCT-CA N007/1). The fermentation residues obtained were dried at 105°C for 16 h to estimate the *in vitro* digestibility of dry matter (IVDDM). They were subsequently treated with a neutral detergent fiber (NDF) solution to determine the *in vitro* digestibility of NDF (IVDFDN), according to the INCT-CA F-001/1 method (Detmann et al., 2012). These procedures were also carried out for periods of 48 and 96 hours.

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2.5 ENERGY ESTIMATE

From the cumulative gas production, the *in vitro* digestibility of organic matter (IVDOM in g kg^{-1} DM) and metabolizable energy (ME in Mcal.kg^{-1} DM) were estimated using equations described by Seker, (2002) for bulky foods using gas production. Digestible energy (DE in Mcal kg^{-1} DM) was estimated according to (NRC, 2007)and total digestible nutrients (TDN in g kg^{-1} DM) according to (NRC, 2016).

2.6 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

The experimental design used was randomized blocks (DRB), with 15 treatments (genotypes) and four replications (incubations), which thus consisted of 4 incubation runs × 15 treatments × 6 replications, plus 6 white bottles per incubation. The cumulative *in vitro* gas production profiles of the 15 cultivars generated in the 4 incubations were analyzed in two steps.

In the first stage, the nonlinear procedure (PROC NLIN) of SAS® (University edition) was used to obtain the best model for the profiles of each of the 15 sorghum cultivars analyzed. The models tested were: first-order asymptotic monomolecular; [**Eq. (1)]** and Gompertz with discrete latency [**Eq. (2)]** (SCHOFIELD; PITT; PELL, 1994)as a single-phase form. The two-phase models tested were the combinations between the two models [**Eqs. (3 to 5)]**:

$$V_t = V_f\left(1 - exp(-kt)\right) \quad \textbf{Eq. (1)}$$

$$V_t = V_f \exp\left(-exp\left(1 + k \times exp(L - t)\right)\right) \quad \textbf{Eq. (2)}$$

$$V_t = V_{f1}\left(1 - exp(-k_1 t)\right) + V_{f2}\left(1 - exp(-k_2 t)\right) \quad \textbf{Eq. (3)}$$

$$V_t = V_{f1}\left(1 - exp(-k_1 t)\right) + V_{f2} \exp\left(-exp\left(1 + k_2 \times exp(L - t)\right)\right) \quad \textbf{Eq. (4)}$$

$$V_t = V_{f1} \exp\left(-exp\left(1 + k_1 \times exp(L - t)\right)\right) + V_{f2} \exp\left(-exp\left(1 + k_2 \times exp(L - t)\right)\right) \quad \textbf{Eq. (5)}$$

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The cumulative production of gases as a function of time (t, h) is represented by the acronym V_t. In Eqs. (1 and 2), Vf represents the asymptotic volume of gas production (mL g^{-1} of DM), and k (for hours) is the substrate degradation rate. The delay time for digestion or discrete latency is represented by the acronym L (hours) [Eqs. (2, 4, and 5)]. The models in Eqs. (3 to 5) are biphasic, with "pools" of fast-moving carbohydrates and slow degradation in the rumen, where V_{f1} and V_{f2} (mL g^{-1} DM) represent the asymptotic gas volume of these two "pools". The parameter k_1 (for hours) is the specific degradation rate of the rapidly digested fraction, and k_2 (for hours) is the specific degradation rate of the slow digestion fraction.

In Equation (3), both "pools" are represented by the first-order asymptotic model. For fast-digesting carbohydrates, the first "pool" is represented by the asymptotic model, while the "pool" of slow-digesting carbohydrates is represented by a sigmoid (Gompertz) function with discrete latency in the models of Eqs. (4 and 5). The average digestion time (ADT, hours) for each model can be calculated as follows:

$$ADT = 1/k \quad \text{(Eq. 1);}$$

$$ADT = 1 / k + "L" \quad \text{(Eq. 2);}$$

$$ADT = 1 / k1 + 1 / k2 \quad \text{(Eq. 3) and}$$

$$ADT = 1 / k1 + 1 / k2 + "L" \quad \text{(Eq. 4 and 5).}$$

The choice of the model that best adjusted to the gas production profiles of each cultivar was carried out using the likelihood criterion of the models evaluated with the calculation of the corrected Akaike criterion (AICc) by several samples, the sum of the squares of the errors (residuals) and several model parameters (Burnham e Anderson, 2004). From the AICc, other calculations were carried out. The differences between the AICc of each model were used to calculate the probability of the model explaining the behavior of the gas production profiles. Finally, the evidence ratio was calculated to

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obtain how much a given evaluated model is better than the others (Burnham e Anderson, 2004). The model selected to describe the gas production profiles of each sorghum cultivar presented an evidence ratio value = 1.

After choosing the best model for each sorghum cultivar, new analyses were carried out to obtain the parameters of the model selected per cultivar in each incubation. In the second stage of analysis, the data were subjected to analysis of variance, and the means were compared using the Scott and Knott test, adopting a probability level of 5%, using the Genes statistical application (CRUZ, 2013).

3 RESULTS

There was a difference ($P<0.05$) for all variables analyzed regarding total gas production, fermentation parameters, energy estimates, dry matter digestibility, neutral detergent insoluble fiber digestibility, and pH, showing that there is genetic variability among the materials used in this study. However, there was no difference (>0.05) for the $N\text{-}NH_3$ variable.

Table 3 presents the values for the fermentative parameters, pH, and $N\text{-}NH_3$. The genotypes BRS 658, BRS 659, Volumax, BRS Ponta Negra, 15F30005, 15F30006, BRS 511, CMSXS 5027, CMSXS 5030 and CMSXS 5043 showed higher gas volumes, with an average value of 195.75 mL g^{-1} DM. Regarding the gas production rate, the genotypes BRS 658, BRS 659, 15F30005, 15F30006, BRS 511, and CMSXS 5027 showed the highest rate, with 0.0129% $hour^{-1}$.

Table 4 shows the results relating to the estimation of silage digestibility and energy. IVDOM presented higher values for genotypes BRS 658, BRS 659, 15F30005, and 15F30006, with 522.19 g kg^{-1} DM. For MS, the genotypes BRS 659 and 15F30006 presented the highest average, at 1.7964 Mcal kg^{-1} DM.

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Table 3- Average estimates of the *in vitro gas* production kinetic parameters of silages from fifteen sorghum cultivars of different aptitudes grown in the first harvest in Sinop/MT in 2020

Cultivars	*in vitro* gas production					
	Vf	k	L	ADT	pH	N-NH $_3$
BRS 658	190.43 a	0.0134 a	7.60 b	82.55 b	7.04 c	9.69
BRS 659	205.05 a	0.0137 a	9.35 b	85.53 b	7.07 c	8.33
Volumax	203.08 a	0.0107 b	10.99 b	105.39 a	7.14 a	8.28
BRS Ponta Negra	197.00 a	0.0104 b	9.13 b	105.85 a	7.11 b	8.26
15F30005	182.75 a	0.0134 a	8.07 b	83.60 b	7.15 a	6.89
15F30006	189.43 a	0.0127 a	8.82 b	88.42 b	7.14 a	7.18
BRS 511	189.95 a	0.0119 a	8.21 b	93.36 b	7.10 b	8.79
CMSXS 5027	191.58 a	0.0125 a	7.32 b	88.27 b	7.04 c	7.66
CMSXS 5030	214.68 a	0.0102 b	9.76 b	118.08 a	7.12 a	6.79
CMSXS 5043	193.63 a	0.0091 b	15.97 a	132.04 a	7.11 a	10.35
CMSXS 5045	173.30 b	0.0101 b	11.87 b	112.22 a	7.13 a	8.38
201934B008	161.63 b	0.0100 b	15.36 a	123.17 a	7.17 a	6.11
AGRI-002E	161.53 b	0.0084 b	15.36 a	135.78 a	7.18 a	10.18
BRS 716	149.68 b	0.0101 b	14.97 a	118.50 a	7.20 a	8.01
CMSXS 7501*	165.05 b	0.0106 b	15.58 a	114.21 a	7.18 a	10.08
P value	0.015	0.025	<0.01	<0.01	<0.001	0.2279
SEM	11.86	0.0010	1.43	10.98	0.034	1.284

Where: Vf asymptotic volume (total) of gas production in mL g^{-1} DM; k: gas production rate per hour; L: latency time in hours; ADT: Average digestion time in hours; $N\text{-}NH_3$: ammoniacal N content in mg dL^{-1}. *Material with *BMR gene*. Means of the genotypes did not demonstrate significant differences by the F test of the analysis of variance. Means followed by the same letter in the column do not differ statistically using the Scott Knott test (P<0.05). Source: Authors.

The pH and N-NH3 values are shown in Table 6. For pH, BRS 658, BRS 659 and CMSXS 5030 obtained the lowest average, 7.05. For ammonia *in vitro* incubations, there was no difference between genotypes, with an average of 8.33 mg dL^{-1}.

Table 5 shows the data relating to IVDDM and IVDNDF in the different evaluation periods. In the 24-hour incubation period, materials BRS 658, BRS 511, CMSXS 5027 and CMSXS 5030 showed the highest DIVMS of 363.77 g kg^{-1} DM. However, during the 48-hour incubation period, DIVMS was higher for genotypes BRS 659, Volumax and CMSXS 5027, with 491.23 g kg^{-1} DM. For DIVMS in the 96-hour period, the

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genotypes BRS659, Volumax, BRS Ponta Negra, 15F30005, 15F30006, BRS 511, CMSXS 5027, CMSXS 5030 and CMSXS 5045 presented the highest values.

Table 4*in vitro* digestibility characteristics of organic matter, metabolizable and digestible energy, and total digestible nutrients of silages of fifteen sorghum cultivars of different aptitudes grown in the first harvest in Sinop/MT in 2020

Cultivars	IVDOM[1]	ME[2]	DE[3]	TDN[4]
BRS 658	518.86 a	1.7119b	2.0876b	473.49b
BRS 659	533.22 a	1.8075 to	2.2043 to	499.94 to
Volumax	496.70b	1.5788c	1.8888c	428.39c
BRS Ponta Negra	490.49b	1.5754c	1.9212c	435.74c
15F30005	515.46 a	1.6941b	2.0660b	468.58b
15F30006	521.22 a	1.7853 to	2.1772 a	493.81 a
BRS 511	507.95b	1.6218b	1.9777b	448.57 b
CMSXS 5027	509.90b	1.6151b	1.9697b	446.74b
CMSXS 5030	503.49b	1.6318b	1.9900b	451.35b
CMSXS 5043	466.39c	1.4267c	1.7399c	394.62c
CMSXS 5045	480.43c	1.5075c	1.8385c	416.98c
201934B008	463.62c	1.4419c	1.7585c	398.83c
AGRI-002E	459.49c	1.4646c	1.7861c	405.10c
BRS 716	456.12c	1.3736c	1.6751c	379.94c
CMSXS 7501*	472.30c	1.5494c	1.8895c	428.56c
P value	<0.001	<0.001	<0.001	<0.001
SEM	0.27	0.0126	0.0153	3.47

Where IVDOM: *in vitro* digestibility of organic matter in g kg^{-1} DM; ME: metabolizable energy in Mcal kg^{-1} DM; DE: digestible energy in Mcal kg^{-1} DM; TDN: total digestible nutrients in g kg^{-1} DM; *Material with *BMR gene.*

[1]IVDOM = 36.1 + 0.464GP (gas production) + 0.605CP; [2]ME= 0.728 + 0.0219GP + 0.0203CP +0.124CF (crude fat); [3]DE= ME/0.82; [4]TDN= (DE*1000)/4,409. Means followed by the same letter in the column do not differ statistically using the Scott Knott test (P<0.05). Source: Authors.

Regarding IVDNDF, in the 24-hour incubation period, the materials BRS 658, BRS 659, Volumax, BRS 511, CMSXS 5027 and CMSXS 5030 had the highest results. However, in the 48-hour period, the largest IVDNDF was from BRS 659. In the 96-hour incubation period, the largest IVDNDF was from the BRS659 and Volumax genotypes.

It is possible to observe that the hybrids BRS 658, BRS 659 and 15F3006 (all forage sorghum) showed a marked degradation up to 24 hours of incubation (Figure 1).

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It was also observed that regardless of time, the degradation of sorghum biomass, mainly BRS 716 and 201934B0008, was lower.

Table 5- Average estimates of *in vitro* digestibility of dry matter and insoluble fiber in neutral detergent at 24, 48 and 96 hours of incubation of silages of fifteen sorghum cultivars of different abilities grown in the first harvest in Sinop/MT in 2020

Cultivars	IVDDM			IVDNDF		
	24	48	96	24	48	96
BRS 658	328.9c	433.5b	523.8b	471.8 a	511.9b	665.7c
BRS 659	364.1 a	496.6 a	627.7 a	464.5 a	565.9 a	722.2 a
Volumax	344.6b	494.8 a	645.4 a	462.9 a	527.8b	731.7 a
BRS Ponta Negra	311.0c	401.1c	581.2 a	455.3c	467.3c	656.3c
15F30005	318.9c	440.7b	558.1 a	454.5b	513.8b	661.8c
15F30006	315.0c	433.1b	604.8 a	447.4b	520.0b	647.7c
BRS 511	372.9 a	461.6b	575.4 a	431.5 a	517.9b	675.7c
CMSXS 5027	360.7 a	482.3 a	590.5 a	423.7 a	538.8b	700.3b
CMSXS 5030	357.4 a	453.3b	607.8 a	406.7 a	520.6b	668.5c
CMSXS 5043	265.6d	368.2c	519.4b	358.2d	417.0d	580.2d
CMSXS 5045	261.9d	385.5c	552.2 a	349.7d	453.0c	574.3d
201934B008	228.5 e	362.2 c	472.5 b	348.3 e	417.1 d	544.6 e
AGRI-002E	228.5 e	318.6 d	481.2 b	320.5 e	373.0 e	504.1 f
BRS 716	235.1 e	321.9 d	458.0 b	315.4 e	375.0 e	499.1 f
CMSXS 7501*	258.9 d	359.6 c	503.6 b	349.7 d	426.1 d	575.7 d
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SEM	6.15	23.10	19.80	1.08	20.66	11.98

Where *in vitro* digestibility of dry matter during periods of 24, 48 and 96 hours of incubation in g kg^{-1} DM; IVDNDF: *in vitro* digestibility of insoluble neutral detergent fiber during periods of 24, 48 and 96 hours of incubation in g kg^{-1} DM; *Material with *BMR gene.* Means followed by the same letter in the column do not differ statistically using the Scott Knott test (P<0.05). Source: Authors.

4 DISCUSSION

The gas in an incubating food is produced from the fermentation of carbohydrates and organic acids (AMER et al., 2012). The highest gas production was found for forage and sweet sorghum, which has a higher concentration of WSC, and this favors the fermentation process by ruminal microorganisms, leading to greater digestion and, consequently, greater gas production. The ones with the lowest production are standard biomass and biomass sweet sorghums, which offer high concentrations of slowly digestible or indigestible fibrous compounds, reducing digestion and gas production.

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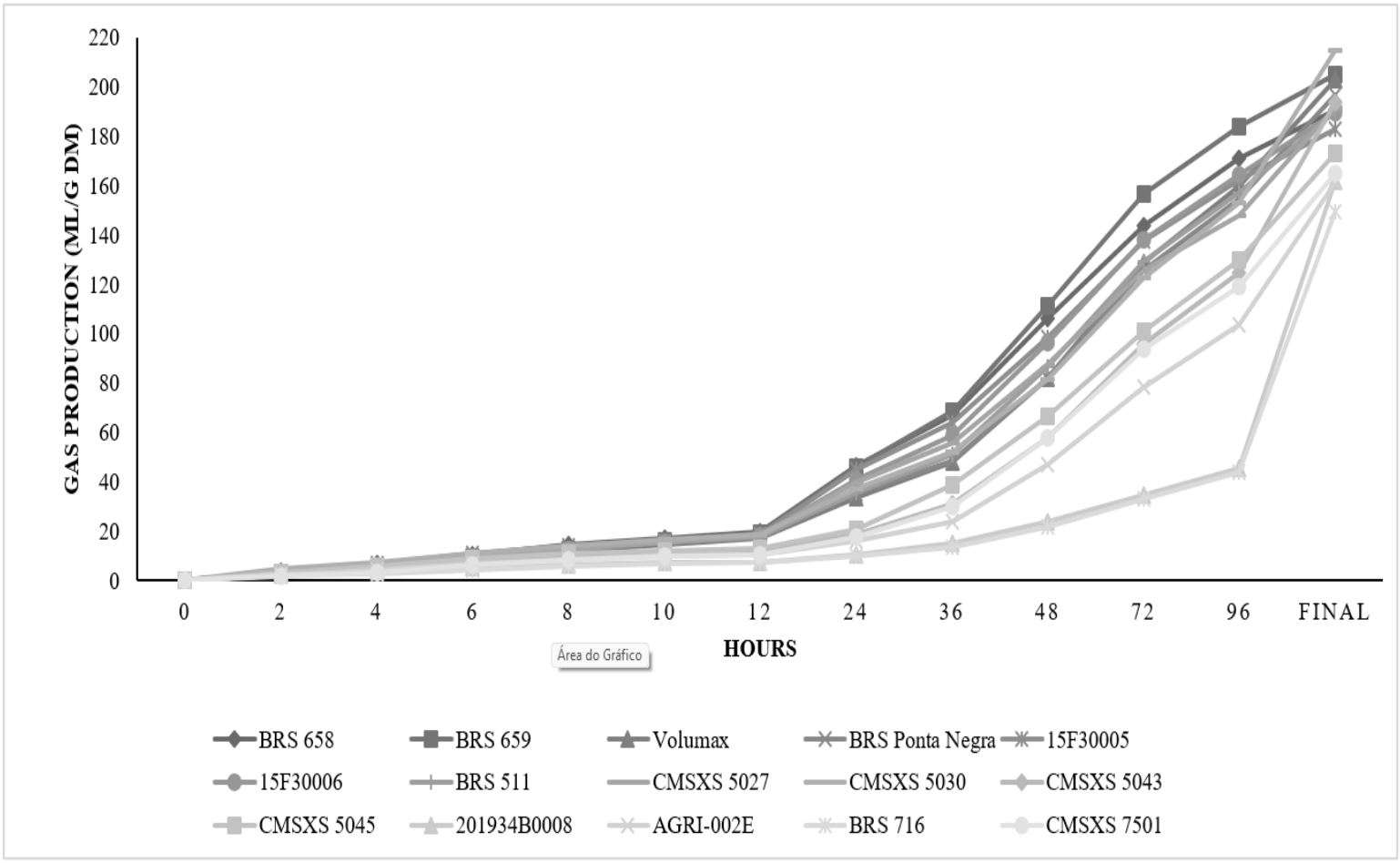
Figure 1 - *In vitro* gas production kinetics of sorghum hybrid silages.



Source: Authors.

Behling Neto et al., (2017) working with forage and saccharine sorghum silage, obtained averages of 185.95 and 184.20 mL g^{-1} DM, respectively, similar to the averages obtained for forage and saccharine materials found in the present study.

Latency represents the time between the incubation of the food and the beginning of fermentation by microorganisms and is related to the degradation of the fibrous fraction (MERTENS; LOFTEN, 1980). The materials with the highest latency and ADT are sorghum biomass, except CMSXS 5043, which is saccharine, which presented the highest amount of ADF and lignin, while those with the lowest latency time and ADT are forage and saccharin and consequently had lower fiber content in their composition.

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In general, the final volume of gas and the average digestion time, as well as the rate of degradation and latency, will depend on the bromatological composition of the food evaluated, especially the amounts of fibrous and nonfibrous fractions (OLIVEIRA et al., 2018).

In this work, the genotypes with the highest IVDOM were forage because they have a lower amount of indigestible fiber in their composition and greater gas production *in vitro*, similar to the values obtained by Khota et al., (2017)when evaluating the silage of cultivar IS 23585, they obtained values in 24 hours of incubation of 571.50 g kg $^{-1}$ DM, and Kaewpila et al., (2021)with forage sorghum silage, they obtained an average of 526.70 g kg $^{-1}$ DM.

In ruminant nutrition, the energy fraction of food can be expressed as digestible energy, metabolizable energy, or total digestible nutrients. Energy is of fundamental importance, as it is used by animals for maintenance and production. In this work, the estimated TDN values are below that recommended for sorghum silages, 640 to 700 g kg^{-1} DM (Keplin, 1992), and this is due to the variation in the composition of the materials, especially in the amounts of iNDF, ADF and lignin, which negatively reflected in gas production, *lag time*, which led to the need to modify the formulas used for the estimates, described by Seker, (2002), using GP values in 48 h in the equation instead of 24 h to obtain data more consistent with the literature. Therefore, it is suggested that for different materials, the model for estimating IVDMO should be adjusted taking the *lag time* value as a guide. It is necessary to adjust this IVDMO and energy estimation model for materials similar to the one evaluated, such as tropical forages, since the model was initially developed using forages from temperate climates. The proof of this is that forage and saccharine materials, which have a lower amount of NDFi and shorter *lag time*, presented estimated values closer to those calculated than standard biomass and biomass saccharine materials, which presented high *lag time* and high concentrations of carbohydrates. fibrous, mainly lignin.

The materials that showed lower digestibility of DM and NDF at all times evaluated, except IVDDM at 96 hours, were biomass materials because they have higher levels of ADF and lignin, which negatively influenced the *in vitro* digestibility of foods. Because

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they are tall, they require a higher concentration of carbohydrates in the cell wall, mainly lignin, necessary to guarantee support and resistance to the plants. These characteristics provide a lower rate of degradation and digestibility of silages made from these materials, as lignin makes it difficult for rumen microorganisms to access the fiber.

For IVDDM, Veriato et al., (2018)using Volumax, an average of 639.50 g kg^{-1} DM was obtained, a value similar to that observed in the present research. When Orrico Junior et al., (2015)evaluating sweet sorghum silages, they obtained an average value of 592.05 kg^{-1} DM, a value close to that obtained in this work for the average of sweet materials. Oliveira et al., (2018)When working with silages from four forage sorghum genotypes, they obtained average DM digestibility in 48 hours of incubation of 595.5 g kg^{-1} DM and Stella et al., (2016)obtained an average of 547.8 g kg^{-1} DM, both values similar to that obtained in this work.

For IVDNDF values in 24 hours, Colombini et al., (2012)values of 367.00 g kg^{-1} DM for forage silages were found, a value close to that found in this work. Xie et al., (2021)with grain sorghum silage *BMR* reported an average of 355.90 g kg^{-1} DM, while Di Marco et al., (2009) obtained averages for saccharine and *BMR* silages of 609.00 and 460.00 g kg^{-1} DM, respectively. Both values are similar to those observed in the present work for saccharine and *BMR* materials, with the results available in the literature, and with those observed in this work, we can observe the variability in the digestibility of the materials, where a large part of this variation is related to the amount of indigestible fiber in the material, especially the amount of lignin.

It is worth highlighting that the CMSXS 7501 genotype showed greater digestibility than the other biomasses, especially regarding IVDNDF. This is because this material contains the *BMR gene*, which has the function of reducing the lignin content in the plant, proving the effectiveness of inserting this gene into the plant.

In production systems where the silage used has high-performance objectives, such as weight gain or high-production dairy cows, the most recommended silages are those made from forage material, as they have a composition more similar to corn silage, with higher quality fiber, which is essential to ensure good production and adequate fat content in milk.

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However, in systems that require a high amount of roughage, such as beef cattle confinements or producers with small areas available to meet their forage demand, the use of silages made from biomass materials is recommended, since the production of green material and DM of these materials was approximately 36% and 41%, respectively, higher than that of forage, with similar values for losses during the ensiling process and the cost of implementing and conducting the crop, which will reduce the production cost per Mg of silage.

Given the results obtained regarding digestion kinetics, the materials that stood out were the commercial forage genotypes BRS 658, BRS 659, and Volumax and the experimental forage 15F30006 and experimental saccharines CMSXS 5027 and CMSXS 5030, making the latter capable of commercial launch and use in the production of silage in animal feed.

DECLARATION OF CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

All authors contributed to the conception and design of the study. The preparation of the material and collection and analysis of data were carried out by Dalton Henrique Pereira, Maria Antônia Bortolucci da Rosa, Flávio Dessaune Tardin, Arthur Behling Neto, Rosemary Lais Galati, Matheus Lima Corrêa Abreu and Carla Silva Chaves. The first draft of the manuscript was written by Juliana Maria Silva de Souza, and all authors commented on previous versions of the manuscript. All the authors have read and approved the final manuscript.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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