

# Chemical-bromatological composition of silages from biomass sorghum genotypes<sup>1</sup>

Flávia de Jesus Ferreira<sup>2</sup>, Caroline Salezzi Bonfá<sup>2</sup>, D'Arc Elly Prates de Oliveira<sup>2</sup>,  
Marcela Azevedo Magalhães<sup>2</sup>, Rafael Augusto da Costa Parrella<sup>3</sup>, Gabriel Machado Dallago<sup>4</sup>

## ABSTRACT

The biomass sorghum [*Sorghum bicolor* (L.) Moench] was developed for energy production, but its agronomic characteristics make it an alternative plant for silage production. This study aimed to evaluate the chemical-bromatological composition of silages from biomass sorghum genotypes. The experimental genotypes B004, B005, B009, B010, B011, B013, B015 and B020, as well as three commercially available genotypes (BRS655, Volumax and K1009), were evaluated. The pH, dry matter, ash, organic matter, crude protein, neutral detergent fiber, acid detergent fiber, hemicellulose and lignin were analyzed. A completely randomized design, with four replications, was used, having the genotypes as treatments. Although significant differences were observed among the 11 genotypes, the chemical-bromatological composition of all them showed their potential to be used for silage production.

**KEYWORDS:** *Sorghum bicolor* (L.) Moench, fodder storage, silage production.

## INTRODUCTION

Pasture-based systems are commonly used in ruminant production. It is a convenient and cost-effective solution to feed animals, but the seasonal forage production threatens the animal performance (Claffey et al. 2019, Evers et al. 2023). For instance, the edaphoclimatic characteristics in tropical countries during the rainy season allow forage production in sufficient quantities and satisfactory quality (Vega Brites et al. 2020). However, the reduction in rainfall, temperature and light during

## RESUMO

Composição químico-bromatológica de silagens de genótipos de sorgo biomassa

O sorgo biomassa [*Sorghum bicolor* (L.) Moench] foi desenvolvido para a produção de energia, mas suas características agrônomicas o tornam uma planta alternativa para a produção de silagem. Objetivou-se avaliar a composição químico-bromatológica de silagens provenientes de genótipos de sorgo biomassa. Os genótipos experimentais avaliados foram B004, B005, B009, B010, B011, B013, B015 e B020, além de três genótipos disponíveis comercialmente (BRS655, Volumax e K1009). Foram determinados o pH, matéria seca, cinzas, matéria orgânica, proteína bruta, fibra em detergente neutro, fibra em detergente ácido, hemicelulose e lignina. Utilizou-se delineamento inteiramente casualizado, com quatro repetições, considerando-se os genótipos como tratamentos. Embora diferenças significativas tenham sido observadas entre os 11 genótipos, a composição químico-bromatológica de todos eles mostrou seu potencial para utilização na produção de silagem.

**PALAVRAS-CHAVE:** *Sorghum bicolor* (L.) Moench, armazenamento de forragem, produção de silagem.

the dry season negatively affects the quantity and quality of forages produced in that season (Giridhar & Samireddypalle 2015). Alternative feeding strategies are necessary to overcome such limitations of pasture systems (Rodrigues et al. 2020) and avoid negative effects on animal performance.

Silage is one of the most common feeding alternatives for ruminant animals during the dry period. Though it can be produced from a range of different plants, corn and sorghum are the most commonly used. However, maize and sorghum

<sup>1</sup> Received: June 02, 2023. Accepted: Aug. 31, 2023. Published: Oct. 18, 2023. DOI: 10.1590/1983-40632023v5376362.

<sup>2</sup> Universidade Federal dos Vales do Jequitinhonha e Mucuri, Faculty of Agricultural Sciences, Diamantina, MG, Brazil. E-mail/ORCID: flaviajferreira@hotmail.com/0000-0001-9735-5980; caroline.bonfa@ufvjm.edu.br/0000-0002-4401-1559; darcrprates92@gmail.com/0000-0002-4158-7835; marcela.magalhaes@ufvjm.edu.br/0000-0003-1563-0390.

<sup>3</sup> Empresa Brasileira de Pesquisa Agropecuária (Embrapa Milho e Sorgo), Sete Lagoas, MG, Brazil. E-mail/ORCID: rafael.parrella@embrapa.br/0000-0001-6599-7487.

<sup>4</sup> University of Manitoba, Faculty of Agricultural and Food Sciences, Department of Animal Science, Winnipeg, MB, Canada. E-mail/ORCID: gabriel.dallago@umanitoba.ca/0000-0002-5725-0815.

are pivotal food resources for human feeding and monogastric animals (Fulgueira et al. 2007), leading to market competition. In the face of the projected increase in population (Zeifman et al. 2022) and demand for animal-sourced products (Alexandratos & Bruinsma 2012), alternative forages are necessary to produce silage to feed ruminant animals, particularly during the dry period (Ramos et al. 2021), while reducing production costs and avoiding market competition.

The first biomass sorghum cultivar [*Sorghum bicolor* (L.) Moench], the BRS 716, was originally developed by the Empresa Brasileira de Pesquisa Agropecuária (Embrapa Milho e Sorgo), in 2014, for the production of energy from biomass burning (Ramos et al. 2021). However, its agronomic characteristics make it a promising alternative for silage production.

Biomass sorghum has a fibrous culm that allows the plants to grow as tall as 5-6 m and produce 50-120 t of dry matter per hectare over a short growth cycle of six months. It is also resistant to lodging, pests, diseases and water restriction (Almeida et al. 2019). Sowing typically occurs in the spring, at the beginning of the rainy season, while harvest occurs in the sugarcane off-season (Borém et al. 2014). Furthermore, biomass sorghum is a fully mechanized crop, enabling efficient and streamlined processes from planting to harvest.

Given its agronomic characteristics, biomass sorghum is an interesting candidate for silage production. It offers an alternative to traditional plants used for human nutrition and feeding monogastric animals, while diversifying the raw materials available for ruminant feeding. Therefore, this study aimed to evaluate the ensilability of biomass sorghum genotypes based on the chemical-bromatological composition of silages produced with them.

## MATERIAL AND METHODS

Eight experimental biomass sorghum genotypes were assessed (B004, B005, B009, B010, B011, B013, B015 and B020), as well as three commercially available sorghum genotypes, including two forage sorghum (BRS655 and Volumax) and one biomass (K1009).

All the sorghum genotypes were sown, cultivated and managed at the Embrapa Milho e Sorgo, in Sete Lagoas, Minas Gerais state, Brazil

(19°28'S, 44°15'08"W and altitude of 732 m), in 2019.

The sowing of all the sorghum genotypes was carried out in the second half of November, and the plants were harvested in the second half of March in the following year. The planting fertilizer consisted of 400 kg ha<sup>-1</sup> of NPK (08-28-16). When plants had between 6 and 8 true leaves, 200 kg ha<sup>-1</sup> of urea were used for top fertilization. The spacing used was 70 cm between rows, with 120,000 plants ha<sup>-1</sup>. All the genotypes were harvested at the recommended stage for silage, when the grains in the panicle achieved physiological maturity after flowering. The plants were harvested by manually cutting them close to the ground. The biomass sorghums were 3.05 m tall at the time, producing an average of 57 t of wet matter per hectare. The next day after harvesting, the genotypes were identified and transported to the Universidade Federal dos Vales do Jequitinhonha e Mucuri, in Diamantina, Minas Gerais state, Brazil, for the experimental procedures.

The experiment was conducted following a completely randomized design, with four replications. The eleven sorghum genotypes were considered as treatments, resulting in 44 experimental units (i.e., silos). The sorghum genotypes were cut into particles measuring between 1.0 and 2.0 cm, using a regulated chopper. The chopped material was weighed using an electronic scale with accuracy of 0.01 g and stored in silos. Before ensiling, one sample of 500 g per genotype was collected from the chopped material to evaluate the chemical-bromatological composition.

The experimental silos were constructed using PVC pipes (100 mm in diameter and 450 mm in length). Shortly after being chopped, the material was manually compacted with wooden sockets to expel the oxygen from the ensiled material and achieve a density of 500 kg m<sup>-3</sup>. After filling the silos, PVC caps equipped with Bunsen-type valves were employed for sealing and secured with adhesive tape. The silos were individually labelled. The arrangement of the experimental silos was randomized, and they were kept sealed for 45 days and shielded from indirect sunlight and moisture.

After opening the silos, the material was homogenized and a sample of 350 g was obtained from each experimental silo. The samples were individually pressed using a hydraulic press to extract the silage juice, which was employed to determine the hydrogen potential (pH) using a Tecnopon

mPA 21 potentiometer with an expanded scale. Another sample of 500 g was extracted from each experimental silo and pre-dried in a forced ventilation oven at 55 °C, for 72 hours (AOAC 1995). Next, the samples were ground in a Willey mill with a 1 mm sieve (AOAC 1995) and placed in individual plastic bags for further laboratory analysis.

The chemical-bromatological analysis was carried out on the material before ensiling (Table 1) and the silage samples after pre-drying. The dry matter, ash and crude protein analyses were carried out according to AOAC (1995). The organic matter content was obtained based on the ash percentual (100 - ash). Neutral detergent fiber, acid detergent fiber, hemicellulose and lignin were measured sequentially (Van Soest et al. 1991).

The statistical analyses were conducted using the R software (R Core Team 2019), always adopting a 5 % significance level. The following statistical model was used in the analysis:  $Y_{ij} = \mu + G_i + \varepsilon_{ij}$ , in which:  $Y_{ij}$  is the observed value for each parameter of the chemical-bromatological composition of the *i*-th genotype in the *j*-th repetition;  $\mu$  is the overall mean;  $G_i$  is the effect of the *i*-th genotype of sorghum; and  $\varepsilon_{ij}$  is the experimental error. The multiple comparisons of the means were performed using the Tukey test. The assumptions of normality and independence of the residues and homoscedasticity were evaluated sequentially with the Shapiro-Wilk, Durbin-Watson and Bartlett tests, respectively. All assumptions were met for the chemical-bromatological variables, except for the lignin. In this case, the Box-Cox transformation was used, and the statistical analysis was carried out in the transformed data.

## RESULTS AND DISCUSSION

The pH is one of the essential parameters in assessing silage quality, since it is a crucial indicator of the preservation of the ensiled material (McDonald et al. 1991). It can indicate whether the ensiling was well carried out and if beneficial microorganisms were favored during the fermentation process, as opposed to deleterious counterparts (McDonald et al. 1991, Tomich et al. 2003, Bonfá et al. 2022). Paiva (1976), Woolford & Pahlow (1998) and Fairbairn et al. (1992) recommended that pH values should be lower than 4.2 units, while McDonald et al. (1991) suggest values equal to or less than 3.8 units, depending on the characteristics of the ensiled material. In our study, the average pH from the silages of the sorghum genotypes ranged between 4.22 and 4.40 (Figure 1). The commercial genotype of sorghum biomass K1009 had the highest ( $p < 0.05$ ) pH value (4.4).

The highest pH values observed may be related to the highest levels of crude protein, as in the genotypes B005 (5.41 %  $\pm$  0.22), B009 (5.11 %  $\pm$  0.24), B020 (5.78 %  $\pm$  0.07), K1009 (5.72 %  $\pm$  0.24) and Volumax (5.94 %  $\pm$  0.17). According to Jobim & Gonçalves (2003), nitrogenous compounds have a high buffering power and, consequently, a greater resistance to reducing pH values. In addition, it is emphasized that the pH values alone cannot be used to assess the quality of the silage without association with other parameters (Cavali et al. 2010). This variable must be associated with the contents of dry matter, crude protein, soluble carbohydrates and fiber, as all these factors can contribute to the fermentative

Table 1. Chemical-bromatological composition of the sorghum genotypes before ensiling (fresh material).

Genotype	DM	Ash	OM	CP	NDF	ADF	Hemicellulose	Lignin
	%							
B004	27.78	6.68	93.32	4.9	55.22	26.46	28.76	5.2
B005	27.90	5.68	94.32	5.1	52.08	25.90	26.18	5.3
B009	26.85	6.98	93.02	5.8	54.71	25.90	28.80	5.5
B010	28.79	5.41	94.59	3.9	56.69	29.06	27.63	4.9
B011	29.39	6.36	93.64	4.1	60.41	30.53	29.88	5.3
B013	34.89	5.35	94.65	5.0	52.22	25.44	26.77	4.3
B015	33.69	7.51	92.49	3.4	55.76	27.43	28.33	5.3
B020	29.33	7.51	92.49	5.8	57.32	26.97	30.35	4.4
BRS655	25.22	7.42	92.58	4.4	45.77	21.26	24.51	4.1
K1009	37.91	7.38	92.62	5.8	54.07	25.44	28.62	5.4
Volumax	29.28	7.90	92.10	6.3	57.91	27.65	30.26	4.7

DM: dry matter; OM: organic matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber.

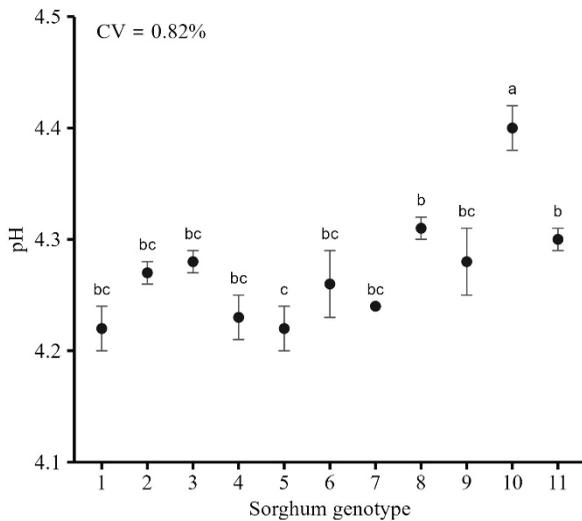


Figure 1. Average hydrogenionic potential (pH) units (points) followed by the standard error (bars) and the silages coefficient of variation (CV; %) of the sorghum genotypes 1 (B004), 2 (B005), 3 (B009), 4 (B010), 5 (B011), 6 (B013), 7 (B015), 8 (B020), 9 (BRS 655), 10 (K1009) and 11 (Volumax). Genotypes followed by different letters are statistically different ( $p < 0.05$ ) according to the Tukey test.

process of the ensiled material and influence the pH values to different extents.

The average dry matter content of the silages varied between 25.5 and 39.1 % (Figure 2A). Similarly to the pH, the highest percentage of dry

matter was observed in the silage of the K1009 genotype ( $p < 0.05$ ). The genotypes B004, B005, B013, B015 and B020 presented average values of dry matter within the interval of 30 to 35 % of dry matter. The dry matter contents of the silages are related to the *in natura* material (Table 1). The K1009 genotype presented 37.91 % of dry matter at the time of ensiling (Table 1), what numerically reflected in the high dry matter contents, even after the fermentation process (Figure 2A). On the other hand, the lowest levels of dry matter were observed in the genotypes B009 and BRS655 after ensiling (Figure 2A), since their dry matter levels were numerically the lowest before ensiling (26.85 and 25.22 %, respectively; Table 1).

The average organic matter content in the silages ranged from 91.4 to 94.0 % (Figure 2B). The lowest levels were found in the genotypes BRS655 (91.4 %  $\pm$  0.26), B020 (91.5 %  $\pm$  0.23) and Volumax (91.7 %  $\pm$  0.08;  $p < 0.05$ ). On the other hand, these genotypes also showed the highest ( $p < 0.05$ ) ash content (Figure 2C). The average ash content of the genotypes BRS655, B020 and Volumax were 8.6  $\pm$  0.26, 8.35  $\pm$  0.23 and 8.3 %  $\pm$  0.08, respectively.

Forage dry matter content significantly influences silage quality (Oude Elferink et al. 2000). An excessive production of effluents can occur when the material to be ensiled has a high moisture content (Oliveira et al. 2010). It makes it

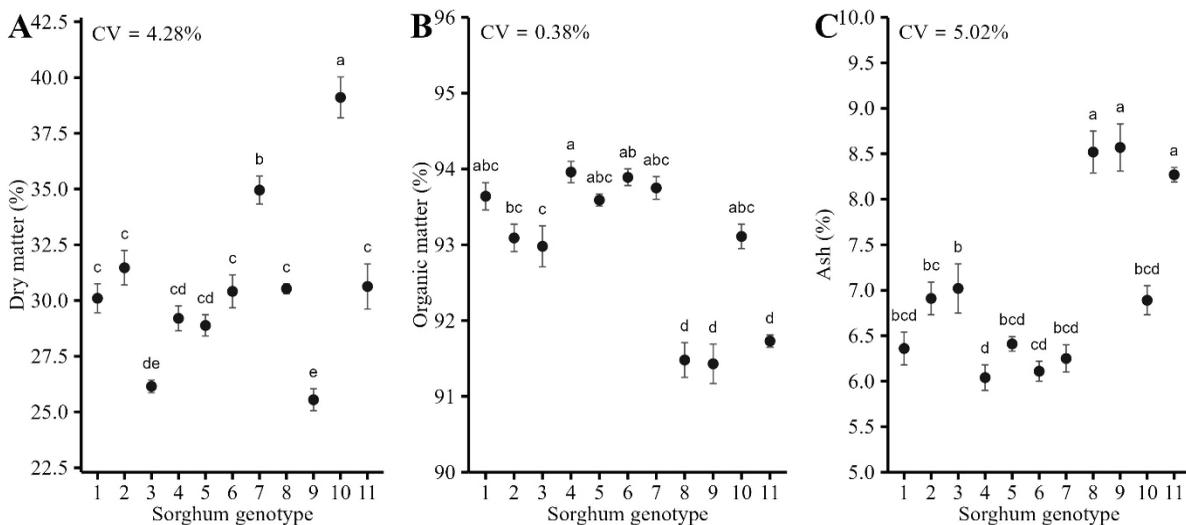


Figure 2. Average dry matter (A), organic matter (B) and ash (C) (points) followed by the standard error (bars) and the coefficient of variation (CV; %) of the silages produced using the sorghum genotypes 1 (B004), 2 (B005), 3 (B009), 4 (B010), 5 (B011), 6 (B013), 7 (B015), 8 (B020), 9 (BRS 655), 10 (K1009) and 11 (Volumax). Genotypes followed by different letters are statistically different ( $p < 0.05$ ) according to the Tukey test.

more difficult to handle the silage and leads to the leaching of digestible nutrients, reducing the overall nutritional value of the silages (Pereira et al. 2007). Additionally, a high humidity favors the increase of proteolysis in the ensiled material and, consequently, the establishment of undesirable bacteria during the fermentation process (Oude Elferink et al. 2000).

According to McDonald et al. (1991), the dry matter content in forages before ensiling is recommended to be between 28 and 35 % to obtain a high-quality silage. If higher than that, compacting and removing oxygen from the material becomes difficult, consequently promoting the growth of undesirable microorganisms such as fungi and yeasts. On the other hand, dry matter levels below 28 % can cause nutrient leaching, high butyric acid production and intense protein degradation (Skonieski et al. 2010). In the present study, the dry matter contents varied among the biomass sorghum genotypes (Table 1), but remained close to the recommended range. However, these results must be evaluated in association with the fibrous components and other parameters of the silages to consider the dry matter levels adequate for the fermentation process.

The crude protein contents found in the ensiled material ranged between 4.0 and 5.9 % (Figure 3). The diets of ruminant animals should not contain a crude protein content lower than 7 %, as values lower than that are considered limiting to ruminal microorganism activity, compromising animal growth and the use of fibrous components of the diet (Van Soest 1994, Pinho et al. 2013). The biomass sorghum silages evaluated in the present study presented crude protein contents below the recommended level. However, this is not an exclusive characteristic of biomass sorghum, but of most tropical forages. For instance, the results found in our study were within the range found in commonly used tropical forages such as *piatã* grass (4.6 % of crude protein; Negrão et al. 2020), sugarcane (3.5 % of crude protein; Gurgel et al. 2019) and elephant grass (3.27 % of crude protein; Bonfá et al. 2017). However, the commercial genotype BRS655 evaluated in the present study presented contents below those reported in the literature (6.07 to 6.76 % of crude protein by Machado et al. 2011 and 6.10 to 6.81 % by Machado et al. 2012). For the commercial genotype Volumax, the crude protein contents were close to those found in the literature (5.55 to 5.91 % of crude protein; Avelino et al. 2011). This difference

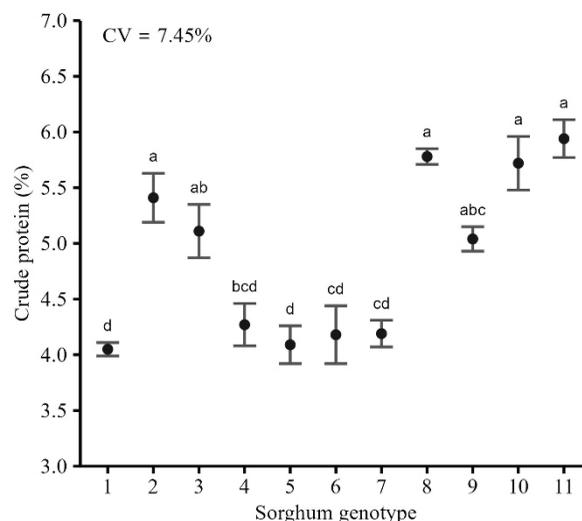


Figure 3. Average crude protein content (points) followed by the standard error (bars) and the silages coefficient of variation (CV; %) of the sorghum genotypes 1 (B004), 2 (B005), 3 (B009), 4 (B010), 5 (B011), 6 (B013), 7 (B015), 8 (B020), 9 (BRS 655), 10 (K1009) and 11 (Volumax). Genotypes followed by different letters are statistically different ( $p < 0.05$ ) according to the Tukey test.

in the crude protein levels may be related to the harvest time, as the later it is, the lower the crude protein content in the material. A common strategy to overcome this limitation is to provide ruminant animals with a nitrogen supplement such as urea. This strategy could also be used to meet the demand for nitrogenous compounds from animals fed with sorghum biomass silage.

Significant differences among the sorghum genotypes were found for the cell wall constituents ( $p < 0.05$ ). The contents of neutral detergent fiber and acid detergent fiber are presented in the Figures 4A and 4B, respectively. The average values ranged between 46.6 and 60.8 % for neutral detergent fiber and 23.0 to 31.8 % for acid detergent fiber. Structural carbohydrates, including cellulose, hemicelluloses, lignin and other less abundant components, such as pectin (Carpita & Gibeaut 1993, Costa 2019), are essential to define the quality of forage to be ensiled. The neutral detergent fiber is a key parameter related to the ruminants' voluntary forage consumption. High levels of neutral detergent fiber negatively influence the voluntary consumption, while very low levels can harm the optimal conditions for ruminal fermentation (Van Soest 1994). In addition, this fraction is related to the physically effective fiber,

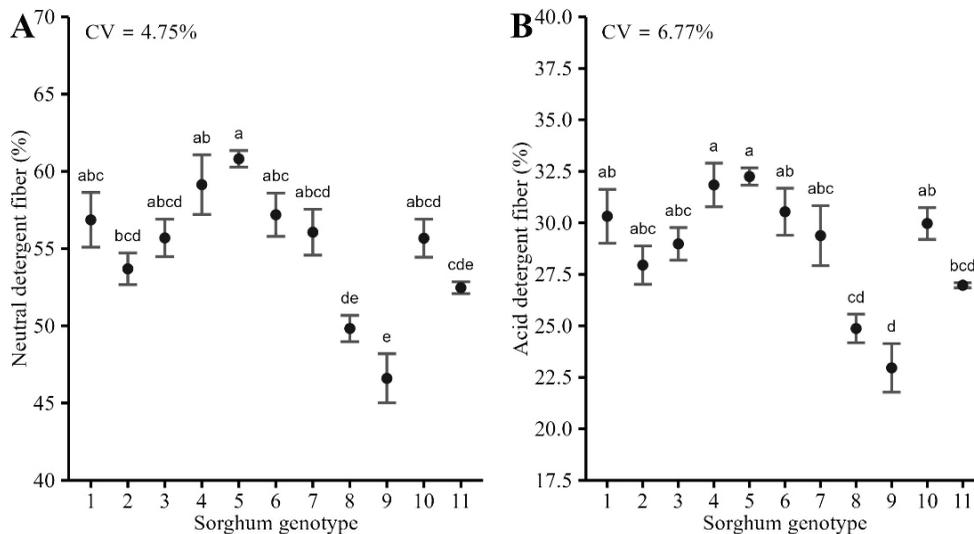


Figure 4. Average neutral detergent fiber average content (A) and acid detergent fiber (B) (points) followed by the standard error (bars) and the silages coefficient of variation (CV; %) of the sorghum genotypes 1 (B004), 2 (B005), 3 (B009), 4 (B010), 5 (B011), 6 (B013), 7 (B015), 8 (B020), 9 (BRS 655), 10 (K1009) and 11 (Volumax). Genotypes followed by different letters are statistically different ( $p < 0.05$ ) according to the Tukey test.

which is the fraction of the food that can stimulate the animal's masticatory and ruminatory activity, what increases the salivary flow with the production of buffering and fermentative products that help to prevent the reduction in the dry matter intake, rumen motility, microbial production and fiber digestibility (Allen 1997).

Also according to Van Soest (1994), the neutral detergent fiber content of the silage must be between 55 and 60 % for a satisfactory digestibility, what was observed for most the genotypes in our study. In addition, the neutral detergent fiber contents of the silages were higher than the contents of ensiled material (i.e., fresh material, as shown in Table 1) for most the genotypes, except for B020 (decreased from 57.3 to 49.8 %  $\pm$  0.85 in the silages) and Volumax (decreased from 57.9 to 52.5 %  $\pm$  0.39 in the silages). According to McDonald et al. (1991), the increase in neutral detergent fiber content during fermentation may occur due to the loss of cell content and concentration of fibrous fractions during fermentation.

On the other hand, acid detergent fiber is associated with the feeding potential digestibility and the cell wall's quality, since it indicates the least digestible fraction (Van Soest et al. 1991, Vasconcelos et al. 2005). In this context, acid detergent fiber values above 30 % may compromise the animals' feeding and use of the forage source

(Moraes et al. 2013). Similarly to the neutral detergent fiber, the acid detergent fiber content increased for most the genotypes after the silage process. The only exceptions were the genotypes B020 (decreased from 26.97 to 24.9 %  $\pm$  0.69 in silages) and Volumax (decreased from 27.65 to 27.0 %  $\pm$  0.12 in silages). Moraes et al. (2013) evaluated dual-purpose sorghum cultivars and reported neutral detergent fiber ranging from 55.57 to 66.65 % and acid detergent fiber from 30.63 to 38.60 %, both of which are similar to the contents found in our study. In addition, Pinedo et al. (2019) evaluated the AG 2002 sorghum cultivar for silage production and found a neutral detergent fiber content close to 52.70 %, similar to the levels found in our study. However, they found higher levels of acid detergent fiber (47.55 %) than reported in the present study. Therefore, our findings regarding neutral detergent fiber and acid detergent fiber align with previous research results, as aforementioned, and the content of both components may not impair the intake and digestibility of the evaluated silages.

The other cell wall components, hemicellulose and lignin, presented significant differences among the evaluated genotypes ( $p < 0.05$ ). The average levels of hemicellulose in the silages ranged between 23.6 and 28.6 % (Figure 5A). In addition, the average content of lignin ranged between 4.5 and 6.5 % (Figure 5B).

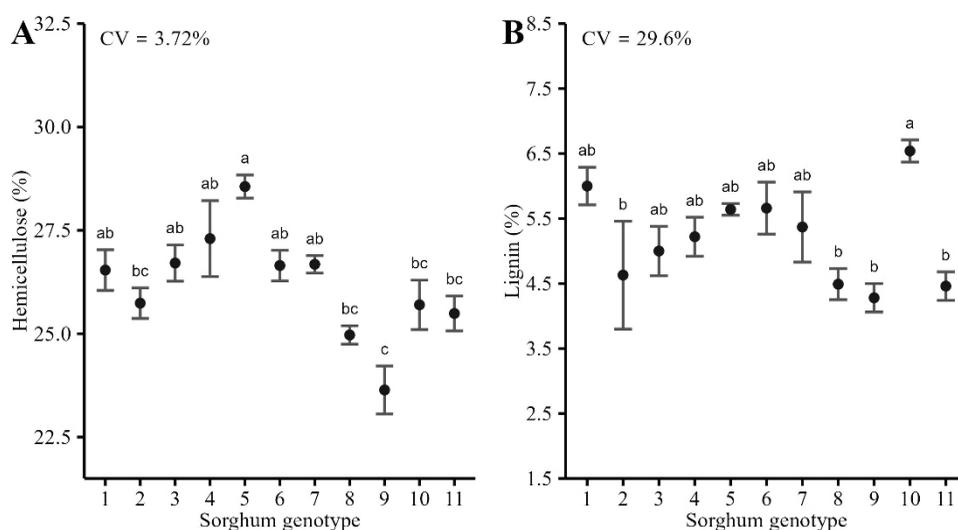


Figure 5. Average hemicellulose (A) and lignin (B; points) followed by the standard error (bars) and the silages coefficient of variation (CV; %) of the sorghum genotypes 1 (B004), 2 (B005), 3 (B009), 4 (B010), 5 (B011), 6 (B013), 7 (B015), 8 (B020), 9 (BRS 655), 10 (K1009) and 11 (Volumax). Genotypes followed by different letters are statistically different ( $p < 0.05$ ) according to the Tukey test.

The silage's hemicellulose contents were reduced in all the cultivars, when compared to the fresh material. The greatest reductions were observed for the cultivars B020 (decreased from 30.35 to 25.0%  $\pm$  0.22 in silages) and Volumax (decreased from 30.26 to 25.5%  $\pm$  0.42 in silages). In the absence of substrates, microorganisms can use hemicellulose during the fermentation process (McDonald et al. 1991), what may explain the reduction of this fraction in the evaluated silages. Despite the reduction, it was still higher than reported in previous studies. For instance, Macedo et al. (2012) reported an average hemicellulose level of 18.3% for the BR601 sorghum cultivar after 49 days of fermentation, while Castro et al. (2008) obtained hemicellulose levels of 27.7% for silages of the BRS Ponta Negra sorghum cultivar after 60 days of fermentation.

Only small changes were observed in the silage's lignin content, when compared to the fresh material. Van Soest (1994) states that the lignin fraction remains stable during the fermentation phase of silages. Reductions may indicate the presence of aerobic fungi because of the entry of oxygen into the silage, what allows the development of undesirable microorganisms during the fermentation process. However, this was not verified in the present study, as both the evaluated biomass sorghum and the commercial genotypes had low levels of lignin. Oliveira et al. (2023) also obtained similar contents

of lignin, varying between 5.05 and 5.73% for silages of the biomass sorghum cultivars B012, B017 and B018 after 60 days of fermentation. In addition, Macedo et al. (2012) found lignin contents above 7.14% for silages of sorghum BR601 after 49 days of fermentation.

Future studies are still needed to better evaluate the quality of silages from biomass sorghum cultivars, analyzing their fermentative profile and aerobic stability, and carrying out animal digestibility tests.

## CONCLUSION

All the evaluated sorghum biomass genotypes (B004, B005, B009, B010, B011, B013, B015, B020, BRS655, Volumax and K1009) showed potential to be used in silage production.

## ACKNOWLEDGMENTS

The authors thank the Universidade Federal dos Vales do Jequitinhonha e Mucuri for supporting this study, and the Embrapa Milho e Sorgo for supplying the sorghum genotypes.

## REFERENCES

ALEXANDRATOS, N.; BRUINSMA, J. *World agriculture towards 2030/2050: the 2012 revision*. Rome: FAO, 2012.

- ALLEN, M. S. Relationship between fermentation acid production in the rumen and requirement for physically effective fiber. *Journal of Dairy Science*, v. 80, n. 7, p. 1447-1462, 1997.
- ALMEIDA, L. G. F.; PARRELLA, R. A. C.; SIMEONE, M. L. F.; RIBEIRO, P. C. O.; SANTOS, A. S.; COSTA, A. S. V.; GUIMARÃES, A. G.; SCHAFFERT, R. E. Composition and growth of sorghum biomass genotypes for ethanol production. *Biomass and Bioenergy*, v. 122, n. 3, p. 343-348, 2019.
- ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS (AOAC). *Official methods of analysis of AOAC International*. 16. ed. Arlington: AOAC International, 1995.
- AVELINO, P. M.; NEIVA, J. N. M.; ARAUJO, V. L.; ALEXANDRINO, E.; BOMFIM, M. A. D.; RESTLE, J. Composição bromatológica de silagens de híbridos de sorgo cultivados em diferentes densidades de plantas. *Revista Ciência Agronômica*, v. 42, n. 1, p. 208-215, 2011.
- BONFÁ, C. S.; GUIMARÃES, C. G.; EVANGELISTA, A. R.; SANTOS, A. S.; PANTOJA, L. A.; MAGALHÃES, M. A.; FABRIS, J. D.; ALMEIDA, L. G. F. Ethanol and organic acid production related to the microbial population in sugarcane silages with admixed crambe (*Crambe abyssinica* Hochst) bran. *New Zealand Journal of Agricultural Research*, v. 66, n. 3, p. 224-243, 2022.
- BONFÁ, C. S.; VILLELA, S. D. J.; CASTRO, G. H. F.; SANTOS, R. A.; EVANGELISTA, A. R.; PIRES NETO, O. S. Silagem de capim-elefante adicionada de casca de abacaxi. *Revista Ceres*, v. 64, n. 2, p. 176-182, 2017.
- BORÉM, A.; PIMENTEL, L.; PARRELLA, R. A. C. *Sorgo: do plantio à colheita*. Viçosa: Ed. UFV, 2014.
- CARPITA, N. C.; GIBEAUT, D. M. Structural models of primary cell walls in flowering plants: consistency of molecular structure with the physical properties of the walls during growth. *The Plant Journal*, v. 3, n. 1, p. 1-30, 1993.
- CASTRO, O. P. C. M.; RÊGO, M. M. T.; AGUIAR, E. M.; LIMA, G. F. C.; MACIEL, F. C.; LÔBO, R. N. B.; LIRA, M. A. Composição bromatológica da silagem de sorgo com níveis crescentes de girassol. In: CONGRESSO NORDESTINO DE PRODUÇÃO ANIMAL, 5.; SIMPÓSIO NORDESTINO DE ALIMENTAÇÃO DE RUMINANTES, 11.; SIMPÓSIO SERGIPANO DE PRODUÇÃO ANIMAL, 1., 2008, Aracaju. *Anais... Aracaju: Sociedade Nordestina de Produção Animal*, 2008. 1 CD-ROM.
- CAVALI, J.; PEREIRA, O. G.; VALADARES FILHO, S. C.; PORTO, M. O.; FERNANDES, F. E. P.; GARCIA, R. Mixed sugarcane and elephant grass silages with or without bacterial inoculant. *Revista Brasileira de Zootecnia*, v. 39, n. 3, p. 462-470, 2010.
- CLAFFEY, A.; DELABY, L.; GALVIN, N.; BOLAND, T.; EGAN, M. The effect of spring grass availability and grazing rotation length on the production and quality of herbage and milk in early spring. *Journal of Agricultural Science*, v. 157, n. 5, p. 434-448, 2019.
- COSTA, R. Parede celular vegetal. *Revista de Ciência Elementar*, v. 7, n. 1, e6, 2019.
- EVERS, S. H.; DELABY, L.; PIERCE, K. M.; HORAN, B. The effects of spring feeding strategy on pasture productivity, sward quality, and animal performance within intensive pasture-based dairy systems. *Journal of Dairy Science*, v. 106, n. 3, p. 1837-1852, 2023.
- FAIRBAIRN, R. L.; ALLI, I.; PHILLIP, L. E. Proteolysis and amino acid degradation during ensilage of untreated or formic acid-treated lucerne and maize. *Grass and Forage Science*, v. 47, n. 4, p. 382-390, 1992.
- FULGUEIRA, C. L.; AMIGOT, S. L.; GAGGIOTTI, M.; ROMERO, L. A.; BASÍLICO, J. C. Forage quality: techniques for testing. *Fresh Produce Journal*, v. 1, n. 2, p. 121-131, 2007.
- GIRIDHAR, K.; SAMIREDDYPALLE, A. Impact of climate change on forage availability for livestock. In: SEJIAN, V.; GAUGHAN, J.; BAUMGARD, L.; PRASAD, C. (ed.). *Climate change impact on livestock: adaptation and mitigation*. New Delhi: Springer, 2015. p. 97-112.
- GURGEL, A. L. C.; CAMARGO, F. C.; DIAS, A. M.; SANTANA, J. C. S.; COSTA, C. M.; COSTA, A. B. G.; SILVA, M. G. P.; MACHADO, W. K. R.; FERNANDES, P. B. Produção, qualidade e utilização de silagens de capins tropicais na dieta de ruminantes. *Pubvet*, v. 13, n. 11, e441, 2019.
- JOBIM, C. C.; GONÇALVES, G. D. Microbiologia de forragens conservadas. In: REIS, R. A.; BERNARDES, T. F.; SIQUEIRA, G. R.; MOREIRA, A. L. (ed.). *Volumosos na produção de ruminantes: valor alimentício de forragens*. Jaboticabal: Funep, 2003. p. 1-26.
- MACEDO, C. H. O.; ANDRADE, A. P.; SANTOS, E. M.; SILVA, D. S.; SILVA, T. C.; EDVAN, R. L. Fermentation characteristics and chemical composition of sorghum silage in function of nitrogen fertilization. *Revista Brasileira de Saúde e Produção Animal*, v. 13, n. 2, p. 371-382, 2012.
- MACHADO, F. S.; RODRIGUEZ, N. M.; GONÇALVES, L. C.; RODRIGUES, J. A. S.; RIBAS, M. N.; PÔSSAS, F. P.; GUIMARÃES JÚNIOR, R.; JAYME, D. G.; PEREIRA, L. G. R. Consumo e digestibilidade aparente de silagens de sorgo em diferentes estádios de maturação. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, v. 63, n. 6, p. 1470-1478, 2011.
- MACHADO, F. S.; RODRIGUEZ, N. M.; RODRIGUES, J. A. S.; RIBAS, M. N.; TEIXEIRA, A. M.; RIBEIRO

- JÚNIOR, G. O.; VELASCO, F. O.; GONÇALVES, L. C.; GUIMARÃES JÚNIOR, R.; PEREIRA, L. G. R. Qualidade da silagem de híbridos de sorgo em diferentes estádios de maturação. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, v. 64, n. 3, p. 711-720, 2012.
- MCDONALD, P.; HENDERSON, A. R.; HERON, S. J. E. *The biochemistry of silage*. 2. ed. Marlow: Chalcombe, 1991.
- MORAES, S. D. D.; JOBIM, C. C.; SILVA, M. S.; MARQUARDT, F. I. Production and chemical composition of hybrid sorghum and corn for silage. *Revista Brasileira de Saúde e Produção Animal*, v. 14, n. 4, p. 624-634, 2013.
- NEGRÃO, F. M.; ZANINE, A. M.; SILVA FILHO, A. S.; SILVA, A. R.; SANTOS, R. M.; CALDEIRA, F. H. B.; LINS, T. O. J. D.; CIRÍACO, A. P.; FREIRIA, L. B.; REIS, R. H. P. Perdas e composição química das silagens de capim-piatã com inclusão de resíduo de feijão. *Research, Society and Development*, v. 9, n. 7, e900974753, 2020.
- OLIVEIRA, D. E. P.; BONFÁ, C. S.; MAGALHÃES, M. A.; FERREIRA, F. J.; DALLAGO, G. M.; PARRELLA, R. A. C. Biomass sorghum silages with sugarcane. *Veterinária e Zootecnia*, v. 30, p. 1-14, 2023.
- OLIVEIRA, L. B.; PIRES, A. J. V.; CARVALHO, G. G. P.; RIBEIRO, L. S. O.; ALMEIDA, V. V.; PEIXOTO, C. A. M. Perdas e valor nutritivo de silagens de milho, sorgo-sudão, sorgo forrageiro e girassol. *Revista Brasileira de Zootecnia*, v. 39, n. 1, p. 61-67, 2010.
- OUDE ELFERINK, S. J. W. H.; DRIEHUIS, F.; GOTTSCHAL, J. C.; SPOELSTRA, S. F. Silage fermentation processes and their manipulation. In: FAO ELECTRONIC CONFERENCE ON TROPICAL SILAGE, 1999, Rome. *Proceedings...* Rome: FAO, 2000. p. 17-30.
- PAIVA, J. A. J. *Qualidade da silagem da região metalúrgica de Minas Gerais*. Belo Horizonte: Escola de Veterinária da UFMG, 1976.
- PEREIRA, E. S.; MIZUBUTI, I. Y.; PINHEIRO, S. M.; VILLARROEL, A. B. S.; CLEMENTINO, R. H. Avaliação da qualidade nutricional de silagens de milho (*Zea mays*, L). *Revista Caatinga*, v. 20, n. 3, p. 8-12, 2007.
- PINEDO, L. A.; SANTOS, B. R. C.; FIRMINO, S. S.; ASSIS, L. C. S. L.; BRAGA, A. P.; LIMA, P. O.; OLIVEIRA, P. V. C.; PINTO, M. M. F. Sorghum silage enriched whit by-products the cupuaçu seed cake. *Brazilian Journal of Development*, v. 5, n. 12, p. 29633-29645, 2019.
- PINHO, R. M. A.; SANTOS, E. M.; RODRIGUES, J. A. S.; MACEDO, C. H. O.; CAMPOS, F. S.; RAMOS, J. P. F.; BEZERRA, H. F. C.; PERAZZO, A. F. Avaliação de genótipos de milheto para silagem no semiárido. *Revista Brasileira de Saúde e Produção Animal*, v. 14, n. 3, p. 426-436, 2013.
- R CORE TEAM. *R: a language and environment for statistical computing*. Version 3.5.3 "Great Truth". Vienna: R Foundation for Statistical Computing, 2019.
- RAMOS, J. C. P.; ROCHA JÚNIOR, V. R.; MONÇÃO, F. P.; PARRELLA, R. A. C.; CAXITO, A. M.; CORDEIRO, M. W. S.; PIRES, D. A. A. Effect of replacing forage sorghum silage with biomass sorghum silage in diets for F1 Holstein × Zebu lactating cows. *Tropical Animal Health and Production*, v. 53, n. 1, e99, 2021.
- RODRIGUES, P. H. M.; PINEDO, L. A.; MEYER, P. M.; SILVA, T. H.; GUIMARÃES, I. C. S. B. Sorghum silage quality as determined by chemical-nutritional factors. *Grass and Forage Science*, v. 75, n. 4, p. 462-473, 2020.
- SKONIESKI, F. R.; NORBERG, J. L.; AZEVEDO, E. B.; DAVID, D. B.; KESSLER, J. D.; MENEGAZ, A. L. Produção, caracterização nutricional e fermentativa de silagens de sorgo forrageiro e sorgo duplo propósito. *Acta Scientiarum Animal Sciences*, v. 32, n. 1, p. 27-32, 2010.
- TOMICH, T. R.; PEREIRA, L. G. R.; GONÇALVES, L. C.; TOMICH, R. G. P.; BORGES, I. *Características químicas para avaliação do processo fermentativo: uma proposta para qualificação da fermentação*. Corumbá: Embrapa Pantanal, 2003.
- VAN SOEST, P. J. *Nutritional ecology of the ruminant*. 2. ed. Ithaca: Cornell University, 1994.
- VAN SOEST, P. J.; ROBERTSON, J. B.; LEWIS, B. A. Methods for dietary fiber and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, v. 74, n. 10, p. 3583-3597, 1991.
- VASCONCELOS, R. C.; PINHO, R. G. V.; REZENDE, A. V.; PEREIRA, M. N.; BRITO, A. H. Efeito da altura de corte das plantas na produtividade da matéria seca e em características bromatológicas da forragem de milho. *Ciência e Agrotecnologia*, v. 29, n. 6, p. 1139-1145, 2005.
- VEGA BRITEZ, G. D.; VARGAS JUNIOR, F. M.; RETORE, M.; SILVA, M. C.; LEDESMA, L. L. M.; SILVA, A. L. A.; MONTESCHIO, J. O.; FERNANDES, T. Effects of type of tropical pasture and concentrate supplementation level on the carcass traits of grazing lambs. *Archives of Animal Breeding*, v. 63, n. 2, p. 283-291, 2020.
- WOOLFORD, M. K.; PAHLOW, G. The silage fermentation. In: WOOD, B. J. B. *Microbiology of fermented foods*. Boston: Springer, 1998. p. 73-102.
- ZEIFMAN, L.; HERTOGE, S.; KANTOROVA, V.; WILMOTH, J. *A world of 8 billion*. New York: UN Department of Economic Social Affairs (DESA), 2022.