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Artículo

Nutritional value of the forage from sorghums evaluated in the Bajío

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Abstract

Sorghum forage generally provides yields similar to that of corn, its silage contains less starch, similar proteins, and more fiber than corn, and its water requirement is lower, which has made it an alternative to forage corn. In 2022, at the Animal Nutrition Laboratory of the Postgraduate Program in Genetic Resources and Productivity, Livestock Program of the College of Postgraduates, Montecillo *Campus* , we carried out the bromatological analysis of forage samples from sorghum cultivars grown during the autumn-winter agricultural cycle of 2021 at the Bajío Experimental Field of INIFAP, with the aim of evaluating their nutritional value. A completely randomized design with 3 replications was used. The statistical analysis was performed through a Tukey test at 5% for the comparison of means between cultivars, using the RStudio 4.3.3 statistical package. The Súper Sorgo 35 cultivar presented the highest values for neutral detergent fiber (76.19%) and total protein (13.52%). The cultivars Silage king (95.6%), Silo Máster (20.05%), ET-V1 (56.87%), and RB Cañero (1.84%) exhibited the highest values for dry matter, ash, acid detergent fiber and ethereal extract, respectively. Sorghum forage showed statistically significant differences between cultivars for all the variables studied, with Silage King and Súper Sorgo 35 standing out with a higher percentage of dry matter and protein, respectively, compared to the rest of the cultivars assessed. The nutritional value of the forage of the sorghums evaluated was outstanding, making this crop an alternative for animal feed.

Keywords:

Sorghum bicolor(L.) Moench, acid detergent fiber, ethereal extract, neutral detergent fiber.

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Introduction

In dairy production, feed represents approximately 60% of the total expenses of this activity; in this sense, the production of milk and meat largely depends on the amount of forage present in the animal diet. Worldwide, animal feeding based on forages utilizes crops that produce low yields and low nutritional value, and therefore, a negative impact on livestock production (Fardin, 2023).

Sorghum can be grown as grain or forage. It is an important forage crop used in livestock systems in many parts of the world due to its adaptability to different environments (Sánchez *et al* ., 2002; Fonseca *et al* ., 2012; Amelework *et al* ., 2015). Sorghum is an ideal forage crop because of its high yield potential, rapid growth and regrowth, drought resistance, ability to grow in hot, dry environments, and survival in waterlogged conditions (Meyer and Brosz, 1979).

The ethanol sorghums evaluated in this research are of intermediate cycle (135 to 140 days to grain maturity), adapt to warm, semi-warm and temperate climates, have autumn-winter and spring-summer sowing dates, sowing density of 15 kg ha-1 and 75 to 85 days to flowering, present a potential biomass yield of 55 to 80 t ha-1, concentrate 16° Brix, and allow 2 to 3 cuts to be made depending on the irrigation, sowing date and locality. Súper Sorgos are hybrids that have an approximate growth rate of 6.4.cm per day, a height to the base of the panicle of 5.2 m at 81 das, and a green matter production of 173 t ha-1, and concentrate 14° Brix. They can be used as biofuel based on their high biomass yield and as forage to feed animals, the demand of which grows every day worldwide.

Forage sorghums are intermediate-cycle hybrids and produce a large, semi-compact, white-grained panicle. They grow from 2.5 to 3.1 m, present an intermediate vegetative cycle with an average of 75 days for cutting and medium-high tillering, are resistant to lodging, and have an adaptability of up to 2 000 masl and a high tolerance to foliar diseases. Forage crops other than sorghum generally tolerate less drought; in addition to this, there is a huge deficit of forage in several countries and it is expected that the deficit of fresh forages will reach between 40 and 60% and that of dry forages, 20%, especially in developing countries; therefore, it is imperative to produce crops that provide forages of good quality and high nutritional value to meet the demand for feed for animal nutrition (Mutalik *et al* ., 2020).

Compared to corn, sorghum uses water more efficiently, which is important in areas where irrigation is limited or there is a greater likelihood of drought. The production cost of forage sorghum is lower compared to corn, mainly due to lower seed and irrigation costs (Bernard, 2015). Water needs are reported to be 30% to 50% lower than those of corn, which is an important factor in areas that rely on irrigation to produce a crop. Forage sorghum can be planted later in the growing season than corn and still produce similar yields. Forage sorghum tolerates lower soil fertility than corn (Borba *et al* ., 2012) and still produces reasonable yields and responds well to fertilization. The fibrous, deep and adventitious root system of forage sorghum (grows up to 140 cm deep) allows it to extract and use moisture and nutrients from the soil more efficiently.

The main selection criteria for improving the nutritional value of forage are greater *in vitro* digestibility of dry matter and lower lignin content (Casler, 2001). The most accurate way to determine the nutritional value of forage is through bromatological analysis, which allowed separating the neutral detergent fibrous (NDF) fraction and acid detergent fibrous (ADF) fraction. The ADF corresponds to lignified cellulose, which is indigestible, so it is negatively correlated with digestibility. A protein content of less than 6% in dry matter is considered deficient (Singh *et al* ., 2018).

On the other hand, in Mexico, at the national level, in 2023, the area planted with forage sorghum was 118 527 ha, of which 96 329 ha were harvested, with a production of 2 718 448 t and an average yield of 28.22 t ha-1 (SIAP, 2023). The state of Coahuila is the main producer of forage sorghum, with a planted area of 24 403 ha and production of 786 020 ha-1 (SIAP, 2023). Most of the production is used for the production of feed. Fardin *et al* . (2023) , when evaluating the nutritional value and agronomic characteristics of forage sorghum under drought stress, reported that the crude protein content of sorghum forage was affected by different levels of irrigation, and the highest protein content was recorded under the mild stress irrigation treatment at 13.6%. The

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crude protein content decreased to 6.9% with the extreme stress treatment and was significantly different among the genotypes evaluated.

Granados-Niño *et al* . (2021) , when evaluating the effect of sorghum cutting height at harvest on forage yield and nutrient value of silage, found that DM yield decreased from harvesting at 40 cm above the ground. The NDF and lignin in silage were higher when harvested at 10 cm, but lignin decreased by 1.4% when cutting at a height greater than 20 cm. NDF digestibility and total digestible nutrient (TDN) concentration increased when harvest was done at 40 cm. The highest content of non-fibrous carbohydrates (NFC) was obtained when harvest was performed at 40 and 50 cm. The net energy for lactation (NEL) of silage increased from harvesting at 20 cm. The optimal pH of the silage was obtained when harvest was done at 30 cm.

This research aimed to evaluate the nutritional value of forage from sorghum cultivars for forage and for ethanol, and Súper Sorgos grown in the Bajío, Mexico, to determine their potential in animal feeding.

Materials and methods

Location of the experimental site

The research was conducted in the Animal Nutrition Laboratory of the Postgraduate Program in Genetic Resources and Productivity, Livestock Program of the College of Postgraduates, Montecillo Campus; however, the materials were evaluated regarding their agronomic characteristics in the Bajío Experimental Field of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP, for its acronym in Spanish), during the autumn-winter agricultural cycle of 2021.

Plant material

The plant material consisted of forage samples of cultivars of forage sorghum: Silo Máster, Silo Miel, and Silage King (control), ethanol sorghums: ET-V1, ET-V2, ET-V3, ET-V4, ET-V5, and RB-Cañero (control), and Súper Sorgos: SS-02, SS-09, and SS-35. Three individuals per genotype were sampled, and samples were taken from the middle stratum of the plants at a rate of 3 leaves per plant. In the laboratory, the samples were dried in an oven at 45 °C and then the leaves of each genotype were ground and a composite sample per genotype was formed.

Experimental design

In the laboratory, a randomized complete experimental design with three replications was used. In the field, the materials were established under a design of randomized complete blocks with four replications, the experimental unit consisted of four furrows of 5 m in length and 0.76 m in width, the sowing was carried out at a continuous seed deposit at a rate of two grams of seeds per linear meter, the total area of the trial was 1 700 m2.

Fertilization

The fertilization was done using the formula 180-40-00; of this, 90-40-00 was applied at sowing and the rest of the nitrogen was applied at 35 das with the formula 90-00-00; urea and triple super phosphate were used as commercial sources.

Variables evaluated

The nutritional value of sorghum cultivars was estimated using the following variables: dry matter (DM), ash (A), neutral detergent fiber (NDF), and acid detergent fiber (ADF) through Van Soest’s (1972) method, protein (TP) using the Kjeldahl method, and ethereal extract (EE) using the Goldfish method.

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Dry matter

Samples of 1 g were used, which were placed in crucibles and dried in an oven at 110 °C for 24 h; subsequently, the percentage of dry matter was determined when the samples reached room temperature using the following equation:

$$\%DM=\frac{weight of the dried sample}{weight of the wet sample}x100$$

Ashes

Samples of 1 g were poured into crucibles and placed in a muffle at 600 °C for 12 h for drying; after that time, the temperature of the muffle was gradually reduced until it reached 100 °C; once this temperature was reached, the samples were extracted and transferred to a desiccator. The percentage of ash was determined when the samples were at room temperature with the following equation:

$$\%A=\frac{(weight of crucible+sample)-(weight of crucible+ash)}{weight of the sample}x100$$

Neutral detergent fiber

Zero point four grams of samples were weighed and placed in an oven at 55 °C for drying; subsequently, they were poured into 50 ml test tubes and added with 35 ml of neutral detergent solution at room temperature and 0.3 g of the enzyme alpha amylase (1.4-alpha-D-glucan-glucano-hydrolase); the test tubes were transferred to a digester with a temperature of 100 °C, from the moment the solution began to boil, the time was measured until one hour had elapsed, then the contents of the tubes were transferred to filter funnels covered with Whatman # 541 filter paper, previously weighed and dried in an oven at 110 °C; the samples contained in the filter funnels were washed with distilled water at 100 °C, and the washing process was repeated until the entire solution was filtered. The same procedure was performed with acetone, on one occasion, the filtering process was carried out by suction with a vacuum pump; subsequently, the filter papers containing the samples were carefully folded and dried in an oven at 100 °C for 8 h, then transferred to a desiccator and once the samples reached room temperature, their weight was recorded. The yields of the recovered neutral detergent fiber were expressed as the percentage of cell wall constituents (CWCs). The percentage of neutral detergent fiber was determined using the following equation:

$$\%NDF=\frac{(weight of paper+sample)-(weight of the paper)}{weight of the sample}x100$$

Acid detergent fiber

Zero point four grams of samples dried in an oven at 55 °C were weighed, then poured into 50 ml test tubes, which were added with 35 ml of the acid detergent solution at room temperature, and transferred to a digester with a temperature of 100 °C, from the moment the solution began to boil, the time was measured until 1 h had elapsed. The contents of the tubes were then transferred to filter funnels covered with Whatman #541 filter paper, previously weighed and dried in an oven at 110 °C; the samples contained in the filter funnels were washed with distilled water at 100 °C, and the washing process was repeated until the entire solution was filtered; the same procedure was done with acetone, on one occasion, the filtering process was carried out by suction with a vacuum pump; subsequently, the filter papers containing the samples were carefully folded and dried in an oven at 100 °C for 8 h, then were transferred to a desiccator. Once the samples reached room temperature, their weight was recorded. The yields of the recovered acid detergent fiber were expressed as the percentage of cell wall constituents (CWCs). The percentage of acid detergent fiber was determined using the following equation:

$$\%ADF=\frac{(weight of paper+sample)-(weight of the paper)}{weight of the sample}x100$$

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Protein

Samples weighing 0.3 g dried in an oven at 55 °C were used, which were poured into mineralization tubes and added with 0.5 g of the catalyst mixture 'K2SO4: CuSO4: Se (10:1:0.1 by weight)' and 3 ml of concentrated H2SO4. The tubes were placed in a mineralization block, previously heated to 100 °C, for the digestion of the organic matter; once the digestion was finished, they were removed from the block and left to stand until they reached room temperature. The contents of the tubes were transferred to a distiller, a 50 ml Erlenmeyer flask with 6 ml of 4% boric acid solution was placed at the condenser end of the distiller. Twelve milliliters of NaOH were added, and distillation was performed until obtaining 20 ml of the distillate, the condenser end was rinsed with the minimum amount of water, and the flask was removed. The distillate was titrated with the titrated solution of hydrochloric acid at 0.1 N. The following equations were used to determine the percentage of protein in the samples:

$$\%nitrogen = \frac{mlHCLnormalityHCL1.4}{gofsample}$$

,

$$\%totalprotein = \%nitrogen6.25$$

Ethereal extract

Fat cups were used, which were dried in an oven at 110 °C for 1 h, then transferred to a desiccator and once they reached room temperature, their weight was recorded, seeking an accuracy of 0.1 mg. Samples weighing 2 g, previously dried in an oven at 100 °C, were used, which were placed inside a clean thimble, which was plugged with cotton, and this was placed in a thimble holder and fixed to the metal supports of the Goldfish equipment. Thirty milliliters of ethyl ether were added to the fat cups and they were attached to the condenser using a threaded ring to prevent ether leakage. The water tap was turned on to cool the condensers and the hot grills were raised until they touched the fat cups. The ignition knob of the grills was turned, watching the cups until the ether began to boil and condense. The extraction period was 8 h, at a condensation rate of cuatro drops of ether per second.

After this time, the equipment was completely turned off and left to cool down, leaving the water tap open. Once the ether from the sample stopped dripping, they were removed along with the thimble holder, and the collection tubes were placed in their place. The fat cups were put back in place, the equipment was turned on and the grills were raised until they touched the cups. Once the ether in the glasses had evaporated, the grills were lowered to prevent the heat from sticking the collected fat to the bottom of the cups. The fat cups were removed and placed inside an extraction hood to disperse the ether that was still in the sample. Once the ether evaporated from the cups, they were placed in an oven at 110 °C for 30 min, after which they were transferred to a desiccator until they reached room temperature and then weighed. The percentage of ethereal extract was calculated using the following equation:

$$\%etherealextract = \frac{weightofcup + sample - (weightofthecup)}{weightofthesample} x100$$

Statistical analysis

The data obtained were subjected to analysis of variance using the statistical package (Rstudio, 2022). In addition, Tukey's test at 5% probability was used to compare means between treatments.

Results and discussion

The analysis of variance showed highly significant differences ($p < 0.01$) between the treatments evaluated (Table 1).

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Table 1. Statistical significance of the mean squares of the variables studied.

Variables	Sources of variation	CV (%)	R2
	Treatments		
Dry matter	0.31**	0.09	0.97
Ash	10.62**	1.48	0.99
Neutral detergent fiber	22.75**	1.06	0.97
Acid detergent fiber	22.3**	1.12	0.98
Total protein	1.74**	4.75	0.83
Ethereal extract	0.25**	5.18	0.78

Significance level $p < 0.01$.

Comparison of means

The Súper Sorgo 35 cultivar showed the highest values of NDF (76.19%) and TP (13.52%), in contrast to the cultivars ET-V3 (67.35%), Súper Sorgo 02 (66.65%), and ET-V1 (65.45%), which presented the lowest values for NDF; nevertheless, ET-V1 had the highest value of ADF (56.87%) and RB Cañero, the lowest value (46.7%); likewise, ETV-3 presented the lowest value for TP (10.18%) (Table 2).

Table 2. Comparison of means between sorghum cultivars.

Treatments	DM	A	NDF	ADF	TP	EE
ET-V1	94.19 c	18.48 b	65.45 d	56.87 a	10.86 b	1.61 b
ET-V2	94.56 b	19.09 b	70.75 c	55.46 b	11.93 b	1.66 b
ET-V3	94.65 b	17.2 c	67.35 d	53.47 b	10.18 c	1.65 b
ET-V4	94.8 b	14.17 d	72.82 b	49.67 b	10.96 b	1.64 b
ET-V5	94.71 b	13.23 e	75.08 b	52.46 b	11.54 b	1.60 b
Súper Sorgo 02	95.12 b	14.82 d	66.65 d	46.49 c	12.16 b	1.45 c
Súper Sorgo 09	94.85 b	14.61 d	70.73 c	47.79 b	12.52 b	1.45 c
Súper Sorgo 35	95.25 b	15.69 d	76.19 a	48.13 b	13.52 a	1.46 c
RB Cañero	94.92 b	14.2 d	73.46 b	46.7 c	11.53 b	1.84 a
Silo Máster	95.15 b	20.05 a	73.98 b	51.34 b	11.68 b	1.50 c
Silo Miel	95.4 b	18.34 b	70.48 c	51.95 b	12.29 b	1.53 b
Silage King	95.6 a	18.21 b	71.53 b	50.74 b	13 b	1.59 b

DM= dry matter; A= ash; NDF= neutral detergent fiber; ADF= acid detergent fiber; TP= total protein; EE= ethereal extract. Means with equal letters within columns are not statistically different, Tukey ≤ 0.05.

Voluntary forage intake of ruminants is a parameter that is related to NDF, which should range between 55 and 60% for proper digestibility, levels above these values negatively influence voluntary intake, and lower levels impair the optimal conditions of rumen fermentation (Van Soest, 1994). The NDF values obtained in this study were higher than the interval reported in the literature, which gives them a low nutritional value in terms of this parameter. The ADF indicates the least digestible fraction and is related to the digestibility of the food potential and the quality of the cell wall (Van Soest *et al* ., 1991; Vasconcelos *et al* ., 2005). Authors such as Moraes *et al* . (2013) indicate that values above 30% can compromise animal feeding and the use of forage sources.

Ferreira *et al* . (2023) , when studying the chemical and bromatological composition of the forage of sorghum genotypes, found values between 25.22 and 37.91 for DM, 3.4 and 6.3 for CP, 45.77 and 60.41 for FDN, and 21.26 and 30.53 for ADF. The authors stated that, although there were significant differences among the 11 genotypes, the chemical-bromatological composition of all the cultivars evaluated evidences their potential to be used in silage production. The results reported in this study are lower than those found in the present research, so their nutritional contribution is compromised.

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The level of crude protein in the diet of ruminants should not be less than 7% since these values limit the activity of microorganisms in the rumen, compromising animal growth (Van Soest, 1994; Pinho *et al* . 2013). In the present research, all the evaluated materials presented percentages higher than 7%, which indicates their good nutritional quality in this aspect.

For the variables DM, A, and EE, the cultivars Silage King (95.6%), Silo Máster (20.05%), and RB Cañero (1.84%), respectively, had the highest values; ET-V1 and ET-V5 showed the lowest values for DM and A; Silo Máster (1.5%), Súper Sorgo 35 (1.46%), Súper Sorgo 02, and Súper Sorgo 09, all with values of 1.45, presented the lowest values for EE.

According to Elferink *et al* . (2000) , silage quality is largely determined by the dry matter content present in the forage used for processing. A high moisture content, in addition to making silage management difficult, leads to the loss of digestible nutrients, reducing its nutritional value (Pereira *et al* ., 2007). If the moisture of the forage is high, the establishment of undesirable bacteria during the fermentation process is favored as a result of the increased degradation of proteins in the silage material (Elferink *et al* ., 2000).

Mejía *et al* . (2019) , when evaluating the production and nutritional quality of the forage of the sweet sorghum cv. Corpoica JJT-18 in monoculture and intercropped with corn and beans, reported values of 16, 6.7, 58.5 and 36% of DM, CP, NDF and ADF, respectively, and indicated that the fresh forage produced by sweet sorghum presented a nutritional quality similar to that of corn in the contents of CP, NDF and ADF and was higher in soluble solids. In contrast, *in situ* degradability and dry matter content were higher in fresh forage of corn. The results obtained for dry matter in this research differ, being superior to those indicated by these authors, which indicates that the evaluated materials have good nutritional characteristics in some of the aspects evaluated.

To obtain a high-quality silage, the dry matter content of the forages must range between 28 and 35%, if it is higher, compaction and oxygen removal is complicated and if it is lower, it leads to loss of nutrients and high production of butyric acid (McDonald *et al* ., 1991; Skonieski *et al* ., 2010). In their work, Gois *et al* . (2022) studied the nutritional and fermentative profile of the forage sorghum Punta Negra irrigated with saline water, and reported values of 35.94% DM, 6.51% CP, 1.85% EE, 52.07%NDF, and 23.85% ADF at zero days of irrigation. For the chemical-bromatological characteristics of the sorghum plant, they observed a decreasing linear behavior for the contents of dry matter and organic matter, whereas a positive linear effect was verified for the crude protein as the leachate fractions increased.

Conclusions

Sorghum forage exhibited statistically significant differences among cultivars for all the variables studied, with Silage King and Súper Sorgo 35 standing out with a higher percentage of dry matter and protein, respectively, compared to the rest of the cultivars evaluated. The nutritional value of the forage of the evaluated sorghums was outstanding in some of the aspects evaluated, so it can be suggested for animal feeding.

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