Colegio de Postgraduados

Nutritional analysis of two corn hybrids (*Zea mays* L.) for forage production

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ABSTRACT

Objective: To characterize and compare the yield and bromatological composition —such as fresh matter, crude protein, and other nutritional indicators— of two corn (*Zea mays* L.) hybrids, developed under fertigation conditions, at three different plant densities.

Design/Methodology/Approach: The experiment was conducted using a factorial experimental design with two factors (hybrids) and three levels (densities).

Results: The CEBU hybrid recorded the highest fresh and dry matter yield. According to the bromatological analysis, it also obtained the highest crude protein (CP) values and total ash content. Meanwhile, the A7573 hybrid reached a higher total carbohydrate content.

Study Limitations/Implications: The low temperatures recorded during the experiment impacted both the corn plant and crop development cycles.

Findings/Conclusions: The agronomic characteristics and nutritional value of evaluated hybrids recorded significant differences. CEBU had a more efficient forage and biomass production in all the evaluated sowing densities (50,000, 62,500, and 83,333 plant ha^{-1}). In the bromatological analysis, CEBU obtained a higher crude protein and ash content than A7573. However, A7573 recorded a higher total carbohydrate content than CEBU.

Keywords: Bromatological composition, forage, plant density, fertigation, and corn.

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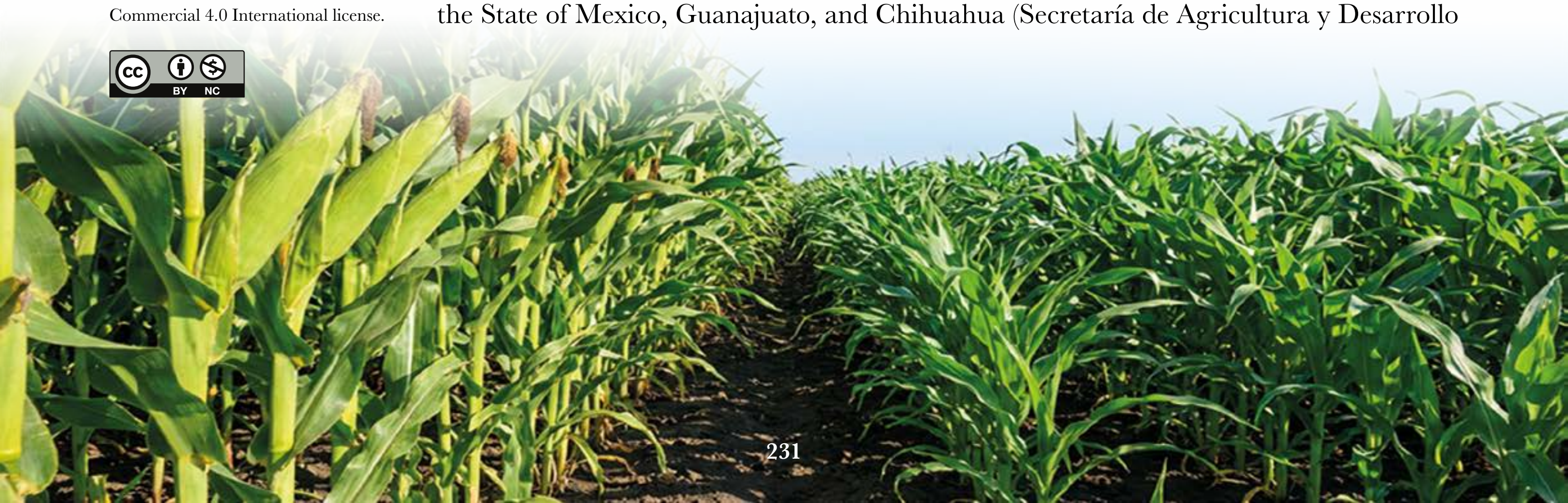
INTRODUCTION

Corn (*Zea mays* L.) is the most important crop in Mexico from a food, political, economic, and social perspectives. Domestic production has reached over 27 million tons, grown in more than 6 million hectares. The main corn producers are Sinaloa, Michoacán, the State of Mexico, Guanajuato, and Chihuahua (Secretaría de Agricultura y Desarrollo



Rural [SADER], 2023). Corn has multiple uses, including forage to feed animals. Corn forage has high nutritional value, and its high dry matter yield per ha results in a high productivity. Nevertheless, forage quality cannot be determined solely by the amount of production, but fundamentally by its nutrient composition —*i.e.*, the type and content of its nutritional components, such as dry matter (DM), crude protein (CP), ashes, fats, neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fiber carbohydrates, and minerals (Ramírez *et al.*, 2024; Maguiña-Maza *et al.*, 2021).

The selection of a corn variety or hybrid as forage depends on its dry matter yield (DMY), which is related to the morphological components of the plant, such as leaves and stems (Rivas *et al.*, 2020). To achieve successful forage production, corn must be established under the right environmental and nutritional conditions that favor its appropriate growth and development (Zulueta-Rodríguez *et al.*, 2020). Corn must receive macro and micronutrients to meet its nutritional requirements. However, the plant usually receives these nutrients through chemical fertilization, due to the low fertility of the soils in the semiarid regions where it is grown (Lagunes-Domínguez, 2018). In this context, fertigation is an efficient alternative that enables the simultaneous application of water and fertilizers, optimizing resources and maintaining productivity in environments with limited water availability (Kalpana and Fanish, 2014).

In their study on fresh corn forage production, Gutiérrez-Guzmán *et al.* (2022) recorded a 55.8 t ha^{-1} yield with the early-cycle Syngenta 8285 variety. The sowing density was 100,000 plants ha^{-1}. The plants were sown with a 0.76 m separation between furrows and were fertilized with a 280-80-00 formula. In addition, in their study about the nutritional composition of the PM 213 hybrid forage, Silva *et al.* (2018) reported the following results: 22.45% DM, 8.47% CP, 24.71% fiber, 42.40% ADF, 53.46% NDF, and 4,366.40 kcal of gross energy.

Therefore, the objective of this study was to characterize two corn (*Zea mays* L.) hybrids and compare their bromatological composition, based on nutrient parameters such as fresh and dry matter, crude protein, carbohydrates, and other nutrient quality indicators. In addition, the forage yield was measured under fertigation conditions with three plant densities to provide a feasible forage production alternative to regional producers. This production could be used to feed cattle during the winter or dry season.

MATERIALS AND METHODS

Study Area

The research was conducted from August 16 to November 15, 2024, in the "Los Chavales" property, located at 22° 35' 07.4" N and 101° 43' 20.3" W, in the municipal seat of Salinas, San Luis Potosí, Mexico.

Hybrid Selection

Two corn hybrids (CEBU and A7573) were selected for the experiment. These hybrids have interesting agronomic characteristics such as resistance to corn stalk lodging, adaptability, and yield potential. The seeds were purchased from ASGROW (Mexico).

Experimental Design

A completely randomized experimental design with a 2×3 factorial arrangement was used. The factors were the two corn hybrids (CEBU and A7573), and the levels were the three plant densities (50,000, 62,500, and 83,333 plants ha^{-1}).

The experiment had six treatments (factor interaction). Each treatment was established in 40 m^2 (4 m wide × 10 m long) plots. Each plot consisted of five 10-m rows with a 0.80 m separation between them. One-meter-wide corridors separated the plots, which resulted in a total useful area of 240 m^2.

Establishment of the Experiment

An organic-mineral fertilizer was prepared with 5 t of dry, raw bovine manure mixture, previously sieved with a 5-mm sieve, to increase the contact area with the mineral fertilizers. Subsequently, the manure was combined with a mineral fertilization formula of 60 N:60 P_2O_5:60 K_2O kg ha^{-1}.

The following quantities were used in the total area of the experiment: 120 kg of manure, 7.0 kg of ammonium sulfate, 6.5 kg of single super phosphate, and 2.4 kg of potassium chloride. The mixture was homogenized and applied as background fertilization, incorporating it into the soil at a ≈30 cm depth. Afterwards, it was covered with soil.

Fertigation was used to supply nutrients to the crops, using the 280 N: 200 P_2O_5: 200 K_2O and 40 MgO kg ha^{-1} formula. Table 1 includes the sources and quantity of fertilizer applied through the irrigation water from September to November 2024.

The nutrient solution was applied twelve times during September and October, and three times in November. The pH was adjusted with phosphoric acid to reach 6.5.

Yield Determination and Biomass Percentage

Plants from each treatment were collected within the useful area of each plot to determine fresh and dry matter yield.

The samples were weighted to obtain the average fresh weight per plant (kg) and subsequently the fresh matter yield (FMY) per ha was calculated (t ha^{-1}) with the following equation:

Table 1. Fertilization doses and water volume applied during the monthly scheduled irrigation to corn grown under fertigation (September-November, 2024).

Soluble fertilizer	Months (2024)		
	September	October	November
Macronutrients	Kilograms per irrigation		
Monoammonium phosphate	0.35	0.22	0.17
Potassium nitrate	0.25	0.50	0.40
Phosphonitrate	0.35	0.55	0.60
Magnesium nitrate	0.20	0.25	0.25
Micronutrients	Grams per irrigation		
Carboxy micros	30.00	30.00	30.00
Water volume applied by irrigation (m^3)	0.90	1.35	1.35

$$FMY = \frac{fresh\,weight\ per\ plant \times Plant\ density\ ha^{-1}}{1000}$$

The samples were placed in a convection drying oven at 65 °C until they reached a constant weight. Subsequently, they were weighed and the dry weight was used to calculate dry matter yield (DMY) (t ha^{-1}) with the following equation:

$$DMY = \frac{dry\,weight\ per\ plant \times Plant\ density\ ha^{-1}}{1000}$$

Dry matter percentage (%) was determined following the methodology described by Gutiérrez-Guzmán *et al.* (2022).

Nutritional Analysis

The nutritional analysis was conducted in the Laboratorio de Química y Bioquímica of the Coordinación Académica Región Altiplano Oeste of the Universidad Autónoma de San Luis Potosí (UASLP).

Crude Protein

Crude protein (CP%) content was determined with the micro-Kjeldahl method, following the AOAC standard (2005) that includes three stages: digestion, distillation, and titration. To determine digestion, 0.25 g of the crushed sample was weighed and subsequently placed in a 100-mL Kjeldahl flask. Afterwards, 1.0 g of catalyst (potassium sulphate and copper sulphate) and 3.5 mL of H_2SO_4 (96%) were added to the flask. The samples were placed in a digester, at 400 °C for approximately two hours, until the mixture changed from black to transparent.

Subsequently, the RapidStill I (Labconco Corp., Kansas City, MO, USA) system was used to distill the mixture, adding 10 mL of distilled water at 40 °C and 10 mL of a 60% NaOH solution. The distillate was collected in an Erlenmeyer flask, mixing 5 mL of boric acid saturated solution and three drops of methyl red as indicator. Distillation stopped when a 50 mL final volume was obtained. Finally, titration was conducted with a HCl 0.09 N standard solution until it turned from green to pink. The crude protein percentage was calculated with the following equation, using the 6.25 factor.

$$CP\% = \frac{Vol.of\ HCl \times N\ of\ HCl \times Meq\ N \times Food\ Factor}{Grams\,of\ sample} \times 100$$

Total Ash Content

The total ash percentage (TA%) was determined following the methodology proposed by Kirk *et al.* (1996). A 3 g sample was crushed and sieved; afterwards, it was briefly ashed over a burner until all visible vapors faded away. Subsequently, the samples were placed in a muffle furnace at 550 °C until white or slightly grey ashes were obtained. The percentage was calculated based on the ratio of ash weight and dry matter initial weight.

Total Carbohydrates

Carbohydrate content was determined with the methodology described by Ammar *et al.* (2013). A small sample (0.05 g) was taken from each treatment and soaked in 20 mL of distilled water. Samples were centrifuged at 4,000 rpm for ten minutes and the extracts (supernatants) were used in the colorimetry reaction. An aliquot (3 mL) of H_2SO_4 (96%) was added to 1 mL extract from each sample. Subsequently, the mixture was stirred for 30 seconds and incubated into an ice bath for 2 minutes. The absorbance was determined at 315 nm in a spectrophotometer, using distilled water as a blank.

Statistical Analysis

The data obtained were analyzed with STATISCA v. 7.0 and Sigma Plot v. 10.0 software. The mean and its corresponding standard error $(\bar{x} \pm SE)$ were the central tendency and dispersion measurements used in the analysis. They were also used to the error bar of figures. An analysis of variance (ANOVA) was used for the contrasts. The ANOVA included a completely randomized design with a 2×3 factorial arrangement, using the CEBU and A7573 hybrids and sowing density (50,000, 62,500, and 83,333 plants ha^{-1}) as factors. Tukey's post-hoc test ($p \leq 0.05$) was used to compare means and to identify significant differences between treatments.

RESULTS AND DISCUSSION

Fresh Forage Yield

In this study, the maximum yields of fresh forage reached 49.08±0.92 and 48.02±2.04 t ha^{-1} (Table 2). These results are partially similar to those reported by Rodríguez-Montalvo *et al.* (2021), who recorded 53.10 and 51.94 t ha^{-1} for the H-564C and HE-3B hybrids, respectively. These hybrids were grown under a high sowing density and with intensive fertilization. Although the results of this study are slightly lower than the results obtained by those authors, they show a similar trend, particularly when the efficient use of the available water resources is considered. Meanwhile, Zaragoza-Esparza *et al.* (2019) reported higher yields with the PUMA 1181 and BUHO hybrids, reaching 58 and 74 t ha^{-1}, respectively. These differences could be the result of genetic factors, favorable edaphoclimatic conditions, or a more intensive agronomic management than those used in this experiment, particularly the delay of crop development due to low temperatures. In contrast, Gutiérrez-Guzmán *et al.* (2022) reported a 32.4 t ha^{-1} yield at a 47.2 cm irrigation depth. This result is similar to the lowest yield recorded in this study (28.56±0.43 t ha^{-1}). During this experiment, the irrigation volume (1,200 m^3 ha^{-1}) was complemented with accumulated precipitation (970 m^3 ha^{-1}). These results confirm the findings of Gutiérrez-Guzmán *et al.* (2022) regarding the importance of water management in the production of forage corn. Overall, the results show that —although fresh forage yield can change depending on the agronomic management, environmental conditions, and

Table 2. Fresh and dry forage yield of two corn hybrids, resulting from the hybrid and sowing density factors and their interaction.

Main factor	**Forage yield (t ha^{-1})**	
Hybrids	**Fresh** $\bar{x}$ ± ***SE***	**Dry** $\bar{x}$ ± ***SE***
CEBU	43.72±2.38b	10.33±0.71a
A7573	38.45±3.01a	9.96±0.57a
Density		
50,000	31.59±1.42b	7.87±0.21b
62,500	43.12±2.54a	10.72±0.46a
83,333	48.55±1.03a	11.85±0.28a
Interaction	**CEBU**	
50,000	34.61±0.89bc	7.65±0.38bc
62,500	47.48±1.84a	11.40±0.51a
83,333	49.08±0.92a	11.96±0.39a
	A7573	
50,000	28.56±0.43c	8.09±0.18c
62,500	38.76±3.14b	10.04±0.57b
83,333	48.02±2.04a	11.74±0.46a

Different letters in the same column indicate significant differences, based on Tukey's HSD test ($P<0.05$).

genetic material— the irrigation volume and timing is a determining factor in fresh forage production.

Dry Forage Yield

Dry matter yield showed significant differences between the sowing densities evaluated. The density of 50,000 plants ha^{-1} recorded the lowest value with the CEBU hybrid (7.65 t ha^{-1}); it was statistically different from the other two densities ($F_{5,\ 0.05}=18.76$, $P<0.05$). On the contrary, the densities of 62,500 and 83,333 plants ha^{-1} recorded the highest yields with CEBU (11.40 and 11.96 t ha^{-1}), while the 83,333 plants ha^{-1} density with A7573 reached 11.74 t ha^{-1} (Table 2). No significant differences were found between both treatments. These results suggest that increasing the sowing density of CEBU up to 62,500 plants ha^{-1} can improve dry matter yield, without productive benefits with an additional increase.

Table 2 shows that the maximum dry forage yield (11.96 t ha^{-1}) was lower than the yield (28.1 and 30.3 t ha^{-1}) reported by Ramírez *et al.* (2024) for the DK 4018, Noble, Antílope, and XR-49 hybrids. Their experiment was carried out during the spring-summer agricultural cycle, harvesting from 121 to 142 days after sowing (DAS). This difference could be attributed to the time of the harvest: the highest values were recorded during more advanced phenological stages (approximate grain maturity at R2, R3, R4, and R5), when more dry matter is accumulated. Meanwhile, this study was carried out during the summer-autumn agricultural cycle, harvesting 91 days after emergence, during earlier phenological stages (VT to R1). This condition could account for the lower yield observed. For their part, Maguiña-Maza *et al.* (2021) recorded an average yield of 22.22 t ha^{-1} at 110 DAS, using four corn genotypes sown at a 60,000 plants ha^{-1} density. Although that result is higher than the maximum value recorded in this study, both fall within a complementary production range that can be subjected to comparisons, strengthening the validity of the findings and confirming the joint influence of sowing density, harvest time, and agroclimatic conditions on the dry matter productivity of forage corn.

Dry Matter Content

Table 3 shows that the dry matter content (%) recorded differences between hybrids at the end of the crop cycle ($F_{1,\ 0.05}=8.31$, $P<0.05$). A7573 hybrid had a higher dry matter percentage (26.27±0.66%) than CEBU (23.56±0.82%). No significant differences ($F_{2,\ 0.05}=0.15$, $P=0.85$) were detected through the analysis of sowing densities; however, the density of 62,500 plants ha^{-1} recorded the highest average value (25.09±1.04%).

Figure 1 shows that in the combined analysis of hybrids and densities there were not significant interaction effects ($F_{5,\ 0.05}=3.27$, $P>0.05$). Values ranged from 22.13% to

Table 3. Nutritional analysis of corn forage regarding the hybrid and plant density per hectare factors.

Main factor	Nutritional analysis			
Hybrid	**DM (%)**	**CP (%)**	**TAC (%)**	**CARBS**
CEBU	23.56±0.82a	9.39±1.02a	22.41±0.27a	19.27±1.74a
A 7573	26.27±0.66b	8.59±0.69a	21.48±1.66a	22.50±0.89b
Density				
50,000	25.24±1.56a	8.93±1.11a	21.28±1.87a	19.33±0.70a
62,500	25.09±1.04a	7.82±1.09a	23.22±1.52a	23.46±1.10a
83,333	24.41±0.41a	10.22±0.87a	21.33±2.06a	19.86±2.65a

Dry matter (DM); crude protein (CP); total ash content (TAC); and total carbohydrates (CARBS). Different letters in the same column indicate statistically significant differences, according to Tukey's HSD test (P<0.05).

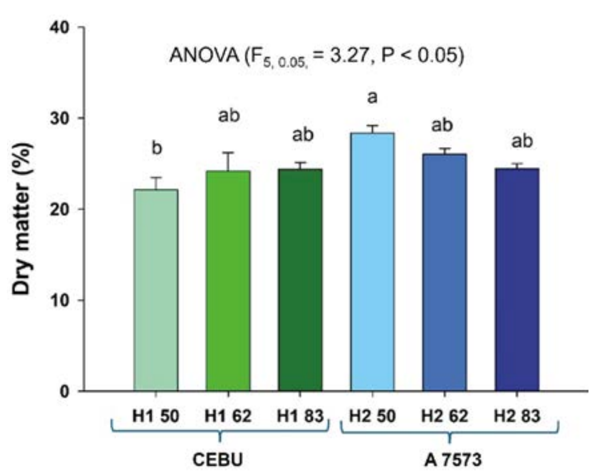


Figure 1. Dry matter content comparison between two forage corn hybrids. Letters on top of the bars indicate statistically significant differences, according to Tukey's test (P<0.05).

28.34%; the highest values were obtained with A7573 at a density of 50,000 plants ha^{-1}. Significant differences between hybrids were observed only with respect to density, with A7573 exhibiting a higher dry matter content than CEBU.

The results of this study are lower than those reported by Zaragoza-Esparza *et al.* (2019), who recorded 31.5% and 35.2% DM for the PUMA 1165 and 1185 hybrids, respectively; both hybrids were grown under irrigation conditions and at a density of 70,000 plants ha^{-1}. Similarly, Gutiérrez-Guzmán *et al.* (2022) obtained 22.42% DM in forage corn, under subsurface drip irrigation (SDI), at a 53 cm irrigation depth and a density of 100,000 plants ha^{-1}. Likewise, Rivas *et al.* (2018) reported 26.71% DM with the single-cross HT-6 forage hybrid, sown at a density of 90,000 plants ha^{-1}. The dry matter in this study ranged from 22.13% to 28.34%, indicating a lower dry biomass accumulation compared to the highest values reported in the literature. Nevertheless, these results are consistent with those obtained under similar management conditions and high sowing densities, in which an increased competition between plants can limit the accumulation of dry matter in plant tissue.

Crude protein

Table 3 shows that the analysis of the crude protein (CP%) content at the end of the crop cycle did not show any significant differences between both hybrids ($F_{1,\ 0.05}=0.55$, $P=0.47>0.05$) and between sowing densities ($F_{2,\ 0.05}=1.35$, $P=0.29$). The combined analysis of hybrids and densities also showed no significant interaction effects. Values ranged from 6.53% to 10.83%; the latter was recorded by CEBU at a density of 50,000 plants ha^{-1} (Figure 2). The maximum crude protein value recorded in this study fell within the range reported by García-Chávez *et al.* (2022), who documented 4.4% and 14.9% contents, under various management conditions.

Meanwhile, Gutiérrez-Guzmán *et al.* (2022) recorded a 10.36% CP with the Syngenta 8285 hybrid, sown at a density of 100,000 plants ha^{-1} and with a subsurface irrigation system at a 93.5 cm depth. Similarly, Zaragoza-Esparza *et al.* (2019) reported CP values from 8.0 to 9.0% in the PUMA 1167 and BUHO hybrids, grown under irrigation conditions

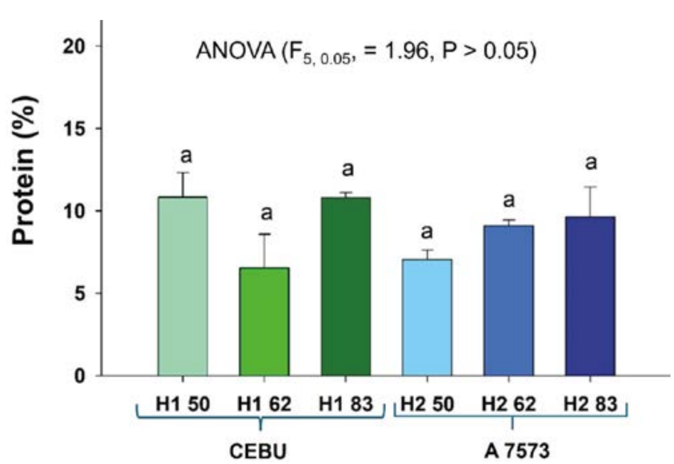


Figure 2. Crude protein content of two corn forage hybrids at three sowing densities. Mean values in the bars do not have significant differences, according to Tukey's test ($P<0.05$).

and at a density of 70,000 plants ha^{-1}. Finally, Ramírez *et al.* (2024) recorded an average of 8.0% CP in four corn hybrids sown at a density of 93,211 plants ha^{-1}, under irrigation conditions, harvested at 121 DAS.

Within this context, the highest value of this study (10.83%) falls within the upper range of previously reported data, suggesting a favorable performance of the genetic material or the management conditions. This result could be associated with such factors as sowing density, harvest time, or the water regime, which, according to previous studies, have a direct influence on the accumulation of crude protein.

Total Ash Content

Table 3 shows that, at the end of the crop cycle, the evaluated hybrids did not exhibit significant differences ($F_{1,\ 0.05}$=0.25; P=0.62) in total ash content (%). Likewise, Table 3 and Figure 3 show no significant differences between sowing densities ($F_{2,\ 0.05}$=0.36; P=0.70>0.05) and the hybrid × density interaction ($F_{5,\ 0.05}$=1.81; P>0.05), respectively. Values fluctuated between 18.55% and 26.30%. The latter value was recorded by A7573, at a density of 62,500 plants ha^{-1}.

These results are higher than the total ash content reported by Ramírez *et al.* (2024) and Solís and Castaño (2022), who registered 6.6% and 13.29%, respectively. Discrepancies in the ash content could be attributed to differences in the phenological stage of the harvest (135 days after emergence), post-silage processes (60-day fermentation), and nitrogen fertilization levels (180 kg N ha^{-1}). These factors can modify the mineral concentration of the plant tissue and consequently its ash content.

Total Carbohydrates

Table 3 shows that the total carbohydrate content (mg g^{-1} DM) at the end of the crop cycle displayed significant differences between the evaluated hybrids ($F_{1,\ 0.05}$=44.91, P<0.01). A7573 had a higher total carbohydrate content (22.50±0.89 mg g^{-1} DM on average) than CEBU (19.27±1.74 mg g^{-1} DM).

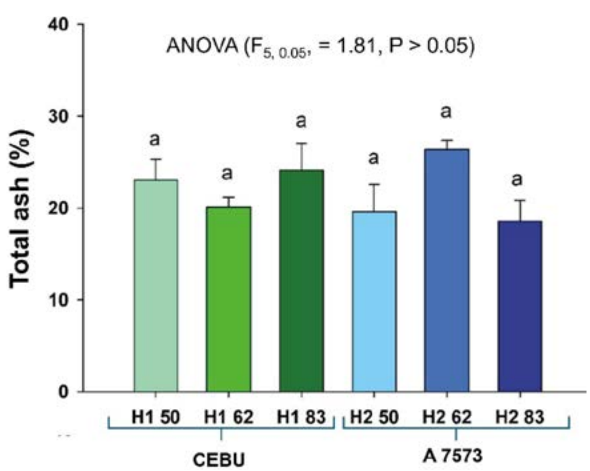


Figure 3. Total ash content (%) in the dry matter (DM) of whole plants from two corn hybrids, harvested at 91 days after emergence. Mean values in the bars do not have significant differences, according to Tukey's test (P<0.05).

Table 3 shows no significant differences ($F_{2, 0.05}=1.72$, $P=0.21>0.05$) for the effect of sowing densities. Nevertheless, the highest value (23.46 ± 1.10 mg g^{-1} DM) was recorded at the density of 62,500 plants ha^{-1}. Figure 4 shows statistically significant differences ($F_{5, 0.05}=59.54$, $P<0.05$) in the hybrid × density interaction, indicating a differential response of hybrids to population density variations. CEBU was statistically different from the other treatments and recorded the lowest carbohydrate content at the density of 83,333 plants ha^{-1}.

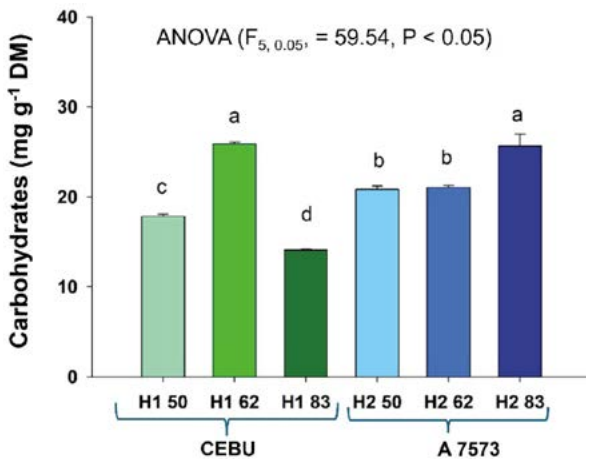


Figure 4. Total carbohydrate content based on hybrid and corn sowing density (%). Letters on top of the bars indicate statistically significant differences, based on Tukey's test ($P<0.05$).

The carbohydrate content values ranged from 14.07 to 25.88 mg g^{-1} DM. The highest value was recorded by CEBU, sown at a density of 62,500 plants ha^{-1}. In the case of A7573, the highest carbohydrate content was reported at a 83,333 plants ha^{-1} density (Figure 4). These results differ from the 87.0 mg g^{-1} DM total carbohydrate content reported by Singh *et al.* (2024). This difference could be attributed to the diverse sampling conditions, as they harvested 135 days after emergence and the matter was subsequently subjected to a silage process. The sample was collected 60 days later. Variations in both post-harvest and sampling management could have significantly influenced carbohydrate levels.

CONCLUSIONS

The results of this research show significant differences between the corn hybrids evaluated, both in their agricultural performance and their nutritional value. The CEBU hybrid had a higher yield in both fresh and dry matter across all sowing densities. According to the nutritional analysis, the CEBU hybrid had a high crude protein and total ash content. However, the A7573 hybrid had the highest total carbohydrate values. The analysis realized in this study allowed to describe and compare the bromatological composition of these two corns (*Zea mays* L.) hybrids, thus meeting the objective of the research. Consequently, it is possible to suggest to regional producers the use of the CEBU hybrid for forage production, with fertigation during the autumn-winter agricultural cycle.

Producers should sow corn at the end of June to prevent a reduction in yield as a result of weather conditions. This recommendation would allow producers to have high-quality and nutritious forage for their cattle during the dry season.

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