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Nutritional Value Evaluation of Corn Silage from Different Mesoregions of Southern Brazil

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Abstract: Corn silage is widely used in livestock farming; however, its quality is easily altered, and one of the factors that has a high influence in this regard is the region of production. The objective was to evaluate the chemical–bromatological composition of 498 samples of corn silage from mesoregions in Southern Brazil during the 2022/2023 summer harvest. The following were studied in relation to our objective: nutritional composition, dry matter, mineral matter, ether extract, starch, crude protein, neutral detergent fiber, acid detergent fiber, acid detergent lignin, total digestible nutrients, total carbohydrates, and fractions of carbohydrates. The silages from Central South-PR had higher levels of starch and ether extract (30.68% ± 6.24% and 3.41% ± 0.92%, respectively), whereas in West-SC, the silages had higher levels in the A + B1 fraction of carbohydrates (49.59% ± 6.34%). Silages in North-PR had higher concentrations of neutral detergent fiber and acid detergent fiber (49.86% ± 5.92% and 29.70% ± 4.38%, respectively), while in Northwest-RS and West-PR, silages had higher levels of the B2 carbohydrate fractions (46.25% ± 1.98% and 44.55% ± 3.84%, respectively). The nutritional composition differences presented were due to the variables of each mesoregion, interfering in the scenario of formulating diets and animal nutrition.

Keywords: chemical analysis; climate variations; dry matter

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1. Introduction

Extensive farming is still characterized as the main form of cattle breeding in Brazil, as it is still thought to be an economical form due to the low investment made. However, this system has low production rates, increases the production cycle, is unprofitable, and has management problems [1].

In contrast, intensive farming practices have increased considerably, aiming to obtain greater profitability, produce better-quality animals, produce more milk, and improve production rates [2]. With this growth, the demand for preserved feeds has also increased. According to a survey conducted by Silvestre and Millen [3], corn silage is the most commonly used roughage in Brazilian feedlots (beef and dairy livestock).

Due to its high productivity, good nutritional value, high energy content, ease of fermentation inside the silo and good acceptance of most species of ruminants, corn (*Zea mays* L.) is the most used crop for making silage in Brazil [4–6]. However, environmental conditions differ considerably between cultivation regions and directly influence the productive and qualitative behavior of this crop, resulting in changes in the yield and quality of the silage produced [7].

The production of corn silage with favorable characteristics depends on several controllable and non-controllable factors; therefore, each step of the process must be carried out precisely to produce high-quality forage [6]. For precise nutrition, diet formulation must be based on accurate and reliable data regarding the forage in question, the time of ensiling and supply to animals, and fundamental factors for improving diet formulation and animal production [8].

The southern region, for example, is characterized by a subtropical climate or Cfa (Köppen classification) [9], which has well-defined seasons and a hot and humid climate that is beneficial for the development of the corn crop [10].

Therefore, the present study aimed to evaluate the chemical composition of corn silage from different mesoregions of Southern Brazil, namely the Central South, North, West, and Southwest of Paraná, West of Santa Catarina, and Northwest of Rio Grande do Sul.

2. Materials and Methods

2.1. Collection Locations

The silages used in this study were collected from different mesoregions of Southern Brazil, divided between the states of Paraná, Santa Catarina, and Rio Grande do Sul, as shown in Figure 1.

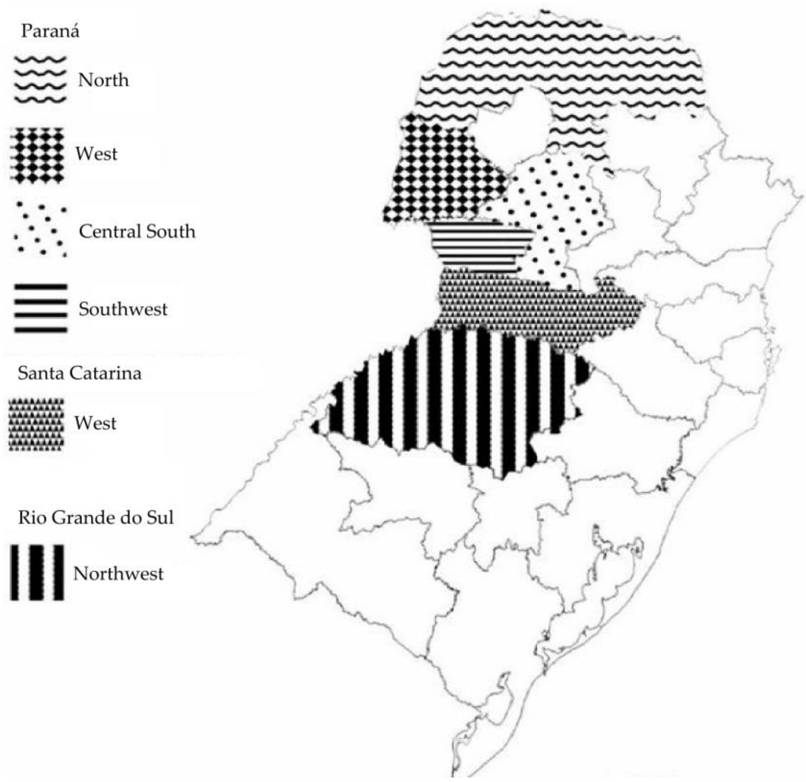

Figure 1. Mesoregions of the southern region of Brazil used for data collection.

These collection areas are of great importance in livestock farming and are characterized by the large presence of milk producers with designated areas for silage production, varying from 2 to 20 ha, and beef producers who have areas of 7 to 50 ha designated for corn silage production.

The climatic description of all the evaluated mesoregions was performed according to the Köppen classification. The climate of the North, West, and Southwest mesoregions of Paraná is of Cfa type—humid subtropical (mesothermal), with no defined dry season, hot summers, and less frequent frosts. The collection areas in these mesoregions have average altitudes of 538, 502, and 565 m, with average maximum temperatures of 27.4, 27.0, and 23.0 °C, and average minimum temperatures of 17.0, 16.9, and 12.6 °C. The annual rainfall averages vary from 1300 to 1500 mm in the North, from 1500 to 1700 mm in the West, and from 1900 to 2100 mm in the Southwest. The Central South mesoregion of Paraná has a Cfb-type Humid Temperate Climate (mesothermal) without a dry season, with a mild summer and a winter with severe and frequent frosts. The collection areas in the Central

South mesoregion have an average altitude of 971 m, with average maximum temperatures of 20.7 °C and average minimum temperatures of 12.4 °C, and the average annual rainfall varies from 1700 to 1900 mm.

The west of Santa Catarina has a Cfb humid temperate (mesothermal) climate, without a dry season and with a cool summer. The average altitude of the areas used for data collection is 630 m, the average annual maximum temperature is 23.0 °C, the average minimum temperature is 13.5 °C, and the average annual rainfall varies from 1460 to 1820 mm.

The Northwest of Rio Grande do Sul has a Cfa-type subtropical (mesothermal) climate, with hot summers, infrequent frosts, and a tendency for rain to concentrate in the summer months, but without a defined dry season. The collection areas in the Northwest of Rio Grande do Sul have an average altitude of 475 m; the average annual maximum temperature is 24.0 °C, the average minimum temperature is 13.7 °C, and the average annual rainfall varies from 1800 to 2000 mm.

2.2. Data Collection

The bromatological analysis reports on corn silages from the 2022/23 harvest were provided by the Chemical Analysis and Ruminant Nutrition Laboratory (NUPRAN) of the State University of Central West of Paraná (UNICENTRO), by the Cooperativa Agrária Agroindústria de Entre Rios (Guarapuava, Brazil) and by Soluções Nutricionais Ltd.a. (NRC; Francisco Beltrão, Brazil).

In total, 517 reports from the states of Paraná, Santa Catarina, and Rio Grande do Sul were obtained and divided into mesoregions, with 62 reports in the Central South mesoregion, 14 in the North mesoregion, 65 in the West mesoregion, 139 in the Southwest mesoregion of Paraná, 225 in the West mesoregion of Santa Catarina, and 12 in the Northwest mesoregion of Rio Grande do Sul.

Based on these reports, a descriptive statistical analysis was carried out in a box plot using the dry matter (DM) of the silages as a measure of variation, with discrepant data, i.e., "outliers", removed from the samples studied (Figure 2).

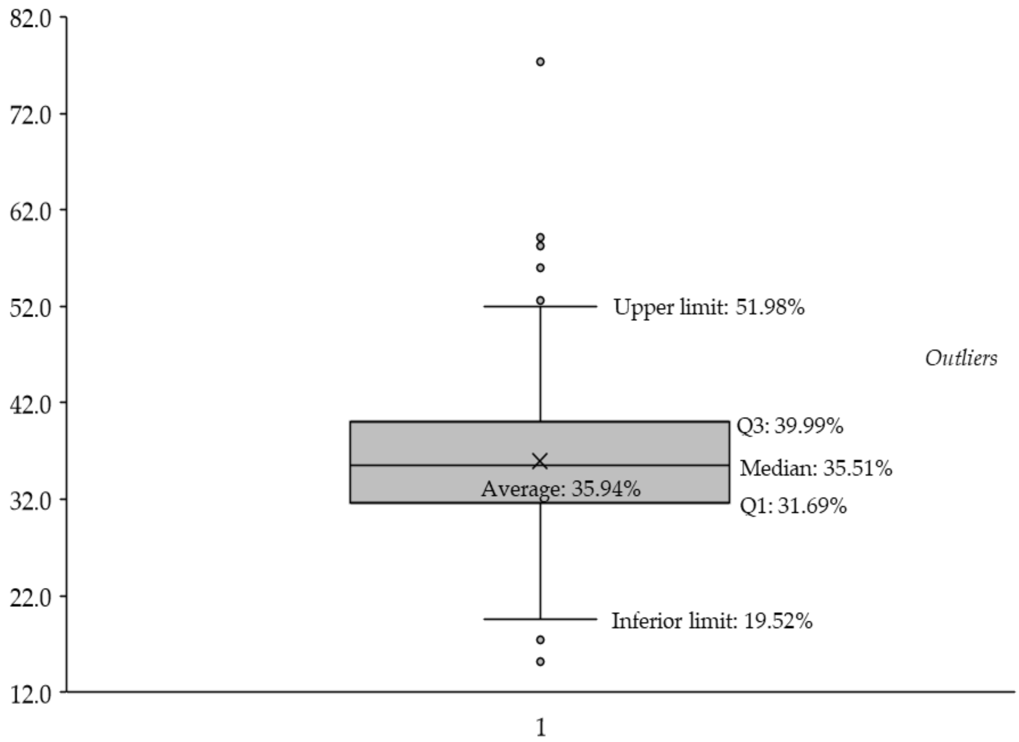

Figure 2. Box plot of the DM content of corn silage harvest 2022/23 from different mesoregions of Southern Brazil.

In total, 498 reports remained after removing the outliers. These were distributed as follows: 60 reports in the Central South mesoregion, 12 in the North mesoregion, 61 in the West mesoregion, 136 in the Southwest mesoregion of Paraná, 218 in the West mesoregion of Santa Catarina, and 11 in the Northwest mesoregion of Rio Grande do Sul.

2.3. Nutritional Value

With the aim of evaluating the nutritional value of the silages studied, and comparing their results between regions, the values of dry matter (DM), mineral matter (MM), ether extract (EE), crude protein (CP), starch, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) are available in the reports. Total digestible nutrients (TDNs) was obtained using the equation TDNs = 87.84 − (0.70 × ADF), as suggested by Bolsen et al. [11].

The carbohydrate fractionation was performed using the equation proposed by Sniffen et al. [12]. Total carbohydrates (TCs): TCs = 100 − (CP + EE + MM); Fraction B2, that is, the fraction slowly degraded in the rumen: B2 = NDF − fraction C; fraction C, which represents the indigestible fraction of the cell wall: C = (ADL × 2.4); and fraction A + B1, which corresponds to the fractions of rapid and medium rumen degradation: A + B1 = 100 − (C + B2).

2.4. Statistical Analysis

Descriptive statistics were used for all data using the SAS program [13]. The main component analyses and non-metric multidimensional scale were performed using the Vegan package from the R statistical program, version 4.3.0, which also enabled the evaluation of the correlations between the variables.

3. Results

Table 1 presents the bromatological–chemical composition of 498 corn silage samples collected from six mesoregions of Southern Brazil, represented by the variables MS, MM, EE, crude protein (CP), starch, NDF, ADF, ADL, TDNs, total CHO, and the percentage of fractions A + B1, B2, and C of carbohydrates.

Table 1. Nutritional value (overall average ± SD/min–max) of corn silages sampled in Southern Brazil (summer harvest 2022/23).

Variables	*n* Mesoregions	*n* Sample	$\overline{X}$ ± SD	min–max
DM, %	6	498	35.82 ± 5.91	19.96–51.98
MM, % DM	6	498	4.66 ± 0.91	2.20–9.98
EE, % DM	6	498	3.29 ± 0.57	1.19–5.64
CP, % DM	6	498	8.11 ± 0.98	4.31–10.84
Starch, % DM	6	498	28.52 ± 6.96	9.63–46.36
NDF, % DM	6	498	43.09 ± 5.17	29.49–61.33
ADF, % DM	6	498	25.33 ± 3.56	14.76–36.98
ADL, % DM	6	498	3.34 ± 1.47	0.60–11.43
TDNs, % DM	6	498	69.87 ± 3.33	56.01–78.00
Total CHO, % DM	6	498	83.92 ± 1.40	79.88–90.51
A+B1 (% Total CHO)	6	498	48.63 ± 6.21	27.11–65.98
B2 (% Total CHO)	6	498	41.83 ± 5.60	23.49–58.51
C (%Total CHO)	6	498	9.54 ± 4.15	1.70–32.61

DM: dry matter; MM: mineral matter; EE: ether extract; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; TDNs: total digestible nutrients; CHO: carbohydrates; A + B1: rapid degradation fraction; B2: slow degradation fraction; C: non-degraded fraction; *n*: sample number; $\overline{X}$: average; SD: standard deviation; min: minimum; max: maximum.

Greater variations were observed in DM, starch, NDF, ADF, fraction A + B1, fraction B2, and fraction C of silage carbohydrates, with variations between the minimum and maximum values of 32.02, 36.73, 31.84, 22.22, 38.87, 35.02, and 30.91%, respectively. The variations were smaller for EE, CP, MM, ADL, TDNs, and total CHO (4.45, 6.53, 7.78, 10.83, 21.99, and 10.63%, respectively).

The same assessments presented in Table 1 were also carried out separately between the mesoregions in question and are presented in Tables 2–4.

Table 2. DM, MM, EE, CP, and starch (average ± SD/min–max) of corn silages sampled in different mesoregions of Southern Brazil (2022/23 harvest).

Mesoregions	*n*	DM, % DM		MM, % DM		EE, % DM		CP, % DM		Starch, % DM	
		$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max
Central South-PR	60	36.50 ± 5.17	26.89–49.68	4.29 ± 1.17	2.35–6.72	3.41 ± 0.92	1.19–5.64	7.06 ± 0.91	5.14–8.62	30.68 ± 6.24	12.64–39.97
North-PR	12	35.83 ± 6.19	24.73–45.70	5.93 ± 1.51	4.36–9.98	2.91 ± 0.58	2.14–3.84	6.32 ± 1.31	4.55–8.35	25.02 ± 5.92	11.49–32.02
West-PR	61	36.92 ± 6.17	23.48–50.57	4.91 ± 0.52	3.64–6.75	2.90 ± 0.41	2.02–4.11	8.56 ± 0.79	6.60–10.65	25.25 ± 8.11	9.63–39.81
Southwest-PR	136	36.27 ± 5.88	22.90–51.63	4.69 ± 0.83	2.53–8.83	3.21 ± 0.49	2.25–5.05	8.33 ± 0.75	4.31–9.70	28.15 ± 6.49	12.02–46.36
West-SC	218	35.24 ± 6.01	19.96–51.98	4.59 ± 0.85	2.20–6.69	3.46 ± 0.44	2.20–4.51	8.19 ± 0.86	5.62–10.84	29.49 ± 6.73	12.28–46.15
Northwest-RS	11	32.07 ± 5.11	24.91–40.04	4.83 ± 0.28	4.36–5.28	2.90 ± 0.22	2.59–3.23	8.77 ± 0.76	7.32–9.95	24.40 ± 6.44	12.97–33.02

PR: Paraná; SC: Santa Catarina; RS: Rio Grande do Sul; %: percentage; DM: dry matter; MM: mineral matter; EE: ether extract; CP: crude protein; n: sample number; X: average; SD: standard deviation; min: minimum; max: maximum.

Table 3. NDF, ADF, ADL, and TDNs (average ± SD/min–max) of corn silages sampled in different mesoregions of Southern Brazil (2022/23 harvest).

Mesoregions	*n*	NDF, (% DM)		ADF, (% DM)		ADL, (% DM)		TDNs, (% DM)	
		$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max
Central South-PR	60	45.56 ± 5.32	35.33–57.59	25.68 ± 3.15	19.94–32.66	4.97 ± 1.21	2.03–8.82	70.07 ± 2.79	64.61–76.19
North-PR	12	49.86 ± 5.92	41.45–61.33	29.70 ± 4.38	23.68–36.59	5.53 ± 2.00	3.93–11.43	66.37 ± 4.42	56.01–72.06
West-PR	61	43.53 ± 4.34	35.39–56.97	25.75 ± 3.63	19.25–35.12	2.62 ± 1.20	1.14–6.01	69.03 ± 4.26	60.43–76.81
Southwest-PR	136	42.66 ± 4.78	31.30–58.82	25.26 ± 3.17	17.66–33.16	2.85 ± 1.19	1.31–6.53	69.95 ± 3.31	58.53–76.00
West-SC	218	42.20 ± 5.19	29.49–58.81	24.95 ± 3.72	14.76–36.98	3.34 ± 1.29	0.60–8.24	70.22 ± 2.93	61.73–78.00
Northwest-RS	11	43.01 ± 2.23	40.33–47.26	25.00 ± 2.27	21.79–28.61	1.83 ± 0.33	1.28–2.41	69.57 ± 4.16	62.15–75.21

PR: Paraná; SC: Santa Catarina; RS: Rio Grande do Sul; %: percentage; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; TDNs: total digestible nutrients; DM: dry matter; *n*: sample number; $\overline{X}$: average; SD: standard deviation; min: minimum; max: maximum.

Table 4. Carbohydrate fractionation (average ± SD/min–max) of corn silages sampled in different mesoregions of Southern Brazil (2022/23 harvest).

Mesoregions	*n*	Total CHO, % DM		A+B1 (% Total CHO)		B2 (% Total CHO)		C (% Total CHO)	
		$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max	$\overline{X} \pm$ SD	min–max
Central South-PR	60	85.09 ± 2.10	79.88–90.51	46.41 ± 6.48	33.01–58.07	39.57 ± 6.51	27.11–52.54	14.02 ± 3.30	5.68–23.83
North-PR	12	84.84 ± 1.77	80.23–86.67	41.18 ± 7.49	27.11–51.14	43.14 ± 5.04	35.34–51.38	15.68 ± 5.82	11.14–32.61
West-PR	61	83.63 ± 1.04	81.04–86.69	47.95 ± 5.21	30.81–57.73	44.55 ± 3.84	35.25–51.67	7.51 ± 3.42	3.24–17.52
Southwest-PR	136	83.76 ± 1.06	81.06–87.09	49.06 ± 5.76	31.68–62.65	42.77 ± 4.66	27.37–53.30	8.17 ± 3.39	3.79–18.80
West-SC	218	83.76 ± 1.26	79.25–87.47	49.59 ± 6.34	31.07–65.98	40.83 ± 5.94	23.49–58.51	9.58 ± 3.67	1.70–23.47
Northwest-RS	11	83.50 ± 0.93	82.41–85.45	48.50 ± 2.51	44.61–51.87	46.25 ± 1.98	43.37–49.66	5.25 ± 0.94	3.69–6.77

PR: Paraná; SC: Santa Catarina; RS: Rio Grande do Sul; %: percentage; DM: dry matter; CHO: carbohydrates; A + B1: rapid degradation fraction; B2: slow degradation fraction; C: non-degraded fraction; *n*: sample number; $\overline{X}$: average; SD: standard deviation; min: minimum; max: maximum.

The DM, MM, EE, CP, and starch contents of silages in the Northwest-RS mesoregion had smaller variations, with a difference between minimum and maximum values of 15.13, 0.92, 0.64, 2.63, and 20.05%, respectively, while the silages evaluated in the West-PR, North-PR, and Central South-PR mesoregions, respectively, showed greater variations for DM, EE, and starch contents (27.09, 2.09, and 30.18%); (20.97, 1.70, and 20.53%); and (22.79, 4.45, and 27.33%) (Table 2).

The West-SC and Southwest-PR mesoregions contained silages with similar variations in DM (32.02 and 28.73%), MM (4.49 and 6.30%), EE (2.31 and 2.80%), CP (5.22 and 5.39%), and starch (33.87 and 34.34%, respectively).

Table 3 presents the NDF, ADF, ADL, and TDN contents, and the NDF and ADL contents of silages belonging to the Northwest-RS mesoregion showed the smallest variations (6.93 and 1.13%, respectively).

The West-PR, Southwest-PR, and West-SC mesoregions produced silages with greater variation in ADF levels (15.87, 15.50, and 22.22%, respectively). Silages collected from Central South-PR, North-PR, and Northwest-RS showed smaller variations in this variable (12.72, 12.91, and 6.82%, respectively).

The TDNs of silages collected in the West- and Southwest-PR mesoregions showed greater variation (16.38 and 17.47%, respectively). The smallest variations were observed in the Central South-PR, North-PR, West-SC, and Northwest-RS mesoregions, at 11.58, 16.05, 16.27, and 13.06%, respectively.

Evaluating the fractionation of carbohydrates present in silages revealed that silages collected in the Central South-PR and West-SC mesoregions had greater variations in total CHO content (10.63 and 7.52%, respectively) (Table 4). Silages collected from the North-PR, West-PR, Southwest-PR, and Northwest-RS mesoregions showed smaller variations of 6.44, 5.65, 6.03, and 3.04%, respectively. Silages collected in Northwest-RS showed less variation for fractions A + B1, B2, and C (7.26, 6.29, and 3.08%, respectively).

Figure 3 presents the principal component analysis (PCA), which aims to reduce the amount of data used, eliminate overlaps, and promote a linear transformation in the data so that the data resulting from this transformation has its most relevant components in the first dimensions on the so-called main axes.

The first two main components, PC 1 (57.90%) and PC 2 (34.60%), explained 92.50% of the total variation in the data, which allowed for a safe interpretation of the variables and mesoregions studied. The contribution of the analyzed variables to the formation of principal components is defined by the length of the arrows and their proximity to the axis. The variables NDF and ADF had a greater influence on the formation of PC 1, whereas fractions A + B1 and CP had less influence. The formation of PC 2 had a greater influence on EE and starch and a lesser influence on the B2 fraction.

Silages collected in the North-PR mesoregion had higher concentrations of MM, ADF, and NDF, but lower concentrations of TDNs and fractions A + B1. In contrast, silages from the Central South-PR mesoregion showed higher concentrations of starch and EE and lower concentrations of the B2 fraction.

Silages collected from the West-PR and Northwest-RS mesoregions contained the highest content of fraction B2 and the lowest content of starch, EE, ADL, total CHO, and fraction C of carbohydrates. Silages from the West-SC and Southwest-PR mesoregions showed higher levels of TDNs and fraction A + B1, and lower concentrations of NDF and ADF.

Correlations between the variables were defined according to the angles formed between them. If the variables form an angle close to 0° or acute, the correlation is high and positive; if it is close to 180°, the correlation is considered high but negative; and if the angle is 90° or close, the variables have little or no correlation [14].

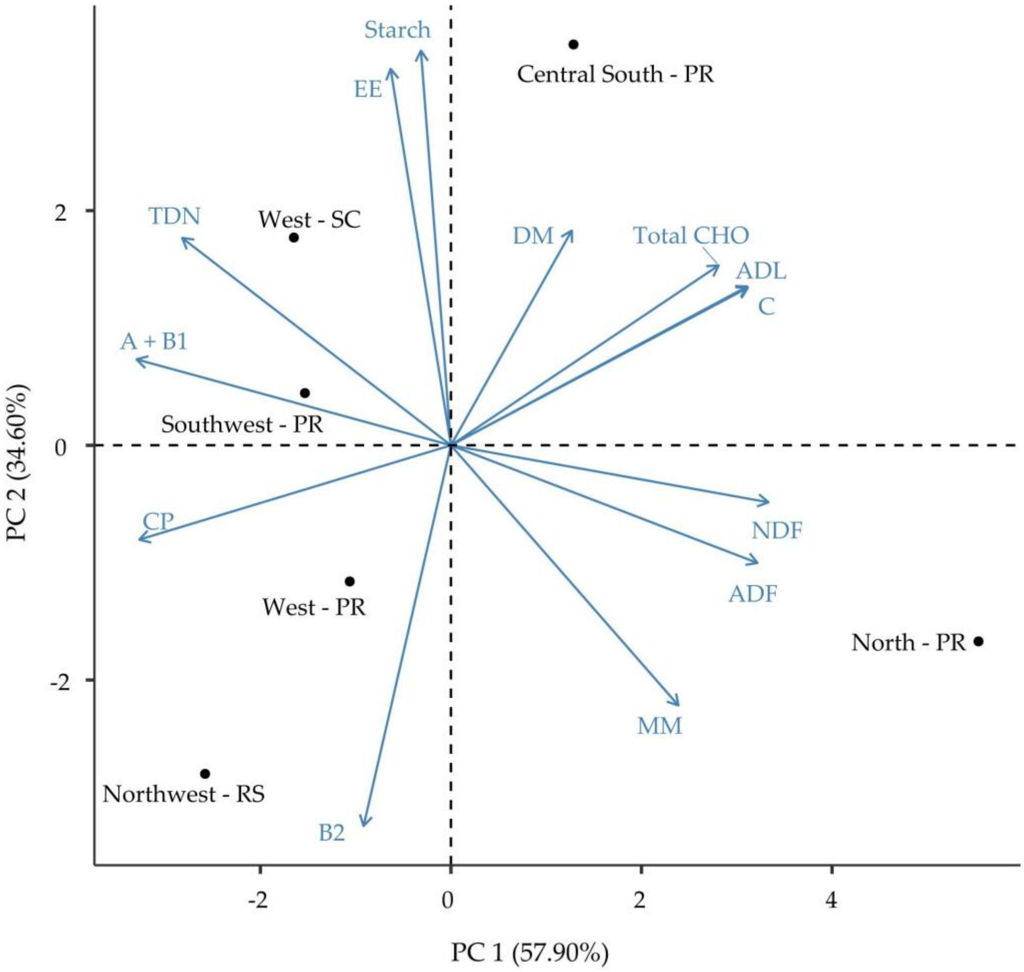

Figure 3. Analysis of main components of corn silages for the mesoregions of Southern Brazil and bromatological–chemical composition variables, referring to the 2022/23 summer harvest.

In view of this, there was a high correlation between ADL and the C fraction with total CHO, NDF, ADF, starch, and EE. High but inversely proportional correlations were observed between MM, ADF, and NDF with TDNs; between NDF and ADF with the A + B1 fraction; between the C, total CHO, and ADL fractions with CP; and between DM and the B2 fraction.

Figure 4 shows the grouping of silages, which is generated based on measures of similarities and dissimilarities; the variables within the group have great homogeneity, whereas there is great heterogeneity between the groups.

The silages from the West-SC and Southwest-PR mesoregions showed similarities, with the silages having higher levels of TDNs and fraction A + B1 and lower levels of NDF, ADF, and MM. The silages from West-PR and Northwest-RS also showed similarities, having a higher content of the B2 fraction and lower levels of starch, EE, ADL, total CHO, and fraction C. Silages from the North-PR and Central South-PR mesoregions differed from the others, establishing separate groups.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

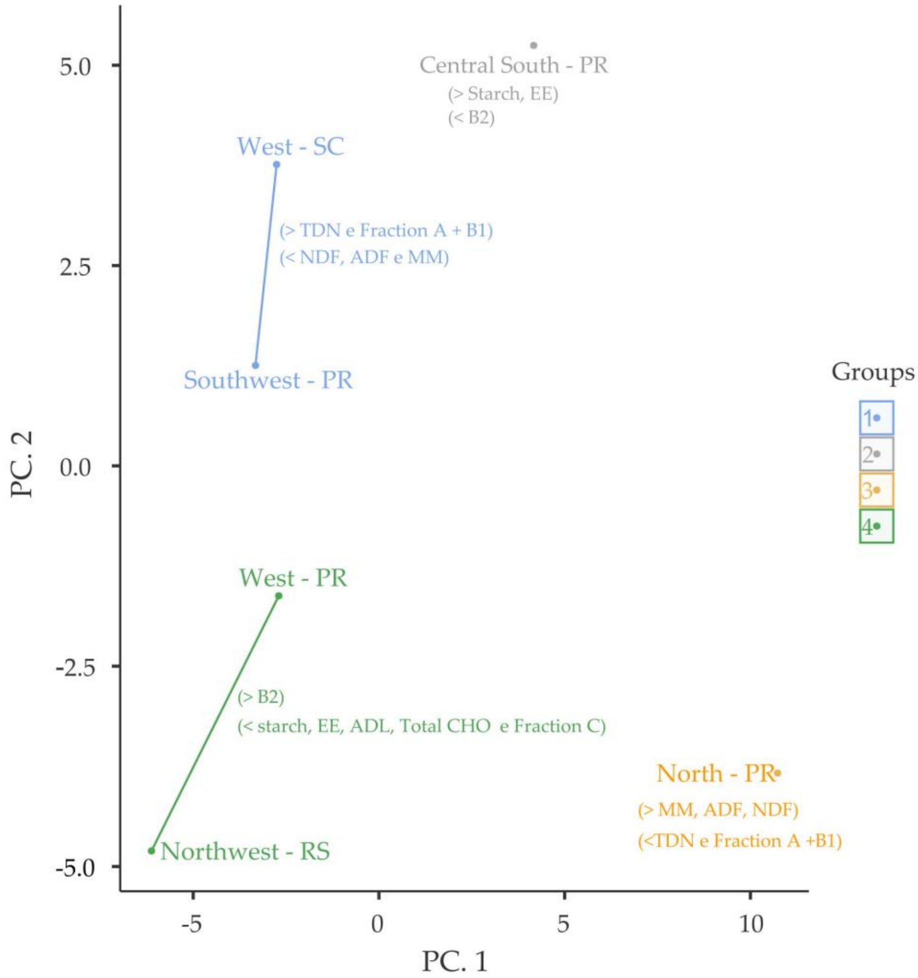

Figure 4. Non-metric multidimensional scale (NMDS) showing the grouping of different mesoregions in Southern Brazil according to the bromatological–chemical composition of corn silages from the 2022/23 harvest. Blue: Group 1; Gray: Group 2; Orange: Group 3; Green: Group 4.

4. Discussion

Generally, the DM content of the evaluated silages was within the recommended range (28–37% DM) as cited in the literature, regardless of the mesoregion (Tables 1 and 2). A variation in DM content may be due to stresses occurring during corn cultivation, such as climate variability (excess or lack of rain), occurrence of insects, especially the corn leafhopper, level of fertilization of crops, origin of samples, climatic conditions on the day of harvest, cutting point, particle processing, storage conditions, and sending the material to the laboratory [8] to which each corn silage was submitted. It is also worth noting that these conditions interfere, whether positively or negatively, in the chemical parameters of silages [15].

In addition to the points mentioned above, the plastic film used to seal the silo also influences the DM content of the silage, whether or not it is associated with the specific mass of the material. For example, films that allow for high oxygen permeability will alter the fermentation process, producing more heat and water inside the silo, in addition to increasing DM loss and damaging the bromatological quality of the silage [16].

Among the evaluated parameters, MM was the most stable. When evaluating silages from different corn hybrids, Neumann et al. [6] found no differences in the MM content. Neumann et al. [17] evaluated different corn hybrids in different cultivation locations and observed a difference in MM content between the locations, suggesting that the type and fertility of the soil in which the hybrid is cultivated may interfere with the concentration of minerals in the plant. The MM content is easily increased by contamination during production (soil), which can increase the concentration of undesirable microorganisms inside the silo, such as those of the Clostridium genus.

The EE content, and especially starch, is directly related to the maturation stage at which the plant is harvested for ensiling, and its content can be affected for this reason [15].

By evaluating the different harvest stages of the corn plant, Buso et al. [18] observed that when the plant grains were in the mealy stage (R4 stage), there was a greater participation of grains in the plant structure, which increased the starch concentration. Upon evaluating corn silage made at different maturation stages, Souza et al. [15] observed a greater share of grains in the plant structure, a higher EE content, and a lower share of fibrous compounds at the time of harvest than at the R4 stage. When the corn plant is ensiled with a DM content below 25%, for example, when it is a young plant, the NDF and starch contents are reduced because of the low deposition of starch in the grains, generating losses in consumption and animal performance [19].

The CP can also be affected by the harvest stage, but to a lesser extent. However, when it comes to preserved feeds such as silage, the fermentation process must be monitored. Silage fermentation inevitably generates proteolysis, which reduces the protein percentage in food. This action can be minimized by ensuring efficiency in the silage-making process, promoting adequate compaction in the ensiled mass, sealing the silo in the shortest possible time with quality plastic film, and avoiding cross-contamination. Even with these possible causes of change in CP, it is important to point out that the values of this nutrient obtained in the present study are within the values reported by Faria et al. [8] and are very close to those of corn silage with good nutritional quality.

The nutritional index of a food product can be measured using its TDN value. When corn silage has low TDN levels, it may have come from an older ensiled plant or one that has undergone environmental stress (water or pest attack) during its cycle, which can lead to less grain filling, reduced starch content, greater stalk participation in older plants, and a greater percentage of leaves in the senescent stage [20].

In addition to the parameters discussed above, the carbohydrates (concentration and absorption) present in corn silage play a fundamental role in animal production, as they directly affect the performance of animals, whether intended for milk or meat production. The ingestion and degradation of silage, in addition to sanitary aspects, are influenced by the concentration of carbohydrates (NDF, ADF, and ADL)—which can be increased by a thickening of the stems and a lignification of the leaves (older plants)—intrinsic characteristics of the plant itself, and the health status of the plant [21].

When silage carbohydrates are divided into A + B1, B2, and C, this indicates the stage the plant was at the time of harvest or whether it may have gone through some stress in addition to indicating nutritional quality. A higher content of fraction A + B1 represents a higher concentration of easily degraded fractions, which is found in younger and healthier plants. In contrast, silages with a higher proportion of fraction C represent silages from more mature plants; that is, they have a higher concentration of lignin [22,23].

In a compilation of 323 corn silage samples evaluated from 2004 to 2015, Faria et al. [8] found average levels of 53.30, 32.02, and 4.25% of NDF, ADF, and ADL, respectively, which were higher than those found in the present study. These inferences indicate that the carbohydrate content obtained in the present study was within acceptable standards without causing losses to animal production.

By evaluating the behavior of the bromatological components of silages within the mesoregions (Figure 3), it was possible to obtain a more accurate understanding of the harvest stage and the occurrence of possible stress arising from the environment.

In the northern mesoregion of Paraná, silages had the highest levels of NDF and ADF but lower levels of TDNs and fraction A + B1, a behavior which may be suggestive of silages made with plants at a more advanced stage, or a reflection of climatic particularities such as greater irregularity in higher rainfall and nighttime temperatures, than the other regions studied, which may have resulted in a higher prevalence of foliar diseases. Plants at a more advanced stage of maturity tend to generate silage with an average NDF content of 45.6% or higher [9]. Foliar diseases result in an increase in these carbohydrates because of the plant's defense mechanism, which increases the production of lignin to prevent the entry of pathogens into the cells, consequently increasing the NDF and ADF contents of the silage [24]. However, fungicides control the incidence of foliar diseases in corn plants and reduce NDF and ADF levels [25]. When there is an increase in fibrous components owing to dilution, it is expected that there will be a decrease in the TDNs and A + B1 fractions.

The opposite was observed in silages made in the Southwest-PR, West-SC, Central South-PR, West-PR, and Northwest-RS mesoregions (Figure 3), which had higher levels of TDNs, fraction A + B1, starch, EE, and fraction B2. These results tend to occur in silages made with plants at younger stages, or very close to the optimum harvest point, and/or are associated with conditions of less irregular precipitation, lower night temperatures than other regions studied, and an even lower prevalence of foliar diseases.

Using silages from the Southwest-PR, West-SC, and Central South-PR mesoregions might result in greater animal performance or, in some way, reduce costs with the inclusion of a concentrate such as TDNs, starch, EE, and fraction A + B1 in the diet. In addition to being highly digested in the rumen, the energy density of these roughages is high as they are compounds made up mainly of non-fibrous carbohydrates [15,26]. The silages from West-PR and Northwest-RS probably had a lower energy input, as they had a greater share of the B2 fraction. The ruminal fermentation of this fraction is extremely dependent on the food passage rate owing to its slow degradation, and this characteristic is related to the levels of cellulose and hemicellulose, which are potentially digestible carbohydrates [12,27].

The positive correlations observed in the present study occurred because these variables were formed by shared compounds. The NDF and ADF contents of the silage are linked to the cellulose, hemicellulose, and lignin concentrations of the plant, which are closely related to the size of the plant, percentage of stem in the plant structure, number of senescent leaves, percentage of bracts plus cob, and phytosanitary status of the plant [25,28].

The total CHO content depends on the concentration of fractions A + B1, B2, and C of carbohydrates, indicating that a higher concentration of total CHO does not always indicate good-quality silage. When the content of fraction A + B1 is higher, it is suggested that it is a silage with greater energy input, which has a fibrous fraction with good digestibility, and with lower proportions of straw and cob, which are portions of the plant that have low degradation, resulting in better-quality silage that will certainly be more useful to animals.

Starch and EE contents are linked to the maturity stage at which the plant is harvested, and both are related to the energy input of the silage; therefore, their relationships are directly proportional [15].

The negative correlations obtained were due to the dilution of the compounds. According to Gralak et al. [29], an increase in the proportion of ADF, which comprises ADL and other fibrous plant compounds, reduces the fractions that represent non-fibrous carbohydrates, negatively interfering with silage quality. The increase in NDF content is related to the simultaneous increase in MM and ADF content, which reduces the TDN content of the silage [24].

The similarity or dissimilarity between the chemical and bromatological compositions of the evaluated silages that originated in the groups (Figure 4) may involve several factors. Evaluating the effects of climatic variables on corn cultivation, Nied et al. [30] presented the results of several studies, demonstrating that precipitation is the main climatic variable that interferes with corn cultivation in Southern Brazil.

In the present study, precipitation and other climatic conditions were not correlated with the bromatological quality of the silages. However, these conditions were possibly similar in the regions where the silages belonged to the same group, and different (both positively and negatively) in the regions where the silages belonged to different groups (Figure 4) in this harvest. Perhaps this is not the reality in all harvests, but these results showed that it is necessary to go beyond the trivial when evaluating the bromatological quality of silages and pay attention to other variables; this applies to all regions of Brazil.

These studies to monitor the nutritional value of corn silages produced at each harvest must be routine in such a way that, over time, it is possible to identify the factors that generate the variations found between the different regions studied, thus aiming to promote technical correction recommendations in the corn ensiling process.

5. Conclusions

In the Southwest-PR and West-SC, the silages presented better nutritional value and a higher proportion of rapidly degrading carbohydrates; in the Central South-PR, the silages presented higher energy content; in the West-PR, Northwest-RS, and North-PR, the silages had a higher content of low-digestible fibers and worse nutritional value.

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