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Nutritional characterization and ruminal degradability of corn silage stored in different silo types

Caracterização bromatológica e degradabilidade ruminal da silagem de milho armazenada em diferentes tipos de silo

Mikael Neumann[1]; Valéria Kalinovski[2]; Ellen Baldissera[2]; Dayana Rochinski da Silveira Pinto[3]; Leonardo Huçalo[3]; Paulo Victor Pinheiro Cesar[4]; Luísa da Costa Venancio[4]; Arno Passarin Filho[5]; Caroline Bordignon da Rosa[5]; Daniel Corrêa Plodoviski[5]*

Highlights

Corn silage in bag silos preserved nutrients better than in trench silos.
Storage in silo bags reduced physical losses of corn silage.
Silo bags increased the ruminal degradability of silage dry matter.

Abstract

This study assessed the nutritional composition, ruminal degradability, physical losses, and fermentation profile of corn silage stored in either trench silos or silo bags. A randomized block design was applied, with two treatments and four replicates, each replicate consisting of one silo. Compared with trench silos, storage in silo bags was more effective at maintaining levels of non-fibrous carbohydrates (NFC) (388.2 vs. 417.7 g kg^{-1} DM), net energy of lactation (NEL) (1.560 vs. 1.591 Mcal kg^{-1} DM), total digestible nutrients (TDN) (685.9 vs. 698.4 g kg^{-1} DM), and relative feed value (RFV) (133 vs. 144). Conversely, corn silage stored in trench silos showed higher values for ash (27.3 vs. 29.8 g kg^{-1} DM), acid detergent insoluble protein (ADIP) (99.49 vs. 110.43 g kg^{-1} CP), neutral detergent fiber (NDF) (451.0 vs. 482.5 g kg^{-1} DM), hemicellulose (193.8 vs. 207.4 g kg^{-1} DM), and acid detergent fiber (ADF) (257.2 vs. 275.0 g kg^{-1} DM).

[1] Agronomist, Ph.D., Researcher at NUPRAN, Animal Production Research Center, CNPq Productivity Research Fellow, and Professor in the Graduate Programs of Agronomy, Crop Production, and Veterinary Sciences, Sustainable Animal Production and Health, Universidade Estadual do Centro-Oeste, UNICENTRO, Guarapuava, PR, Brazil. E-mail: neumann.mikael@hotmail.com

[2] Veterinarian, Master's Student of the Graduate Program in Agronomy, Crop Production, UNICENTRO, Guarapuava, PR, Brazil. E-mail: kalinovskivaleria@gmail.com; ellen_baldissera@outlook.com

[3] Veterinarian, UNICENTRO, Guarapuava, PR, Brazil. E-mail: dayarochinski@gmail.com; leohucalo12@gmail.com

[4] Veterinarian, Master of Science in Veterinary Sciences, with emphasis on Sustainable Animal Production and Health; UNICENTRO, Guarapuava, PR, Brazil. E-mail: paulo_victor147@hotmail.com; luisacosta23@outlook.com

[5] Veterinarian, Master of Science in Agronomy, with emphasis on Crop Production, UNICENTRO, Guarapuava, PR, Brazil. E-mail: arnopassarin@gmail.com; caroldarosa99@hotmail.com; danielplodoviski@gmail.com

* Author for correspondence

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Storage in silo bags also reduced dry matter losses throughout the feeding period compared to trench silos (8.20 vs. 6.10 % in the first period, 9.40 vs. 2.50 % in the second, and 9.70 vs. 2.60 % in the third).
Key words: Dry matter losses. Silage fermentation profile. Ruminal microbiota.

Resumo

O presente estudo avaliou a composição bromatológica, degradabilidade ruminal, perdas físicas e o perfil fermentativo de silagens armazenadas em silo tipo trincheira ou tipo bag. Para tanto, o delineamento experimental utilizado foi de blocos casualizados, composto por dois tratamentos, com quatro repetições cada, onde cada repetição constou de um silo. Quando comparado ao silo trincheira, o armazenamento da silagem de milho em silo bag manteve de modo mais eficiente os valores de carboidratos não fibrosos (388,2 e 417,7 g kg^{-1} da MS respectivamente), energia líquida de lactação (1,560 e 1,591 Mcal kg^{-1} da MS respectivamente), nutrientes digestíveis totais (685,9 e 698,4 g kg^{-1} da MS respectivamente) e valor relativo do alimento (133 e 144 respectivamente). Em relação ao silo bag, o silo trincheira apresentou maiores valores de matéria mineral (27,3 contra 29,8 g kg^{-1} da MS), proteína insolúvel em detergente ácido (99,49 contra 110,43 g kg^{-1} da PB), fibra em detergente neutro (451,0 contra 482,5 g kg^{-1} da MS), hemicelulose (193,8 contra 207,4 g kg^{-1} da MS) e fibra em detergente ácido (257,2 contra 275,0 g kg^{-1} da MS). No silo bag houve redução de perdas físicas de MS durante todo o período de utilização da silagem comparado ao silo trincheira (8,20 contra 6,10 % da MS no primeiro período, 9,40 contra 2,50 % da MS no segundo período e 9,70 contra 2,60 % da MS no terceiro período).
Palavras-chave: Perdas de matéria seca. Perfil fermentativo da silagem. Microbiota ruminal.

Introduction

Forage conservation systems should be evaluated based not only on the quality of the resulting product, but also on the extent of material losses from harvest until the silage is removed from the silo for animal consumption. While some decline in quality is inevitable, proper management practices can reduce aerobic respiration of the ensiled mass, promote adequate fermentation, minimize effluent production, and limit aerobic exposure during both ensiling and the feeding period. These measures help reduce nutrient losses and preserve the chemical composition and digestibility of silage (Borreani et al., 2018; Neumann et al., 2021a).

The type of storage silo and sealing method used for corn silage directly influence the nutritional quality and digestibility of the stored material. An effective silo must maintain an anaerobic environment to support the proliferation of lactic acid bacteria, which convert soluble sugars into organic acids, rapidly lowering pH and minimizing nutrient losses while preserving the silage over time (Neumann et al., 2021a; Santos et al., 2023).

Forage can be ensiled in a variety of storage structures, including surface silos, trench silos, silo bags, and plastic-wrapped bales (Santos et al., 2023). In trench silos, aerobic exposure of the ensiled mass allows continued respiration and enzymatic activity. These enzymes degrade soluble carbohydrates and convert part of the soluble protein into non-protein nitrogen, increasing crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin concentrations (Melo et al., 2023). The main advantages of trench silos are their low construction cost and the ease of filling, construction, and loading operations, as well as the possibility of adjusting their capacity according to herd size and forage requirements (Mousquer et al., 2015).

By contrast, silo bags create a hermetically sealed environment, relying on the permeability of the plastic film for effective preservation (Bartosik et al., 2023). High carbon dioxide and low carbon concentrations develop inside the bag through microbial activity, which is destabilized if the bag is punctured (Taher et al., 2019). These silos typically feature a multilayer polyethylene barrier, including a UV protective layer, preventing gas exchange with the external environment and maintaining anaerobic conditions throughout ensiling (Bartosik et al., 2024). Silo bags can be placed anywhere on a farm without the need for permanent structures such as trench silos, although they require specialized equipment for filling (Bartosik et al., 2023; Mousquer et al., 2015).

Many studies use experimental silos that provide basic anaerobic conditions but often produce different results from those obtained under real field conditions (Santos et al., 2023). Studies reflecting practical farm conditions are therefore essential, particularly comparing silo bags and trench silos. The objective of the present study was to evaluate the nutritional composition and ruminal dry matter disappearance of corn silage stored in these two silo types.

Material and Methods

Description of the experimental area

The experiment was conducted at the Laboratory of Feed Analysis and Ruminant Nutrition and at the Teaching, Research and Extension Unit for Feedlot Beef Cattle of the Animal Production Center (NUPRAN), affiliated with the Master's Program in Veterinary Sciences of the Agricultural and Environmental Sciences Department, State University of the Center-West (CEDETEG/UNICENTRO), in Guarapuava, Paraná state (PR), Brazil (25º23′02″S, 51º29′43″W; 1,100 m.a.s.l.).

The climate in the Guarapuava region is classified as humid subtropical mesothermal according to the Köppen classification, with no dry season, cool summers, mild winters, and average annual rainfall of 1,944 m. The mean annual minimum and maximum temperatures are 12.7 and 23.5 °C, with average relative humidity of 77.9%.

The soil in the experimental area is classified as Typic Hapludox (*Latossolo Bruno Típico*). The area used for corn cultivation has been managed in recent years with annual winter pastures and summer corn crops. The soil was fertilized with phosphorus and potassium before each growing season according to the Fertilization and Liming Requirements for Paraná State (Pavinato et al., 2017).

Crop establishment and harvest

Before planting the corn crop, weeds and insects were chemically controlled using glyphosate-based herbicide (Roundup

Original DI®, 3.4 L ha^{-1}) combined with mineral oil (Assist®, 1.0 L ha^{-1}) and an insecticide containing thioacetimidate (216 g L^{-1}) and methanol (383.5 g L^{-1}) (Bazuka® 216 SL: 0.595 L ha^{-1}). Post-emergence control involved the herbicides Atrazine (Atrazina Nortox 500 SC®: 5 L ha^{-1}) and Tembotrione (Soberan®, 0.24 L ha^{-1}), and the insecticides Beta-cyfluthrin + Pyrethroid (Turbo®: 0.1 L ha^{-1}), Thioacetimidate + Methanol (Bazuka® 216 SL: 0.595 L ha^{-1}), and Spinetoram + Propylene glycol (Exalt®: 0.1 L ha^{-1}).

The crop was established in the second half of October using the P2501 hybrid (Pioneer®), a simple non-transgenic hybrid suitable for grain and silage production. Sowing was carried out under no-till conditions, with 0.45 m row spacing and a seeding depth of 0.04 m, targeting a final stand of 85,000 plants ha^{-1}. Base fertilization consisted of 530 kg ha^{-1} of 8-30-20 (N-P-K), and 420 kg ha^{-1} of urea (46-00-00) was applied as topdressing.

Corn plants were harvested for silage at the R4 (dough) stage, 122 days after emergence (DAE), using a JF® precision forage harvester (C-120 AT S2), adjusted to produce particles between 8 and 12 mm.

Before ensiling, the whole plant (original material) was sampled homogeneously and representatively to determine plant height, first ear insertion height (m), and number of dry leaves per plant. Plants were then fractioned into structural components: stalk, leaves, husks, cobs, and grains. Samples of whole and de-grained plants and individual components were weighed and pre-dried in a forced-air oven at 55ºC for 72 hours, then reweighed to determine dry matter (DM) content. The dried samples were then ground in a Wiley mill using a 1-mm screen. This procedure enabled estimation of ensiled DM yield (kg ha^{-1}), and assessment of the physical structure and DM content of the plant and its components, providing agronomic characterization of the crop.

Ensiling process

The harvested material was stored in eight silos: four trench silos (15 m length × 1.2 m width × 1.2 m height) and four silo bags (15 m length × 1.2 m diameter). The experiment followed a randomized block design with two treatments and four replicates, each replicate corresponding to one silo.

In the trench silos, compaction was performed mechanically using a tractor and the silage was sealed with 200 μm double-sided polyethylene film (Carga Pesada®), while in the silo bags ensiling was carried out using a Silomaster bagger and conveyor (JF Máquinas Agrícolas®) and sealing with 220 μm double-sided polyethylene film (Extraplast®). The conditions during ensiling made it possible to achieve a specific mass ranging from 200 to 250 kg de MS m^{3-1}.

Sampling and evaluations

All silos were opened simultaneously, 150 days after ensiling. During the feeding period, a 15 cm slice of silage was removed daily over 100 consecutive days to feed feedlot beef cattle. The timing of silo opening was determined by the availability and scheduling of research facilities rather than as an experimental variable.

Physical DM losses were measured daily throughout the 100-day period by weighing visibly deteriorated silage removed during feeding. These values were corrected for dry matter content.

Twice a week during the feeding period, representative samples were collected from the silo face, weighed, and pre-dried in a forced-air oven at 55º C for 72 hours to determine partial DM content. The samples were ground using a Wiley mill with a 1 mm screen, homogenized on a dry matter basis, and then combined proportionally for chemical composition analysis.

The following proximate composition analyses were performed: total dry matter (DM) at 105 ºC for 4 hours (AOAC 934.01) (Association of Official Analytical Chemists [AOAC], 1995), crude protein (CP) using the micro-Kjedahl method (D. J. Silva & Queiroz, 2009), ether extract (EE) (AOAC 920.39) (AOAC, 1995), and mineral matter (MM) (AOAC 942.05) (AOAC, 1995) by incineration at 550 °C for 4 hours. Neutral detergent fiber (NDF) (FDN) (Van Soest et al., 1991), acid detergent fiber (ADF) and lignin (LIG) (Goering & Van Soest, 1970) were determined using thermostable α-amylase (Termamyl 120L, Novozymes Latin América Ltda.). Non-fibrous carbohydrates (NFC) were calculated by difference [NFC =100 - (CP + EE + MM + NDF)]. Hemicellulose and cellulose contents were also estimated by difference between NDF – ADF and ADF – LIG, respectively (D. J. Silva & Queiroz, 2009).

Neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) were determined according to Van Soest et al. (1991).

Total digestible nutrients (TDN, %) were estimated using the equation: TDN (%) = 87.84 – (0.70 x ADF). The relative feed value (RFV) was calculated as: RVF = [(%TDN x DMI) ÷ 1.29] x 100 (Bolsen et al., 1996), where DMI represents dry matter intake as a percentage of body weight. The net energy of lactation (NEL) was estimated using the equation: NEL = (0.0245 x TDN) – 0.12 (Moe & Tyrrell, 1976). Dry matter intake as a percentage of body weight (DMI%) was estimated by: DMI% = 120 ÷ NDF.

The concentrations of acetic acid, propionic acid, and ethanol in the silage samples from both silo types were determined according to the method described by Erwin et al. (1961). Analyses were performed by gas chromatography using a Shimadzu© GC-2010 Plus chromatograph equipped with an AOC-20i automatic injector, a Stabilwax-DA™ capillary column (30 m × 0.25 mm ID × 0.25μm df; Restek©), and a flame ionization detector (FID). Samples were acidified with 1 M phosphoric acid (Ref. 100573, Merck©) and fortified with the WSFA-2 standard (Ref. 47056, Supelco©). For analysis, 15 g of each silage sample were blended with 200 mL of distilled water for one minute, strained, and centrifuged. A 1 μL aliquot of the supernatant was injected with a split ratio of 40:1, using helium as the carrier gas at a linear velocity of 42 $cm.s^{-1}$. The chromatographic run time was 11.5 minutes. The injector and detector temperatures were 250 ºC and 300ºC, respectively. The oven temperature program began at 40 ºC, increased to 120 ºC at 40 ºC min^{-1}, then from 120 ºC to 180ºC at 10 ºC min^{-1}, and finally 180 ºC to 240 ºC at 120ºC min^{-1}, holding at 240 ºC for 3 minutes. Quantification was performed using calibration curves prepared from dilutions of the WSFA-2 standard (Ref. 47056, Supelco©), glacial acetic acid (Ref. 33209, Sigma-Aldrich©), and HPLC-grade ethanol (Ref. 459828, Sigma-Aldrich©) under the same analytical conditions. Peak detection and integration were carried out using GCsolution v. 2.42.00 software (Shimadzu©).

The in situ ruminal degradability of the silages from the two silo types was determined according to Nocek (1988). Two cannulated Jersey steers (average body weight of 750 kg) from the Beef Cattle Teaching Unit of the State University of the Central-West (UNICENTRO) were used, following approval by the Animal Ethics Committee (CEUA/UNICENTRO) under protocol no. 019/2023. The animals were adapted to a diet containing 50% corn silage and 50% concentrate, housed in pens with access to a socialization paddock, and fed twice daily with free access to water via automatic troughs.

For ruminal incubation, 5 g of each previously composite, pre-dried, and ground sample were placed in nylon bags (10 cm x 12 cm, 50 μm pore size) of known weight, in line with Nocek's (1988) recommendations. The bags were sealed and attached to a nylon string with a 100 g lead weight at one end.

Bags were inserted into the rumen of both animals simultaneously in reverse order of incubation time. The first bags incubated were those for 168 hours, followed by 120, 96, 84, 72, 60, 48, 36, 24, 12, 6 and 0 hours. Samples corresponding to time 0 were incubated for 5 minutes before all bags were removed. Immediately after removal, the bags were immersed in ice cold water for 20 minutes to halt microbial activity, then washed, dried in a forced-air oven at 55 °C for 72 hours, and weighed to determine in situ ruminal degradability. Each treatment was evaluated at eight incubation times, with four replicates analyzed in duplicate.

The ruminal dry matter disappearance rate was calculated as the difference between the pre- and post-incubation weights across time points. The kinetic parameters of DM degradation were estimated following Orskov and McDonald (1979) using the model: $DP = a + b\,(1-e^{-ct})$, where DP is the potential ruminal disappearance rate, a the soluble fraction (SF) (0 h incubation), b the potentially degradable fraction (PDF) (96 h incubation minus a), and c the undegradable fraction (UDF) (100 – degraded value at 96 h) (Goes et al., 2010).

Additionally, the in situ ruminal degradability of NDF was determined at 120, 168, and 240 hours. NDF degradability was calculated as the difference between NDF concentration before and after incubation, following Goeser and Combs (2009).

Statistical analysis

All data were subjected to analysis of variance (ANOVA), and treatment means were compared with the F-test at a 5% significance level, using the SAS statistical package (Statistical Analysis System Institute [SAS Institute], 1993). Data on the dry matter disappearance rate were evaluated by regression analysis using the Proc Reg procedure in SAS (SAS Institute, 1993).

Results and Discussion

At the time of ensiling, the corn plants exhibited the following agronomic traits: average plant height of 2.34 m, ear height of 1.20 m, and a high stay-green score, with an average of 2.1 dry leaves per plant. The ensiled DM yield reached 30,624 kg ha^{-1}, with a structural composition (on a DM basis) of 19.70% stalk, 20.40% leaves, 14.80% husks plus cobs, and 45.10% grains. Average DM contents for the whole plant, stalk, leaves, husks, cobs, and grains were 22.40, 27.58, 25.00, 36.65, and 62.00%, respectively.

As shown in Table 1, the mean DM, CP, EE, cellulose, and ADL contents in the resulting silages did not differ significantly (P>0.05) between storage types.

Table 1
Effect of trench silo and silo bag storage systems on the chemical composition of corn silage

Parameter	Silo type		Mean	*P*	SEM
	Trench	Bag			
DM, g kg^{-1}	290.3	289.6	289.9	0.8905	3.46
MM, g kg^{-1} DM	29.8	27.3	28.5	0.0053	0.45
CP, g kg^{-1} DM	74.8	76.0	75.4	0.6906	2.11
NDIP, g kg^{-1} CP	168.7	169.9	169.4	0.6104	5.95
ADIP, g kg^{-1} CP	110.4	99.5	104.9	0.0201	3.87
EE, g kg^{-1} DM	24.7	28.0	26.4	0.9006	3.66
NFC, g kg^{-1} DM	388.2	417.7	403.0	0.0156	4.72
NDF, g kg^{-1} DM	482.5	451.0	466.7	0.0053	6.88
HEM, g kg^{-1} DM	207.4	193.8	200.6	0.0090	4.09
ADF, g kg^{-1} DM	275.0	257.2	266.1	0.0245	4.42
CEL, g kg^{-1} DM	236.0	222.6	229.3	0.1209	5.35
LIG, g kg^{-1} DM	39.1	34.6	36.08	0.1025	1.65
NEL, Mcal kg^{-1} DM	1.560	1.591	1.576	0.0243	0.008
TDN, g kg^{-1} DM	685.9	698.4	692.1	0.0244	3.08
RVF	133.0	144.0	138.0	0.0065	2.46

P: probability value; SEM: standard error of the mean; DM: dry matter; MM: mineral matter; CP: crude protein; NDIP: neutral detergent insoluble protein; ADIP: acid detergent insoluble protein; EE: ether extract; NFC: non-fibrous carbohydrates; NDF: neutral detergent fiber; HEM: hemicellulose; ADF: acid detergent fiber; CEL: cellulose; LIG: lignin; NEL: net energy for lactation; TDN: total digestible nutrients; and RFV: relative feed value. Means followed by different lowercase letters in the row differ significantly according to the F-test (P< 0.05).

However, silages stored in trench silos displayed higher ash (mineral matter), NDF, ADF, and hemicellulose values ($P<0.05$), whereas those stored in silo bags showed higher values ($P<0.05$) for NFC, RFV, NEL, and TDN.

The lower ash content in silo bags compared with trench silos (27.3 vs. 29.8 g kg-1 DM, respectively) may be due to a more efficient fermentation process, which reduced organic matter losses (Negrão et al., 2016). These findings are consistent with those of Schmidt et al. (2015), who attributed these differences to DM losses during fermentation, which concentrated the remaining mineral matter.

The greater aerobic exposure observed during the filling of trench silos, compared with silo bags, likely increased the availability of oxygen to aerobic microorganisms before sealing. Once anaerobiosis was established, this favored the proliferation of heterofermentative bacteria, which are less efficient at conserving DM and energy than homofermentative bacteria (Borreani at al., 2018). Losses in ensiled feed are directly related to the fermentation process, whose efficiency depends on the speed of pH decline under anaerobic conditions. If oxygen and aerobic microorganisms remain present, the nutritional value of the silage decreases due to the depletion of DM and energy (Macêdo & Santos, 2019). These losses tend to be smaller in silo bags, where filling and sealing occur simultaneously, while trench silos require longer filling times, exposing the material to aerobic conditions until sealing is complete.

No significant difference in NDIP was observed between silages from trench silos and silo bags, with average values of 168.76 and 169.96 g kg^{-1} CP, respectively. However, ADIP was higher ($P < 0.05$) in silages from trench silos (110.43 g kg^{-1} CP) when compared with silo bags (99.49 g kg^{-1} CP).

This difference can be explained by the higher ADF content in trench silos, since ADIP represents the protein fraction bound to ADF, which is poorly degradable and partially unavailable due to its association with lignin (Bonfá et al., 2015).

Higher NDIP and ADIP contents reduce protein degradation because of the complexation between proteins and structural carbohydrates, thereby reducing nitrogen availability for rumen microbial protein synthesis and limiting the use of other nutrients (Bonfá et al., 2015).

The low NFC content in trench silo silages (383.2 vs. 417.7 g kg^{-1} DM, respectively) suggests a more favorable environment for the proliferation of microorganisms that consume soluble carbohydrates during fermentation (Gandra et al., 2022; Pereira et al., 2021). Soluble carbohydrates serve as substrates for lactic acid bacteria, but yeasts that grow in the presence of oxygen may consume the lactic acid produced, reducing the nutritional value of the silage and destabilizing the anaerobic environment within the silo (M. R. Silva et al., 2018). Thus, the lower NFC concentration reflects the consumption of soluble carbohydrates by lactic acid bacteria, whose fermentation products were subsequently depleted by yeasts, leading to further silage degradation.

High-quality silage typically contains lower levels of NDF and ADF, since these parameters indicate the extent of plant tissue degradation (K. F. Garcez et al., 2023). Consequently, this silage exhibits greater digestibility and contributes to better feeding efficiency, enabling greater inclusion of forages in ruminant diets (Gralak et al., 2014). According to Neumann et al. (2024), corn silage produced in the Central-Southern region of Paraná state generally contains 45.56% (±5.32) NDF and 25.68% (±3.15) ADF. The results obtained in this study fall within these ranges, confirming the nutritional adequacy of the silage for ruminant feeding.

The NDF fraction is associated with structural carbohydrates (cellulose, hemicellulose, and pectin), whereas the ADF fraction comprises cellulose, lignin, silica, and protein present in the sample (M. R. Silva et al., 2018). The ADF fraction represents the portion of the cell wall that is least digestible by rumen microorganisms and is a major limiting factor in ruminant performance in tropical regions (Gralak et al., 2014).

The decline in NDF and ADF contents in the silo bags may result from the hydrolysis of the digestible fraction, meaning that a larger proportion of fibrous carbohydrates was hydrolyzed by the organic acids produced during ensiling (Larsen et al., 2017). The cellulosic biomass of plants is composed of cellulose polymers linked by hydrogen bonds, embedded within hemicellulose and lignin. Cellulose and hemicellulose molecules are subject to hydrolysis and fermentation, generating by-products that can sometimes inhibit microbial fermentation (Ramos et al., 2022).

The intermolecular bonds of hemicellulose are broken through hydrolysis by xylanase and mannanase enzymes, which act via acetic acid. These enzymes, known as hemicellulases, are produced by bacteria that efficiently degrade plant material (Ramos et al., 2022).

RFV reflects the higher feed intake potential of the diet, since it indicates a greater proportion of grain in the total forage biomass. This dilutes the fibrous fraction and directly influences intake capacity and ruminal degradability (Marafon et al., 2015). However, based on the data in Table 1, there was no significant difference in degradability among treatments in the present study.

The TDN value tends to decrease as ADF concentration increases, since a larger proportion of cell wall components reduces the contribution of digestible carbohydrates (Paris et al., 2015). Energy loss from silage can be quantified by the disappearance of its nutritional components, which is directly proportional to the loss of organic matter (Marafon et al., 2015), as observed in this study.

With respect to the ruminal degradability of dry matter at incubation times of 24, 48, 96, and 168 hours (Table 2), there were no significant differences ($P>0.05$) between silo types, with mean values of 51.70, 63.62, 69.03, and 75.18%, respectively. Ruminal degradability is generally inversely proportional to the ADF content of silage (Gralak et al., 2014; Neumann et al., 2021b), meaning that higher ADF levels tend to reduce degradability. However, this relationship was not confirmed in the present study because although ADF values were higher in the trench silos, ruminal degradability did not differ from that observed in the silo bags.

Nonetheless, the higher NFC concentrations recorded in the silo bags may have influenced ruminal degradation kinetics, resulting in the lack of statistical differences in dry matter degradability (P<0.05).

No significant differences in indigestible neutral detergent fiber (iNDF) were observed between treatments. According to Harper and McNeill (2015), iNDF is a major factor affecting the dry matter degradability of ruminant diets, a finding consistent with the present study, which found no differences in either DM degradability or iNDF.

The iNDF fraction prevents microbial access and colonization because it is closely associated with lignin, which inhibits the hydrolysis of polysaccharides into monosaccharides and their subsequent conversion into short-chain fatty acids, rendering this fraction indigestible (Costa et al., 2015).

This association with other feed components reduces ruminal degradability, making iNDF an undesirable component. The aim is therefore to minimize or eliminate this complex, since fiber is a nutritionally significant energy source for ruminants and is used by the ruminal microbiota to synthesize microbial protein (Costa et al., 2015; Pinto et al., 2019).

Table 2
In situ ruminal degradability of corn silage stored in trench silos and silo bags, showing dry matter (DM) degradation kinetics at different incubation times (24, 48, 120, and 168 h), characterization of soluble, degradable, and insoluble fractions, and indigestible neutral detergent fiber (iNDF) (120, 168, and 240 h)

Parameter	Silo type		Mean	*P*	SEM
	Trench	Bag			
DM degradability		% of DM			
. 24 h incubation	52.34	51.07	51.70	0.4264	0.75
. 48 h incubation	63.27	63.98	63.62	0.7262	0.98
. 120 h incubation	69.40	68.65	69.03	0.7515	1.14
. 168 h incubation	74.58	75.59	75.18	0.1260	0.35
DM fractions		% of DM			
. Soluble fraction	38.88	38.51	38.69	0.8419	0.88
. Degradable fraction	32.81	33.54	33.17	0.6429	0.76
. Insoluble fraction	28.32	27.95	28.13	0.5913	0.33
Indigestible neutral detergent fiber (iNDF)		% of NDF			
. 120 h	75.54	76.83	76.18	0.2910	0.567
. 168 h	81.54	82.42	81.98	0.2047	0.31
. 240 h	81.72	82.93	82.32	0.1482	0.37

P: probability value; SEM: standard error of the mean. Means followed by different lowercase letters in the row differ significantly according to the F-test (P< 0.05).

No significant differences were found between treatments across the incubation periods assessed (120, 168, and 240 hours). However, methodological differences exist regarding the ruminal incubation time required to accurately measure iNDF, since this time influences the estimation of the indigestible fiber fraction (Moraes et al., 2019).

Table 3 presents the physical DM losses and mean values for the fermentative profile of corn silage stored in different silo types.

Physical depreciation was observed in both treatments but was greater in trench silos at different stages of feed-out, demonstrating the losses that can occur during ensiling (Marafon et al., 2015).

The lateral and upper portions of trench silos are more vulnerable to aerobic deterioration, which compromises anaerobic stability, favors the growth of spoilage microorganisms, and prompts a decline in DM content as the level of nutrient depletion increases (Neumann et al., 2017).

These findings are consistent with those of Marafon et al. (2015), who reported that DM losses primarily occur near the periphery and along the silo walls, contributing to reduced ruminal degradability of carbohydrates and the organic fraction. The lower hemicellulose content in silo bag systems can be attributed to its use as an energy source by acid-producing microorganisms during the fermentation process, resulting in lower losses overall (B. S. Garcez et al., 2016).

Table 3
Evaluation of physical losses at different storage intervals and concentrations of acetic acid, propionic acid, and alcohol in corn silage stored in trench silos and silo bags

Parameter	Silo type		Mean	*P*	SEM
	Trench	Bag			
Physical losses, % DM:					
. 0 to 28 days.	8.20	6.10	7.15	0.0059	0.11
. 29 to 56 days	9.40	2.50	5.95	0.0008	0.18
. 57 to 89 days	9.70	2.60	6.15	0.0005	0.16
Organic acids, g kg^{-1} DM:					
. Acetic acid	27.510	26.880	27.1900	0.7168	9.05
. Propionic acid	0.425	0.379	0.4024	0.3804	0.16
. Alcohol	0.889	1.010	0.9950	0.4994	0.23

P: probability value; SEM: standard error of the mean. Means followed by different lowercase letters in the row differ significantly according to the F-test ($P < 0.05$).

The microbial groups active in ensiled material produce different types of acids depending on their ability to ferment simple sugars to support their growth. Each microbial group follows a specific fermentation pathway according to the substrate used, and these pathways vary in their quantitative and qualitative efficiency, leading to greater or lesser energy or DM losses (Kung et al., 2018).

Nevertheless, lactic acid production is the main driver of the fermentation process, and its formation is closely associated with fermentation quality. However, it should not be evaluated in isolation, since factors such as DM content and the buffering capacity of the forage also influence pH decline (Bai et al., 2021).

Figure 1 shows that DM degradability was greater in trench silos than silo bags in the initial 72 hours of incubation, whereas between 72 and 96 hours, silo bags exhibited a higher degradability rate.

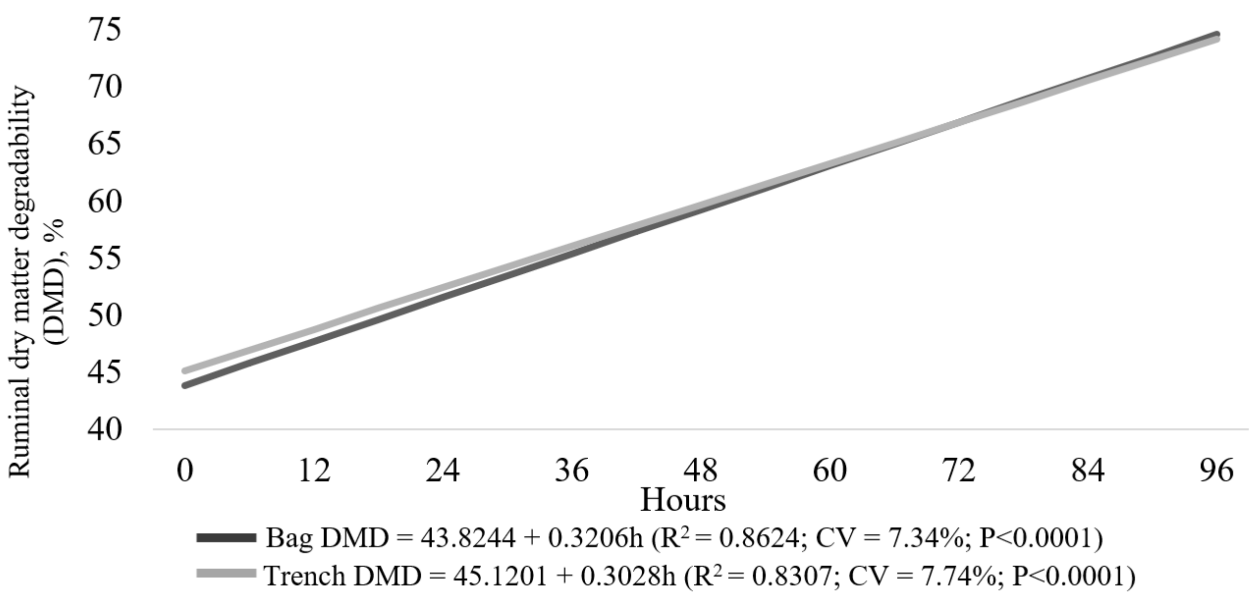

Figure 1. In situ ruminal dry matter degradability (DMD) of corn silage stored in trench silos and silo bags.

This reduced degradability may be related to the limited activity of enzymes produced by ruminal microorganisms, which occurred up to 72 hours in the trench silos and after 72 hours in silo bags (B. S. Garcez et al., 2016).

The silo bags maintained a higher proportion of dense, slowly degradable fibrous cells, decreasing the availability of cellulose and hemicellulose to ruminal microorganisms. This may have caused a temporary energy shortage for the rumen microbes due to the limited availability of cellulose and hemicellulose from these polysaccharides, explaining the lower degradation rate observed during the initial phase of incubation (B. S. Garcez et al., 2016).

Further research is needed to better characterize the chemical composition and nutritional dynamics of silages stored in different silo types, given the variability reported in the literature.

Conclusion

Storage in silo bags provided suitable conditions for maintaining the nutritional value of corn silage, while also reducing physical dry matter losses during the feeding period. However, no significant differences were observed in the ruminal degradability of silage between silo bag and trench silo systems.

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