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# Corn grain processing improves chemical composition and fermentative profile of rehydrated silage

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**ABSTRACT.** This study evaluated the effects of the rehydration and ensiling of corn grain with two geometric mean diameters (GMD) of 0.55 and 1.83 mm obtained by the diameter of the sieved used on the fermentation characteristics and chemical composition of the silage. The experimental design was completely randomized with two treatments and six replications, as follows: rehydrated fine-corn grain silage (RFS) and rehydrated coarse-corn grain silage (RCS). Ground corn was rehydrated with water to achieve moisture levels close to 350 g $kg^{-1}$. There was no effect on the dry matter recovery, though the recovery rate was high, with values greater than 97% in both silages. The particle size influenced the fiber content, with lower values in the RFS. The acetic and lactic acid concentrations were higher in the RFS, but the pH of the silages did not change. Oxygen exposure changed the pH of silages to 4.25 and 4.38 for RFS and RCS, respectively. After opening the silos, the silages showed high aerobic stability after 90 hours, which resulted in lower deterioration and lesser loss of quality. The geometric mean diameter of corn grain affects the silage fermentative profile and nutritional value.

**Keywords:** organic acids; particle size; processing grain; storage losses.

## Processamento dos grãos de milho melhoram a composição química e perfil fermentativo de silagem reidratada

**RESUMO.** O objetivo da pesquisa foi avaliar os efeitos da reidratação do grão de milho em dois diâmetros geométricos médios (DGM = 0,55 e 1,83 mm) sobre perfil fermentativo e composição química das silagens. O experimento foi conduzido em delineamento inteiramente casualizado sendo os tratamentos: silagem de milho finamente reidratado (SMFR) e silagem de milho moído e reidratado (SMMR), com seis repetições. Os materiais foram reidratados com água objetivando níveis de umidade próximos a 350 g $kg^{-1}$. Em ambas as silagens foram verificadas uma recuperação da matéria seca superior a 97%; porém sem diferença entre ambas. Houve influência do tamanho de partícula sobre a porção fibrosa, com valores inferiores observados para a SMFR. A concentração de ácido acético e lático foi maior para a SMFR, porém sem promover alterações significativas no pH da silagem. O pH foi diferente apenas na fase de exposição ao oxigênio, com valores de 4,25 e 4,38 para a SMFR e SMMR, respectivamente. Após a abertura dos silos, ambas as silagens demonstraram alta estabilidade aeróbia, acima de 90 horas, evidenciando menor atividade de espoliação e menor perda de qualidade. Concluiu-se que o DGM dos grãos de milho afetou o perfil fermentativo e nutricional da silagem.

**Palavras-chave:** ácidos orgânicos; perdas de estocagem; processamento de grãos; tamanho de partícula.

## Introduction

Livestock production systems seek efficiency, profitability and sustainability; thus becoming essential to optimize the feeding aspects, particularly the unfavorable cost ratio of raw materials, especially concentrates. Corn is widely used in concentrates, especially due to the starch-rich composition and the significant domestic production of this crop. However, there are some limitations and inconsistencies regarding animal performance, especially related to the variable chemical composition, vitreousness, storage and use of dry grains (Defoor, Galyean, Salyer, Nunnery, & Parsons, 2002). Therefore, technologies and methodologies to improve starch digestibility become relevant and one of those is rehydrated silage.

Rehydration of corn grains consists of returning the dry grain to adequate moisture for the fermentation process in the silo, enabling proper storage adequate to the needs of different livestock production systems. This technique reduces storage losses (pests, temperature changes, humidity etc.), increases digestibility compared to dry milled or whole kernel, reduces transport spending, and minimizes the market effects on price fluctuations (Arcari, Martins, Tomazi, Goncalves, & Santos, 2016).

In this context, the rehydration of corn grains is a good strategy to achieve the prior advantages, since the technique should follow the good fundamentals of conservation to obtain a high-quality final product. For example, if the oxygen was trapped into the opened silo, yeasts could be still able to assimilate lactic acid, reducing the aerobic stability and accelerating the process of silage deterioration (Johnson et al., 2002; Muck, Moser, & Pitt, 2003), which results in silage with low nutritional value and sanitary quality (Borreani & Tabacco, 2014). Besides that, we hypothesized that the milling could also influence the quality parameters of rehydrated silage.

This study aimed to evaluate the nutritional value, fermentative profile, aerobic stability and dry matter recovery of rehydrated corn silage for two particle sizes, finely and coarsely ground.

## Material and methods

The experiment was conducted at the facilities of the Animal Nutrition Laboratory of the Agrarian and Environmental Sciences Sector located at the State University of the Center-West (UNICENTRO), in Guarapuava, State of Paraná, Brazil.

The flint corn (Commercial corn by Cooperativa Agrária – Guarapuava-PR) with 880 g kg$^{-1}$ average dry matter content and 760 g kg$^{-1}$ vitreousness (VIT) was used in this study and the nutritional evaluation are presented in Table 1. The VIT was determined manually following the methodology described by Dombrink-Kurtzman and Bietz (1993). The corn kernels were ground in a hammer mill with sieves measuring 2 mm and 6 mm. The particle size was estimated of the physical forms of processed corn sieves used the technique described by Yu, Huber, Santos, Simas, and Theurer (1998). As a result, it was obtained geometric mean diameters (GMD) of 0.60 and 1.85 mm, sieves 2 and 6 mm, respectively.

The experimental design was completely randomized with two treatments and six replications, as follows: Rehydrated fine-corn grain silage (2 mm sieve) (RFS) and Rehydrated coarse-corn grain silage (6 mm sieve) (RCS).

**Table 1.** Chemical composition of dry coarse and fine corn before ensiling process.

| Item | Treatments | |
|---|---|---|
| | Coarse | Fine |
| Neutral detergent fiber, g kg$^{-1}$ DM | 117.0 | 116.5 |
| Acid detergent fiber, g kg$^{-1}$ DM | 73.1 | 55.4 |
| Hemicellulose, g kg$^{-1}$ DM | 43.9 | 61.1 |
| Crude protein, g kg$^{-1}$ DM | 96.7 | 96.7 |
| Mineral matter, g kg$^{-1}$ DM | 10.1 | 9.3 |

The GMD were 0.55 and 1.85 mm for RFS and RCS treatments, respectively. Grains were rehydrated with clean water (water with no impurities) to reach the final moisture of 350 g kg$^{-1}$ using the equation: Water volume (L) = [Moisture mass of the corn (kg) * (Final moisture (g kg$^{-1}$) – Initial moisture (g kg$^{-1}$))/100 – Final moisture (g kg$^{-1}$)]/Specific mass of the liquid (kg L$^{-1}$). This procedure was based on the principle that rehydrated or wet grain silage has fewer microorganisms that can interfere with the quality and preservation of the material.

Subsequently, the samples were vacuum-ensiled (1000 g of grain/silo) in solder plastic mini-bags (Nylon Polyethylene, 150 microns, 25 cm x 35 cm) using a vacuum packager (Tecmaq TM-280). After oxygen removal, silos were sealed and kept in closed rooms at room temperature where they remained for 120 days.

The experimental silos were weighed at the time of ensiling and after opening to estimate dry matter recovery (RMS/DMR), given by the difference between the initial and final DM content, in relation to the DM amount of ensiled forage using the equation described by Jobim, Reis, Schoken-Iturrino, and Rosa (1999).

Aerobic stability was determined by placing the silage in plastic buckets, which were kept in a closed environment with controlled temperature (25°C). The temperature in the silo was measured every 6 hours using a digital thermometer placed at the center of the sample during exposure to air for 6 consecutive days. The room temperature was measured by a digital thermometer placed next to the silos. Aerobic stability was defined as the number of hours that the temperature of the silage was stable before rising more than 2°C above room temperature (Taylor & Kung Junior, 2002). During the aerobic exposure and each temperature measurement, silage samples were collected to determine the pH value.

Pre-dried samples were used to determine total dry matter (DM) in an oven at 105°C, crude protein

(CP) by the micro Kjeldahl method and mineral matter (MM) was determined by incineration at 550°C for 4 hours (Association Official Analytical Chemist, AOAC, 1995). The neutral detergent fiber (NDF) using α-amylase and acid detergent fiber (ADF) were determined following the method of Van Soest, Robertson, and Lewis (1991). The starch content was determined by an enzymatic method (AOAC, 1995) (method 996.11).

Lactic acid concentration was determined by the colorimetric method (Pryce, 1969) and the sample readings were performed using a MARCONI® Janway 6305 spectrophotometer at $\lambda = 565$ nm. The concentrations of alcohols, esters, acetone and volatile fatty acids were determined by gas chromatography with mass detection (GC-MS) (GCMS QP plus 2010, Shimadzu, Kyoto, Japan) using capillary column (Stabilwax, Restek®, Bellefonte , USA, 60 m, 0.25 mm ø, 0.25 μm crossbond carbowax polyethylene glycol) and analytical parameters according to manufacturer recommendations.

The DM contents of the rehydrated corn silages were corrected for losses by volatilization during sample drying according to the equation proposed by Porter and Murray (2001): True DM Content (g $kg^{-1}$) = 1.011 × ODM + 1.24. Where ODM = oven-dried mass.

The chemical composition and dry matter recovery data were compared by analysis of variance, using the PROC MIXED at 0.05 probability level, because the evaluated corn samples were made from several sub-samples collected over the time of silage utilization. The average aerobic stability and pH were determined by performing repeated measurements over time (PROC REG) of Statistical Analysis System (SAS, 2009) version 9.2.

## Results and discussion

The variables dry matter (DM), crude protein (CP), and mineral matter (MM) were not different ($p > 0.05$) among treatments (Table 2). On the other hand, the starch content differed among treatments with 712.2 and 720.7 g $kg^{-1}$ for RFS and RCS, respectively. The lower starch content (g $kg^{-1}$ DM) of RFS possibly resulted from physical and chemical changes during the fermentation process.

The neutral detergent fiber (NDF) and acid detergent fiber (FDA) values were also different ($p < 0.05$) between the two treatments, and the rehydrated fine-corn grain silage (RFS) had lower mean values compared to coarsely ground grain silage (RCS).

It is assumed that processing in 2 mm sieve theoretically increased starch availability to microorganisms, especially lactic acid bacteria (LAB). Therefore, the concentration of organic acids increased and allowed proteolysis of hydrophobic proteins (zeins), thus increasing the fermentability of starch present in the endosperm. Lower NDF and ADF values in rehydrated corn silage with lower particle size were not associated with an acidic hydrolytic activity on the hemicellulose, according to the theory of McDonald (1981), since ADF decreased in both treatments. Rezende et al. (2014) evaluated the effect of adding water or whey during corn rehydration process and reported that the moisture content influenced both variables, NDF and ADF. Further, Rezende et al. (2014) evaluated the composition of corn grain silage with inoculant and reported values of 231 and 439 g $kg^{-1}$ DM for NDF and ADF, respectively. These values are higher than those values observed in this study.

**Table 2.** Chemical composition of rehydrated fine (RFS) and coarse (RCS) corn silages after 120 d of ensiling.

| Item[2] | Treatments[1] | | SEM[1] | P-values |
|---|---|---|---|---|
| | RFS | RCS | | |
| Dry matter, g $kg^{-1}$ NM | 658 | 651 | 0.18 | 0.52 |
| Mineral matter, g $kg^{-1}$ DM | 9.4 | 9.9 | 0.01 | 0.38 |
| Neutral detergent fiber, g $kg^{-1}$ DM | 82.8 | 90.7 | 1.31 | 0.01 |
| Acid detergent fiber, g $kg^{-1}$ DM | 31.9 | 38.3 | 0.07 | 0.03 |
| Hemicellulose, g $kg^{-1}$ DM | 50.9 | 52.4 | 0.01 | 0.21 |
| Crude protein, g $kg^{-1}$ DM | 90.9 | 88.7 | 0.09 | 0.51 |
| Starch, g $kg^{-1}$ DM | 712.2 | 720.7 | 0.05 | 0.04 |

RFS: Rehydrated fine-corn grain silage (2 mm sieve); RFS: Rehydrated coarse-corn grain silage (6 mm sieve); SEM: standard error of the mean.

Rezende et al. (2014) observed similar CP contents (99 g $kg^{-1}$) for rehydrated corn silage (average moisture, 350 g $kg^{-1}$) and reported that values above this level might undergo intensive deamination and proteolysis. This may have occurred as a result of greater degradation of starch-protein matrix (Hoffman et al., 2011) and suggests a greater starch digestibility of the rehydrated corn.

Silage DM content and pH at the time of ensiling were not affected ($p > 0.05$) by the treatments, demonstrating the homogeneity of the 2 mm (RFS) and 6 mm sieve (RCS) treatments (Table 3). The DM recovery (DMR) was also similar between treatments, averaging 976 and 979 g $kg^{-1}$ DM, for RFS and RCS treatments, respectively. The high DM recovery observed in both silages could be attributed to the type of experimental silos used, especially vacuum silos, since losses are basically from gases. Rezende et al. (2014) also reported high DMR (985 g $kg^{-1}$), similar to the values observed in this study.

The DM values of silages were close to 650 g kg$^{-1}$ and were not affected by the treatments. Weinberg and Ashbell (2003) stated that DM values below 650-700 g kg$^{-1}$ have higher osmotic activity and less production of organic acids, a result from slow fermentation, while the deficit of sugars or soluble carbohydrates may also reduce water (AW) and microbial activity (Jobim et al., 1999). However, raw materials with the same DM content behave differently, for example, harvested and ensiled high moisture corn had better fermentation characteristics compared to rehydrated and ensiled dried corn grain (Goodrich, Byers, & Meiske, 1975).

The pH values of RFS and RCS silages were not significantly different at the silo opening, but the higher concentrations of the organic acids (lactic and acetic) lead to the pH decrease in the RFS silages. Likewise, the fermentation products propionic acid, butyric acid, and ethanol were not significantly different.

The lactic acid concentration was different ($p < 0.03$) between silages, with values of 1.23% and 0.88% DM for RFS and RCS, respectively. Similarly, acetic acid concentrations were also different ($p < 0.01$) with higher values for RFS (0.48% DM) compared to RCS (0.28% DM). The production of acetic acid (71%) was higher for RFS. The production of the main organic acids is affected by the ensiling process used, maturity and corn grain composition, moisture at the time of ensiling and the epiphytic population of microorganisms (Lopes, Biaggionni, Berto, Sartori, & Boff, 2005; Muck et al., 2003; Weinberg & Ashbell, 2003).

Grain silages, either wet or rehydrated, tend to have lower amount of soluble nutrients, affecting the conditions for growth and efficacy of the necessary microorganisms to promote adequate fermentation and preservation of the material (Muck, 2010; Silva, Smith, Barnard, & Kung, 2015). However, the results indicated that the quality of both silages was not negatively influenced by the treatments.

Furthermore, the finely ground corn silage (RFS) had a better fermentation profile probably because it provided higher amount of soluble carbohydrates to lactic acid producing bacteria. This fact explains the production of the main organic acids obtained in RFS, where acetic and lactic acid concentrations were higher, which can be a result of grain processing since the finer particles had larger contact surface causing greater exposure of the cell content.

The production of lactic acid observed for RFS (1.23%) was higher than the values observed by Goodrich et al. (1975) and Rezende et al. (2014) of 1.17 and 1.3%, respectively, for raw materials with moisture content about 35%. The acetic acid concentration was higher in the RFS (0.48%) and RCS (0.28%) silages, compared to 0.22% values reported by Rezende et al. (2014).

The average pH values were different ($p < 0.02$) during the aerobic exposure phase. The RFS had lower pH (4.25) compared to RCS (4.38), probably because the level of the acetic and lactic acids was higher in RFS (Table 3).

**Table 3.** Fermentation profile and aerobic stability of rehydrated fine (RFS) and coarse (RCS) corn silage, after 120 d of ensiling.

| Parameters | Treatments[1] | | SEM[1] | P-values |
|---|---|---|---|---|
| | RFS | RSC | | |
| Corn grain at ensiling | | | | |
| pH | 5.57 | 5.54 | 0.12 | 0.62 |
| Silage | | | | |
| Dry matter, g kg DM | 642.2 | 637.3 | 0.01 | 0.55 |
| Dry matter recovery, g kg$^{-1}$ DM | 976 | 979 | 0.01 | 0.48 |
| pH | 3.91 | 3.98 | 0.01 | 0.71 |
| Lactic acid, % DM | 1.23 | 0.88 | 0.01 | 0.03 |
| Acetic acid, % DM | 0.48 | 0.28 | 0.001 | <0.01 |
| Lactic: Acetic | 2.54 | 3.12 | 0.06 | 0.05 |
| Propionic Acid, mg kg$^{-1}$ DM | 107 | 118 | 7.45 | 0.42 |
| Butyric Acid, mg kg$^{-1}$ DM | 82 | 85 | 3.8 | 0.70 |
| Ethanol, % DM | 0.36 | 0.30 | 0.06 | 0.37 |
| Period of aerobic exposure (6 days) | | | | |
| pH | 4.25 | 4.38 | <0.01 | 0.02 |
| maximum temperature, °C | 23.70 | 23.90 | 0.04 | 0.65 |
| aerobic stability, hour | 92 | 98 | 0.09 | 0.55 |
| Heating rate, %/ hour | 2.25 | 2.41 | 1.12 | 0.10 |

[1]RFS: Rehydrated fine-corn grain silage (2 mm sieve); RFS: Rehydrated coarse-corn grain silage (6 mm sieve); SEM: standard error of the mean.

The pH of the RCS also oscillated more during the evaluation period, as shown in Figure 1A. The maximum temperature was not significantly ($p = 0.65$) different during the aerobic stability evaluation phase. The temperature remained low and became unstable after 92 and 98 hours for RFS and RCS, respectively (Figure 1B). However, the heating rate tended to increase ($p = 0.10$) at an average 2.41 and 2.25%/hour for RCS and RFS, respectively.

Consequently, the concentration of acids affected the silage pH oscilation and temperature, demonstrating better aerobic stability with rehydrated corn silage.

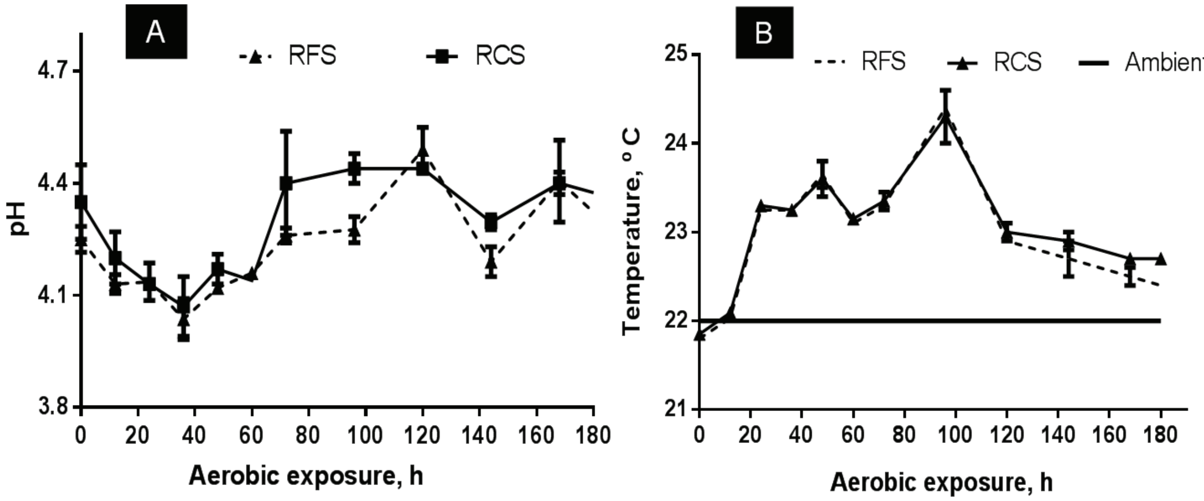


**Figure 1.** A. pH measurements over time for the rehydrated fine (RFS) and coarse corn grain silages (RCS) during the aerobic phase. B - Temperature over time for the rehydrated fine and coarse corn grain silages during the aerobic phase.

## Conclusion

The geometric mean diameter of corn grain affected the fermentative profile and nutritional chemical composition of silage. Rehydrated ground corn grain silage had adequate fermentative profile and enabled nutrient preservation with low DM loss and high stability in the phase of oxygen exposure, regardless of the geometric mean diameter of the corn grain.

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