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Research Article

A survey of whole-plant corn silages from Minas Gerais dairy farms

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ABSTRACT: Whole-plant corn silage (WPCS) is a commonly used forage for feeding dairy cattle in Brazil. The aim of this study was to evaluate on-farm ensilaging practices and the nutritional value, microbiology and fermentation profiles of WPCS from dairy farms in the south of the state of Minas Gerais, Brazil. Silages from 54 dairy farms located in nine cities were sampled and a questionnaire was distributed for completion to describe the herd profile and ensilage practices. Herd size ranged from 8 to 1,000 lactating cows, and 52 % of the farms had fewer than 50 cows in lactation. The majority of the farms cultivated hard endosperm texture hybrids (52 %) and used pull-type forage harvesters (87 %). Double-sided plastic was the most used form of silo sealing (56 %) and 28 % used inoculants. Lactic acid bacteria count was greater than 6.01 log CFU g^{-1} in 60 % of the samples, and the mean populations of enterobacteria and *Bacillus* spp. were 4.23 and 4.09 log CFU g^{-1}, respectively. Silo size ranged from 100 to 250 m^3 in 44 % of the farms, and the silage removal rate was below 15 cm of the face/d in 41 % of cases. Silage dry matter (DM) concentration was 33 ± 3 % of fresh matter, NDF concentration was 57 ± 7 % of the DM, and in vitro NDF digestibility was 35 ± 11 % of the NDF. Silages with high DM concentrations had large particle size, affecting the nutritional value and the fermentative pattern. Improvements in ensiling practices can potentially inhibit the growth of spoilage microorganisms and raise the nutritional value of silages.

Keywords: aerobic deterioration, ensilaging practices, dairy farming, lactic acid bacteria

Introduction

Whole-plant corn silage (WPCS) is an important forage source for large- and small-scale dairy farms in the southern region of Minas Gerais. The region's high altitude (more than 700 m above sea level) makes it suitable for corn production as the result of its relatively cool summer nights. Forage corn offers high dry matter yield per unit of land, allowing for a high animal stocking rate and a high concentration of energy per unit of dry matter, thereby reducing the need for concentrated feedstuffs per unit of milk produced.

However, ensiling practices can vary and may affect the nutritional value of WPCS, such as plant maturity at harvest and silage dry matter concentration (Shinners et al., 2000), hybrid endosperm texture (Correa et al., 2002; Ferraretto and Shaver, 2015), fiber particle size (Johnson et al., 2002), and degree of kernel processing (Bal et al., 2000). Additionally, the use of a microbial inoculum (Arriola et al., 2011), storage duration (Der Bedrosian et al., 2012), and other ensiling practices (Weinberg and Ashbell, 2003) can affect the silage fermentation profile, animal intake and performance (Santos et al., 2017).

The ensiling process involves agronomic, physical, chemical, and microbiological aspects that are integrated and thereby determine the quality of the silage produced. Few studies have been conducted correlating the chemical and microbiological aspects of WPCS with ensiling practices. Thus, the aim of this study was to gather information on silage practices capable of determining the silage fermentation profiles and nutritive values of silage on Minas Gerais dairy farms with variation in herd sizes and degree of adoption of technology.

Materials and Methods

Profile of farms and ensiling practices

Corn silage samples were collected in 2014, from 54 dairy farms in the cities of Lavras (21°14′ S, 44°59′ W, 919 m) (6), Elói Mendes (21°36′ S, 45°33′ W, 907 m) (6), Silvianópolis (22°01′ S, 45°50′ W, 897 m) (6), São Sebastião do Paraíso (20°55′ S, 46°59′ W, 991 m) (6), Passos (20°43′ S, 46°36′ W, 745 m) (6), Muzambinho (21°22′ S, 46°31′ W, 1048 m) (6), Piranguinho (22°24′ S, 45°31′ W, 837 m) (6), Itumirim (21°19′ S, 44°52′ W, 871 m) (6), and Nepomuceno (21°14′ S, 45°14′ W, 840 m) (6). The selection of farms for the study was made in conjunction with the federal Brazilian Agricultural Extension Service (EMATER-MG, Empresa de Assistência Técnica e Extensão Rural, MG, Brazil). Technicians from each city involved in the study proposed a list of six farms to represent small and large scale dairy farms. Next, the research team randomly selected a sub-sample of farms. The same researcher visited every farm to collect the survey data and WPCS samples for laboratory analysis.

Physical and chemical analyses

The temperature of the silage was taken at nine equidistant points to represent the face of the bunker silos using a thermometer inserted to a depth of 20 cm. The first three points were 0.30 m from the top, with two of these points 0.30 m from the walls and one at mid-width.

Three other points were 0.30 m from the bottom of the silo, with two of these points 0.30 m from the walls and one at mid-width. Finally, three more points were at mid-height with two of these points 0.30 m from the walls. Silage samples were taken from across the complete face of the silo at a depth of 0.20 m and homogenized. The samples were collected and placed in sterile plastic bags, stored in ice boxes, and immediately transported to the microbiology laboratory. A fraction of each sample was dried in a forced-air oven at 55 °C for 72 h and ground through a 1-mm mesh screen with a Wiley mill. The samples were analyzed for their DM concentration by drying them at 100 °C for 24 h (AOAC, 1990), for water-soluble carbohydrates (WSC) using the phenol-sulfuric method (Dubois et al., 1956), and for their starch (Hall et al., 2001) and crude protein (CP) using the Kjeldahl method (AOAC, 1990). Their neutral detergent fiber (NDF) was analyzed with porous crucibles according to van Soest et al. (1991) with α-amylase and sodium sulfite, and non-fiber carbohydrates (NFC) were calculated by the arithmetic difference of conventional chemical variables (NRC, 2001). The in vitro digestibility of DM and NDF was determined using 24 h incubations following the first step of Tilley and Terry's (1963) procedure. The geometrical mean particle size of the fresh WPCS was measured using screens 19 mm and 8 mm in diameter and the pan of the Penn State Particle Size Separator, according to Kononoff (2003) and Baker and Herrman's (2002) methodology. The kernel processing score (KPS) was determined according to Ferreira and Mertens (2005) using dried WPCS samples. The estimate of milk production per ton of DM was calculated using the MILK 2006 spreadsheet developed by Shaver and Lauer (2006). Another sample was used to determine pH value, microbial population, and fermentation end-products.

Fermentation profile and microbiological analyses

Water extracts were generated to determine the pH and microbial and fermentation profiles. To prepare the water extracts, 25 g of fresh corn silage was blended in 225 mL of 0.1 % sterile peptone water and homogenized in an orbital mixer for 20 min at 20 g. Then, the pH of each sample was determined (Digimed Analítica, model DM 20®). Water extracts (2 mL) were acidified with 10 µL of 50 % (vol/vol) H_2SO_4 and frozen at -5 °C until the analysis of the fermentation end-products (Canale et al., 1984). The acidified water extracts were analyzed for lactic acid, acetic acid, propionic acid, butyric acid, ethanol, and 1,2-propanediol by high-performance liquid chromatography (Shimadzu model LC-10Ai; Shimadzu Corp., Tokyo, Japan) (Carvalho et al., 2012).

Sequential ten-fold dilutions were prepared to quantify the microbial groups. For the enumeration of LAB, pour plating onto de Man, Rogosa, and Sharpe agar (M641I, Hi Media, Mumbai, India) plus nystatin (4 mL L^{-1}) were used. The plates were incubated at 37 °C for 48 h. Microorganisms of the *Enterobacteriaceae* family were enumerated by plating in the medium eosin methylene blue agar (EMB, Difco, Sparks, USA) after 24 h of incubation at 37 °C. Samples for the mesophilic aerobic spore count (*Bacillus* spp.) had been previously submitted to 80 °C for 10 min to induce sporulation, and the nutrient agar medium (M001, HiMedia, Mumbai, India) was used to count these microorganisms. The plates were incubated at 37 °C for 24 h under aerobic conditions. Yeasts and molds were enumerated using dichloran rose bengal chloramphenicol medium (DRBC, Difco; Becton Dickinson, Sparks, MD, USA). The plates were incubated at 28 °C for 72 h.

Statistical analysis

Data on the farms' characteristics and the results of the physicochemical and microbiological analyses were grouped into classes and descriptive statistics were reported (Mean, standard deviation, minimum, maximum). Pearson correlation coefficients between continuous variables were generated by the XLSTAT 7.5.2 software program (Addinsoft's, New York, NY, USA).

Results and Discussion

Farm profiles

Table 1 shows herd size and milk yield per farm and per cow. The number of lactating cows in the herd ranged from 8 to 1,000; 52 % of the farms had fewer than 50 cows, and only 4 % had more than 500 cows. Daily milk production per farm ranged from 90 to 15,000 L and farms with less than 500 L of milk per day were predominant (43 % of total). Small producers represented the majority of the farms sampled, but large dairy operations supplied the majority of total milk yield, in accordance with the production profile of Brazilian dairy farms (IBGE, 2014). Milk yield per cow ranged from 3 to 28 L d^{-1} and had similar distribution among farms with production per cow lower than 10 L d^{-1} (30 %), from 10 to 20 L d^{-1} (37 %), and greater than 20 L d^{-1} (33 %). Farms sampled in this survey had greater milk production per

Table 1 – Herd size, daily milk production, and yield per cow on 54 dairy farms in Minas Gerais. Data provided by the producer.

Variable	% answers	Mean	SD	Minimum	Maximum
Lactating cows					
< 50	51.9	99	163.1	8	1,000
50 - 100	25.9				
101 - 500	18.5				
> 500	3.7				
Milk production (L d^{-1})					
< 500	42.6	1,401	2,376.8	90	15,000
500 - 1000	25.9				
1001 - 5000	24.1				
> 5000	7.4				
Milk per cow (L d^{-1})					
< 10	29.6	16	7.4	3	28
10 - 20	37.0				
> 20	33.3				

SD = Standard deviation.

cow and per farm than the average Brazilian and Minas Gerais dairy farm (IBGE, 2014), suggesting that farms using corn silage may have greater cow productivity and daily milk production than the average dairy farm.

Silage practices

Silage management practices are reported in Table 2. The majority of farms (39 %) cultivated medium-hard hybrids, 22 % did not know the hardness of the hybrid, and 26 % of the farms reported the use of floury endosperm hybrids. Hardness is a physical characteristic that influences the quality and processing of corn, and vitreousness is an indirect measure of hardness, the latter being a variable that adversely affects the digestibility of starch present in corn grain (Correa et al., 2002). Among the 477 corn hybrids available in the 2015/2016 crop on the Brazilian seed market, 9 % were mealy, 67 % semi-hard, and 24 % had endosperm characterized as hard (Cruz et al., 2015). Apparently, the choice for floury endosperm hybrids was proportionally higher in the farms of this study than the proportion of available soft endosperm hybrids in the Brazilian market, suggesting that this characteristic was of some value to dairy producers, although kernel vitreousness was not directly evaluated in this survey. Flint (hard) endosperm corn hybrids have been shown to adversely affect starch digestibility (Correa et al., 2002), especially during the late maturity stages of the plant (Pereira et al., 2004), depending on the degree of kernel damage during harvesting.

When asked about the ideal corn maturity for silage harvesting, all of the producers reported using the kernel milk line and the dry matter content of the plant to indicate the ideal harvest time, which takes place when the milk line is displayed in half of the grain and the dry matter content reaches approximately 33 %. This is in agreement with Heguy et al. (2016), who conducted a survey of silage management in California's dairies and found that 75 % of producers harvested at this same stage in corn maturity.

The majority of farms (67 %) harvested corn with their own equipment and most (87 %) use a harvester tensioned by a tractor (Table 2). The use of harvesters tensioned by a tractor is still common in Brazil (Bernardes and Rêgo, 2014) due to the low cost of such equipment, the small size of cultivated areas, and the hilly topography of many farms. However, tensioned harvesters can provide low-income crop silages with a lower processed grain fraction and low particle size uniformity. This finding highlights an issue that demands further attention in future investigations of silage management practices (Bernardes and Rêgo, 2014). Harvesting equipment with some sort of grain processing device was used on only 20 % of the farms. Harvester blades were sharpened daily or more than once daily on 82 % of the farms, in order to achieve adequate kernel damage.

The capacity of the silos ranged from 72 to 1,375 m^3, with approximately 44 % of the evaluated properties' silos capable of holding volumes ranging from between

Table 2 – Type of hybrid, harvesting and ensiling procedures, silage temperature, and particle size of corn silages from 54 dairy farms in Minas Gerais.

Variable	% answers	Mean	SD	Minimum	Maximum
Hybrid texture					
floury	25.9	–	–	–	–
flint	13.0				
medium-hard	38.9				
unknown	22.2				
Equipment origin					
own equipment	66.6	–	–	–	–
rented	24.1				
cooperative	9.3				
Characteristic of the harvesters					
tensioned by tractor	87.0	–	–	–	–
self-propelled	13.0				
Harvesters with grain crackers					
Yes	20.4	–	–	–	–
No	79.6				
Sharpening of blades					
beginning of ensiling	18.5	–	–	–	–
daily	48.2				
more than once a day	33.3				
Capacity of silos (m^3)					
< 100	13.0	299.0	250.6	72.0	1,375.0
100 - 250	44.4				
251 - 500	25.9				
501 - 750	9.3				
> 750	7.4				
Use of microbial inoculum					
Yes	27.8	–	–	–	–
No	72.2				
Coverage					
black plastic film	29.5	–	–	–	–
double-sided plastic films	55.6				
white plastic	3.7				
double-sided plastic + additional coverage	9.3				
film with oxygen barrier	1.9				
Duration of storage (days)					
< 30	14.8	116	87.3	20	380
30 - 90	40.7				
91 - 150	20.4				
> 150	24.1				
Feed-out rate (cm d^{-1})					
< 15	40.7	21	12.7	3	60
15 - 30	48.2				
> 30	11.1				
Silage temperature		27	3.76	19	37
< ambient temperature	27.8				
2 °C above ambient temperature	18.5	27	3.76	19	37
> 2 °C above ambient temperature	53.7				
Ambient temperature		25	2.42	20	29
Geometrical mean particle size (mm)[1]					
< 7.5	24.1	8.6	1.3	6.4	11.9
7.5 - 9.5	53.7				
> 9.5	22.2				
Particle size distribution (% fresh silage)[2]					
> 19 mm		8	2.72	2.61	20.8
8 - 19 mm		56.24	9.42	36.5	75.38
< 8 mm		35.76	10.64	16.94	58.82

[1]Kansas State University: MF-2051. Baker and Herrman (2002); [2]Diameter of screens of the Penn State Particle Separator; SD = Standard deviation.

100 and 250 m^3 (Table 2). Small size silos were used in most farms, reflecting the largest proportion of small herds (Table 1). Small silos allow for faster filling rates, adequate packing, and reduced aerobic dry matter loss during ensiling. Silage feed-out rate was greater than 15 cm d^{-1} on 59 % of the farms, ranging from 3 to 60 cm d^{-1}. A considerable proportion of farms (41 %) unloaded less than 15 cm of silage panel per day, suggesting that silos were oversized relative to herd size in many farms. According to Martin et al. (2004), the removal of layers with at least 15 cm of panel silage minimizes losses due to aerobic spoilage. However, for most unstable silages, as in the case of corn silage, or in conditions of high humidity and/or high temperatures, a layer of at least 30 cm d^{-1} should be removed (Muck et al., 2003). The major determinant of the daily layer removal was the number of animals to be fed. Although most of the silos with greater storage capacity were found on the properties with the highest number of animals, lower feed rates were observed in these silos, demonstrating that the design of the silos offers immense potential for improvement in the quality of the silage.

Adequacy of silo design is a potential variable in the improvement in silage quality. This is consistent with the silage temperature data. Only 27 % of the silos had temperatures below the ambient temperature, while 54 % of the silos had temperatures at least 2 °C above ambient temperature, which is indicative of the beginning of the decay process due to the metabolism of undesirable aerobic microorganisms (Kung and Shaver, 2001).

Microbial silage additives were used in 28 % of the farms (Table 2). According to the producers, the application of inoculants was carried out with the aim of improving the fermentation and/or reducing silage storage time; however, most of the producers were unable to state what type of inoculum (microorganism) was used and why they had chosen that particular additive.

Double-sided plastic film was the sealant most frequently used for sealing the silo (56 %), followed by black plastic (30 %). Additional coverage (usually ground) to the double-sided film was reported by 9 % of producers. Of the properties evaluated, 8 % used white plastic and only 2 % used film with an oxygen barrier (Table 2). These results corroborate those obtained by Bernardes and Rêgo (2014) who found that double-sided plastic film was most often used (85 %) by the producers, followed by black plastic (10 %). Double sided plastic was used by 71 % of dairy producers in California, USA to cover silage piles; however, oxygen barrier plastic was also popular among dairies, with 88 % using this technology (Heguy et al., 2016).

Processing and nutrient composition

Silage processing and nutrient composition are reported in Table 3. The mean dry matter (DM) content and crude protein (CP), neutral detergent fiber (NDF), nonfibrous carbohydrates (NFC), starch, digestibility in vitro dry matter (DigINVITRO DM), and the estimate of milk production (EMP) showed values compatible with those found in the literature (Ali et al., 2014; Filya and Sucu, 2010; Li and Nishino, 2011) (Table 3).

The DM content of the silages evaluated ranged from 284.0 g kg^{-1} to 405.0 g kg^{-1}, with a mean value of 332.4 g kg^{-1}. This considerable variation in silage DM concentration may be related to the low output of the harvesters used, the phenotypic differences of the hybrids planted, as well as imprecision in the correct definition of the mid-point of the milk line. Despite wide variation, 56 % of the samples had concentrations ranging from 300.0 to 350.0 g kg^{-1}, which is recommended as this range allows for adequate starch accumulation in the kernel fraction of the plant without incurring significant losses in the total digestibility of the nutrients (Bal et al., 2000).

The mean crude protein concentration in silage dry matter was 70.7 g kg^{-1} and 57 % of the samples had more than 70 g kg^{-1} crude protein. The mean concentration of NDF was high for corn silage (568.7 g kg^{-1} of dry matter), and ranged from 444.0 to 703.0 g kg^{-1}. The concentrations of starch (170.0 to 428.0 g kg^{-1}) and NFC (115.0 to 410.0 g kg^{-1}) also had high variability. Dry matter (35 to 76 %) and NDF (15 to 67 %) in vitro digestibilities were also highly variable from one farm to the next. Variations in plant maturity at harvesting, use of fertilizer, silage storage and unloading procedures, and hybrid type may explain the high variability in silage composition and are potential factors for improving forage nutritive value. The prevalence of high concentrations of protein and NDF is in agreement with the trend to increased proportions in dry matter concentration between 300 and 350 g kg^{-1}, suggesting that harvesting of immature plants had taken place on many farms.

The geometric mean particle size (GMPS) of the samples varied considerably, from 6.4 to 11.9 mm, with 54 % between 7.5 and 9.6 mm (Table 2). This change in the pattern of mean particle size can be partially explained by variation in plant dry matter content and the different forms of regulation (blades and counter blades) of the machines. Despite the particle distribution of fresh silage, the values presented are the mean of all the samples: 56 % (37 to 75 %) of particles were between 8 and 19 mm and 36 % (17 to 59 %) of particles were less than 8 mm in diameter (Table 2).

Many producers reduce the GMPS to improve grain breakage during the harvesting of the plant. Larger particle sizes can reduce consumption. Kononoff et al. (2003) worked with four corn silage particle sizes in the diets of lactating cows and a linear decrease was observed in dry matter intake as particle size increased. The large particle size reduces the rate of passage of solids through the rumen, reducing the voluntary intake of dry matter (Heinrichs, 1996). However, the smaller particles may predispose animals to the occurrence of certain metabolic disorders, such as bloat and acidosis. Large particles affect feed sorting behavior. The effect of diet particle size on feed sorting is related to ease of sorting and preference for the forage component. Separation of forage particles

Table 3 – Nutrient composition, kernel processing, and digestibility of corn silages from 54 dairy farms in Minas Gerais.

Variable	% answers	Mean	SD	Minimum	Maximum
Dry matter (g kg^{-1} of fresh)					
< 300	16.7				
300 - 350	55.6	332.4	28.6	284.0	405.0
> 350	27.8				
Dry matter digestibility (%)					
< 55	35.2				
55 - 65	20.4	60.7	10.7	34.7	76.2
> 65	44.4				
Kernel processing score (% of starch < 4.75 mm)					
< 50	22.2				
50 - 70	48.1	62.4	12.1	39.1	84.9
> 70	29.6				
Neutral detergent fiber digestibility (%)					
< 30	27.8				
30 - 40	48.1	35.1	10.5	14.9	66.7
> 40	24.1				
Composition (g kg^{-1} of dry matter):					
Crude protein					
< 60	13				
60 - 70	29.6	70.7	8.8	55.0	98.0
> 70	57.4				
Neutral detergent fiber					
< 500	14.8				
500 - 600	55.6	568.7	65.8	444.0	703.0
> 600	29.6				
Non-fiber carbohydrates					
< 250	35.2				
250 - 350	48.1	283.1	72.2	115.0	410.0
> 350	16.7				
Starch					
< 250	31.5				
250 - 350	40.7	294.9	65.2	170.0	428.0
> 350	27.8				
Estimated milk production (kg of milk t DM^{-1})[1]		997.7	220.1	556.6	1,510.2

[1]Estimate milk production (Shaver and Lauer, 2006); SD = Standard deviation.

from grain components occurs more easily when particle size is distinct in the diet (Miller-Cushon and DeVries, 2017). In addition to factors related to the animals, mean particle size can affect the porosity, density, effluent production, fermentation, and, indirectly, the aerobic deterioration of silage (Muck et al., 2003).

Silages had on average 36 % of particles below the 8 mm diameter screen of the Penn State Particle Separator (Table 2). The 8 mm mesh screen has been proposed as the threshold of physically effective NDF in lactating cow diets (Zebeli et al., 2012). Increased proportions of fine particles in corn silage require the introduction of a source of long forage particles in lactating cow diets (usually hay or haycrop silages) to obtain adequate ruminal function (acidosis control). Regulating the harvesting equipment so as to obtain small particle size was apparently the strategy used to secure an adequate degree of kernel processing. The association of small particle size regulation of the equipment and plants which were not excessively mature apparently favored the occurrence of a low proportion of silages (22 %) with inadequate kernel processing (KPS < 50 %) compared to the proportion of silages (30 %) with adequate kernel processing (KPS > 70 %) (Table 3). In this sample set of corn silage, the undesirable presence of fine fiber particles was a more important issue in obtaining adequate processing than inadequate kernel processing. Increasing silage DM concentration at harvest (more advanced maturity of the plant), to achieve increased DM production per unit of land, without a simultaneous improvement in farm machinery for harvesting and processing may result in inadequate KPS of hard endosperm hybrids, resulting in reduced ruminal and total tract starch digestibility. The decision of harvesting at low maturity was adequate for the type of hybrid (flint) and machinery available (no kernel processor).

Estimated milk production per ton of dry matter silage among the evaluated farms averaged 997.7 kg t^{-1} of DM, ranging from 556.6 to 1,510.2 t^{-1} kg of DM (Table 3).

This index considers nutrient concentration as a whole. The results showed that variation in the nutritional value of the silages was relatively high, which may consequently affect milk production capacity. Oliveira et al. (2011), evaluating the productivity and nutritional value of corn silage produced from different hybrids in southern Brazil, found no significant differences in milk production estimates based on the nutritional value of silages, and the authors reported an estimated mean of 1,313 kg t^{-1} of DM.

Fermentative characteristics

The pH of the silage evaluated ranged from 3.6 to 6.1 (Table 4). Of the total samples, 56 % had pH values below 4.0. These values are within the recommended levels, between 3.8 and 4.2 (Kung and Shaver, 2001). There was wide variation in concentration of the main fermentation products. The mean lactic, acetic, and propionic acid contents were 51.1 g kg^{-1} DM (ranging from 11.0 to 87); 12g kg^{-1} DM (ranging from 0.0 to 24.9), and 15.2 g kg^{-1} DM (ranging from 1.5 to 40.4), respectively, (Table 4).

A lactic acid content above 60.0 g kg^{-1} DM was observed in 37 % of the samples, and these values are considered ideal for well-preserved silage (Kung and Shaver, 2001). The concentration of lactic acid is higher in the initial days of fermentation when the water-soluble carbohydrate content is higher (McDonald et al., 1991). However, the concentration of this metabolite can be reduced by the metabolism of certain microorganisms, which can use it as a substrate. Some *Lactobacillus* species, such as *L. hilgardii* and *L. buchneri*, can convert lactic acid into acetic acid and 1,2-propanediol (Elferink et al., 2001). Bacteria of the species *L. diolivorans* can convert 1,2-propanediol into propanol and propionic acid (Krooneman et al., 2002), contributing to increases in the content of these metabolites during fermentation.

The production of acetic acid occurs due to the heterolactic metabolism of LAB present in the silage. This metabolite can also be produced early in the fermentation process by enterobacteria that compete with LAB for the available substrates, thereby reducing the production of lactic acid (McDonald et al., 1991). A number of microorganisms, such as *Propionibacterium* sp. and *Clostridium propionicum*, are responsible for the production of propionic acid in silage (McDonald et al., 1991).

The butyric acid content ranged from 0.0 to 3.8 g kg^{-1} DM, with a mean of 0.7 g kg^{-1} DM, similar to that reported by Santos et al. (2015) and Wang et al. (2014). Most samples (78 %) had a butyric acid content of less than 1.0 g kg DM^{-1}, which corresponds to the optimum values recommended by Kung and Shaver (2001) (Table 4). According to Nkosi et al. (2009), butyric acid concentrations above 0.1 g kg^{-1} DM reflect the microbial activity of the genus *Clostridium* spp. on the ensiled material and are related to lower decline rates and higher final pH values in silages. The concentration of ethanol observed in the silages evaluated ranged from 3.5 to 36.1 g kg^{-1} DM, and 22 % of the samples and demonstrated an ethanol content of above 20.0 g kg^{-1} DM. The presence of ethanol in silage is undesirable since it indicates the growth and metabolism of yeast, along with lost DM (Kristensen et al., 2007).

Table 4 – Fermentation profile of corn silages from 54 dairy farms in Minais Gerais.

Variable	% results	Mean	SD	Minimum	Maximum
pH					
< 4	55.6				
4 - 4.5	38.9	4.1	0.4	3.6	6.1
> 4.5	5.6				
Lactic acid (g kg^{-1} DM)					
< 30	16.7				
30 - 60	46.3	51.1	18	11	87
> 60	37				
Acetic acid (g kg^{-1} DM)					
< 10	37				
10 - 20	57.4	12	6	0	24.9
> 20	5.6				
Propionic acid (g kg^{-1} DM)					
< 5	14.8				
5 - 10	22.2	15.2	9	1.5	40.4
>10	63				
Butyric acid (g kg^{-1} DM)					
< 0.5	64.8				
0.5 - 1	13	0.7	0.9	0	3.8
> 1	22.2				
Ethanol (g kg^{-1} DM)					
< 10	40.7				
10 - 20	37	14.3	8.6	3.5	36.1
> 20	22.2				

SD = Standard deviation.

Population of microorganisms

Of the silages evaluated, 61 % had an LAB population exceeding 6.0 CFU g^{-1} log (Table 5). After sealing the silo, there was an exponential increase in the population of LAB that normally stabilized and may have decreased with fermentation. Data in the literature shows that in experimental silos of corn silage, the LAB population was initially 8.54 log CFU g^{-1} which increased to values close to 9.08 log CFU g^{-1} after 10 days of fermentation. In extended fermentation periods, these values may decrease, as was noted by Santos et al. (2015), who observed a mean LAB population of 7.73 log CFU g^{-1} after 90 days of fermentation. In a farm-scale silo, under controlled conditions, a population of over 6 log CFU g^{-1} may be considered appropriate.

Undesirable microorganisms were found in considerably high numbers in silages. The mean population of enterobacteria was 4.23 log CFU g^{-1}, and 69 % of silages presented counts above 4.0 log CFU g^{-1}. While the mean population of aerobic spore-forming bacteria (mainly of the genus *Bacillus*) was 4.09 log CFU g^{-1}, 65 % of the samples had a population above 4.0 log CFU g^{-1}.

The yeast population averaged 3.82 log CFU g^{-1}, with a maximum of 7.12 log CFU g^{-1}. The maximum mold population was 5.73 log CFU g^{-1}; however, approximately 60 % of the samples showed a population above the mean.

Table 5 – Microbiology profile of corn silages from 54 dairy farms in Minais Gerais.

Variable	% results	Mean	SD	Minimum	Maximum
LAB (log UFC g^{-1})					
< 5	11.1				
5 - 6	27.8	6.25	1.08	3.54	7.97
> 6	61.1				
Enterobacteriaceae (log UFC g^{-1})					
< 2	14.8				
2 - 4	16.7	4.23	2.08	0	6.92
> 4	68.5				
Spores of aerobic mesophilic (log UFC g^{-1})					
> 2	13.0				
2 - 4	22.2	4.09	1.8	0	6.19
> 4	64.8				
Molds (log UFC g^{-1})					
< 2	38.9				
2 - 4	40.7	2.13	1.91	0	5.73
> 4	20.4				
Yeast (log UFC g^{-1})					
< 2	18.5				
2 - 4	27.8	3.82	2.20	0	7.12
> 4	53.7				

SD = Standard deviation.

Study of correlations

The linear correlation coefficients between pairs of variables are reported in Table 6. Farms with larger volumes of milk per day and larger size of silos produced silages with lower NDF concentrations (r = -0.29 and -0.34, respectively) and higher starch concentrations (r = 0.29 and 0.36), which is nutritionally more desirable. This suggests that the production of silages with high nutritive value is more challenging in small farming scenarios. Daily milk yield per farm was also positively correlated to silage pH (r = 0.70) and negatively correlated with acetic acid concentration (r = -0.30), suggesting that the challenge of obtaining adequate silage fermentation increased with larger silo sizes. These results may be associated with slower filling and inadequate packing of large silos as well as inadequate practices during silage unloading.

The correlation between silage NDF concentration and DM digestibility was negative (r = -0.55), as had been expected for corn silages (Fonseca et al., 2002; Khan et al., 2015). NDF digestibility was negatively correlated to silage NDF concentration (r = -0.35), which was unexpected, since immature corn plants have higher NDF concentrations and higher NDF digestibility than mature plants (Bal et al., 2000). A plausible explanation for this finding is that the height at harvesting had increased in farms with silage with low NDF concentrations, and the more indigestible fiber in stems close to the soil remained in the field during harvesting, although this could not be elucidated by the questions in our survey.

The degree of kernel processing (KPS) had a positive correlation with in vitro DM digestibility (r = 0.42), but NDF digestibility was not significantly correlated with DM digestibility. This data suggests that achieving adequate starch digestibility is more important than selecting or harvesting hybrids to achieve increased NDF digestibility as a route to obtaining highly digestible silage. The positive correlation between the KPS and in vitro digestibility of DM also suggests that kernel processing may have affected starch digestibility in the silo, since dried silage samples were ground to similar particle size before the in vitro incubations.

The higher the silage DM concentration, the lower the KPS (r = -0.66), the NDF digestibility (r = -0.43), the CP concentration (r = -0.27) and the concentration of lactic acid (r = -0.32) and the higher the particle size of the silage (r = 0.48). Advanced plant maturity (high DM concentration) had negative effects on kernel processing and silage fermentation profile and, as expected, reduced NDF digestibility and CP concentration (Bal et al., 2000).

Fermentation profile was not strongly correlated to nutritive value. None of the fermentation and microbiological variables were correlated to the digestibilities of DM and NDF, except ethanol (r = 0.28 with NDF digestibility). More digestible silages had more ethanol. The higher starch concentration in this silage can explain more water-soluble carbohydrates for fermentation and ethanol production by yeasts. The correlation between particle size (GMPS) with acetate concentration was negative (r = -0.28) and with yeast concentration was positive (r = 0.27), suggesting that long silage particles had a negative impact on fermentation profile and silage microbiology.

Significant correlations were observed between the silage's fermentative characteristics and its population of microorganisms. Negative correlations were observed between acetic and propionic acid concentrations and the populations of yeast, enterobacteria, and LAB (Table 6). According to Moon (1983), propionic acid, in combination with acetic acid, has a synergistic effect capable of reducing the growth of yeasts and molds. A positive correlation was also observed between the population of these aerobic deterioration microorganisms and the difference between the temperature of the silage and that observed in the environment, confirming that these microorganisms act as a major spoiler of silage when the silos are opened (Table 6).

Lactic acid content was positively correlated with the concentrations of acetic (r = 0.295) and propionic (r = 0.281) acids and ethanol (r = 0.397). This may possibly be related to LAB's heterofermentative metabolism.

It is possible that the inhibition of growth of *Enterobacteriaceae* was due to the metabolism of LAB, which promoted acidification of the silage. Negative correlation between the content of lactic acid and the pH value (-0.366) was observed between the silages evaluated. In addition, lower pH values were associated with lower yeast counts (0.285) and aerobic spore-forming microorganisms (0.294) as well as with silo capacity (0.550). Losses caused by *Enterobacteriaceae* metabolism and sporulating aerobic microorganisms during fermentation can be minimized through efficient ensiling practices that

Table 6 – Pearson correlation coefficients between variables of corn silages from 54 dairy farms in Minais Gerais.

Variable	MP	DM	CP	NDF	NFC	STA	IVDDM	GMPS	KPS	DNDF	MPT	pH	LAT	ACE	PROP	BUT	ETA	LAB	ENT	AME	FF	YET	CAP	FT	DRR	ST-AT
MP	**1**																									
DM	0.064	1																								
CP	-0.126	-0.272	1																							
NDF	**-0.292**	-0.019	0.038	**1**																						
NFC	0.265	0.093	-0.228	**-0.921**	**1**																					
STA	**0.292**	0.201	-0.160	**-0.894**	**0.850**	**1**																				
IVDDM	0.245	-0.184	0.031	**-0.551**	**0.450**	**0.485**	**1**																			
MPS	0.265	**0.483**	-0.204	-0.052	0.189	0.220	-0.082	**1**																		
KPS	0.187	**-0.660**	-0.042	-0.097	0.088	-0.009	**0.420**	-0.260	**1**																	
DNDF	-0.046	**-0.432**	0.188	**-0.352**	0.255	0.191	0.264	**-0.318**	0.185	**1**																
MPT	0.142	**-0.335**	0.110	**-0.748**	**0.656**	**0.573**	**0.450**	-0.187	0.242	**0.858**	**1**															
pH	**0.697**	0.072	-0.075	-0.108	0.134	0.071	0.106	0.101	0.092	-0.160	-0.028	**1**														
LAT	-0.261	**-0.316**	0.247	-0.084	0.038	0.092	0.088	-0.093	0.020	0.142	0.138	**-0.366**	**1**													
ACE	**-0.301**	-0.139	-0.145	0.011	0.008	0.016	-0.107	**-0.285**	-0.014	0.088	0.029	-0.212	0.295	1												
PROP	-0.208	-0.027	-0.024	-0.090	0.090	0.118	-0.159	-0.196	-0.108	-0.030	0.001	-0.115	**0.281**	0.785	1											
BUT	0.009	-0.081	-0.123	-0.042	0.085	0.015	-0.023	0.074	0.026	0.150	0.141	-0.007	0.102	0.323	0.325	1										
ETA	-0.125	-0.183	0.156	-0.032	-0.006	0.018	0.039	-0.105	0.013	**0.275**	0.198	-0.204	**0.397**	-0.012	0.052	0.062	**1**									
LAB	0.128	0.096	0.066	0.125	-0.082	-0.160	0.013	0.167	-0.017	0.121	0.019	0.146	-0.257	**-0.556**	**-0.649**	-0.114	0.000	**1**								
ENT	-0.013	0.186	-0.021	0.248	-0.218	-0.220	-0.070	0.140	-0.109	-0.172	-0.259	-0.074	**-0.333**	**-0.451**	**-0.522**	-0.116	**-0.386**	**0.511**	**1**							
AME	0.184	0.080	-0.060	0.137	-0.073	-0.233	-0.176	0.061	-0.071	0.129	0.033	**0.294**	**-0.312**	-0.226	-0.206	0.154	-0.058	0.261	0.106	**1**						
FF	-0.054	-0.142	-0.126	0.023	0.059	-0.061	-0.228	-0.102	-0.098	0.206	0.152	0.013	0.103	**0.277**	0.095	**0.325**	-0.095	0.052	-0.012	**0.380**	1					
YET	0.187	0.119	-0.100	0.132	-0.042	-0.225	-0.164	**0.274**	-0.221	-0.087	-0.133	**0.285**	-0.049	**-0.306**	**-0.316**	0.050	0.058	**0.521**	**0.297**	**0.424**	**0.408**	**1**				
CAP	**0.647**	0.111	-0.176	**-0.343**	**0.378**	**0.364**	0.219	0.201	0.170	-0.109	0.116	**0.424**	-0.074	-0.092	0.073	-0.092	0.123	-0.156	**-0.406**	0.197	0.082	0.117	**1**			
FT	-0.122	0.101	-0.067	0.231	-0.227	-0.213	-0.216	0.054	-0.144	-0.109	-0.211	-0.007	-0.002	**0.291**	**0.328**	**0.318**	0.243	-0.084	-0.178	-0.004	0.100	0.170	-0.025	**1**		
DRR	0.066	-0.025	-0.154	0.006	0.012	0.035	0.110	0.113	0.151	-0.215	-0.135	-0.007	0.008	0.056	0.041	-0.003	-0.025	-0.224	-0.189	-0.042	0.063	0.049	0.181	0.097	**1**	
ST-AT	-0.015	-0.083	0.095	-0.048	0.109	-0.005	-0.083	-0.113	-0.065	0.012	0.042	0.112	0.092	-0.059	-0.183	-0.193	-0.023	**0.305**	0.070	0.174	**0.366**	**0.297**	-0.013	-0.199	-0.001	**1**

Bold values are different from 0 with a significance level alpha = 0.05; MP = milk production (informed by the producer); DM = Dry matter; CP = Crude protein; NDF = Neutral detergent fiber; NFC = Non-fibrous carbohydrates; STA = Starch; IVDDM = Digestibility in vitro of DM; GMPS = Geometrical mean particle size; KPS = Kernel Processing Score; NDFD % NDF = NDF digestibility (DNDF); MPT = estimated milk t^{-1} (Shaver and Lauer, 2006); LAT = Lactic acid; ACET = Acetic acid; PROP = Propionic acid; BUT = Butyric acid; ETA = Ethanol; LAB = Lactic acid bacteria; ENT = Enterobacter; AME = aerobic mesophilic spores; FF =Molds; YET = yeasts; CAP = Capacity silo (m^3); FT = Fermentation time; DRR = Daily rate of removal; ST-AT = difference between the temperature of the silage and that observed in the environment.

reduce the concentration of oxygen in the silo and ensure the maintenance of the anaerobic conditions necessary for fermentation (Driehuis and Elferink, 2000).

The lower LAB population observed in the silages with higher acetic and propionic acid contents can be explained by the inherent sensitivity of the LAB's acidity conditions, since during the fermentation process even the species that are more resistant lose viability (Lin et al., 1992).

There was large variation in silage quality between farms sampled in the south of Minas Gerais, suggesting that there is opportunity for improvement in silage harvesting, storage, and unloading practices. Mean silage NDF concentration was high and DM concentration tended to be low, suggesting that immature harvesting was adopted to obtain adequate kernel processing with hard endosperm corn hybrids and pull-type silage harvesters. Silage nutritive value was not strongly correlated to silage fermentation profile, but was positively associated to the degree of kernel processing. Long particle corn silage had lower concentrations of acetic acid and higher yeast concentrations than short particle silage. In collaboration with local agencies for rural development, additional assistance, such as training and workshops, is needed for farmers in this part of the state to improve silage quality and increase the efficiency of dairy production systems.

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