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Quality of sorghum silage in the feed-out period: evaluation of hybrids, silo layers, and mass structure

Qualidade da silagem de sorgo no período de desensilagem: avaliação de híbridos, estratos do silo e estrutura da massa

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Abstract
This study aimed to evaluate the chemical and fermentation quality of silage from two sorghum hybrids in different layers of the silo feed-out face, as well as the interference of the aerobic exposure time of structured and/or unstructured silo face (after feed-out). The AG-2005E hybrid silage presented higher crude protein content and higher pH compared to hybrid AG-60298 (6.33% and 4.0 versus 6.06% and 3.8, respectively). Silages from stratum 0 to 20cm had the lowest dry matter content and the highest crude protein content (38% and 6.35%, respectively). The pH did not differ between layers, and the NH_3 content was higher in the stratum 60 to 80cm (4.5%). During 72 hours of aerobic exposure, the unstructured silage presented a higher increase in temperature than the silage from the structured face, but this period was not enough to result in differences in dry matter, mineral matter, NH_3, and pH. The chemical and fermentation quality of the silage was directly influenced by hybrid and silo stratum. After aerobic exposure, silage from the structured face seems to suffer less interference compared to the silo feed-out face.
Keywords: field evaluation; aerobic degradation; silo post-opening; nutritional quality; specific silage mass.

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Resumo
O objetivo deste trabalho foi avaliar a qualidade químico-fermentativa da silagem de dois híbridos de sorgo nos diferentes estratos da face do silo e a interferência do tempo de exposição aeróbia da face do silo estruturada e/ou desestruturada (após desensilagem). A silagem do híbrido AG-2005E apresentou maior teor de proteína bruta e pH mais elevado em comparação à do híbrido AG-60298 (6,33% e 4,0 contra 6,06% e 3,8, respectivamente). As silagens do estrato de 0 a 20 cm tinham o menor teor de matéria seca e o maior teor de proteína bruta (38% e 6,35%, respectivamente). O pH não diferiu entre os estratos e o teor de NH_3 foi maior no estrato de 60 a 80 cm (4,5%). Com o avanço das 72 horas de exposição aeróbia, a silagem desestruturada

apresentou maior incremento de temperatura em relação à silagem da face estruturada, mas esse tempo não foi suficiente para mostrar diferenças entre os teores de matéria seca, matéria mineral, NH_3 e pH. O híbrido de sorgo e o estrato do silo interferem diretamente na qualidade químico-fermentativa da silagem. Após a exposição aeróbia, a silagem do painel do silo estruturado parece sofrer menor interferência em relação à silagem após ser desensilada.
Palavras-chave: avaliação a campo; degradação aeróbia; pós-abertura do silo; qualidade nutricional; massa específica da silagem.

Introduction

Sorghum is often used in animal feed, most commonly as silage. In addition to being a good alternative feed for ruminants, recent studies have pointed out the use of sorghum silage to feed equines[1], increasing the need for understanding its quality.

As with other types of preserved foods, sorghum silage may have its nutritional value altered due to the procedures adopted for production, preservation, and use, through biochemical and microbiological phenomena occurring before and during the fermentation process, as well as in the silo feeding phase.

Handling after opening the silo is essential to maintain the quality of the silage, as a few hours of exposure to atmospheric air can compromise the entire storage process. At that moment, the anaerobic environment, one of those responsible for forage preservation, becomes aerobic, and with the penetration of oxygen into the ensiled mass, an intense multiplication of microorganisms and high nutrient consumption begin[2]. According to Montes *et al*.[3], these changes in silage are accompanied by an increase in pH, temperature, and ammonia nitrogen concentration. Therefore, monitoring these variables during the feed-out phase is important to assess the losses that have occurred.

Several studies have already been carried out aiming to quantify nutritional losses of silages in aerobiosis[4-5]. However, most are conducted using laboratory silos under controlled conditions and do not represent real field conditions, where there is a wide range of environmental temperature and the conditions for microorganism development are more favorable(6).

Another point to be considered is the specific mass achieved at the time of ensiling, since, according to Borreani *et al*.[6], the isolated factor that most influences the efficiency of silage preservation is the degree of anaerobiosis achieved in the silo. Amaral *et al*.[2] added that the specific mass interferes with the rate of air movement in the ensiled mass, and consequently with the potential for deterioration during storage and after opening the silo.

The different layers of the silo face exposed to the environment can present quantitative variations due to all these characteristics, as well as the early removal of the silage for feeding can lead to high losses. Thus, the objective of this study was to evaluate the chemical and fermentation quality of silage from two sorghum hybrids in different silo layers and the interference of aerobic exposure time on the silage from the structured and unstructured feed-out face of the silo.

Material and methods

The experiment was carried out at the Animal Science Department of the Federal University of Santa Maria, located in the Central Depression of the state of Rio Grande do Sul (RS). Soil in the area is classified as Dystrophic Red Clay. The implantation area is characterized by soil with a sandy and friable surface texture, being naturally acidic, poor in organic matter and most nutrients, with low base saturation. The region climate is Cfa - humid subtropical - according to the Köppen classification.

Upon planting the sorghum hybrids, the soil in the experimental area presented the following chemical properties: pH water: 5.0; P: 9.6mg L^{-1}; K: 69.6mg L^{-1}; OM: 2.9%; Al: 0.9 cmolc L^{-1}; Ca: 6.0 cmolc L^{-1}; Mg: 3.3 cmolc L^{-1}; Effective CEC: 10.5 cmolc L^{-1}; and base saturation: 60%. Crops were planted in a no-tillage system on a residual straw of the forage mixture of black oat (*Avena strigosa*) and Italian ryegrass (*Lolium multiflorum*) dried with Glyphosate. Seeds of the dual-purpose sorghum hybrids AG-2005E and AG-60298 were previously treated with Thiodicarb-basedinsecticide and sown at a spacing of 90 cm between rows and a seed depth of 1 cm. Sowing density was adjusted aiming at a final population of 160,000 plants ha^{-1}.

Basal fertilization consisted of 300 kg ha^{-1} 10-18-20 fertilizer (N-P_2O_5-K_2O), and 35 days after planting, 150 kg ha^{-1} topdressing urea was applied. The management of sorghum crops did not involve agronomic practices to control weeds and diseases with chemical products or crop practices.

Hybrids were harvested when the hybrids were between the floury and doughy grain stages at a cutting height of 20 cm from the ground level. Plants were chopped with the aid of an ensilage machine adjusted to an average particle size of 1 cm. The collected material was stored in surface silos with 1.0 m in height, 4.5 m in width, and 8.0 m in length, compacted (Table 1), and sealed with a 150 μm polyethylene canvas.

Table 1. Silage specific mass (kg of NM m^{-3}) of sorghum hybrids AG-2005E and AG-60298, as a function of mass characteristics (structured and unstructured) during feed-out and silo layer

Hybrid	Silo face	Silo layer, cm				Average
		0 a 20	20 a 40	40 a 60	60 a 80	
AG-2005E	Structured	508.4	442.5	375.0	364.2	422.5
	Unstructured	338.9	385.0	250.0	242.8	281.7
AG-60298	Structured	583.3	532.4	500.0	450.0	516.4
	Unstructured	354.8	323.9	304.2	273.7	314.2

Silos were opened 180 days after silage making. Aspects related to the quality of the silage and process of the feed-out phase were evaluated, comparing the aerobic degradation of the compacted material on the face of the structured silo with the material on the face of the removed and unstructured silo of the materials evaluated.

Both the exposure of the silo face (structured silo face) and the surface placed in the wooden box (unstructured silo face) were delimited in a mosaic system, consisting of four layers (0 to 20 cm, 20 to 40 cm, 40 to 60 cm and 60 to 80 cm), in which each stratum has dimensions of 20 cm in height, 30 cm in width and 20 cm in length.

A 20 cm long slice of the silo face (80 cm high, divided into four layers: 0 to 20 cm, 20 to 40 cm, 40 to 60 cm, and 60 to 80 cm) was taken, and then weighed and packed in a wooden box with the same height (80 cm) and width (3.0 m) as the silo. After that, the silo face was left as homogeneous as possible (Figure 1).

Figure 1. Structured silo face (panel) and unstructured (box), and silo layers (0 to 20 cm, 20 to 40 cm, 40 to 60 cm and 60 to 80 cm).

During the experimental period, the temperatures of the silages in the different layers of the silo were measured with a rod thermometer inserted 10 cm into the mass, at different times of aerobic exposure (0, 6, 12, 18, 24, 30, 36, 48, 60 and 72 hours after opening the silo). Samples (300 g) were also collected from each stratum for chemical analysis.

Aliquots of the samples were pressed in a cover pump to extract the juice from the silage and used for pH analysis, using a digital potentiometer (Digimed) and ammonia nitrogen as a percentage of total nitrogen (NH_3 TN^{-1}), according to the technique described by AOAC[7].

Another part of the silage samples was weighed and pre-dried in a forced air oven at 55℃ for 72 hours, then they were ground in a Wiley mill with a 1 mm mesh sieve. In pre-dried and ground samples, the total dry matter content at 105 ℃ and total nitrogen (TN) were determined by the micro Kjeldahl method - being multiplied by the factor 6.25 to obtain the crude protein and mineral matter content by incineration at 550 ℃, according to AOAC[7].

The experiment was carried out in a 2 × 2 × 10 factorial arrangement, with two sorghum hybrids (AG-2005E and AG-60298), two removing conditions (structured and unstructured silo face), and 10 times of aerobic exposure of the silage (0, 6, 12, 18, 24, 30, 36, 48, 60, 72 hours), in a randomized block experimental design, with four replications, using split-plots so that the effect of the sorghum hybrid was placed in the main plots (structured and unstructured face of the silo), with the face of the silo organized in blocks (depth of the silo layer: 0 to 20 cm, 20 to 40 cm, 40 to 60 cm and 60 to 80 cm) and the aerobic exposure times (10 strokes) in the sub-plots, these being randomly assigned to the main plots. Data collected for each parameter were tested by analysis of variance, through the statistical program SAS (1993), and the differences between the means were analyzed by Tukey's test at a significance level of 5%.

The statistical model used was as follows: $Y_{ijk1m} = \mu + HS_i + EM_j + ES_k + (HS*EM)_{ij} + (HS*EM*ES)_{ijk} + TE_1 + (HS*NT)_{i1} + (EM*NT)_{j1} + (HS*EM*TE)_{ijk1m}$; where Y_{ijk} = dependent variables; μ = mean of observations; HS_i = effect of hybrid sorghum of order "*i*", being 1 - sorghum silage AG-2005E and 2 - sorghum silage AG-60298; EM_j = effect of the structure of the removed mass of order "*j*", being 1 - structured silage and 2 - unstructured silage; ES_k = effect of the depth of silo stratum of order "*k*", being 1 - 0 to 20 cm, 2 - 20 to 40 cm, 3 - 40 to 60 cm and 4 - 60 to 80 cm; $(HS*EM)_{ij}$ = effect of interactions between the *i*-th sorghum hybrid and the *j*-th structure of the removed mass; $(HS*EM*ES)_{ijk}$ = random effect based on repetition within the combination $(HS*EM)_{ij}$ (Error a); TE_1 = effect of aerobic exposure time of order "*k*" silage, being 1 - 0 hours, 2 - 6 hours, 3 - 12 hours, 4 - 18 hours, 5 - 24 hours, 6 - 30 hours, 7 - 36 hours, 8 - 48 hours, 9 - 60 hours and 10 - 72 hours; $(HS*TE)_{i1}$ = effect of the interaction between the *i*-th sorghum hybrid and the *1*-th aerobic exposure time of the silage; $(EM*TE)_{i1}$ = effect of the interaction between the *j*-th of the removed mass structure and the *1*-th aerobic exposure time of the silage; $(HS*EM*TE)_{ij1}$ = effect of the interaction between the *i*-th sorghum hybrid and the *j*-th of the removed mass structure and the *1*-th aerobic exposure time of the silage; E_{ijk1m} = residual random error (error b), assuming normal distribution equal to zero and variance^2.

Data relating to temperature, dry matter, mineral matter, crude protein, ammonia nitrogen, and silage pH were also subjected to polynomial regression analysis, considering variables of hours of aerobic exposure through the PROC REG procedure of the SAS software (1993).

Results and discussion

The interaction $(HS*EM*TE)_{ij1}$ was initially tested, but due to the low magnitude, it was removed from the statistical model. Even though at the harvest time the two hybrids had similar dry matter content, after opening the silos, the silage of hybrid AG-60298 recorded lower dry matter than hybrid AG-2005E (38.3% and 42.1%, respectively; Table 2), which may be a reflection of the greater specific mass in the silage of hybrid AG-60298 (516.4 against 422.5 kg NM m^{-3}; Table 1), which according to Loures[8], leads to greater production and/or losses as effluent and consequent increase in the dry matter content.

Table 2. Dry matter, ash, and crude protein content of silages of sorghum hybrids AG-2005E and AG-60298, as a function of silo layer

Hybrid	Silo layer, cm				Average
	0 a 20	20 a 40	40 a 60	60 a 80	
			Dry matter, % AF		
AG-2005E	39.2	42.6	44.7	41.9	42.1^{A}
AG-60298	36.8	39.4	40.1	36.8	38.3^{B}
Average	38.0^{c}	41.0^{ab}	42.4^{a}	39.4^{bc}	
			Ash, % DM		
AG-2005E	4.8	4.7	4.4	4.6	4.6^{A}
AG-60298	4.8	4.3	4.7	4.6	4.6^{A}
Average	4.8^{a}	4.5^{a}	4.6^{a}	4.6^{a}	
			Crude protein, % DM		
AG-2005E	6.44	6.35	6.22	6.29	6.33^{A}
AG-60298	6.26	6.09	6.01	5.88	6.06^{B}
Average	6.35^{a}	6.22^{ab}	6.11^{b}	6.09^{b}	

Different uppercase letters, in the column, differ the hybrids by the F test at 5%.
Different lowercase letters, in the line, differ the silo strata by the Tukey test at 5%.

The silage contained in the 0 to 20 cm stratum had the lowest dry matter content (38.0%) due to the gravitational effect on water contained in the entire silo. However, silages from this stratum did not differ significantly from the silages from the stratum closest to the sealing polyethylene (60 to 80 cm). In this case, high ambient temperatures stimulate an increase in temperature inside the silo, causing the accumulation of sweat on the covering canvas, raising the moisture of silages.

Along with a large part of the extracellular water that falls to the lower part of the silo, several organic compounds are carried, such as sugars, organic acids, and soluble nitrogen compounds[8]. Thus, silages from the lowest stratum (0 to 20 cm) had the highest crude protein content (6.35%), while the silages from the upper stratum (40 to 60cm and 60 to 80cm) had 6.11% and 6.09%, respectively.

There was a difference ($P<0.05$) for crude protein between sorghum hybrids. Silage of hybrid AG-2005E had 6.33%, while the silage of hybrid AG-60298 had a crude protein content of 6.06%. This difference is basically due to the expression genetic of the hybrids regarding this nutrient[9]. Similar results were described by Machado *et al*.[10], with an average of 6.17% of crude protein for three sorghum hybrids at a similar harvest stage.

McDonald *et al*.[11] stated that more than 75% nitrogen found in silages is represented by true protein, but that protein degradation by enzymes, lactic, enteric, and clostridium bacteria can significantly change the composition of the nitrogen fraction, even generating an increase and/or high levels of ammonia nitrogen. As the procedures for making silages were adequate, neither high levels of NH_3 nor differences were detected between the silages of the evaluated hybrids (Table 3).

Table 3. NH_3 content and pH of silages from sorghum hybrids AG-2005E and AG-60298, as a function of silo layer

Hybrid	Silo layer, cm				Average
	0 a 20	20 a 40	40 a 60	60 a 80	
			NH_3, % TN		
AG-2005E	4.2	3.3	4.2	4.7	4.1^{A}
AG-60298	3.6	3.7	3.8	4.2	3.8^{A}
Average	3.9^{ab}	3.5^{b}	4.0^{ab}	4.5^{a}	
			pH		
AG-2005E	3.90	4.01	3.95	3.98	4.0^{A}
AG-60298	3.78	3.71	3.79	3.87	3.8^{B}
Average	3.84^{a}	3.86^{a}	3.87^{a}	3.93^{a}	

Different uppercase letters, in the column, differ the hybrids by the F test at 5%.
Different lowercase letters, in the line, differ the silo strata by the Tukey test at 5%.

As for the silo layer, the highest NH_3 content was found in silages in the 60 to 80 cm stratum, but differing only from silages in the 20 to 40 cm stratum ($P<0.05$). As NH_3 is in the form of a gas with high volatility, it is more common to concentrate in the upper layer of the silo. Regarding the result found for the lower stratum, the higher protein content present in this stratum may have caused these NH_3 contents.

NH_3 contents described indicate that the silages had good fermentation during storage. According to Neumann[12], the first qualitative variations observed after opening the silo affect the NH_3 content and pH of the silage, therefore, the evaluation of the two parameters described in Table 3 are excellent for evaluating silage quality.

Silage of hybrid AG2005E had a higher pH than the silage of hybrid AG-60298 (4.0 versus 3.8). The higher dry matter content of hybrid AG-2005E determined lower specific mass in the silage, which, according to Machado *et al*.[10] may hinder the fermentation and distribution of the produced acids, resulting in higher pH.

Results described by Neumann *et al*.[12] show that in corn silage the greatest deterioration occurs in the upper stratum of the silo, due to the rise in temperature and higher pH values. In the present study, despite the differences in specific mass and dry matter between the evaluated layers, the pH did not show any significant difference.

Figure 2 illustrates the comparative behavior and regression equations for sorghum hybrids for temperature (a), dry matter (b), mineral matter (c), and crude protein (d). Figure 3 shows the same variables (e; f; g; h) for silages from the structured and unstructured face of the silo. Results of both tables were discussed simultaneously to facilitate comparisons.

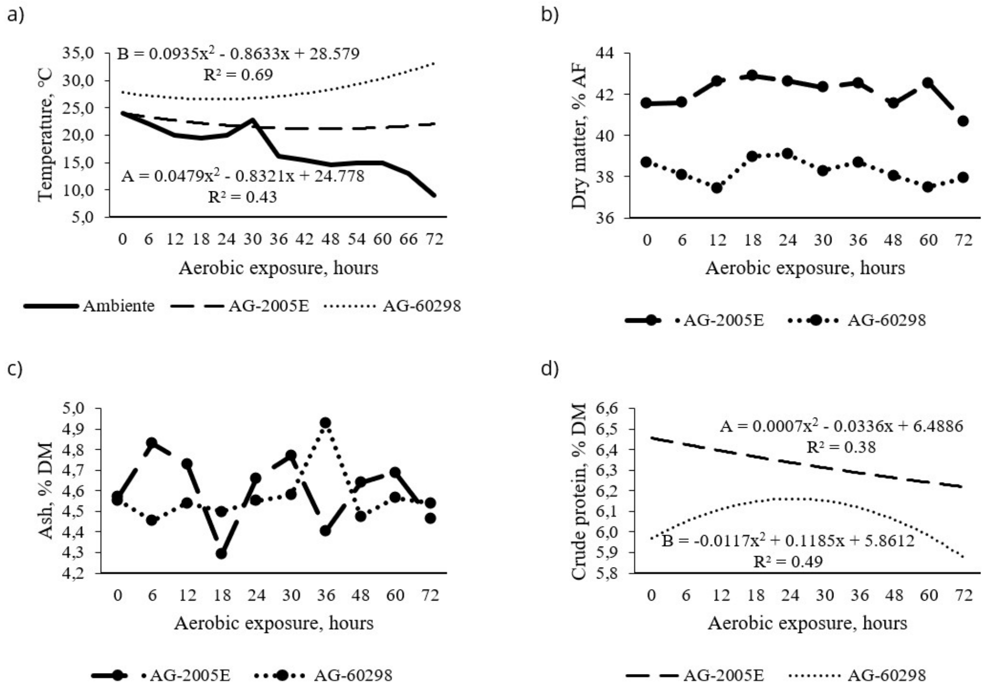

Figure 2. Temperature (a), dry matter (b), ash (c), and crude protein (d) of the silages of sorghum hybrids AG-2005E and AG-60298, as a function of different aerobic exposure times

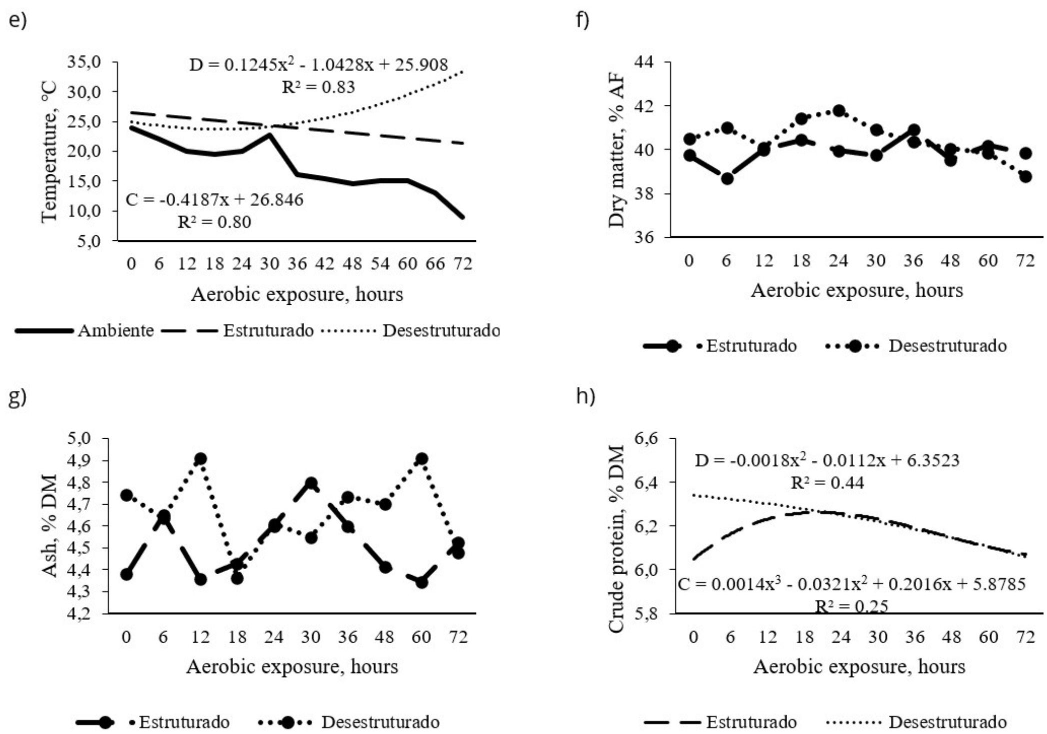

Figure 3. Temperature (e), dry matter (f), ash (g), and crude protein (h) of the silages of the structured and unstructured face of the silo in the removed mass as a function of the different times of aerobic exposure (Regression equations: C = structured; D = unstructured)

The temperature rise of silages differed between the hybrids, with a quadratic behavior for both. The silage of hybrid AG-60298 presented a higher temperature than the silage of hybrid AG-2005E since silo opening (a).

A quadratic trend is also observed in silage from the unstructured face of the silo (e), with a more significant increase after 36 hours of evaluation. This is an indication that animals can have their performance decreased, in addition to being exposed to toxins, when fed silage exposed to air for long periods, because, according to Weinberg[13], this temperature increase occurs simultaneously with the development of microorganisms and nutrient consumption. The structured face silage showed a decreasing linear behavior, following more closely the ambient temperature.

Ashbell[14] and Zhang[15] explain that between 20 and 30 ℃ there is maximum development of yeasts in silage when exposed to air and that at temperatures below 20 ℃, the silage becomes more stable. Thus, the drop in ambient temperature (below 20 ℃) observed after 36 hours of evaluation (a; e) makes further conclusions in this regard difficult. It is not possible to infer that this behavior is the same when temperatures can be substantially warmer, but it can be stated that air penetration results in higher silage temperatures.

There was no statistical difference between silages of hybrids AG-60298 and AG-2005E for dry matter content as a function of the hours of aerobic exposure. Also, no significance was detected between the structured and unstructured silo face silages for the same variable.

The 72-hour time was not enough to result in differences for ash content of the silages (c; g). The few variations observed with the advance of hours are related to changes in the relative humidity of the ambient air and its interference with the moisture content of the silage. Tabacco *et al*.[4] described a significant increase in ash and crude protein contents of sorghum silage after 7 and 14 days of aerobic exposure. According to these authors, with the initial consumption of carbohydrates by deteriorating microorganisms, there is a concentration of these nutrients in the dry matter.

In the present study, there was a decrease ($P<0.05$) in the crude protein contents as a function of the aerobic exposure time, both for the hybrids (d) and for the structured and unstructured faces of the silo (h). With the revolving of the ensiled mass, the nitrogen that makes up much of the crude protein may have been more easily volatilized in the first hours[16], explaining the more accentuated decline in silage from the unstructured face of the silo.

Nout[17] also suggests that molds may act in silages with higher pH and that they have the potential to degrade more complex components, such as proteins. Even though silage from hybrid AG-2005E had a higher pH (j) and coincidently a more abrupt drop in the crude protein content (d), it cannot be said that there was an action of molds, as the pH of both silages was below 4 (Figure 4).

Ammonia nitrogen contents did not change according to aerobic exposure time, indicating good silage preservation during the 72 hours in which they were evaluated.

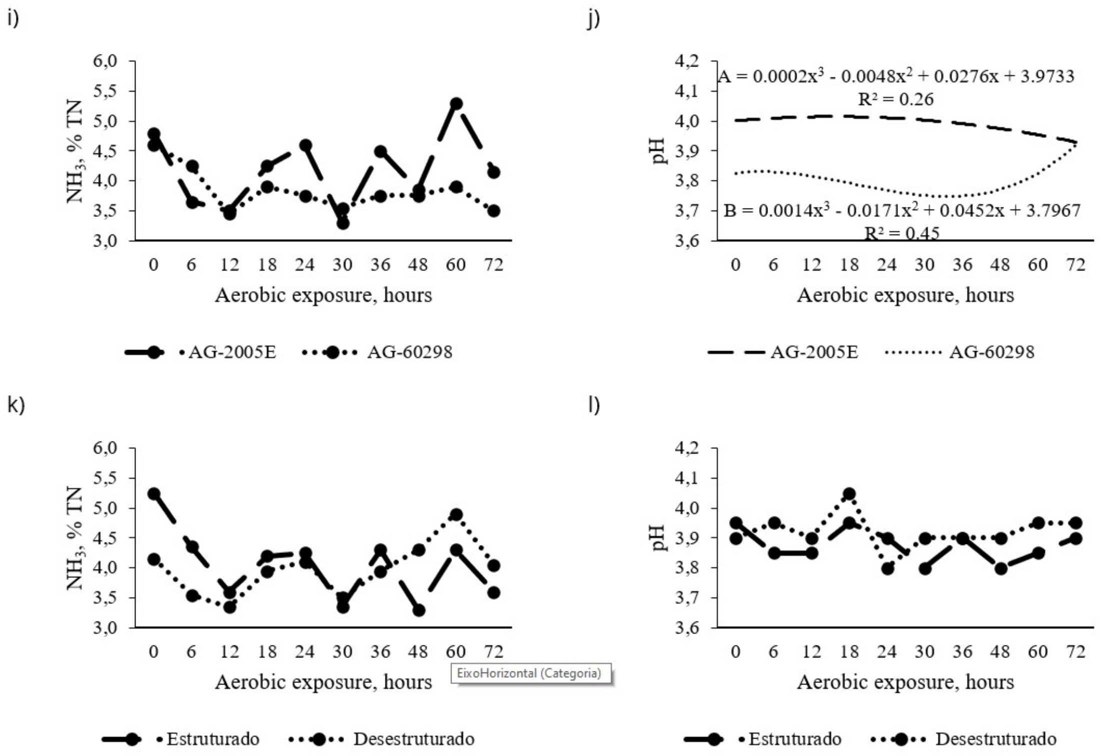

Figure 4. Ammonia nitrogen (i; k) and pH (j; l) of sorghum hybrids AG-2005E and AG-60298 silages and silo face in removed mass as a function of different aerobic exposure times (Regression equations: A = AG-2005E; B=AG-60298).

Conclusion

The sorghum hybrid directly affects the chemical and fermentation quality and the silage characteristic after opening the silo. Silage quality also changes according to the silo layer, mainly as a result of the specific mass achieved at each point. After exposure to air, silage from the structured silo face seems to suffer less interference in quality compared to silage after being removed. Studies with similar conditions, for longer periods, are required for more accurate conclusions.

Conflict of interests

The authors declare no conflict of interest.

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