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# THE EFFECT OF HARVEST DATE AND ADDITIVES ON CHEMICAL COMPOSITION AND AEROBIC STABILITY OF SORGHUM SILAGE

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## ABSTRACT

The objective of the experiment was to determine the effect of harvest date of sweet sorghum forage and the addition of bacterial, bacterial-chemical or chemical additives on chemical composition, fermentation quality and aerobic stability of the silages obtained. Sweet sorghum (Sorghum saccharatum, cv. Sucrosorgo 506) forage mown at two dates (E – 28 September 2008 and L – 13 October 2008) was ensiled in 120 L experimental silos. Forage from each harvest date was ensiled without (E-UT, L-UT) or with the addition of Lactobacillus buchneri ($5.0\times10^5$ cfu·g$^{-1}$ of forage) – E-LB, L-LB; L. buchneri ($5.0\times10^5$ cfu·g$^{-1}$of forage) with potassium sorbate (0.3 g·kg$^{-1}$ of forage) – E-LBS, L-LBS; propionic acid, formic acid and ammonium propionate (3 ml·kg$^{-1}$ of forage) – E-PFA, L-PFA. Both, forage harvest date and applied additives had a significant effect ($P<0.001$) on dry matter (DM), crude protein (CP) and true protein (TP), water-soluble carbohydrates (WSC), neutral-detergent fibre (NDF), acid-detergent fibre (ADF) and the starch content in silages. All the additives limited the degradation of protein to ammonia. The additives prevented butyric fermentation and limited ($P<0.001$) alcoholic fermentation in the silages. Forage harvest date itself had no influence on the silage aerobic stability. However, significant interaction between the effect of harvest date and additives was found. The duration of aerobic stability was 36-41 h for untreated silages, 84-88 h for silages with L. buchneri, 95-99 h for silages with L. buchneri and potassium sorbate, and 66-68 h for silages with the chemical preservative.

**Key words:** sorghum silage; harvest date; additives; chemical composition; aerobic stability

## INTRODUCTION

In many regions of Europe, whole-plant maize silage is the basic feed used in the feeding of dairy cows and fattening cattle. Over the last five years, in some Central European countries, especially in Poland, maize cultivation has been going through an increasingly difficult period due to extreme weather conditions, such as drought and lack of precipitation. Artificial irrigation of plants would help to maintain high maize yields, but this procedure cannot be used because of the high water deficit in Poland. The growing problems in maize cultivation have caused a necessity to find alternative plants suitable for cultivation in the climatic and soil conditions of Poland.

Sweet sorghum (Sorghum saccharatum L.) is an alternative ensilage material, which can be used to replace or supplement maize, because water requirements for sorghum are low and vary between 450 - 650 mm during the vegetation period (Critchley and Siegert, 1991). Sweet sorghum is adapted to the drier climates due to the ability of leaves to roll, what reduces transpiration and large number of fibrous roots that multiply water absorption area (Bennett et al., 1990). In the Polish climatic conditions, sorghum forage for ensiling is harvested at the heading or half bloom stage, which corresponds to the period of

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maize harvested for silage. Sorghum forage, mown at the above-mentioned stages of growth, is characterized by a lower DM content (not exceeding 240 g·kg$^{-1}$), but contains more WSC, NDF and ADF compared to a whole-plant maize forage (Podkówka, 2006; Śliwiński and Brzóska, 2006). Delaying sorghum harvest date until the end of October increases the DM content of plants but reduces the energy value and nutrient digestibility, which is due to the ongoing process of plant cell wall lignification (Podkówka, 2006; Śliwiński and Brzóska, 2006). In ensiled forage, which has a low DM and a high WSC content, the fermentation process is very intensive and the resulting silages are rich in lactic acid (LA). Silages with a high LA concentration and a low DM content are particularly susceptible to aerobic deterioration once the silage has been exposed (Ohmomo et al., 2002). Thus, increasing the aerobic stability of sorghum silages is an important issue, especially when sorghum silage is the only feed in the ration for calves or dry cows.

The high fermentation quality and increased aerobic stability of silages made from fresh forage can be obtained by ensiling sorghum with bacterial inoculants containing heterofermentative lactic acid bacteria or chemical preservatives containing mixtures of low-molecule organic acids and their salts (Henderson, 1993; Holzer et al., 2003; Kung et al., 2004). By degrading LA, heterofermentative strains of Lactobacillus buchneri bacteria produce several metabolites, mainly acetic acid (AA), which reduces the population of yeasts responsible for aerobic deterioration of silages (Driehuis et al., 1999; Oude Elferink et al., 2001; Holzer et al., 2003). Organic acids added to ensiled forages prevent or limit butyric fermentation, reduce DM losses, protein and WSC breakdown during fermentation, and limit the growth of yeasts and moulds in silages (Henderson, 1993; Kung et al., 2000; Selwet, 2005; Slottner and Bertilsson, 2006; Stryszewska and Pyś, 2006).

The aim of the present study was to determine the effects of harvest date of sweet sorghum forage and the addition of Lactobacillus buchneri bacteria (with or without potassium sorbate) and a mixture of propionic acid, formic acid and ammonium propionate on fermentation quality, chemical composition and aerobic stability of the silages obtained.

## MATERIAL AND METHODS

### Materials and experimental design

The experiment was carried out at the Experimental Unit and laboratory of the Department of Animal Nutrition and Feed Management, University of Agriculture in Krakow, Poland (50° 03' 41" N, 19° 56' 18" E). In the experiment, sweet sorghum (cv. Sucrosorgo 506) forage, obtained from field cultivation (Top Farms in Głubczyce - 50° 12' 00" N, 17° 50' 03"E, 357 meters above sea level) was mown at two dates (E - 28 September 2008 – half bloom stage of growth; L - 13 October 2008 – soft dough stage of growth) and ensiled. Forage was mown using a Claas Jaguar 840 self-propelled forage harvester equipped with a roller and cut into 15-20 mm particles.

The forage from each harvest date was ensiled without an additive (as a control variant) – E-UT and L-UT; with a Lalsil Fresh LB bacterial additive (Lactobacillus buchneri – $5.0\times10^5$ cfu·g$^{-1}$ of forage) – E-LB and L-LB; with a bacterial-chemical additive composed of Lalsil Fresh LB inoculant (Lactobacillus buchneri – $5.0\times10^5$ cfu·g$^{-1}$ of forage) and potassium sorbate (PS) (0.3 g·kg$^{-1}$ of forage) – E-LBS and L-LBS; and with an Euromold®L-Plus MC chemical additive (3 ml·kg$^{-1}$ of forage) – E-PFA and L-PFA. The chemical preparation contained 45% of PA, 30% of formic acid (FA) and 15% of ammonium propionate (AP) per 1 litre. To make E-UT and L-UT silages, freshly cut and chopped forage was compacted in the silos. To make E-LB, L-LB, E-LBS and L-LBS silages, chopped forage was placed on polyethylene sheeting, volume-sprayed with water extracts appropriate for each variant of bacterial or bacterial-chemical inoculant (5 g of inoculant per 4 l of water per 1 tone of forage), and the whole forage was thoroughly mixed and compacted in the silos. To make

E-PFA and L-PFA silages, forage was volume-sprayed with a chemical additive. Sorghum was ensiled in 120 L polyethylene experimental silos closed with latch covers to allow fermentation gases to escape. Each silage variant was made in four replicates. The silos with ensiled biomass were stored in a closed facility at 15±2°C for 60 days.

### Chemical analysis

Forage and silages were analyzed for the dry matter content by drying the samples at 105°C for 12 h. The DM content of silages was corrected to volatile losses (Dulphy and Demarquilly, 1981). The buffering capacity of forage was determined according to Playne and McDonald (1966). To determine pH, weighted portions (50 g) of silages (collected immediately after the opening of silo) were placed into glass containers, soaked with distilled water to a volume of 500 ml and placed into a cold store room (5°C for 24 h). The solution was then filtered through a soft filter paper No. 388 (FILTRAK, Germany) into an Erlenmayer flask. The pH of the filtrate was determined using a pH Ion Analyser MA 235 (METTLER TOLEDO, Switzerland). The concentrations of LA, AA, PA, FA and butyric acid (BA) in silages were determined using a liquid chromatography. Weighted samples of silages (50 g) were soaked with distilled water (at a ratio of 1:3), mixed for 1 min, and filtered through a soft filter paper No. 388 (FILTRAK, Germany) into an Erlenmayer flask. The filtrate was mixed with

0.05 M $H_2SO_4$ (at a ratio of 9:1) and frozen at –20°C until further analysis. After thawing and filtering the solution through a hard filter paper No. 390 (FILTRAK, Germany), the analysis was performed using an LC 5000 liquid chromatograph with a UV/VIS detector (INGOS, Czech Republic) and an Ostion LG-KS0800 $H^+$ column (TESSEK, Czech Republic). Operating parameters were: column temperature 50°C, mobile phase 0.005 M $H_2SO_4$. The ethanol content in the silage was determined using gas chromatography. The water filtrate of the silages was mixed with 30% metaphosphoric acid (at a 5:1 ratio) and frozen until further analysis. After thawing and filtering the solution through a hard filter paper No. 390 (FILTRAK, Germany), the analysis was performed using a Varian Star 3400 CX gas chromatograph (VARIAN, USA) with an FID detector and a DB-FFAP capillary column (30 m in length x 0.53 mm in diameter), using argon as carrier gas. Column operating temperature was 90-205°C, sample injector temperature - 200°C and detector temperature - 240°C. The determination of organic acids and ethanol in the silages was done using an external standard. The $NH_3$-N content of water extracts from silages was determined using Conway's method (1962).

Forage and silage samples intended for further chemical analyses were dried at 50°C for 48 h and ground in a Fritsch Pulverisette 15 laboratory mill (FRITSCH, Germany) into 1.0 mm sieve size. The samples for further research were analysed for the levels of crude ash (AOAC, 2005) and crude fat (AOAC, 2005) using an Ankom XT 15 extractor (ANKOM, USA). The total-N content was determined according to Kjeldahl (AOAC, 2005), and protein-N according to Licitra et al. (1996), using a Kjeltec™ 2200 unit (FOSS, Denmark). The NDF, ADF and ADL (acid-detergent lignin) were determined according to Goering and Van Soest (1970), using an Ankom$^{220}$ Fibre Analyser (ANKOM, USA). Cellulose content was calculated from the difference between ADF and ADL, whereas hemicellulose content was determined from the difference between NDF and ADF. Starch content was determined using the method of Faisant et al. (1995), while WSC content - using the colorimetric method (Dubois et al., 1956).

**Measurement of aerobic stability**

Aerobic stability of sorghum silages was tested for 7-d in an air-conditioned facility at ambient temperature of 20±1°C, using the Honig's method (1985). The temperature of the silages was measured in the conditions of aerobic exposure using a Squirrel 2020 data logger (GRANT, Great Britain). Temperature was logged at 60-minute intervals as a means from two measurements taken 30 minutes apart. The aerobic stability was measured concerning the number of hours during which the temperature of silages did not exceed ambient temperature of the air-conditioned facility by 3°C (Honig, 1985).

**Calculations and statistics**

The results of chemical analysis of silages and the aerobic stability test were analyzed using the GLM procedure of SAS Version 9.1 (SAS, 2004). The following equation was used as a model for the comparison of the effect of harvest date and addition of silage preparations on chemical composition and aerobic stability of silages:

$$Y_{ij} = \alpha_i + \beta_j + \alpha\,\beta_{ij} + \varepsilon_{ijk},$$

where: $Y_{ij}$ is the observation, $\alpha_i$ is the effect of harvest date (i=2), $\beta_j$ is the effect of additive used (j=3), $\alpha\,\beta_{ij}$ is the effect of interaction between harvest date and additive used, $\varepsilon_{ijk}$ is the residual error. In case of a significant harvest date and additive interaction the means were separately compared using the PDIFF option and the Benferroni *t* procedure.

## RESULTS

The nutrient content and buffering capacity of sorghum forage are presented in Table 1. In sorghum plants, the concentration of most nutrients increased as vegetation progressed. The highest increase was concerning WSC and starch, the content of which in the forage from the later harvest date was 39% and 76% higher, compared to the earlier harvest date. The CP, TP and cellulose content in sorghum forage decreased as vegetation progressed. The increased WSC and starch content, paralleled by a lower concentration of CP, reduced the buffering capacity of forage from the later harvest date.

**Table 1: Chemical composition and buffering capacity of sorghum forage**

| Item | | Harvest date E | Harvest date L |
|---|---|---|---|
| Dry matter | (g·kg$^{-1}$) | 224.5 | 234.5 |
| | | (g·kg$^{-1}$ DM) | |
| Crude ash | | 61.4 | 61.8 |
| Crude protein | | 81.2 | 77.2 |
| True protein | | 58.9 | 52.1 |
| Crude fat | | 20.9 | 24.5 |
| NDF | | 598.0 | 619.9 |
| ADF | | 351.4 | 359.0 |
| ADL | | 35.3 | 46.9 |
| Cellulose | | 316.1 | 312.1 |
| Hemicellulose | | 246.6 | 260.2 |
| Starch | | 48.7 | 80.8 |
| WSC | | 159.9 | 198.3 |
| Buffering capacity | (meq·kg$^{-1}$ DM) | 247.0 | 202.0 |

Table 2 shows the nutrient content in sorghum silages made without additives (E-UT, L-UT) and with the addition of bacterial inoculant (E-LB, L-LB), bacterial-chemical inoculant (E-LBS, L-LBS) or chemical preservative (E-PFA, L-PFA). Both, forage harvest date and the silage additives had significant effect (P<0.001) on DM, CP and TP, WSC, NDF, ADF and starch content in silages. E-UT and L-UT silages had the lowest concentration of CP and TP. The level of these components was found to be increased in all the silages made with the additives. The greatest amount of CP and TP was found in E-PFA and L-PFA silages. E-UT, E-LB, E-LBS and E-PFA silages were characterized by a higher content of CP and TP compared to the level of these components in L-UT, L-LB, L-LBS and L-PFA silages, but the differences were not significant (P>0.05).

**Table 2: Chemical composition of sorghum silages**

| Type of silage | Dry matter | Crude protein | True protein | WSC | NDF | ADF | Starch |
|---|---|---|---|---|---|---|---|
| | (g·kg$^{-1}$) | (g·kg$^{-1}$ DM) | | | | | |
| E-UT | 212.3$^{ad}$ | 69.6 | 46.1 | 78.1$^{a}$ | 596.9 | 351.8 | 46.7 |
| E-LB | 209.3$^{a}$ | 75.1 | 50.3 | 87.0$^{e}$ | 600.3 | 349.2 | 47.3 |
| E-LBS | 210.2$^{a}$ | 76.4 | 50.7 | 86.8$^{e}$ | 601.1 | 353.4 | 48.0 |
| E-PFA | 218.9$^{be}$ | 78.0 | 53.9 | 125.1$^{d}$ | 603.2 | 354.0 | 50.3 |
| L-UT | 223.2$^{b}$ | 66.4 | 40.3 | 95.4$^{b}$ | 616.7 | 360.7 | 77.3 |
| L-LB | 215.1$^{de}$ | 71.2 | 45.0 | 97.1$^{b}$ | 620.6 | 352.3 | 78.3 |
| L-LBS | 216.2$^{de}$ | 72.3 | 46.3 | 95.8$^{b}$ | 619.5 | 362.0 | 79.9 |
| L-PFA | 228.1$^{c}$ | 75.5 | 47.6 | 165.9$^{e}$ | 622.6 | 364.2 | 82.6 |
| SEM | 2.30 | 1.37 | 1.46 | 10.10 | 3.77 | 1.95 | 5.98 |
| Effect of: | | | | | | | |
| - harvest date | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 |
| - additive | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 |
| - harvest date × additive | 0.03 | 0.73 | 0.73 | <.001 | 0.72 | 0.05 | 0.75 |

$^{a-e}$ Means in the same column followed by different superscript letters differ significantly; SEM – standard error of mean

**Table 3: pH value, $NH_3$-N (g·kg$^{-1}$ of total-N), organic acids (g·kg$^{-1}$ DM) and aerobic stability (h) of sorghum silages**

| Type of silage | pH | $NH_3$-N | Ethanol | Lactic acid | Acetic acid | Propionic acid | Formic acid | Butyric acid | LA/TA (%) | Aerobic stability |
|---|---|---|---|---|---|---|---|---|---|---|
| E-UT | 3.80 | 65.9$^{a}$ | 19.4$^{a}$ | 85.3 | 24.0 | 0.0 | 0.0 | 2,0 | 76.7 | 36$^{a}$ |
| E-LB | 3.70 | 43.4$^{c}$ | 10.1$^{b}$ | 61.3 | 35.5 | 1.5 | 0.0 | 0.0 | 62.3 | 84$^{b}$ |
| E-LBS | 3.73 | 40.0$^{cd}$ | 11.7$^{bc}$ | 60.0 | 37.1 | 1.7 | 0.0 | 0.0 | 60.7 | 99$^{c}$ |
| E-PFA | 4.05 | 33.6$^{f}$ | 9.4$^{d}$ | 25,9 | 10.9 | 3.8 | 0.8 | 0.0 | 62.6 | 68$^{d}$ |
| L-UT | 3.83 | 70.9$^{b}$ | 20.9$^{a}$ | 87.7 | 25.2 | 0.0 | 0.0 | 1.8 | 76.5 | 41$^{a}$ |
| L-LB | 3.71 | 42.6$^{cd}$ | 11.5$^{bc}$ | 63.3 | 36.0 | 1.2 | 0.0 | 0.0 | 62.4 | 88$^{b}$ |
| L-LBS | 3.70 | 39.3$^{de}$ | 10.6$^{c}$ | 61.5 | 38.8 | 1.9 | 0.0 | 0.0 | 60.2 | 95$^{c}$ |
| L-PFA | 4.07 | 35.6$^{ef}$ | 8.1$^{d}$ | 27.7 | 11.1 | 3.9 | 0.6 | 0.0 | 64.0 | 66$^{d}$ |
| SEM | 0.05 | 4.96 | 1.68 | 8.04 | 4.04 | 0.52 | 0.12 | 0.31 | 2.42 | 8 |
| Effect of: | | | | | | | | | | |
| - harvest date | 0.50 | 0.02 | 0.74 | 0.0011 | 0.04 | 0.79 | 0.14 | 0.52 | 0.60 | 0.05 |
| - additive | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 | <.001 |
| - harvest date× additive | 0.33 | 0.001 | 0.01 | 0.92 | 0.55 | 0.29 | 0.10 | 0.74 | 0.54 | 0.01 |

LA/TA – lactic acid in total acid; $^{a-f}$ Means in the same column followed by different superscript letters differ significantly; SEM – standard error of mean .

The WSC content in the sorghum silages depended on the forage harvest date and the ensiling additive. The WSC level in L-UT, L-LB, L-LBS and L-PFA silages was an average of 16-33% ($P<0.001$) greater compared to E-UT, E-LB, E-LBS and E-PFA silages. The lowest WSC content was characteristic of E-UT and L-UT silages, and the greatest amount of WSC was found in E-PFA and L-PFA silages.

The starch content in sorghum silages depended on the forage harvest date ($P<0.001$) and on the additive used ($P<0.001$). In L-UT, L-LB, L-LBS and L-PFA silages, starch level was at average of 64-67% greater compared to E-UT, E-LB, E-LBS and E-PFA silages.

Fermentation parameters and aerobic stability of sorghum silages are presented in Table 3. The pH of E-LB, L-LB, E-LBS and L-LBS silages was lower compared to E-UT and L-UT silages. The highest pH was characteristic of E-PFA and L-PFA silages.

The greatest concentration of $NH_3$-N was found in E-UT and L-UT silages. The use of additives reduced ($P<0.001$) $NH_3$-N amount in the silages. The ethanol content in silages made with the additives was 2-fold lower ($P<0.001$) than the ethanol level in the silages without additives.

In the experiment, no effect ($P>0.05$) of sorghum forage harvest date on pH value and ethanol content of the silages made was found.

E-UT and L-UT silages were characterized by the highest concentration of LA. A significantly lower amount of this acid was found in the silages treated with the ensiling preparations. The AA content in E-LB, L-LB, E-LBS and L-LBS silages was greater in comparison to the AA level in E-UT, L-UT, E-PFA and L-PFA silages. E-UT and L-UT silages contained no PA. FA was only found in E-PFA and L-PFA silages, while BA occurred only in E-UT and L-UT silages.

E-UT and L-UT silages were aerobically stable for 36 and 41 h, respectively. A significantly ($P<0.05$) greater resistance to aerobic deterioration was characteristic of E-PFA and L-PFA (68 and 66 h); E-LB and L-LB (84 and 88 h); and E-LBS and L-LBS silages (99 and 95 h, respectively).

## DISCUSSION

The greatest DM content in silages made with chemical preservative containing PA, FA and AP resulted from the low intensity of fermentation in the ensiled plant biomass. Organic acids strongly inhibit fermentation bacteria, as a result of which only small amounts of the nutrient substrate in the form of WSC are degraded (Henderson, 1993).

Ensiling sorghum with the additives used increased the CP and TP of the silages, compared to the content of these compounds in the untreated silages. The fact that protein breakdown in the silages with L. buchneri or with L. buchneri and PS was limited, could result from the negative effect of the metabolic products of this bacterial strain and sorbic acid salts on protein-degrading microorganisms during the fermentation process (Henderson, 1993; Holzer et al., 2003; Purwin et al., 2006). The best protection of proteins against degradation was obtained by ensiling sorghum with a chemical preservative. The highest CP and TP content in these silages was due to the restrictive effect of chemical compounds found in the preservative on the bacteria-degrading proteins during the fermentation of the ensiled plants (Henderson, 1993; Muck et al., 1996; Stryszewska and Pyś, 2006). In the experiment with sorghum forage, the progressing vegetation was paralleled by the increasing WSC content. The same relation was found for the silages made. The lowest WSC level in the untreated silages resulted from the most intensive fermentation in the silo. Ensiling sorghum with L. buchneri alone or together with PS did not reduce the WSC level in the silages made. The WSC content in the sorghum silages did not decrease in other studies in which forage was ensiled with the addition of Lactobacillus plantarum and Streptococcus faecium (Schmidt et al., 1997) or Propionibacterium acidipropionici and L. plantarum bacteria (Filya et al., 2004). Sorghum silages made with the chemical preservative were characterized by the highest WSC content due to the restrictive effect of organic acids in the preservative on lactic acid bacteria (McDonald et al., 1991; Henderson, 1993).

NDF and ADF content in the sorghum silages resulted mainly from the amount of these components in the forage before ensiling. As vegetation progressed, the amount of these components in forage increased, as was reflected in the silages made. A similar relation was found for NDF and ADF content by Karsli et al. (2002). The addition of L. buchneri alone or together with PS to the ensiled sorghum reduced pH of the silage. Higher pH of untreated silages could be affected by higher concentration of ammonia, which neutralizes organic acids (McDonald et al., 1991). Ensiling sorghum with a chemical preservative highly reduced (by a factor of 2 or 3) the concentration of organic acids produced during fermentation, resulting in the highest pH of these silages. In the experiment of Schmidt et al. (1997), the addition of FA at the amount of 0.5% of fresh sorghum increased the silage pH ($P<0.05$). Silage pH was reduced ($P<0.05$) by increasing the FA supplement to 0.75 and 1.00% of fresh sorghum (Schmidt et al., 1997).

Ensiling sorghum with L. buchneri alone or together with PS limited significantly ($P<0.001$) protein degradation to ammonia in the silages obtained. High concentration of AA and PA formed by this strain of bacteria, limited the

growth of microorganisms which degrade proteins to ammonia, as reported by other authors (Henderson, 1993; Filya, 2003; Holzer et al., 2003). The limited breakdown of proteins to ammonia in acid-treated silages (E-PFA and L-PFA) resulted from the restrictive effect of the preservative components on protein-degrading bacteria (McDonald et al., 1991; Henderson, 1993). In the study by Schmidt et al. (1997), ensiling sorghum forage with FA reduced the ammonia content in silages by a factor of 2-3. The forages low in DM and high in WSC are particularly susceptible to the alcoholic fermentation caused by yeasts (McDonald et al., 1991; Henderson, 1993). In the present study, ensiling sorghum forage with L. buchneri, with or without PS, reduced the amount of ethanol in the silages. A high level of AA produced by the L. buchneri strain limited the activity of yeasts efficiently. Alcoholic fermentation was not limited in the experiments conducted by other authors, in which sorghum forage was ensiled with cellulolytic enzymes (Rodriguez et al., 1997), L. plantarum, S. faecium with cellulolytic enzymes (Schmidt et al., 1997); and L. buchneri and L. plantarum (Filya, 2003).

In the present experiment, the lowest ethanol concentration was found in sorghum silages with a chemical preservative, as indicated by the efficient limitation of the yeast activity by organic acids during the fermentation of the ensiled forage (Kung et al., 2004; Selwet, 2005). In the study by Schmidt et al. (1997), FA (0.5, 0.75 and 1.00% of fresh sorghum) added to the sorghum forage prevented alcoholic fermentation in the silages.

By degrading LA, heterofermentative lactic bacteria L. buchneri produce considerable amount of AA and other metabolites, including PA (Oude Elferink et al., 2001; Filya, 2003; Holzer et al., 2003). Such an activity of this strain of bacteria was confirmed in the present study. Sorghum silages made using L. buchneri, with or without PS, were characterized by the highest concentration of AA and the lowest percent participation of LA in the sum of organic acids. The lowest amount of LA and AA in the silages with a mixture of PA, FA and AP resulted from the inhibitory effect of these acids on fermentation bacteria (McDonald et al., 1991; Henderson, 1993).

The organic acid level of sorghum silages determined the resistance of these feeds to the aerobic deterioration after the silos had been opened. During a 7-d aerobic exposure, the silages made with L. buchneri and PS were the most stable, followed by the silages made with L. buchneri bacteria alone. In these silages, the sum of AA and PA was the highest. These organic acids could reduce efficiently the population of yeasts and moulds responsible for the aerobic deterioration of silages (Oude Elferink et al., 2001; Holzer et al., 2003).

Sorghum silages without additives showed the lowest resistance to the aerobic deterioration. These silages were characterized by the lowest concentration of AA and PA in relation to LA, which may have had an effect on their low aerobic stability. The addition of a mixture of PA, FA and AP to the ensiled sorghum increased the aerobic stability of silages by 24 h at average compared to the analogous period in untreated silages. The sum of AA, PA and FA in the silages with this preservative did not exceed 15-16 $g \cdot kg^{-1}$ DM. In addition, these silages retained the largest amount of WSC. It can, therefore, be suggested that such a low concentration of acids determining the aerobic stability of silages was insufficient to inhibit the activity of microorganisms, which were responsible for aerobic deterioration while having easy access to large amounts of the nutrient substrate.

The silages made without additives, regardless of the highest level of AA, were characterized by a lower resistance to aerobic deterioration, compared to the silages made with chemical preservatives. It could have resulted from the fact, that untreated silages contained repeatedly more LA, which is one of the main nutrient substrates for pathogenic microorganisms, which are responsible for aerobic deterioration (Lowes et al., 2000; Knický, 2005). Furthermore, untreated silages compared to silages made with chemical preservatives did not contain PA and FA, which strongly inhibit the growth of undesirable microorganisms (Knický, 2005; Selwet, 2005).

## CONCLUSION

Sorghum forage harvest date influenced the all analysed nutrient contents of the silages obtained. It had no effect on the pH value, ethanol and organic acids content in the ensiled plant biomass. Ensiling sorghum with the addition of a mixture of propionic acid and formic acid with ammonium propionate had the best effect in limiting WSC degradation during the fermentation. The addition of L. buchneri bacteria, especially together with potassium sorbate, to the ensiled sorghum resulted in the highest resistance of silages to aerobic deterioration.

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## REFERENCES


AOAC. 2005. Association of Official Analytical Chemists. *Official Methods of analysis*. 18th ed., Current Through Revision 2, 2007, AOAC, Arlington, Washington DC.

BENNETT W.F., TUCKER B.B., MAUNDER A.B. 1990. *Modern Grain Sorghum Production*. First Edition. Iowa State University Press. Iowa, USA.

CONWAY E.J. 1962. *Microdiffusion Analysis and Volumetric Error*. 5th ed. Crosby Lockwood and Son. London, UK.

CRITCHLEY W., SIEGERT K. 1991. Water Harvesting. A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. Food and Agriculture Organization of the United Nations. Rome, Italy.

DRIEHUIS F., OUDE ELFERINK S.J.W.H., SPOELSTRA S.F. 1999. Anaerobic lactic acid degradation during ensilage of whole crop maize inoculated with Lactobacillus buchneri inhibits yeast growth and improves aerobic stability. *Journal of Applied Microbiology*, 1999, 87, p. 583-594.

DUBOIS M., GILLES K.A., HAMILTON J.K., ROBERTS P.A., SMITH F. 1956. Colorimetric methods for determination of sugar and related substances. *Analytical Chemistry*, 1956, 28, p. 350-356.

DULPHY J.P., DEMARQUILLY C. 1981. Problèmes particuliers aux ensilages. In: *C. Demarquilly (Editor). Prevision de la valuer nutritive des aliments des ruminants. Publications de l'INRA*, 1981,Versailles, France, p. 81-104.

FAISANT N., PLANCHOT V., KOZLOVSKI F., PACOURET M.P., COLONNA P., CHAMP M. 1995. Resistant starch determination adapted to products containing high level of resistant starch. *Science des Alimentes*, 1995, 15, p. 83-89.

FILYA I. 2003. The effect of *Lactobacillus buchneri* and *Lactobacillus plantarum* on the fermentation, aerobic stability, and ruminal degradability of low dry matter corn and sorghum silage. *Journal of Dairy Science*, 2003,86, p. 3575-3581.

FILYA I., SUCU E., KARABULUT A. 2004. The effect of *Propionibacterium acidipropionici*, with or without *Lactobacillus plantarum*, on the fermentation and aerobic stability of wheat, sorghum and maize silage. *Journal of Applied Microbiology*, 2004, 97, p. 818-826.

GEORING H., VAN SOEST P.J. 1970. Forage fiber analysis. *USDA Agricultural Handbook*, USA, 379, p. 1-20.

HENDERSON N. 1993. Silage additives. *Animal Feed Science and Technology*, 1993, 45, p. 35-56.

HOLZER M., MAYRHUBER E., DANNER H., BRAUN R. 2003. The role of Lactobacillus buchneri in forage preservation. *Trends in Biotechnology*, 2003,21, p. 282-287.

HONIG H. 1985. Determination of aerobic deterioration – *System Völkenrode. Landbauforsch. Völkenrode*, SH 2, p. 3.

KARSLI M.A., YILMAZ Í., DENÍZ S., NURSOY H., DENEK N. 2002. Effects of harvesting sorghum varieties at varying maturities on silage quality and digestible dry matter. *Sağlik Bilimleri Dergisi*, 2002, 8(1-2), p. 22-27.

KNICKÝ M. 2005. Possibilities to improve silage conservation. Effects of crop, ensiling technology and additives. *Doctoral Thesis. Swedish University of Agricultural Science*, Uppsala, Sweden, p. 34.

KUNG L. JR., ROBINSON J.M., RANJIT N.K., CHEN J.K., GOLD C.M., PESEK J.D. 2000. Microbial population, fermentation and products, and aerobic stability of corn silage treatment with ammonia or a propionic-based preservative. *Journal of Dairy Science*, 2000, 83, p. 1479-1486.

KUNG L. JR., MYERS C.L., NEYLON J.M., TAYLOR C.C., LAZARTIC J.A., MILLS J.A., WHITER A.G. 2004. The effects of buffered propionic acid-based additives or combined with microbial inoculation on the fermentation of high moisture corn and whole-crop barley. *Journal of Dairy Science*, 2004, 87, p. 1310-1216.

LICITRA G., HERNANDEZ T.M., VAN SOEST P.J. 1996. Standardization of procedures for nitrogen fraction of ruminal feeds. *Animal Feed Science and Technology*, 1996, 57, p. 347-358.

LOWES K.F., SHEARMAN C.A., PAYNE J., MACKENZIE D., ARCHER D.B., MERRY R.J., GASSON J. 2000. Prevention of yeast spoilage in feed and food by the yeast mycocin HMK. *Applied and Environmental Microbiology*, 2000, 66, p. 1066-1076.

MCDONALD P., HENDERSON A.R., HERON J.E. 1991. *The Biochemistry of Silage.* Second Edition, Chalcombe Publications, Marlow, U.K.

MUCK R.E., MERTENS D.R., WALGENBACH R.P. 1996. Proteolysis in different forage silages. *ASAE Paper No. 961031*, ASAE St. Joseph, MI, USA.

OHMOMO S., TANAKA O., KITAMOTO H.K., CAI Y. 2002. Silage and microbial performance, old story but new problems. *Japan Agricultural Research Quarterly*, 2002, 36, p. 59-71.

OUDE ELFERINK S.J.W.H., KROONEMAN J., GOTTSCHAL J.C., SPOELSTRA S.F., FABER F., DRIEHUIS F. 2001. Anaerobic conversion of lactic acid to acetic acid and 1.2-propanediol by *Lactobacillus buchneri. Applied and Environmental Microbiology*, 2001, 67, p. 125-132.

PLAYNE M.J., MC DONALD P. 1966. The buffering constituents of herbage and of silage. *Journal of the Science of Food and Agriculture*, 1966, 17, p. 264-268.

PODKÓWKA L. 2006. Sorghum. (In Polish). *Hoduj z Głową*, 6, p. 17-22.

PURWIN C., ŁANIEWSKA-TROKENHEIM Ł., WARMIŃSKA-RADYKO I., TYWOŃCZUK J. 2006. Silage quality: microbiological, health-promoting and production aspects. (In Polish). *Veterinary Medicine*, 2006, 62, p. 865-869.

RODRIGUEZ A.A., RUST S.R., SCHLEGEL M.L., RIQUELME E.O., YOKOYAMA M.T., BRNETT R.J. 1997. Fermentation characteristics of forage sorghum ensiled with commercial enzyme preparation. *Archivos Latinoamericanos de Produccion Animal*, 5, Suplemento 1, p. 79-82.

SAS. 2004. *SAS/STAT User's Guide*. Version 9.1. SAS Institute Inc., Cary, NC, USA.

SCHMIDT J., SIPOCZ J., KASZÁCS I., SZAKÁCS G., GYEPES A., TENGERDY R.P. 1997. Preservation of sugar content in ensiled sweet sorghum. *Bioresource Technology*, 1997, 60, p. 9-13.

SELWET M. 2005. Effect of preservatives based on formic acid on the development of yeasts and mould fungi in silages. (In Polish). *Veterinary Medicine*, 2005, 61, p. 349-352.

SLOTTNER D., BERTILSSON J. 2006. Effect of ensiling technology on protein degradation during ensilage. *Animal Feed Science and Technology*, 2006,127, p. 101-111.

ŚLIWIŃSKI B.J., BRZÓSKA F. 2006. The history of sorghum cultivation and its nutritive value as a silage crop. (In Polish). *Postępy Nauk Rolniczych*, 2006, 1, p. 25-37.

STRYSZEWSKA K., PYŚ J.B. 2006. Effects of different silage additives on the microbial population and aerobic stability of maize silage. *Journal of Animal Feed Science*, 2006,15, Supplement 1, p. 121-124.