Effects of Different Acidifiers Mixed with Corn Flour on Silage Quality of Banana Stems, Leaves, and Pseudostems (Postprint)

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Abstract

To investigate the effects of combining different acidifiers with corn flour on the silage quality of high-moisture banana stems/leaves and pseudostems, this experiment utilized fresh banana stems/leaves and pseudostems (after 48 h of standing, with corresponding moisture contents of 91.1% and 94.8%) as silage materials, with various acidifiers and corn flour added during ensiling. For banana stem/leaf silage, treatments comprised 10% corn flour (YY group), 10% corn flour + 0.6% formic acid (YJ group), 10% corn flour + 0.4% acetic acid (YS group), and 10% corn flour + 0.5% calcium propionate (YB group), along with a control group without acidifier or corn flour (CK1 group). For banana pseudostem silage, treatments comprised 10% corn flour (JY group), 10% corn flour + 0.6% formic acid (JJ group), 10% corn flour + 0.4% acetic acid (JS group), and 10% corn flour + 0.5% calcium propionate (JB group), along with a control group without acidifier or corn flour (CK2 group). After 45 days of ensiling, the silage was opened and subjected to sensory evaluation and laboratory analysis. The results demonstrated that sensory evaluation scores for banana stem/leaf and pseudostem silage treated with different additives were superior to those of the corresponding control groups (CK1 and CK2). Compared with the respective control groups, the YY and JY groups with corn flour addition exhibited significantly reduced pH ($P<0.05$), significantly increased lactic acid content ($P<0.05$), and significantly decreased ammonia nitrogen content ($P<0.05$). The YJ, YS, and YB groups with different acidifiers showed no significant differences in dry matter, crude protein, neutral detergent fiber, and acid detergent fiber contents compared with the YY group ($P>0.05$), whereas the JY group had significantly lower dry matter, neutral detergent fiber, and total phenol contents than the JJ group ($P<0.05$). Furthermore, among both banana stem/leaf and pseudostem groups, the groups with formic acid and corn flour addition (YJ and JJ groups) exhibited the lowest lactic acid content and the highest soluble carbohydrate content. These findings indicate that adding acidifiers and corn flour during ensiling can improve the silage quality of high-moisture banana stems/leaves and pseudostems, with the best silage quality achieved through the addition of formic acid and corn flour.

Full Text

Effects of Mixing Different Acidifiers with Maize Powder on the Silage Quality of Banana Stems and Leaves and Banana Pseudostems

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Abstract

This study investigated the effects of mixing different acidifiers with maize powder on the silage quality of high-moisture banana stems and leaves and banana pseudostems. Fresh banana stems and leaves and banana pseudostems (which were left to stand for 48 hours, resulting in moisture contents of 91.1% and 94.8%, respectively) were used as silage materials. For banana stems and leaves silage, the treatments were: 10% maize powder (YY group), 10% maize powder + 0.6% formic acid (YJ group), 10% maize powder + 0.4% acetic acid (YS group), and 10% maize powder + 0.5% calcium propionate (YB group), with a control group without any additives (CK1 group). For banana pseudostem silage, the treatments were: 10% maize powder (JY group), 10% maize powder + 0.6% formic acid (JJ group), 10% maize powder + 0.4% acetic acid (JS group), and 10% maize powder + 0.5% calcium propionate (JB group), with a control group without any additives (CK2 group). After 45 days of ensiling, sensory and laboratory evaluations were conducted on the silages from each group.

The results showed that the sensory evaluation scores for both banana stems/leaves and pseudostems treated with different additives were superior to their respective control groups (CK1 and CK2). Compared with the control groups, the addition of maize powder alone (YY and JY groups) significantly reduced pH ($P<0.05$), significantly increased lactic acid content ($P<0.05$), and significantly decreased ammonia nitrogen content ($P<0.05$). The YJ, YS, and YB groups treated with different acidifiers showed no significant differences in dry matter, crude protein, neutral detergent fiber, and acid detergent fiber contents compared with the YY group ($P>0.05$). However, the JY group had significantly lower dry matter, neutral detergent fiber, and total phenol contents than the JJ group ($P<0.05$). Among all groups, those treated with formic acid and maize powder (YJ and JJ groups) had the lowest lactic acid content and the highest soluble carbohydrate content. These findings indicate that adding acidifiers and maize powder can improve the silage quality of high-moisture banana stems and leaves and banana pseudostems, with the combination of formic acid and maize powder producing the best silage quality.

Keywords: acidifier; maize powder; banana stems and leaves; banana pseudostems; silage quality

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Banana is a high-yield, fast-growing monocotyledonous herbaceous plant rich in protein, vitamins, trace elements, and various active components, offering high nutritional, medicinal, and edible value. It is widely cultivated in tropical and subtropical regions of China such as Guangdong, Guangxi, Yunnan, and Hainan, and has become a major fruit crop in southern China, ranking alongside apples, grapes, and citrus as one of the world' s four major fruits. After banana harvest, the plants generate large quantities of by-products including stems, leaves, and pseudostems. Due to their wide distribution, large volume, and collection difficulties, only a small portion is utilized as fertilizer or fuel, resulting in tremendous resource waste. Moreover, the favorable rainfall and heat conditions in southern China lead to high moisture content and rich nutrients in fresh banana stems and leaves, creating ideal conditions for bacterial growth. If not utilized promptly, these materials decompose and cause environmental pollution. When used as feed, banana stems and leaves can be fed fresh or after drying, but fresh feeding is difficult to preserve and store, limiting the feeding period. Drying treatment lacks appropriate machinery and consumes excessive energy, making it too costly. Ensiling banana by-products represents one of the best methods for preserving feed nutritional value, addressing both resource waste and improving palatability. Currently, research on banana stems and leaves as roughage for ruminants is scarce. Due to their high moisture content, producing conventional silage is challenging, making it practically important to explore special silage production using additives. This study aimed to investigate the effects of mixing different acidifier types with maize powder on the silage quality of high-moisture banana stems and leaves and banana pseudostems, and to identify suitable acidifier and maize powder combinations to provide theoretical and technical support for future banana stems and leaves silage production.

1.1 Experimental Materials

Banana stems/leaves and pseudostems were collected from Wuming County, Guangxi Province, while maize powder was purchased from the local market. The acidifiers used for silage were: formic acid (FA, analytical grade, 98% purity), acetic acid (EA, analytical grade, $ $99.5% purity), and calcium propionate (CP, analytical grade, $ $98% purity).

1.2.1 Experimental Design

This experiment used banana stems/leaves and pseudostems as raw materials, divided into two main groups: banana stems/leaves group and banana pseudostems group. Both silage experiments adopted a single-factor design, with five treatment groups for each material and three replicates per group. The experimental design is shown in Table 1 .

1.2.2 Silage Preparation

Banana stems/leaves and pseudostems harvested in September were left in natural conditions for 48 hours before being brought to the laboratory for ensiling in silage bags. The materials were chopped to 2–3 cm lengths. In the banana stems/leaves group, stems and leaves were mixed at a 7:3 ratio. According to the experimental design, maize powder and different acidifiers were added to each group, thoroughly mixed, packed into silage bags, vacuum-sealed with a Magis vacuum sealer, and labeled. All groups were stored indoors at the Ruminant Nutrition Metabolism and Regulation Laboratory of Yangzhou University. After 45 days, the bags were opened for sampling. During the storage period, indoor temperature ranged from 13–24°C, with an average of 18.5°C.

1.3 Detection Indicators and Methods

After 45 days, silage bags were opened, the fermented silage samples were removed and mixed thoroughly, and all indicators were measured at the Ruminant Nutrition Metabolism and Regulation Laboratory of Yangzhou University.

1.3.1 Sensory Evaluation Sensory evaluation was conducted according to the German Agricultural Society (Deutsche Landwirtschafts-Gesellschaft, DLG) silage quality sensory scoring standards, assessing odor, texture, and color. Odor was scored in 4 grades (2–14 points), texture in 4 grades (0–4 points), and color in 3 grades (0-2 points). The total score determined the grade: Grade 1 (excellent) 16–20 points, Grade 2 (good) 10-15 points, Grade 3 (fair) 5–9 points, and Grade 4 (spoiled) 0–4 points.

1.3.2 Conventional Nutritional Component Analysis Fresh silage material (200 g) and fermented samples (150 g) were dried in a 65°C oven for 48 hours, cooled to constant weight, and dry matter (DM) content was determined. The remaining dried samples were ground through a 1 mm sieve using a micro plant sample grinder and stored in self-sealing bags for analysis. Total nitrogen (TN), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude ash (Ash) contents were determined according to Zhang Liying' s "Feed Analysis and Feed Quality Detection Technology" (3rd edition). Soluble carbohydrate (WSC) content was measured using the anthrone-sulfuric acid colorimetric method according to Owens et al. Total phenol (TP) and total tannin (TT) contents were determined using the Folin-Ciocalteu reagent method according to Makkar et al. Non-tannin phenol (NTP) content was calculated as the difference between TP and TT contents. Condensed tannin (CT) content was measured using the hydrochloric acid-butanol method according to Porter et al.

1.3.3 Fermentation Quality Analysis Fresh silage samples (35 g) were placed in a capped wide-mouth plastic bottle with 75 mL distilled water, stirred evenly, sealed, and extracted at 4°C for 48 hours. The extract was filtered through four layers of gauze and qualitative filter paper. One portion of the filtrate was used for immediate pH measurement, while another was stored at -20°C for ammonia nitrogen (NH3-N) and organic acid [lactic acid (LA), acetic acid (AA), propionic acid (PA), and butyric acid (BA)] determination. NH3-N content was determined using the phenol-hypochlorite colorimetric method according to Broderick. Organic acid contents were measured by gas chromatography according to Kawamoto et al. and Khan et al.

1.4 Data Analysis

Data were organized using Excel 2012 and analyzed using SPSS 22.0 software for one-way ANOVA, with Duncan' s multiple comparison test for post-hoc analysis.

2.1 Nutritional Components and Polyphenol Contents of Silage Materials

The nutritional component contents of banana stems/leaves and pseudostems are shown in Table 2 . Overall, banana stems/leaves had higher nutritional component contents than banana pseudostems. The DM and WSC contents of banana stems/leaves were 2.84% and 3.59% higher than those of banana pseudostems, respectively. Banana stems/leaves also had higher TP, NTP, and TT contents, while CT content was lower than that of banana pseudostems.

2.2 Sensory Evaluation of Silages

As shown in Table 3 , the color of all silages was similar to the raw materials, with stable scores. In terms of texture, except for slight mold on the surface of CK2 group silage, all other groups maintained good stem/leaf structure without mold. All treatment groups had stronger aromatic odors compared with CK1 and CK2 groups. Overall, CK2 group had the lowest score (Grade 3, fair), while CK1 group scored Grade 2 (good), and all other groups achieved excellent grades.

2.3 Nutritional Components and Polyphenol Contents of Banana Stems and Leaves Silage

As shown in Table 4 , the DM content of YY group was significantly higher than that of CK1 group ($P<0.05$), while NDF and ADF contents were significantly lower ($P<0.05$). Compared with YY group, the YJ, YS, and YB groups treated with three acidifiers showed significantly reduced Ash content (P<0.05), but no significant differences in DM, CP, NDF, or ADF contents (P>0.05). Among the three acidifier groups, YJ group had significantly higher TP content than YS group (P<0.05), while no significant differences were observed in NTP, TT, or CT contents among groups (P>0.05).

2.4 Nutritional Components and Polyphenol Contents of Banana Pseudostem Silage

As shown in Table 5 , the DM content of JY group was significantly higher than that of CK2 group (P<0.05), while Ash, NDF, ADF, and CT contents were significantly lower (P<0.05). Compared with JY group, JJ group showed significantly increased DM, NDF, TP, and CT contents (P<0.05), while JS group showed significantly increased CP, NDF, TP, and CT contents (P<0.05). Among the three acidifier groups, YS group had the highest NDF content, significantly higher than other groups (P<0.05).

2.5 Fermentation Quality of Banana Stems and Leaves Silage

As shown in Table 6 , the lactic acid content of CK1 group was significantly lower than that of YY group (P<0.05), while pH was significantly higher (P<0.05). Compared with YY group, the YJ, YS, and YB groups treated with three acidifiers produced no butyric acid, and YJ and YB groups had significantly reduced pH (P<0.05). Among the three acidifier groups, YS group had significantly higher pH than other groups (P<0.05), YJ group had significantly lower lactic acid content than other groups (P<0.05), and YB group had significantly higher propionic acid content than other groups (P<0.05).

2.6 Fermentation Quality of Banana Pseudostem Silage

As shown in Table 7 , the lactic acid content of CK2 group was significantly lower than that of JY group (P<0.05), while pH was significantly higher (P<0.05). Compared with JY group, JJ group had significantly reduced lactic acid content (P<0.05), JS group had significantly increased acetic acid content (P<0.05), JB group had significantly increased propionic acid content (P<0.05), and JJ and JB groups had significantly reduced pH (P<0.05). Among the three acidifier groups, JJ group had significantly lower lactic acid content than JS and JB groups (P<0.05), JS group had significantly higher acetic acid content than JJ and JB groups (P<0.05), and JB group had significantly higher propionic acid content than JJ and JS groups (P<0.05). Neither JJ nor JB groups produced butyric acid.

2.7 WSC Content and NH3-N/TN Ratio of Silages

As shown in Figure 1 [Figure 1: see original paper], for both silage materials, the control groups without acidifiers or maize powder (CK1 and CK2) had the lowest WSC contents, while the groups treated with maize powder and formic acid

(YJ and JJ) had the highest WSC contents. No significant differences in WSC content were observed among YS, YB, and YY groups in banana stems/leaves, or among JS, JB, and JY groups in banana pseudostems (P>0.05).

As shown in Figure 2 [Figure 2: see original paper], for both silage materials, the control groups without acidifiers or maize powder (CK1 and CK2) had the highest NH3-N/TN ratios, while the groups treated with maize powder and formic acid (YJ and JJ) had the lowest NH3-N/TN ratios.

3.1 Effects of Different Acidifiers Mixed with Maize Powder on Sensory Evaluation

Silage is an excellent method for preserving nutrients in high-moisture crops, but successful silage requires good fermentation conditions. Sufficient soluble sugar content and appropriate moisture levels in silage materials under anaerobic conditions are prerequisites for successful fermentation. Banana stems/leaves and pseudostems have high moisture content and relatively low WSC content, making them unsuitable for direct ensiling. Adding appropriate maize powder and acidifiers can greatly improve silage quality. In this experiment, silages from different treatments were scored according to DLG silage quality sensory standards based on odor, texture, and color. Overall, the combination of formic acid and maize powder achieved the most stable and highest scores for both silage materials, demonstrating excellent silage effects. The slight mold observed on CK2 group surfaces may be attributed to the excessively high moisture content of banana pseudostems, with residual air in the fine fiber channels of the pseudostem core and fewer lactic acid bacteria on the surface, creating favorable conditions for mold and spoilage organisms.

3.2 Effects of Different Acidifiers and Maize Powder on Nutritional Components and Polyphenol Contents

Maize powder, as a nutritional absorbent, provides WSC for silage materials while adjusting moisture content, thereby reducing microbial consumption of nutrients. In this study, all treatment groups with added acidifiers and maize powder had significantly higher DM contents than control groups without additives, primarily because control groups lacked maize powder addition. All other groups had DM contents above 13% without significant differences, indicating that maize powder effectively increased silage DM content. Wang Chunfang found that banana stems and whole plants with over 90% moisture could be effectively preserved through ensiling, consistent with our results, demonstrating that high-moisture banana stems/leaves and pseudostems can be ensiled. Fransen et al. proposed that adding absorbents to high-moisture crop silage can reduce effluent loss and nutrient loss, thereby improving fermentation effects. WSC is the material basis for lactic acid bacteria fermentation, and sufficient soluble sugar in raw materials ensures silage success. The formic acid groups had the highest WSC contents for both banana stems/leaves and pseudostems. Liu Yanfang et al. reported that adding formic acid to amaranth silage significantly increased WSC content at the end of fermentation, consistent with our results and also confirmed in Lv Wenlong' s research. NDF and ADF, as main components of roughage, are important for regulating the concentrate-to-forage ratio in ruminant diets, promoting rumination, and ensuring rumen health. All treatment groups showed significantly reduced NDF and ADF contents compared with their respective control groups after ensiling, indicating that microbial fermentation during silage can reduce fiber content.

Tannins have both beneficial and detrimental effects on ruminants. Appropriate tannin content can improve protein utilization efficiency and reduce bloating, while excessive tannin content can reduce feed intake and cause adverse reactions. The TP content measured in banana stems/leaves in this experiment was relatively low, similar to Wang Chunfang' s findings that different banana plant parts have significantly different TP contents, with banana stems generally having lower TP content than leaves.

3.3 Effects of Different Acidifiers and Maize Powder on Fermentation Quality

Organic acid content and composition in silage reflect fermentation quality, with lactic acid being most important and generally considered higher content is better. In this experiment, formic acid groups had the lowest lactic acid content for both banana stems/leaves and pseudostems, likely because formic acid is the strongest organic acid and its addition inhibited all microbial activities, including lactic acid bacteria growth and reproduction, resulting in significantly lower lactic acid content than other groups. With deeper research on silage additives, acetic acid has been found to effectively inhibit yeast and fungal growth, playing an important role in improving aerobic stability of silage. In this experiment, acetic acid groups had higher acetic acid content than other groups in both materials, mainly because added exogenous acetic acid increased the final fermentation product. Calcium propionate groups had significantly higher propionic acid content than other groups because calcium propionate, as a propionate salt, can dissociate propionate ions during ensiling, thereby increasing propionic acid content. All groups produced no or only trace amounts of butyric acid, indicating good silage fermentation quality.

Silage pH is closely related to fermentation quality, with pH below 4.2 generally considered successful. In banana stems/leaves and pseudostems silage, except for CK1 (pH 4.27) and CK2 (pH 5.29) groups, all other groups achieved excellent quality grades.

The NH3-N/TN ratio reflects the degree of protein and amino acid decomposition in silage, with higher ratios indicating more protein breakdown and poorer silage quality. Well-preserved silage should have NH3-N/TN ratios below 10%. All groups in this experiment had NH3-N/TN ratios below 10%, indicating good preservation of banana stems/leaves and pseudostems silage.

4 Conclusion

1. For high-moisture banana stems/leaves and pseudostems, adding maize powder during ensiling produces better results than natural silage.
2. For high-moisture banana stems/leaves and pseudostems, adding acidifiers with maize powder produces better silage effects than natural silage.
3. Overall, the combination of formic acid and maize powder produced the best silage effects for high-moisture banana stems/leaves and pseudostems.

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Note: Figure translations are in progress. See original paper for figures.