THE EFFECTS OF DIFFERENT TREATMENTS ON FERMENTATION QUALITY AND GREENHOUSE GAS EMISSIONS OF ENSILED WHEAT STRAW

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ABSTRACT

Wheat straw, a globally abundant agricultural by-product, faces challenges in ensiling and feed utilization due to its low moisture and carbohydrate content. To address this, in this research, a microbial-enzyme synergistic system was developed using *Lactiplantibacillus* (L.) strains ZA3 and FG1 (commercial strain) with cellulase to enhance the feed quality and aerobic stability of wheat straw silage. Results showed that all treatments improved fermentation quality over the control, with lower pH value, ammonia nitrogen content and harmful microbes counts, higher lactic acid bacteria counts and lactic acid content, and *Lactobacillus* and *Weissella* dominating throughout ensiling and aerobic exposure stages. Among which, *L. plantarum* subsp. *plantarum* ZA3 treated group performed best. Morover, these treatments also reduced emission of greenhouse gas including CO_2, CH_4 and N_2O. Aerobic exposure tests also confirmed that added LAB can significantly extended feed preservation. This study provides theoretical and technical support for utilizing wheat straw as silage feed.

Keywords: wheat straw, silage, lactic acid bacteria, feed quality, greenhouse gases

INTRODUCTION

The rapid expansion of the global livestock industry has increased demand for feed resources (Pang, *et al.*, 2024). Wheat (*Triticum aestivum* L.) produces up to 1 billion tonnes of straw annually, representing an abundant and accessible roughage source rich in water soluble carbohydrates (WSC) and crude fibre (Wang, *et al.*, 2023). Silage is an effective strategy for nutrient preservation and palatability improvement via organic acid production, thereby increasing feed intake (Pang, *et al.*, 2024). In this study, wheat straw was ensiled with lactic acid bacteria (LAB) and cellulase to optimise fermentation quality, enhance aerobic stability, and reduce greenhouse gas emissions. This work provides a theoretical and technical basis for improving feed quality and promoting the efficient and sustainable utilization of wheat straw in ruminant production.

MATERIAL AND METHODS

Wheat straw (cv. Bainong 207) was obtained from Henan, China. Two *Lactiplantibacillus plantarum* strains (ZA3 and FG1) and a commercial cellulase were used as additives. Six treatments were established: WS (control), ZA3, FG1, CEL (cellulase), ZC (ZA3 + cellulase), and FC (FG1 + cellulase). After 3 and 30 days (d) of ensiling, samples were exposed to aerobic conditions for 1 and 7 d, respectively. Fermentation characteristics, chemical composition, greenhouse gas emissions, and microbial parameters were determined after each open.

RESULTS AND DISCUSSION

During ensiling, pH declined while WSC, ammoniacal nitrogen (NH_3-N), and lactic acid (LA) increased across all treatments; notably, the ZA3 group exhibited the lowest pH and highest LA ($P < 0.05$). Upon aerobic exposure, pH and NH_3-N increased, whereas organic acids decreased; ZA3 consistently maintained superior fermentation characteristics ($P < 0.05$). At 3 d, pH and NH_3-N reached minimum levels, while WSC peaked at 30 d. Silage fermented for 30 d showed smaller fluctuations in pH and LA during aerobic exposure, indicating greater aerobic stability.

Crude protein (CP) decreased with fermentation time ($P < 0.05$) but remained higher in treated groups than in the control, suggesting improved protein preservation. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) decreased in all treatments; ZA3 most effectively reduced NDF, while FG1 showed the greatest ADF degradation ($P < 0.05$). During aerobic exposure, CP proportion increased, likely due to losses of other components, while NDF and ADF rose but remained lower than in the control.

Silage production significantly suppresses greenhouse gas emissions, with CO_2 emissions being the highest throughout the silage process, followed by CH_4. With the exception of CH_4 emissions in the FG1 group at 15 d of fermentation and N_2O emissions in the CEL group at 3 d of fermentation, the suppression of gas emissions in all treatment groups was significantly greater than that in the control group ($P < 0.05$). This may be due to the acidic environment during ensilage inhibiting

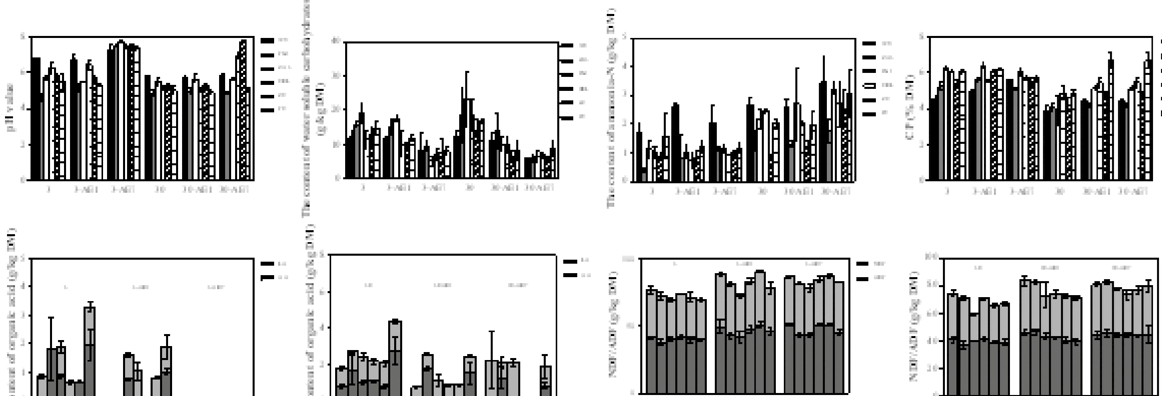

Fig. 1: Fermentation quality and chemical composition of silage

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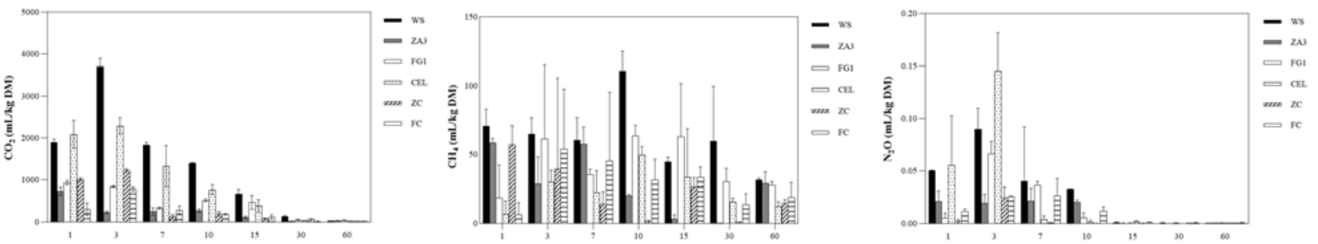

Fig. 2: Dynamics of greenhouse gas emissions from silage

the proliferation of gas-producing bacteria and reducing the degradation of organic matter.

During the silage process, the number of lactic acid bacteria in all treatment groups was significantly higher than that in the control group ($P < 0.05$), whilst the numbers of aerobic bacteria, fungi and other microorganisms were significantly reduced ($P < 0.05$). During aerobic exposure, this microbial trend was reversed. At the community level, *Lactiplantibacillus* became dominant after ensiling and remained so during aerobic exposure, contributing to pH stability, while aerobic genera such as *Sporolactobacillus* increased post-exposure. Fungal composition shifted from increased *Candida* and reduced plant pathogens (e.g., *Alternaria*) during ensiling to dominance of *Wickerhamomyces* and *Pichia* under aerobic conditions.

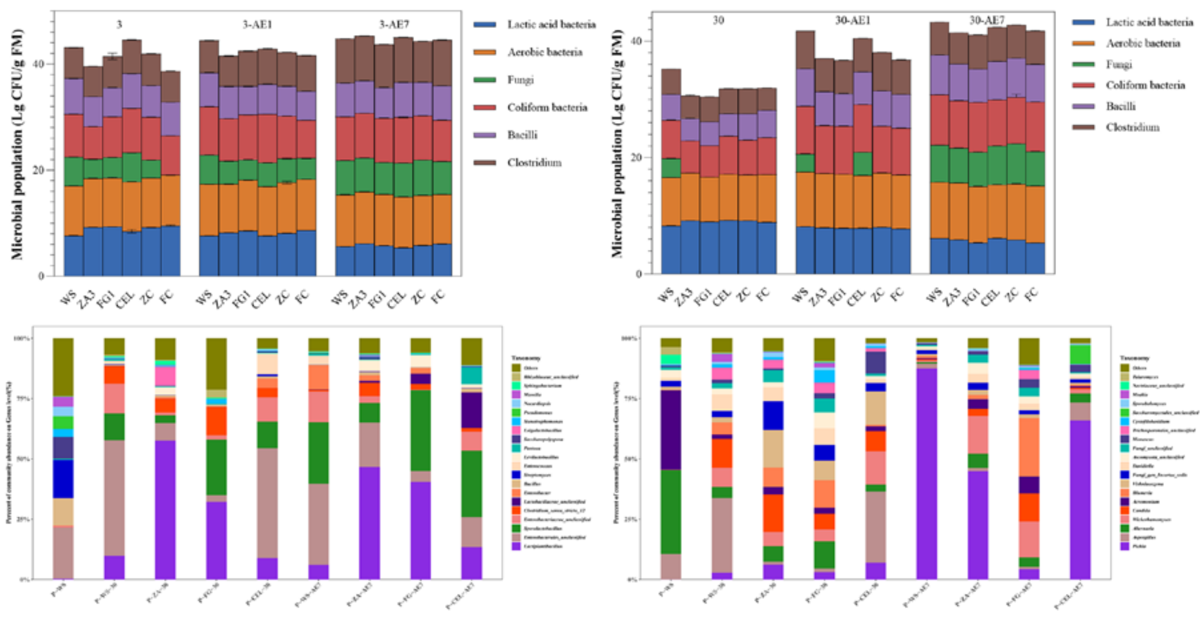

Fig. 3: Changes in microbial population (above) and community composition

CONCLUSION

This study systematically evaluated the effects of additive treatments on fermentation quality and greenhouse gas emissions during the ensiling and aerobic exposure of wheat straw. By regulating microbial community structure, all treatments lowered pH, increased beneficial LAB abundance, and suppressed harmful microorganisms, thereby improving fermentation quality and aerobic stability. LAB dominance inhibited gas-producing microbes and associated metabolic pathways, contributing to reduced greenhouse gas emissions. Among treatments, ZA3 showed the best overall fermentation performance. Microbial succession analysis highlighted the central role of LAB in maintaining pH stability and aerobic stability, while reduced fungal pathogens improved silage safety. These findings provide referenceer for improving feed utilization efficiency of straw.

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