Journal of Agricultural Science and Technology A 16 (2026) 29-35
doi: 10.17265/2161-6256/2026.01.004

Effect of a Propionic- and Formic-Acid-Based Chemical Additive on Corn Silage: Fermentative Profile, Aerobic Stability, and Performance of Lactating Dairy Cows

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Abstract: Organic acids play a crucial role in silage fermentation and aerobic stability by inhibiting the growth of spoilage microorganisms such as fungi and yeasts. This study evaluated the effects of a propionic- and formic-acid-based chemical additive on the fermentative profile, aerobic stability, dry matter losses, and performance of lactating dairy cows fed re-ensiled whole-plant corn silage with high dry matter content. The study was conducted in two trials. In Trial 1, whole-plant corn was treated with a chemical additive (Lupro-Mix® NA) and stored in experimental silos using a completely randomized design with four replicates per treatment: untreated silage (control) and silage treated with 4 L t^{-1} of fresh matter. The additive significantly reduced ethanol, 1, 2-propanediol, ethyl lactate, and ethyl acetate concentrations, as well as dry matter losses, while markedly increasing propionic acid concentration, resulting in greater aerobic stability. In Trial 2, the same additive was applied to re-ensiled corn silage stored in commercial bag silos and fed to lactating cows under a crossover design. Treated silage resulted in a numerical reduction in ingestion time and promoted increases in dry matter intake, milk yield, fat-corrected milk, and milk energy, with a tendency toward higher milk protein content. The use of a propionic- and formic-acid-based chemical additive effectively reduced storage losses, improved aerobic stability, and showed potential to enhance dairy cow performance.

Key words: Aerobic stability, chemical additive, corn silage, dairy cows, fermentation, organic acids.

1. Introduction

Whole-plant corn silage is one of the primary forage sources used in intensive dairy production systems worldwide due to its high energy content and consistent nutritional value [1, 2].

However, silages with elevated dry matter are more susceptible to aerobic deterioration after silo opening, which can result in nutrient losses and reduced feeding efficiency [3].

Aerobic spoilage is primarily driven by yeasts and molds that metabolize organic acids, increasing silage temperature and pH while compromising its quality [4].

Chemical additives containing organic acids have been widely adopted to control undesirable microorganisms. Propionic acid exhibits strong antifungal activity, whereas formic acid promotes rapid acidification and restricts bacterial development [5, 6].

The expansion of silage commercialization has increased the need for re-ensiling practices, making strategies that improve aerobic stability increasingly important [7].

Therefore, evaluating technologies capable of reducing storage losses while maintaining animal productivity is essential for improving the efficiency of dairy production systems and then, we hypothesized that the application of a propionic- and formic-acid-based additive would improve

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fermentation quality, enhance aerobic stability, reduce dry matter losses, and maintain animal performance.

The objective of this study is to evaluate the effects of a propionic- and formic-acid-based chemical additive on the fermentative profile, aerobic stability, and dry matter losses of whole-plant corn silage, as well as its implications for intake behavior and performance of lactating dairy cows fed re-ensiled silage.

2. Materials and Methods

2.1 Experimental Design and Silage Preparation

Whole-plant corn was harvested at approximately 40% dry matter, chopped, and ensiled to evaluate the effects of a chemical additive on silage fermentation and aerobic stability. The experimental design followed a completely randomized design with four replicates per treatment, as commonly adopted in silage preservation studies [8, 9].

Treatments consisted of: (i) untreated silage (control); and (ii) silage treated with a propionic- and formic-acid-based chemical additive (Lupro-Mix® NA) applied at 4 L t^{-1} of fresh matter.

The chemical additive composition was 35% propionic acid, 21% sodium formate, 20% formic acid, 4% sodium propionate, and 20% water, following manufacturer recommendations and previous studies evaluating organic-acid-based preservatives [5, 10].

2.2 Chemical Composition and Fermentation Analysis

After silo opening, silage samples were collected and analyzed for dry matter, crude protein, ether extract, ash, neutral detergent fiber, and acid detergent fiber according to standard procedures described by Buxton et al. [9].

Fermentation products, including pH, lactic acid, acetic acid, propionic acid, ethanol, 1, 2-propanediol, ethyl lactate, and ethyl acetate, were determined by the following methodologies widely used in silage evaluation studies [4, 11, 12].

Dry matter losses were estimated based on mass balance before and after ensiling, as described by Goeser et al. [13].

All fermentation parameters and DM losses are presented in Table 1.

Table 1 pH values and volatile concentrations in corn silage treated or not with a chemical additive.

Item	Treatments[1]			
	CON	LUPRO	SEM	*P*-value
DMcorr, % As Fed	44.50	44.20	0.22	0.32
pH	3.62	3.52	0.068	0.33
Lactic acid, % DMcorr	2.29	2.44	0.54	0.84
Acetic acid, % DMcorr	0.72	0.70	0.04	0.71
Ethanol, % DMcorr	0.43	0.09	0.03	<0.01
Propionic acid, mg/kg DMcorr	38	2865	136	<0.01
Butyric acid, mg/kg DMcorr	9	14	2.7	0.23
1, 2-propanediol, mg/kg DMcorr	257	28	34	<0.01
Ethyl lactate, mg/kg DMcorr	148	31	6.6	<0.01
Ethyl acetate, mg/kg DMcorr	37	7	3.1	<0.01
1-propanol, mg/kg DMcorr	6	5	2.5	0.69
LAB, cfu/g forage	6.14	5.50	0.145	0.03
Yeasts, cfu/g forage	3.78	3.73	0.023	0.27
DM loss, %	4.33	3.89	0.069	<0.01

[1] LUPRO: Corn silages treated with Lupro-Mix® (35% propionic acid; 21% sodium formate; 20% formic acid; 4% sodium propionate; 20% water) at 4 L/t fresh matter; CON: Corn silages without additives. SEM: Standard error of the mean; DMcorr: Corrected dry matter; LAB: Lactic acid bacteria.

Table 2 Aerobic stability of corn silage treated or not with a chemical additive.

Item	Treatments[1]			
	CON	LUPRO	SEM	*P*-value
Aerobic stability, h	78	144	10.3	<0.01
Maximum temperature, °C	38	29	1.79	0.03
Time to reach maximum temperature, h	153	228	14.8	0.01
Accumulated temperature 5 days, °C	12	1	3.5	0.06
Accumulated temperature 10 days, °C	69	23	5.7	<0.01

[1] LUPRO: Corn silage treated with Lupro-Mix® (35% propionic acid; 21% sodium formate; 20% formic acid; 4% sodium propionate; 20% water) at 4 L ton^{-1} fresh matter; CON: Corn silage without additives. SEM: Standard error of the mean.

Table 3 Feeding behavior and performance of Holstein dairy cows fed corn silages treated or not with a chemical additive.

Item	Treatments[1]			
	CON	LUPRO	SEM	*P*-value
Intake, min.	219.5	198.0	8.4	0.09
Rumination, min.	511.5	495.5	14.62	0.44
Chewing, min.	736.0	693.5	18.18	0.12
Number of meals, n.	9.2	9.0	0.33	0.67
Meal time, min.	24.7	22.8	1.05	0.23
DMI, kg/d	19.2	19.5	0.41	0.68
Milk, kg/d	20.1	20.4	0.37	0.53
Milk/DMI	1.05	1.07	0.023	0.60
Fat, %	3.78	3.83	0.066	0.56
Protein, %	3.29	3.38	0.033	0.09
Lactose, %	4.25	4.3	0.026	0.15
Fat, kg	0.752	0.782	0.0154	0.19
Protein, kg	0.655	0.685	0.011	0.08
Lactose, kg	0.857	0.882	0.182	0.35
MUN, mg/dL	17.7	17.4	0.32	0.48
Glucose 6h, mg/dL	56.9	58.1	0.84	0.34
Net Energy for Lactation (kg/d)	14.0	14.5	0.24	0.14
4% FCM, kg/d	19.3	19.9	0.33	0.23

[1] LUPRO: Corn silages treated with Lupro-Mix® (35% propionic acid; 21% sodium formate; 20% formic acid; 4% sodium propionate; 20% water) at 4 L ton^{-1} fresh matter; CON: Corn silages without additives. SEM: Standard error of the mean; DMI: Dry matter intake; MUN: Milk urea nitrogen; 4% FCM: 4% fat-corrected milk.

2.3 Aerobic Stability Evaluation

Aerobic stability was evaluated by exposing silage samples to air and continuously monitoring silage temperature (Table 2). Aerobic stability was defined as the time required for silage temperature to rise 2 °C above ambient temperature, according to established methodologies [3, 8].

Maximum temperature, time to reach peak temperature, and accumulated temperature over 5 and 10 days were also recorded to characterize the extent of aerobic deterioration [3].

2.4 Animal Trial and Feeding Management

In the second trial, the same chemical additive was applied to re-ensiled corn silage stored in commercial bag silos and fed to lactating Holstein cows. The experiment followed a crossover design with animals allocated into randomized blocks, a design commonly used to evaluate dietary treatments in dairy cows [14].

Cows were fed total mixed rations formulated to meet nutrient requirements, and feeding behavior variables, including ingestion time, rumination, and mastication, were recorded following procedures described by

Maekawa et al. [15].

Milk yield was recorded daily, and milk samples were analyzed for fat, protein, and lactose according to standard dairy performance evaluation protocols [14].

Performance measurement variables were recorded and are presented in Table 3.

2.5 Ruminal pH Measurement

Ruminal fluid samples were collected from rumen-cannulated cows over a 12-hour period following feeding. Samples were filtered, and pH was immediately measured using a calibrated digital pH meter, following procedures described by Maekawa et al. [15]. For context insertion, the temporal variation of ruminal pH is presented in Figure 1.

2.6 Statistical Analysis

Data from the silage experiment were analyzed using a completely randomized design. Animal performance data were analyzed using mixed models including the fixed effects of treatment and period and the random effect of block, as described by Kristensen et al. [14].

Ruminal pH data were analyzed as repeated measures over time. The covariance structure was selected based on Akaike's information criterion. Treatment effects were considered significant at $P \leq 0.05$ and tendencies at $0.05 < P \leq 0.10$, following standard statistical practices in animal science research.

3. Results and Discussion

3.1 Chemical Composition

The chemical composition of corn silage was not affected by the application of the chemical additive (Table 4), indicating that the treatment did not alter the nutritional value of the forage but instead acted primarily on microbial dynamics during the fermentation process.

Dry matter averaged 43.7%, confirming that the crop was harvested at an advanced maturity stage. High dry matter silages typically present greater porosity and

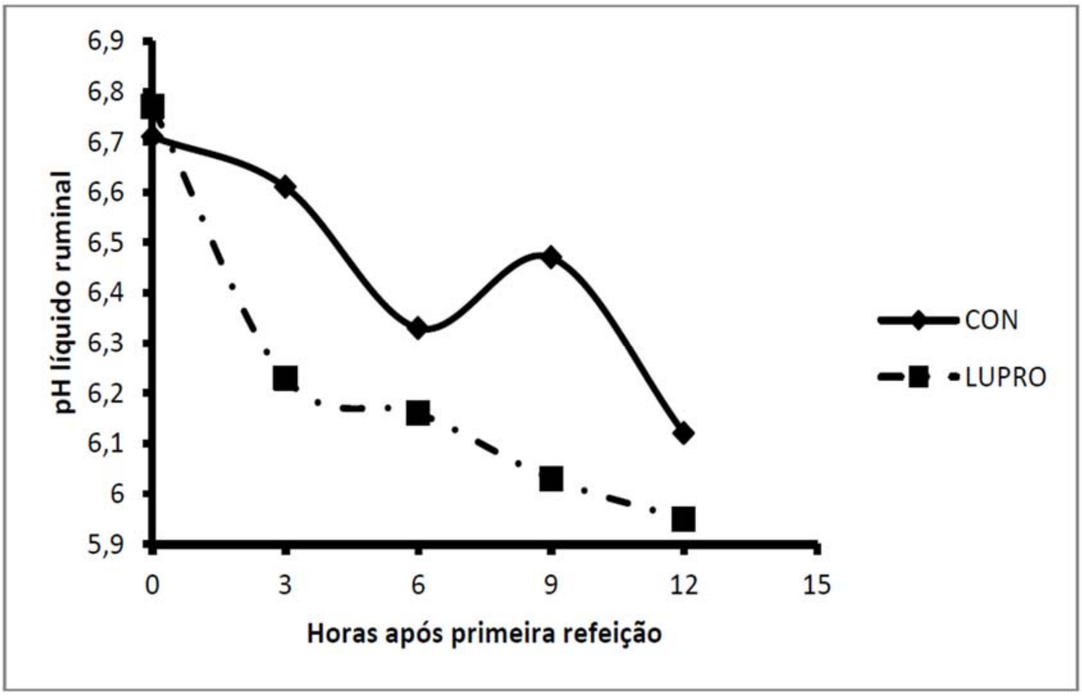

Fig. 1 Rumen liquid pH, 12-hour period after the first meal.
LUPRO - Corn silages treated with Lupro-Mix® (35% propionic acid; 21% sodium formate; 20% formic acid; 4% sodium propionate; 20% water) at a concentration of 4 L ton^{-1} of fresh matter. CON - Corn silages without additive supplementation. (Ptrt = 0.10; Ptime = <0.01; Ptrt*time = 0.37; SEM = 1.11).

Table 4 Corn silage composition treated or not with Chemical additive.

Item	Treatments[1]			
	CON	LUPRO	SEM	*P*-value
Dry matter, % As fed	43.9	43.6	0.19	0.22
Crude protein, % DM	6.2	6.1	0.15	0.87
Neutral detergent fiber, % DM	43.2	45.2	1.14	0.22
Acid detergent fiber, % DM	19.8	20.7	0.74	0.41
Ether extract, % DM	2.2	2.0	0.07	0.11
Ash, % DM	2.9	3.1	0.29	0.58
Non-fiber carbohydrates, % DM	45.5	43.7	2.05	0.76

[1] LUPRO - Corn silages treated with Lupro Mix 35 (35% propionic acid, 21% sodium formate, 20% formic acid, 4% sodium propionate, 20% water) at 4 L ton^{-1} fresh matter. CON: Corn silages without additives. DM: Dry Matter.

oxygen retention, factors that favor microbial activity and increase the risk of aerobic deterioration. This reinforces the importance of preservation strategies capable of stabilizing the silage mass.

The absence of compositional changes agrees with previous findings demonstrating that organic-acid-based additives generally influence fermentation pathways rather than nutrient concentration [5].

From a practical perspective, maintaining nutritional composition while improving conservation is desirable because it enhances feed efficiency without requiring adjustments in diet formulation.

3.2 Fermentation Characteristics and Dry Matter Recovery

Marked differences were observed in the fermentative profile between treatments (Table 2). The additive substantially reduced ethanol concentration along with 1, 2-propanediol, ethyl lactate, and ethyl acetate, indicating effective suppression of undesirable microorganisms.

Ethanol production is strongly associated with yeast metabolism and represents a direct loss of fermentable energy. Therefore, limiting its formation improves nutrient preservation and increases the amount of digestible substrate available to the animal. Reduced ethanol concentrations have consistently been linked to improved aerobic stability in corn silage [4].

A pronounced increase in propionic acid concentration was also observed in treated silage, a response that likely played a central role in controlling fungal growth. Propionic acid disrupts microbial cell membranes and interferes with metabolic activity, thereby delaying spoilage when silage is exposed to oxygen [16].

Importantly, the reduction in dry matter losses confirms that the additive improved the overall efficiency of the ensiling process. Even modest decreases in storage losses can translate into substantial economic benefits at the farm level due to greater recovery of harvested nutrients.

Similar improvements in fermentation quality have been reported when propionic-acid-based preservatives were applied to corn silage [5], supporting the consistency of the present results.

3.3 Aerobic Stability

The higher concentration of antifungal compounds in treated silage resulted in greater aerobic stability, demonstrating the effectiveness of organic acids in controlling deterioration after silo opening.

Aerobic spoilage is typically initiated by yeasts that metabolize lactic acid, producing carbon dioxide and heat. Once this process begins, silage temperature rises rapidly, accelerating nutrient degradation and reducing palatability. Consequently, strategies that inhibit yeast activity are essential for maintaining silage quality [17].

The improved stability observed in this study suggests that treated silage remained microbiologically stable for longer periods, reducing the likelihood of secondary fermentation. Comparable responses have been reported in studies evaluating organic acids as preservatives [18].

From a management standpoint, enhanced aerobic stability is particularly valuable in high dry matter silages, which are inherently more susceptible to oxygen infiltration.

3.4 Impacts on Dairy Cow Performance

Cows fed treated silage showed a numerical reduction in ingestion time and increases in dry matter intake, milk yield, fat-corrected milk, and milk energy (Table 4).

Additionally, a tendency toward higher milk protein content was observed, suggesting improved nutrient utilization.

Although not all variables reached statistical significance, the consistent direction of responses indicates that improved silage preservation likely enhanced diet quality. Better fermentation reduces the formation of undesirable metabolites that can depress intake and impair animal performance.

Maintaining intake is particularly relevant because reduced dry matter consumption is often the earliest indicator of compromised silage quality.

Studies conducted under commercial conditions have similarly reported that improved fermentation and aerobic stability are associated with better productive responses in dairy cows [13].

Importantly, the absence of negative effects on performance confirms that the additive can be adopted without compromising productivity.

3.5 Integrated Interpretation and Practical Implications

Collectively, the results indicate that the primary benefits of the additive were associated with improved preservation rather than direct stimulation of milk production. This distinction is critical because technologies that reduce storage losses while maintaining animal performance contribute directly to production efficiency.

As silage systems become increasingly intensive, minimizing nutrient losses during storage is as important as maximizing crop yield. The findings therefore support the adoption of organic-acid-based additives as a practical strategy to enhance feed management in modern dairy operations.

4. Limitations of the Study

Despite the positive effects observed on fermentation quality and aerobic stability, some limitations of this study should be considered. Only one application rate of the chemical additive was evaluated, which prevents the establishment of dose response relationships and optimal inclusion levels under different production conditions. Additionally, the animal trial was conducted over a relatively short experimental period, and longer-term studies may provide a more comprehensive understanding of the impacts on productivity and nutrient utilization. Future research should therefore explore different additive doses, extended feeding periods, and diverse environmental conditions to further validate the applicability of this technology in commercial dairy systems.

5. Conclusion

The application of a propionic- and formic-acid-based chemical additive effectively reduced dry matter losses and improved aerobic stability of corn silage. Moreover, treated silage-maintained animal performance while showing indications of improved nutrient utilization. These findings support the use of organic-acid-based additives as a practical strategy to enhance silage preservation and feeding efficiency in dairy production systems.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the São Paulo Research Foundation (FAPESP), for the research grant provided to Luiz Gustavo Nussio. The authors also thank all staff and students involved in the experimental work for their valuable assistance.

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