TRADE-OFF BETWEEN FERMENTATION QUALITY AND AEROBIC STABILITY OF CORN SILAGE

Loučka, R.[1], Homolka, P.[1], Jančík, F.[1], Koukolová, V.[1], Kubelková, P.[1]

[1]Institute of Animal Science, Přátelství 815, 104 00 Prague-Uhříněves, Czech Republic

ABSTRACT

Aerobic stability (AS) temperature exerts a highly significant effect on corn silage quality, with practical consequences for feed management under warming climate conditions. A complete 3×2×2 factorial experiment tested three treatments (untreated control, Formasil® Maize Propio containing *L. buchneri* and propionic acid, homofermentative *L. plantarum* inoculant) at two fermentation temperatures (20 °C, 30 °C) followed by aerobic exposure at 20 °C and 30 °C. Twenty-three samples were analyzed after 40-day fermentation. AS at 20 °C preserved 12.7% higher NEL (6.85 vs. 6.08 MJ/kg DM; p < 0.001), 62.5% more lactic acid (3.60 vs. 2.21% DM; p < 0.001), and lower pH (4.03 vs. 4.32; p = 0.002). Formasil produced the highest acetic acid content (avg. 1.35% DM; p = 0.024) and achieved best performance at 20 °C AS (NEL 7.02 MJ/kg DM, DM losses 2.96%). *L. plantarum* showed the highest LA/VFA ratio (4.61; p = 0.006), indicating homofermentative pathway dominance. No butyric acid was detected in any sample. A fundamental trade-off exists between fermentation pathway optimization and temperature-dependent aerobic stability, requiring climate-specific additive selection strategies.

Keywords: lactic acid bacteria, heterofermentative inoculant, biological additives, climate warming, dry matter losses

INTRODUCTION

Corn silage is a key component of dairy cow diets worldwide, and its quality is increasingly jeopardized by warming temperatures associated with climate change. Aerobic deterioration, driven primarily by yeasts and moulds, degrades nutritional value, generates heat, and may produce mycotoxins. Temperature during aerobic exposure is a critical but often underestimated determinant of silage quality at feed-out. Biological silage additives differ in their mechanisms: homofermentative bacteria (e.g. *L. plantarum*) rapidly lower pH via lactic acid production, while heterofermentative strains (e.g. *L. buchneri*) additionally produce acetic acid and 1,2-propanediol, improving aerobic stability. The objective of this study was to quantify the effect of two contrasting AS temperatures (20 °C vs. 30 °C) on corn silage quality and to evaluate the temperature-dependent efficacy of two biological additives.

MATERIAL AND METHODS

A complete 3×2×2 factorial experiment was designed. Treatment factor: (K) untreated control, (F) Formasil® Maize Propio (*L. buchneri* + propionic acid, 1 g/t FM), (P) *L. plantarum* homofermentative inoculant (1 g/t FM). Fermentation temperature: 20 °C or 30 °C for 40 days. Aerobic stability (AS) temperature: 20 °C or 30 °C post-fermentation exposure. Corn forage from a single harvest (initial DM ~ 35%) was ensiled in LDPE vacuum bags (n = 23 bags total; some combinations with one replicate for technical reasons). Fermentation quality (lactic acid, acetic acid, butyric acid) was determined by HPLC (VVS Verměřovice s.r.o., protocols 128625–130925). Nutritional parameters (DM, crude protein, starch, NDF, ADF, NEL) were determined by NIR and standard gravimetric methods. DM losses were calculated as (35.0 − measured DM) / 35.0 × 100. VFA was defined as the sum of acetic and butyric acids (butyric acid = 0 in all samples). Statistical analysis used one-way ANOVA for treatment effects and Student's t-test for temperature effects (Statistica v.13; α = 0.05).

RESULTS AND DISCUSSION (PRELIMINARY)

All 23 samples were free of butyric acid, confirming successful anaerobic fermentation without clostridial activity across all treatment combinations and temperatures.

AS temperature exerted highly significant effects on energy value, lactic acid content, and pH (Table 1). Silage exposed at 20 °C retained 12.7% higher NEL (6.85 vs. 6.08 MJ/kg DM) and 62.5% more lactic acid (3.60 vs. 2.21% DM) than at 30 °C. The higher AS temperature promotes accelerated yeast activity, leading to oxidation of lactic acid to CO_2 and H_2O, pH reversion, and energy losses — a process Rooke and Hatfield (2003) termed ‚fermentation reversal.' The lower pH at 20 °C AS (4.03 vs. 4.32; p = 0.002) reflects better preservation of the fermentation profile. DM losses and LA/VFA ratio were not significantly affected by AS temperature (p > 0.05), likely due to high variability and the limited number of replicates.

Biological additives significantly influenced acetic acid content (F = 4.515; p = 0.024) and the LA/VFA ratio (F = 6.731; p = 0.006). Formasil produced the highest acetic acid (mean 1.35% DM across both AS temperatures), corresponding to the heterofermentative activity of *L. buchneri* converting lactic acid to acetic acid and 1,2-propanediol. This mechanism is the basis of its antimicrobial effect against yeasts. At 20 °C AS, Formasil achieved the best performance with the highest NEL (7.02 MJ/kg DM) and lowest DM losses (2.96%), suggesting that acetic

Tab. 1: Effect of AS temperature on corn silage quality parameters. Values are mean ± SD (n = 12 for 20 °C AS; n = 11 for 30 °C AS). Significance: *** p < 0.001; ** p < 0.01; ns = not significant. VFA = acetic acid (butyric = 0); LA/VFA = lactic acid to volatile fatty acids ratio

Parameter	AS 20 °C	AS 30 °C	Diff.	Diff. (%)	p-value
NEL (MJ/kg DM)	6.85 ± 0.33	6.08 ± 0.51	+0.77	+12.7	0.0003***
pH	4.03 ± 0.18	4.32 ± 0.19	−0.28	−6.6	0.002**
Lactic acid (% DM)	3.60 ± 0.54	2.21 ± 0.71	+1.38	+62.5	0.0000***
Acetic acid (% DM)	1.22 ± 0.60	0.67 ± 0.18	+0.54	+81.0	0.008**
LA/VFA	3.48 ± 1.22	3.47 ± 1.22	+0.01	+0.4	0.977 ns
DM losses (%)	4.57 ± 3.71	2.38 ± 13.87	+2.18	+91.7	0.604 ns

https://doi.org/10.11118/978-80-7701-093-1-0154

Tab. 2: Corn silage quality parameters by treatment and AS temperature. Shaded rows = Formasil. * = significantly highest within column ($p < 0.05$, Tukey HSD). K = control; LA = lactic acid; VFA = volatile fatty acids (acetic acid); homo = homofermentative; hetero = heterofermentative

Treatment	AS temp.	DM losses (%)	NEL (MJ/kg DM)	pH	Acetic acid (% DM)	LA/VFA	LA/VFA classification
Control	20 °C	7.44	6.53	4.05	0.95	3.83	homo
Control	30 °C	2.48	5.92	4.20	0.73	3.61	homo
Formasil	**20 °C**	**2.96**	**7.02**	**3.85**	**1.99***	**2.01**	**hetero**
Formasil	30 °C	0.14	5.97	4.38	0.67	3.02	mixed
Plantarum	20 °C	3.31	7.00	4.20	0.71	4.61*	homo
Plantarum	30 °C	5.24	6.45	4.40	0.60	3.88	homo

acid inhibition of yeasts is most effective at lower temperatures where yeast proliferation rates are inherently slower. At 30 °C AS, treatment differences narrowed, indicating that elevated temperature overwhelms the antimicrobial capacity of achievable acetic acid concentrations.

L. plantarum achieved the highest LA/VFA ratio (4.61 at 20 °C AS), confirming efficient homofermentative pathway dominance with minimal undesirable fermentation by-products. However, this superior fermentation profile was accompanied by reduced aerobic protection at 30 °C AS (DM losses 5.24%), because high lactic acid concentrations provide an ideal substrate for lactate-assimilating yeasts. This represents the same fundamental trade-off between fermentation quality and aerobic stability previously identified in alfalfa silage (Muck *et al.*, 2018), here confirmed for corn silage under a temperature-dependent context. Each degree Celsius increase above 25 °C can approximately double the rate of aerobic deterioration (Rooke and Hatfield, 2003), which magnifies these treatment differences considerably under warm conditions.

CONCLUSION

AS temperature has a greater and more consistent effect on corn silage quality than additive type: reducing AS temperature from 30 °C to 20 °C preserved 12.7% more energy (NEL) and 62.5% more lactic acid. Formasil (*L. buchneri* + propionic acid) achieved optimal performance at 20 °C AS (NEL 7.02 MJ/kg DM, DM losses 2.96%) with the highest acetic acid content (1.35% DM), supporting aerobic stability. *L. plantarum* provided the best homofermentative profile (LA/VFA 4.61) but offered less protection at elevated AS temperatures. These results identify a fundamental trade-off: additives optimizing fermentation quality may be less protective under warm feed-out conditions, necessitating climate-specific additive selection. In warm regions or during summer feeding (>25 °C), Formasil or equivalent heterofermentative/combination additives are recommended, combined with rapid feed-out management (<24 h air exposure). In cool regions (<20 °C), either additive type performs well. All treatments effectively prevented clostridial fermentation, confirming that both biological strategies reliably protect corn silage during anaerobic storage.

REFERENCES

Borreani, G., Tabacco, E., Schmidt, R. J., Holmes, B. J., Muck, R. E. 2018. Silage review: Factors affecting dry matter and quality losses in silages. *Journal of Dairy Science*. 101, 3952–3979.

Kleinschmit, D. H., Schmidt, R. J. 2007. Effect of various inoculants on the fermentation and aerobic stability of corn silage. *Journal of Dairy Science*. 90(Suppl. 1), 379.

Kung, L. Jr., Shaver, R. D., Grant, R. J., Schmidt, R. J. 2018. Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. *Journal of Dairy Science*. 101, 4020–4033.

Muck, R. E., Nadeau, E. M. G., McAllister, T. A. *et al*. 2018. Silage review: Recent advances and future uses of silage additives. *Journal of Dairy Science*. 101, 3980–4000.

Oliveira, A. S., Weinberg, Z. G., Ogunade, I. M. *et al*. 2017. Meta-analysis of effects of inoculation with homofermentative and facultative heterofermentative LAB on silage fermentation, aerobic stability, and dairy cow performance. *Journal of Dairy Science*. 100, 4587–4603.

Rooke, J. A., Hatfield, R. D. 2003. Biochemistry of ensiling. In: *Silage Science and Technology*. ASA-CSSA-SSSA, Madison, USA, pp. 95–139.

Wilkinson, J. M., Davies, D. R. 2013. The aerobic stability of silage: Key findings and recent developments. *Grass and Forage Science*. 68, 1–19.

Contact Information

Radko Loučka: email: loucka.radko@vuzv.cz