

BACTERIAL INOCULANTS MODIFYING FERMENTATION PROCESSES AND SILAGE QUALITY – A REVIEW OF RESEARCH RESULTS

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Abstract

*Proper feeding of cows, including dairy cows, and good-quality feed are factors affecting production performance as well as herd welfare. High-quality silage is characterized, among other things, by aerobic stability, i.e. high resistance of the feed to aerobic deterioration, which depends on the proper course of fermentation processes during ensiling. In properly prepared silages, fermentation processes are carried out by epiphytic microorganisms inhabiting the plant material and may be supported by microorganisms introduced through inoculation. Bacterial inoculants (modifiers) differ in the qualitative and quantitative composition of the bacteria used. These include homofermentative lactic acid bacteria (*Lactobacillus acidophilus*, *L. casei*, *L. curvatus*, *L. paracasei*, *L. plantarum*, *L. salivarius*, *Lactococcus acidilactici*, *Enterococcus faecium*, *Pediococcus acidilactici*, *P. pentosaceus*), heterofermentative lactic acid bacteria (*Lactobacillus buchneri*, *L. brevis*, *L. diolivorans*, *L. hilgardii*, *L. kefir*, *L. parafarraginis*, *L. fermentum*, *Leuconostoc*, *Bifidobacterium*), obligately heterofermentative lactic acid bacteria, mixtures of obligately heterofermentative lactic acid bacteria, and other microorganisms that are not lactic acid bacteria. Modern modifiers are intended to support proper fermentation processes, accelerate them, and help maintain the correct course of fermentation by directing and then stabilizing these processes. Compounds formed during homofermentation and heterofermentation, including propionic acid, 1,2-propanediol and acetic acid, have a preservative effect on silage by inhibiting the growth of yeasts and other harmful microorganisms, thereby extending the aerobic stability of silages.*

Keywords: silage, lactic acid bacteria, quality parameters

Introduction

The course of fermentation processes during ensiling depends largely on the consortium of microorganisms present and on the metabolites they produce. Continuous investigation of microbial communities occurring on plants, as well as those active during ensiling, is necessary to

obtain high-quality silage (Yang et al., 2022). Understanding the sequence of individual fermentation phases and the correlations between them, microorganisms, and their metabolites should be a focus of contemporary research. During feed ensiling, one effective way to reduce potential nutrient losses is the use of bacterial inoculants. Between 2020 and 2023, a marked increase in the production of maize silage was observed. Particular attention should be paid to the economic aspect related to the cost-effectiveness of bacterial inoculants (Liu et al., 2024). The use of inoculants is considered economically justified and consistent with good agricultural practice. Owing to advances in research, lactic acid bacteria are taxonomically described as facultatively and obligately heterofermentative and homofermentative bacteria. The activity of bacterial preparations should be directed toward: (i) improving fermentation processes, (ii) reducing losses during ensiling, (iii) improving nutritional value, and (iv) extending the aerobic stability of feed.

Characteristics of good-quality silage

Good-quality silage is characterized by an appropriate pH (3.8–4.2 for maize silage; 4.2–4.6 for grass silage), high nutritional value, palatability (pleasant smell, well-preserved structure, olive-green colour), aerobic stability (resistance to secondary fermentation), and proper microbiological quality. It is estimated that each 10°C increase in silage temperature doubles the biological activity of the microbiota inhabiting it. Aerobic stability is defined as the number of days during which silage exposed to air at 20°C does not exceed the ambient temperature by more than 3°C (Kukier et al., 2015). Good grass silage containing 30–35% dry matter should have a pH of 4.3–4.7. Lactic acid content should be 6–10%, acetic acid 1–3%, propionic acid <1%, and butyric acid 0.5–1%. Ammonia as a proportion of total nitrogen should range from 8 to 12%. Ethanol should account for 0.5–1%. This level of dry matter ensures a proper balance between starch content, digestibility, and fibre content. It also enables adequate compaction of green material in the silo.

Beneficial bacteria (lactic acid bacteria) naturally colonizing plants occur in relatively low numbers, whereas undesirable microorganisms such as enterobacteria, *Clostridium* spp., *Bacillus* spp., *Listeria* spp., and fungi (yeasts and moulds) are more abundant; therefore, ensiling should be supported with inoculants (silage additives, modifiers). A good inoculant should limit heating of plant material, inhibit fungal growth, prevent secondary fermentation, and reduce alcohol formation.

The family *Lactobacillaceae*

Lactobacillaceae is the only family within *Lactobacillales* that includes both homofermentative and heterofermentative microorganisms (Zheng et al., 2020).

Homofermentative lactic acid bacteria

These include, among others, *Lactobacillus delbrueckii*, *L. acidophilus*, *L. casei* (*Lacticaseibacillus casei*), *L. curvatus* (*Latilactobacillus curvatus*), *L. paracasei* (*Lacticaseibacillus paracasei*), *L. plantarum* (*Lactiplantibacillus plantarum*), *L. salivarius* (*Ligilactobacillus salivarius*), and *L. melliventris*. These bacteria use glucose and fructose as substrates for lactic acid fermentation. Glucose metabolism proceeds through glycolysis, in which one glucose molecule yields two pyruvate molecules, two ATP molecules, and two NADH⁺ molecules, which are subsequently used in the reduction of pyruvate to lactic acid. Lactate dehydrogenase is the enzyme required for these transformations and converts pyruvate into lactic acid. Only small amounts of pyruvate are converted during this process into carbon dioxide, acetic acid, and ethanol (Ratajczak and Piotrowska-Cyplik, 2017). This metabolic pathway is highly beneficial because

it limits dry matter losses in silage (dry matter should be around 30–35%), reduces the concentrations of acetic and butyric acids and ammonia, and, above all, promotes an increase in lactic acid content and a decrease in pH (Kung, 2018). Results reported by other authors indicate a considerable reduction in dry matter content in maize silages inoculated with homofermentative lactic acid bacteria (Guo et al., 2021). Oliveira et al. (2017) showed that inoculants containing homofermentative bacteria effectively inhibited the growth of *Clostridium* and moulds but had no effect on silage aerobic stability. Based on a meta-analysis of 130 papers, the authors indicated that the effectiveness of homofermentative bacteria largely depends on the type of ensiled plant. The results showed a beneficial effect of homofermentative bacteria on reducing pH in alfalfa and other legume silages, but not in maize and sorghum silages. Conversely, these bacteria reduced acetic acid concentration in most silages, except those prepared from alfalfa and other legumes. Grass, maize, and sorghum silages supplemented with homofermentative bacteria had lower dry matter losses than control silages. Inoculation produced the desirable reduction in butyric acid and ammonia content and increased lactic acid levels regardless of the type of ensiled plant. The course of fermentation may have been influenced by differences in non-structural carbohydrate content and buffering capacity among plant species.

The effect of homofermentative lactic acid bacteria on the aerobic stability of silage is inconclusive. The analysis of research results by Oliveira et al. (2017) did not confirm a significant effect of homofermentative lactic acid bacteria on changes in silage aerobic stability. The authors reported higher yeast counts in inoculated silages than in controls. Increased yeast abundance combined with a reduced acetic acid concentration may explain the deterioration in aerobic stability of silages inoculated with homofermentative bacteria. Yeasts are the principal initiators of aerobic feed deterioration. In contrast, after applying *L. plantarum* to maize silage, Guo et al. (2021) reported an increase in lactic acid concentration and reductions in pH, butyric acid and ammonia concentrations, and yeast counts. The authors suggest that delayed maize harvest is an important factor shaping these parameters. In silages harvested later (15 days after reaching full maturity), pH and acetic acid concentration increased, whereas lactic acid levels decreased. Divergent research findings do not fully confirm the high effectiveness of homofermentative lactic acid bacteria in producing silages of desirable quality. This prompted research on new preparations containing mixtures of homofermentative and heterofermentative bacteria.

Heterofermentative lactic acid bacteria

Bacteria in this group include, among others, *Lactobacillus buchneri* (*Lentilactobacillus buchneri*), *L. brevis* (*Levilactobacillus brevis*), *L. diolivorans* (*Lentilactobacillus diolivorans*), *L. hilgardii* (*Lentilactobacillus hilgardii*), *L. kefir* (*Lentilactobacillus kefir*), *L. parafarraginis* (*Lentilactobacillus parafarraginis*), *L. fermentum* (*Limosilactobacillus fermentum*), and *Bifidobacterium* spp. Heterofermentation is carried out by bacteria lacking some enzymes required for glycolysis. Glucose is therefore transformed by a pathway different from that used in homofermentation. In the first stage, glucose degradation proceeds exclusively through the pentose phosphate pathway, involving glucose-6-phosphate, 6-phosphogluconate, and ribulose-5-phosphate, which is then converted by epimerase to xylulose-5-phosphate. In a thiamine pyrophosphate-dependent reaction, xylulose-5-phosphate is cleaved by phosphoketolase to glyceraldehyde-3-phosphate and acetyl phosphate. Acetyl phosphate is either converted to acetate by acetate kinase with simultaneous phosphorylation of ADP, or reduced to ethanol via acetyl-CoA and acetaldehyde. Glyceraldehyde-3-phosphate is oxidized through the fructose-bisphosphate pathway and ultimately converted to lactic acid. Ultimately, heterofermentation of 1 mole of glucose yields 1 mole of lactic acid, 1 mole of ethanol, and 1 mole of carbon dioxide. Bacteria of the genus *Bifidobacterium* conduct heterofermentation differently from other heterofermentative bacteria, using the phosphoketolase pathway. In this process, 2 moles of glucose produce 2 moles of lactic acid and 3 moles of acetic acid. Ethanol and CO₂ formed

during heterofermentation contribute unfavourably to dry matter losses, making this metabolic pathway less efficient than homofermentation (Ratajczak and Piotrowska-Cyplik, 2017).

Obligately heterofermentative lactic acid bacteria

L. buchneri effectively extends silage aerobic stability because of its ability to metabolize lactic acid to acetic acid and 1,2-propanediol. Subsequently, 1,2-propanediol can be converted to propionic acid by *L. diolivorans* (Selwet, 2021). A new strain capable of direct synthesis and metabolism of 1,2-propanediol, *L. buchneri* A KKP 2047p, has been identified (Zielińska et al., 2017). *L. buchneri* grows more slowly than homofermentative bacteria; only after completion of the main initial fermentation does it begin to slowly convert lactic acid into acetic acid. The resulting acetic and propionic acids exert fungistatic effects on yeasts and moulds, which metabolize lactate and thereby cause losses and reduce silage aerobic stability. Aerobic stability refers to silage resistance to deterioration in the presence of oxygen and is crucial for maintaining high feed quality. The more aerobically stable the silage, the less spoilage and loss of nutritional value occur during feeding. *L. hilgardii*, which has a mechanism of action similar to that of *L. buchneri*, may prevent dry matter losses and extend silage aerobic stability. Extending aerobic stability reduces dry matter losses, which may reach as much as 30%. Arriola et al. (2021a) found no effect of these two bacterial species on silage aerobic stability. The effect of these species depends on the strain used and the preparation dose (Selwet, 2022). A meta-analysis by Kleinschmit and Kung (2006) showed that control maize silages had an aerobic stability of 25 hours. An inoculant dose containing $<10^5$ cfu *L. buchneri* g⁻¹ fresh maize extended stability to 35 hours. Increasing the dose to $>10^5$ cfu *L. buchneri* g⁻¹ fresh maize prolonged resistance to aerobic deterioration to 503 hours. Recommended application rates in commercial preparations range from 10^5 to 4×10^5 cfu *L. buchneri* g⁻¹ fresh matter, and for high-moisture maize, 6×10^5 cfu g⁻¹ fresh matter. Concerns about dry matter losses caused by excessive acetic acid production also proved unfounded. Most studies showed only a 1 percentage point increase in dry matter losses at doses of approximately 10^5 cfu g⁻¹ fresh matter. Such a small difference relative to control silages was compensated by the extended stability of the resulting silages.

Mixtures of obligately heterofermentative lactic acid bacteria

Combinations of different bacterial species, e.g. *L. buchneri* with *L. brevis*, *L. parafarraginis*, and *L. hilgardii*, play an important role in silage production technology (Arriola et al., 2021a). Mixtures of heterofermentative bacteria have been used to reduce dry matter losses and extend silage aerobic stability compared with silages inoculated with a single strain such as *L. buchneri*. Current research focuses on isolating strains of obligately heterofermentative bacteria that can extend silage aerobic stability more effectively than *L. buchneri*. After applying *L. brevis*, Danner et al. (2003) recorded an extension of aerobic stability to 72 hours compared with 40 hours in control silage. The authors used a very high inoculant dose (7×10^8 cfu g⁻¹ fresh matter), higher than commercial levels. The literature also includes studies on sugarcane, a plant not cultivated in the temperate climate zone. These studies showed that addition of a pure *L. brevis* strain (DSM23231), either alone or in combination with *L. kefir* (DSM19445) at 2×10^5 cfu g⁻¹, did not alter acetic acid concentration, increased yeast counts, and had no effect on silage aerobic stability (Daniel et al., 2015). Avila et al. (2014) showed that sugarcane silages treated with two *L. hilgardii* strains (CNCM I-4784 and CNCM I-4785) had higher concentrations of acetic acid and 1,2-propanediol than control silages or silages inoculated only with *L. brevis*. Silages supplemented with *L. hilgardii* had lower dry matter losses and lower ethanol and butyric acid concentrations than control silages. Aerobic stability was not prolonged in these studies. Assis et al. (2014), using *L. hilgardii* at 1×10^6 cfu g⁻¹ maize, observed an extension of silage aerobic stability only on day 90 of ensiling. When comparing inoculated and control silages on day 30, the authors found no differences in the time to heating. Polukis et al.

(2016) applied *L. hilgardii* CNCM I-4785 and *L. buchneri* 40788 at 6×10^5 cfu g⁻¹ to high-moisture maize. In both cases, the authors observed increased production of acetic acid and 1,2-propanediol and reduced yeast counts compared with control silages. At the same time, aerobic stability measured on days 30 and 90 was 250 hours for inoculated silages and 31 and 49 hours, respectively, for controls. Arriola et al. (2021b) demonstrated extended aerobic stability in 79% of silages prepared from different plant species after applying a mixture of *L. buchneri* and *L. hilgardii* compared with inoculation with *L. buchneri* alone. This effect resulted from increases in acetic acid (47%), propionic acid (35%), and 1,2-propanediol (269%), accompanied by reduced mould and yeast counts. Bernardi et al. (2019), studying a mixture of *L. buchneri* and *L. brevis* in maize silage, also observed increased aerobic stability and reduced mould and yeast counts, but reported a 50% increase in dry matter losses. Gomes et al. (2021), in sugarcane silages ensiled with *L. hilgardii* CNCM I-4785, *L. buchneri* NCIMB 40788, or their mixture, reported increased acetic acid concentration, reduced yeast counts, and extended aerobic stability. *L. buchneri* used alone proved most effective compared with *L. hilgardii* and the *L. buchneri* + *L. hilgardii* mixture applied at 3×10^5 cfu g⁻¹ fresh matter. Ferrero et al. (2021), however, showed that a mixture of these two strains extended silage aerobic stability more effectively than either strain used alone (dose $\leq 1 \times 10^5$ cfu g⁻¹).

Mixtures of homofermentative and obligately heterofermentative lactic acid bacteria

Mixtures of these bacterial groups are intended to increase benefits and reduce losses associated with their use. Homofermentative bacteria (*L. plantarum*, *L. lactis*, *E. faecium*, *P. acidilactici*) favourably improve the course of fermentation and reduce dry matter losses in silages. However, they do not have a significant effect on improving silage aerobic stability. Therefore, inoculants should be supplemented with heterofermentative strains such as *L. buchneri*, *L. brevis*, or *L. hilgardii*, which possess such properties. In most studies, the main components of inoculants are *L. buchneri* and *L. brevis*. These inoculants are additionally supplemented with *L. plantarum*, *L. lactis*, *E. faecium*, and *P. pentosaceus*. Li et al. (2021), using a mixture of *L. buchneri* and *L. plantarum* (10^5 g⁻¹ fresh timothy matter), reported reduced butyric acid and ammonia concentrations, lower yeast counts, and lower pH compared with control silages. Arriola et al. (2021b) obtained a synergistic effect from mixtures of these bacteria, expressed as extended aerobic stability of maize silage, except for sorghum silage. A beneficial effect of bacterial mixtures on improving the aerobic stability of maize and alfalfa silages was also reported by Blajman et al. (2020). The use of bacterial mixtures causes a rapid pH decrease during the initial phase of ensiling. Schmidt et al. (2009) studied alfalfa silages treated with *L. buchneri* and with a mixture of *L. buchneri* and *P. pentosaceus*. Five days after ensiling began, the pH of silages supplemented with *L. buchneri* was higher than that of controls, whereas the bacterial mixture (*L. buchneri* and *P. pentosaceus*) caused a marked reduction in feed pH relative to control samples. Addah et al. (2012) found that during the first week of ensiling, barley silages supplemented with *L. buchneri*, *L. plantarum*, and *L. casei* had lower pH than control silages. Arriola et al. (2015), using preparations containing *L. buchneri* and *P. pentosaceus* or *P. pentosaceus* and *Propionibacterium freudenreichii* in grass silages, observed a faster reduction in pH during the first 7 days of ensiling compared with control samples. Dominance of *L. buchneri* is often associated with lower lactic acid concentration and higher acetic acid content, which extends silage aerobic stability. Some studies, however, show no improvement in aerobic stability after the use of combined inoculants. Adesogan and Salawu (2004) used an inoculant containing *L. buchneri*, *P. pentosaceus*, and *L. plantarum* in pea-wheat silages and compared its effect with control silages and silages treated with *L. buchneri* or formic acid. None of the preparations improved feed aerobic stability. Acetic acid content was higher in control silages (26–42 g kg⁻¹ DM) than in silages supplemented with the combined inoculant. Kang et al. (2009) tested a combined preparation (*L. casei*, *L. buchneri*) in silages made from two maize

varieties. Inoculation improved stability in only one variety, whereas silage prepared from the other variety had reduced aerobic stability compared with controls. Thomas et al. (2013) investigated the effects of a combination of *L. buchneri*, *P. acidilactici*, *P. pentosaceus*, *L. plantarum*, and *E. faecium* on ensiling four sorghum varieties. Chemical analysis showed that none of the silages exhibited characteristics of predominantly heterofermentative lactic fermentation. Two varieties were classified as predominantly homofermentative, but inoculation did not improve aerobic stability in any silage. Diepersloot et al. (2021) found that sorghum silages treated with a mixture of *L. plantarum* DSM 21762, *L. buchneri* DSM 12856, and *L. diolivorans* DSM 32074 showed enhanced heterofermentative processes, increased acetic acid concentration, inhibited fungal growth, and extended aerobic stability after 56 days of ensiling from 36 h (control) to 191 h (bacterial combination).

Other bacteria

Among other bacterial species, *Streptococcus bovis*, *Propionibacterium acidipropionici*, and *Bacillus spp.* may be used as inoculants. *Bacillus spp.* and *Propionibacterium spp.* have found the widest application in bacterial preparations. Lara et al. (2016) suggested inoculation with *Bacillus spp.* to improve the aerobic stability of maize silages. The authors compared three treatments (control, *Bacillus subtilis*, and a mixture of *L. plantarum* with *B. subtilis*). Silages supplemented with *B. subtilis* had lower yeast counts and extended aerobic stability compared with the other treatments. Gandra et al. (2016) reported higher butyric acid and lower acetic acid concentrations in sugarcane silages inoculated with *L. buchneri* compared with silages treated with a combination of *L. buchneri* and *B. subtilis*. Aerobic stability was similar in both cases and longer than in the control. Keles et al. (2010), using a commercial preparation for grass ensiling containing *L. plantarum*, *Serratia rubidaea*, and *B. subtilis*, found no improvement in aerobic stability compared with the control. *Propionibacterium spp.* are used to improve silage aerobic stability through the production of propionic acid. Filya et al. (2004) studied the effects of *P. acidipropionici*, *L. plantarum*, and their mixture on wheat, maize, and sorghum silages and obtained similar results for all three plants. *P. acidipropionici* increased acetic and propionic acid concentrations and reduced yeast counts. After application of the *P. acidipropionici* + *L. plantarum* mixture, concentrations of lactic, acetic, and propionic acids were similar to those in samples supplemented with *L. plantarum*, which contained more lactic acid and less acetic acid than controls. Pure *P. acidipropionici* produced silages with extended aerobic stability and low yeast counts. *S. bovis* is a species similar to bacteria used in inoculants. It is common in the rumen but not in silage. It grows very rapidly but is less resistant to decreases in environmental pH than true lactic acid bacteria. Ferreira et al. (2013) reported a beneficial effect of *S. bovis* on reducing pH to 3.83 in inoculated elephant grass silages compared with the control (pH 4.01), and on the fermentation process by reducing dry matter losses. They also observed lower mould, yeast, and *Enterobacteriaceae* counts and higher lactic acid bacteria counts than in control silages.

Factors affecting inoculant efficacy

Errors in silage preparation may be associated with an inappropriate harvest date and developmental stage of the plants intended for ensiling, which may reduce the rate of plant-mass ensiling and increase dry matter and energy losses (Guo et al., 2021). Attention should be paid to the buffering capacity of the ensiled plants, dry matter content, simple sugar content, moisture, and developmental stage of the plant material. Alfalfa and clover are examples of plants that are difficult to ensile because of their low dry matter content and high buffering capacity, which prevents a rapid decrease in pH. Plants that are easy to ensile include maize, other cereals, and grasses with high simple-sugar content and low buffering capacity. For grasses, alfalfa, and

clover, wilting is an appropriate practice because it increases dry matter content without loss of simple-sugar concentration. Proper application of bacterial silage additives during silage preparation is important, including calibration of applicators for manual and mechanical dosing to obtain a homogeneous suspension. Inadequate sealing of silos, bags, and wrapped bales, as well as poor compaction of plant material, promote the growth of moulds and yeasts that reduce silage aerobic stability. Limiting air access to silage is necessary to reduce dry matter losses in feed, which may amount to about 2% per month (Schmidt et al., 2009). It should be emphasized that bacterial inoculants have a beneficial effect on the chemical composition and aerobic stability of silages only when the silage has been prepared correctly.

Bacterial survival

Environmental conditions may play a key role in the survival of bacteria involved in fermentation processes. The most important physical and chemical factors include moisture, temperature, acidity, water-soluble carbohydrate content as a nutrient substrate for lactic acid bacteria, and exposure to sunlight. Commercial inoculants should be stored according to the manufacturer's recommendations, i.e. at low temperature, in a dry environment, and with limited oxygen access. Before bacterial modifiers are applied, the bacterial concentration in the preparation should be determined in accredited laboratories and compared with the manufacturer's declaration. Bacterial concentrations most commonly range from 10^4 to 10^{11} cfu g⁻¹. A concentration of 10^5 cfu g⁻¹ is considered sufficient to dominate epiphytic bacterial populations, ensure proper fermentation, and obtain aerobically stable silage (Zi et al., 2021). Prolonged exposure of a prepared bacterial suspension to sunlight and high temperature is a mistake. It results in high bacterial mortality as early as 24 hours after preparation, particularly in water containing chlorine or hydrogen peroxide.

Epiphytic bacteria colonizing plant material

The composition of epiphytic microbial communities is a very important factor that may influence changes in the microbiota during ensiling. Populations of epiphytic microorganisms in fresh plant material may depend on plant species, geographical location, and climatic conditions. To create appropriate conditions in ensiled plant material, bacteria introduced with inoculants must dominate the epiphytic bacterial population. Addah et al. (2014) suggested that the bacterial population in inoculants should be 10% higher than the epiphytes occurring on plants. Some reports indicate no relationship between epiphytic microorganisms and those introduced with modifiers and the ensiling process of maize and alfalfa (Yang et al., 2002). These discrepancies result from differences in epiphytic bacterial abundance among plant species, e.g. from 100 to 10×10^6 cfu g⁻¹ in alfalfa and from 10×10^6 cfu g⁻¹ in maize. Wang et al. (2021) considered that during soybean ensiling, the epiphytic bacterial population should not be lower than 10^5 cfu g⁻¹ fresh matter in order to obtain good-quality silage. Further research appears necessary on the role of epiphytic bacteria in relation to microorganisms applied in inoculant preparations, particularly undesirable epiphytic bacteria such as endospore-forming *Clostridium* spp. and *Pseudomonas* spp., which influence butyric fermentation and protein degradation.

Inoculant composition

This is one of the most important factors affecting the effectiveness of bacterial preparations. Homofermentative lactic acid bacteria should be added to improve the fermentation process and reduce dry matter losses, rather than to improve silage aerobic stability. Heterofermentative lactic acid bacteria should be used mainly to extend feed aerobic stability. Lactic acid bacterial strains used in mixtures may differ in effectiveness under changing environmental conditions. Therefore, inoculants should be formulated using strains whose efficacy has been confirmed in

scientific studies, particularly strains dedicated to specific plant species and isolated from habitats where those plants are grown. For example, a mixture of homofermentative *E. faecium* or *P. pentosaceus* used as a starter culture (capable of fermenting hexoses at higher pH) is often supplemented with *L. plantarum*, whose fermentative activity increases at lower environmental pH values (Kung, 2018).

Summary

The development and use of modern bacterial inoculants (modifiers) has been and continues to be aimed at solving many of the problems encountered by farmers during technological processes associated with silage production. The most important objectives are to ensure efficient production of lactic acid in the ensiled mass, and thus a rapid decrease in silage pH accompanied by suppression of butyric acid bacteria. Reducing yeast counts is important for extending silage aerobic stability. In addition to studies conducted directly on commercial silage farms, laboratory studies using bioreactors are also performed. These studies are aimed at preselecting microorganisms involved in ensiling on the basis of their metabolic properties, gas and ethanol production, and effects on silage pH (Wang et al., 2021). All of the above issues are likely to influence the welfare and performance of animals fed such feeds by inhibiting harmful microorganisms and stimulating the development of beneficial microbiota in the gastrointestinal tract.

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BACTERIAL INOCULANTS MODIFYING FERMENTATION PROCESSES AS RELATED TO SILAGE QUALITY– A REVIEW OF RESEARCH RESULTS

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SUMMARY

Proper feeding of cows, including dairy cows, and good-quality feed are factors that affect production results and the welfare of the herd. High-quality silage is characterized by, among other things, aerobic stability, i.e. high resistance of the feed to aerobic decomposition, which is determined by properly occurring fermentation processes during its ensiling. In properly prepared silage, epiphytic microorganisms inhabiting the plant material will carry out fermentation processes and may be supported by microorganisms introduced by inoculation. Bacterial inoculants (modifiers) differ in the qualitative and quantitative composition of the bacteria used. These include: homofermentative lactic acid bacteria (*Lactobacillus acidophilus*, *L. casei*, *L. curvatus*, *L. paracasei*, *L. plantarum*, *L. salivarius*, *Lactococcus acidilactici*, *Enterococcus faecium*, *Pediococcus acidilactici*, *P. pentosaceus*), heterofermentative lactic acid bacteria (*Lactobacillus buchneri*, *L. brevis*, *L. diolivorans*, *L. hilgardii*, *L. kefir*, *L. parafarraginis*, *L. fermentum*, *Leuconostoc*, *Bifidobacterium*), obligatory heterofermentative lactic acid bacteria, mixtures of obligatory heterofermentative lactic acid bacteria, and other microorganisms that are not lactic acid bacteria. Modern modifiers are designed to support proper fermentation processes, accelerate them and help maintain them in the right direction. Those created during homofermentation and heterofermentation include, among others, lactic and acetic acids having a preservative effect on silage, inhibiting the growth of yeast fungi and other harmful microorganisms, thereby extending the aerobic stability of silage.

Keywords: silage, lactic acid bacteria, quality parameters