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Silage review: Recent advances and future uses of silage additives[1]

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ABSTRACT

Additives have been available for enhancing silage preservation for decades. This review covers research studies published since 2000 that have investigated the efficacy of silage additives. The review has been divided into 6 categories of additives: homofermentative lactic acid bacteria (LAB), obligate heterofermentative LAB, combination inoculants containing obligate heterofermentative LAB plus homofermentative LAB, other inoculants, chemicals, and enzymes. The homofermentative LAB rapidly decrease pH and increase lactic acid relative to other fermentation products, although a meta-analysis indicated no reduction in pH in corn, sorghum, and sugarcane silages relative to untreated silages. These additives resulted in higher milk production according to the meta-analysis by mechanisms that are still unclear. *Lactobacillus buchneri* is the dominant species used in obligate heterofermentative LAB silage additives. It slowly converts lactic acid to acetic acid and 1,2-propanediol during silo storage, improving aerobic stability while having no effect on animal productivity. Current research is focused on finding other species in the *Lb. buchneri* group capable of producing more rapid improvements in aerobic stability. Combination inoculants aim to provide the aerobic stability benefits of *Lb. buchneri* with the silage fermentation efficiency and animal productivity benefits of homofermentative LAB. Research indicates that these products are improving aerobic stability, but feeding studies are not yet sufficient to make conclusions about effects on animal performance. Novel non-LAB species have been studied as potential silage inoculants. *Streptococcus bovis* is a potential starter species within a homofermentative LAB inoculant. *Propionibacterium* and *Bacillus* species offer improved aerobic stability in some cases. Some yeast research has focused on inhibiting molds and other detrimental silage microorganisms, whereas other yeast research suggests that it may be possible to apply a direct-fed microbial strain at ensiling, have it survive ensiling, and multiply during feed out. Chemical additives traditionally have fallen in 2 groups. Formic acid causes direct acidification, suppressing clostridia and other undesired bacteria and improving protein preservation during ensiling. On the other hand, sorbic, benzoic, propionic, and acetic acids improve silage aerobic stability at feed out through direct inhibition of yeasts and molds. Current research has focused on various combinations of these chemicals to improve both aerobic stability and animal productivity. Enzyme additives have been added to forage primarily to breakdown plant cell walls at ensiling to improve silage fermentation by providing sugars for the LAB and to enhance the nutritive value of silage by increasing the digestibility of cell walls. Cellulase or hemicellulase mixtures have been more successful at the former than the latter. A new approach focused on *Lb. buchneri* producing ferulic acid esterase has also had mixed success in improving the efficiency of silage digestion. Another new enzyme approach is the application of proteases to corn silage to improve starch digestibility, but more research is needed to determine the feasibility. Future silage additives are expected to directly inhibit clostridia and other detrimental microorganisms, mitigate high mycotoxin levels on harvested forages during ensiling, enhance aerobic stability, improve cell wall digestibility, increase the efficiency of utilization of silage nitrogen by cattle, and increase the availability of starch to cattle.
Key words: silage, inoculant, enzyme, formic acid, propionic acid

INTRODUCTION

For decades, producers have had a wide variety of silage additives available to assist in forage preservation. Silage additives generally fall into one or more of 4 cat-

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egories based on their effects on silage preservation: (1) fermentation stimulants, (2) fermentation inhibitors, (3) aerobic deterioration inhibitors, and (4) nutrients and absorbents (McDonald et al., 1991; Kung et al., 2003a). McDonald et al. (1991) and Kung et al. (2003a) provide extensive reviews of silage additives from a European and North American perspective, respectively. Their reviews cover both additives that are currently in use as well as ones that have diminished in practice.

The aim of the current review is to summarize new research results on silage additives published since the review of Kung et al. (2003a). For those products that have been on the market for a long time, such as formic acid and homofermentative lactic acid bacteria (**LAB**), the emphasis has been placed on new information regarding their benefits rather than a full review. The reader is encouraged to consult earlier reviews for more information on these additives. In contrast, more complete reviews are presented for silage additives that were nascent at or did not exist before the beginning of the 21st century.

Silage additives can have more than 1 mode of action based on the 4 categories above. In addition, the above categorization focuses on effects largely within the silo; however, the effects of these additives on livestock are often more important to the producer to merit their use. Thus, this review has been divided into 6 groups of additives from a practical perspective of a producer: homofermentative LAB, obligate heterofermentative LAB, combination inoculants containing obligate heterofermentative LAB plus homofermentative or facultative heterofermentative LAB, other inoculants (non-LAB species), chemicals, and enzymes. Within each group, we will discuss effects on silage fermentation, aerobic stability, and livestock intake and utilization. We conclude with what we see as future opportunities for additives to improve silage fermentation characteristics and feed nutritional value and to minimize losses.

HOMOFERMENTATIVE LAB

Effects on Silage Fermentation

The oldest and most common bacterial inoculants for making silage are the homofermentative LAB. Today most of the bacteria in this group are recognized taxonomically as facultative heterofermentative LAB species rather than obligate homofermentative species (Pahlow et al., 2003). The facultative heterofermentative LAB ferment hexoses, such as glucose, the same as obligate homofermenters, producing almost exclusively lactic acid. This is in contrast to obligate heterofermenters that produce other compounds from hexoses in addition to lactic acid. The facultative heterofermenters differ from obligate homofermenters by possessing phosphoketolase. This enzyme allows facultative heterofermenters to ferment pentoses, producing primarily lactic and acetic acids. Common facultative heterofermentative strains include *Lactobacillus plantarum*, *Lactobacillus casei*, *Enterococcus faecium*, and various *Pediococcus* species. Silages treated with one or more of these bacteria are often lower in pH, acetic acid, butyric acid, and ammonia-N but higher in lactic acid content and exhibit better DM recovery compared with untreated silages (Muck and Kung, 1997). A recent meta-analysis of 130 articles revealed that the effects of these inoculants varied by crop (Oliveira et al., 2017). Inoculation reduced the pH of silages in temperate and tropical grasses and in alfalfa and other legumes, but not in corn, sorghum, and sugarcane. The reduction in acetic acid by inoculation was significant for all crops except for alfalfa and other legumes. Dry matter recovery was 2.8 percentage units higher in grass silages compared with untreated, unaffected corn and sorghum silages, and reduced by 2.4 percentage units in sugarcane silage. In contrast, the reduction in butyric acid and ammonia-N and the increase in lactic acid from inoculation were unaffected by forage type.

Effects on Animal Production

Animal trials have also revealed that these bacteria have not only enhanced silage fermentation but also have improved milk production, daily gain, or feed efficiency (Weinberg and Muck, 1996). A recent meta-analysis of 31 lactating dairy cattle studies indicated that inoculation with homofermentative or facultative heterofermentative LAB increased raw milk production (0.37 kg/d; $P < 0.01$), with only a trend for increased DMI and no effect on feed efficiency (Oliveira et al., 2017). Trends were observed for increased milk fat and milk protein concentrations for cows fed inoculated silage. Milk production increases by inoculation were not affected by forage type, inoculant species, or level of milk production.

Improvements in animal performance from feeding inoculated silage are difficult to explain. In some studies, changes in common silage characteristics due to silage inoculant use cannot explain the magnitude of improvements in milk production observed (Muck et al., 2013). In other cases, there are experiments where the inoculant did not affect silage fermentation compared with untreated silage, even though inoculation increased animal productivity (Kung and Muck, 2015).

Several hypotheses exist on the cause of improved animal performance, including inhibition of detrimental microbes and toxin production (Ellis et al., 2016b), interaction of LAB with rumen microbes, and alteration