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Silage review: Animal and human health risks from silage[1]

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ABSTRACT

Silage may contain several agents that are potentially hazardous to animal health, the safety of milk or other animal food products, or both. This paper reviews published literature about microbial hazards, plant toxins, and chemical hazards. Microbial hazards include *Clostridium botulinum*, *Bacillus cereus*, *Listeria monocytogenes*, Shiga toxin-producing *Escherichia coli*, *Mycobacterium bovis*, and various mold species. High concentrations of *C. botulinum* in silage have been associated with cattle botulism. A high initial concentration of *C. botulinum* spores in forage in combination with poor silage fermentation conditions can promote the growth of *C. botulinum* in silage. The elevated pH level that is generally associated with aerobic deterioration of silage is a major factor influencing concentrations of *L. monocytogenes*, Shiga toxin-producing *E. coli*, and molds in silage and may also encourage survival and growth of *M. bovis*, the bacterium that causes bovine tuberculosis. Soil is a major source of *B. cereus* spores in silage; growth of this bacterium in silage appears to be limited. Hazards from plant toxins include pyrrolizidine, tropane and tropolone alkaloids, phytoestrogens, prussic acid, and mimosine, compounds that exist naturally in certain plant species that may contaminate forages at harvesting. Another group of toxins belonging to this category are ergot alkaloids, which are produced by endophytic fungal species in forages such as tall fescue grass, sorghum, and ryegrass. Varying effects of ensiling on the degradation of these plant toxins have been reported. Chemical hazards include nitrate, nitrite, and toxic oxide gases of nitrogen produced from nitrate and high levels of butyric acid, biogenic amines, and ammonia. Chemical and microbiological hazards are associated with poorly fermented silages, which can be avoided by using proper silage-making practices and creating conditions that promote a rapid and sufficient reduction of the silage pH and prevent aerobic deterioration.

Key words: silage quality, pathogens, toxins, chemical hazards

INTRODUCTION

The production of well-preserved, high-quality silages depends mainly on the composition of the forage at ensiling and the application of appropriate silage-making practices. The main principles of silage preservation are a rapid achievement of a low pH by lactic acid fermentation and the maintenance of anoxic conditions (Pahlow et al., 2003). Lactic acid bacteria play a key role in ensuring the success of the ensiling process. They are capable of converting fermentable carbohydrates that are present in forage crops at a high rate to lactic acid and, to a lesser extent, acetic acid. Chemical and biological silage additives can assist in making well-preserved silages by promoting a rapid reduction in silage pH and preventing aerobic deterioration (Kung et al., 2003; Muck et al., 2018). Properly made and managed silage is an excellent feed that poses no health risks to humans or livestock. In fact, the microbes in such silages may have probiotic effects on livestock (Weinberg et al., 2003). However, different undesirable microorganisms may develop in silage when the pH is insufficiently reduced or when oxygen is available. These undesirable microorganisms include both those that are detrimental for the nutritional quality of silage, for instance yeasts and butyric acid bacteria, and those that can be hazardous to animal health or the safety of milk or other animal food products, such as *Clostridium botulinum*, *Bacillus cereus*, *Listeria monocytogenes*, *Escherichia coli*, other *Enterobacteriaceae* species, and molds. The health hazard can be the microorganism itself or a metabolite that is produced, such as mycotoxins produced by certain molds. In addition to microbial health hazards, silages may contain toxic chemical substances resulting from ensiling of the forage crop or from various contaminants.

In this paper, 3 types of health hazards associated with silage are described. First, hazards associated

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with the growth and metabolism of undesirable microorganisms during ensiling, including *C. botulinum*, *B. cereus*, *L. monocytogenes*, Shiga toxin-producing *E. coli*, and molds. Second, toxins present in plant tissues at harvest that may survive the ensiling process. Finally, chemical hazards associated with undesirable silage fermentations, including nitrogenous gases, high butyric acid levels, and biogenic amines.

MICROBIAL HAZARDS

Clostridium botulinum

Clostridium species are gram-positive, obligate anaerobic spore-forming bacteria. Clostridia require relative high pH values (>4.5), high forage moisture concentration (>70%), and high water activity (from 0.952 to 0.971) for growth; hence, they are inhibited in silages if rapid acidification reduces the pH to 4 or below within 3 d (Muck et al., 2003). The critical pH that inhibits clostridial growth varies with the plant moisture content (Figure 1). Therefore, factors that predispose the plant to high moisture concentrations at harvest or ensiling or that delay the pH decline during ensiling can favor clostridial growth. The buffering capacity of the ensiled crop is an important factor in the development of clostridia, as the higher the buffering capacity the more lactic acid must be produced to achieve the critical pH to inhibit clostridial growth. Hazards associated with production of butyric acid by clostridia are discussed under the butyric acid subsection in the chemical hazard section below.

Non-pathogenic *Clostridium* species that commonly occur in silage include *C. tyrobutyricum*, *C. beijerinckii*, *C. butyricum*, and *C. sporogenes* (Pahlow et al., 2003; Driehuis, 2013; Doyle et al., 2015). Pathogenic *Clostridium* species include *C. perfringens*, *C. difficile*, *C. tetani*, and *C. botulinum* (Doyle et al., 2015). Of these pathogenic species, only *C. botulinum* is occasionally associated with silage.

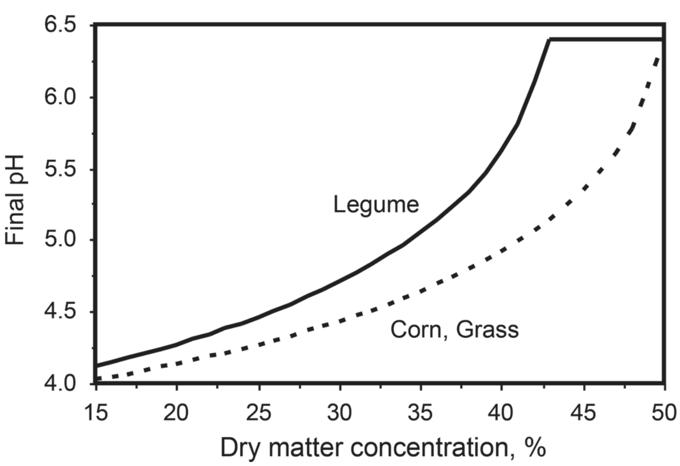

Figure 1. The pH below which growth of *Clostridium tyrobutyricum* ceases. Adapted based on equations of Leibensperger and Pitt (1987).

The species *C. botulinum* is a heterogeneous group of bacteria that has the ability to produce the neurotoxin botulinum, the agent that causes botulism. Botulinum is a protein toxin and is believed to be the most potent toxin in nature (Schantz and Johnson, 1992). Four discrete groups of *C. botulinum* bacteria exist (Table 1; Collins and East, 1998; Carter and Peck, 2015). *Clostridium botulinum* Groups I and II are primarily responsible for human botulism; *C. botulinum* Group III is responsible for botulism in various animal species, primarily birds and cattle; and *C. botulinum* Group IV does not appear to be associated with botulism in humans or animals (Carter and Peck, 2015). Seven different types of botulinum toxins are recognized, designated types A to G (Collins and East, 1998; Carter and Peck, 2015). Botulinum types C and D and occasionally type B are associated with botulism in animals, whereas botulism in humans is associated with the remaining botulinum types and type B. The different *C. botulinum* groups also differ significantly with respect to their phenotypic properties, such as minimum and optimal growth temperatures, proteolytic activity, carbohydrate metabolism, and the heat resistance of spores (Table 1).

Botulism is a severe disease in both humans and animals; the fatality rate is high, at approximately 5 to 10% of cases in humans and generally higher than 10% in cattle (Galey et al., 2000; Sobel et al., 2004; Payne et al., 2011). Botulism in cattle is an intoxication caused by ingestion of feed (or water) contaminated with botulinum toxin. Table 2 gives an overview of published cases of feed-associated botulism in cattle, including the identified botulinum toxin type and the confirmed or presumed source of *C. botulinum* spores or toxin. Contaminated silages were involved in many of these cases. In an outbreak of cattle botulism affecting multiple farms in the Netherlands, *C. botulinum* type B and botulinum toxin type B were detected in ensiled brewers' grains and grass silage at one of these farms (Haagsma and Ter Laak, 1978a,b; Notermans et al., 1981). Spores of *C. botulinum* type B were detected in cow feces and manure from cattle that was fed the contaminated ensiled brewers' grains and which had been spread over grass pastures for fertilization (Notermans et al., 1981). The 2 following years, spores of *C. botulinum* type B were detected in 5 grass silages produced from these pastures and botulinum toxin type