J. Dairy Sci. 101:4034–4059
https://doi.org/10.3168/jds.2017-13788

Silage review: Mycotoxins in silage: Occurrence, effects, prevention, and mitigation[1]

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ABSTRACT

Ensiled forage, particularly corn silage, is an important component of dairy cow diets worldwide. Forages can be contaminated with several mycotoxins in the field pre-harvest, during storage, or after ensiling during feed-out. Exposure to dietary mycotoxins adversely affects the performance and health of livestock and can compromise human health. Several studies and surveys indicate that ruminants are often exposed to mycotoxins such as aflatoxins, trichothecenes, ochratoxin A, fumonisins, zearalenone, and many other fungal secondary metabolites, via the silage they ingest. Problems associated with mycotoxins in silage can be minimized by preventing fungal growth before and after ensiling. Proper silage management is essential to reduce mycotoxin contamination of dairy cow feeds, and certain mold-inhibiting chemical additives or microbial inoculants can also reduce the contamination levels. Several sequestering agents also can be added to diets to reduce mycotoxin levels, but their efficacy varies with the type and level of mycotoxin contamination. This article gives an overview of the types, prevalence, and levels of mycotoxin contamination in ensiled forages in different countries, and describes their adverse effects on health of ruminants, and effective prevention and mitigation strategies for dairy cow diets. Future research priorities discussed include research efforts to develop silage additives or rumen microbial innocula that degrade mycotoxins.
Key words: animal performance, health, mycotoxin

INTRODUCTION

Mycotoxins are a group of secondary metabolites secreted by fungal organisms mostly belonging to the genera *Aspergillus*, *Fusarium*, *Alternaria*, and *Penicillium* (Yiannikouris and Jouany, 2002; Bennett and Klich, 2003; Kabak et al., 2006). Several fungal species belonging to these genera can produce mycotoxins such as aflatoxins, ochratoxins, trichothecenes, zearalenone (**ZEA**), fumonisins, and several other mycotoxins considered minor or emerging mycotoxins (Bennett and Klich, 2003; Gallo et al., 2015, 2016; Loi et al., 2017). Fungi often thrive well in environments with high humidity, high temperature, and oxygen access during all stages of plant production and storage (Egal et al., 2005). Toxic effects, such as reduced feed intake and milk production, reproductive problems, immunosuppression, and death can occur when animals are fed mycotoxin-contaminated diets (Whitlow and Hagler, 2005; Zain, 2011).

Mycotoxins are present in a range of livestock feeds including concentrates, green forages, hays, and silages (Biomin, 2016). A 3-yr (2009 to 2011) survey on the worldwide occurrence of mycotoxins revealed that 81% of 7,049 livestock feed samples collected from the Americas, Europe, and Asia were positive for at least one mycotoxin (Rodrigues and Naehrer, 2012). Another recent 4-yr mycotoxin survey in Poland revealed that up to 95% of feedstuffs contained at least one mycotoxin (Kosicki et al., 2016). Most research studies have focused primarily on mycotoxin occurrence in cereal grains (Binder, 2007; Zinedine et al., 2007; Bhat et al., 2010), perhaps because they are consumed in greater quantities by humans than other feeds. Relatively few studies have surveyed mycotoxins in silages (O'Brien et al., 2006), which account for a major portion of dairy cow diets (Cheli et al., 2013). Yet a survey by Driehuis et al. (2008a) revealed that the contribution of ensiled forage to mycotoxin ingestion in dairy cows on 24 farms

Received September 5, 2017.
Accepted October 28, 2017.
[1]This article is part of a special issue on silage management.
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in the Netherlands was approximately 3 times more than that of other feed ingredients. A review of the literature reveals that the contribution of silage mycotoxins to the total amount of mycotoxins ingested by cows can be greater than the maximum concentrations allowed or recommended in ruminant diets by the US FDA and European Union (Table 1).

The ubiquitous nature of mycotoxins and the severity of the effects of some mycotoxins on human health make them a major food safety concern (CAST, 2003). In addition to the severity of their effects on livestock and human health, direct costs of disposal of condemned food and feed ingredients, and indirect costs of regulatory enforcement and quality control measures caused by fungal toxin contamination in the United States were estimated at approximately $1 billion per annum (CAST, 2003; Milicevic et al., 2010). The occurrence of mycotoxins in silage was recently reviewed by Wambacq et al. (2016), with particular emphasis on incidence and prevalence in Europe. However, our review gives more insight into the current silage mycotoxin prevalence surveys and studies around the world, including the consequent effects of the major mycotoxins on performance and health of ruminants. Therefore, the aim of this article is to review the literature on mycotoxin contamination of ensiled forages, including predisposing factors for mycotoxin production, to discuss the current state of knowledge on sequestration and degradation of mycotoxins in dairy cow diets, and to suggest future mycotoxin research priorities.

FACTORS THAT PREDISPOSE TO MOLD AND MYCOTOXIN PRODUCTION IN SILAGE

Ensiled forages may contain a mixture of mycotoxins, originating from pre-harvest contamination by *Fusarium* and *Aspergillus* species (Baath et al., 1990; Uegaki et al., 2013; Gallo et al., 2015) and or from postharvest contamination with toxigenic molds that are common in silage, such as *Aspergillus* and *Penicillium* (Garon et al., 2006; Fink-Gremmels, 2008; Alonso et al., 2013). However, many common molds do not produce mycotoxins, and the presence of molds in silage does not indicate the presence of mycotoxins nor does their absence confirm mycotoxins are absent (Zain, 2011).

Both environmental and physiological conditions are known to influence synthesis of mycotoxins. Temperature, water activity (**aw**), and insect activity are the major factors influencing mycotoxin contamination of feedstuffs (Coulombe, 1993). Molds can grow between 10 and 40°C, between pH 4 and 8, and when aw is greater than 0.7 (Whitlow and Hagler, 2005; Magan and Aldred, 2007). However, the conditions for mold growth and for mycotoxin formation are not necessarily the same (Whitlow and Hagler, 2005). For instance, *Fusarium* molds can grow aggressively at 25 to 30°C without producing mycotoxins, whereas at freezing temperatures, they produce large quantities of mycotoxins with minimal growth (Joffe, 1986; Whitlow and Hagler, 2005).

Oxidative stress also often induces toxigenic pathways in various fungi (Reverberi et al., 2010; Ponts, 2015). This oxidative response, often defined by production of peroxide, is triggered by the host plant upon fungal infection and could promote synthesis of mycotoxins by fungi (Baidya et al., 2014; Ponts, 2015). The production of peroxide causes the biosynthesis of different mycotoxins by fungi (Sheridan et al., 2015). In support, a glycogen synthase kinase gene in *Fusarium*, with putative role as a transcription factor that directly promotes mycotoxin production, was expressed following growth of the fungus under oxidative stress (Qin et al., 2015). An acidic pH (pH = 3) has also been suggested to be a prerequisite for deoxynivalenol (**DON**) production by *Fusarium* (Merhej et al., 2010). However, this does not agree with evidence of DON production on the field or during storage because pH is rarely as low as 3.0 in growing crops or stored feeds. In addition, DON production may not be attributed to acidic pH values because oxidative stress and acidification often occur together in fungi (Pérez-Sampietro and Herrero, 2014).

Molds can grow in wet feeds such as silage, if oxygen is not limiting (Whitlow and Hagler, 2005). Delayed harvesting, slow or delayed filing of silos, inadequate packing and sealing of silos, slow feedout rates, bridging in silage bags, and damaged plastic wrap, bags, or silo covers can create a conducive microclimate for mold proliferation and mycotoxin production (Whitlow and Hagler, 2005). Other factors that may predispose feeds to mold growth and mycotoxin production include physical damage to corn ears (Teller et al., 2012) and damage to plants and silo covers by rodent, rain, hail, and drought.

TYPES OF MYCOTOXINS IN ENSILED FORAGES

More than 400 mycotoxins occur naturally; however, only a few have been studied extensively (Njumbe et al., 2015; Fromme et al., 2016). Mycotoxins that are frequently present in ensiled forages include trichothecenes, fumonisins, aflatoxins, ZEA, mycophenolic acid, and roquefortine C (Driehuis et al., 2008b; Schmidt et al., 2015).