Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 14 (11)
November 2021
DOI: http://dx.doi.org/10.36560/141120211446
Article link: https://sea.ufr.edu.br/SEA/article/view/1446

ISSN 2316-9281

Mycotoxin absorbents in dairy cattle

Corresponding author
João Rafael de Assis
UNIFASIPE – Centro Universitário
joaorafael_zootecnista@hotmail.com

Aline Cardoso Mota de Assis
Universidade do Estado de Mato Grosso – Sinop

Geferson Antonio Fernandes
NEPI – UFMT

Eloiza Baena da Silva
UNIFASIPE – Centro Universitário

Juslei Figueiredo da Silva
UNIFASIPE – Centro Universitário

Rafael Laurindo Morales
UNIFASIPE – Centro Universitário

Alvaro Carlos Galdos-Riveros
UNIFASIPE – Centro Universitário

Igor Vivela Cruz
UNIFASIPE – Centro Universitário

Abstract. Ingestion of mycotoxins by animals causes damage to the production system and can still be transferred to animal products, including milk. Due to its carcinogenic and genotoxic potential, the intake of mycotoxins, especially aflatoxins, is relevant to human health. The use of mycotoxin-absorbing agents has gained attention in dairy cattle nutrition. Therefore, it aimed to conduct a literature review on the use of mycotoxin absorbers in the dairy cattle diet. Mycotoxin absorbing agents can be of organic or inorganic origin, the inorganic ones being the most studied. Inorganic and organic agents have been shown to be effective in reducing the transfer of aflatoxin M1 to milk. However, the inclusion of mixed agents (organic and inorganic) is promising as a potential for mycotoxin absorption. In general, organic, inorganic and mixed absorbents showed positive results in improving the antioxidant and inflammatory status in the liver.
Keywords: Toxin, Livestock feed, Mycotoxin absorber

Introduction

Mycotoxins are a group of toxic compounds produced by filamentous fungi in growing forages or stored rations. These when ingested can reduce food consumption, health and the productive and reproductive performance of domestic and human animals (OGUNADE et al. 2016).

Among mycotoxins, aflatoxin B1 (AFB1) is the most problematic in dairy cows, as its metabolite, aflatoxin M1 (AFM1) can be transferred to milk (DIAZ et al., 2004). Thus, it may impact the health of consumers of milk and its derivatives.

Many approaches have been employed to reduce the risk of ingestion of aflatoxin by cattle and the resulting aflatoxicosis. Ozonation and ammonization can minimize the production and effects of toxins in corn and cottonseed meal (CAST, 2003). However, these approaches are expensive and time-consuming (KUTZ et al., 2009), so they are not normally used on dairy farms. Recently, a new approach to research is the use of mycotoxin absorbers. It consists of compounds of great molecular weight capable of reducing the bioavailability of mycotoxin in the gastrointestinal tract.

Therefore, it aimed to conduct a literature review on the use of mycotoxin absorbing agents for dairy cattle.

Contextualization and Analysis

Mycotoxins in dairy cattle production

Mycotoxins are secondary metabolites of low molecular weight and produced by filamentous fungi that promote adverse effects in humans and animals. The most relevant mycotoxin groups found in feed for animal feed are produced by three main fungi genera: Aspergillus (aflatoxins (AFs) and ochratoxin A (OTA)), Penicillium (OTA) and Fusarium species (trichothecenes, fumonisins (FBs) and zearalenone (ZEN)) (Table 1) (ASSIS et al., 2019).

Mycotoxinogenic fungi can develop on plants in the field or during the storage period (YIANNIKOURIS; JOUANY, 2002). In addition, inadequate harvesting practices, drying, handling, packaging and inadequate transport conditions contribute to increasing the risk of mycotoxin production (BHAT et al., 2010).

Recently, Assis et al. (2019), carried out an extensive review of the action of the main mycotoxins on the metabolism and performance of ruminants. Highlighting that the main harms found were changes in the metabolic state of hepatoprotective enzymes, immunosuppression, reduced digestibility of dry matter, production of AGV’s, microbial protein synthesis and pathological disorders such as liver and neurological damage. In the productive performance, there is a reduction in food intake, weight gain, feed conversion, milk production, loss of body weight and in severe cases of intoxication, it can evolve until the death of the animal. In relation to reproductive performance, mycotoxins can promote delayed reproduction, non-synchronized ovarian cycles, reduced conception rate, lower percentages of childbirth, abortion and infertility.

Many diseases in humans have been related to mycotoxin intake, mainly due to chronic consumption. The main toxic effects are: carcinogenicity, genotoxicity, hepatotoxicity, nephrotoxicity, estrogenicity, reproductive disorders, immunosuppression and dermal irritation (ANFOSSI et al., 2010).

The mycotoxin with the greatest carcinogenic potential is aflatoxin B1 (AFB1). And up to 6% of AFB1 in the diet can be transferred to milk as hydroxy-AFB1 and aflatoxin M1 (GALVANO et al., 1996; EFSA, 2004; UPADHAYA et al., 2010). Thus, aflatoxin M1 (AFM1) represents a safety risk in milk and dairy products (IARC, 2002; LIU; WU, 2010). The maximum amount of AFM1 in milk allowed by the United States Food and Drug Administration (FDA, 2000) is 0.5 μg / kg of milk and by the National Health Surveillance Agency of Brazil (ANVISA, 2011) is 0.5 μg / kg of milk. While the maximum concentration of AFM1 in milk allowed by the European Commission is 0.05 μg / kg (EFSA, 2004).

In this context, there is a need to add substances that promote the inhibition and / or inactivation of mycotoxins contained in the animals' diets. Thus, the use of mycotoxin-absorbing additives seems to be an alternative to circumvent the problems arising from the contamination of mycotoxins in the feed of farm animals.

Main mycotoxin absorbers

Mycotoxin absorbing agents are compounds of high molecular weight that bind to the mycotoxins present in contaminated foods, limiting their bioavailability after ingestion. Mycotoxins can bind to absorbent agents through different types of interactions: hydrophobic bonds, hydrogen bonds, electrostatic attraction or repulsion and coordination bonds (DI GREGORIO et al., 2014).

It is important that the mycotoxin complex and absorbent agent (mycotoxin + absorbent) are stable throughout the digestive tract. Thus, its stability at variable pH and the physical-chemical properties of the toxins is one of the crucial parameters to be evaluated to avoid the desorption of the toxin in the gastric tract (AVANTAGGIATO et al., 2005; HUWIG et al., 2001; KABAK et al., 2006). In general, the absorbent agents most used in animal nutrition can be divided into two groups: inorganic and organic compounds.

Inorganic absorbers

Aluminosilicates

Aluminosilicates are the most abundant group of rock-forming minerals and the basic structure of silicate clay minerals consists of the association of aluminum tetrahedral and octahedral silica sheets, both having hydroxyl and oxygen groups (DI GREGORIO et al., 2014).

Within this group, there are two main subclasses: phyllosilicates and tectosilicates. Philosilicates include bentonites, montmorillonites, smectites, kaolinites and illites. They can absorb substances on their surface or within their interlaminar space. On the other hand, silicate ceilings are formed by zeolites, which provide a large specific bonding surface, as well as size, shape and charge selectivity (HUWIG et al., 2001).

Table 1. Main mycotoxins found in food for farm animals

Fungi	Micotoxina
Aspergillus flavus, Aspergillus parasiticus	Aflatoxins: AFB1, AFB2, AFG1, AFG2
Aspergillus ochraceus, Penicillium verrucosum, Penicillium viridicatum	Ocratoxina A
Fusarium graminearum	Zearalenone
Fusarium verticillioide, Fusarium proliferatum	Fumonisins: FB1, FB2
Fusarium graminearum, Fusarium sporotrichioides, Fusarium poae, Fusarium equiseti	Trichothecenes: DON, 3- or 15-Ac-DON, NIV (tipe B), T-2, HT-2 (tipe A)

3-Ac-DON = 3-acetyloxynivalenol; 15-Ac-DON = 15-acetyloxynivalenol; AF = aflatoxins; AFB1 = aflatoxin B1; AFB2 = aflatoxin B2; AFG1 = aflatoxin G1; AFG2 = aflatoxin G2; DON = deoxynivalenol; FB1 = fumonisin B; FB2 = fumonisin B2; HT-2 = HT-2 toxin; NIV = nivalenol; OTA = ochratoxin A; T-2 = T-2 toxin; ZEN = zearalenone.

Hydrated calcium and sodium aluminum silicate (ACSH)

ACSH has been shown to act as an enterosorbent that binds strongly and selectively to aflatoxins in the animals' gastrointestinal tract, decreasing their bioavailability and toxicity (HARPER et al., 2010; NEEFF et al., 2013; PHILLIPS et al., 2008).

Evidence suggests that aflatoxins can react at various locations in the ACSH particles, especially in the interim region, but also at the edges and basal surfaces (KOLOSOVA and STROKA, 2011). Furthermore, another form of AFB1 sorption by ACSH surfaces may involve the interaction or chelation of AFB1 with cations (especially Ca) or with various metals (DI GREGORIO et al., 2014).

Bentonites (montmorillonites)

In the case of bentonites, they are characterized by being phyllosilicate clays with layers of crystalline microstructure of variable composition. They are often called smectites because clay is the dominant mineral. In general, the degree of effectiveness of bentonite absorption depends on the amount of montmorillonite and interchangeable cations in its composition (KOLOSOVA and STROKA, 2011).

Montmorillonite is composed of layers of octahedral aluminum and tetrahedral silicon coordinated with oxygen atoms. The large surface area and high cation exchange capacity of the smectite group make them capable of adsorbing organic substances through the penetration of cations and polar molecules. Bentonites have shown great efficacy in the absorption of mycotoxins, specifically aflatoxins (KONG et al., 2014; MAGNOLI et al., 2011) and other mycotoxins (ZEN, OTA and FBs) in several studies (RAMOS et al., 1996a, b; AVANTAGGIATO et al., 2005; MIAZZO et al., 2005; WANG et al., 2012).

Zeolites

The zeolite tectosilicates consist of a set of tetrahedra of SiO4 and AlO4 joined in several regular arrangements through shared oxygen atoms to form a three-dimensional structure similar to a cage. The partial replacement of Si^{4+} by Al^{3+} results in an excess of negative charge that is compensated by alkaline and alkaline earth cations, such as sodium, calcium and potassium ions (DAKOVIC et al., 2003; HUWIG et al., 2001).

Studies have shown that natural zeolite-clinoptilolite can adsorb aflatoxins and other mycotoxins, such as fumonisins (DAKOVIC et al., 2010). However, modified zeolites are more effective than natural ones in relation to the absorption of fumonisins (BAGLIERI et al., 2013).

Organic adsorbents

Yeast cell wall (YCW)

YCW consists mainly of proteins, lipids and polysaccharides, such as glucans and mannans, being the two main constituents of the last fraction. YCW exhibits a wide variety of mycotoxin absorption loci, as well as different binding mechanisms such as hydrogen bonds, ionic or hydrophobic interactions (RINGOT et al., 2007).

Studies suggest that PCL has a broader spectrum of mycotoxin sorption, such as ZEN, OTA and FBs (FRUHAUF et al., 2012; PFOHL-LESZKOWICZ, et al., 2015; SHETTY and JESPERSEN, 2006), including DON, being the β-glucan fraction of YCW was directly correlated with the binding process (FAUCET-MARQUIS et al., 2014). The *Saccharomyce cerevisiae* mannans have also been shown to be effective in binding DON at different pH values (CAVRET et al., 2010).

Activated carbon (AC)

AC is an insoluble powder produced by the pyrolysis of several organic compounds, followed by its chemical or physical activation in order to develop a highly porous structure. *In vitro* data suggest potential affinity for several mycotoxins, however, the *in vitro* efficacy of AC in relation to some mycotoxins has not been confirmed *in vivo* (AVANTAGGIATO et al., 2005).

Generally, the adsorption properties of AC depend on the source materials, surface area and pore size distribution (KOLOSOVA and STROKA, 2011). However, AC is nonspecific, therefore, the essential nutrients for the development of animals such as vitamins and minerals (VEKIRU et al., 2007) are also adsorbed.

Mycotoxin absorbers used in dairy cattle

Systematically, in Table 2, there follows a compilation of experimental data on the effects of the use of mycotoxin absorbing agents in diets for dairy cattle.

Table 2. Use of mycotoxin absorbers in dairy cattle.

Mycot	Absorbent	Animal	Treatments	Result	References
AFB1	SolisMos (AA)	Dairy cows	Toxin (20 or 40 µg AFB1 / kg DM) Ex2: 0.25% AA + 20 µg AFB1 / kg DM Ex3: 0.25% AA + 40 µg AFB1 / kg DM	Both ↑ antioxidant status in the liver (superoxide dismutase) Ex2 ↓ AFM1 in milk and ↑ AGV production..	Xiong et al. (2015)
AFB1	Bentonite clay (BC); Fermentation product Saccharomyces cerevisiae (SC)	Dairy cows	Toxin (1,725 mg AFB1 / animal day) T1 = Toxin + 200 g BC / animal day T2 = Toxin + 35 g mix (BC + SC) / animal day	T1 and T2 ↓ AFM1 concentration in milk. T2 prevented ↓ milk production and T1 avoided ↑ OGT.	Jiang et al. (2018)
AFB1	YCW; DY; AL; BY	Dairy cows	Toxin (480 µg AFB1 / animal day) 20 g / day of YCW 20 g / day of DY 20 g / day of AL 20 g / day BY	↓ 78%, 89%, 45% and 50% of milk AFM1 for YCM, AL, DY and BY, respectively.	Gonçalves et al. 2017
AFB1	Solis NovasilPlus MTB-100	Dairy cows	Toxin (112 µg AFB1 / kg DM) Toxin + 0.56% Solis in diet Toxin + 0.56% of NovasilPlus in DM of diet Toxin + 0.56% MTB-100 in DM of diet	Solis and NovasilPlus ↓ the concentration of AFM1 in milk.	Kutz et al. 2009
AFB1	NovasilPlus	Dairy cows	Toxin (100 µg AFB1 / kg MS) Toxin + 0.5% NovasilPlus in DM of diet Toxin + 1% NovasilPlus in DM of diet	NovasilPlus ↓ the concentration of AFB1 in milk, better values at the dose of 1% DM daily.	Maki et al. 2016a
AFB1	LFPS; HFPS; LFSBC	Dairy cows	Toxin (1,725 µg AFB1 / animal day) 20 g LFPS / animal day 20 g HFPS / animal day 20 g LFSBC / animal day	Absorbents ↓ the time required to ↓ the concentration of AFM1 in milk after withdrawing AFM1 from the diet. Only LFPS prevented the adverse effects of AFM1 on milk and on the production of fat-corrected milk.	Ogunade et al. 2016
AFB1	Calibrin clay A (CAA; montmorillonite)	Dairy cows	Toxin (75 µg AFB1 / kg diet) Toxin + 0.2% CAA in DM of diet Toxin + 1% CAA in DM of diet	Does not hear the effect of the absorbent	Queiroz et al. 2012
AFB1	Argila (vermiculita, não tronita e montmorilonita).	Dairy cows	Toxin (100 µg AFB1 / kg DM) Toxin + 0.5% clay in DM Toxin + 1% clay in DM Toxin + 2% clay in DM	Ruminal clay supplementation reduced the transfer of AFM1 from the rumen to milk and feces.	Sulzberger, et al. 2017
AFB1	Biorigin (yeast and bentonite)	Dairy cows	Toxin (100 µg AFB1 / kg DM) Toxin + 30 g of Biorigin / animal day Toxin + 60 g of Biorigin / animal day	Additives can be beneficial in reducing inflammation during the AFB1 challenge.	Weatherly et al. 2018

↑ = increased; ↓ = reduced; AFB1 = aflatoxin B1; AFM1 = aflatoxin M1; AL = altolized yeast; BY = partially dehydrated brewery yeast; DM = dry matter; DY = dry yeast; HFPS = high-dose fermentation product of S. cerevisiae; LFPS = low-dose fermentation product of S. cerevisiae; LFSBC = fermentation product of *S. cerevisiae* containing low dose combined with sodium bentonite clay; MTB-100 = yeast-derived cell wall glucomannan; Mycot = mycotoxin; NovasilPlus = calcium montmorillonite clay; OGT = oxalacetic glutamic transaminase; Solis = mixture of aluminosilicate mineral clays; YCW = yeast cell wall.

Table 2. Use of mycotoxin absorbers in dairy cattle (continuation)

Mycot	Absorbent	Animal	Treatments	Result	References
AFB1	YCAL MTB-04 MTB-06 MTB-04-06 Astra-Ben 20	Dairy cows	Toxin (94 ppb / DM) Toxin + 100 g YCAL / cow day Toxin + 10 g MTB-04 / animal day Toxin + 10 g MTB-06 / animal day Toxin + 10 g MTB-04-06 / animal day Toxin + 227 g Astra-Ben 20 / animal day	Only Astra-Ben 20 ↓ the concentrations of AFM1 in milk.	Kissell, et al. 2012
AFB1	Sodium bentonite; Activated charcoal	Dairy goats	Toxin (100 ppb of AFB1 / day) Toxin + 1% sodium bentonite from DMI Toxin + 1% activated carbon from DMI	Both ↓ the concentration of AFM1 in the milk.	Rao e Chopra, 2001
AFB1	NovasilPlus	Dairy cows	Toxin (121 ppb of AFB1 / animal day) Toxin + 6 g of NovasilPlus / animal day Toxin + 12.1 g NovasilPlus / animal day	The dose of 6 g ↓ 55% of AFM1, while 12.1 g ↓ 68% of AFM1 in milk.	Maki et al. 2016b
AFB1	Toxy-Nil ou UnikePlus	Dairy cows	Toxin (2.8 mg AFB1 / animal day) Toxin + 100 g of Toxy-Nil / animal day Toxin + 100 g of UnikePlus / animal day	Unike Plus ↓ 52% AFM1 and Toxy-Nil ↓ 63% AFM1 in milk.	Rodrigues et al. 2019
AFB1	FloMatrix (aluminosili cate clay)	Dairy cows	Toxin (100 µg AFB1 / kg MS) Toxin + 113 g FloMatrix / animal day Toxin + 227 g of FloMatrix / animal day	The adsorbents had a positive effect on milk production and inflammation of hepatocytes and ↓ the transfer of AF in milk.	Pate et al. 2018
AFB1	SolisMos	Dairy cows	Toxin (20 µg AFB1 / kg DM) Toxin + 0.25% SolisMos in DM of diet	The additive ↓ the transfer of AFM1 in milk and oxidative stress. Improved immunological condition and rumen fermentation.	Xiong et al. 2018
DON e FB	Mycofix (composed of minerals and enzymes)	Dairy cows	Toxin (897.3 µg DON / kg DM and 1,247.1 µg FB / kg DM) Toxin + 35 g of Mycofix / animal day	^ Digestibility of DM and NDF. ↓ activity of liver transaminases due to high doses of mycotoxins.	Gallo et al. 2020
AFB1	Smectite clay (SA)	Dairy cows	Toxin (2.13 g of FB1 / kg DM in diet) Toxin + 100 g SA / animal day	AE ↓ the concentration of AFM1 in milk at 64.8%.	Gallo et al. 2019
AF	Calcium montmorillo nite (CM)	Dairy cows	Toxin (50 ppb of AF) Toxin + 0.125% CM of DMI Toxin + 0.25% CM of DMI	Inclusion of CM ↓ the concentration of AFM1 in milk.	Maki et al. 2017
AFB1	YCAL	Dairy sheep	Toxin (60 µg AFB1 / kg of food) Toxin + 2 g of YCAL / kg of food	↓ absorption of AFB1 and ↑ the elimination of AFB1 and AFM1 in the sheep's feces. There was no effect on the transfer of milk in AFM1.	Firmin et al. 2011

↑ = increased; ↓ = reduced; AF = aflatoxin; AFB1 = aflatoxin B1; AFM1 = aflatoxin M1; Astra-Ben20 = yeast extract, aluminum silicate and sodium bentonite; DMI = dry matter consumption; DON = deoxynivalenol; FB = fumonisins; NDF = neutral detergent fiber; DM = dry matter; MTB-04 = 2004 yeast derived cell wall glucomannan; MTB-06 = 2006 yeast derived cell wall glucomannan; MTB-04-06 = mixture of cell wall glucomannan derived from yeast from 2004-2006; Mycot = mycotoxin; NovasilPlus = montmorillonite calcium clay; YCAL = yeast cell wall extract and aluminosilicate; Solis = mixture of aluminosilicate mineral clays; Toxy-Nil = heat treated sepiolite, calcium propionate, calcium citrate and yeast wall purified oligosaccharides; UnikePlus = heat treated sepiolite, calcium propionate and yeast wall purified oligosaccharides.

Final considerations

The main mycotoxin absorbing agents can be of organic and inorganic origin. Inorganic are basically clay minerals (aluminosilicates) consisting mainly of silica and aluminum that can be divided into two subclasses: phyllosilicates and tectosilicates. In the group of organic absorbents there is activated carbon and derivatives of yeast cell wall, where the latter is the most used.

Absorbents based on aluminosilicate clays are more efficient in reducing the transfer of AFM1 to milk. Inorganic absorbents are found mainly in patented formulas such as NovasilPlus products, SolisMos and others.

However, there are few studies with the use of organic absorbents in dairy cattle. Absorbent agents are mainly the basis of yeast cell wall. Apparently, the results have been shown to be effective in reducing the transfer of AFM1 in milk, despite the few studies carried out.

However, studies conducted with the union of organic and inorganic absorbing agents have shown promise. As is the case with the products Toxy-Nil, Unike Plus and Astra-Bem 20 that were efficient in reducing the concentration of AFM1 in milk.

In general, in some studies, organic, inorganic and mixed (organic + inorganic) absorbents. They have shown positive results in improving the antioxidant and inflammatory status in the liver.

Therefore, there are absorbents effective in reducing AFM1 in milk. It is enough to establish whether the formulation of mixtures of aluminosilicate clays with yeast cell wall veins are more efficient as absorbents than solely inorganic or organic. Additionally, additives composed of minerals and enzymes such as Mycofix deserve attention, since it promoted an increase in the digestibility of DM and NDF, it also reduced the activity of liver transaminases due to the high doses of mycotoxins.

References

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (ANVISA, 2011). Resolução de Diretoria Colegiada n°.7, de 18 de fevereiro de 2011. Limites máximos tolerados para micotoxinas em alimentos. Disponível em: < https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2011/res0007_18_02_2011_rep.html>. Acesso em: 03/08/2021.

ANFOSSI, L.; BAGGIANI, C.; GIOVANNOLI, C.; GIRAUDI, G. Mycotoxins in food and feed: Extraction, analysis and emerging technologies for rapid and on-field detection. Recent Patents on Food, Nutrition & Agriculture, Jun;2(2), p. 140-53,

ASSIS, J. R.; ASSIS, A. C. M.; NUNES, D.; CARLOS, A. B.; CARVALHO T. T.; GALDOS-RIVEROS, A. C. Micotoxinas no metabolismo e desempenho de animais ruminantes. Journal of Biology & Pharmacy, v. 15, n. 4, out/dez 2019.

AVANTAGGIATO, G.; SOLFRIZZO, M.; VISCONTI, A. Recent advances on the use of adsorbent materials for detoxification of Fusarium mycotoxins. Food Addit. Contam., 22, 379–388, 2005.

BAGLIERI, A.; REYNERI, A.; GENNARI, M.; NEGRE, M. Organically modified clays as binders of fumonisins in feedstocks. J. Environ. Sci. Health, 48, 776–783, 2013.

BHAT, R., RAI, R.V., KARIM, A.A.Mycotoxins in food and feed: present status and future concerns. Compr. Rev. Food Sci. Food Saf., 9, 57–81, 2010.

CAST (Council for Agricultural Science and Technology). Mycotoxins: Risks in Plant, Animal, and Human Systems. CAST, Ames, IA, 2003.

CAVRET, S.; LAURENT, N.; VIDEMANN, B.; MAZALLON, M.; LECOEUR, S. Assessment of deoxynivalenol (DON) adsorbents and characterisation of their efficacy using complementary in vitro tests. Food Addit. Contam., 27, 43–53, 2010.

DAKOVIC, A.; KRAGOVIC, M.; ROTTINGHAUS, G. E.; SEKULIC, Z., MILICEVIC, S.; MILONJIC, S. K.; ZARIC, S. Influence of natural zeolitic tuff and organozeolites surface charge on sorption of ionizable fumonisin B1. Colloids Surf., B 76, 272–278, 2010.

DAKOVIC, A.; TOMASEVIC-CANOVIC, M.; ROTTINGHAUS, G.; DONDUR, V.; MASIC, Z. Adsorption of ochratoxin A on octadecyldimethyl benzyl ammonium exchangedclinoptilolite-heulandite tuff. Colloids Surf., B 30, 157–165, 2003.

DI GREGORIO, M. C.; DE NEEFF, D. V.; JAGER, A. V.; CORASSIN, C. H.; DE PINHO CARÃO, A. C.; DE ALBUQUERQUE, R.; DE AZEVEDO, A. C.; FERNANDES OLIVEIRA, C. A. Mineral adsorbent for prevention mycotoxins in animal feed. Toxin Rev., 33, 125–135, 2014.

DIAZ, D. E., W. M. HAGLER, J. T. BLACKWELDER, J. A. EVE, B. A. HOPKINS, K. L. ANDERSON, F. T. JONES, AND L. W. WHITLOW. Aflatoxin binders II: Reduction of aflatoxin M1 in milk by sequestering agents of cows consuming aflatoxin in feed. Mycopathologia, 157:233–241, 2004.

EFSA (European Food Safety Authority). Opinion of the scientific panel on contaminants in the food chain on a request from the Commission related to aflatoxin B1 as undesirable substance in animal feed. EFSA J. 39, p. 1–27, 2004. Disponível em: <https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2004.39>. Acesso em: 03/08/2021.

FAUCET-MARQUIS, V.; JOANNIS-CASSAN, C.; HADJEBA-MEDJDOUB, K.; BALLET, N.; PFOHL-LESZKOWICZ, A. Development of an in vitro method for the prediction of mycotoxin binding on yeast-based products: case of aflatoxin B1, zearalenone and ochratoxin A. Appl. Microbiol. Biotechnol., 98, 7583–7596, 2014.

FIRMIN, S.; MORGAVI, D. P; YIANNIKOURIS, A.; BOUDRA, H. Effectiveness of modified yeast cell wall extracts to reduce aflatoxin B1 absorption in dairy ewes. J. Dairy Sci., 94 :5611–5619, 2011.

FOOD AND DRUG ADMINISTRATION (2000). Guidance for Industry: Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed. Disponível em: <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-action-levels-poisonous-or-deleterious-substances-human-food-and-animal-feed#afla>. Acesso em 03/07/2021.

FRUHAUF, S.; SCHWARTZ, H.; OTTNER, F.; KRSKA, R.; VEKIRU, E. Yeast cell based feed additives: studies on aflatoxin B1 and zearalenone. Food Addit. Contam., 29, 217–231, 2012.

GALLO, A.; MINUTI, A.; BANI, P.; BERTUZZI, T.; PICCIOLI CAPPELLI, F.; DOUPOVEC, B.; FAAS, J.; SCHATZMAYR, D.; TREVISI, E. A mycotoxin-deactivating feed additive counteracts the adverse effects of regular levels of Fusarium mycotoxins in dairy cows. Journal of Dairy Science, vol. 103 No. 12, 2020.

GALLO, A.; ROCCHETTI, G.; PICCIOLI CAPPELLI, F.; PAVONE, S.; MULAZZI, A.; KUIJK, S. V.; HAN, Y.; TREVISI, E. Effect of a Commercial Bentonite Clay (Smectite Clay) on Dairy Cows Fed Aflatoxin-Contaminated Feed. Dairy, 1, 135–153, 2020.

GALVANO, F.; PIETRI, A.; BERTUZZI, T.; FUSCONI, G.; GALVANO, M.; PIVA, A.; PIVA, G. Reduction of carry-over of aflatoxin from cow feed to milk by addition of activated carbons. J. Food Prot., 59, p. 55–554, 1996.

GONÇALVES, B. L.; GONÇALVES, J. L.; ROSIM, R. E.; CAPPATO, L. P.; CRUZ, A. G.; OLIVEIRA, C. A. F.; CORASSIN, C. H. Effects of different sources of Saccharomyces cerevisiae biomass on milk production, composition, and aflatoxin M1 excretion in milk from dairy cows fed aflatoxin B1. Journal of Dairy Science, Vol. 100 No. 7, 2017.

HARPER, A. F.; ESTIENNE, M. J.; MELDRUM, J. B.; HARRELL, R. J.; DIAZ, D. E. Assessment of a hydrated sodium calcium aluminosilicate agent and antioxidant blend for mitigation of aflatoxin-induced physiological alterations in pigs. J. Swine Health Prod., 18, 282–289, 2010.

HUWIG, A.; FREIMUND, S.; KAPPELI, O.; DUTLER, H. Mycotoxin detoxication of animal feed by different adsorbents. Toxicol. Lett., 122, 179–188, 2001.

IARC (International Agency for Research on Cancer). Some traditional herbal medicines, some mycotoxins, naphthalene and styrene. Summary of data reported and evaluation. In: IARC Monographs on the Evaluation of the Carcinogenic Risk to Humans, v. 82, p 171–175, Int. Agency Res. Cancer, Lyon, France, 2002.

JIANG, Y.; OGUNADE, I. M.; KIM, D. H.; LI, X.; PECH-CERVANTES, A. A.; ARRIOLA, K. G.; OLIVEIRA, A. S.; DRIVER, J. P.; FERRARETTO, L. F.; STAPLES, C. R.; VYAS, D.; ADESOGAN, A. T. Effect of adding clay with or without a Saccharomyces cerevisiae fermentation product on the health and performance of lactating dairy cows challenged with dietary aflatoxin B1. Journal of Dairy Science, vol. 101 No. 4, 2018.

KABAK, B.; DOBSON, A. D. W.; VAR, I. Strategies to prevent mycotoxin contamination of food and animal feed: a review. Crit. Rev. Food Sci. Nutr., 46, 593–619, 2006.

KISSELL, L.; DAVIDSON, S.; HOPKINS, B. A.; SMITH, G. W.; WHITLOW, L. W. Effect of experimental feed additives on aflatoxin in milk of dairy cows fed aflatoxin-contaminated diets. Journal of Animal Physiology and Animal Nutrition, 97 (2013) 694–700, 2012.

KOLOSOVA, A.; STROKA, J. Substances for reduction of the contamination of feed by mycotoxins. A review. World Mycotoxin J., 4, 225–256, 2011.

KONG, C.; SHIN, S. Y.; KIM, B. G. Evaluation of mycotoxin sequestering agents for aflatoxin and deoxynivalenol: an in vitro approach. SpringerPlus, 3, 346–351, 2014.

KUTZ, R. E.; J. D. SAMPSON, L. B. POMPEU, D. R. LEDOUX, J. N. SPAIN, M. VAZQUEZ-ANON, AND G. E. ROTTINGHAUS. Efficacy of Solis, NovasilPlus, and MTB-100 to reduce aflatoxin M1 levels in milk of early to mid-lactation dairy cows fed aflatoxin B1. J. Dairy Sci., 92:3959–3963, 2009.

KUTZ, R. E.; SAMPSON, J. D.; POMPEU, L. B.; LEDOUX, D. R.; SPAIN, J. N.; VÁZQUEZ-AÑÓN, M.; ROTTINGHAUS, G. E. Efficacy of Solis, NovasilPlus, and MTB-100 to reduce aflatoxin M1 levels in milk of early to mid lactation dairy cows fed aflatoxin B1. Journal of Dairy Science, vol. 92 No. 8, 2009.

LIU, Y.; WU, F. Global burden of aflatoxin-induced hepatocellular carcinoma: A risk assessment. Environ. Health Perspect., 118, p. 818–824, 2010.

MAGNOLI, A. P.; MONGE, M. P.; MIAZZO, R. D.; CAVAGLIERI, L. R.; MAGNOLI, C. E.; MERKIS, C. I.; CRISTOFOLINI, A. L.; DALCERO, A. M.; CHIACCHIERA, S. M. Effect of low levels of aflatoxin B-1 on performance, biochemical parameters, and aflatoxin B1 in broiler liver tissues in the presence of monensin and sodium bentonite. Poultry Sci., 90, 48–58, 2011.

MAKI, C. R.; HANEY, S.; WANG, M.; WARD, S. H.; RUDE, B. J.; BAILEY, R. H.; HARVEY, R. B.; PHILLIPS, T. D. Calcium Montmorillonite Clay for the Reduction of Aflatoxin Residues in Milk and

Dairy Products. Dairy and Vet Sci J., 2017; 2(3): 555587, 2017.

MAKI, C. R.; MONTEIROB, A. P. A.; ELMOREA, S. E.; TAOB, S.; BERNARDB, J. K; HARVEYC, R. B.; ROMOSERA, A. A.; PHILLIPS, T.D. Calcium montmorillonite clay in dairy feed reduces aflatoxin concentrations in milk without interfering with milk quality, composition or yield. Animal Feed Science and Technology, 214, 130–135, 2016a.

MAKI, C. R.; THOMAS, A. D.; ELMORE, S. E.; ROMOSER, A. A.; HARVEY, R. B.; RAMIREZ-RAMIREZ, H. A.; PHILLIPS, T. D. Effects of calcium montmorillonite clay and aflatoxin exposure on dry matter intake, milk production, and milk composition. Journal of Dairy Science, Vol. 99 No. 2, 2016b.

MIAZZO, R.; PERALTA, M. F.; MAGNOLI, C.; SALVANO, M.; FERRERO, S.; CHIACCHIERA, S. M.; CARVALHO, E. C.; ROSA, C. A.; DALCERO, A. Efficacy of sodium bentonite as a detoxifier of broiler feed contaminated with aflatoxin and fumonisin. Poultry Sci., 84, 1–8, 2005.

NEEFF, D. V.; LEDOUX, D. R.; ROTTINGHAUS, G. E.; BERMUDEZ, A. J.; DAKOVIC, A.; MURAROLLI, R. A.; OLIVEIRA, C. A. F. In vitro and in vivo efficacy of a hydrated sodium calcium aluminosilicate to bind and reduce aflatoxin residues in tissues of broiler chicks fed aflatoxin B1. Poultry Sci., 92, 131–137, 2013.

OGUNADE, I. M.; ARRIOLA, K. G.; JIANG, Y.; DRIVER, J. P.; STAPLES, C. R.; ADESOGAN, A. T. Effects of 3 sequestering agents on milk aflatoxin M1 concentration and the performance and immune status of dairy cows fed diets artificially contaminated with aflatoxin B. J. Dairy Sci., 99:6263–6273, 2016.

PATE, R. T.; PAULUS COMPART, D. M.; CARDOSO, F. C. Aluminosilicate clay improves production responses and reduces inflammation during an aflatoxin challenge in lactating Holstein cows. J. Dairy Sci., 101:1–14, 2018.

PFOHL-LESZKOWICZ, A.; HADJEBA-MEDJDOUB, K.; BALLET, N.; SCHRICKX, J.; FINK-GREMMELS, J. Assessment and characterisation of yeast-based products intended to mitigate ochratoxin exposure using in vitro and in vivo models. Food Addit. Contam., 32, 604–616, 2015.

PHILLIPS, T. D.; AFRIYIE-GYAWU, E.; WILLIAMS, J.; HUEBNER, H.; ANKRAH, N. A.; OFORI-ADJEI, D.; JOLLY, P.; JOHNSON, N.; TAYLOR, J.; MARROQUIN-CARDONA, A.; XU, L.; TANG, L.; WANG, J. S. Reducing human exposure to aflatoxin through the use of clay: a review. Food Addit. Contam., 25, 134–145, 2008.

QUEIROZ, O. C. M.; HAN, J. H.; STAPLES, C. R.; ADESOGAN, A. T. Effect of adding a mycotoxin-sequestering agent on milk aflatoxin M1 concentration and the performance and immune response of dairy cattle fed an aflatoxin B1-contaminated diet. Journal of Dairy Science, vol. 95 No. 10, 2012.

RAMOS, A. J.; FINK-GREMMELS, J.; HERNÁNDEZ, E. Prevention of toxic effects of mycotoxins by means of nonnutritive adsorbent compounds. J. Food Prot., 59, 631–641, 1996a.

RAMOS, A. J.; HERNÁNDEZ, E.; PLA-DELFINA, J. M.; MERINO, M. Intestinal absorption of zearalenone and in vitro study of non-nutritive sorbent materials. Int. J. Pharm., 128, 129–137, 1996b.

RAO, S. B. N.; CHOPRA, R. C. Influence of sodium bentonite and activated charcoal on aflatoxin M1 excretion in milk of goats. Small Ruminant Research, 41 (2001) 203–213, 2001.

RINGOT, D.; LERZY, B.; CHAPLAIN, K.; BONHOURE, J. P.; AUCLAIR, E.; LARONDELLE, Y. In vitro biosorption of ochratoxin A on the yeast industry by-products: comparison of isotherm models. Bioresour. Technol., 98, 1812–1821, 2007.

RODRIGUES, R. O.; RODRIGUES, R. O.; LEDOUX, D. R.; ROTTINGHAUS, G. E.; BORUTOVA, R.; AVERKIEVA, O.; MCFADDEN, T. B. Feed additives containing sequestrant clay minerals and inactivated yeast reduce aflatoxin excretion in milk of dairy cows. Journal of Dairy Science, vol. 102, no. 7, 2019.

SHETTY, P. H.; JESPERSEN, L. Saccharomyces cerevisiae and lactic acid bacteria as potential mycotoxin decontaminating agents. Trends Food Sci. Technol., 17, 48–55, 2006.

SULZBERGER, S. A.; MELNICHENKO, S.; CARDOSO, F. C. Effects of clay after an aflatoxin challenge on aflatoxin clearance, milk production, and metabolism of Holstein cows. Journal of Dairy Science, vol. 100 No. 3, 2017.

UPADHAYA, S. D.; PARK, M. A.; HA, J. K. Mycotoxins and their biotransformation in the rumen: A review. Asian-australasian. J. Anim. Sci., 23, 1250–1260, 2010.

VEKIRU, E.; FRUHAUF, S.; SAHIN, M.; OTTNER, F.; SCHATZMAYR, G.; KRSKA, R. Investigation of various adsorbents for their ability to bind aflatoxin B1. Mycotox. Res., 23, 27–33, 2007.

WANG, J. P.; CHI, F.; KIM, I. H. Effects of montmorillonite clay on growth performance, nutrient digestibility, vulva size, faecal microflora, and oxidative stress in weaning gilts challenged with zearalenone. Anim. Feed Sci. Technol., 178, 158–166, 2012.

WEATHERLYA, M. E.; PATEA, R. T.; ROTTINGHAUSB, G. E.; ROBERTI FILHOC, F. O.; CARDOSOA, F. C. Physiological responses to a yeast and clay-based adsorbent during an aflatoxin challenge in Holstein cows. Animal Feed Science and Technology, 235, 147–157, 2018.

XIONG, J. L.; WANG, Y. M.; ZHOU, H. L.; LIU, J. X. Effects of dietary adsorbent on milk aflatoxin M1 content and the health of lactating dairy cows exposed to long-term aflatoxin B1 challenge. J. Dairy Sci., 101:8944–8953, 2018.

XIONG, J. L.; WANG, Y. M.; NENNICH, T. D.; LI, Y.; LIU, J. X. Transfer of dietary aflatoxin B1 to milk aflatoxin M1 and effect of inclusion of adsorbent in the diet of dairy cows. Journal of Dairy Science Vol. 98 No. 4, 2015.

YIANNIKOURIS, A.; JOUANY, J.P. Mycotoxins in feeds and their fate in animals: a review. Animal Research, v.51, p.81-99, 2002.