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Influence of grains postharvest conditions on mycotoxins occurrence in milk and dairy products

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Abstract

Mycotoxins are secondary metabolites produced by some filamentous fungi, which can cause toxic effects in humans and animals. The purpose of the study was to report the influence of postharvest conditions of grains and animal feed on the occurrence of mycotoxins in milk and dairy products which are widely consumed worldwide and have several health benefits for consumers. Among the most toxic mycotoxins are aflatoxins (AFs), with AFB_1 being the most toxic and present in grains and cereals used in the feeding of dairy cows. After ingestion, AFB_1 is converted to AFM_1, which is excreted in milk, being a source of direct contamination to consumers of this product and dairy products. Thus, knowledge about this substance and the care that can be taken to reduce the consumption of contaminated food is a matter of great importance concerning public health and food safety. This review reports that the temperature and humidity at which the grains are stored, are the main conditions that can be controlled during storage, aiming to reduce the growth of fungi and the production of mycotoxins. This work reinforces that the continuous control of mycotoxins in milk and dairy products is of vital importance to obtain a safe product. Besides, strategies to mitigate the development of fungal contamination have been carefully revised to prevent the formation of these toxic substances.

Keywords: Toxigenic fungi; Aflatoxin M_1; food safety; public health.

Practical Application: This work discusses strategies to mitigate the fungal development to prevent the formation of mycotoxin and milk contamination.

1 Introduction

Fungi have the ability to transform organic materials into a rich and diverse set of useful products and provide distinct opportunities for tackling the urgent challenges before all humans. Fungal biotechnology can advance the transition from our petroleum-based economy into a bio-based circular economy and has the ability to sustainably produce resilient sources of food, feed, chemicals, fuels, textiles, and materials for construction, automotive and transportation industries, for furniture and beyond. Fungal biotechnology offers solutions for securing, stabilizing and enhancing the food supply for a growing human population, while simultaneously lowering greenhouse gas emissions (Meyer et al., 2020). However, fungi can cause economic losses regarding food deterioration and contamination (Bernardi et al., 2019). Food contamination by fungi occurs in several ways, however, the most worrying form is since some genera of filamentous fungi can produce secondary metabolites, which have toxic characteristics (Conte et al., 2020). These metabolites are called mycotoxins and, when present in food, they cause adverse effects to consumers, called mycotoxicosis (Liao et al., 2019). In this context, the presence of mycotoxins in crops and animal products is a serious problem globally and calls for efforts to safeguard consumers' health globally (Coppock et al., 2018).

The development of fungi depends on several factors such as substrate composition, temperature, moisture content, water activity, relative humidity, redox potential, and pH (Van Long et al., 2017). Besides, inadequate harvest and post-harvest practices, insect attacks, dry periods, poor fertilization, and competition with other crops may also favor the growth of mycotoxin-producing fungi (Manu et al., 2019).

Toxigenic fungi are considered villains in food for both human and animal consumption (Conte et al., 2020). This is due to the fact that some species have the ability to release toxins with high toxic potential, causing serious complications to consuming organisms (mycotoxicoses). These substances

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originating from toxigenic fungi are called mycotoxins and are produced mainly by fungi of the genera *Fusarium*, *Aspergillus* and *Penicillium*. There are several types of mycotoxins, such as aflatoxins (AFB_1, AFB_2, AFG_1, AFG_2 and AFM_1), ochratoxin A (OTA), deoxynivalenol (DON), fumonisins (FB_1 and FB_2), patulin (PAT) and zearalenone (ZEA) (Luo et al., 2018; Al-Jaal et al., 2019). These toxins are present mainly in grains, cereals and oilseeds, such as wheat, corn, oats, rice, coffee, beans, nuts, peanuts, among others, but they can also be present in foods such as meats, milk and their derivatives, mainly from the consumption of feed produced with contaminated raw materials (Al-Jaal et al., 2019; Yang et al., 2020). It is also important to mention that after aflatoxin AFB_1 is ingested by dairy cattle in feed, this mycotoxin undergoes biotransformation by partially converting it into AFM_1 that is excreted in milk. In addition, both may be present in the processing of dairy products (Wochner et al., 2017).

It is important to note that milk is considered as a healthy product with substantial health benefits. Therefore, dairy foods could be considered an essential component of an equilibrated diet from a nutritional and functional point of view. It is noteworthy that they are excellent sources of proteins and minerals, especially calcium in a highly bioavailable form. Dairy products can also be considered an excellent matrix for the release of bioactive compounds. Dairy products can improve health or well-being and, when consumed at recommended levels, their benefits include improved immune system function, reduced risk of cardiovascular, reduced risk of bone mass loss, and protection against free radical damage (Verruck et al., 2019a). Since milk and milk products are daily consumed in many parts of the world and they are especially important in the diets of children, who may be more vulnerable to adverse effects from $AFM_{1,}$ multiple nations around the world have enacted food safety regulations for the presence of AFM_1 in milk and other dairy products (Turna & Wu, 2021).

In this sense, the consumption of contaminated food can cause serious complications in the short and long term. In humans, teratogenic, carcinogenic, immunosuppressive, and mutagenic effects have been described mainly. For animals, the consumption of feed and grains, especially corn, when contaminated with mycotoxins can cause low food intake, worsen the conversion of nutrients into body mass, thus reducing weight and can reduce productive capacity (Silva et al., 2021; Yang et al., 2020). It is worth mentioning that high AFM_1 levels in milk indicate high levels of AFB_1 in animal feed. This may imply that the crops used to make that feed such as maize, may have high AFB_1 levels, which upon consumption could harm both animal and human health (Turna & Wu, 2021).

The monitoring of mycotoxin content in food is done with great caution, and some foods are subjected to analysis of these contaminants both before domestic market consumption and for export. In this sense, both grains, kinds of cereal, oilseeds, and by-products of these raw materials are periodically evaluated for the content of mycotoxins present, as well as knowledge of their harmful effects on consumers. Thus, the implementation of increasingly lower tolerated ceilings has been reported in the regulations of several countries. These measures aim to ensure that produced food does not have contaminants above acceptable levels. Another important factor that is highlighted in this context is the control of these foods, because, considering that contamination can occur during cultivation and not only in the storage stage, it is necessary to the adoption of practices of crop management, and disease control in the field, as well as in post-harvest to minimize the risks of contamination (Shi et al., 2018).

In this context, Zhang et al. (2019) state that the factors that most influence the production of these toxins are related to storage conditions, as humidity and temperature are the most important factors affecting both the growth and production of toxins. Thus, the moisture requirements may vary between the species of fungi, both in the lower limit of growth moisture and in the interval over which they will prevail. Temperature is another factor that affects grain storage, and the interaction of biotic and abiotic factors that promote grain deterioration is crucial. As the grain is commonly harvested dry or may have its moisture content reduced to a safe level, it now has a less important role than temperature. Thus, the knowledge and understanding of the control of these two variables during storage is extremely important, because the rigid control of these conditions after harvest directly reflects on the chemical health of foods most commonly compromised by mycotoxins. In this sense, the present study aimed to report current information in the literature on the influence of postharvest conditions of grains and animal feed on the occurrence of mycotoxins in milk and dairy products.

2 Mycotoxins overview

Mycotoxins and health disorders associated with the consumption of these contaminants in humans and animals have been recognized as a major health and also an economic problem. When ingested, mycotoxins can cause acute or chronic episodes of diseases, with carcinogenic, mutagenic, teratogenic, estrogenic, hemorrhagic, nephrotoxic, hepatotoxic, neurotoxic, and immunosuppressive effects. Mycotoxins are not equally toxic, their toxicity changes during metabolism, while the susceptibility of animals and humans varies with species, age, nutrition, duration of exposure, and other factors (Moretti et al., 2017). The assessment of adverse health effects is complex by multiple exposures to various mycotoxins, which can lead to additive, synergistic, or antagonistic toxic effects (Ficheux et al., 2012).

The fungi can contaminate the grains through the soil or during planting, harvesting, drying, transportation, and storage of products (Ismaiel & Papenbrock, 2015). Also, another important form of food contamination is when they are exposed to the condition of stress and nutrient unbalance, in which mycotoxins can be produced on food matrices (Telles et al., 2017). The main genera of fungi that are the cause of the formation of these contaminants *are Aspergillus, Penicillium,* and *Fusarium.* There are hundreds of identified mycotoxins, but not all have been equally studied. Given the higher occurrence and degree of toxicity, the studies already conducted focus on mycotoxins of the type aflatoxins, patulin, fumonisins, zearalenone, ochratoxins, trichothenines, citrinin, cyclopiazonic acid, gliotoxin and griseofulvin as well as their metabolites (Luo et al., 2018).

It is important to note that the optimal conditions of fungal growth are not necessarily the same for the production of mycotoxins. However, if fungal growth is controlled, the production of mycotoxins can be indirectly controlled. It is worth highlighting the possibility of occurrence of the synergistic effect when different species of fungi contaminate the same food, so under appropriate conditions, more than one toxin is produced using the same substrate. Thus, there is a need to know each toxin separately and the most favorable conditions for its production (Oga et al., 2014).

According to Torres et al. (2014), the main foods affected by the presence of fungi are grains, cereals, and some oilseeds, with peanuts having the highest rates of contamination, constituting a public health problem. In this context, maximum limits of the presence of the main mycotoxins are established by several countries and Table 1 shows the maximum levels stipulated by the "Codex Alimentarius".

3 Grain storage conditions and association with mycotoxin production

The release of mycotoxins by the producing fungi is caused by several factors, which can be divided into two groups, those that influence the production of mycotoxins in the stage of cultivation and harvest and those related to the postharvest period (Tran et al., 2020). In the stage of cultivation is where fungi are inserted in food, however, their growth depends on specific conditions, and the main fungi that attack grains, cereals, and oilseeds are considered fungi of the field, which act in high water activity, being the species of *Fusarium graminearium* and *Aspergillus flavus* representing these groups. *Aspergillus flavus* is also considered, as *Penicillium verucossum,* a mycotoxin-producing fungus during the storage stage, given that these fungi can release mycotoxins even in foods with low water activities (Midio & Martins, 2000).

Table 1. Maximum levels of mycotoxins in food recommended by the "Codex Alimentarius Commission".

Mycotoxin	Product	Maximum level (μg kg-1)
Total aflatoxins (B1, B2, G1, G2)	Peanuts, almonds, hazelnuts, pistachios and Brazil nuts for processing	15
	Peanuts, almonds, hazelnuts, pistachios, and Brazil nuts for fresh consumption	10
Aflatoxin M1	Milk	0.5
Ochratoxin A	Wheat, barley and rye	5
Deoxynivalenol	Foods composed of cereals for infant and young children	200
	Flour, semolina, corn, barley and wheat flakes	1000
	Wheat, corn and barley for food processing	2000
Fumonisins B1, B2	Corn grain	4000
	Corn flour	2000

In addition to the type of fungus present in these grains, cereals, and oilseeds, other factors, such as climatic conditions, water availability, management during cultivation, and type of crop are high influencers in the amount and type of mycotoxins present in food (Ráduly et al., 2020). Besides, the post-harvest stages, among which transport, drying, and storage stand out, can be key steps to reduce the number of mycotoxins in food (Perrone et al., 2020).

Concerning contamination in the cultivation phase, some authors point out that the climatic condition is the one that most influences the production of mycotoxins by fungi (Stanciu et al., 2017). In some studies, data are found that evidence that the higher the humidity and temperature during cultivation, the greater the number of fungi and mycotoxins found in these crops (Kluczkovski, 2019). Thus, in countries where climate change is less intense between seasons, a higher prevalence of these contaminants is found in food (Piacentini et al., 2015). Under certain specific conditions, weather might pose a negative influence on the prevention or control of mycotoxins, due to marked environmental variances between regions, and even between crops planted with different dates of sowing (Ponce-García et al., 2018). Tabuc et al. (2009), studied the presence of mycotoxins in cereals and, they realized through the data obtained in their study, that the cold climate prevents the accumulation of some mycotoxins during cultivation, showing the high correlation of contamination of products with the climate in which they are cultivated.

However, storage is a very worrying step and it is possible to control the production of mycotoxins. This is because the conditions to which food and products are subjected may or may not be favorable for the development of fungi and/or the production of mycotoxins (Luzardo et al., 2016). The conditions related to the composition of food itself, pH, presence of metals and oxygen are extremely important and should be taken into account during the storage of these products. Also in this context, the moisture of the grains, as well as the temperature at which they are stored, are the conditions with the greatest impact on grain quality about the presence of these contaminants (Ponce-García et al., 2018; Ashraf et al., 2021).

For Soldati (2010), temperature and time are closely related to the production of these toxins. However, the minimum temperature for the fungus to grow is not necessarily the minimum temperature with which the toxin is produced, because usually, the production of mycotoxins occurs at a higher temperature. The temperature range that is considered optimal for the production of mycotoxins is between 24 °C and 28 °C. In this sense, considering the storage temperature together with time, the grains can be stored for longer periods when the temperature is maintained in the range between eight and 10 ºC and the relative humidity of the air does not exceed 70%. In this sense, the binomial temperature and humidity should be chosen according to the time that is necessary to store the grains, making this step allow adequate sanitary control of these products (Brooker et al., 1992).

Based on what has been described above, it is emphasized that fungal contamination before harvest is mainly governed by plant host fungi and other biological interactions, while the appearance of fungi in the postharvest stage is due to physical (humidity and temperature) and biotic (insects) factors (Mohapatra et al., 2017). In this context, Mannaa & Kim (2017) divided the mycotoxin-producing species into three distinct groups. According to the authors, the field fungi (pre-harvest) where the species of the genus *Alternaria, Epicaccum and Fusarium are* included with aw = 1.0. The second group consists of storage fungi post-harvest), represented by the species of the genus *Aspergillus, Eurotium* and *Penicillium* with aw < 1.0. Finally, the third fungal group is classified as intermediate (off-season), being composed of the species of the genus *Aureobasidium, Cladosporium, Geotrichum* and *Verticullium* which develop during the storage stage in aw between 0.95 and 1.0.

Stored grains and seeds can be affected by some problems, such as fungal growth and the production of toxins by them. Besides, during storage, there is a loss of germination power and dry matter, in addition to changes in nutritional value (Mohapatra et al., 2017). The deterioration of the grain begins with the increase of moisture due to the condensation of water by the effect of "cold wall contact", mainly with metal structures, and by the emergence of a "hot spot" by a grain load with a moisture content of level higher than the limit for safe storage. They can induce loss of germination capacity and dry matter loss (Fleurat-Lessard, 2017).

Gruzdevienè et al. (2006) analysed flax seed infection at harvest and during storage, found the predominantly fungi of the genus *Alternaria* and *Fusarium*. The authors observed fungal development for eight months in a storage site. There was an increase in internal and external contamination by fungal propagules. As a rule, the number of mycotoxins found in the flaxseed of some cultivars was very low, however, a large increase in mycotoxins was observed during storage. In the storage stage, the level of contamination by fungi can vary mainly by factors such as humidity, temperature variations. Since the storage temperature does not exceed 15 °C and has air humidity of 40%.

The amount of water present in a product, such as in food is directly related to the relative humidity of the air and, when these products are stored in an environment with a high concentration of humidity, the food absorbs a certain content of the same. Also in this context, the water activity (a_w) of food, which is characterized by the amount of water available for the occurrence of chemical, physical reactions and also for microbial metabolism will be changed depending on the amount of water present in the environment. It is known that the greater the availability of free water in a food, the higher the rates of microbial metabolism and, in foods with reduced a_w, and the reactions occur more slowly (Damoraran & Parkin, 2019).

Fungal proliferation becomes lower when food is stored at low relative humidity. It is known that the lower the amount of water available in these foods, the lower the production of mycotoxins. This is because mycotoxins are considered secondary metabolites of the process of obtaining energy that happens at the cellular level and, decreasing the rate of metabolism, consequently, the production of mycotoxins is also slowed (Adeyeye, 2016).

The growth of toxigenic fungi occur in a_w above 0.8, however, each species presents a minimum value for its growth, as can be observed in Table 2. In this table, some values of a_w are shown for fungal proliferation and the production of mycotoxins by the main toxigenic fungi (Andrade & Caldas, 2015). As can be observed, the production of mycotoxins by fungi requires higher values of a_w when compared to the fungus requirement. Therefore, the proliferation or presence of fungi is not necessarily tied to the presence of mycotoxins in a certain matrix, and an adequate condition is necessary for the release of these contaminants.

Another extremely important factor that has a direct influence on fungal growth and mycotoxin production is the temperature. It is known that most fungi have optimum growth at room temperature and, with this, it is done the control of several processes within the food industry (Midio & Martins, 2000). About toxigenic fungi, Table 3 shows the temperature values for the growth of some fungal species and the production of mycotoxins by them. In general, the optimum growth temperature remains between 20 and 30 °C, with a minimum temperature of three to seven degrees Celsius for fungal growth (Vujanovic et al., 2001).

Several authors studying the influence of temperature and a_w on fungal growth and mycotoxin production have concluded that these two factors are dependent on each other. Besides, through these two factors, it is possible to ensure a longer storage time of grains with a lower incidence of fungi and the presence of mycotoxins (Wawrzyniak et al., 2018). Depending on the fungal

Table 2. Conditions of a_w for fungal growth and mycotoxin production by some species of toxigenic fungi.

Fungi	Mycotoxin	Fungal growth		Mycotoxin production	
		Minimum	Optimum	Minimum	Optimum
A. flavus	AFs	0.80	0.98	0.82	0.95-0.99
A. parasiticus	AFs	0.80-0.83	0.99	0.86-0.87	0.95
A. ochraceous	OTA	0.79	0.95-0.99	0.83	0.98-0.99
A. carbonarius	OTA	0.85	0.96-0.98	0.92	-
P. verrucossum	OTA	0.80	-	0.86-0.87	-
F. graminearum	DON	0.90	-	0.95	-
F. culmorum	DON	0.87	-	0.96-0.99	-
F. verticillioides	FUMO	0.87	-	0.92	-
F. proliferatum	FUMO	0.88	-	0.92	-
P. verrucosum	OTA	0.80	-	0.86-0.87	-
A. carbonarius	OTA	0.96	-	0.95-0.98	-

Table 3. Temperature conditions (in °C) for fungal growth and mycotoxin production by some species of toxigenic fungi.

Fungi	Fungal growth		Mycotoxin production
	Range of T (°C)	T (°C) Optimum	T (°C) Optimim
A. flavus	10-48	33	13-37
B. parasiticus	12-42	32	12-40
B. ochraceous	-	25	-
F. graminearum	24-26	-	25
F. culmorum	0-31	21	25
F. verticillioides	2.5-37	25	-
F. proliferatum	-	25	-
P. verrucosum	0-31	20	0-31
B. carbonarius	10-41	30	15-20

species in question, the temperature or amount of water present will be a factor of greatest influence and several studies have been conducted to increasingly ensure the health of products such as grains, cereals, and oilseeds from the point of view of the presence of mycotoxins (Shibamoto & Bjeldanes, 2014). In general, it is known that the higher the temperature and the higher the moisture content of the grains, the shorter the grain useful time about fungal proliferation. On the other hand, when using intermediate temperatures with also reduced moisture content, the shelf life of the products increases considerably (Wawrzyniak et al., 2018).

Grains, cereals, and oilseeds when stored at temperatures close to 25 °C and relative humidity of 26% are suitable for consumption for up to one week. On the other hand, when this humidity, for example, is reduced to 18% and the temperature to about five degrees Celsius, the storage time grows to up to 50 weeks, showing the high correlation between these two factors (Pitt & Hocking, 2009).

The control of fungal growth and the production of mycotoxins is extremely important for obtaining products suitable for human and animal consumption. In this sense, the control of some factors, such as temperature and a_w the most commonly affected foods is of fundamental importance, with constantly seeking an adequate safety of the foods that are consumed by the population (Kluczkovski, 2019; Wawrzyniak et al., 2018).

4 Influence of animal feed on the occurrence of mycotoxins

The incidence of mycotoxins in the products is variable and sporadic in different years and geographic locations due in part to the variation in climatic conditions. Climate can significantly affect growth, distribution, and mycotoxin production in fungi and its increasing change has the potential to increase the risks that mycotoxigenic fungi pose to food and feed safety (Magnoli et al., 2019).

Many developing countries and transitional nations are unaware of the prevalence of mycotoxins in animal products while most do not have strict monitoring and surveillance practices regarding safety of animal products. The livestock management practices mainly focus on increasing the production and yield without much consideration on the safety of the animal product (Coppock et al., 2018). Mycotoxin residues are transferred from the feed to products of animal origin; however, less attention has been paid to this in such countries (Andrade et al., 2020).

Toxic residues in animal products are mainly related to the consumption of contaminated feed or forages. Animal by-products viz., meat, milk, and eggs are obtained after consumed feedstuff has been subjected to enzymatic and microbial transformations leading to the production of absorbable metabolites in the gut. During this process, nutrients, volatile fatty acids, and metabolites (toxic and beneficial) are absorbed into the bloodstream of the animal and may be later excreted through urine and feces. The toxins that are not excreted generally remain as residues in the edible organs and muscles. Monogastric and younger animals are more sensitive to mycotoxins than ruminant and older animals. Grazing animals are also exposed to mycotoxin intake which corresponds to a high level of mycotoxins in their products including meat and milk (Adegbeye et al., 2020).

Several factors can alter the nutrition of animals such as species, breed, genetics, sex, consumption of ration, diet energy level, nutrients availability, room temperature, air humidity, health status among others. Poultry, pigs, and aquatic vertebrates are very sensitive to mycotoxins. Because of their high consumption, they are exposed to cereal mycotoxins and chronic contamination. Ruminants are usually more resistant to the adverse effects of mycotoxins since the rumen microbiota partially degrades mycotoxins. It is important to highlight that mycotoxins' effects on horses are limited when compared to those of other animals (Bhat et al., 2010).

The most economically important mycotoxins in terms of their prevalence and their negative effects on animal performance are aflatoxin B_1 (AFB_1), DON, ZEA, OTA, trichothecenes, and fumonisin B_1 (FB_1). The high ingestion of mycotoxins can cause deterioration in animal health and productivity. The diseases caused by mycotoxins, the mycotoxicosis, reduce animal production and increase conversion rates. Moreover, they generate greater morbidity and mortality. Low mycotoxins concentrations can cause subclinical losses in production and increase the risk and incidence of other diseases. It is important to consider the exposure to mycotoxins co-contamination due to the harmful additive and/or synergistic effects on animal health. The use of a safe diet in which the risk of mycotoxin contamination can be minimized and the cost/benefit is accurately quantified should allow the maximization of herd productivity (Magnoli et al., 2019).

5 Mycotoxins in milk and dairy products

Milk is one of the main sources of nutrients essential for the growth, development, and maintenance of human health. It is worth mentioning that dairy products are related to nutritive value and positive health benefits attached to these products and are widely consumed in the world (Verruck et al., 2019b). However, if good agricultural practices are not careful done, it can also be a vehicle of toxic agents, causing serious health risks in individuals who consume, especially children (Gabai & Novelli, 2018).

Among food contaminants, aflatoxins stand out, as secondary metabolites of fungi of the *Aspergillus* genus relevant to human and animal health. Among the aflatoxin analogs identified so far, aflatoxin B_1 (AFB_1) is the most prevalent and the most toxic. Aflatoxin B_1 is known as a natural carcinogenic agent (hepatotoxicity) and its incidence is high in several raw materials such as grains and, consequently, rations and silage, which are part of the dairy cattle diet. When ingested by animals, it undergoes liver biotransformation, partially converting to aflatoxin M_1, which is excreted in milk (Figure 1). Once present in milk, these aflatoxins can withstand most treatments for obtaining dairy products, therefore, they can be present in cheeses and yogurts (Wochner et al., 2019). AFB_1 and AFM_1 are classified as cancerous agents for humans and animals by the International Agency for Research on Cancer (IARC). According to the agency, there is sufficient evidence regarding the carcinogenicity of AFB_1 and AFM_1 in humans and experimental animals to classify it in carcinogenicity group 1 (International Agency for Research on Cancer, 2012).

Sibaja (2019) conducted a survey of the occurrence of AFM_1 in milk and dairy products in Latin America and the Caribbean in the literature, as well as the estimated risk of exposure of this population by daily intake (ID). The results show that 70% (n=3267) and 63% (n=969) of the milk and dairy samples analysed in the last 15 years were contaminated by AFM_1, at concentrations range of 0.001-23.10 μg L^{-1} and 0.001–18.12 μg kg^{-1}, respectively. In addition, the highest ID values were observed in Brazil, Costa Rica, Colombia and Mexico, i.e., 0.0024, 0.0010, 0.0012 and 0.0209 μg kg^{-1} mc day^{-1}, respectively. Besides, a study was conducted in 51 samples of milk powder marketed in the Caribbean region of Colombia, in which the occurrence of FMA_1 was found at levels ranging from 0.20 to 1.19 μg kg^{-1}, Finally, it was estimated that the maximum ingested level of AFM_1 in milk powder consumption in this region is 0.013 μg kg^{-1} mc day^{-1}, which is above the estimated average consumption for Latin America according to the FAO/WHO Joint Committee of Experts (0.0058 μg kg^{-1} mc day^{-1}).

The current Brazilian legislation stipulates the maximum concentration of 20 μg.kg^{-1} of aflatoxins in food intended for human consumption. Concentrations of up to 50 μg.kg^{-1} are allowed for raw materials intended for animal consumption. Regarding the presence of AM_1 in milk, RDC Nº. 07 of 2011 stipulates a maximum of 5.0 μg.kg^{-1} and 0.5 μg.kg^{-1} for milk powder and fluid milk, respectively (Brasil, 2011). Due to the high toxicity of aflatoxins, many countries have established stricter regulations for aflatoxins in food, and these values vary widely between different countries. In Brazil and the United States the maximum residue limit (MRL) of AM_1 in milk is the same, however, in most Asian and European countries, the acceptable levels of this mycotoxin are 10 times lower.

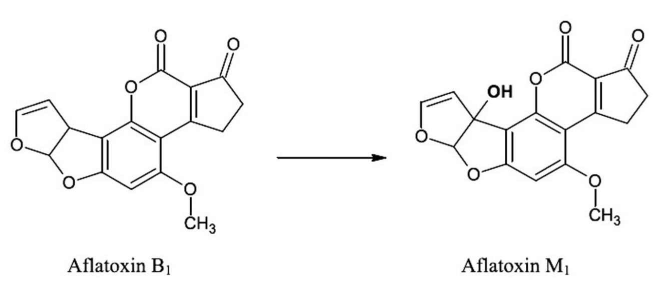

Figure 1. Schematic reaction of transformation of aflatoxin B_1 in aflatoxin M_1. Source: adapted from Wochner et al. (2017).

Hajmohammadi et al. (2020) investigated samples of raw cow's milk produced during the summer and winter in an Iran province. All milk samples had high frequency of AFM_1 contamination, with higher AFM_1 levels (74 ng/L) in the summer compared with the milk samples produced during winter (47 ng/L). Forty per cent of the analysed samples could be considered as not safe for human consumption, since they had AFM_1 levels above the Maximum Permitted Level (MPL) established in Iran (50 ng/L). The authors reported the need for urgent measures to control aflatoxins in the production of milk samples with a special focus on the food management of the dairy cow in order to avoid aflatoxin contamination in milk. Ahmadi (2020) studied the probable public health hazard imposed by bovine milk in relation to AFM_1 in the West of Iran. The assessment of AFM_1, using an ELISA test, indicated 62.22% and 21.11% of 45 samples of raw and pasteurized milk were above the permissible content of Codex and Iranian standard levels, respectively.

In the study conducted by Daou et al. (2020) was reported high contamination levels of AFM_1 in raw, pasteurized, and UHT milk in addition to dairy products. The consumption of milk and dairy in Lebanon can be considered hazardous and may present a significant risk on the health of the Lebanese population especially children. Therefore, there is an urgent need for governmental authorities to set a clear strategy that aims at reducing AFM_1 contamination. This strategy must include; supporting small scale farms and educating farmers on proper practices that increase milk quality; ensuring the safety of feed administered to cattle; strengthening collection centers and cooperatives and supplying them with necessary laboratory equipment to facilitate analysis of milk delivered to them; and finally reinforcing strict regulations and measures and continuously monitoring AFM_1 contamination in order to preserve the quality and ensure the safety of milk and dairy products consumed by Lebanese population. In this context, Gonçalves et al. (2021) evaluated the occurrence of AFM_1 in bulk raw and pasteurized milks, and the resulting Minas Frescal cheese manufactured in cheese-processing plants from São Paulo, Brazil and a high incidence of AFM_1 was observed in samples. This reinforces the need to control AFM_1 in dairy products. Although all samples complied with the Brazilian's MPL for AFM_1 in milk or cheese, 1 sample (4%) of raw milk and 2 samples (8%) of pasteurized milk contained AFM_1 levels exceeding the European MPL of 0.05 μg/L. As a consequence, the AFM_1 milk concentration levels reported could contribute for the overall exposure to dietary aflatoxins.

In other countries such as Uruguay, AFM_1 levels are also worrisome, considering that in some studies the amount of samples with a concentration higher than MRL is 11% of the samples evaluated. Studies conducted in Europe, Africa and Asia also corroborate that the presence of mycotoxins in both plant and animal foods is a worrying point when related to food safety and public health (Capelli et al., 2019; Min et al., 2020; Sharma et al., 2020). In this sense, some studies have been conducted in order to perform the decontamination of food products (Assaf et al., 2019; Porto et al., 2019). Adsorption through nonviable microorganisms and clay materials are the most effective, promising approaches for decontamination of AFM_1 from milk and dairy products (Muaz et al., 2021).

5 Conclusion

The presence of mycotoxins in food and feed is a public health problem since these products are consumed by humans and animals, respectively. In this sense, effective control at all stages of the production chain is extremely important. Some factors, such as the temperature and humidity at which the grains are stored, are the main conditions that can be controlled during storage, aiming to reduce the growth of fungi and the production of mycotoxins. Animal feed contaminated with toxins results in animal products with health risks, especially bovine milk. Further studies on exploring the prevalence of mycotoxins in different materials and strategies to minimize their occurrence and harmful effects are highly encouraged.

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