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MYCOTOXINS - INCIDENCE, IMPACT ON FEED, FOOD SAFETY, FOOD CHAIN AND ECONOMIC LOSSES

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Abstract

Mycotoxin contamination in animal feed is a significant point of concern within the European food supply network. These toxic secondary metabolites produced by fungi have the potential to contaminate feed and pose a risk of making their way into the human diet via animal products like meat, milk, and eggs. The consequences of mycotoxin contamination extend beyond animal health, affecting economies and public health, presenting complex issues for agricultural producers, regulatory bodies, and consumers. Even with stringent controls and surveillance in place, mycotoxins remain a persistent issue. This study provides updated findings on the prevalence of mycotoxins globally and specifically in Europe, with a focus on analyzing the incidence of ochratoxin A both worldwide and within European contexts. The dispersion of mycotoxina within a given region can have considerable economic consequences for the trade of animal feed, directing stakeholders toward making informed decisions about the types of analyses in which they should allocate more resources.

Key words: *mycotoxin prevalence, food safety, ochratoxin A, cereals, economic impact*

INTRODUCTION

The presence of mycotoxins in animal feed represents a critical vulnerability in the European food chain. In a worldwide study examining the prevalence of mycotoxins, 77% of feed ingredient samples from North America were found to contain at least one mycotoxin at levels exceeding the established threshold [24]. Another estimation imply that 25-50% of the world's food crops are affected by mycotoxins [5]. Worldwide investigations have revealed that between 30% and 100% of food and feed samples exhibit co-contamination with mycotoxins, even when the levels of individual mycotoxins remain under the designated safe thresholds. This phenomenon heightens the significance of mycotoxin management because of the potential cumulative and possibly synergistic harmful impacts these toxins can have when present together [25]. Mycotoxins, toxic secondary metabolites produced by fungi, have the potential to contaminate feed and subsequently enter the human food supply through meat, milk, or eggs [30]; [36]. The financial and health-related consequences of mycotoxins have a broad and significant impact, posing challenges to farmers, policymakers, and consumers alike [20].

Aflatoxins (AFB1, AFB2, AFG1, AFG2, AFM1, and AFM2) [21], zearalenone (ZEN), fumonisin B1 (FB1), patulin, ochratoxin A (OTA), and deoxynivalenol (DON) are the mycotoxins of significant importance in terms of agroeconomics, specifically food safety and food security, as well as public health [8]; [37]. The range of adverse health effects encompasses acute poisoning, disorders of the central nervous, cardiovascular, and pulmonary systems, as well as hepatotoxicity, nephrotoxicity, immunosuppression, genotoxicity, carcinogenicity, disorders at the level of intestinal tract, leading to potential fatality [11]; [19]; [23]. For animals, these substances have the effect of decreasing the rate of growth in juvenile animals, and in certain cases, they disrupt the natural mechanisms of resistance and compromise the animals' ability to mount an immune response, thereby increasing their vulnerability to infections [14]. It has been established that they possess immunosuppressive properties and could impede the process of DNA synthesis [4].

The molds predominantly responsible for mycotoxins productions are *Aspergillus, Penicillium, and Fusarium* fungi [12]; [3]; [1], and these can grow on a diverse array of crops and food and feedstuffs that includes, but is not limited to, maize, sorghum, millet, wheat, rice, various spices, dried fruits, apples, coffee beans, and cocoa [35]. The production of mycotoxins is contingent upon specific environmental conditions, particularly warm and humid settings, which are prevalent during the stages of harvesting, handling, storage, and processing. Certain mycotoxins, including deoxynivalenol (DON), zearalenone (ZEN), and fumonisin (FB), have the potential to contaminate grains either during the preharvest stage or in the field. Conversely, aflatoxin (AF) and ochratoxin (OT) can arise during storage because of inadequate postharvest practices. The primary route of mycotoxin exposure is through ingestion, which presents a significant health risk to both humans and livestock [35]; [4].

Mycotoxin regulations have been established in more than 100 countries, and the maximum acceptable limits vary greatly from country to country [37]. The European Union harmonized regulations for the maximum levels of mycotoxins in food and feed among its member nations [25]. Despite rigorous regulations and monitoring systems in place, the enduring presence of mycotoxins continues to be a matter of concern.

The present review provides a comprehensive analysis of the presence of mycotoxins in feed commodities within the European region and focuses on the presence of ochratoxin A in feed commodities. This analysis is based on a systematic review that places particular emphasis on the health hazards associated with the agrifood value chain. We aim to explore the multiple dimensions of mycotoxins issue, especially ochratoxin A, focusing also on its economic impact and implications for food security and public health in Europe.

MATERIALS AND METHODS

To quantify the incidence of mycotoxins in European feed market, we analyzed data on mycotoxins in all feed commodities, for all kind of animal consumers (ruminants, poultry, fish etc.) to identify mycotoxin prevalence and how these varied across Europe in the last 3 years. Data on feed mycotoxin analysis were supplied by the DSM World Mycotoxin Surveys published on the downloads of DSM-Firmenich Animal Nutrition & Health, for 2021 - 2023 period [8], [9], [10]. Data were filtered to retain samples that had as origin countries from Europe for analyzing total risk posed by mycotoxins and the prevalence of the main six mycotoxins in feed commodities, and from the world and Europe, for analyzing the prevalence of the ochratoxin A in feed commodities.

Data were analyzed using Microsoft Excel of Microsoft 365 Personal All edition (v. 2023).

RESULTS AND DISCUSSIONS

The prevalence of mycotoxins in feed commodities within the European region

The prevalence of mycotoxins can vary due to a multitude of factors including climate, agricultural practices, and the efficacy of regulatory frameworks. Furthermore, the presence of mycotoxins in feed commodities is subject to seasonal and yearly fluctuations, making it difficult to give a straightforward ranking. Therefore, analyzing the mean data for several years, for all feed categories can allow some general observations and conclusions, as follows:

Southern European Countries: Due to warmer climates, countries like Spain, Italy, and

Greece may be more susceptible to certain types of mycotoxins like aflatoxins.

Eastern European Countries: Nations like Romania, Poland, and Ukraine have been noted in some studies to have elevated levels of mycotoxins like deoxynivalenol (DON) and zearalenone. This could be due to various factors, including less stringent regulatory oversight in some cases.

Northern European Countries: While less conducive to some types of mycotoxins, countries like the UK, Germany, and Scandinavia can still suffer from others like ochratoxins that prefer cooler, temperate climates.

Western European Countries: France, Belgium, and the Netherlands generally have rigorous testing and regulatory frameworks but are not immune to the problem.

It is important to consider that these observations may not be consistent, and they are also influenced by the international trade of feed commodities. Different countries have different standards and frequencies for testing for mycotoxins, making direct comparisons challenging [6].

One of the ways to compare data are the analysis performed by multinational companies, that are using the same working protocols all over the world. According to DSM World Mycotoxin Survey, the total risk of mycotoxins contaminations in Europe in feed, in the period 2021 – 2023 has an obvious rising trend in 2023, compared with the previous 2 years, with a pick for Southern Europe (Fig. 1). Generally, northern Europe has a lower risk of mycotoxin contamination when compared with the Central and Southern Europe.

Aflatoxins, zearalenone, deoxynivalenol, T2, fumonisin, and ochratoxin A are the main mycotoxins affecting feed. Their prevalence is of maximum importance for the animal production industry and millions of Euro are spent for the mycotoxin analysis yearly.

Aflatoxins are produced by *Aspergillus flavus* and *Aspergillus parasiticus* and are abundant in warm and humid regions of the world [34].

Zearalenone (ZEN), is a potent estrogenic metabolite produced by some *Fusarium* and *Gibberella* species [18].

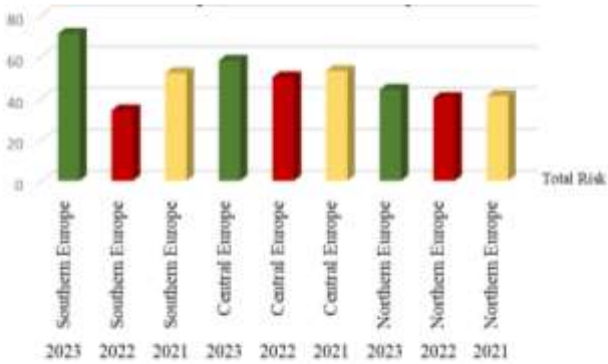

Fig. 1. The total risk of mycotoxins contaminations in Europe, in the period 2021 – 2023
Source: data according to DSM World Mycotoxin Survey [8, 9, 10].

Deoxynivalenol (DON) is one of several mycotoxins produced by certain *Fusarium* species that frequently infect corn, wheat, oats, barley, rice, and other grains in the field or during storage [29].

T-2 toxin is the most toxic fungal secondary metabolite produced by different *Fusarium* species, being also the most common cause of poisoning that results from the consumption of contaminated cereal-based food and feed reported among humans and animals [16].

Fumonisin is a mycotoxin produced by the fungus *Fusarium verticillioides*, a common contaminant of corn and corn products [28].

Ochratoxin A are produced by *Aspergillus ochraceus* and *Penicilium verrucosum* and are at least ten times more toxic than ochratoxin B, ochratoxin C or citrinin [15].

The evolution of the prevalence of these main six mycotoxins in Europe in the period 2021-2023 (Fig. 2) depicts quite alarming situation for Southern Europe in 2023, especially for zearalenone, and fumonisin. As a general remark, deoxynivalenol is the mycotoxins usually present in all the areas, every year, while for fumonisin the prevalence is very variable, depending on the region and testing period, indicating a correlation with the climatic conditions.

Huge amount of data is available on DSM World Mycotoxin Surveys, based on yearly reports from around 25,000 samples, 120,000 analyses, from samples from around 80 countries.

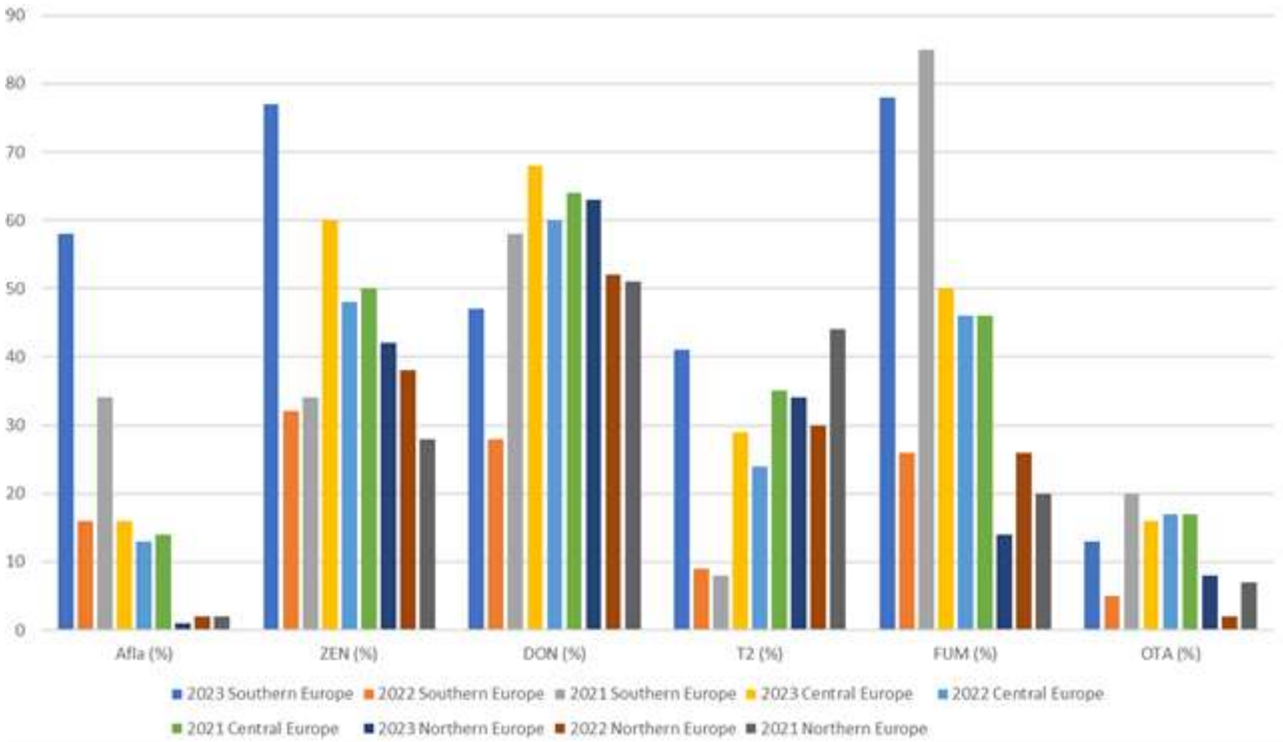

Fig. 2. The prevalence of the main six mycotoxins in feed commodities within the European region
Source: data according to DSM World Mycotoxin Survey [8, 9, 10].

The presence of ochratoxin A in feed commodities in the world

The presence of ochratoxin A (OTA) in the food chain has raised serious health concerns due to its toxicological properties, which include nephrotoxicity, immunotoxicity, and potential carcinogenic effects. The fungi responsible for OTA production, of *Aspergillus* and *Penicillium* genous [33], can proliferate on crops pre-harvest, during storage, or along the food supply chain. *Aspergillus ochraceus* grows better in oilseeds *Penicillium. verrucosum* may grow better in wheat and corn. Generally, the formation of OTA takes place predominantly post-harvest, particularly in cereal and cereal-based products that have not been adequately dried. Various factors contribute to the production of OTA, including environmental variables like temperature and moisture levels, as well as the quality and type of the seeds involved [7].

Given its stability, OTA can endure food processing techniques, thereby posing a significant risk for end consumers, either animal or human. European Food Safety Authority (EFSA) and the Food and Agriculture Organization (FAO) have established maximum permissible limits for OTA in different matrices, however, regulations are often challenging to enforce due to the widespread nature of this contaminant and gaps in surveillance.

The Commission of the European Communities Recommendation 2006/576 established the values for OTA in feedstuffs at a level of 250 μg/kg for cereals and cereal products, at 50 μg/kg for completary and complete feedstuffs for pigs and at 100 μg/kg for completary and complete feedstuffs for poultry [7].

Swine exhibit a higher vulnerability to ochratoxin A (OTA) exposure relative to other livestock species [33]. In Italy, research by Pozzo et al., 2010, detected contamination of ochratoxin A (OTA) in swine feed, with concentrations ranging from 0.22 to 38.4 μg/kg, while [27], in the Czech Republic, Zachariasova et al., 2014, reported an average OTA concentration of 3 μg/kg, noting that just a single sample surpassed the European Union's advised OTA limit of 50 μg/kg [38].

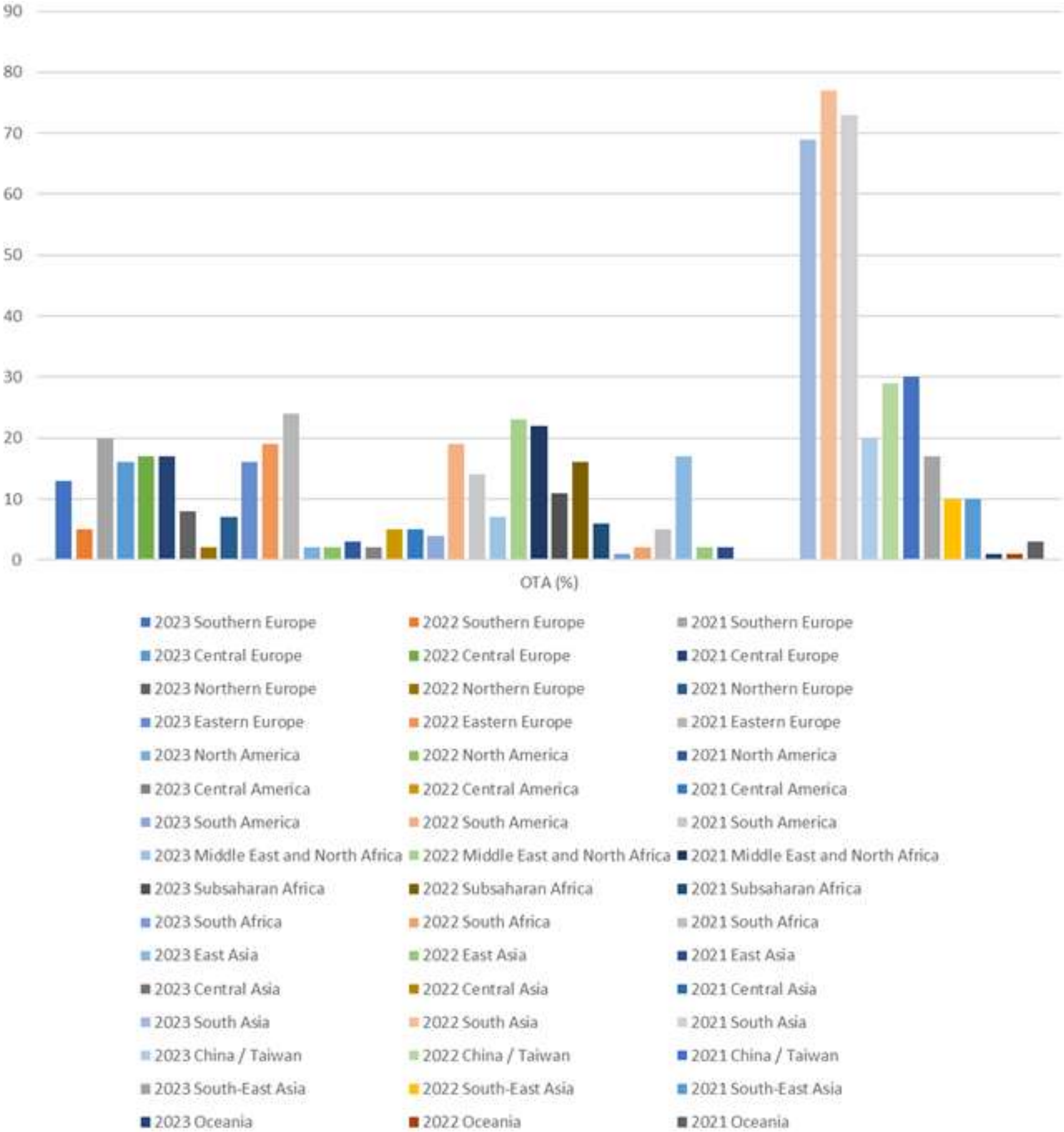

Fig. 3. The prevalence of the ochratoxin A in feed commodities in the world
Source: data according to DSM World Mycotoxin Survey [8, 9, 10].

At the world level, the prevalence of OTA in feed is below 10% Northern Europe, North and Central America, South Africa, and Oceania (Fig 3). Southern, Eastern and Central Europe, South America, Subsaharan Africa, and South- East Asia generally have a prevalence of OTA between 10-20%. The situation is alarming in China/Taiwan, with a prevalence of more than 20-30%, and even more in South Asia, where OTA can be found in more than 70% of the analyzed samples.

The presence of ochratoxin A in feed commodities in Europe

The prevalence of ochratoxin A in feed commodities in Europe was below 10% in Northern Europe, with a minimum in 2022, when it only been 2% (Fig.4.) The same pattern happened for Southern Europe, where in 2022 the prevalence was only 5%, although in 2021 this was 20% and in 2023 raised to 13%. As the summer of 2022 was Europe's worst drought in the last 500 years [31], one possible explanation could rely on the lack of humidity, that did not favor the fungi development. Still, for Eastern and Central Europe, the decreasing trend continued in 2023, indicating that the lack of water in the first part of the season can contribute to a dramatical drop down of the presence of mycotoxines in feed commodities.

Still, Eastern Europe has an average prevalence of almost 20%, indicating also that other measures should be put in place to reduce the mycotoxins risk for human and animal health.

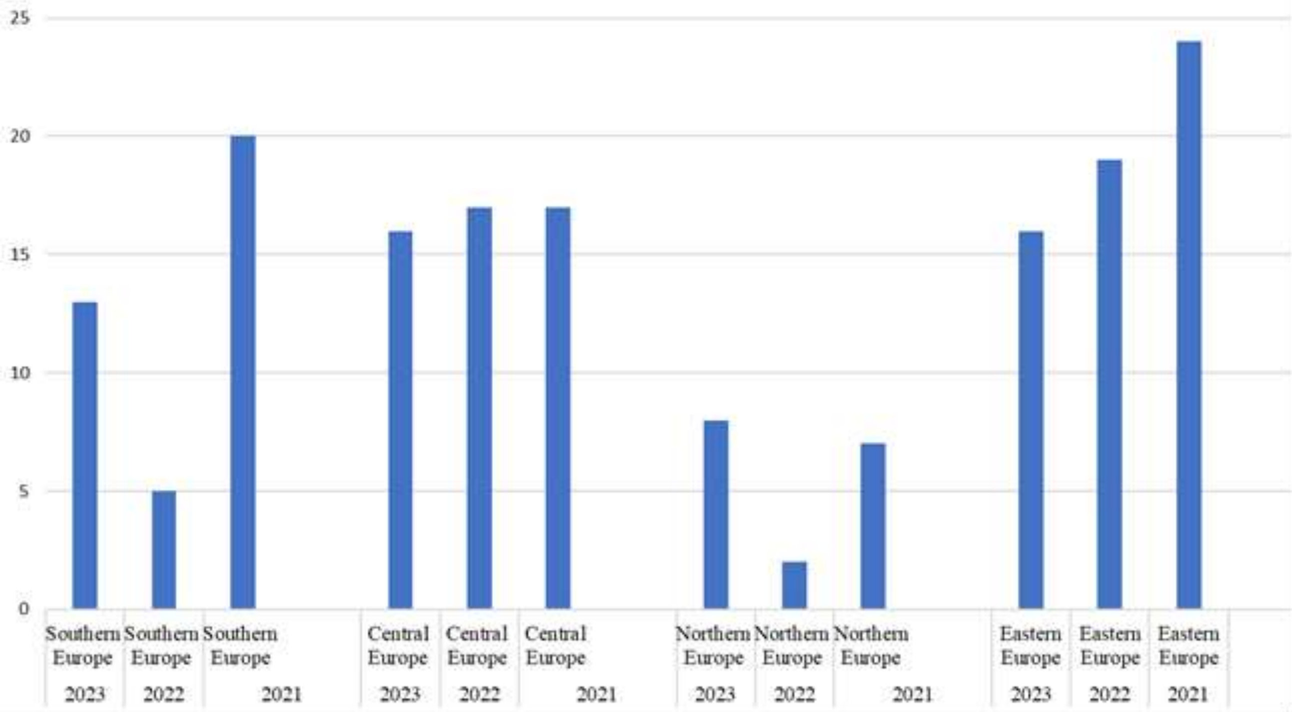

Fig. 4. The prevalence of the ochratoxin A in feed commodities within the European region
Source: data according to DSM World Mycotoxin Survey [8, 9, 10].

Impact on feed, food safety and food chain

The economic repercussions of mycotoxins in animal feed are extensive and multi-faceted. The presence of mycotoxins in animal feed has a ripple effect on food security and public health. Residues can accumulate in animal-derived products, such as meat and milk, which may then be consumed by humans. Long-term exposure to low levels of these toxins can lead to chronic health issues, including immune suppression and carcinogenic effects. The mycotoxin issue thus extends beyond the agricultural community to affect the general population, posing challenges for public health officials and medical researchers.

The expansion of international trade and the increasing complexity of supply chains are introducing novel challenges in ensuring food and feed safety across the globe. A precautionary strategy for consumer protection should encompass a Risk Assessment that accounts for every phase of the worldwide food supply chains. There exist significant knowledge deficits within the trade structures of these chains, particularly in logistical components like transportation and storage [2].

European countries have established stringent regulations concerning mycotoxin levels in animal feed, aligned with guidelines from the European Food Safety Authority (EFSA). However, the ever-changing climatic conditions and global feed supply chains add layers of complexity to regulatory enforcement. Additionally, the variety of mycotoxins and their different impacts on various animal species complicate the regulatory landscape.

Non-compliance not only leads to economic losses but also hampers market access, as some countries outside the EU have even stricter regulations concerning mycotoxins in imported animal products.

Regardless of regulations, many possible strategies may be adopted by farmers, to reduce mycotoxins contaminations. Focker et al., 2020, mentions the use of a fungicide to control Fusarium head blight, use of resistant maize cultivars and/or biocontrol, improved storage management, innovative milling strategies and use of mycotoxin degrading enzymes for bioethanol production [13].

Economic impact

In US, Mitchel et al., 2016 estimate that only aflatoxin contamination in corn could cause losses ranging from US$52.1 million to US$1.68 billion annually [22]. Some studies suggest that the European Union could face annual losses ranging from €3 to €5 billion due to the adverse effects of mycotoxins on livestock health and productivity [17].

Table 1. Different categories of costs related to the presence of mycotoxins in feed commodities within the European region

Direct costs	Indirect costs	Research and development Costs
Feed Contamination and Waste: Mycotoxin-contaminated feed often has to be discarded to prevent further risks, leading to waste and requiring replacement with uncontaminated feed.	Testing and Monitoring: To comply with regulations and ensure the safety of animal feed, producers often need to invest in mycotoxin testing, which can be expensive.	Innovation and Technology: Firms may invest in research to develop mycotoxin-resistant feed varieties or more effective detoxifying agents, which is a long-term but essential cost.
Reduced Feed Efficiency: Animals consuming low levels of mycotoxins may exhibit reduced feed conversion rates, affecting productivity and thus increasing costs per unit of animal product.	Regulatory Penalties: Non-compliance with mycotoxin regulations can result in fines and other penalties.	Detection and Analysis: Developing, refining, and implementing new detection methods for various mycotoxins in feed. This includes the cost of purchasing and maintaining sophisticated analytical equipment, reagents, and materials.
Veterinary Expenses: Animals exposed to mycotoxins may require medical treatment for symptoms ranging from digestive issues to severe illnesses. This adds to the veterinary costs, including both medicines and professional services.	Market Access and Trade Restrictions: Exceeding mycotoxin limits can result in restricted market access, both domestically and internationally, as some markets may ban products from sources with known mycotoxin issues.	Surveillance Programs: Conducting regular monitoring and surveillance of feedstocks to assess mycotoxin levels, which requires ongoing funding for sample collection, testing, and data analysis.
Decreased Animal Productivity: Mycotoxins can impact the growth rates, reproductive capacity, and milk production of livestock. Reduced productivity means fewer marketable goods and thus, lower revenues.	Consumer Confidence: News of mycotoxin contamination can erode consumer trust, leading to reduced demand and prices for animal products.	Prevention and Control Strategies: Investing in the development of new feed additives or treatments that can inhibit mycotoxin production or mitigate their effects. This involves funding laboratory research, field trials, and regulatory approval processes.
Mortality: In severe cases, exposure to mycotoxins can lead to animal deaths, resulting in immediate economic loss for the producers.	Loss of Man-hours: Managing a mycotoxin outbreak involves significant time and labor, including diagnosing the problem, treating affected animals, and implementing preventive measures.	Data Management and Software Development: Developing software for the prediction, management, and documentation of mycotoxin risks, which includes costs for programmers, data scientists, and IT infrastructure.
Loss of Market Access: For feed producers and exporters, the presence of mycotoxins can lead to restrictions in certain markets, which can have significant financial implications.	Litigation Costs: In extreme cases, failure to manage mycotoxins effectively could lead to legal consequences, adding litigation costs to the economic burden	Collaborative Research: Funding joint research initiatives with academic institutions, government agencies, and industry partners to advance the understanding and management of mycotoxin contamination.

Source: Pitt et al., 2012 [26].

Regarding contamination with deoxynivalenol (DON) in Europe from 2010 to 2019, Johns et al., 2022 reported that 75 million tons of wheat, accounting for 5% of the wheat intended for human consumption, was relegated to animal feed as it surpassed the threshold of 750 µg/kg due to Fusarium head blight contamination. his downgrading led to an economic loss of around €3 billion, a figure that was estimated without considering additional losses from diminished crop yields, the presence of other mycotoxins associated with Fusarium head blight, or the expenses related to fungicide treatments and mycotoxin assays. Consequently, this estimate represents only a portion of the overall economic burden imposed by head blight [17].

Another modeling calculation in wheat in EU indicated annual losses due to mycotoxins at a level of 5-10%, which equates to €1.2-2.4 billion in lost income just [32].

The economic impact could be evaluated considering the direct costs and the indirect costs [26], but also the research costs, as a separate category (Table 1). Direct costs include immediate losses from rejection or destruction of contaminated feed, increased veterinary expenses, and decreased animal productivity. Indirect costs extend to market restrictions, especially in terms of exports, as well as additional costs for testing and monitoring to ensure feed quality. The financial burden disproportionately affects smaller farms that may lack the resources for extensive monitoring and compliance, exacerbating economic disparities within the agricultural sector.

Moreover, indirect costs such as loss of market access for exports due to stricter import regulations in other countries, as well as the financial burden of constant feed monitoring, add to this considerable economic impact.

This enduring issue challenges the stability and profitability of the European livestock industry, affecting small-scale farmers and large enterprises alike.

CONCLUSIONS

The persistent occurrence of mycotoxins in animal feed continues to pose a substantial risk within Europe's feed supply chain. Despite extensive regulatory measures and surveillance efforts, the intricate nature of mycotoxin contamination makes it an ongoing challenge. The repercussions are economically significant, with implications for the agricultural industry and the wider economy. Understanding the distribution of particular mycotoxin within a given region can have considerable economic consequences for the trade of animal feed, directing stakeholders toward making informed decisions about the types of analyses in which they should allocate more resources.

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REFERENCES

[1]Abdel-Wahhab, M.A., Kholif, A.M., 2008, Mycotoxins in Animal Feeds and Prevention Strategies: A Review. Asian Journal of Animal Sciences, 2: 7-25. doi: 10.3923/ajas.2008.7.25

[2]Achten, E., Zupaniec, M., Mader, A., Mädge, I., Bodi, D., Spolders, M., Kowalczyk, J., Horn, B., Schafft, H.A., 2019, Global feed supply chains − Plant resources for animal feed. In Feed and food safety in times of global production and trade. Bundesinstitut für Risikobewertung, Berlin. doi 10.17590/20190930-102623

[3]Armendáriz, C. R., Fernández, Á. J. G., Gironés, M. C. L. R., de la Torre, A. H., 2014, Mycotoxins. Encyclopedia of Toxicology, 424–427. doi:10.1016/b978-0-12-386454-3.00519-4

[4]Awuchi, C.G., Ondari, E.N., Nwozo, S., Odongo, G.A., Eseoghene, I.J., Twinomuhwezi, H., Ogbonna, C.U., Upadhyay, A.K., Adeleye, A.O., Okpala, C.O.R., 2022, Mycotoxins' Toxicological Mechanisms Involving Humans, Livestock and Their Associated Health Concerns: A Review. Toxins:14(167). doi:10.3390/toxins14030167

[5]Borutova, R., 2019, The economic impact of mycotoxins, Poultry World, https://www.poultryworld.net/health-nutrition/the-

economic-impact-of-mycotoxins/, Accessed on November 1, 2023.
[6]Chhaya, R. S., O'Brien, J., Cummins, E., 2021, Feed to fork risk assessment of mycotoxins under climate change influences - recent developments. Trends in Food Science & Technology. doi:10.1016/j.tifs.2021.07.040
[7]Denli, M., Perez, J. F., 2010, Ochratoxins in feed, a risk for animal and human health: control strategies. Toxins, 2(5), 1065–1077. doi.org/10.3390/toxins2051065.
[8]DSM-Firmenich, 2023, DSM World Mycotoxin Survey, The Global Threat. January – June 2023. https://www.dsm.com/anh/news/downloads/whitepapers-and-reports/download-the-dsm-firmenich-world-mycotoxin-survey-january-to-june-2023.html, Accessed on October 26, 2023
[9]DSM-Firmenich, 2022, 2022 dsm-firmenich World Mycotoxin Survey Report. https://www.dsm.com/anh/news/downloads/whitepapers-and-reports/dsm-world-mycotoxin-survey-2022-report.html , Accessed on October 26, 2023
[10]DSM-Firmenich, 2021, 2021 dsm-firmenich World Mycotoxin Survey Report. https://www.dsm.com/anh/news/downloads/whitepapers-and-reports/2021-dsm-world-mycotoxin-survey-report.html, Accessed on October 26, 2023
[11]EFSA, 2023, Mycotoxins. https://www.efsa.europa.eu/en/topics/topic/mycotoxins#, Accessed on October 26, 2023
[12]Eskola, M., Kos, G., Elliott, C. T., Hajšlová, J., Mayar, S., Krska, R., 2019, Worldwide contamination of food-crops with mycotoxins: Validity of the widely cited "FAO estimate" of 25%. Critical Reviews in Food Science and Nutrition, 1–17. doi:10.1080/10408398.2019.1658570
[13]Focker, M., van der Fels-Klerx, H.J., Magan, N., Edwards, S.G., Grahovac, M., Bagi, F., Budakov, D., Suman, M., Schatzmayr, G., Krska, R., de Nijs, M., 2020, The impact of management practices to prevent and control mycotoxins in the European food supply chain: MyToolBox project results. doi: 10.3920/WMJ2020.2588
[14]Grenier, B., Applegate, T., 2013, Modulation of Intestinal Functions Following Mycotoxin Ingestion: Meta-Analysis of Published Experiments in Animals. Toxins, 5(2), 396–430. doi:10.3390/toxins5020396
[15]Gupta, R. C., 2018, Veterinary Toxicology, Academic Press, Elsevier Inc., doi.org/10.1016/C2016-0-01687-X
[16]Janik, E., Niemcewicz, M., Podogrocki, M., Ceremuga, M., Stela, M., Bijak, M., 2021, T-2 Toxin-The Most Toxic Trichothecene Mycotoxin: Metabolism, Toxicity, and Decontamination Strategies. Molecules (Basel, Switzerland), 26(22), 6868. https://doi.org/10.3390/molecules26226868
[17]Johns, L.E., Bebber, D.P., Gurr, S.J., 2022, Emerging health threat and cost of Fusarium mycotoxins in European wheat. Nat Food 3, 1014–1019. https://doi.org/10.1038/s43016-022-00655-z
[18]Kaur, Y., Verma, R.K., 2023, Plant-Microbe Interaction - Recent Advances in Molecular and Biochemical Approaches. Volume 1: Overview of Biochemical and Physiological Alteration During Plant-Microbe Interaction, 1st Edition. doi:10.1016/B978-0-323-91875-6.00006-2,
[19]Latham, R.L., Boyle, J.T., Barbano, A., Loveman, W.G., Brown, N.A., 2023, Diverse mycotoxin threats to safe food and feed cereals. Essays Biochem. 67(5):797-809. doi: 10.1042/EBC20220221
[20]Marc, R.A., 2022. Implications of Mycotoxins in Food Safety. Chapter 1. Form Mycotoxins and Food Safety - Recent Advances. IntechOpen. doi:10.5772/intechopen.102495
[21]Mehmood, N., Sohail, F., Sohail, S., Aslam, M., Ali, M., Ijaz, N., Rana, H., 2012, Carcinogenic Properties of Aflatoxins in Maize Production and Recent Technologies Involved. Austin Journal of Nutrition and Food Sciences. 9(2): 1157.
[22]Mitchel, N.J., Bowers, E., Hurburgh, C., Wu, F., 2016, Potential economic losses to the US corn industry from aflatoxin contamination, Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 33(3):540-50. doi: 10.1080/19440049.2016.1138545
[23]Omotayo, O.P., Omotayo, A.O., Mwanza, M., Babalola, O.O., 2019, Prevalence of Mycotoxins and Their Consequences on Human Health. Toxicological Research, 35(1), 1–7. doi:10.5487/tr.2019.35.1.001
[24]Paulk, C., Truelock, C., 2021, Mycotoxins in poultry feed. https://www.world-grain.com/articles/16274-mycotoxins-in-poultry-feed, Accessed on 20 October 2023.
[25]Pinotti, L., Ottoboni, M., Giromini, C., Dell'Orto, V., Cheli, F., 2016, Mycotoxin Contamination in the EU Feed Supply Chain: A Focus on Cereal Byproducts. Toxins 8(2):45. doi: 10.3390/toxins8020045.
[26]Pitt, J.I., et al., 2012, Economics of Mycotoxins: Evaluating Costs to Society and Cost-Effectiveness of Interventions. IARC Scientific Publications, Lyon, 119-129. http://www.ncbi.nlm.nih.gov/pubmed/23477200
[27]Pozzo, L., Cavallarin, L., Nucera, D., Antoniazzi, S., Schiavone, A., 2010, A survey of ochratoxin A contamination in feeds and sera from organic and standard swine farms in Northwest Italy. J. Sci. Food Agric, 90, 1467–1472
[28]Smith, G.W., 2018, Veterinary Toxicology (Third Edition), Academic Press, Elsevier Inc., doi.org/10.1016/C2016-0-01687-X.
[29]Sobrova, P., Adam, V., Vasatkova, A., Beklova, M., Zeman, L., Kizek, R., 2012, Deoxynivalenol and its toxicity. Interdiscip Toxicol. (3):94-9. doi: 10.2478/v10102-010-0019-x.
[30]Stoev, S.D. 2023, Foodborne diseases due to underestimated hazard of joint mycotoxin exposure at low levels and possible risk assessment. Toxins, 15, 464, https://doi.org/10.3390/toxins15070464
[31]Tandon, A., 2022, Climate change made 2022's northern-hemisphere droughts 'at least 20 times' more likely. https://www.carbonbrief.org/climate-change-made-2022s-northern-hemisphere-droughts-at-least-20-times-more-likely/. Accessed on October 28, 2023

[32]Van Es-Sahota, S., 2023, Professor Rudolf Krska: "Challenges need to be faced with cutting edge research" https://www.dairyglobal.net/specials/professor-rudolf-krska-challenges-need-to-be-faced-with-cutting-edge-research. Accessed on October 30, 2023

[34]Vlachou, M., Pexara, A., Solomakos, N., Govaris, A., 2022, Ochratoxin A in Slaughtered Pigs and Pork Products. Toxins:14, 67. doi:10.3390/toxins14020067

[35]Wexler, P., 2014. Encyclopedia of Toxicology, Third Edition. Academic Press, Elsevier Inc. p

[36]WHO, 2023, Mycotoxins, https://www.who.int/news-room/fact-sheets/detail/mycotoxins. Accessed on October 26, 2023

[37]Xu, R., Kiarie, E.G., Yiannikouris, A., Sun, L., Karrow, N.A., 2022, Nutritional impact of mycotoxins in food animal production and strategies for mitigation. J Animal Sci Biotechnol 13, 69, doi:10.1186/s40104-022-00714-2

[38]Yu, J., Pedroso, I.R., 2023, Mycotoxins in Cereal-Based Productsand Their Impacts on the Health of Humans, Livestock Animals and Pets. Toxins, 15, 480. https://doi.org/10.3390/toxins15080480

[39]Zachariasova, M., Dzuman, Z., Veprikova, Z., Hajkova, K., Jiru, M., Vaclavikova, M., Hajslova, J., 2014, Occurrence of multiple mycotoxins in European feeding stuffs, assessment of dietary intake by farm animals. Anim. Feed Sci. Technol, 193, 124–140.