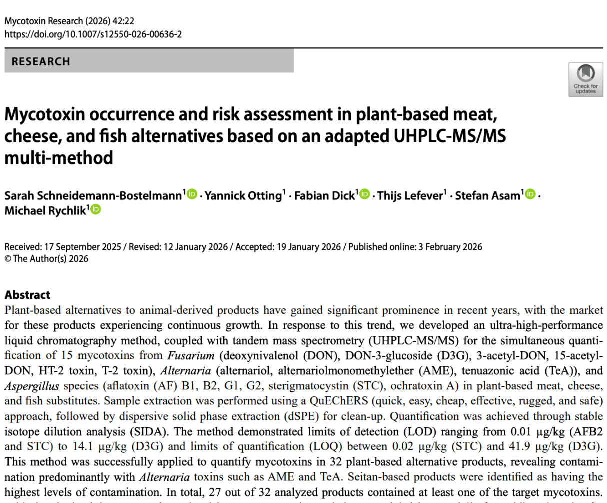
Mycotoxins in Food: Implications for Health

1



Mycotoxin Research (2026) 42:22
https://doi.org/10.1007/s12550-026-00636-2

RESEARCH

Mycotoxin occurrence and risk assessment in plant-based meat, cheese, and fish alternatives based on an adapted UHPLC-MS/MS multi-method

Sarah Schneidemann-Bostelmann[1] · Yannick Otting[1] · Fabian Dick[1] · Thijs Lefever[1] · Stefan Asam[1] · Michael Rychlik[1]

Received: 17 September 2025 / Revised: 12 January 2026 / Accepted: 19 January 2026 / Published online: 3 February 2026
© The Author(s) 2026

Abstract
Plant-based alternatives to animal-derived products have gained significant prominence in recent years, with the market for these products experiencing continuous growth. In response to this trend, we developed an ultra-high-performance liquid chromatography method, coupled with tandem mass spectrometry (UHPLC-MS/MS) for the simultaneous quantification of 15 mycotoxins from *Fusarium* (deoxynivalenol (DON), DON-3-glucoside (D3G), 3-acetyl-DON, 15-acetyl-DON, HT-2 toxin, T-2 toxin), *Alternaria* (alternariol, alternariolmonomethylether (AME), tenuazonic acid (TeA)), and *Aspergillus* species (aflatoxin (AF) B1, B2, G1, G2, sterigmatocystin (STC), ochratoxin A) in plant-based meat, cheese, and fish substitutes. Sample extraction was performed using a QuEChERS (quick, easy, cheap, effective, rugged, and safe) approach, followed by dispersive solid phase extraction (dSPE) for clean-up. Quantification was achieved through stable isotope dilution analysis (SIDA). The method demonstrated limits of detection (LOD) ranging from 0.01 µg/kg (AFB2 and STC) to 14.1 µg/kg (D3G) and limits of quantification (LOQ) between 0.02 µg/kg (STC) and 41.9 µg/kg (D3G). This method was successfully applied to quantify mycotoxins in 32 plant-based alternative products, revealing contamination predominantly with *Alternaria* toxins such as AME and TeA. Seitan-based products were identified as having the highest levels of contamination. In total, 27 out of 32 analyzed products contained at least one of the target mycotoxins.

- *Measured 15 mycotoxins in a variety (32) of commercial plant-based meats and cheeses.*
- In total, 27 out of 32 analyzed products contained at least one of the target mycotoxins.
- Seitan-based products were identified as having the highest levels of contamination.
- However, none of the detected concentrations exceeded the established regulatory limits or recommended values, as *plant-based alternatives are not specifically included in the relevant food safety regulations.*

2

A quantitative analysis of the mycotoxin content in PBAPs revealed that contamination was both universal and pronounced. While Alternaria toxins were present across all product groups, Aspergillus toxins were detected only sporadically, and Fusarium toxins were found exclusively in wheat-based alternatives. 29 out of 32 products showed contamination with at least one mycotoxin. Seitan products were particularly affected by contamination with both Fusarium and Alternaria toxins.

However, this is only a part of the real situation. To assess the safety of plant-based alternatives in general, additional aspects such as pesticide residues, heavy metal contamination, processing contaminants, and the nutritional composition of the products would need to be evaluated.

Mycotoxin Research (2026) 42:22

3

Major Groups of Mycotoxins

- **Aflatoxins**:
  - **Source**: Produced mainly by *Aspergillus* mold species.
  - **Common foods**: Peanuts, corn, tree nuts, and rice.
  - **Health effects**: Severe liver damage and an increased risk of liver cancer.
- **Ochratoxins**:
  - **Source**: Produced by *Aspergillus* and *Penicillium* molds.
  - **Common foods**: Grains, coffee, and dried fruits.
  - **Health effects**: Kidney damage and immune system suppression.
- **Fumonisins**:
  - **Source**: Produced primarily by *Fusarium* mold.
  - **Common foods**: Maize and corn-based products.
  - **Health effects**: Gastrointestinal and nervous system disturbances.

https://www.who.int/news-room/fact sheets/detail/mycotoxins

4

Major Groups of Mycotoxins

- **Trichothecenes** (including deoxynivalenol/vomitoxin):
  Source: Produced by *Fusarium* mold.
  Common foods: Wheat, barley, and oats.
  Health effects: Vomiting, nausea, and digestive tract distress.

- **Zearalenone**:
  Source: Produced by *Fusarium* species.
  Common foods: Cereal grains like corn, wheat, and sorghum.
  Health effects: Estrogen-like hormonal disruptions.

- **Patulin**:
  Source: Produced by *Penicillium* and *Aspergillus* molds.
  Common foods: Apples, pears, and apple juice.
  Health effects: Nausea, vomiting, and gastrointestinal irritation.

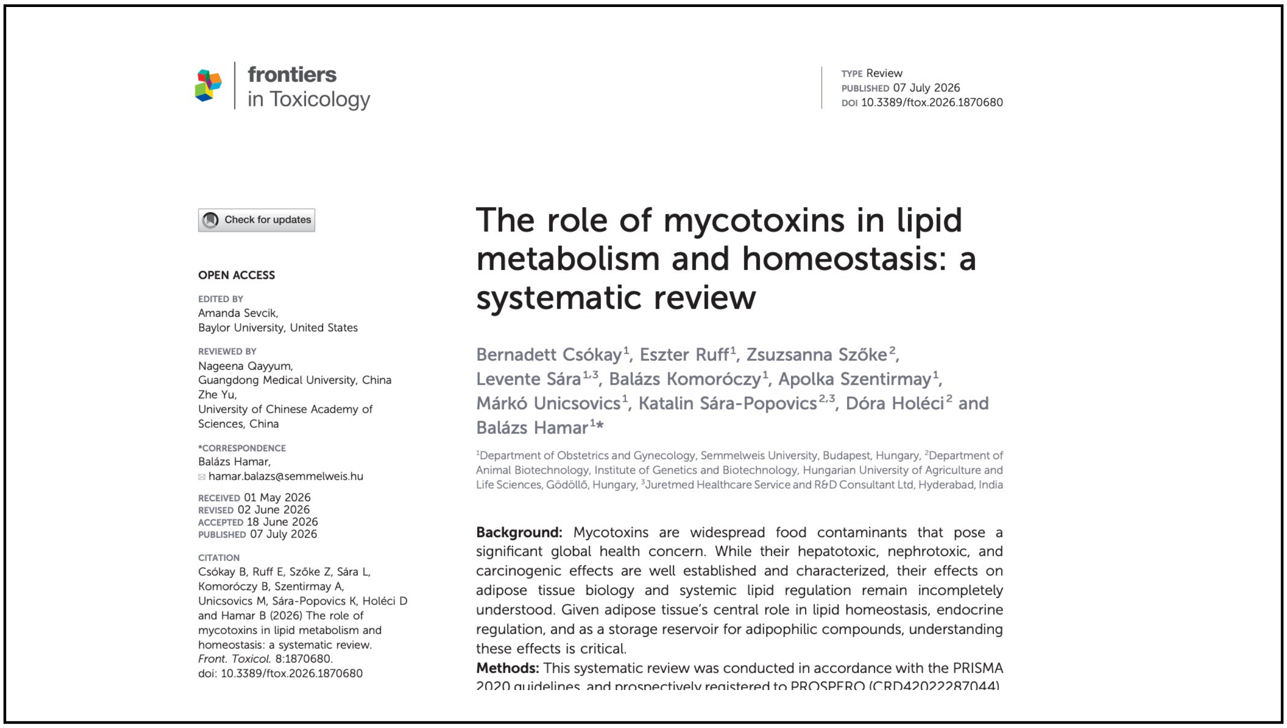
https://www.who.int/news-room/fact sheets/detail/mycotoxins

5

Key Mechanisms of Disruption

•**Cellular and DNA Damage:** Mycotoxins like aflatoxins cause oxidative stress and bind to DNA or cellular proteins. This leads to mutations, cell cycle arrest, and tissue necrosis.
•**Immune Suppression:** Prolonged exposure weakens the immune system by altering white blood cell structures and lowering resistance to bacterial and viral infections.
•**Organ Toxicity:** Ingested toxins target primary filtering organs. For example, ochratoxins damage the kidneys, while aflatoxins accumulate in and injure the liver.
•**Endocrine Disruption:** Certain compounds, such as zearalenone, mimic hormones and disrupt the endocrine balance, which can affect development and reproductive health.
•**Gastrointestinal Disruption:** Toxins damage the gut lining and alter gut microbiota, resulting in inflammation, malabsorption, nausea, and vomiting

6



frontiers in Toxicology

TYPE Review
PUBLISHED 07 July 2026
DOI 10.3389/ftox.2026.1870680

Check for updates

OPEN ACCESS

EDITED BY
Amanda Sevcik,
Baylor University, United States

REVIEWED BY
Nageena Qayyum,
Guangdong Medical University, China
Zhe Yu,
University of Chinese Academy of Sciences, China

*CORRESPONDENCE
Balázs Hamar,
hamar.balazs@semmelweis.hu

RECEIVED 01 May 2026
REVISED 02 June 2026
ACCEPTED 18 June 2026
PUBLISHED 07 July 2026

CITATION
Csókay B, Ruff E, Szőke Z, Sára L, Komoróczy B, Szentirmay A, Unicsovics M, Sára-Popovics K, Holéci D and Hamar B (2026) The role of mycotoxins in lipid metabolism and homeostasis: a systematic review. *Front. Toxicol.* 8:1870680.
doi: 10.3389/ftox.2026.1870680

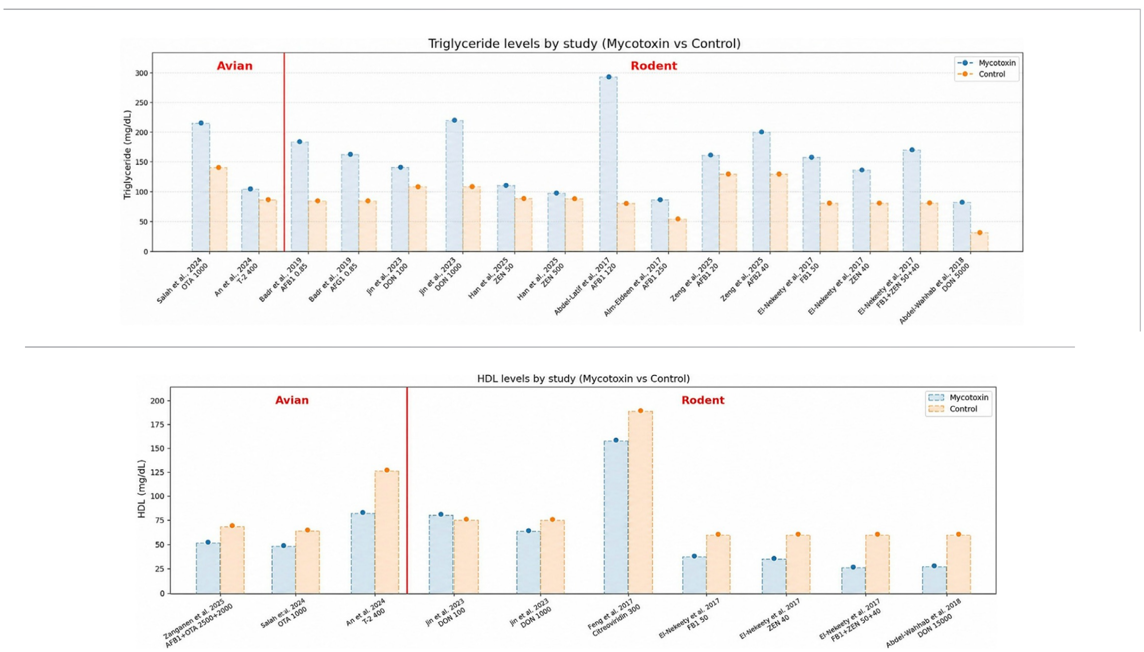
The role of mycotoxins in lipid metabolism and homeostasis: a systematic review

Bernadett Csókay[1], Eszter Ruff[1], Zsuzsanna Szőke[2], Levente Sára[1,3], Balázs Komoróczy[1], Apolka Szentirmay[1], Márkó Unicsovics[1], Katalin Sára-Popovics[2,3], Dóra Holéci[2] and Balázs Hamar[1]*

[1]Department of Obstetrics and Gynecology, Semmelweis University, Budapest, Hungary, [2]Department of Animal Biotechnology, Institute of Genetics and Biotechnology, Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary, [3]Juretmed Healthcare Service and R&D Consultant Ltd, Hyderabad, India

Background: Mycotoxins are widespread food contaminants that pose a significant global health concern. While their hepatotoxic, nephrotoxic, and carcinogenic effects are well established and characterized, their effects on adipose tissue biology and systemic lipid regulation remain incompletely understood. Given adipose tissue's central role in lipid homeostasis, endocrine regulation, and as a storage reservoir for adipophilic compounds, understanding these effects is critical.
Methods: This systematic review was conducted in accordance with the PRISMA 2020 guidelines, and prospectively registered to PROSPERO (CRD42022287044)

7



8

toxins MDPI

Toxins (Basel). 2023 Aug 23;15(9):515. doi: 10.3390/toxins15090515

Endocrine Effect of Some Mycotoxins on Humans: A Clinical Review of the Ways to Mitigate the Action of Mycotoxins

Klaudia Kościelecka [1], Aleksandra Kuć [1], Daria Kubik-Machura [1], Tomasz Męcik-Kronenberg [1,*], Jan Włodarek [2], Lidia Radko [2,*]

Author information Article notes Copyright and License information

PMCID: PMC10535190 PMID: 37755941

Abstract

Fungi such as *Aspergillus* spp. and *Fusarium* spp., which are commonly found in the environment, pose a serious global health problem. This study aims to present the results of epidemiological studies, including clinical cases, on the relationship between human exposure to some mycotoxins, especially zearalenone and aflatoxin, and the occurrence of reproductive disorders. In addition, examples of methods to reduce human exposure to mycotoxins are presented. In March 2023, various databases (PubMed, Google Scholar,

9

frontiers in Cellular and Infection Microbiology

REVIEW
published: 26 February 2018
doi: 10.3389/fcimb.2018.00060

Check for updates

Mycotoxin: Its Impact on Gut Health and Microbiota

*Winnie-Pui-Pui Liew and Sabran Mohd-Redzwan**

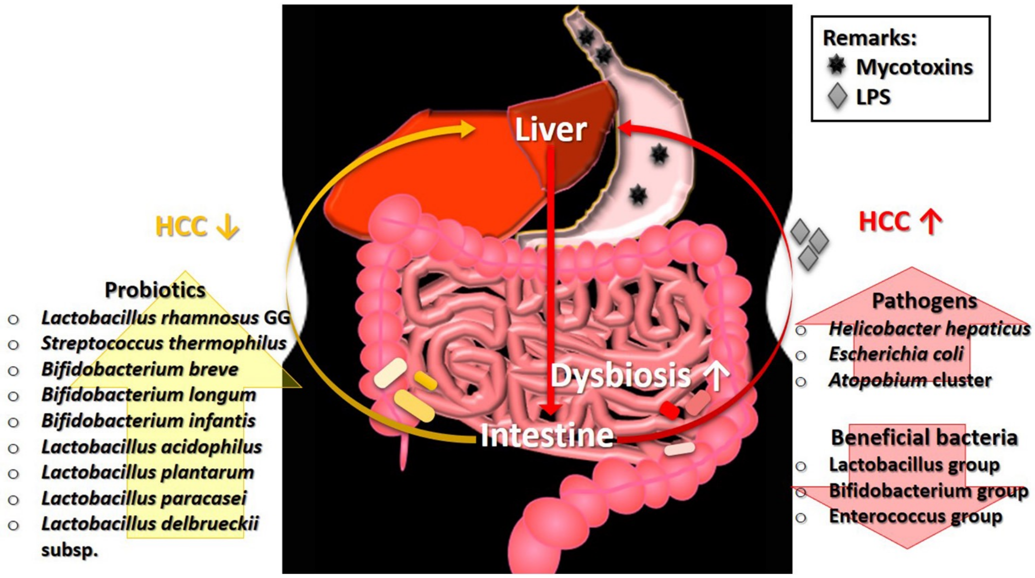
Department of Nutrition and Dietetics, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, Malaysia

OPEN ACCESS

Edited by:
Venkatakrishna Rao Jala, University of Louisville, United States

The secondary metabolites produced by fungi known as mycotoxins, are capable of causing mycotoxicosis (diseases and death) in human and animals. Contamination of feedstuffs as well as food commodities by fungi occurs frequently in a natural manner and is accompanied by the presence of mycotoxins. The occurrence of mycotoxins' contamination is further stimulated by the on-going global warming as reflected in some findings. This review comprehensively discussed the role of mycotoxins (trichothecenes, zearalenone, fumonisins, ochratoxins, and aflatoxins) toward gut health and gut microbiota. Certainly, mycotoxins cause perturbation in the gut, particularly in the intestinal epithelial. Recent insights have generated an entirely new perspective where there is a bi-directional relationship exists between mycotoxins and gut microbiota, thus suggesting that our gut microbiota might be involved in the development of mycotoxicosis. The bacteria–xenobiotic interplay for the host is highlighted in this review article. It is now well established that a healthy gut microbiota is largely responsible for the overall health of the host. Findings revealed that the gut microbiota is capable of eliminating mycotoxin from the host naturally, provided that the host is healthy with a balance gut microbiota. Moreover, mycotoxins have been demonstrated for modulation of gut microbiota composition, and such alteration in gut microbiota can be observed up to species level in some of the studies. Most, if not all, of the reported effects

10



11

foods MDPI

Foods. 2024 Oct 31;13(21):3502. doi: 10.3390/foods13213502

Mycotoxins in Food: Cancer Risks and Strategies for Control

Alice N Mafe [1], Dietrich Büsselberg [2,*]

Editor: Robert L Buchanan

Author information Article notes Copyright and License information

PMCID: PMC11545588 PMID: 39517285

Abstract

Mycotoxins are toxic compounds produced by fungi such as *Aspergillus*, *Penicillium*, and *Fusarium*, contaminating various food crops and posing severe risks to food safety and human health. This review discusses mycotoxins‘ origins, significance, and impact, particularly in relation to cancer risk. Major mycotoxins like aflatoxins, ochratoxins, fumonisins, zearalenone, and patulin are examined, along with their sources and affected foods. The carcinogenic mechanisms of these toxins, including their biochemical and

12

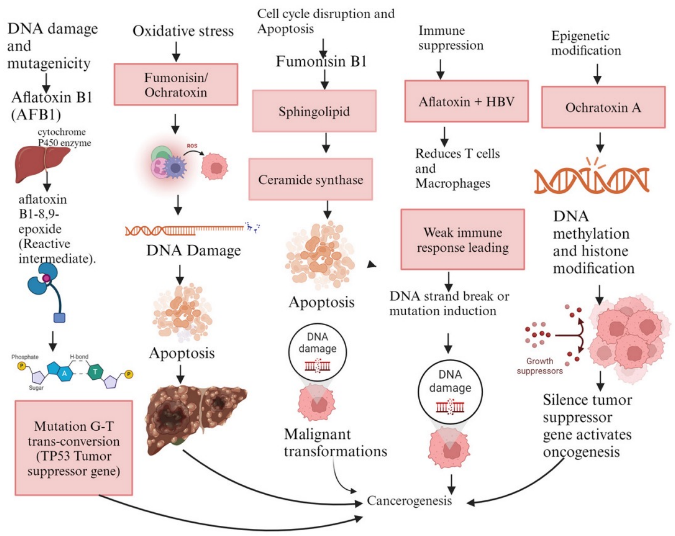
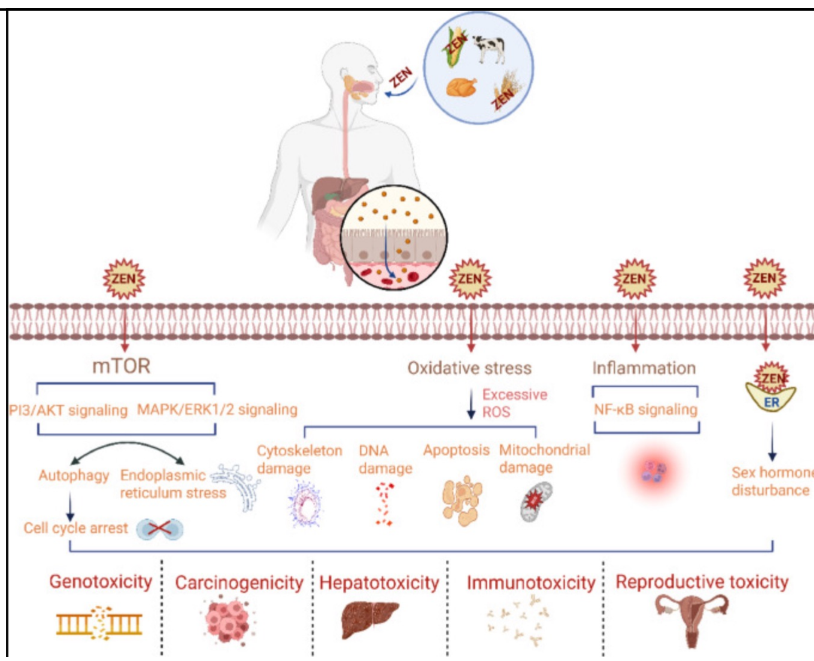


Figure 2. Mechanisms of carcinogenicity for aflatoxin B1, fumonisins, and ochratoxin A. Legend: AFB1: aflatoxin B1, HBV: hepatitis B virus, ROS: reactive oxygen species, TP53: tumor suppressor gene. The figure was generated using BioRender.

Table 4. Mechanisms of carcinogenicity caused by mycotoxins.

13



14

Effects of mycotoxins in foods on human health and strategies for prevention and control: A review

Nan Long [a], Huan Peng [a], Yida Wang [a], Changhong Zhou [b], Zhao Wang [a] Show more

View PDF Cite Add to Mendeley Share 10.1016/j.jfutfo.2025.05.014

Article Recommended articles Metrics

Highlights

- Systematically synthesizes classic and recent studies on the health impacts of various mycotoxins.
- Highlights diverse/synergistic effects, severe health risks, and underlying mechanisms.
- Discusses prevention and control strategies, emphasizing the promise of biological approaches.
- Proposes integrated management frameworks to mitigate mycotoxin-related health risks.

Outline

15

Table 3. Toxic levels of various mycotoxins in food.

Mycotoxin	Toxic Level in Food	Food Sources
Aflatoxins	Maximum allowable limit: 4 µg/kg (EU regulation). Toxic level associated with health risks: 0.5 µg/kg [46].	Nuts, grains, corn, and spices. Peanuts, tree nuts, and maize.
Zearalenone	Maximum allowable limit: 100 µg/kg (EU regulation). Toxic level associated with health risks: 50 µg/kg [47].	Cereals, grains, maize, and animal feed. Maize products, wheat, barley.
Patulin	Maximum allowable limit: 50 µg/kg (EU regulation). Toxic level associated with health risks: 25 µg/kg.	Apples, apple juice, and apple-based products. Processed fruit products.
Fumonisins	Maximum allowable limit: 4000 µg/kg (EU regulation) [48]. Toxic level associated with health risks: 2000 µg/kg.	Corn and corn-based products. Maize and maize flour.
Ochratoxin A	Maximum allowable limit: 3 µg/kg (EU regulation). Toxic level associated with health risks: 1 µg/kg [49].	Coffee, cereals, and dried fruit. Wine, grains, and legumes.
Deoxynivalenol (DON)	Maximum allowable limit: 1750 µg/kg (EU regulation). Toxic level associated with health risks: 1000 µg/kg [50].	Wheat, barley, and oats. Cereal products and animal feed.
T-2 Toxin	Maximum allowable limit: 1000 µg/kg (EU regulation). Toxic level associated with health risks: 500 µg/kg [51].	Cereal grains and animal feed. Wheat, barley, and oats.

16