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Mycotoxin - Producing Fungi in Staple Crops: Risk Assessment and Management

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Mycotoxins are toxic secondary metabolites produced by certain filamentous fungi that commonly infect staple crops such as maize, wheat, rice, barley, sorghum and groundnuts. These toxins pose serious risks to human and animal health, reduce agricultural productivity and create significant economic losses globally. Mycotoxin contamination can occur pre-harvest, during harvest or throughout storage and processing. The term **"mycotoxin"** was first used in the **1960s** to describe the toxin associated with contaminated peanuts in animal feed and the loss of turkeys in **England (Turkey-X-disease**). This mycotoxin was later identified as the *Aspergillus flavus* toxin **aflatoxin B1**. Major mycotoxin-producing fungi belong primarily to the genera *Aspergillus*, *Fusarium*, and *Penicillium*. Climate change, poor agricultural practices, inadequate storage and global trade have increased the frequency and severity of contamination events. Environmental conditions such as high temperature and humidity increase the risk of fungal growth and mycotoxin production. Other factors that affect contamination include pH, fungal strain and substrate. These metabolites primarily affect the seed quality, germination, viability, seedling vigour, growth of root and coleoptile.

This article discusses the major mycotoxins in staple crops, their health impacts, methods of risk assessment and management strategies.

Major Mycotoxin-Producing Fungi and Associated Toxins

1. Aflatoxins

- **Produced by:** *Aspergillus flavus*, *Aspergillus parasiticus*,*Aspergillus nomius*
- **Common in:** Maize, groundnuts (peanuts), rice, sorghum, nuts, spices, oilseeds and cottonseed
- **Major toxin:** Aflatoxin B1 (AFB1)

Several types of aflatoxins exist, but food contamination usually involves aflatoxins B1, B2, G1 and G2 for crops and M1 for milk. Aflatoxin B1 is classified as a Group 1 carcinogen by the International Agency for Research on Cancer.

Health effects:

- Hepatocellular carcinoma
- Immune suppression
- Growth impairment in children
- Acute aflatoxicosis at high doses
- Inhibits proteins synthesis

2. Ochratoxin A (OTA)

- **Produced by:** *Aspergillus ochraceus*, *Penicillium verrucosum*, *Penicillium viridicatum*
- **Common in:** Wheat, barley, coffee, dried fruits, rye, oat, coffee, grapes and wine

Ochratoxin A is nephrotoxic and possibly carcinogenic. It has been linked to chronic kidney disease in some regions.

Health effects:

- Kidney damage
- Potential carcinogenicity
- Immunotoxic effects

3. Fumonisins

- **Produced by:** *Fusarium verticillioides*, *Fusarium proliferatum*
- **Common in:** Grains mainly maize and maize products

Fumonisin B1 is associated with esophageal cancer and neural tube defects.

Health effects:

- Esophageal cancer
- Neural tube defects
- Liver and kidney toxicity
- Leukoencephalomalacia(LEM)/ hole in the head syndrome in horses
- Cause a variety of illnesses in animals, especially damage to their brains, heart, liver and kidneys.

4. Deoxynivalenol (DON, Vomitoxin)

- **Produced by:** *Fusarium graminearum*
- **Common in:** Wheat, barley, maize, oat and other grains

DON is a trichothecenemycotoxin that inhibits protein synthesis.

Health effects:

- Nausea and vomiting
- Immunomodulation
- Reduced feed intake in livestock

5. Zearalenone (ZEN)

- **Produced by:** *Fusarium graminearum*, *Fusarium culmorum*
- **Common in:** Maize, wheat, barley,sorghum,rice

Zearalenone is estrogenic and affects reproductive health.

Health effects:

- Infertility,abortion
- Hyperestrogersim
- Hormonal imbalance
- Reproductive disorders in livestock

6. Patulin

- **Produced by:** *Penicillium sp.*, *Aspergillus sp.* and *Byssochylamys* molds
- **Common in:** Apple

Health effects:

- Nausea
- Vomiting

7. **Ergot alkaloid**

- **Produced by:** *Claviceps purpurea*, *Claviceps paspali*
- **Common in:** Pearl millet, Rye, cereal grain

Health effects:

- Convulsions
- Vasoconstriction
- Necrosis of extremities

Risk Assessment of Mycotoxins

Risk assessment involves four major steps:

1. Hazard Identification

Identification of toxic fungal metabolites present in food or feed.

2. Hazard Characterization (Dose–Response Assessment)

Determination of toxicological effects and establishment of:

- Tolerable Daily Intake (TDI)
- No Observed Adverse Effect Level (NOAEL)

- Benchmark Dose (BMD)

International regulatory bodies such as the World Health Organization and the Food and Agriculture Organization establish guideline levels through expert committees like JECFA.

3. Exposure Assessment

Estimation of dietary intake based on:

- Contamination levels in staple crops
- Food consumption patterns
- Processing effects

4. Risk Characterization

Integration of toxicity data and exposure levels to determine public health risk.

Factors Influencing Mycotoxin Contamination

Pre-Harvest Factors

- Drought stress
- Insect damage
- High temperature
- Crop genotype susceptibility
- Poor irrigation management

Post-Harvest Factors

- High grain moisture (>13–15%)
- Warm storage temperatures
- Poor aeration
- Insect infestation
- Delayed drying and harvesting

Optimum temperature for mycotoxin production

Mycotoxin	Temperature(°c)	Water activity
Aflatoxin	33	0.99
Ochratoxin	25-30	0.98
Fumonisin	15-30	0.9-0.995
Zearalenone	25	0.96
Deoxynivalenole	26-30	0.995

Mannaa (2017)

Detection and Monitoring

Reliable detection is essential for risk management.

Analytical Methods

- High-Performance Liquid Chromatography (HPLC)
- Liquid Chromatography–Mass Spectrometry (LC-MS/MS)
- Enzyme-Linked Immunosorbent Assay (ELISA)
- Rapid test kits (lateral flow devices)

Management Strategies

Effective mycotoxin control requires integrated approaches across the food chain.

1. Pre-Harvest Management (Field)

- Use of resistant crop varieties- Resistant varieties can reduce fungal infection and subsequent mycotoxin production.
- Crop rotation- Alternates crops in a field across seasons, reducing fungal populations that target specific crops and lowering mycotoxin contamination risk.
- Good Agricultural Practices (GAP)- Ensure proper fertilization and tillage to reduce plant stress and improve soil health. Apply consistent irrigation to minimize drought stress, a major contributor to *Aspergillus flavus* and subsequent aflatoxin contamination. Time harvests to avoid high moisture or rain, which can lead to mould growth.
- Biological control- Biocontrol products containing atoxigenic strains have shown success in reducing aflatoxin levels in maize and groundnuts .A marine strain of ***Bacillus***

megaterium was shown to have biocontrol activity against *A. flavus* on peanut kernels. It inhibits the aflatoxin biosynthesis regulatory genes expression. ***Trichoderma*** **spp**., ***P. fluorescens***, ***B. subtilis*** and ***Rhodococcus erythropolis***, showed considerable biocontrol activities against *A. flavus* and limited the production of aflatoxins.

- Timely planting and harvesting- Time harvests to avoid high moisture or rain, which can lead to mould growth.
- Chemicals - Carbendazim, Napam, Vapam, PMC, EMC and Captan, Propionic acid (PA), Isobutynite and ammonium butyrate, Sorbic acid can be used against fungal spoilage in storage grains.
- Grain treatment- Seeds can also be treated with fungicides such as Mancozeb (Dithane M-45) and Benomyl (Benlate) at the rate of 3g/kg.

2. Post-Harvest Management (Storage and Processing)

- Rapid drying to safe moisture levels- Moisture level for cereal grains, legumes and oil seeds should be about 12, 10 and 8%.
- Hermetic storage systems- storage of food grains in an airtight storage structure, which may be flexible or rigid, an over-ground or under-ground structure.

(i) Organic hermetic storage (ii) Vacuum hermetic storage and (iii) Modified atmospheric storage

- Fumigation- Fumigation with phosphine may be useful in retarding fungal spoilage during short term storage of high moisture grain (15-19% m.c. for wheat).
- Proper ventilation
- Regular inspection
- Insect control

3. Regulatory Control

Many countries establish maximum permissible limits for mycotoxins in food and feed. Regulatory and monitoring approaches are essential for managing mycotoxin contamination and ensuring food safety. Regulatory bodies, such as the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA), establish guidelines and standards for maximum allowable levels of mycotoxins in food and feed.

For example:

- European Union has strict aflatoxin limits
- Codex Alimentarius provides international standards for trade

Regulatory enforcement and food safety education are critical components of management.

FDA Mycotoxin Action Levels (Human Food)

- **Total Aflatoxins (B1, B2, G1, G2):** 20 ppb in food, peanuts, tree nuts and corn intended for human consumption.
- **Aflatoxin:** 0.5 ppb in milk.
- **Patulin:** 50 ppb in apple juice and apple products.
- **Deoxynivalenol (DON/Vomitoxin):** 1 ppm in finished wheat products; 10 ppm for grains/non-wheat ingredients (with usage restrictions).
- **Fumonisins:** Vary by product; 2–4 ppm in human corn products.

FDA Mycotoxin Guidance Levels (Animal Feed)

- **Aflatoxins:**

➢ 20 ppb: Corn/peanut products for immature animals and dairy cattle.
➢ 100 ppb: Breeding beef cattle, swine, and mature poultry.
➢ 200 ppb: Finishing swine (lbs).
➢ 300 ppb: Finishing beef cattle.

- **Fumonisins (Total):**

➢ 5 ppm: Corn/byproducts for equids/rabbits (max 20% of diet).
➢ 20 ppm: Swine/catfish (max 50% of diet).
➢ 30 ppm: Breeding ruminants/poultry (max 50% of diet).

DON/Vomitoxin

➢ 5 ppm: Grains/byproducts for swine (max 20% of diet).

- 10 ppm: Grains/byproducts for ruminating beef/feedlot cattle (max 50% of diet)

Future Perspectives

- Climate-resilient crop breeding
- Predictive modeling using AI and remote sensing
- Improved rapid detection technologies
- Integrated One Health approaches
- Stronger international cooperation

Conclusion

Mycotoxin contamination in food might not be inevitable and its presence could threaten the food security of many countries especially developing ones. However, the implementation of proper methods from the beginning of the food chain until the end including all stages of production like planting, harvest, drying, storage, processing, packaging, transport; helps to decrease the level of contamination and maintain it below the tolerable levels assigned by different countries. Strict recommendations that preserve the benefit of the consumer in the first place need to be enforced and rapid and reliable analysis methods to determine fungal and mycotoxin contamination must be applied to ensure food safety.