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Aflatoxin in Chilli: Small Toxin, Big Risk

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Introduction

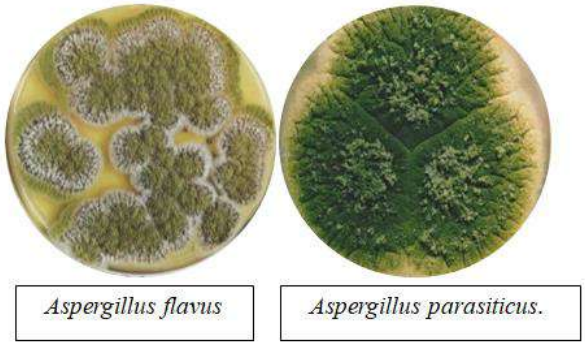
Chilli (*Capsicum annuum* L.) belongs to the Solanaceae family and has a diploid chromosome number of 2n = 24. It is among the most widely grown spice and vegetable crops in the world. The crop originated in Central America (Perry *et al.*, 2007) and is now a staple of cuisines across the globe, prized for its bright color, distinctive flavour and pungency. Besides its culinary value, chilli supports the livelihoods of many farmers and makes a substantial contribution to international trade.

India is one of the world's foremost chilli exporters. The country ships roughly 6.01 lakh tonnes of chilli annually, worth about US$1.5 billion and making up nearly 34% of its total spice exports. Its main buyers include China, the USA, Bangladesh and the UAE. In 2023-24, India's overall spice exports reached US$4.46 billion and chilli accounted for the largest share. About 70% of the chilli produced is consumed within the country, either in households or by the spice industry, while the remainder is exported as processed and quality-graded products. Despite this strong market position, the chilli trade is frequently disrupted by price fluctuations, stringent quality standards and food safety regulations, which makes it both a dynamic and an economically vital sector.

Like many crops, chilli is prone to fungal diseases such as wilt and anthracnose and these infections can carry over into the post-harvest stage and degrade quality. Among such problems, aflatoxin contamination is one of the most serious yet least visible threats to chilli production and marketing. Aflatoxins were first identified in the 1960s after the Turkey X disease outbreak in England, which was traced to toxins produced by *Aspergillus flavus*. By the 1970s, aflatoxin contamination had been reported in dried red chilli from India and Southeast Asia, showing that spices are vulnerable commodities (Manoj *et al.*, 2023). Within India, chilli-growing regions differ in their risk of contamination: Andhra Pradesh and Telangana are classified as high-risk, while Karnataka, Tamil Nadu, Maharashtra and Madhya Pradesh are considered moderate-risk because of their warm, humid climates and post-harvest handling challenges.

Aflatoxins are difuranocoumarin and related derivatives synthesized through the polyketide biosynthetic pathway by certain filamentous fungi. These toxins are highly dangerous because they are carcinogenic, heat-stable and

difficult to remove once formed. Even small quantities can make chilli unsafe for consumption and lead to rejection in international markets. Aflatoxin contamination in chilli is primarily caused by fungi belonging to the genus *Aspergillus*, especially *Aspergillus flavus* and *Aspergillus parasiticus*. Taxonomically, these are classified under Kingdom Fungi, Phylum Ascomycota, Class Eurotiomycetes, Order Eurotiales and Family Trichocomaceae. Which are widely distributed in tropical and subtropical regions and pose serious risks to food safety and public health.



Aspergillus flavus | *Aspergillus parasiticus.*

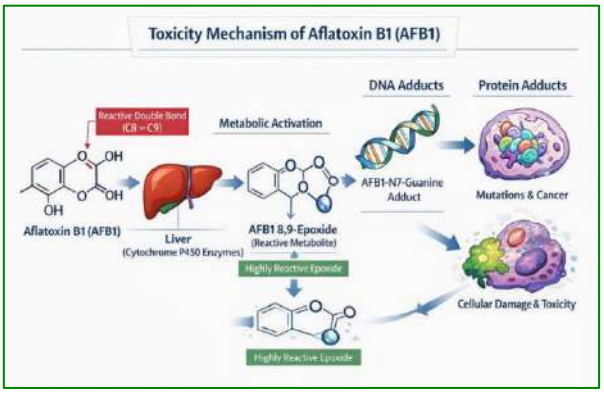
Types of Aflatoxin

More than 18 aflatoxins have been identified so far, out of which AFB_1, AFB_2, AFG_1, AFG_2, AFM_1 and AFM_2 are of greatest importance from a public health perspective. B_1, B_2, G_1 and G_2 are naturally produced by toxigenic *Aspergillus* species, whereas M_1 is a metabolite formed in the liver of mammals after consumption of B_1 and is subsequently secreted into milk and dairy products. When exposed to ultraviolet light, aflatoxins exhibit characteristic blue or green fluorescence, which explains the designation of the B and G series, while the M series refers to aflatoxins associated with milk and dairy products (Ayob *et al.*, 2022). The maximum allowable limit of aflatoxin in chilli set by the European Union (EU) is 10 µg/kg (European Commission, 2006), whereas the limit set by the Food Safety and Standards Authority of India is 30 µg/kg (FSSAI, 2011).



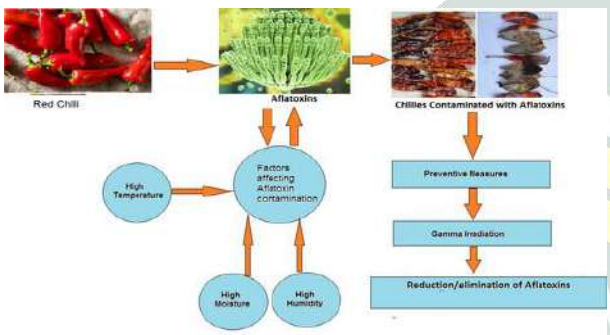
Why is Aflatoxin B_1 (AFB_1) more toxic?

AFB_1 is the most toxic and carcinogenic because of its unique chemical structure, particularly the double bond at the C8–C9 position in the furan ring. In the liver, cytochrome P450 enzymes convert AFB_1 into a highly reactive compound called AFB_1-8,9-epoxide. This metabolite binds strongly to DNA, forming AFB_1–N7-guanine adducts that cause mutations and initiate cancer. It can also bind to proteins, leading to liver damage and impaired cellular function. Due to its strong mutagenic and carcinogenic effects, AFB_1 (Ayob *et al.*, 2022) is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer.



Why chilli is prone to Aflatoxin contamination?

Chilli is highly prone to aflatoxin contamination due to both pre and post-harvest factors like warm temperatures (25–35 °C), high humidity, rainfall or drought stress, Insect damage and poor post-harvest practices such as improper and slow drying, High moisture content (>10–12%) during storage mechanical and insect damage and long storage. Its nutrient-rich composition (oils, sugars and proteins) further supports fungal growth by *Aspergillus flavus* and *Aspergillus parasiticus* (Ain *et al.*, 2025).



Why fresh chilli is less affected than red dried and powdered chilli?

Fresh green chilli is less prone to aflatoxin contamination mainly because of its short shelf life and intact condition. The pods are typically sold or consumed soon after harvest, so toxigenic *Aspergillus* species have little time to colonise them and produce toxin. The intact skin acts as a physical barrier and bioactive compounds such as capsaicinoids may offer some antifungal protection. In contrast, red dried chilli is stored for weeks to months and slow or uneven drying, rain exposure or moisture uptake during storage creates conditions that favour *A. flavus* growth and aflatoxin production. Chilli powder is the most vulnerable form. Grinding mixes the contamination from a few infected pods through the whole batch and the fine particles have a large surface area that readily absorbs moisture, making the powder both widely and persistently exposed to risk**.**

The problems associated with aflatoxin contamination in chilli:

Aflatoxin contamination has significant health, economic and trade impacts. Many importing countries have strict limits on aflatoxin levels and if chilli consignments exceed these limits, they may be rejected in international markets as well in domestic markets leading to heavy losses. This is because of the reduction inthe quality of chilli, includes discoloration, off-flavor and shorter shelf-life.

Detection methods

Aflatoxin in chilli can be detected using several analytical methods, depending on the required sensitivity, cost and purpose (Liu *et al.*, 2022). Visual inspection detects moldy or damaged pods at preliminary stage. Rapid screening methods such as ELISA kits, lateral flow assays and fluorometric tests are used at field-level detection. Confirmatory and quantitative analysis is done using HPLC with fluorescence detection or LC-MS/MS, which provide high sensitivity and accuracy. Thin Layer Chromatography (TLC) is used for basic qualitative analysis, while newer methods like biosensors and PCR-based detection of toxigenic *Aspergillus* strains support early and precise monitoring.

Mitigation Strategies

Integrated approaches spanning the pre-harvest, harvest and post-harvest stages help mitigate

aflatoxin contamination in chilli (Ayob *et al*., 2022). Growing resistant varieties, particularly those high in pungency or capsaicinoids, can suppress *Aspergillus* growth because of their antimicrobial properties and sound agronomic practices further limit fungal development. Biological control with beneficial microbes such as *Bacillus subtilis*, *Lactobacillus* spp., or atoxigenic strains of *A. flavus* suppresses toxigenic fungi through competition and antifungal metabolites, while integrated pest management (IPM) reduces insect damage that gives fungi a point of entry.

At harvest, pods should be picked at proper maturity, and wet conditions and mechanical injury should be avoided. Post-harvest management is especially critical. It involves rapid, uniform drying to a safe moisture level of 10-12%, careful sorting to remove damaged or mouldy pods and storage in cool, dry, well-ventilated conditions (relative humidity below 70% and temperature below 25°C) with moisture-proof packaging. Natural preservatives such as chitosan and essential oils can further inhibit fungal growth in storage. Chemical and physical treatments, including sodium metabisulfite, ozonation, irradiation and controlled heat processing, can lower aflatoxin levels, although complete elimination is difficult. Regular monitoring by ELISA, HPLC or rapid detection kits, together with the application of HACCP principles, ensures continuous risk control across the supply chain. Finally, training farmers and workers in proper drying, storage, early sorting and the safe use of biocontrol agents is essential for reducing aflatoxin contamination sustainably and for securing food safety and market acceptance of chilli.

Conclusion

Aflatoxin contamination is a serious food safety concern in chilli. These toxins are highly poisonous and carcinogenic and they threaten both consumer health and international trade. The good news is that the problem can be kept in check with an integrated farm-to-fork approach that combines good agricultural practices, proper drying and storage, biological control and routine monitoring. Adopting Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Point (HACCP) systems and complying strictly with FSSAI, Codex Alimentarius and other international standards, makes this goal both practical and achievable. Ultimately, preventive measures coordinated across the whole value chain protect consumers, improve chilli quality and build lasting market acceptance and export potential.

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