Aflatoxin M1 in Milk: A Food Safety Concern in India

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Abstract

Aflatoxin M1 (AFM1) contamination of milk represents a persistent and often underestimated food safety challenge, particularly in countries with high milk consumption such as India. AFM1 is a hydroxylated metabolite of aflatoxin B1 (AFB1) that is excreted into milk following the ingestion of contaminated feed by lactating animals, thereby directly linking feed quality to dairy safety. Owing to its pronounced thermal stability, AFM1 is not effectively eliminated by conventional milk processing techniques, including pasteurization and ultra-high-temperature treatment, resulting in its presence in raw, processed, and value-added dairy products. This review critically examines the pathways of AFM1 transfer from feed to milk, its biological behavior, and the health risks associated with chronic low-dose exposure, with particular emphasis on vulnerable populations such as infants and young children. Global surveillance data reveal widespread occurrence of AFM1 in milk, with notable regional variability driven by climatic conditions, feed management practices, and regulatory frameworks. The paper highlights substantial divergence in international regulatory limits and discusses the implications for public health protection and trade. Evidence consistently identifies feed as the most effective control point for mitigating AFM1 contamination, while post-contamination interventions in milk remain limited in efficacy. The review underscores the need for an integrated farm-to-fork strategy encompassing improved feed management, robust surveillance, and harmonized, science-based regulations to reduce population-level exposure and safeguard public health.

Keywords: Aflatoxin M1; Milk safety; Dairy feed contamination; Mycotoxins; Food safety regulation; Public health

1.Introduction

Milk is widely recognized as a nutritionally complete food and represents a cornerstone of human diets from infancy through old age, with particular significance for infants, children, and elderly populations due to its provision of high-quality proteins, fats, vitamins, and essential minerals. Despite these benefits, milk can also function as an inadvertent vehicle for contaminants that are undetectable to consumers yet pose serious public health concerns. Among these, aflatoxin M1 (AFM1) has emerged as a persistent and globally significant hazard. Unlike many contaminants introduced during processing, AFM1 originates from on-farm conditions, arising as a hydroxylated metabolite of aflatoxin B1 (AFB1) when lactating animals consume feed contaminated with this potent mycotoxin produced by *Aspergillus* species. Following ingestion, AFB1 undergoes hepatic biotransformation and is subsequently excreted into milk as AFM1, thereby directly linking feed quality to milk safety. Compounding this risk, AFM1 exhibits marked thermal stability and is not reliably eliminated by conventional milk processing technologies, including pasteurization and ultra-high-temperature (UHT) treatment, allowing it to persist in raw, pasteurized, and UHT milk as well as in a wide range of dairy products. Over the past decade, surveillance and analytical studies conducted across multiple continents have consistently reported the occurrence of AFM1 in milk, in some instances at concentrations exceeding established regulatory limits. Taken together, these findings position AFM1 as a complex global food safety challenge that transcends the dairy value chain and reflects the interconnected influences of agricultural practices, animal nutrition, climatic variability, regulatory frameworks, and human health.

2. Pathways of Aflatoxin M1 transfer to milk

The presence of aflatoxin M1 (AFM1) in milk originates well before dairy products reach consumers and is intrinsically linked to contamination of animal feed with aflatoxin B1 (AFB1). AFB1 is predominantly produced in feed commodities such as maize, cottonseed, groundnuts, and other cereal grains when crops are cultivated, harvested, or stored under warm and humid conditions that favour the proliferation of toxigenic *Aspergillus* species. While tropical and subtropical regions are especially vulnerable to such contamination, AFB1 occurrence is not confined to these areas and has been reported across a wide range of agroclimatic conditions. Upon consumption of contaminated feed by lactating animals, AFB1 is rapidly absorbed from the gastrointestinal tract and metabolized in the liver, resulting in the excretion of AFM1 into milk. Available evidence indicates that approximately 0.3–6% of ingested AFB1 is transferred into milk as AFM1, with substantial variability influenced by animal species, milk yield, stage of lactation, and overall dietary composition. AFM1 typically becomes detectable in milk within 12–24 h of exposure and may persist for several days even after contaminated feed is withdrawn, reflecting both its metabolic kinetics and binding behavior. Crucially, AFM1 exhibits a strong affinity for the milk matrix and high thermal stability, which explains why conventional processing methods, including pasteurization and ultra-high-temperature (UHT) treatment, do not effectively reduce its concentration. Consequently, comparable AFM1 levels are frequently observed in raw, pasteurized, and UHT milk, a finding that has been consistently corroborated by surveillance and monitoring studies worldwide.

3. Biological and health effects of prolonged low-dose

Aflatoxin M1 (AFM1) is classified by the International Agency for Research on Cancer (IARC) as a Group 1 carcinogen, reflecting sufficient evidence of its carcinogenicity in humans and underscoring its relevance as a serious food safety hazard. Although AFM1 is less potent than its parent compound aflatoxin B1 (AFB1), chronic dietary exposure, even at low concentrations, is associated with meaningful long-term health risks. The liver is the primary target organ, and sustained intake of AFM1 has been linked to an increased risk of hepatocellular carcinoma, particularly in populations already burdened by co-existing risk factors such as chronic hepatitis infections or nutritional deficiencies. Infants and young children are of particular concern because milk and milk-based products constitute a major proportion of their daily diet, resulting in disproportionately higher exposure on a body-weight basis during critical stages of growth and development. Beyond its carcinogenic potential, accumulating evidence indicates that AFM1 exposure may also contribute to immunosuppression, impaired growth, and reduced nutrient absorption, effects that can further exacerbate vulnerability in sensitive populations. Collectively, these health implications highlight the imperative for rigorous surveillance, risk mitigation, and control measures across the entire dairy value chain to minimize human exposure to AFM1.

4. Worldwide prevalence and distribution

Global surveillance data clearly indicate that aflatoxin M1 (AFM1) contamination of milk is a widespread phenomenon, although its prevalence and severity vary substantially across regions as a function of climatic conditions, feed management practices, and regulatory oversight. In Asia and the Middle East, studies from South and West Asian countries, including India, Iran, Pakistan, and Lebanon, consistently report high detection rates, with AFM1 identified in more than half of analyzed milk samples and a considerable proportion exceeding the European Union regulatory limit of 0.05 μg kg⁻¹. A comprehensive survey in Lebanon further demonstrated the presence of AFM1 in raw, pasteurized, and ultra-high-temperature (UHT) milk, with dietary exposure assessments indicating a measurable contribution to population-level liver cancer risk. In contrast, several African countries report some of the highest AFM1 concentrations worldwide, with studies from Ethiopia, Kenya, Sudan, and Tanzania documenting maximum levels in raw milk that exceed the United States regulatory limit of 0.5 μg kg⁻¹ by several fold; these elevated concentrations are frequently linked to limited feed monitoring, the predominance of informal dairy sectors, and environmental conditions that favor fungal growth. European countries generally exhibit lower AFM1 contamination levels, reflecting the effectiveness of stringent feed regulations and well-established surveillance systems; however, the toxin is not entirely absent, as seasonal fluctuations in feed quality—particularly during drought years—can still result in detectable AFM1 in milk, underscoring the need for continued vigilance. In Southeast Asia, multi-year monitoring in Malaysia has revealed relatively low AFM1 occurrence in fresh cow milk, with concentrations typically remaining below national limits but occasionally exceeding the more stringent EU threshold, highlighting how even moderate contamination rates can persist under climatic conditions conducive to mycotoxin production. Collectively, these regional patterns emphasize the global nature of AFM1 contamination and the need for context-specific yet coordinated strategies to mitigate exposure across diverse dairy production systems.

5. Divergence in Aflatoxin M1 standards: regulatory frameworks and rationale

A defining feature of aflatoxin M1 regulation is the pronounced disparity in maximum permissible limits across national jurisdictions, reflecting differing risk assessment approaches and policy priorities. The European Union enforces a highly protective limit of 0.05 μg kg⁻¹ for milk, whereas the United States permits concentrations up to 0.5 μg kg⁻¹, representing a tenfold difference in allowable exposure. Many low- and middle-income countries either adopt one of these benchmarks as a reference standard or lack fully implemented and enforceable regulatory limits for AFM1. This heterogeneity in regulatory frameworks complicates international dairy trade and contributes to inconsistencies in food safety assurance, while simultaneously prompting important questions regarding acceptable levels of risk, particularly for vulnerable population groups such as infants and young children who experience higher exposure relative to body weight.

Table 01: Regulatory limits for aflatoxin M1 in milk worldwide

Region / Authority	Maximum permissible limit for AFM1
European Union	0.05 μg/kg
United States (FDA)	0.5 μg/kg
Malaysia	0.5 μg/kg
Lebanon (adopted EU)	0.05 μg/kg
Codex Alimentarius	0.5 μg/kg (guideline)

6. Feed as a critical control point: insights from surveillance

Because aflatoxin M1 (AFM1) originates from the metabolic conversion of aflatoxin B1 (AFB1) present in animal feed, prevention strategies are most effective when implemented upstream at the level of feed production, storage, and management. A detailed surveillance study from Spain illustrates this principle, showing that although most feed samples complied with European Union limits for AFB1, contamination levels varied significantly with season and feeding system. In particular, total mixed rations and silage-based feeding regimes were associated with higher aflatoxin burdens than compound feeds, with elevated concentrations observed mainly during spring and winter, when feed quality and storage conditions are more variable. These findings reinforce the central importance of controlling AFB1 in animal feed as the most reliable means of reducing AFM1 contamination in milk. Once AFM1 is present in the milk matrix, opportunities for effective removal are extremely limited, underscoring the critical need for proactive, feed-focused interventions across the dairy production chain.

7. Post-contamination control of Aflatoxin M_1 in milk

Over the past decade, numerous physical, chemical, and biological approaches have been investigated to reduce aflatoxin M1 (AFM1) concentrations in milk, including adsorption using binding agents, fermentation-based treatments, and enzymatic degradation. Although some of these interventions have achieved partial reductions, their effectiveness has generally been inconsistent, and most have been unable to reliably lower AFM1 levels below the stringent European Union regulatory limit without adversely affecting milk quality or functional properties. As a result, post-harvest detoxification strategies are widely regarded as supplementary rather than definitive solutions, a conclusion reinforced by comprehensive reviews emphasizing that such measures cannot replace preventive interventions based on proper feed storage, good agricultural and manufacturing practices, and effective regulatory monitoring. The continued presence of AFM1 in milk highlights the interconnected and systemic nature of food safety challenges across the dairy value chain, which are likely to be further intensified by climate change through increased temperatures and humidity that favor aflatoxin contamination of feed crops. At the same time, rising demand for milk and dairy products in low- and middle-income countries has the potential to increase population-level exposure. Addressing these converging risks requires an integrated farm-to-fork strategy that combines rigorous monitoring of animal feed for aflatoxin B1, adoption of improved storage and handling practices, regular surveillance of milk and dairy products, greater harmonization of regulatory standards where feasible, and targeted protection of vulnerable groups, particularly infants and young children, through the application of more stringent safety limits.

8. Conclusion

Aflatoxin M1 (AFM1) contamination of milk exemplifies a covert food safety hazard, as it is colourless, tasteless, and generally undetectable without laboratory-based analysis, yet capable of exerting significant adverse health effects. These risks are particularly pronounced in regions with high levels of milk consumption and limited regulatory oversight, where population exposure may be both frequent and sustained. Evidence from a wide range of geographical settings demonstrates that AFM1 contamination is not a localized issue but a global challenge shaped by interactions among agricultural practices, climatic conditions, and policy environments. Although the complete elimination of AFM1 from the dairy supply is unlikely in the short term, substantial risk mitigation is achievable through preventive feed management, robust and continuous surveillance, and the implementation of science-based regulatory frameworks. Ensuring the safety of milk therefore extends beyond a purely technical or industrial concern and represents a critical public health imperative, given its direct impact on vulnerable populations, particularly infants and young children who rely heavily on milk as a dietary staple.

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