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Agronomic management of aflatoxin contamination in groundnut (*Arachis Hypogaea* l.): Evidence-based analysis and integrated field strategies

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Abstract
Aflatoxin contamination in groundnut (*Arachis hypogaea* L.) is a major constraint affecting crop productivity, quality and marketability, particularly under tropical conditions. The problem is closely associated with agronomic practices, environmental stress and soil–plant–microbe interactions. Groundnut is highly vulnerable due to its geocarpic nature, which exposes pods to soil-borne fungal inoculum. Agronomic factors such as irrigation management, nutrient balance, soil conditions and crop protection play a crucial role in determining contamination levels. Recent research highlights that improved crop management practices, including timely irrigation, balanced fertilization, and biological interventions, can significantly reduce aflatoxin incidence. This review emphasizes agronomic approaches for managing aflatoxin contamination in groundnut, integrating physiological, environmental and microbial perspectives for sustainable production. An evidence-based synthesis of agronomic practices is presented to support integrated management strategies.

Keywords: Aflatoxin, agronomic practices, biocontrol, groundnut, irrigation, nutrient management

Introduction

Groundnut is an important oilseed crop widely cultivated under rainfed and irrigated conditions. However, aflatoxin contamination caused by *Aspergillus flavus* severely affects its productivity, quality and export potential (Wild and Gong, 2010; Kumar *et al*., 2017) [7, 11].

The occurrence of aflatoxin is strongly influenced by agronomic factors such as soil moisture, temperature, nutrient availability and crop stress conditions (Hell and Mutegi, 2011) [5]. Under drought and high-temperature conditions, plants become more susceptible to fungal invasion and toxin production. Therefore, understanding the role of agronomic practices is essential for effective management.

Role of Agronomic Factors in Aflatoxin Contamination

Aflatoxin contamination is not only a biological problem but also an agronomic issue. Crop stress conditions, particularly moisture stress during pod development, significantly increase contamination risk (Waliyar *et al*., 2015) [10].

Groundnut's geocarpic growth habit exposes developing pods directly to soil, increasing vulnerability to fungal infection. Agronomic interventions that reduce stress and improve soil conditions can substantially lower contamination levels. Fig 1 shows the agronomic factors influencing aflatoxin contamination in groundnut.

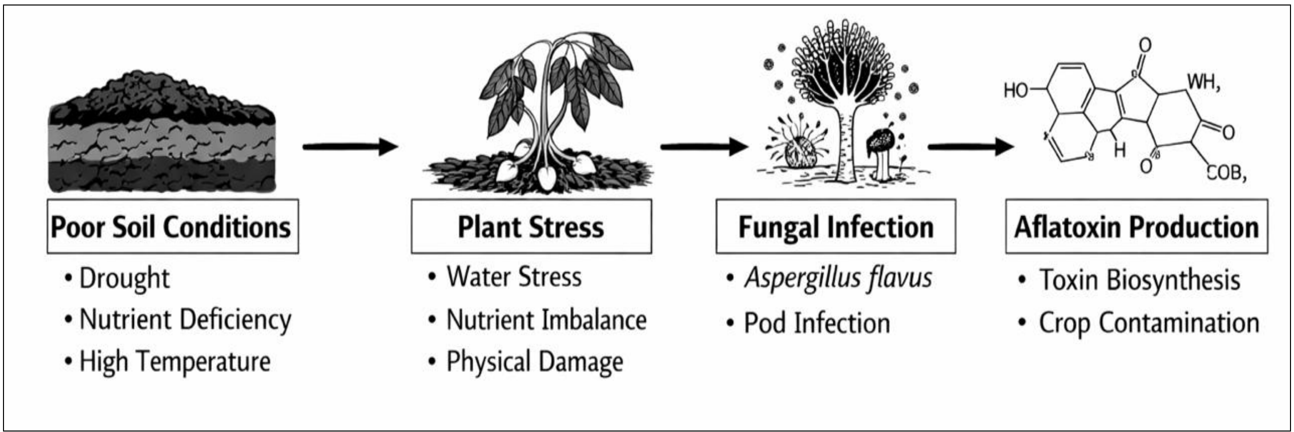

Fig 1: Agronomic factors influencing aflatoxin contamination in groundnut

Irrigation Management and Soil Moisture

Moisture stress is one of the most critical factors influencing aflatoxin contamination. Drought conditions during flowering and pod filling stages increase susceptibility to *A. flavus* infection (Hell and Mutegi, 2011) [5].

Timely irrigation helps maintain optimal soil moisture, reduces plant stress and minimizes fungal colonization.

Studies indicate that maintaining optimal soil moisture reduces aflatoxin contamination significantly compared to rainfed conditions (Waliyar *et al*., 2015) [10]. Fig. 2 illustrates the relationship between moisture content and aflatoxin production in groundnut.

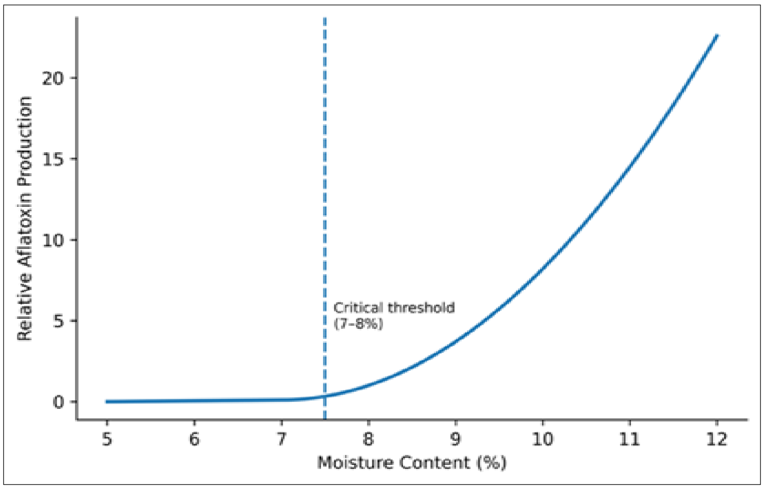

Fig 2: Effect of moisture content on aflatoxin production in groundnut.

A comparative summary of published studies on the influence of agronomic practices on aflatoxin contamination in groundnut is presented in Table 1.

Table 1: Influence of agronomic practices on aflatoxin contamination in groundnut.

Study	Location / Condition	Agronomic Factor	Treatment Details	Aflatoxin Reduction (%)	Key Findings
Waliyar *et al.*	Semi-arid tropics	Irrigation	Supplemental irrigation during pod filling	40–60	Reduced drought stress lowers contamination
Hell and Mutegi	Sub-Saharan Africa	Crop stress	Improved crop management under stress	30–50	Stress conditions increase aflatoxin risk
Cotty *et al.*	Field conditions	Biocontrol	Non-toxigenic *A. flavus* application	70–90	Competitive exclusion reduces toxin production
Kumar *et al.*	Controlled trials	Nutrient management	Balanced fertilization (NPK + micronutrients)	20–35	Improved plant health reduces susceptibility
Amaike and Keller	Laboratory & field	Temperature stress	High temperature exposure	Increased contamination	Stress activates toxin biosynthesis genes
Mahato *et al.*	Storage conditions	Moisture control	Drying below 7% moisture	50–80	Low moisture suppresses fungal growth
Klich	Soil systems	Soil type	Sandy vs clay soils	Higher in sandy soils	Low moisture retention increases risk
Williams *et al.*	Developing countries	Storage	Poor storage conditions	High contamination (>80%)	Storage environment critical factor

The data presented in Table 1 clearly indicate that agronomic practices significantly influence aflatoxin contamination in groundnut. Among various interventions, biological control using non-toxigenic strains of *Aspergillus flavus* shows the highest reduction (70–90%), followed by moisture management through proper drying and irrigation. Nutrient management and stress mitigation also play important roles in reducing plant susceptibility. These findings highlight the importance of integrated agronomic strategies in minimizing aflatoxin risk under field and storage conditions.

Nutrient Management and Soil Fertility

Balanced nutrient management plays a key role in reducing aflatoxin contamination.

- Phosphorus improves root growth and energy transfer
- Calcium strengthens pod integrity and reduces infection
- Zinc and boron enhance plant defense mechanisms

Deficiency of essential nutrients increases plant stress and susceptibility to fungal infection (Kumar *et al.*, 2017) [7]. Integrated nutrient management involving organic and inorganic sources improves soil health and reduces contamination risk.

Soil Type and Field Conditions

Soil characteristics influence aflatoxin contamination:

- Sandy soils → higher risk due to low moisture retention
- Clay soils → lower risk due to better water-holding capacity

Soil temperature and aeration also affect fungal growth. Proper field management, including mulching and soil amendments, can help regulate these conditions.

Role of Biological Interventions

Application of non-toxigenic strains of *Aspergillus flavus* has emerged as an effective agronomic strategy. These strains compete with toxigenic strains, reducing aflatoxin production through competitive exclusion (Cotty *et al.*, 2007) [2].

Use of biofertilizers and beneficial microbes improves:

- Soil microbial balance
- Nutrient availability
- Plant resistance

Critical Analysis and Research Gap

Although several studies highlight the role of agronomic practices, there is limited integration of:

- Nutrient × moisture interaction
- Soil microbiome influence
- Climate change effects on aflatoxin dynamics

Most studies are location-specific, and there is a need for multi-location trials to develop region-specific recommendations.

Post-Harvest Storage and Aflatoxin Contamination

Post-harvest storage plays a crucial role in determining the extent of aflatoxin contamination in groundnut, often contributing more significantly than pre-harvest factors under improper conditions. Even when contamination at harvest is low, unfavorable storage environments can rapidly increase aflatoxin levels due to fungal proliferation. The primary determinants of contamination during storage include kernel moisture content, temperature, relative humidity, storage duration, and physical damage to pods (Waliyar *et al*., 2015; Hell and Mutegi, 2011) [5, 10].

Moisture content is the most critical factor influencing aflatoxin development during storage. Groundnut kernels with moisture levels above 7–8% provide favorable conditions for the growth of *Aspergillus flavus*. Increased water activity enhances fungal metabolism and activates aflatoxin biosynthesis pathways, resulting in rapid toxin accumulation. Therefore, immediate drying of harvested pods to safe moisture levels (<7%) is essential to prevent contamination (Waliyar *et al*., 2015; Mahato *et al*., 2019) [9, 10].

Temperature and relative humidity further influence fungal growth and toxin production. Elevated temperatures (25–35°C) and high relative humidity (>70%) create an ideal microenvironment for fungal colonization. Under such conditions, even short storage durations can lead to significant aflatoxin accumulation. Poor ventilation and traditional storage structures often exacerbate these conditions by trapping moisture and heat, thereby increasing contamination risk (Hell and Mutegi, 2011) [5].

Mechanical damage and insect infestation are additional factors that contribute to post-harvest contamination. Cracked or damaged kernels provide entry points for fungal infection, while insect activity increases kernel susceptibility and facilitates fungal spread. Studies have shown that proper sorting and removal of damaged pods can significantly reduce aflatoxin levels in stored groundnut (Mahato *et al*., 2019) [9].

The duration of storage also plays an important role, as prolonged storage under suboptimal conditions leads to cumulative fungal growth and toxin accumulation. Therefore, minimizing storage duration and ensuring periodic monitoring of storage conditions are critical for maintaining grain quality.

Effective management of aflatoxin during storage requires an integrated approach involving rapid drying, maintenance of low moisture content, use of improved storage structures, proper aeration, and pest control. Adoption of hermetic storage systems and moisture-proof containers has shown promising results in reducing aflatoxin contamination by limiting oxygen availability and fungal growth.

Figure 3 illustrates the conceptual model of aflatoxin contamination during storage, highlighting the sequential process from poor storage conditions to fungal growth, kernel infection, and toxin accumulation. The model emphasizes that timely intervention at the storage stage can effectively interrupt the contamination pathway and safeguard groundnut quality.

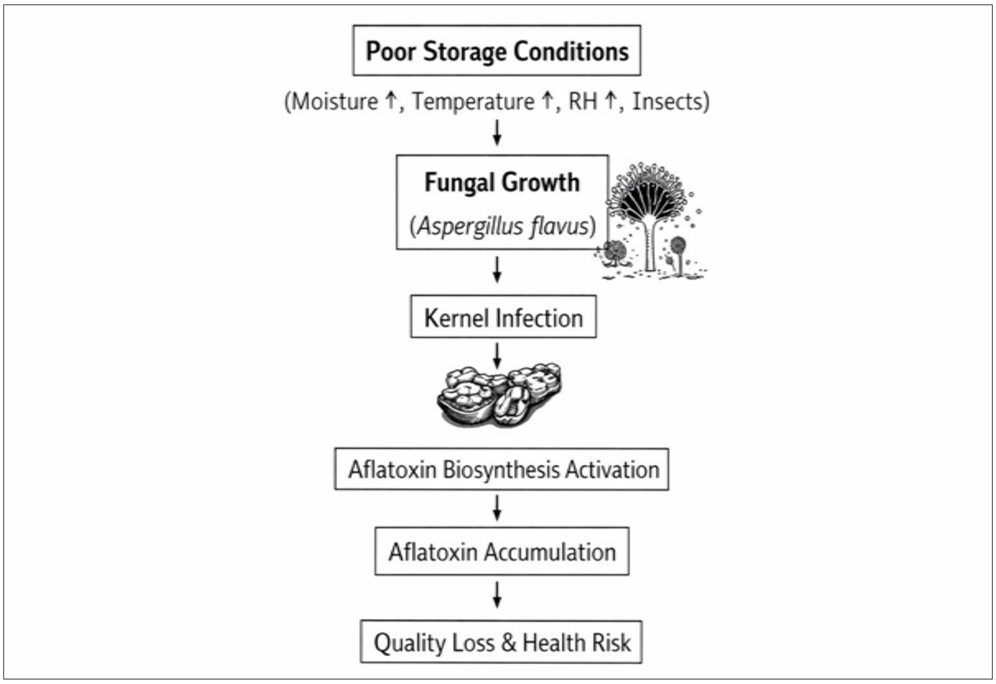

Fig 3: Conceptual model of aflatoxin contamination during storage of groundnut.

This model highlights that improper storage conditions significantly accelerate aflatoxin development. Therefore, maintaining low moisture content and proper storage environment is essential to minimize contamination.

Future Research Directions

Future research should focus on:

- Development of stress-resilient groundnut varieties
- Integration of biofertilizers with nutrient management

- Precision irrigation techniques
- Climate-smart agronomic practices

Discussion

Aflatoxin contamination in groundnut is a complex phenomenon governed by the interaction of multiple agronomic and environmental factors. The evidence presented in Table 1 clearly demonstrates that agronomic interventions such as irrigation, nutrient management and biological control significantly reduce contamination levels under field conditions. Among these, biocontrol strategies using non-toxigenic *Aspergillus flavus* strains show the highest effectiveness, followed by moisture management practices.

Figure 1 illustrates that plant stress induced by drought, nutrient imbalance and unfavorable soil conditions acts as a primary trigger for fungal infection and subsequent toxin production. These findings are further supported by Figure 2, which highlights the critical role of moisture, showing a sharp increase in aflatoxin production beyond the threshold level of 7–8%. This indicates that moisture management is a key control point both in field and post-harvest stages.

The integration of field and storage factors is crucial in determining the final level of contamination. While pre-harvest agronomic practices influence plant susceptibility and initial infection, post-harvest conditions such as kernel moisture, temperature and storage environment govern fungal proliferation and toxin accumulation, as depicted in Figure 3. Improper storage can negate the benefits of good field management, leading to rapid aflatoxin buildup even when initial contamination is low.

Therefore, an integrated approach combining stress mitigation in the field with proper post-harvest handling and storage management is essential for effective control of aflatoxin contamination. This holistic strategy ensures interruption of the contamination pathway at multiple stages, thereby improving groundnut quality, safety and marketability. Future studies should focus on developing integrated agronomic models that combine field and storage interventions under varying climatic conditions.

Conclusion

Aflatoxin contamination in groundnut is strongly influenced by agronomic factors, particularly moisture stress, nutrient imbalance and soil conditions. Adoption of integrated agronomic practices, including irrigation management, balanced fertilization and biological control, can significantly reduce contamination and improve crop productivity. A holistic approach is essential for ensuring safe and sustainable groundnut production. The integration of pre-harvest agronomic practices with post-harvest storage management provides a comprehensive strategy for minimizing aflatoxin contamination. Such approaches are essential for ensuring food safety and enhancing the export quality of groundnut.

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