

Management of Aflatoxigenic Fungi and Aflatoxin Contamination in Maize (*Zea mays* L.) and Groundnut (*Arachis hypogaea* L.): A Review of Biofungicides and Chemical Fungicides

Janet Uchechukwu ITELIMA

Department of Plant Science and Biotechnology, Faculty of Natural Sciences, University of Jos, Jos, Nigeria
Corresponding Authors Email: janetitelima@yahoo.com

Direct Research Journal of Biology and Biotechnology



Vol. 12(2), Pp. 67-72, October 2026

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<https://journals.directresearchpublisher.org/index.php/drjbb>; <https://www.ajol.info/index.php/djbb>

Review Article

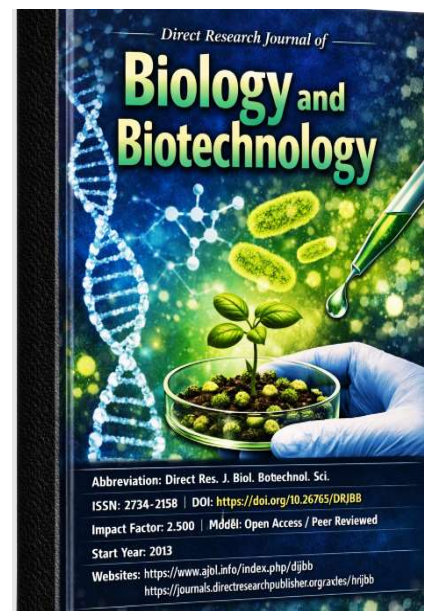
ISSN: 2734-2158

Received 20 August 2026, Accepted 20 September 2026, Published 11 October 2026

ABSTRACT

*Aflatoxin contamination of maize (*Zea mays* L.) and groundnut (*Arachis hypogaea* L.) remains a major food-safety, agricultural and economic challenge in Nigeria and other parts of sub-Saharan Africa. Aflatoxins are mainly produced by species within *Aspergillus* section *Flavi*, particularly *A. flavus* and *A. parasiticus*, and contamination can occur before harvest and increase during harvesting, drying, transportation and storage. Aflatoxin B₁ is of particular concern because of its potent carcinogenic and hepatotoxic properties. Recent evidence continues to demonstrate substantial aflatoxin contamination of Nigerian maize, with contamination frequently exceeding regulatory limits (Bashir et al., 2025). Management therefore requires interventions capable of reducing both fungal colonisation and toxin production. This review examines microbial biofungicides, plant-based biofungicides and chemical fungicides for the management of aflatoxigenic fungi and aflatoxin contamination in maize and groundnut. Particular attention is given to atoxigenic *A. flavus* biocontrol technology, plant extracts and essential oils, as well as the efficacy and limitations of synthetic fungicides. Evidence from Nigeria and other African countries indicates that atoxigenic *A. flavus* products can substantially reduce aflatoxin contamination under farmers' field conditions. Plant-derived products, particularly essential oils and extracts containing antifungal phytochemicals, also show considerable promise as environmentally compatible alternatives or complements to synthetic fungicides. However, variability in efficacy, formulation stability, environmental conditions and commercial-scale application remains challenging. An integrated management approach combining biological control, plant-based products, appropriate chemical interventions, resistant cultivars and good agricultural and postharvest practices is therefore recommended for sustainable reduction of aflatoxin contamination.*

Keywords: aflatoxin, *Aspergillus flavus*, *Aspergillus parasiticus*, maize, groundnut, biofungicides, plant extracts, essential oils, chemical fungicides, biological control



Citation: J. U. Itelima (2026). Management of Aflatoxigenic Fungi and Aflatoxin Contamination in Maize (*Zea mays* L.) and Groundnut (*Arachis hypogaea* L.): A Review of Biofungicides and Chemical Fungicides. *Direct Research Journal of Biology and Biotechnology*. Vol. 12(2), Pp. 67-72. <https://doi.org/10.4314/djbb.v12i2.8>

INTRODUCTION

Maize and groundnut are important food and cash crops in Nigeria, contributing substantially to human nutrition, livestock feeding, household income and agricultural

trade. However, both commodities are highly susceptible to colonization by aflatoxigenic fungi and subsequent contamination with aflatoxins. The principal fungi

associated with aflatoxin production belong to *Aspergillus* section *Flavi*, particularly *A. flavus* and *A. parasiticus* (Moral et al., 2020; Akullo et al., 2025).

Aflatoxin contamination is influenced by interactions among fungal populations, crop susceptibility and environmental conditions. Drought stress, high temperature, insect damage, mechanical injury, delayed harvesting, inadequate drying and improper storage can favour fungal infection and toxin production. These conditions are particularly important in tropical and subtropical regions where temperature and moisture may favour *Aspergillus* development (Ncube & Maphosa, 2020; Mdindikasia et al., 2024).

The problem remains significant in Nigeria. In a recent investigation of maize obtained from seven states in North-West Nigeria, aflatoxins were detected in 80.9% of samples, while 42.8% exceeded the Nigerian regulatory limit of 4 µg/kg for total aflatoxins. Half of the *Aspergillus* section *Flavi* isolates recovered were aflatoxigenic, and all toxigenic isolates were identified as *A. flavus* (Bashir et al., 2025). A recent systematic review of Nigerian maize contamination also demonstrated substantial geographical and seasonal variation, with aflatoxins among the most prevalent mycotoxins detected (Adejumo et al., 2025).

The consequences extend beyond food safety. Chronic dietary exposure to aflatoxin, particularly aflatoxin B₁ (AFB₁), is associated with serious health consequences, while contamination can reduce commodity quality, limit market access and increase economic losses. Consequently, effective management must address fungal infection and toxin formation throughout the crop value chain.

Statement of the Problem

Aflatoxin contamination of maize and groundnut remains difficult to control because contamination may begin in the field and continue or intensify during harvesting, drying, transportation and storage. The problem is compounded by climatic stress, poor agronomic practices, insect damage, inadequate storage facilities and limited access to effective control technologies. Although chemical fungicides can suppress fungal development, their effectiveness against aflatoxin accumulation is not always consistent, while repeated use may contribute to concerns regarding residues, environmental effects and resistance development. There is therefore a need for safer, effective and sustainable approaches that can reduce both aflatoxigenic fungi and aflatoxin accumulation.

Justification of the Review

The importance of maize and groundnut to food security, nutrition, livestock production and rural livelihoods makes aflatoxin management particularly important in Nigeria. Biological control has already demonstrated substantial field-level potential in Nigeria and other African countries,

while plant-derived antifungal compounds provide an additional source of potentially affordable and environmentally compatible control agents (Bandyopadhyay et al., 2019; Agbetiameh et al., 2020). However, no single intervention is likely to provide complete protection under all production and storage conditions. Combining microbial biofungicides, plant-based products, appropriate chemical fungicides and good agricultural and postharvest practices may therefore provide more reliable and sustainable management.

Aim

The aim of this review is to examine the management and control of aflatoxin and aflatoxigenic fungi contamination of maize and groundnut, with particular emphasis on microbial and plant-based biofungicides and chemical fungicides.

Objectives

The review specifically seeks to

1. Examine the major aflatoxigenic fungi associated with maize and groundnut;
2. Discuss factors responsible for aflatoxin contamination;
3. Evaluate microbial biofungicides, particularly atoxigenic *A. Flavus*;
4. Examine plant-based biofungicides, including extracts and essential oils;
5. Assess the efficacy and limitations of chemical fungicides;
6. Compare biological and chemical approaches to aflatoxin management; and
7. Discuss prospects for integrated and sustainable management of aflatoxin contamination.

REVIEW METHODOLOGY

This article is framed as a narrative review of published evidence on aflatoxigenic fungi and the management of aflatoxin contamination in maize and groundnut, with emphasis on microbial biofungicides, plant-derived products and chemical fungicides. The manuscript cites primary studies and reviews from Nigeria and other African settings, together with studies of antifungal mechanisms and formulation. Evidence is synthesised thematically according to the seven objectives: fungal agents and contamination drivers; microbial biocontrol; botanical extracts and essential oils; chemical fungicides; comparative performance and limitations; and integrated management. Field efficacy, laboratory inhibition, reduction of aflatoxin biosynthesis and removal/degradation of pre-existing toxin are treated as distinct outcomes and should not be interpreted as interchangeable.

Aflatoxigenic Fungi and Aflatoxin Contamination

A. flavus is the most important aflatoxin-producing species associated with maize and groundnut. Some strains produce aflatoxins, whereas others are naturally atoxigenic. *A. parasiticus* is also capable of producing aflatoxins, including both B- and G-type toxins. Aflatoxin B₁ is particularly important because of its high toxicity and carcinogenicity (Moral et al., 2020; Akullo et al., 2025). Contamination can occur before harvest when plants experience drought, heat stress, insect injury or other forms of physiological stress. In groundnut, contamination may occur through infection of pods in the soil, particularly under conditions that favour drought stress and fungal development. After harvest, delayed drying, high grain moisture, mechanical damage and poor storage can encourage fungal proliferation and toxin production (Ncube & Maphosa, 2020; Mdindikasia et al., 2024). The persistence of contamination along the value chain means that management should not focus exclusively on the field. Effective control requires interventions extending from crop establishment and harvest through drying, transportation, storage and processing.

Management and Control Strategies

Good Agricultural and Pre-harvest Practices

Good agricultural practices provide the foundation for aflatoxin management. Appropriate planting dates, adequate soil fertility, effective weed management, irrigation where feasible, control of insect pests and timely harvesting can reduce crop stress and susceptibility to fungal infection. In groundnut, avoiding prolonged exposure of mature pods to adverse soil conditions and ensuring proper curing and drying are particularly important (Ncube & Maphosa, 2020; Mdindikasia et al., 2024).

The use of resistant or less susceptible cultivars is also an important long-term strategy. Groundnut breeding programmes have identified resistance-related traits, although genotype × environment interactions can complicate the development and deployment of consistently resistant cultivars (Ncube & Maphosa, 2020). Recent Nigerian research has similarly identified maize genotypes showing lower colonisation and reduced aflatoxin accumulation, demonstrating the potential of host resistance as part of integrated management (Adebayo et al., 2025).

Microbial Biofungicides

Microbial biofungicides are among the most promising alternatives to conventional chemical control. One of the best-established approaches involves the application of naturally occurring atoxigenic *A. flavus* strains. These strains do not produce aflatoxins but can competitively colonise the crop environment and displace toxigenic *A.*

flavus populations. The resulting reduction in the population of aflatoxin-producing fungi can substantially reduce contamination (Moral et al., 2020).

The Aflasafe technology represents an important example of this approach in Africa. In Nigeria, extensive field evaluations demonstrated strong and consistent reductions in aflatoxin contamination. Over a decade of research and field deployment culminated in commercial use, including application over approximately 36,000 ha of maize in 2018 (Bandyopadhyay et al., 2019). The technology has subsequently been used beyond experimental research through private-sector-led programmes in Nigeria (Ola et al., 2022).

The effectiveness of atoxigenic strains has also been demonstrated elsewhere in Africa. In Ghana, two atoxigenic biocontrol products reduced aflatoxin contamination by approximately 99% across 800 maize and groundnut farmers' fields, illustrating the potential of locally adapted atoxigenic strains (Agbetiameh et al., 2020). The persistence of biocontrol strains is another important consideration. Studies in Nigeria have shown that the frequency of Aflasafe application can influence the persistence and effectiveness of the active ingredients, with carry-over of atoxigenic strains offering opportunities for more cost-effective application programmes (Atehnkeng et al., 2022). Nevertheless, efficacy can vary according to crop, environment, fungal population structure and management conditions.

Plant-Based Biofungicides

Plant-based biofungicides represent an important complementary approach to microbial biological control. They include aqueous or organic plant extracts, powders, essential oils and purified plant-derived compounds. Their antifungal activity is associated with bioactive constituents such as phenolics, flavonoids, terpenoids, alkaloids and sulphur-containing compounds.

Plant extracts have attracted particular interest in sub-Saharan Africa because many potentially useful plants are locally available and relatively inexpensive. Recent reviews identify plant extracts among promising approaches for reducing fungal contamination and degrading or reducing aflatoxins in maize and groundnut products (Akullo et al., 2025).

Essential oils are especially promising because several of their constituents possess strong antifungal and antiaflatoxigenic activities. A comprehensive review of plant essential oils reported their ability to inhibit fungal growth and aflatoxin production, with activity linked to disruption of fungal membranes, interference with cellular metabolism and effects on pathways associated with aflatoxin biosynthesis (Zhang et al., 2024).

Recent experimental evidence also supports their application to groundnut. Obedi et al. (2025) evaluated clove (*Syzygium aromaticum*), cardamom (*Elettaria cardamomum*) and garlic (*Allium sativum*) essential oils against *A. flavus* associated with groundnut. Clove and

Table 1: Comparison of Biofungicides and Chemical Fungicides

Control approach	Major advantages	Major limitations
Atoxigenic. <i>A.flavus</i>	Highly effective under field conditions; targets toxigenic fungal populations; environmentally compatible	Requires appropriate strain selection, formulation and field application
Plant extracts	Locally available; potentially inexpensive; contain multiple antifungal compounds	Variable composition and efficacy; extraction and standardisation challenges
Essential oils	Strong antifungal activity; several have antiaflatoxigenic properties	Volatility, cost, formulation and possible effects on food aroma
Synthetic fungicides	Rapid and relatively predictable activity; established application systems	Residues, resistance concerns and environmental considerations; variable effect on aflatoxin
Integrated management	Combines complementary mechanisms and reduces dependence on one method	Requires farmer training, coordination, monitoring and appropriate technology

Note. Comparison synthesised from Lagogianni and Tsitsigiannis (2018), Das and Chaudhari (2023), and Akullo et al. (2025). The relative performance of each approach depends on crop, product, dose, application timing and whether the endpoint is fungal growth or aflatoxin concentration.

cardamom oils demonstrated strong inhibition of fungal growth, with reported reductions of approximately 92% and 88%, respectively. These findings demonstrate the potential of plant-derived essential oils as natural antifungal treatments for stored groundnut. Other botanicals of interest include neem (*Azadirachta indica*), ginger (*Zingiber officinale*), lemongrass (*Cymbopogon citratus*), bitter leaf (*Vernonia amygdalina*) and other medicinal and aromatic plants. Their activity is likely to vary according to plant chemotype, extraction method, concentration and fungal strain. Consequently, laboratory activity should not automatically be interpreted as equivalent to field or storage efficacy.

An additional emerging area is the use of nanoformulations and encapsulation technologies to improve the stability, dispersibility and controlled release of plant-derived compounds. Such approaches may overcome some limitations of essential oils, including volatility, poor water solubility and rapid loss of activity. However, safety, cost, regulatory acceptance and food-quality effects require further evaluation before widespread application.

Chemical Fungicides

Chemical fungicides remain important tools for fungal disease management because of their relatively rapid activity, predictable formulation and established application technologies. Fungicides investigated against *A. flavus* include compounds from several chemical groups, although their ability to suppress aflatoxin production may differ from their ability to inhibit fungal growth.

Lagogianni and Tsitsigiannis (2018) evaluated azoxystrobin, boscalid, cyprodinil, fludioxonil and cyprodinil plus fludioxonil against *A. flavus*. Cyprodinil and fludioxonil were particularly effective against mycelial growth in vitro, while azoxystrobin strongly inhibited conidial germination at appropriate concentrations. Their findings demonstrate that chemical fungicides can interfere with fungal development, although chemical control of aflatoxin contamination requires careful consideration of timing, formulation and environmental conditions. Chemical control has several limitations. Fungicide efficacy may be reduced by environmental

conditions, inappropriate application timing and variability among fungal populations. Repeated use may also increase selection pressure for resistant populations and raises concerns regarding pesticide residues and environmental contamination. Importantly, suppression of visible fungal growth does not necessarily guarantee elimination of aflatoxins that may already have been produced. Chemical fungicides should therefore be regarded as one component of a broader integrated management programme rather than a stand-alone solution. Table 1 shows the Comparison of Biofungicides and Chemical Fungicides their major advantages and limitations.

Integrated Management of Aflatoxin Contamination

Evidence increasingly supports integrated management rather than dependence on a single intervention. In maize and groundnut, an effective programme should begin with appropriate cultivar selection and good field management, followed by timely harvesting, rapid drying, sorting, safe transportation and suitable storage. Microbial biocontrol can reduce the population of toxigenic *Aspergillus*, while plant-based products may provide additional suppression during production or storage.

Chemical fungicides may be incorporated where appropriate and where registered for the intended crop and use. However, their use should follow label recommendations and regulatory requirements, with attention to application timing and residue management. Integrated approaches are particularly important because aflatoxin contamination is controlled by several interacting factors. Recent reviews of groundnut management emphasise that no single intervention is sufficient and that biological, cultural, agronomic, breeding, chemical and postharvest strategies should be combined (Mndikasia et al., 2024). Similarly, recent work on maize and groundnut confirms the importance of combining pre- and postharvest practices with biological control and plant-derived interventions (Karthikeyan et al., 2025).

Challenges and Future Prospects

Despite considerable progress, several challenges remain. First, biological and plant-based products require

standardisation to ensure consistent efficacy. Plant-derived products can vary considerably in chemical composition according to plant variety, geographical origin, maturity, extraction method and storage conditions. Second, promising laboratory results need to be validated under real field and storage conditions. Third, the adoption of biological products requires farmer awareness, appropriate distribution systems, regulatory support and cost-effective formulations.

Future research should prioritise locally adapted atoxigenic *A. flavus* strains, combinations of microbial and plant-based biofungicides, improved essential-oil formulations, nanoencapsulation where scientifically and regulatorily justified, resistant maize and groundnut varieties, and predictive systems based on environmental risk factors. Research should also investigate whether combinations of plant-derived products and microbial biocontrol agents can provide additive or synergistic protection without negatively affecting seed quality or beneficial microorganisms.

Nigeria would particularly benefit from coordinated surveillance of aflatoxin contamination, strengthened regulatory enforcement, improved farmer education and wider adoption of validated biological control technologies. The development of affordable plant-based formulations from locally available botanicals could further expand management options for smallholder farmers.

Critical Comparison and Evidence Gaps

The evidence reviewed supports a distinction between interventions with demonstrated field performance and those that remain promising but require further validation. Nigerian and Ghanaian studies cited in this manuscript provide field-based support for atoxigenic *A. flavus* products, although performance depends on the selected strains, crop ecology, formulation and application practice. These findings should not be generalised to every product or production setting without local validation.

Plant extracts and essential oils offer multiple candidate antifungal compounds and may be locally sourced, but laboratory inhibition of *A. flavus* does not by itself establish prevention of aflatoxin accumulation in stored food. Studies should report the botanical identity, extraction method, chemical composition, dose, exposure duration, food matrix and both fungal and toxin endpoints. Sensory effects, residue/safety considerations, stability and cost also require evaluation before recommending routine use. Chemical fungicides have a more established application infrastructure in crop protection, but their impact on aflatoxin must be demonstrated for the particular crop and use. Reduced mycelial growth or conidial germination is not equivalent to reduced aflatoxin concentration. Product registration, label compliance, residues, resistance management and environmental risks must therefore be considered alongside efficacy.

A priority research gap for Nigeria is the limited availability, within the evidence assembled here, of

standardised head-to-head trials comparing microbial, botanical and chemical interventions under the same maize and groundnut field or storage conditions. Future studies should include toxin concentration, fungal incidence, crop/seed quality, persistence, non-target effects, cost per treated area or tonne, farmer acceptability and performance across seasons. Combination studies should test compatibility and possible antagonism as well as additive or synergistic effects.

Accordingly, integrated management should be understood as a coordinated programme rather than the untested mixing of products. It should combine preventive agronomy and resistant cultivars, locally adapted atoxigenic biocontrol where approved, timely harvest and drying, sorting, moisture-safe storage, representative testing and traceability. Botanical or chemical products should be incorporated only when efficacy, food safety and regulatory suitability are demonstrated for the intended use.

CONCLUSION

Aflatoxin management in maize and groundnut requires interventions that address both toxigenic fungi and toxin contamination across the crop value chain. The reviewed evidence identifies atoxigenic *A. flavus* biocontrol as a comparatively well-supported approach in field settings in Nigeria and other African countries. Plant extracts and essential oils are promising complementary options, but their laboratory activity should not be treated as proof of reliable field or storage performance. Chemical fungicides may contribute to fungal disease management where the product is registered for the intended use, but fungal-growth suppression does not necessarily prevent or remove aflatoxins. The evidence therefore supports integrated management built around locally appropriate biological control, resistant or less susceptible cultivars, good agricultural practices, timely harvesting, rapid drying, safe storage, testing and traceability. The review also identifies a need for better standardised comparative trials in Nigerian maize and groundnut systems, including efficacy, safety, persistence, compatibility and economic feasibility. These conclusions are consistent with the seven objectives, while the strength of each recommendation should remain proportional to the type and quality of evidence available. The most sustainable strategy is therefore an integrated system combining resistant or tolerant cultivars, good agricultural practices, microbial biofungicides, selected plant-based products, appropriate chemical interventions and improved postharvest management. Such an approach offers the greatest prospect of reducing aflatoxin contamination, improving food safety and protecting the economic value of maize and groundnut production in Nigeria.

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