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Review Article

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Monitoring aflatoxins contamination in maize using chemical treatments

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Abstract

Aflatoxins (AFs) contamination, which is primarily driven by *Aspergillus flavus* and *A. parasiticus*, represents a global threat to food safety and the agricultural economy, with maize (*Zea mays* L.) being one of the most susceptible staple crops. These secondary metabolites are potent carcinogens, linked to hepatocellular carcinoma and immunosuppression among others. Contamination is heavily influenced by environmental stressors, particularly drought and high temperatures, which are increasingly prevalent due to global climate change. While pre-harvest and post-harvest management strategies such as biocontrol and secure storage have shown efficacy, they are often insufficient to prevent AFs contamination. Oxidative stress is closely associated with aflatoxin biosynthesis, where the fungus produces toxins as a defensive mechanism against reactive oxygen species in its environment. Consequently, the application of chemical agents has emerged as a promising strategy for mitigation. Natural and synthetic antioxidants can suppress *Aspergillus* growth and reduce toxin accumulation in stored grains. Emerging techniques also highlight the use of antioxidant-rich phenolic compounds as redox mediators to enhance the enzymatic disruption of AF biosynthetic pathway. This review concludes that integrating antioxidant-based interventions into holistic farm-to-market management systems is vital for improving maize safety and protecting vulnerable populations.

Keywords: Aflatoxins; Maize; *Aspergillus*; Antioxidants; Food safety

1. Introduction

Mycotoxins are toxic secondary metabolites that are synthesized by some fungal genera, like *Fusarium*, *Aspergillus*, and *Penicillium*, which contaminants estimated between 60 and 80% of the world's food crops [1]. The most common mycotoxins are aflatoxins (carcinogens found in nuts and dairy products), ochratoxins (common in coffee and grains), zearalenone (an estrogenic toxin in cereals), fumonisins (in maize), trichothecenes (causing aleukia), and patulin (in apple products) [2]. These compounds are dangerous to human and animal health because they are carcinogenic, mutagenic, teratogenic, and immunosuppressive [3]. Environmental factors like moisture and high temperatures are the main factors that promote fungal growth and toxin production that are common during storage processes, transport, and pre-harvest [4]. Since mycotoxins are stable at high temperatures and toxic even at low concentrations, a lot of countries have set regulatory limits on mycotoxins in food and feed products, usually between 2 and 20 part per billion (ppb) [5].

Maize (*Zea mays* L.) Family Poaceae is one of the most economically important cereal crops across the globe, a major source of food, nutrition security, and income to commercial farmers [6]. Over 197 million hectares of land worldwide are under maize farming and yield about 1.13 billion tons [7]. It enables it to find wide application in industries in human consumption and bio energy, like the production of bioethanol [8]. Maize is very susceptible to infection by toxigenic fungi belonging to the genera *Aspergillus* and *Fusarium* and contamination by their toxigenic mycotoxins during its storage, harvesting, and growth [6]. Climate change is linked

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to this vulnerability since the conditions of the environment, such as heat and unpredictable precipitation occurrence during periods of the crop lifecycle, such as grain filling and silking, can decrease the yields and increase the toxin level [9]. To reduce the growth of molds, *such as Aspergillus* and *Fusarium* as major producers of mycotoxins that spoil grains by producing mycotoxins, it is important to dry the grains [10]. Since maize is an important component of the global food and feed chain, ensuring its quality and protection against these biological and environmental hazards is a major concern for global food security [7]. Despite the vast number of published articles and reviews concerning mycotoxin contamination in diverse food and feedstuffs, the present review sheds light on aflatoxin contamination in maize and maize products with reference to chemical management of this contaminant, which has not been addressed previously with this particularity.

2. Mycoflora of maize

The mycoflora of maize is famous for a rich number of fungal species involved in contaminating the crop both at post-harvest and pre-harvest levels [11]. According to Nesci et al. [12], *Aspergillus*, *Fusarium*, and *Penicillium* genera were found to be the most maize-related fungal genera. The frequency of fungi in maize kernels indicated that *Aspergillus flavus* is the most common (52%), then *Fusarium* spp. (25%) and *Penicillium* spp. (21%) [13]. Some typical isolates of infected maize grains are *Aspergillus flavus, A. parasiticus, A. niger,* and *Rhizopus nigricans* [14]. These organisms are the main sources of spoilage contamination, cause loss of the grain quality, and deteriorate proteins [15]. This mycoflora is responsible for the toxic synthesis and carcinogenic secondary metabolites, such as AFs and fumonisins, dangerous to health and humans' life [2]. Saleh et al. [14] recorded that *A. parasiticus* (32.5%) and *A. flavus* (47.5%) were the dominant fungi in corn with low levels of AFs (AFB_1, AFB_2, AFG_1 and AFG_2) all under international safety limits.

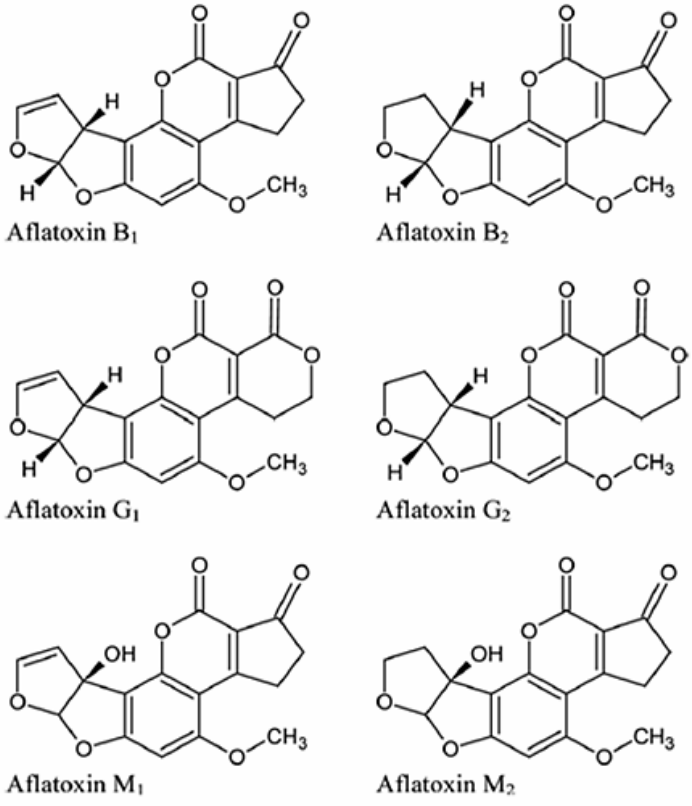

Figure 1. Chemical structure of aflatoxins adopted from Hassane [24].

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3. Aflatoxins

Aflatoxins are very toxic and carcinogenic secondary metabolites that are produced by filamentous fungi of the genus *Aspergillus*, like *A. flavus* and *A. parasiticus*, which are contaminants of crops [16]. Environmental factors affect their production and grow under warm and humid conditions with temperatures best between 25°C and 35°C and high moisture content [17]. These toxins are classified into four primary types—AFB_1, AFG_1, AFB_2, and AFG_2—named for the green (G) or blue (B) fluorescence they emit under ultraviolet light, alongside their hydroxylated metabolites AFM_1 and AFM_2, which are commonly detected in animal products such as milk [18] (Figure 1). Among these congeners, AFB_1 is identified as the most potent and prevalent toxicant, because of its direct link to liver cancer and its ability to cause acute aflatoxicosis, with the relative toxicity ranking generally established as $B_1 > G_1 > B_2 > G_2$ [5, 19]. Due to their severe health impacts, including mutagenic, teratogenic, and immunosuppressive effects, AFs are classified as Group 1 human carcinogens by the International Agency for Research on Cancer (IARC) [20]. AFB_1 causes acute/chronic aflatoxicosis, hepatocellular carcinoma, immunosuppression, and stunted growth in children. In milk, AFM_1 is concern to the infants [21].

The synthesis of AFs is an enzymatic process that requires the expression of genes such as *aflP*, *aflE*, and *aflQ*, which transform precursors such as acetyl-CoA into AFB_1, AFG_1, AFB_2, and AFG_2. AFB_1 is metabolized to AFB_1-8,9-epoxide, leading to DNA damage and liver cancer [22]. Exposure to humans and animals by inhalation, ingestion, or skin contact, and linked to clinical effects including lethal acute aflatoxicosis, liver cancer, and growth retardation in children [23]. Aflatoxins occur in a variety of agricultural products, like maize, wheat, rice, peanuts, and spices, and cause economic losses and a high risk to world food security [17].

4. Aflatoxin biosynthesis

Aflatoxin biosynthesis in *Aspergillus* was governed by a cluster which includes 30 genes, where its activation is regulated mainly by *aflR* and *aflS* genes, and at least 27 enzymatic processes have been implicated [25, 26]. Table (1) and Figure (2) illustrate a summary of the consequences in the AFB_1 biosynthesis pathway.

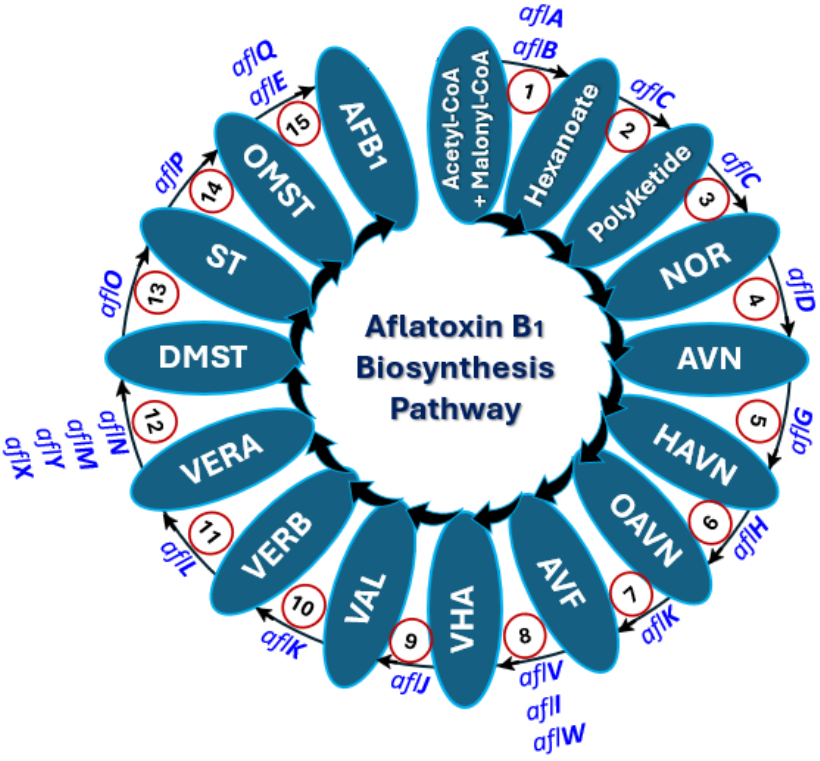

Figure 2. Aflatoxin B1 pathway. Numbers and abbreviations refer to enzymes stated in table 1.

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Table 1. Aflatoxin B1 pathway cluster genes and enzymes involved in biosynthesis.

No.	Compound/Substrate	Abbreviation	Enzyme	Gene	Action
1	Acetyl-CoA & Malonyl-CoA	-	Fatty acid synthase	*aflA* & *aflB*	Condensation
2	Hexanoate	-	Polyketide synthase	*aflC*	Chain elongation
3	Polyketide	-	Polyketide synthase	*aflC*	Cyclization
4	Norsolorinic acid	NOR	Reductase	*aflD*	Reduction
5	Averantin	AVN	P450 monooxygenase	*aflG*	Oxidation
6	5′-Hydroxyaverantin	HAVN	Alcohol dehydrogenase	*aflH*	Oxidation
7	5′-Oxoaverantin	OAVN	Synthase	*aflK*	Bisfuran ring closure
8	Averufin	AVF	Oxidase	*aflV*, *aflI*, & *aflW*	Oxidation
9	Versiconal hemiacetal acetate	VHA	Esterase	*aflJ*	Cyclodehydration
10	Versiconal	VAL	VERB synthase	*aflK*	Bisfuran ring closure
11	Versicolorin B	VERB	Desaturase	*aflL*	Oxidation
12	Versicolorin A	VERA	Dehydrogenase/ketoreductase Monooxygenase	*aflN*, *aflM*, *aflY*, & *aflX*	Reduction
13	Demethylsterigmatocystin	DMST	O-Methyltransferase I / O-methyltransferase B	*aflO*	Methylation
14	Sterigmatocystin	ST	O-Methyltransferase A / O-methyltransferase II	*aflP*	Methylation
15	O-methylsterigmatocystin	OMST	Oxidoreductase/P450 monooxygenase	*aflQ* & *aflE*	Oxidation
16	Aflatoxin B_1	AFB_1	-	-	

5. Aflatoxigenic fungi

Aflatoxigenic fungi are primarily secondary metabolite producers belonging to the *Aspergillus* section *Flavi*, with *A. flavus* and *A. parasiticus* being the most prevalent species identified in global food and feed contamination [11]. The 24 *Aspergillus* species produce aflatoxins are divided into sections *Ochraceorosei*, *Flavi*, and *Nidulantes* [27]. Other producers are species like *A. parvisclerotigenus, A. nomius, A. bombycis, A. pseudotamarii*, and others of the section *Ochraceorosei* like *A. ostianus* [28, 29]. These fungi are common in air and soil, and they attack crops, such as maize, cotton, and peanuts during both post-harvest and pre-harvest stages [30]. Abiotic factors, like high temperatures (optimally 25–37°C) and high-water activity (more than 0.85 a_w), play an important role in their growth and production of toxins [31]. Toxigenic fungi, such as *A. flavus* and *A. parasiticus*, contaminated grains (corn, rice, and wheat). High-performance liquid chromatography (HPLC) and Thin-layer chromatography (TLC) were used to identify 21 of 22 isolates yielding AFs, including AFB_1, AFG_1, AFB_2, and AFG_2. The AFB_1 levels were between 0.02 and 875.03 ng/g, with the highest produced being AFG_2 [32, 33].

6. Environmental factors affecting aflatoxin production

The toxin production and growth of *Aspergillus* species are sensitive to biotic and abiotic environmental factors, with water activity **(a_w)** and temperature being the main factors that affect the production of toxins and fungal growth [5, 34]. Studies show that optimal temperature ranges for the

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production of aflatoxin are between 29°C and 33°C, and high-water activity of about 0.99 a_w [35]. Temperatures lower than 25°C or above 37°C are not conducive to biosynthesis, and production is slowed down at moisture below 0.85 *aw* and between 0.70 and 0.75 *aw* [5]. Agricultural substrates, such as moisture content, poultry feed is found to be the first limiting factor, with no biosynthesis at 11% moisture content, and growth increasing with moisture content to 17% moisture content [36]. Oxidative stress was identified as a critical prerequisite for aflatoxin production [37]. High temperature and drought, generated by climate change, are environmental stressors causing the buildup of reactive oxygen species (ROS) like hydrogen peroxide (H_2O_2) in the fungus [38]. The hypothesis is that the fungus induces biosynthesis of aflatoxin as a defense to counter these free radicals and reduce damage to the cell [3].

It has been suggested that aflatoxin production can have a functional role for the fungus, as ROS scavenging under oxidative stress and as a deterrent against frugivorous insects [11]. Such a relationship is supported by the fact that the expression of the aflatoxin gene cluster (*aflR* and *aflS*) in the environment is decimated by the antioxidant's introduction (caffeic acid, phenolic compounds, and selenium) and reduce toxin accumulation [37]. Also, gaseous composition (including CO_2 concentrations), pH (with the optimal range which is between 4 and 6), and the presence of nitrogen and carbon sources also control the toxigenicity of *Aspergillus* strains and metabolic activity [39].

7. Worldwide limits for aflatoxins in food

The control of AF in food and feed traces began in the late 1960s, and presently, about 120 nations have enacted specific regulatory limits to enable international trade and reduce health risks [40]. The multinational and national organizations set standards, and the Codex Alimentarius Commission, the United States Food and Drug Administration (US FDA), and the European Union (EU) are the main standards [41]. The EU has some limits in the world with 2 μg/kg (ppb) for AFB_1 and 4 μg/kg for total AFs in maize and peanuts that are eaten directly by humans [6]. The US FDA, like Brazil, China, and Ecuador, applies a higher level of 20 μg/kg for total AFs in human food [42]. In the East African Community (EAC), there are regulatory thresholds that have been passed to ensure food safety, with the maximum permissible level of AFB_1 at 5 μg/kg and total AFs at 10 μg/kg [43]. The acceptable levels of Aflatoxin M1 in milk, with the EU setting the levels at 0.05 μg/kg, and the US setting the levels at 0.50 μg/kg [42]. In these legal systems, the implementation of these rules in developing areas has been a main problem associated with food shortage, socioeconomic factors, and poor infrastructure [44].

8. Detection of aflatoxins

At the biological level, qualitative methods like UV fluorescence of special media, ammonia vapor test are cheap culture tools that allow separation of toxigenic and atoxigenic strains of fungi [45]. Identification of these strains is based on culture methods, such as green or blue fluorescence under UV light on coconut milk agar or detection of a color change when the vapors of ammonia are added [46], or modern molecular Polymerase Chain Reaction (PCR) assays [14]. Three types of analysis methods: immune-chemical, chromatographic, and spectroscopic used to detect and quantify AFs [47].

Several chromatographic and spectroscopic methods are utilized for detection and quantification of mycotoxins. Chromatographic techniques, including TLC, HPLC, and Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS), have been identified as reference standards because they are accurate [48]. TLC is a non-specific and low-cost screening method, but high-performance TLC (HPTLC) can enhance accuracy with specific mycotoxins such as AFs and ochratoxin A, but Gas chromatography (GC) is limited due to the low volatility of mycotoxins, though GC-MS is used for volatile mycotoxins like patulin. Liquid chromatography (LC), especially LC-MS/MS, is common in sensitive, selective, and has the capability of analyzing multiple mycotoxins at the same time without the need to be derivatized. The upgrade of sensitivity and separation efficiency is ultra-HPLC (UHPLC) and high-performance liquid chromatography (HPLC), which is combined with mass spectrometry detectors or fluorescence [49]. In the cutting-edge approach to detecting mycotoxins range and their metabolites in trace concentrations in complex food samples is LC-MS/MS [48]. Enzyme-Linked Immunosorbent Assay (ELISA) is the most used rapid immune-chemical method of high screening with high throughput, while immune-dipsticks and lateral flow devices (LFDs) are convenient and used during inspections [47]. Green methods of rapid, non-destructive, and real-time monitoring are explored using

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emerging and spectroscopic technologies, like Hyperspectral Imaging (HSI), Surface-enhanced Raman Spectroscopy (SERS), and biosensors [50]. Molecular-based methods, including Cluster Amplification Pattern (CAP) and multiplex PCR analysis, provide accurate ways to determine the genetic capability of fungi for toxins production by monitoring deletions in the aflatoxin biosynthesis gene cluster [51].

9. Management of aflatoxin production

Mycotoxin detoxification and prevention are done through a method that encompasses both the post-harvest and pre-harvest phases. The pre-harvest period is characterized by emphasizing proactive control initiatives like the cultivation of resistant crop varieties. Adoption of good farming practices, fertilization systems, and optimization of irrigation, effective pest management, and harvesting at the right time to reduce mycotoxin formation. After harvest, detoxification processes use three methodologies: chemical, where the use of ozone and chitosan is involved; biological, where microbial degradation pathways are exploited; and physical, where controlled drying processes and sorting are used. Other new ways that use applications of nanotechnology, plant-based extracts, and novel binding agents are developing the field and can be integrated into a multi-layered defense mechanism against contamination of mycotoxin in the food production chain [52].

Prevention by Good Agricultural Practices (GAPs), biocontrol (as atoxigenic *Aspergillus* strains), awareness campaigns, and predictive modeling, chemical (ozone and ammonization), bio-based (microbial degradation), and physical (irradiation, sorting) processes are applied to reduce aflatoxin in contaminated products [27]. Chemical (e.g., oxidation), physical (e.g., drying and adsorption), and biological (e.g., transgenic crops, competitive inhibition) are traits of aflatoxin contamination reduction. Protective effects are reported with feed additives and antioxidants (e.g., clay binders and polyphenols) [53]. To address contamination while maintaining food quality and nutritional integrity, researchers have developed three primary categories of mycotoxin reduction strategies [54].

Current management strategies involve a combination of physical, chemical, and biological control methods, with a growing emphasis on eco-friendly alternatives like biopesticides and natural plant extracts to prevent contamination and mitigate economic losses [55]. Effective management necessitates an integrated "farm-to-fork" approach, utilizing pre-harvest strategies like biological control with atoxigenic strains and crop resistance, alongside post-harvest interventions such as rapid drying, sorting, and innovative enzymatic or chemical detoxification [41].

9.1. Chemical Control of aflatoxin production

Chemical control in the production of aflatoxin has a lot of agents, such as inorganic and organic acids, oxidizing agents, alkalis, synthetic antioxidants, and fungicides [56]. One of the most effective and cost-effective methods of decontaminating feed is ammonium solutions or ammonification with gaseous ammonia, which irreversibly changes the molecular structure of the toxin [41]. The alkaline treatment process of nixtamalization using calcium hydroxide is an effective way of reducing the concentration of aflatoxin in maize by opening the lactone rings, in conditions of acidity such as digestion [57, 58].

Organic acids like propionic acids, tartaric, lactic, and citric have high inhibition rates (up to 92%) and convert aflatoxin B_1 to less toxic derivatives [48]. The most effective agents that can degrade AFs are oxidizing agents, like ozone, which reacts electrophilically with the C8–C9 double bond of the furan ring, and the reaction is efficient (up to 100 %) when alkaline pH levels are present [6]. The use of fungicides (cyprodinil, azoxystrobin, and fludioxonil) to prevent conidia germination and fungal growth, and a mixture of fludioxonil and cyprodinil is reported to be the most effective in decreasing contamination by up to 83% [38]. Synthetic antioxidants like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) help in preventing the growth of *A. flavus* [56, 59]. Zeolites activated by charcoal and other types of clays, like hydrated sodium calcium aluminosilicate (HSCAS) and bentonite, are used as chemical adsorbents that are added into the diet of animals to prevent absorption into the blood by binding toxins in the gastrointestinal tract [41, 42].

Antioxidant-based control measures against the production of aflatoxin, mainly based on oxidative stress, are a prerequisite to toxin production and fungal growth [60]. expressive of a defensive response to scavenge reactive oxygen species (ROS) and mitigate cellular damage caused by environmental

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stressors like drought and heat, aflatoxin biosynthesis is triggered by aflatoxigenic fungi, like *Aspergillus* section *Flavi* [61]. Consequently, the biological need of the fungus to produce toxins is reduced by the application of antioxidant compounds into the crop environment, thereby reducing the oxidative stress [37]. Propyl paraben (PP), BHT, and BHA are synthetic phenolic antioxidants which have great efficacy as fungi-toxicants. PP and BHA are effective in achieving 100 % inhibition of fungal growth as well as aflatoxin B_1 accumulation at concentrations of 10–20 mmol/L [62]. The application of BHT needs caution, since sub-inhibitory levels of the compound (e.g., 100 mg/L) have been observed to promote the aflatoxin production, which could be more than 6 times higher than untreated controls [63]. Antioxidants help in interfering with mitochondrial respiration, changing the cell membrane permeability, and suppressing the expression of the aflatoxin biosynthetic gene cluster, including *aflR* and *aflS* genes [1].

Phenolic acids and natural phytochemicals provide food-grade options for aflatoxin management [12]. Caffeic acid shows a strong anti-aflatoxigenic effect, which is able to decrease production of aflatoxin by over 95% without affecting fungal growth through inducing alkyl hydroperoxide reductases that deactivate organic peroxides [37]. Ferulic acid and trans-cinnamic acid are effective in inhibiting *A. parasiticus* and *A. flavus* populations in maize, and particular combinations show inhibition of aflatoxin B_1 under various water activity levels [12]. The other natural antioxidants, like tea polyphenols, gallic acid in walnut tannins, and isoflavones in peanuts, have also been shown to inhibit the production of toxin by regulating fungal oxidative stress responses [64].

Selenium (Se) biofortification is a new combined approach, which regulates the concentrations of aflatoxin and increases the nutritional value of crops [11]. Se does not inhibit the growth of fungi, but a non-lethal dose (0.86 µg/g) leads to a decrease in the maximum aflatoxin B_1 production by toxigenic strains. Antioxidant treatment by Se has been shown to enhance the Darwinian fitness of atoxigenic strains relative to toxigenic counterparts, which is a critical property to biocontrol strategies of competitive exclusion [11]. Additional layers of control are offered by biological extracts and essential oils (EOs) that have high antioxidant activity [60].

Oil of clove, rich in eugenol (83.25%), and blend essential oils of oregano, cinnamon, and lemongrass demonstrate synergistic inhibitory effects on toxin production and fungal growth by inducing ultrastructural damage to the hyphae and silencing early biosynthetic genes, such as *aflD* and *aflC* [30]. Lactic acid bacteria (LAB) have a role in bio-protection through the release of a cell-free supernatant (CFS) high in peptides and phenolic acids that supplement the functional antioxidants of crops like maize, which is effective in protecting against fungal infestation [15]. Pok et al. [65] tested the ability of three citrus flavonoids; neohesperidin, naringin, and quercetin to inhibit the accumulation of AF in maize contaminated with *A. parasiticus* and found an effective combination of flavonoids (0.24 mM neohesperidin, 0.39 mM naringin, and 0.40 mM quercetin), when applied to maize at 0.95 water activity (a_w), reduced AFB_1, AFG_1, AFB_2, and AFG_2 accumulation by 85% to 100%. This same mixture also shows high effects at a higher 0.98 a_w, achieving 93% to 98% reduction. Table (2) presents chemical agents as a strategy for reducing AFs in maize.

10. Conclusion

Aflatoxin contamination in maize remains a critical global issue due to its significant health risks and economic impacts, but the use of antioxidants presents a promising multi-faceted strategy for mitigation. Research indicates that oxidative stress acts as a prerequisite for aflatoxin biosynthesis, and therefore, the introduction of antioxidants, including elements like selenium, phenolic acids such as caffeic acid, and synthetic compounds like BHA or propyl paraben, can effectively suppress toxin production by alleviating this stress. Furthermore, certain antioxidants can selectively enhance the fitness of atoxigenic strains over toxigenic counterparts, which facilitate more effective biological control through competitive exclusion. While natural extracts, such as plant-based essential oils and organic acids, offer eco-friendly alternatives to traditional synthetic fungicides, the timing and concentration of their application are vital for efficacy. Ultimately, integrating antioxidant treatments into broader integrated pest management strategies, particularly through pre-harvest biofortification and improved post-harvest storage practices, is essential for ensuring the safety and nutritional quality of maize supplies worldwide.

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Table 2. The use of chemical control agents for reducing AF contamination by toxigenic fungi in maize substrates across affecting AFs-producing fungus and biosynthesis, and through decontamination of accumulated AFs.

Substrate	Toxigenic fungus	Initial toxin concentration	Chemical agent	Applied concentration	Toxin reduction (%)	Reference
Chemical control of aflatoxigenic fungi and AF biosynthesis						
Maize	*Aspergillus flavus* RCM89	109.65 ppm AFB_1	trans-cinnamic acid (CA)	25 mM	100%	[11]
			ferulic acid (FA)	30 mM		
			CA-FA mixture	25 + 30 mM		
Maize kernels	*A. flavus*	109.65 ppb AFB_1	trans-cinnamic acid (CA)	25 mM	100%	[12]
			Ferulic acid (FA)	30 mM		
			trans-cinnamic acid (CA) + Ferulic acid (FA)	25 mM + 30 mM		
Maize	*A. parasiticus*	0.12 ppm AFs	Propionic acid	0.25%	100%	[36]
		1.19 ppm AFs		0.5%		
		0.15 ppm AFs	Benzoic acid	0.3%		
		1.34 ppm AFs		0.5%		
		0.19 ppm AFs	Tartaric acid	0.4%		
Maize kernels	*A. flavus*	27.5 - 32.3 µg/kg AFB_1	Citric acid (in biopolymer formulation)	0.5%	81%	[67]
Maize	*A. flavus* NRRL 3357	1.95 µg/g AFB_1	Cinnamon, Oregano, Lemongrass Composite Essential Oil (COL-CEO)	0.6 - 1.0 µL/disc	67.53% - 72.68%	[61]
Maize	*A. flavus*	83 µg/kg AFB_1	Ozone	90 mg/L for 20-40 min	78% - 88%	[6]
Maize	*A. flavus*	0.01 µg/L AFB_1	Curcumin and blue light (430 nm)	1000 µM (for 14 days)	100%	[70]
Chemical control of accumulated AFs						
Maize	*A. flavus*	1000 ng/mL AFB_1 and 250 ng/mL AFB_2	Vanillic acid + laccase	1 mM	26% for AFB_1 and 26.6% for AFB_2	[66]
Maize	*A. flavus* and *A. parasiticus*	0.01 µg/L AFs	Ammonium bicarbonate	0.80%	100%	[68]
Maize flour	*A. flavus*	53.60 µg/kg AFB_1	Ozone (O3)	75 mg/L (for 60 min)	78.76%	
Maize	*A. flavus*	56.91 - 61.66 µg/kg AFB_1	Ozone	6 mg/hour	100%	[58]
Maize	*A. flavus*	358.6 µg/kg AFB_1	Free radicals (via power ultrasound)	1.65 W/cm3	21.2%	[69]

*ppm: part per million.

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Author's contributions

Marwa A. Mahmoud, **Abdallah M. A. Hassane**, and **Nageh F. Abo-Dahab:** Conceptualization, literature review, writing-original draft, preparation graphics and software, writing-reviewing and editing.

Conflict of interest statement

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Data Availability

No such data is used.

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