Zagazig Veterinary Journal, ©Faculty of Veterinary Medicine,
Zagazig University, 44511, Egypt.
Volume 52, Number 3, p-282:299 September 2024
DOI: 10.21608/zvjz.2024.302311.1252

REVIEW ARTICLE

The Potential Implication of Botanicals in Mitigating Mycotoxin Detrimental Effects: A Comprehensive Review

Gamal Shams, Esraa M. Fahmy, Emad Adeeb*, Ibrahim Abed, Ahmed Helal, and Tarek Khamis
Pharmacology Department, Faculty of Veterinary Medicine, Zagazig University, Zagazig 44511, Egypt.
*Corresponding author e-mail: eadeeb5@gmail.com

ABSTRACT

Secondary fungal metabolites known as mycotoxins are generated by numerous toxic fungal species and present in a variety of feed stocks, especially in plants that are subjected to pre- and post-harvest handling, storage, and transportation. They have potential to infect humans and animals with sickness. Because of mycotoxin's detrimental effects on health and economy, mycotoxins are a major threat to food security and safety. Under specific environmental conditions, such as high temperatures and humidity, together with unsuitable storage circumstances, mycotoxin release occurs and seeps into agricultural products, primarily crops as corn and soybean. It is vital to develop innovative approaches that can lessen the negative effects of mycotoxin contamination on the economy, trade sector, public health, and quality and nutritional content of food and feed while maintaining those benefits. Many tactics have been used to reduce the presence of mycotoxin contamination; however, they frequently lack the necessary effectiveness. Some active ingredients of therapeutic plants may be used as anti-mycotoxin. Extracts from a variety of plants, and many ingredients are commonly used to lessen the mycotoxicosis in both humans and animals. Enzymes were recently evaluated to determine if they can eliminate the mycotoxins during food preparation. The possibility of enzymes modification or their combination with other medications, still unclear and need more research. Specifically, the creation of β-cyclodextrin-based nano sponges that are encased in bioactive plant-derived substances to avoid growing toxic fungi and to eliminate the mycotoxin contamination from food and feed, all without endangering the health or environment of users. In order to prevent toxic fungal invasion and cleanse mycotoxins, this review demonstrates the application of herbal extracts and their phytochemicals. The purpose of this review was to clarify how the botanicals` substances in plant extracts could be used for mitigating mycotoxins without compromising the nutritional content of feed.
Keywords: Mycotoxins; Anti-mycotoxin; Broilers; Herbal extracts.

Introduction

The most common genera of toxic fungi producing mycotoxins are *Fusarium, Altenaria, Claviceps, Penicillium, Aspergillus,* and *Stachybotrys.* These mycotoxins have no discernible biochemical significance for the growth or development of fungi. Nonetheless, virulence, development, and pathogenicity are all influenced by certain secondary metabolites [1]. Contamination of food and feed by toxic fungi is a major health hazard that has been documented since agriculture and food production were first practiced by humans. As secondary metabolites, mycotoxins are produced by a variety of fungal species [2]. Mycotoxins with low concentrations may be toxic to humans and animals [1, 3]. Additionally, the growth of toxic fungus on food and feed is mostly encouraged by specific biotic conditions with temperature and humidity as environmental factors. Mycotoxin existence with high rates is typically found in countries in the tropics, like sub-Saharan Africa and Asia, due to the conditions are ideal for their growth. Food contamination can occur in any of the food chain's phases, from planting to harvest, together with handling, packing, shipping, and entire or retail transaction [2]. Pre-harvest, post-harvest, and throughout production, mycotoxins mostly infect commodities including nuts, cereals, grains, and by-products [4, 5]. Infected crops can also introduce toxins into the food chain through direct or indirect consumption by humans or animals using them as food sources. Consequently, they can be found in eggs, milk, and meat [6]. Once mycotoxins enter the food and feed chain, their harmful effects become permanent and are hard to be totally removed. In the agricultural sector, mycotoxins reduce the growth rates, fertility, immunity, and the production of eggs, milk and meat. They also raise the mortality rate [7]. Due to mycotoxins ability to cause severe toxic effects, including certain mutagenic, hepatotoxic, genotoxic, nephrotoxic, carcinogenic, teratogenic qualities, and immunosuppressive, mycotoxins have a wide range of health impacts which can lead to infections, such as hemorrhage, oedema, toxic hepatitis, hepatic carcinoma, immunosuppression and esophageal cancer. The most common mycotoxins that are significant to agriculture include ochratoxins (OTA), trichothecenes, fumonisins (FBs), aflatoxins (AFs), and zearalenone (ZEN). Because of the potential health concerns they offer to both humans and animals, they have received significant attention [8, 9]. Moreover, the contamination of food and feedstuffs by mycotoxins results in a reduction of their nutritional value, quality, and safety [6]. To reduce the risks to human and animal health that mycotoxins pose, several nations have set regulatory limitations on their presence in agricultural commodities [10]. Numerous strategies have been developed to prevent and regulate mycotoxins in feed and food. These techniques work well to stop the growth of toxic fungi and related mycotoxins formation before, during, and after food harvesting [6]. To disinfect mycotoxins, chemical procedures employ substances such as oltipraz, butylated hydroxytoluene, sodium hydroxide, hydrochloric acid, and butylated hydoxyxyanisole [11, 12]. Physical techniques include irradiation, ultraviolet light, pulsed light, cold plasma, and sorting, milling, and dehulling. The absorbents or binders such bentonite, zeolites, sepiolite clay, and activated charcoal are used in other physical processes successfully used to remove mycotoxins. However, obstacles to their routine application still exist, including high implementation prices, possible insufficient specificity, or selective action, poor adsorption, and lingering negative effects against certain mycotoxins [13]. Yeasts, probiotic bacteria, and their enzymes are used in microbiological approaches, which effectively reduce mycotoxin levels in food as well as feed [12]. However, these microbes and their enzymes frequently obstruct the flow of nutrients, producing unwanted byproducts. In addition, their applications are still restricted by by-products of enzymatic degradation [12]. Veterinary medicine uses plants and their extracts as a treatment to control a wide range of problems and diseases that face the veterinary medicine in general. Synthetic fungicides are typically used to control phytotoxic fungal species, but their use is gradually being restricted because of the harmful effects that pesticides have on one health [1]. Herbs, spices, essential oils, and crude extracts are examples of botanicals that offer excellent choices for the development of nutraceuticals and biofungicides intended to mitigate mycotoxicosis and associated illnesses. Additionally, it has been acknowledged that different plant parts, including the flower, leaves, stem, root, seed, and peels, continue to have an inhibitory effect on microbes, such as bacteria, fungi, and insects [14]. In general, botanicals are thought to be safer and more ecologically friendly sources of biological factors for the management of mycotoxins and fungi in food or feed [15, 16]. They offer a synergistic oncoming as protectors against contamination by fungi and mycotoxin and further activate the mechanisms in plant tissues that trigger their defensive mechanisms **(Figure 1)**. They are also more cost-effective than other materials used for the same purpose [16, 17]. They include a range of phytochemicals with pharmacological qualities that can be used to treat different illnesses. In order to reduce the growth of toxic fungus and mycotoxin contamination in food and feed, a recent study has looked into the potential use of herbals as nutraceuticals and bio-fungicides [9]. Because of their strong antibacterial properties, medicinal herbal extracts, essential oils, and phytochemicals have become popular choices seeking environmentally friendly preservatives to increase food and food product shelf life [18, 19]. We discuss the application of botanicals' solubility when used as biofungicides to stop growing of mycotoxigenic fungus and their contamination.

Herbal extracts for mitigation of fungi and mycotoxins

The value of herbals

In less developed countries, mycotoxins cause enormous financial losses in trade and agricultural output. According to estimates, mycotoxins may contaminate between 60 and 80 percent of crops worldwide, resulting in large financial losses [20]. Approximately 80% of people worldwide still receive their primary healthcare from traditional medicine, according to the World Health Organization [21]. Additionally, a recent investigation has sparked the interest in both developed and developing nations' usage of herbal and their components as nutraceuticals in this regard [9]. Because they are widely distributed geographically and abundant in nature, plants are an advantageous tool for drug discovery. Because of their application in conventional medicine, a sizable number of pharmaceuticals have been manufactured from plants [22]. Africa possesses an abundance of therapeutic herbs. Nevertheless, there is a need for more research in this area because few studies discussed using their components for mycotoxin detoxification [23]. An overview of different herbals with antifungal properties can be found in the sections below. Additionally, in order to increase availability, determine the strongest efficacy of herbal, and improve the stability against oxidation and degradation, we employ a nano encapsulation strategy through the creation and application of Nano sponges.

Using phytochemicals as therapeutics

As a defense against harmful microbes, insects, and unfavorable environmental circumstances, plants create secondary metabolites. Phytochemicals as metabolites are some non-nutritive extent, and these called essential oils [24]. Nonetheless, because of their antibacterial qualities, they can shield humans and animals against some illnesses brought on by germs or toxins connected to them [25, 26]. Metabolites are the most promising chemo-preventative agents for future medication development and study. According to their chemical structures, the principal classes of phytochemical substances that have been found to date are different [27]. Chlorophyll, organic acids, carotenoids, essential oils, tannins, aromatic acids, glucosinolates, flavonoids, phytosterols, carotenoids, tocols, terpenoids, and proteases inhibitors are some of these main groups [15]. Because these substances have antioxidant, anti-inflammatory, anti-mutagenic, antigenotoxic, antibacterial, anthelmintic, anticarcinogenic, and antiproliferative qualities, they may function either directly or indirectly to fend off diseases or pathogens [28, 29]. To improve the growth performance, disease management, and product quality, natural herbs such as spices, fragrant oils, olives, and plant extracts should be mixed with animal feed [30].

The impact of herbal extracts and their phytochemical components on mycotoxin and their capacity for detoxification

Mycotoxins' toxic and genotoxic effects can be mitigated by plants through the presence of antimutagens, antimicrobials, antioxidants, or anticarcinogens [31]. Antioxidants protect the cell membranes Fand macromolecules by scavenging free radicals [32]. Furthermore, phytochemicals causing fungi cytotoxicity through altering osmotic and redox balance, disrupting cell membrane permeability and functions, and inhibiting enzymes involved in the synthesis of cell wall components, cytoplasmic and mitochondrial enzymes, and cell compartments [33]. Nevertheless, xenobiotic detoxification and biotransformation pathways are also induced by herbal extracts and their constituents also phytochemicals have the ability to both trigger enzymes for phase II detoxification and stop the enzymes that cause phase I carcinogens activation [34]. In food and feed, the bioactive chemicals utilized as additions in plants to prevent the growth of fungi and the contamination of aflatoxin (AF) (Table 1). It will be leading to lowering the hazards associated with the mutagenic and carcinogenic properties of mycotoxins such AFs [35].

Table 1: list of studies on how plant extracts and their constituents affect the toxicity caused by mycotoxins

Defending agent	Scientific name	Tested mycotoxin	Mode of action	References
Turmeric	*Curcuma longa*	Aflatoxins toxicity	Protective effects against aflatoxins toxicity and oxidative damage. Thymidine uptake 1 (TUP1) is suppressed when proteinase production is reduced and H+-ATPase activity is inhibited, which results in acidification of the extracellular and intracellular matrix and inhibition of hyphae formation.	[36, 37]
Tomatoes	*Solanum lycopersicum*	T-2 toxin, aflatoxins, ochratoxins, and zearalenone	Reduced T-2 toxin-induced oxidative stress and protected against oxidative, inflammatory, hormonal, and reproductive damage in mice produced by AFB1, ochratoxins, and zearalenone.	[38]
Silybum	*Silybum marianum*	ochratoxins toxicity	Inhibited ochratoxins toxicity.	[23]
Cherry	*Withania somnifera*	ochratoxins toxicity	Inhibited ochratoxins toxicity in vivo.	[23]
Rosemary	*Rosmarinus officinalis*	*A. flavus* mycelium.	Lowers the amount of ergosterol produced and the biomass of *A. flavus* mycelium.	[39]
Clove	*Syzygium aromaticum*	Hyphae	Induces both early (nuclear condensation) and late (plasma membrane damage) apoptosis in hyphae. It also downregulates the genes in charge of protein and fat metabolism in fungi, namely lipase (*lipA*), metalloprotease (*metP*), and secondary metabolism global regulator (*laeA*).	[40]
tannic acid	Tannins	Mycelium	Production of reactive oxygen species, which leads to mitochondrial malfunction and rupturing of the plasma membrane.	[41]

Green tea	*Camellia sinensis*	*Candida* spp.	Lesions form on the cell membrane as a result of cellular and plasma membrane damage, enhanced membrane permeability and a decrease in membrane integrity, which leads to an osmotic imbalance and ultimately, cell death of *Candida* spp.	[41]
Origanum	*Origanum vulgare*	Ergosterol synthesis	Prevents the release of cellular ions after ergosterol synthesis. Suppression of methylglyoxal and lipid peroxidation in situ.	[42]
Camphor	*Cinnamomum camphora*	Mycelium	Reduces ergosterol production and biomass of mycelium.	[39]
Moringa leaf extract	*Moringa oleifer*	Mycelium	The group that received treatment with moringa saw a reduction in DNA damage, p53 gene suppression, improved blood balance, less damage to the liver and kidneys, and an improvement in the histological image.	[43]
Red ginseng extract	*Panax ginseng Meyer*	Aflatoxin	After four weeks of injection, red ginseng (150 mg/kg body weight) alleviated the histological and biochemical changes brought on by the aflatoxins in rats.	[44]
Holy basil and Ajwain	*Ocimum tenuiflorum (OT)* and *Trachyspermum ammi*	Aflatoxin	Ajowan eliminates the aflatoxins, while ochratoxins decreases the formation of aflatoxins.	[10]
Tea tree oil	*Melaleuca alternifolia*	Aflatoxin	A kilogram of food containing one milliliter of tea tree oil helps reduce the gliosis and oedema caused by aflatoxin-induced brain damage.	[45]
Genkwanin	A non-glycosylated flavonoid	Aflatoxin B1	Against the biochemical, inflammatory, and histological damage that aflatoxin B1 causes in rats.	[2] [46][1]

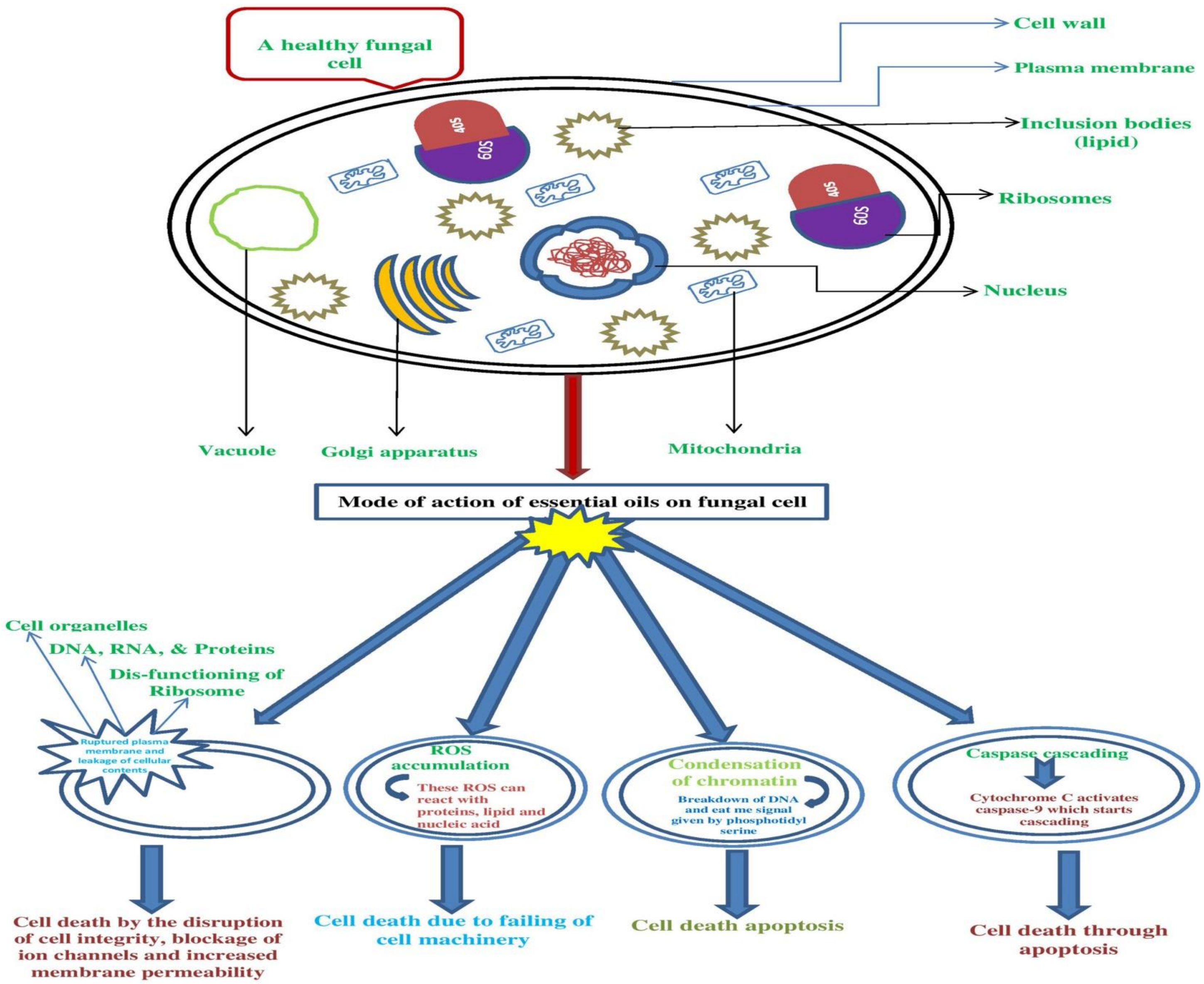

Figure 1: Probable mechanism of actions of essential oils/phytochemicals and their formulations against mycotoxins producing fungi [18]. https://ifst.onlinelibrary.wiley.com/doi/10.1111/ijfs.15563

Herbal plants with potential antioxidant properties were investigated for their antifungal and anti-mycotoxigenic properties against phytopathogenic fungal strains such as, *Fusarium verticillioides*, *A. flavus*, and *A. ochraceous*. According to the findings, the chosen medicinal herbs may be utilized to find biofungicides that could stop food spoiling caused by oxidation [9]. Wild stevia extracts have been shown to have antifungal, antioxidant, and anti-mycotoxigenic qualities against *A. flavus*, *A. ochraceus*, *A. niger*, and *F. moniliforme* [47]. In addition, it has been discovered that essential oils can successfully control the growth of mycotoxigenic fungi and the mycotoxins they produce, including *Penicillium citrinum*, *F. moniliforme*, *F. graminearum*, *Alternaria alternata*, *A. favus*, *A. oryzae*, *A. niger*, and *P. viridicatum*[48]. Applying *Carum carvi L* essential oil at concentration of 1.5 μL/g showed total inhibition of *A. parasiticus* growth, and similarly, 4.5 μL/g showed complete inhibition of *A. flavus* growth in addition to the strain's ability to secrete aflatoxins in polenta. Furthermore, it was observed that 50.0 µL/g of *Juniperus communis L.* essential oil completely prevented A. *flavus* from producing aflatoxin in polenta, whereas a concentration of 35.0 µL/g of *J. communis L.* essential oil demonstrated high effectiveness against *A. flavus* IKB and *A. parasiticus*, with percentage inhibition ranging from 42.4 to 79.8% [49]. Examples of chemicals that have been extracted from plants and utilized as supplements for food and feed are curcumin and ellagic acid. These substances enhance the glutathione-S-transferase activity, which is involved in xenobiotic detoxification, and inhibit the metabolism of aflatoxin B1 (AFB1). They were also discovered to be protective against the mutagenicity of strains TA98 and TA100 of *Salmonella* Typhimurium caused by AFB1, both in rat and chicken models and via the Ames experiment [50]. Numerous publications have previously shown that curcumin exhibits antimutagenic, anticarcinogenic, and antiproliferative characteristics against a range of mutagens in both vitro and vivo settings [51]. The natural substance that was extracted from grape skin is called resveratrol, which can both in vitro and in vivo prevent mycotoxin-induced toxicity [52]. Tomatoes, papayas, and other red fruits and vegetables naturally contain lycopene, a substance that has been shown to protect mice from reproductive, hormonal, and *Zearalenone* oxidative damage [53]. Additionally, lycopene decreased the oxidative stress and apoptosis that AFB1 and OTA caused in rats [38]. The ability of a few particular natural culinary spices such as garlic, fenugreek, ginger, clove, sacred basil, lemongrass, and thyme to degrade food. These spices are generally used by the Ethiopian community to flavor and preserve food. By identifying the toxin in samples treated and untreated with extract, the effectiveness of the spice extracts in reducing aflatoxin was examined using electrochemical and LC-MS/MS (Liquid chromatography–mass spectrometry–more specifically) techniques. After one hour of exposure to the AFB1 standard at 25 °C, the findings indicated that garlic had the highest AFB1 degrading activity, then the other dietary spices and lemon. The outcomes also demonstrated that chemical change of the AFB1 parent could be a potential mechanism of AFB1 degradation [30]. Olive pomace extract has an inhibitory action against plant pathogens as *Fusarium oxysporum*, *Pythium spp.*, *Sclerotinia sclerotiorum*, *Verticillium dahlia*, and *Botrytis cinerea* [54]. Plant extracts from *Corymbia citriodora* produce different chemicals looked into the detoxification of AFB1 and AFB2 in vitro and in vivo. After 72 hours of incubation, they found that the leaf extracts had reached their maximal detoxifying at pH 8 and 30 °C. *Trachyspermum ammi* seed extracts have been shown to be useful in the creation of herbal supplements for food and feed that are safe for biological systems. *Rosmarinus officinalis*, *Origanum vulgare*, *Psidium cattleianum*, and *Passifora aqueous* plant extracts' capacity to alata to degrade AFB1 was assessed. After 48 hours of incubation, the extract from *Rosmarinus officinalis* showed the highest percentage of AFB1 degradation (range: 49.0–60.3%), followed by *O. vulgare* (range: 30.7%–38.3%) [55]. Plant extracts' antigenotoxicity against genotoxicity produced by AFB1 was examined and the results demonstrated that, in both the Vitotox and Ames tests, the majority of plant extracts from various species, including *Xylopia parviflora, Rhoicissus sekhukhuniensis, Podocarpus henkellii, Podocarpus elongatus, Agapanthus praecox, Helichrysum petiolare, Hexalobus monopetalus, Friesodielsia obovate, Monanthotaxis caffra*, *Protea hybrid*, *Protea roupelliae*, *Monodora junodis*, *Uvaria caffra*, and *Xylopia parviflora* showed moderate to strong antimutagenic potency [56]. Feed additives made from medicinal plants found in South Africa, namely *Silybum marianum, Centella asiatica,* and *Withania somnifera,* were found to offer some protection against the growth inhibitory effect of OTA and the resulting immunosuppression in broiler chicks. However, only *Centella asiatica* showed this protective effect [23]. The *S. marianum* extracts showed some hepatoprotective advantages on broiler chicks exposed to OTA, in addition to a nephroprotective impact against OTA toxicity. A recent evaluation examined the application of ginger essential oils (GEO) as a fumigant agent for maize grains that have been kept by Nerilo *et al.* [57]. According to their analysis, geranial (14.16%) and α-zingiberene (23.85%) make up the majority of GEO. Additionally, their findings showed that *A. flavus* was suppressed and that 25 and 50 µg/g, respectively, showed antifungal action against AFB1 and AFB2 synthesis. The application of utilizing phytochemicals and their unrefined extracts as nutraceuticals and biofungicides is subject to certain restrictions, even though compounds found in plant extracts are effective in controlling toxic fungus and their poisons. These restrictions are expanded upon in the section that follows. Applying bioactive plant components or metabolites is one of the most beneficial ways to minimize exposure to these mycotoxins and the detrimental impacts they have on health [3, 31]. Many secondary metabolites found in medicinal plants, which has been demonstrated that certain substances, such as alkaloids, polyphenols, terpenoids, flavonoids, and tannins, exhibit the in vitro fungitoxic qualities indicated in Table 1.

Present restrictions on phytochemicals' applications as biofungicides

Concerns regarding the toxicity, safety, and quality of these goods are raised by the growing requirement for the usage of herbal extracts and their constituents. The mycotoxins can contaminate plant materials that have therapeutic qualities [31, 58]. Moreover, the mutagenesis and toxicity were denoted for numerous plant extracts used as food additives and in conventional medicine. Because of this, a careful evaluation of their toxicological characteristics is required. Priority is given to those who don't exhibit any toxic behaviors [31]. Utilizing plant extracts, particularly their bioactive components, is beneficial for the identification and creation of novel antifungal and nutraceutical drugs, as an alternative to traditional fungicides, phytochemicals that are bioactive and their derivatives that have potent antifungal and anti-mycotoxigenic qualities should be regularly evaluated due to the prevalence of harmful fungal manifestations. Additionally, formulations for nanoencapsulation are provided, showing a low-side-effect synergistic activity between encapsulate and phytochemical. When compared to conventional antifungal agents, using antifungal medications in natural formulations offers safe, efficient, and environmentally friendly properties against mycotoxins and fungus, making them excellent for using in agricultural [59]. According to a previous research, it is possible to completely comprehend the fundamental principles of phytochemicals' anti-mycotoxigenic and anti-fungal mechanism of action in opposition to mycotoxigenic fungi by doing the following **(Figure 1)** [42]:-

- Suppression of ergosterol production, a significant sterol that controls the biogenesis of plasma membranes.

- Fungal cell membrane rupture.
- Generation of ROS, or oxidative stress which caused by reactive oxygen species.

When combined with phytochemicals, nanoencapsulation (such as nanofiber, nanotube, nanogel, nanoemulsion, nanoliposome, nanosponge, and nanoparticle) offers viable paths to investigate potential tactics to increase effectiveness and battling fungus resistance in situations where traditional antifungal medications fail [26]. The significance and urgency of big data strategies for quickening the process of identifying active components were highlighted by Powers *et al.* [48]. They assessed the ability of 82 essential oils to fight against fungal growth such as *Candida albicans*, *Candida niger*, and *Candida neoformans* using a vast amount of data. The outcomes showed that the properties of the essential oils antifungal susceptibility were like this: A. *Niger* > *C. albicans* > *C. neoformans*. However, the full range of applications for phytochemical substances is limited by their use alone. Their inability to alter the organoleptic properties of food or feed, high volatility, low bioavailability, instability, and lack of infrastructure and supplies for their extraction and filtration are the reasons for this limitation [15, 33]. Coherent partnerships in research between universities, research centers, governmental organizations, the food and pharmaceutical businesses and worldwide stakeholders are necessary to overcome these challenges. Furthermore, a variety of cutting-edge technologies, such nanotechnology, may be able to partially address few of these limitations [24, 58]. To elicit the factors indicated above, phytochemical substances may be contained in edible coatings or combined with nanoparticles, as those found in nanosponges [33, 58].

Modern technology for modifying the botanicals to detoxify mycotoxins

Advances in nanotechnology have resulted in a large number of uses in nanomedicine including the agricultural industry. There has been substantial progress in the application of nanotechnology to lower mycotoxin contamination in agriculture in the feed and food supply chain [58]. The utilization of plant phytochemicals to produce nanoparticles has substantially enhanced their suitability as mycotoxin-detoxifying agents in agriculture in the era of green nanotechnology [58]. Herbal extracts and their phytochemicals combined with nanotechnology have demonstrated notable benefits in the pharmaceutical, agricultural, and cosmetic sectors because of their enhanced surface area and ability to protect the included substances from environmental influences that are both internal and external, phytochemicals encapsulated in nanoparticles have shown considerable efficacy over their free form [24]. In addition to offering regulated release of antifungal substances to create active packaging that preserves feed and food integrity during storage, nanocarriers can protect bioactive phytochemical substances against heat and photodegradation, preventing fungal development and mycotoxin contamination [60]. Additionally, these plant-based medications' harmful effects were lessened [61]. Various nanocarriers, such as liposomes, polymeric nanoparticles, metal nanoparticles, nanosponges, and polymeric micelles, are currently employed for drug delivery. When it comes to medication delivery methods for plant based goods in cosmetics, medicine, and agriculture, all of these nanocarriers have been shown to be successful [7]. This work emphasizes the utilization of cyclodextrin nanosponges as phytochemical carrier vehicles since, regrettably, there isn't much information in the literature about the use of biofungicides encapsulated in nanosponge form.

Using nanosponges to encapsulate the phytochemicals with antifungal and detoxifying properties

There are various types of nanosponges, but cyclodextrin is the most popular and has great potential for encapsulating phytochemicals. Cyclodextrin nanosponges are naturally occurring polymers made of an oligosaccharide ring that are produced by the enzymatic breakdown of starch. It is simple to modify significant physicochemical characteristics of the nanomaterials, such as the size of the polymeric mesh, polarity, and release of integrated bioactive molecules, by using different kinds of cross-linkers and adjusting the degree of cross-linking, which is a fascinating characteristic of nanosponges based on cyclodextrin [48]. According to Haimhoffer *et al.* [62], cyclodextrins have three well-known isomers: alpha (α), beta (β), and gamma (ɣ). These isomers contain the inclusion and exclusion of forms with various medications to enhance their cytotoxicity, solubility, permeability, and stability [63]. In order to mitigate fungal invasion and mycotoxin contamination, the usage of nanosponges can be very important. Very few researches have looked into the application of nanosponges in mycotoxicology, despite their many uses and advantageous qualities. In aqueous solutions, Thipe *et al.* [7] examined the OTA sorption capacity and properties of a nanosponge based on β-cyclodextrin (polyurethane-cyclodextrin polymer). According to the findings, materials made of cyclodextrin nanosponge effectively decreased the amounts of OTA in spiked aqueous solutions, which ranged from 1 to10 μg/L. It was indeed possible to bring the amounts of OTA in polluted red wine down to throughout the permissible limits of 2 μg/L, from as high as 10 μg/L. Additionally, a highest level of binding capacity of 220 μg OTA per g of polymer was revealed by deduction from the *Langmuir isotherm* for nanosponge sorption data. In another study, β-cyclodextrin and methylene bis-diphenyl diisocyanate were combined in a 1:5 ratio to create a sorbent material for solid phase extraction based on a nanosponge [7]. The β-cyclodextrin polyurethane polymer, a new polymer, was utilized to remove and purge OTA from wine with grape juice. According to the findings, the range of OTA recoveries (0.5–20 ng/mL) in the spiked beverages was 69.1–86.5% in grape juice and 77.0 – 89.4% in wine. Also, the study was conducted wherein polyurethane-β-cyclodextrin polymers, namely those cross linked with tolylene 2,4-diisocyanate, were produced. The complex that resulted showed communities of binding sites that helped in the extraction of patulin from apple juice [64]. In Tg (vtg1: mCherry) zebrafish embryos and HeLa cells, Hungarian researchers looked at how β-cyclodextrin counteracted the negative effects of ZEN, a xenoestrogenic mycotoxin. The findings showed that at pH 7.4 (K = 1.4 – 4.7 × 104 L / mol), ZEN could create stable combinations with β-cyclodextrins that are methyl-, sulfobutyl-, and succinyl-methyl-substituted. The resulting complexes, or modified cyclodextrins, significantly decreased or completely abolished the death caused by HeLa cell loss of viability and ZEN in zebrafish embryos. Sub-lethal consequences of ZEN were further mitigated by co-treatment with β-cyclodextrins [65]. The fluorescence and molecular spectroscopy techniques were used to examine the relationship between alternative toxin and γ- and β-CDs. They also looked at employing the unsolvable β-CD bead polymer (BBP) to recover the mycotoxin alternative found in aqueous (water-based) solutions. The findings showed that natural γ-CD at pH 7.4 significantly boosted alternatives' fluorescence. Such alternatives formed the highest stable complexes with natural γ-CD and quaternary ammonium derivatives at pH 10.0, which is acidic / physiological. Moreover, alternariol toxin was effectively extracted from aqueous medium by β-CD bead polymer (BBP). The polymer's β-CD component significantly enhanced the ability of BBP to bind alternariol [66]. The effects of selectively encasing hydroxypropyl-β-cyclodextrin (HPCD) and star anise essential oil (SAEO) on the oil's composition, volatility, stability, and antibacterial action. The findings indicated that encasing (SAEO) improved its antibacterial stability in a 24-hour period and significantly reduced its offensive smell. Additionally, it improved the SAEO's ability to inhibit *Rhizopus stolonoifer, Saccharomyces cerevisiae, and E. coli* [67]. The effectiveness of β-cyclodextrin nanosponges in encasing the polyphenols chlorogenic acid, rutin, and phloridzin assessed by using 1,1′-carbonyldiimidazole as the cross linker in a 1:3 ratio of nanosponge /cross linker. The findings demonstrated that rutin had the highest encapsulation effectiveness (83.7%), followed by chlorogenic acid (77.5%) and phloridzin (87.2%), with hydrogenated diisocyanato dicyclohexylmethane (HMDI) showing the best outcomes [68]. The impact of cyclodextrins (CDs) and the matrix of olive pomace extract on the intestinal permeability and bio-accessibility of the primary polyphenols found in olive pomace was assessed by *Radić et al*.[54]. Furthermore, the encapsulation of these polyphenols with cyclodextrins led to a significant increase in the tyrosol's bioaccessibility by creating inclusion complexes and blocking tyrosol from adhering to reaction combinations contain bile salts and other macromolecules that mimic the breakdown of olive pomace extract. The encapsulating of phytochemicals in cyclodextrin-based nanosponges for use as nutraceuticals and biofungicides to combat mycotoxigenic fungus and mycotoxins has not been studied, despite the acknowledged pharmacological potency because of their ability to bind and neutralize, nanosponges may be extremely important in this era of the fourth industrial revolution (4IR), in the detoxification of mycotoxins [66]. Since nanoemulgels, also known as integrated hydrogel cellulose nanosponges, have garnered the interest of many scientists have worked on the discovery and creation of different medications, and cyclodextrins as nanosponges, which widely used in a variety of applications. These are polymeric emulsion systems that reinforce the food packaging's total antifungal activity industry by combining the complementary synergistic capabilities of hydrogels and nanofibers or nanosponges [69]. The lemongrass oil that was encapsulated shown increased action against Candida albicans by an antifungal agent [70]. Although it is still in its infancy, nanoemulgels are extensively used in the medical field and are also being used in agriculture. Nonetheless, as an alternative to traditional antifungal treatments in the agriculture industry, nanoemulgels are expected to gain more traction. To assess a nanoformulation's overall ecotoxicology, cycle analysis of any nanoformulation intended for agricultural uses must be done first.

Conclusion

As phytotoxic fungal inhibitors, a variety of plant extracts and essential oils may provide an option to manage adulteration of mycotoxin in feed and food. Food contamination throughout the pre-harvest and post-harvest phases can produce fungi toxin, which can cause significant financial losses. The mycotoxins are effective even at low doses. The pharmacological and nutraceutical characteristics of phytochemicals, which have antifungal actions, were recognized. This decade has seen a lot of research on the application of phytochemicals to protect birds against the harmful effects of mycotoxins. To further combat the detrimental impacts of mycotoxins and reinstate poultry farming, several extensive research utilizing existing or innovative additives and using them simultaneously are required. Finding substitute methods for detoxifying mycotoxin is crucial for maintaining food safety. It was seen from the research reviewed here that mycotoxins can be reduced or detoxified with minimal to no adverse effects when botanical extracts and their phytochemicals are used in conjunction with nanosponge encapsulation technology. The effectiveness of herbal extracts or their utilizing phytochemicals to remove mycotoxin contamination can be enhanced by based-nanosponge encapsulated herbal extracts or bioactive substances, as in this review. With potent mycotoxin-inhibiting and antifungal properties, these bioactive compounds are very effective at low concentrations and further boost the bioavailability of safe, bioactive substances used as fungicides in agriculture that don't harm the environment. Many natural items are being utilized in medical applications. as well as the mitigation of mycotoxin toxicity; this includes binders like charcoal, herbal items like cumin or black seeds, garlic, and sustaining therapies like vitamin C, E, and A. In the future, the government agencies ought to specific actions to reduce the spread of mycotoxins; via means of food laws and regulations storing and calculating the levels of mycotoxin throughout the times of storage.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Jamil, M.; Khatoon, A.; Saleemi, M.K.; Abidin, Z.U.; Abbas, R.Z.; Ul-Hassan, Z.; Bhatti, S.A.; Irshad, H.; Imran, M. and Raza, Q.S. (2024): Use of phytochemicals to control the Mycotoxicosis in poultry. JWPR, 80(1): 237-250 .

[2] Onyeke, C.C. (2020): Review of mycotoxins in foods in Nigeria. Food Control, 118: 107376 .

[3] Hernandez-Valdivia, E.; Valdivia-Flores, A.; Cruz-Vazquez, C.; Martinez-Saldaña, M.; Quezada-Tristan, T.; Rangel-Muñoz, E.; Ortiz-Martinez, R.; Medina-Esparza, L. and Jaramillo-Juarez, F. (2021): Diagnosis of subclinical aflatoxicosis by biochemical changes in dairy cows under field conditions. Pak Vet J, 41(1) .

[4] Balendres, M.A.O.; Karlovsky, P. and Cumagun, C.J.R. (2019): Mycotoxigenic fungi and mycotoxins in agricultural crop commodities in the Philippines: A review. Foods, 8(7): 249 .

[5] Gbashi, S.; Madala, N.E.; De Saeger, S.; De Boevre, M.; Adekoya, I.; Adebo, O.A. and Njobeh, P.B. (2018): The socio-economic impact of mycotoxin contamination in Africa. Mycotoxins-Impact and Management Strategies .

[6] Hojnik, N.; Cvelbar, U.; Tavčar-Kalcher, G.; Walsh, J.L. and Križaj, I. (2017): Mycotoxin decontamination of food: Cold atmospheric pressure plasma versus “classic” decontamination. Toxins, 9(5): 151 .

[7] Thipe, V.C.; Bloebaum, P.; Khoobchandani, M.; Karikachery, A.R.; Katti, K.K. and Katti, K.V. Green nanotechnology: nanoformulations against toxigenic fungi to limit mycotoxin production. Nanomycotoxicology: Elsevier; 2020 .p. 155-188.

[8] Ashraf, A.; Saleemi, M.K.; Mohsin, M.; Gul, S.T.; Zubair, M.; Muhammad, F.; Bhatti, S.A.; Hameed, M.R.; Imran, M. and Irshad, H. (2022): Pathological effects of graded doses of aflatoxin B1 on the development of the testes in juvenile white leghorn males. Environmental Science and Pollution Research, 29(35): 53158-67 .

[9] Dikhoba, P.; Mongalo, N.; Elgorashi, E. and Makhafola, T. (2019): Antifungal and anti-mycotoxigenic activity of selected South African medicinal plants species. Heliyon ,5(10) .

[10] Haque, M.A.; Wang, Y.; Shen, Z.; Li, X.; Saleemi, M.K. and He, C. (2020): Mycotoxin contamination and control strategy in human, domestic animal and poultry: A review. Microbial pathogenesis, 142: 104095 .

[11] Palade, L.M.; Pertea, A.M. and Taranu, I. (2021): Response of antioxidant status in kidney of pigs exposed to aflatoxin B1 to dietary grape seed meal. Archiva Zootechnica, 24(1): 17-30 .

[12] Karlovsky, P.; Suman, M.; Berthiller, F.; De Meester, J.; Eisenbrand, G.; Perrin, I.; Oswald, I.P.; Speijers, G.; Chiodini, A. and Recker, T. (2016): Impact of food processing and detoxification treatments on mycotoxin contamination. Mycotoxin research, 32: 179-205 .

[13] Çelik, K. The efficacy of mycotoxin-detoxifying and biotransforming agents in animal nutrition. Nanomycotoxicology: Elsevier; 2020. p. 271-284.

[14] Saleemi, M.K.; Ashraf, K.; Gul, S.T.; Naseem, M.N.; Sajid, M.S.; Mohsin, M.; He, C.; Zubair, M. and Khan, A. (2020): Toxicopathological effects of feeding aflatoxins B1 in broilers and its ameliosration with indigenous mycotoxin binder. Ecotoxicology and environmental safety, 187: 109712 .

[15] Adebo, O.A. and Gabriela Medina-Meza, I. (2020): Impact of fermentation on the phenolic compounds and antioxidant activity of whole cereal grains: A mini review. Molecules, 25(4): 927 .

[16] Prakash, B.; Kedia, A.; Mishra, P.K. and Dubey, N. (2015): Plant essential oils as food preservatives to control moulds, mycotoxin contamination and oxidative deterioration of agri-food commodities–Potentials and challenges. Food control, 47: 381-391 .

[17] Meng, D.; Garba, B.; Ren, Y.; Yao, M.; Xia, X.; Li, M. and Wang, Y. (2020): Antifungal activity of chitosan against Aspergillus ochraceus and its possible mechanisms of action. Int J Biol Macromol, 158: 1063-1070 .

[18] Kumar, P.; Mahato, D.K.; Gupta, A.; Pandhi, S.; Mishra, S.; Barua, S.; Tyagi, V.; Kumar, A.; Kumar, M. and Kamle, M. (2022): Use of essential oils and phytochemicals against the mycotoxins producing fungi for shelf-life enhancement and food preservation. IJFST, 57(4): 2171-2184

[19] Murtaza, B.; Li, X.; Dong, L.; Saleemi, M.K.; Iqbal, M.; Majeed, S.; Ali, A.; Li, G.; Jin, B. and Wang, L. (2023): In-vitro assessment of a novel plant rhizobacterium, Citrobacter freundii, for degrading and biocontrol of food mycotoxin deoxynivalenol. Toxicon, 227: 107095 .

[20] Eskola, M.; Kos, G.; Elliott, C.T.; Hajšlová, J.; Mayar, S. and Krska, R. (2020): Worldwide contamination of food-crops with mycotoxins: Validity of the widely cited ‘FAO estimate’of 25%. Crit rev food sci nutr, 60(16): 2773-2789 .

[21] World Health Organization. Programme on Traditional Medicine. (2001). Legal status of traditional medicine and complementary/alternative medicine : a worldwide review. WHO/EDM/TRM/2001.2(1/3/2024).

[22] Dias, D.A.; Urban, S. and Roessner, U. (2012): A historical overview of natural products in drug discovery. Metabolites, 2(2): 303-336 .

[23] Stoev, S.; Njobeh, P.; Zarkov, I.; Mircheva, T.; Zapryanova, D.; Denev, S. and Dimitrova, B .(2019) :Selected herbal feed additives showing protective effects against ochratoxin A toxicosis in broiler chicks. World Mycotoxin J, 12(3): 257-268 .

[24] Prakash, B.; Kumar, A.; Singh, P.P. and Songachan, L. (2020): Antimicrobial and antioxidant properties of

phytochemicals: Current status and future perspective. Functional and preservative properties of phytochemicals: 1-45 .
[25] Shin, B. and Park, W. (2018): Zoonotic diseases and phytochemical medicines for microbial infections in veterinary science: current state and future perspective. Front Vet Sci, 5: 166 .
[26] Redondo-Blanco, S.; Fernández, J.; López-Ibáñez, S.; Miguélez, E.M.; Villar, C.J. and Lombó, F. (2020): Plant phytochemicals in food preservation: Antifungal bioactivity: A review. J Food Prot, 83(1): 163-171 .
[27] Das, S.; Chaudhari, A.K.; Singh, A.; Singh, V.K.; Dwivedy, A.K. and Dubey, N.K. Foodborne microbial toxins and their inhibition by plant-based chemicals. Functional and preservative properties of phytochemicals: Elsevier; 2020. p. 165-207.
[28] Velu, G.; Palanichamy, V. and Rajan, A.P. (2018): Phytochemical and pharmacological importance of plant secondary metabolites in modern medicine. Bioorganic phase in natural food: an overview: 135-156 .
[29] Lahlou, Y.; Rhandour, Z.; Amraoui, B. and Bamhaoud, T. (2019): Screening of antioxidant activity and the total polyphenolic contents of six medicinal Moroccan's plants extracts. J Mater Environ Sci, 10(12): 1332-1348 .
[30] Negera, M. and Washe, A.P. (2019): Use of natural dietary spices for reclamation of food quality impairment by aflatoxin. J Food Qual, 2019(1): 4371206 .
[31] Makhuvele, R.; Naidu, K.; Gbashi, S.; Thipe, V.C.; Adebo, O.A. and Njobeh, P.B. (2020): The use of plant extracts and their phytochemicals for control of toxigenic fungi and mycotoxins. Heliyon, 6(10) .
[32] Wu, Q.; Wang, X.; Nepovimova ,E.; Wang, Y.; Yang, H.; Li, L.; Zhang, X. and Kuca, K. (2017): Antioxidant agents against trichothecenes: new hints for oxidative stress treatment. Oncotarget, 8(66): 110708 .
[33] Loi, M.; Paciolla, C.; Logrieco, A.F. and Mulè, G. (2020): Plant bioactive compounds in pre-and postharvest management for aflatoxins reduction. Front Microbiol, 11: 243 .
[34] Wu, J.-C.; Lai, C.-S.; Tsai, M.-L.; Ho, C.-T.; Wang, Y.-J. and Pan, M.-H. (2017): Chemopreventive effect of natural dietary compounds on xenobiotic-induced toxicity. JFDA, 25(1): 176-186 .
[35] Mathuria, N. and Verma, R.J. (2007): Aflatoxin induced hemolysis and its amelioration by turmeric extracts and curcumin in vitro. Acta Pol Pharm, 64(2): 165-168 .
[36] Limaye, A.; Yu, R.-C.; Chou, C.-C.; Liu, J.-R. and Cheng, K.-C. (2018): Protective and detoxifying effects conferred by dietary selenium and curcumin against AFB1-mediated toxicity in livestock: a review. Toxins, 10(1): 25 .
[37] Narayanan, V.S.; Muddaiah ,S.; Shashidara, R.; Sudheendra, U.; Deepthi, N. and Samaranayake, L. (2020): Variable antifungal activity of curcumin against planktonic and biofilm phase of different candida species. Indian J Dent Res, 31(1): 145-148 .
[38] Hedayati, N ;.Naeini, M.B.; Nezami, A.; Hosseinzadeh, H.; Wallace Hayes, A.; Hosseini, S.; Imenshahidi, M. and Karimi, G. (2019): Protective effect of lycopene against chemical and natural toxins: A review. BioFactors, 45(1): 5-23 .
[39] da Silva Bomfim, N.; Kohiyama ,C.Y.; Nakasugi, L.P.; Nerilo, S.B.; Mossini, S.A.G.; Romoli, J.C.Z.; Graton Mikcha, J.M.; Abreu Filho, B.A.d. and Machinski Jr, M. (2020): Antifungal and antiaflatoxigenic activity of rosemary essential oil (Rosmarinus officinalis L.) against Aspergillus flavus. Food Addit Contam: Part A, 37(1): 153-161 .
[40] Muñoz Castellanos, L.; Amaya Olivas, N.; Ayala-Soto, J.; De La O Contreras,

C.M.; Zermeño Ortega, M.; Sandoval Salas, F. and Hernández-Ochoa, L. (2020): In vitro and in vivo antifungal activity of clove (Eugenia caryophyllata) and pepper (Piper nigrum L.) essential oils and functional extracts against Fusarium oxysporum and Aspergillus niger in tomato (Solanum lycopersicum L.). Int J Microbiol, (1): 1702037 .

[41] Behbehani, J.; Irshad, M.; Shreaz, S. and Karched, M. (2019): Synergistic effects of tea polyphenol epigallocatechin 3-O-gallate and azole drugs against oral Candida isolates. JMM, 29(2): 158-167 .

[42] Chaudhari, A.K.; Singh, V.K.; Das, S.; Prasad, J.; Dwivedy, A.K. and Dubey, N.K. (2020): Improvement of in vitro and in situ antifungal, AFB1 inhibitory and antioxidant activity of Origanum majorana L. essential oil through nanoemulsion and recommending as novel food preservative. Food Chem Toxicol, 143: 111536 .

[43] Adeyeye, S.A. (2016): Fungal mycotoxins in foods: A review. Cogent Food & Agriculture, 2(1): 1213127 .

[44] Abd El-Hack, M.E.; Samak, D.H.; Noreldin, A.E.; El-Naggar, K. and Abdo, M. (2018): Probiotics and plant-derived compounds as eco-friendly agents to inhibit microbial toxins in poultry feed: a comprehensive review. Environ Sci Pollut Res, 25: 31971-31986 .

[45] de Freitas Souza, C.; Baldissera, M.D.; Descovi, S.; Zeppenfeld ,C.; Eslava-Mocha, P.R.; Gloria, E.M.; Zanette, R.A.; Baldisserotto, B. and da Silva, A.S. (2019): Melaleuca alternifolia essential oil abrogates hepatic oxidative damage in silver catfish (Rhamdia quelen) fed with an aflatoxin-contaminated diet. Comparative Biochemistry and Physiology Part C: Toxicol Pharmacol, 221: 10-20 .

[46] Ullah, M.I.; Majeed, S.; Arshad, M.; Altaf, N.; Luqman, M.; Abdullah, A. and Afzal, M. (2021): Effect of emamectin benzoate with leaf extracts of Parthenium hysterophorus and Moringa oleifera on the digestibility and survival indices of Spodoptera litura (Lepidoptera: Noctuidae). Sarhad J Agric, 37(3): 830 .

[47] Abdel-Fattah, S.; Badr, A.; Seif, F.-H.A.; Ali, S. and Hassan, R. (2018): Antifungal and anti-mycotoxigenic impact of eco-friendly extracts of wild stevia .

[48] Powers, C.N.; Satyal, P.; Mayo, J.A.; McFeeters, H. and McFeeters, R.L. (2019): Bigger data approach to analysis of essential oils and their antifungal activity against Aspergillus niger, Candida albicans, and Cryptococcus neoformans. Molecules, 24(16): 2868 .

[49] Kocić-Tanackov, S.; Dimić, G.; Jakšić, S.; Mojović, L.; Djukić-Vuković, A.; Mladenović, D. and Pejin, J. (2019): Effects of caraway and juniper essential oils on aflatoxigenic fungi growth and aflatoxins secretion in polenta. J Food Process Preserv, 43(12): e14224 .

[50] Saleemi, M.K.; Raza, A.; Khatoon, A.; Zubair, M.; Yongping, X.; Murtaza, B.; Li, X.; Jamil, M.; Imran, M. and Muhammad, F. (2023): Toxic effects of aflatoxin B1 on Hematobiochemical and histopathological parameters of juvenile white Leghorn male birds and their amelioration with vitamin E and Moringa Oleifera. Pak Vet J, 43(3): 405-411 .

[51] Khan, H.; Ullah, H. and Nabavi, S.M. (2019): Mechanistic insights of hepatoprotective effects of curcumin: Therapeutic updates and future prospects. Food Chem Toxicol, 124: 182-191 .

[52] Tabeshpour, J.; Mehri, S.; Shaebani Behbahani, F. and Hosseinzadeh, H. (2018): Protective effects of Vitis vinifera (grapes) and one of its biologically active constituents, resveratrol, against natural and chemical toxicities: A comprehensive review. Phytother res, 32(11): 2164-2190 .

[53] Aydin, S.; Palabiyik, Ş.S.; Erkekoglu, P.; Sahin, G.; Başaran, N. and Giray, B.K. (2013): The carotenoid lycopene protects

rats against DNA damage induced by Ochratoxin A. Toxicon, 73: 96-103 .

[54] Radić, K.; Dukovski, B. J.; Čepo, D. V. (2020): Influence of pomace matrix and cyclodextrin encapsulation on olive pomace polyphenols' bioaccessibility and intestinal permeability, Nutrients, 12 (3).

[55] Iram, W.; Anjum, T.; Iqbal, M.; Ghaffar, A. and Abbas, M. (2016): Structural elucidation and toxicity assessment of degraded products of aflatoxin B1 and B2 by aqueous extracts of Trachyspermum ammi. Front Microbiol, 7: 346 .

[56] Makhuvele, R.; Matshoga, R.; Antonissen, R.; Pieters, L.; Verschaeve, L. and Elgorashi, E.E. (2018): Genotoxicity and antigenotoxicity of selected South African indigenous plants. S AFR J BOT, 114: 89-99 .

[57] Nerilo, S.B.; Romoli, J.C.Z.; Nakasugi, L.P.; Zampieri, N.S.; Mossini, S.A.G.; Rocha, G.H.O.; Gloria, E.M.d.; Abreu Filho, B.A.d. and Machinski Jr, M. (2020): Antifungal activity and inhibition of aflatoxin production by Zingiber officinale Roscoe essential oil against Aspergillus flavus in stored corn grains. Ciência Rural, 50, e20190779.

[58] Thipe, V.C.; Keyster, M. and Katti, K.V. (2018): Sustainable nanotechnology: mycotoxin detection and protection. Nanobiotechnology applications in plant protection: 323-349 .

[59] Rai, M.; Ingle, A.P.; Pandit, R.; Paralikar, P.; Anasane, N. and Santos, C.A.D. (2020): Curcumin and curcumin-loaded nanoparticles: Antipathogenic and antiparasitic activities. Expert rev Anti-Infect Therapy, 18(4): 367-379 .

[60] Bahrami, A.; Delshadi, R.; Assadpour, E.; Jafari, S.M. and Williams, L. (2020): Antimicrobial-loaded nanocarriers for food packaging applications. Adv colloid Interface Sci, 278: 102140 .

[61] Pushpalatha, R.; Selvamuthukumar, S. and Kilimozhi, D. (2018): Cross-linked, cyclodextrin-based nanosponges for curcumin delivery-Physicochemical characterization, drug release, stability and cytotoxicity. J Drug Deliv Sci Technol, 45: 45-53 .

[62] Haimhoffer, Á.; Rusznyák, Á.; Réti-Nagy, K.; Vasvári, G.; Váradi, J.; Vecsernyés, M.; Bácskay, I.; Fehér, P.; Ujhelyi, Z. and Fenyvesi, F. (2019): Cyclodextrins in drug delivery systems and their effects on biological barriers. Sci Pharm, 87(4) :33 .

[63] Kumar, S.; Pooja; Trotta, F. and Rao, R. (2018): Encapsulation of babchi oil in cyclodextrin-based nanosponges: physicochemical characterization, photodegradation, and in vitro cytotoxicity studies. Pharmaceutics, 10(4): 169 .

[64] Appell ,M.; Evans, K.O.; Jackson, M.A. and Compton, D.L. (2018): Determination of ochratoxin A in grape juice and wine using nanosponge solid phase extraction clean-up and liquid chromatography with fluorescence detection. J Liq Chromatogr Relat Technol, 41(15-16): 949-954 .

[65] Faisal, Z.; Garai, E.; Csepregi, R.; Bakos, K.; Fliszár-Nyúl, E.; Szente, L.; Balázs, A.; Cserháti, M.; Kőszegi, T. and Urbányi, B. (2020): Protective effects of beta-cyclodextrins vs. zearalenone-induced toxicity in HeLa cells and Tg (vtg1: mCherry) zebrafish embryos. Chemosphere, 240: 124948 .

[66] Fliszár-Nyúl, E.; Lemli, B.; Kunsági-Máté, S.; Szente, L. and Poór, M. (2019): Interactions of mycotoxin alternariol with cyclodextrins and its removal from aqueous solution by beta-cyclodextrin bead polymer. Biomolecules, 9(9): 428 .

[67] Zhang, G.; Yuan, C. and Sun, Y. (2018): Effect of selective encapsulation of hydroxypropyl-β-cyclodextrin on components and antibacterial properties of star anise essential oil Molecules, 23(5): 1126 .

[68] Ramirez-Ambrosi, M.; Caldera, F.; Trotta, F.; Berrueta, L.A. and Gallo, B. (2014): Encapsulation of apple

polyphenols in β-CD nanosponges. J Incl Phenom Macrocycl Chem, 80: 85-92 .
[69] Oun, A.A ;.Shankar, S. and Rhim, J.-W. (2020): Multifunctional nanocellulose/metal and metal oxide nanoparticle hybrid nanomaterials. Crit Rev Food Sc Nutr, 60(3): 435-460 .
[70] Amornvit, P., Choonharuangdej, S., & Srithavaj, T. (2014): Lemongrass-incorporated tissue conditioner against Candida albicans culture. JCDR, 8(7), ZC50.

الملخص العربي

الآثار المحتملة للنباتات في التخفيف من آثار السموم الفطرية الضارة : مراجعة شاملة.

جمال شمس ، أسراء محمد ، عماد أديب* ، إبراهيم عابد ، أحمد هلال و طارق خميس
قسم الفارماكولوجيا- كلية الطب البيطري - جامعة الزقازيق 44511

من نتائج الأيض الثانوية الفطرية المعروفة باسم السموم الفطرية و التي تنتج بواسطة العديد من الأنواع الفطرية السامة وتوجد في مجموعة متنوعة من مخزونات العلف، خاصة في النباتات التي تخضع للمناولة والتخزين والنقل قبل وبعد الحصاد حيث لديهم القدرة على إصابة الإنسان والحيوان بالمرض بسبب الآثار الضارة للسموم الفطرية على الصحة والاقتصاد، تشكل السموم الفطرية تهديدا كبيرا للأمن الغذائي والسلامة. في ظل ظروف بيئية محددة، مثل ارتفاع درجات الحرارة والرطوبة، إلى جانب ظروف التخزين غير المناسبة، يحدث إطلاق السموم الفطرية ويتسرب إلى المنتجات الزراعية، وخاصة المحاصيل مثل الذرة وفول الصويا.

هناك طرق مختلفة لتحديد السموم الفطرية في الغذاء، بما في ذلك أجهزة الاستشعار الحيوية، والتحليل اللوني، وغيرها من التقنيات المتطورة. ومن الضروري تطوير أساليب مبتكرة يمكن أن تقلل من الآثار السلبية للتلوث بالسموم الفطرية على الاقتصاد وقطاع التجارة والصحة العامة والجودة والمحتوى الغذائي للأغذية والأعلاف مع الحفاظ على تلك الفوائد. تم استخدام العديد من التكتيكات لتقليل وجود التلوث بالسموم الفطرية؛ إلا أنها تفتقر- في كثير من الأحيان- إلى الفعالية اللازمة.

قد تستخدم بعض المواد النباتية العلاجية كمضاد للسموم الفطرية. يتم استخدام مقتطفات من مجموعة متنوعة من النباتات والعديد من المكونات بشكل شائع لتقليل التسمم الفطري لدى كل من البشر والحيوانات. تم تقييم الإنزيمات مؤخرا لمعرفة ما إذا كان بإمكانها التخلص من السموم الفطرية أثناء تحضير الطعام. من الممكن تعديل الإنزيمات أو دمجها مع أدوية أخرى، مما يتطلب المزيد من الأبحاث. على وجه التحديد، إنشاء إسفنج نانوية مغلفة بمواد مشتقة من النباتات النشطة بيولوجيا لتجنب نمو الفطريات السامة وإزالة التلوث بالسموم الفطرية من الأغذية والأعلاف، كل ذلك دون تعريض صحة المستخدمين أو بيئتهم للخطر.

من أجل منع الغزو الفطري السام وتطهير السموم الفطرية، يدرس هذا البحث استخدام المستخلصات العشبية والمواد الكيميائية النباتية الخاصة بها.