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Environment, Data, and Advanced Materials for Mycotoxin Management: Emerging Strategies for Detection, Prediction, and Sustainable Control

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ABSTRACT

Mycotoxin contamination remains a persistent challenge across agricultural and food systems because toxin formation is governed by interconnected environmental, biological, storage, and processing conditions. Temperature, moisture, relative humidity, water activity, pH, substrate composition, fungal species, and storage duration can collectively influence fungal growth and toxin production, making conventional endpoint monitoring insufficient for proactive risk management. At the same time, advances in functional materials and analytical technologies are creating new opportunities for sensitive detection and targeted removal of mycotoxins. This review connects three increasingly important dimensions of mycotoxin management: environmental conditions, data-driven assessment, and advanced materials. Particular attention is given to carbon-based materials, including graphene, graphene oxide, carbon nanotubes, carbon dots, and related nanocomposites, together with quantum dots and magnetic nanomaterials used for sensing, adsorption, and detoxification. Their physicochemical, optical, electrochemical, and surface properties enable sensitive recognition of toxins such as aflatoxin B1 while also providing opportunities for contaminant capture and removal. Emerging control strategies involving cold atmospheric plasma, polyphenols, natural essential oils, and functional nanomaterials are further evaluated from efficacy and sustainability perspectives. Building on these developments, the review discusses how environmental monitoring data, material-performance information, and sensing outputs could be integrated through data-driven models to support contamination prediction, material selection, and timely intervention. Rather than treating detection and remediation as independent processes, an integrated environment–

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data–materials framework is proposed for moving toward predictive and adaptive mycotoxin management. Remaining challenges include matrix effects, material safety, scalability, data quality, sensor reproducibility, and validation under real food and agricultural conditions.

Keywords: Mycotoxins; Environmental Monitoring; Data-Driven Prediction; Graphene-Based Materials; Sustainable Remediation

Highlights

- Environmental conditions strongly influence fungal growth and mycotoxin formation throughout the food supply chain.
- Graphene-based and carbon nanomaterials offer sensitive platforms for mycotoxin recognition and detection.
- Magnetic nanomaterials and other functional materials provide promising routes for mycotoxin adsorption and removal.
- Data-driven integration of environmental and sensing information could enable earlier prediction of contamination risks.
- Connecting environment, data, and materials can support more adaptive and sustainable mycotoxin management.

1. Introduction

Mycotoxin contamination is difficult to manage because it does not begin or end at a single point in the food-production chain. Toxigenic fungi can develop before harvest, during transportation, under storage conditions, and during subsequent food processing [1]. Their behavior is influenced by the surrounding environment, meaning that contamination cannot be understood solely by identifying the fungal species present in a commodity. Temperature, moisture, relative humidity, rainfall, water activity, pH, nutrient availability, crop characteristics, and storage duration can interact to determine whether conditions favor fungal proliferation and toxin production. The source material, for example, describes temperature, humidity, storage conditions, substrate composition, pH, and water activity as important factors affecting mycotoxin development [2]. This environmental dependence makes mycotoxin contamination both a food-safety concern and an environmental monitoring problem. Changes in climatic and local environmental conditions can alter the conditions under which toxigenic fungi develop. At the same time, agricultural practices, harvesting conditions, storage environments, and characteristics of individual food matrices introduce additional variability. Preventive systems such as good agricultural practices, good storage practices, good manufacturing practices, and Hazard Analysis and Critical Control Points remain fundamental for controlling these risks. However, preventive management can be strengthened when environmental observations are combined with technologies capable of detecting contamination at low concentrations [1-3].

Advanced materials have become particularly important in this context. Carbon-based nanomaterials possess physicochemical characteristics that make them attractive for both sensing and contaminant removal. Carbon dots, carbon nanotubes, graphene, and graphene oxide have been incorporated into fluorescence, electrochemical, photoelectrochemical, immunological, and aptamer-based sensing systems. The high surface area, electrical behavior, optical characteristics, and opportunities for surface functionalization

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provided by these materials can improve interactions between the sensing platform and target mycotoxin [2]. Graphene-based materials are particularly interesting because they can bridge material science with analytical detection. Graphene oxide provides a large functional surface and good hydrophilicity, while its oxygen-containing functional groups facilitate bioconjugation. Its ability to participate in fluorescence quenching and adsorption processes has supported the development of sensitive platforms for aflatoxin B1 detection. Combining graphene with metallic nanoparticles, polymers, aptamers, antibodies, and other functional components can further modify electron transfer, molecular recognition, and signal amplification [4-6].

Materials development alone, however, does not resolve the complexity of mycotoxin management. A highly sensitive sensor can establish whether a toxin is present, but effective prevention also requires understanding when, where, and under what environmental conditions contamination is likely to develop. This creates an opportunity for a stronger connection between environmental monitoring and data analysis. Environmental and food-production systems now generate multiple forms of information, including temperature and humidity records, storage histories, crop and substrate characteristics, sensor responses, toxin concentrations, and material-performance measurements. Data-driven approaches could potentially identify relationships within these heterogeneous datasets that are difficult to evaluate through isolated measurements [5]. Predictive models may therefore complement analytical detection by estimating contamination risk, identifying influential environmental variables, interpreting complex sensing signals, or supporting the selection of appropriate intervention strategies. Such integration should nevertheless be approached carefully. A data-driven model is only as reliable as the observations used to develop and validate it. Differences among crops, fungal strains, geographic regions, analytical methods, and environmental conditions can limit model transferability. Similarly, nanomaterial-based sensing systems that demonstrate excellent analytical performance under controlled laboratory conditions may behave differently when applied to complex food matrices. The document itself demonstrates the diversity of reported sensing configurations, ranging from carbon nanotube systems to graphene-based aptasensors and quantum-dot platforms [6]. Detection must also be connected with practical control. Beyond graphene-based sensing, several approaches have been investigated for reducing mycotoxin concentrations or suppressing their production. Cold atmospheric plasma generates reactive species capable of degrading complex biological molecules and has been investigated for mycotoxin detoxification under relatively mild operating conditions. Naturally derived polyphenols and essential oils represent another direction, while magnetic nanoparticles, nanocellulose, chitosan-based materials, and other nanostructured adsorbents offer opportunities for toxin capture and removal. These developments suggest that the next stage of mycotoxin management may depend less on a single detection or treatment technology and more on the ability to connect different layers of information. Environmental measurements can indicate when contamination conditions are developing; advanced sensors can provide rapid analytical evidence; functional materials can support detection or removal; and data-driven methods can help organize these observations into actionable information [7]. Accordingly, this review examines mycotoxin management through an integrated environment–data–materials perspective. It discusses environmental factors controlling mycotoxin occurrence, advances in graphene and related materials for detection, emerging remediation and detoxification technologies, and opportunities for data-driven prediction and decision support.

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Particular attention is given to the connections among these areas and to the challenges that must be addressed before laboratory advances can be translated into reliable, scalable, and environmentally responsible food-safety solutions.

2. Innovative strategies for controlling mycotoxins in foods

Factors influencing mycotoxin production and contamination in foods- Mycotoxins are often consumed by humans through polluted cereals, cereal-based commodities, including animal's meat that have been subjected to mycotoxins. Many common foods including agricultural goods can develop mycotoxins. Since mycotoxins could be created in circumstances that are both reliant as well as distinct from those required for the development of fungi, they provide a risk of infection across the whole food supply chain, through prior to harvesting through post-harvest storage. Mycotoxin generation in agricultural and food crops has been discussed as a potential target for the food-safety management system FSMS, which consists of examinations and preventive steps for controlling the safety and hygiene in food companies. GHP- good hygiene practices, GAP- good agricultural practices, GSP- good storage practices, GMP- good manufacturing practices, HACCP- hazard analysis and critical control point constitute some of the processes and oversight policies that make up a standard FSMS, that are employed to regulate the food manufacturing environment and guarantee the health and safety of the products that are produced. Good practices for avoiding the production of mycotoxins include keeping animal feed and food at the appropriate temperature, RH as well as humidity levels. Groundnuts with a moisture level of 6.5 % will not grow or produce mycotoxins for up to half a year of storage, whereas corn dehydrated to a humidity content of 15.6 % or lower is more unlikely to do so during storing. Elevated CO2 with little O2 in storage facilities significantly decreased Aspergillus fungal proliferation and biological aflatoxin formation. Co-mixing cereals in storage can enhance their vulnerability to mycotoxins contaminants, while longer storage durations can cause a rise in fungal biomass at increased moisture content when the product permeates. Longer periods of storage at higher water content and the ideal temperature for fungi to thrive result in significantly higher levels of Ochratoxin A production after contamination with Aspergillus carbonarius. Mycotoxin prevention and regulation can be greatly aided by the HACCP framework, which ensures the implementation of best practices across the production, preservation, organising, tracking, and separation phases through the use of incremental improvements. Mycotoxin prevention and control can be achieved by the implementation of the Hazard Analysis and Critical Control Points (HACCP) system, as detailed in a thorough guidebook [1,2]. Mycotoxin hazard analysis has recently shown that pre-harvest practices such as preparing the soil (rotation of crops, tillage, and cover cropping) growing and intercropping, which use of herbal extracts, and fungal biocontrol substances can significantly affect mycotoxin production. Post-harvest therapies including ultraviolet (UV) rays, and ozone were also found to be essential. Still, environmental and cultural factors may play a role in creating these routines. Climate, regional microecosystem variability, and relative humidity all have a role in mycotoxin development and severity. For example, the ideal environment for fungal growth and mycotoxin generation is 26 o C [3, 4], although this value depends on the varieties, species, and growing conditions, and after harvesting temperature. Rising temperatures hinder fungal growth and the creation of mycotoxins by altering the gene expression profile, however mycotoxins have been demonstrated to tolerate boiling for 20-25 min up to 112 o C [5, 6]. Most fungi are airborne

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however others, particularly yeast cells, can be autonomous anaerobic organisms [7] meaning that elevated CO2 levels have no effect on fungal biomass. Moreno-Pedraza et al. found that mycotoxin synthesis takes place in acidic conditions with a pH of 4.5, whereas alkaline environments hinder the development of fungi and mycotoxin generation. Several species of mould thrive in water activities between 0.88 and 0.97, but mycotoxin production is inhibited in water activities below 0.93 [8]. Extreme wet periods and rainfall before to harvest have been demonstrated to impact mycotoxin amounts in wheat and the dispersal of aflatoxin in maize. Since tropical climates are not optimal for fungal growth and mycotoxin production, agricultural products from subtropical and temperate regions are more probable to be tainted. The moisture content of grains can be reduced by drying them after harvest; processing at temperatures of 42 o C is recommended. The amount to which mycotoxins are produced and contaminated depends on a number of site-specific parameters, including the kind of the substrate, the fungal composition, and the accessibility of nutrients. Mould thrives on meals high in carbohydrates because they provide the nitrogen and carbon that mycotoxigenic fungus need to thrive. While tryptophan suppresses fungal growth, tyrosine promotes mycotoxin formation (together with glucose, lipids, and fructose) [3]. Since various factors, such as as substrate structure, pH, temperature, and osmotic pressure, among others, can influence growth [9], it is essential to consider how these factors interact with one another. More AFB1 production by A. flavus has been associated with higher sugar concentrations in the media [10]. Most filamentous fungus may hydrolyze sugars, especially simple carbohydrates that are stimulated or easily accessible for decomposition, to create energy for sustaining development. Mycotoxin generation may be limited to specific fungus species or strains due to differences in toxicity and the environmental requirements for toxin development and propagation. Aspergillus flavus was discovered to generate aflatoxin B1 within the temperatures of 14 and 45 o C, and Aspergillus carbonarius was found to produce ochratoxin within the temperatures of 9 and 41 o C.

3. Aflatoxin B1 detection based on nanomaterials

Carbon nanomaterials intriguing properties, such as high and tuneable emission of fluorescence, high water dissolution, and minimal toxic effects, have been seen in carbon dots, a special type of carbon-based zero-dimensional 0-D substance. A competing fluorometric immunoassay based on carbon dots modified using MnO2 nano-sheets was created for the detection of AFB1. Carbon dots may generate immunocomplexes that boost fluorescence. The ALP-mediated peeling of MnO2 nanosheets was shown to be responsible for the increase, since it led to the decoupling of carbon dots. Raising the PEC photoelectrochemical response of carbon dots-modified MnO2 nanosheets by H2O2-mediated etching reaction, Lin's team created the PEC immunological detecting device for the detection of AFB1. AFB1 was detected with an unparalleled level of sensitivity by combining aptamer-modified gold nanoparticles Au-NPs using distinct fluorescence nitrogen-doped carbon dots. The luminescence was re-established when particular reactions involving AFB1 with the aptamer released nitrogen-doped carbon dots. The amount of infused AFB1 may be estimated by the amount of fluorescence restoration in the nitrogen-doped carbon dots. The test could identify as little as 5pg/ml [11]. Since their discovery in 1991, carbon nanotubes, also known as CNTs, have been put to use to be 1D wires, catalysts aid, and in the modification of solid electrodes and efficient SPE adsorption agents to boost electrode area of contact and absorption density for absorption of the target molecules [12- 14]. They can be used in the

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electrochemical identification of trace chemicals when coated on carbon electrodes. Evidence suggests that CNTs can be utilised to amplify signals because they boost the electrochemical reactions of a variety of biomolecules. Coating a glassy carbon electrode GCE by CNT increases the amplitude of an electrochemical signal by roughly a couple of orders of magnitude compared to an untreated GCE [15]. Using produced carboxylated-MWCNTs on ITO glass, Singh et al describe an innovative approach for creating an electrochemical biosensor. Monoclonal AFB1 antibody anti-AFB1 [16] were used to modify the c-MWCNTs over an ITO electrode, allowing for the detection of AFB1. The small amount of functional CNT showed they had a high affinity for AFB1. The bio polymer chitosan has been employed extensively as a biological molecules' immobilisation matrix [17] due to its responsive amino as well as hydroxyl functional groups. The usage of SWCNT-chitosan to develop an electrochemical immunosensor has been shown by Zhang and coworkers. The nanotubes are insoluble in water due to their strong attraction relationship; chitosan is employed to circumvent this problem. Research has shown that a CNTs/chitosan GCE has greater sensitivity. With a dosage range of 0.02-101 ng/ml, the CNT sensor showed a low limit of detection of 3.4 pg/ml for AFB1 [18]. The enhancement of the signal was achieved by modifying the electrode with MWCNT along with chitosan in a second indirect competitive ELISA-based technique. To further improve the ratio of signal to noise of optical biosensors, which CNTs may be employed to effectively quench a wide range of fluorophores. The fluorescence of the dye is suppressed [19] when it comes into contact with the MWNTs because of p-p layering interactions among the bases of DNA of the aptamer with the CNTs. Later adding a target molecule, which binds specifically to the target and eliminates the aptamer from the MWNTs' surface, restores the previously suppressed fluorescence. There is a linear relationship between this retrieved fluorescence intensity and the concentration of interest [20].

Graphene, its oxide- Graphene is a nanomaterial with an exceptionally thin structure, consisting of a single atom layer. This specimen is remarkable in the field of materials science due to its two-dimensional form. Graphene demonstrates superior electrical and thermal conductivity compared to carbon nanotubes (CNTs) due to its monolithic structure and greater surface area [21, 22]. Graphene oxide (GO) is commonly used as an adsorbent in scientific studies for the detection of aflatoxin B1 (AFB1). The conjugation between the aromatic ring in the mycotoxins and the 06 members C-ring in graphene sheets is considered to be the primary reason for its effective adsorption of mycotoxins. Moreover, graphene oxide (GO) possesses remarkable hydrophilicity, making it highly suitable for bioconjugation applications. Additionally, GO can be synthesized financially in laboratories and contains a wide range of oxygen-containing chemical groups, further enhancing its versatility. Importantly, GO requires minimal activation for bioconjugation purposes. Effective deployment of labels for immunoassays with lateral flow has been accomplished using both graphene oxide as well carboxylated graphene oxide. The optical detection threshold and termination point in AFB1 are quantified at 0.3 and 1 ng /mL, respectively, which are achieved within a 15-min timeframe [23]. This accomplishment represents a significant decrease in time compared to the use of AuNPs. Graphene oxide is highly useful in biosensors because it can both produce and absorb the light across a wide range of wavelengths, from near-infrared NIR to ultraviolet UV. The dual nature of this optical characteristic, which can act as both a receiver and a donor at the same time, provides researchers with numerous possibilities for designing detection patterns based on fluorescent signals. CNTs are able to effectively capture alongside bind single-stranded DNA

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molecules, leading to the quenching of their emission of fluorescence. The ability to distinguish between signals signal-to-background ratio is better in graphene oxide (GO) as opposed to carbon nanotubes CNTs because of GO's planar configuration and increased adsorption and desorption capacity. Graphene oxide has been widely used as a luminescent platform in biosensor development for detecting aflatoxin B1- AFB1. This is mainly attributed to its ability to quench fluorescence signals by adsorbing single-stranded DNA (ssDNA) probes that are labelled with fluorophores. In the one-to- one binding experiment, each AFB1 aptamer demonstrates a unique affinity for a specific AFB1 molecule, leading to a restricted attachment between them. The amplification experiment with AFB1 can be replicated using DNase I. Graphene oxide was used to protect aptamers from enzymatic degradation by nucleases. This approach was employed to create a highly sensitive fluorescence sensor with a detection thresholds of 0.34 mg /ml. To improve biosensing capabilities, it is common practice to combine graphene to metal nanoparticles (NPs). The author has developed an intricate fluorescent sensor for detecting AFB1 by utilizing GO-Au nanocomposites, which have strong fluorescence-quenching abilities, particularly when combined with HCR amplifiers. In contrast to using conventional graphene oxide, incorporating GO-Au nanocomposites (GO-Au NCs) significantly enhanced the efficiency of quenching the DNA probe with fluorophore-labelling. This improvement allowed for the attainment of a remarkably low detection limit of 0.03 pg/ mL. Geleta developed an electrochemical aptamer biosensor, known as rGO/MoS2/PANI @AuNPs/Apt, which can effectively detect AFB1 in a broad linear range of 0.01 fg /mL - 1.0 fg /mL. This biosensor demonstrates a remarkable low detection, rendering it a valuable tool for the detection of AFB1. The detection threshold is established at an extremely low value of 0.02 fm/ml [24]. A sensor was fabricated using a composite film composed of a conducting polymer with gold nanoparticles, as well as an ionic liquid. This film was deposited onto a modified gold electrode. The presence of an ionic liquid creates an ideal environment for an antibody, allowing it to maintain its normal functions without any impairment. The presence of both graphene and gold nanoparticles AuNPs enables fast electron transfer processes. The dynamic range of the values [25] extends from 3.3 femtomolar to 0.31 picomolar. In addition, the system exhibits a remarkably low identification limit, as low as 1 femtomolar. CdTe-GO-QDs were used to create a quencher system by attaching a thiolated aptamer specific to AFB1 onto the surface of the QDs through ligand-exchange. The use of graphene oxide has been found to significantly reduce the luminescence released by aptamer-modified QDs.

Quantum Dots- The semiconductor nanocrystals known as quantum dots (QDs) are composed of atoms from groups II–VI or III–V [26]. Typically, a particle's size is less than 10 nm [27, 28]. In recent years, quantum dots (QDs) have taken the place of organic dyes in fluorescent labelling and fluorescence donor/acceptor systems. Optoelectronic characteristics of QDs have drawn attention. These characteristics include a narrow with symmetric emission wavelength range, size-dependent light-emitting modification, and a wide range of wavelengths for excitation that enable simultaneous excitation of several fluorescence colours. The peculiar qualities of QDs are making them more and more well-liked. Due to their resistance to photobleaching, quantum dots (QDs) are advantageous in numerous sensing applications [29]. When conjugated to aptamers or antibodies, quantum dots (QDs) retain their emission characteristics and selectivity with ease. QDs may be able to find aflatoxin B1 (AFB1) due to their distinct characteristics. In this study, the use of QDs as AFB1 labels in immunoassays

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along with biosensors is investigated. Frequently used in immunoassays are QDs. Utilizing immunoassays, AFB1 is frequently identified and measured. Compared to enzymes and chemical dyes, QDs have advantages. QDs exhibit excellent photoluminescence. Förster Resonance Energy Transfer - FRET is used by biosensors because it provides quick and accurate detection. This phenomenon has been researched by researchers. QDs in the field of analytical chemistry have attracted interest because of their optical characteristics. Semiconductor QDs at the nanoscale glow according to their size. They can now be used as signal transducers on many sensor platforms. In-depth research has been done on QD metal content as a signal indicator of analyte concentration. Analyte concentration is determined by QD metal content. Target analytes can control fluorescence emission by including metals into the QD structure. The design of AFB1-m/pAb QD assembly probes has been successful. AFB1 detection was first accomplished by Zhang et al. utilizing CdTe QDs as the fluorescence probe. Unlike ELISA, the current method does not require lengthy incubation or washing steps. The fluorescence technique is costly, time-consuming, and complex considering its sensitivity and precision. Fluorescence detection is impacted by quality control during QD manufacture, particularly in regard to shape, size, and surface characteristics. Consequently, electrochemical immune sensors that have excellent sensitivity, straightforward signal amplification, and inexpensive and simple apparatus are growing more and more common. EC with fluorescent immunoassays were contrasted by Zeng. Labels were PbS-QDs with an LBL assembly. The electrochemical immunoassay had good sensitivity to detect AFB1 at 0.045 ng /mL [30]. The outcome is explained by ions that are liberated from QDs after acid breakdown. In comparison to a fluorescent immunoassay, ion release improves current responsiveness and increases sensitivity. Core-shell QDs - CuInS2/ZnS have been created to detect aflatoxin B1 (AFB1) using a fluorescence-linked immunoassay method. The stability and quantum yield of photoluminescence are improved by a ZnS shell. When compared to an enzyme-based immunoassay, the sensitivity of a QD-immunoassay was four times higher [31]. Numerous events can be translated by charge transfer extinction, electrochemiluminescence ECL, including photoelectrochemical (PEC) processes used to modify QD luminescence. For the study of interactions between molecules, fluorescence resonant energy transfer- FRET, is a highly effective technique. Understanding the dynamics of biomolecules and their proximity to one another is made possible by the transfer of energy between two fluorophores. FRET aids in the comprehension of intricate biological procedures involving molecular recognition events. This essay discusses how immunology depends on antigens. Immunological reactions in organisms are brought on by antigens. Antibody interactions have been extensively studied in molecular biology. Attention has been drawn to FRET. A recipient or quencher molecule receives energy through FRET from a donating molecule [32]. QDs are interesting biosensors due to their distinctive optical properties. For FRET biosensors that target aflatoxin B1 (AFB), QDs can be combined with organic colors with graphene oxide-gold/silver NPs to create donor-acceptor pairs. This approach might provide AFB1 biosensing systems that are highly sensitive and focused. QDs are the ideal donors for FRET applications. Energy recipients Au-Ag NPs and GO are seen in FRET. In contrast to dyes, Cd/Se QDs were labeled in Aswani Kumar's study to create FRET sensors. Graphene oxide Cd/Se QD fluorescence is slowed down by the aptamer-GO interaction. The aptamer and AFB1 combine to increase the intensity of fluorescence. A delicate assessment approach was developed by this work. At a limit of detection of 4*103 ng/ml, the method displayed a linear response

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that ranged from 2*103 to 2*105 ng /ml [33]. FRET was investigated in this study. Fluorescence was given by QDs while being accepted by Au NRs. A biosensor that uses ECL has dual-signaling FRET built in. Dual ECL signals were produced using luminol along with CdTe/CdS/ZnS QDs. ECL is attracting interest because of the potential uses. QDs are potential ECL emitters because they are semiconductor nanocrystals with distinctive optical and electrical properties. The role of gold nanorods as QD quenchers and the luminol enhancers is investigated in this study. This study looks into the applications of HRP/Au NRs in nanotechnologies to comprehend the mechanics and assess the performance of HRP/Au NRs, QDs, as well as luminol interactions. The usage of nanoparticles in a variety of scientific domains is advanced by this research. The target and AFB1 combine to increase the ECL signal from QDs. Additionally, AFB1 reduces luminol signal. The ECL intensity ratio, namely the ratio of QDs to luminol, and the AFB1 concentration have a strong linear relationship, according to the sensing system used in this investigation. The linear connection indicates that the device is capable of accurately identifying AFB1 levels from 5 pM up to 10 nM. This sensor is capable of detecting AFB1 in concentrations as low as 0.12 pM [34]. For quantum dots (QDs) to emit light at various wavelengths, they must be enlarged. A responsive AFB1 immunosensor was made using QDs with different sizes. Using FRET, this immunosensor was created. Utilizing diverse antigen (AFB1)-labeled green, fluorescent QD along with monovalent monoclonal antibodies (mAb)-labeled red QDs, we created a unique donor-acceptor pair configuration. This study examines the applications of this peculiar donor-acceptor combination in many fields. This study demonstrates that a FRET-immunoassay is capable of measuring AFB1 concentrations precisely to 0.05-5 ng/mL. This test found 0.04 ng/mL. Results from a commercial ELISA kit and the FRET-based immunoassay were comparable [15, 4]. An AFB1 biosensor based on FRET was developed by Zekavati et al. The acceptor, AFB1-albumin, was labeled with the fluorophore Rho 123, a natural dye. Anti-AFB1 antibody that had been QDs-labeled served as the donor in this biosensor [35]. The Rho 123 dye (acceptor) as well as quantum dots (donor) were found to be sufficiently near to allow energy transfer in this investigation. This research presents a simple, quick and easy and effective homogenous competitive detection technology that does not require substantial washing and separating. QDs are commonly utilized in PEC detectors because of their effective photocurrent conversion. A high-sensitivity PEC biosensor for aflatoxin B1 (AFB1) detection was created by Liu et al. CdTe QDs were deposited on the electrode surface of the sensor via a silver-assisted ion-exchange process (Ag2Te / Cd2). This approach was selected because CdTe ion nanocrystals are capable of exchanging silver ions (Ag) 40 times more frequently than cadmium ions (Cd2). Sensor detection times have been shortened by rapid ion exchange. This system operates as follows: A conjugate that can recognize AFB1 called AFB1-BSA was used to tag Ag NPs. The quantity of AFB1-BSA on Ag NPs reduced as AFB1 concentration rose. This drop was brought on by competitive tests. As Ag NPs fell, exchanged CdTe QDs also did. Photocurrent grew as a result. These results are supported by earlier research [36].

4. Strategies for controlling mycotoxins in foods

Cold plasma- Being the fourth state of matter, plasma is an ionized gas that has gone through either complete or partial ionization. It is produced by exposing neutral gas to an electric current, which dissociates the molecules of gas [37, 38]. Plasma is emitted when applied voltage exceeds the breakdown voltage, thereby producing reactive oxygen alongside nitrogen

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species (RONS). Hojnik et al. [39] and Wielogorska et al. [38] report that it is feasible to generate non-thermal cold plasma at the atmosphere's pressure and ambient temperature, with an additional advantage of relatively little use of energy. Cold atmospheric plasma (CAP) may be employed either directly or indirectly by exposing water, solutions of buffers, and acids to plasma the discharge process, which allows the production of scrubbing sanitizers with wide-spectrum effectiveness [40, 41]. The distinctive combination of reactive chemistries, including O2, H2O2, O3, -OH, and NO3, as well as UV photons and an electric field, are accountable for its antimicrobial effects and the capacity to degrade complicated biochemical molecules. These reactive chemistries operate at ambient temperatures, resulting in the manifestation of non-thermal properties [42]. Consequently, the use of non-thermal cold atmospheric plasma (CAP) has evolved as an economically viable and expedient methodological strategy for eliminating of pathogenic microbes present in various consumables and agricultural goods. According to Esua, Cheng, and Sun [43], this method has the benefit of maintaining the fundamental attributes of these products. Nonetheless, the efficacy of the method is dependent on the molecular structure of mycotoxin and the precise processing parameters. On wheat, the effect of ablation voltage, gas form, length of processing, matrix features, and food moisture level on deoxynivalenol (DON) degradation rate has been proven. However, the use of 50 kV voltage to the atmosphere's plasma for eight minutes resulted in a significant reduction of 25%. Intriguingly, it was discovered that greater amounts of moisture improved the effectiveness of the process. In particular, the efficacy jumped from 9.6% towards 36.1% as the relative humidity rose from 8% to 20%. In the research carried out by Chen et al., little impact on the general quality of wheat were observed, with the sole exception of a slight increase in its whiteness. In a comparable manner the effectiveness of breakdown of T-2 toxin as well as it's main metabolite HT-2 toxin upon oat flour was discovered to be influenced by variables such as the flour's relative humidity, the exposure time, and the gas used to generate cold plasma. By interacting with oxygen molecules derived from a frigid plasma, the samples underwent effective oxidation. This process produced carbon monoxide along with nitrogen gas (N2), which were essential for attaining maximum reductions of 43.2 and 38.5 percent for T-2 as well HT-2 toxins, correspondingly. Particularly, such reductions occurred if nitrogen gas was used as the producing gas, as Kis et al. stated. In a separate study, increasing the voltage that was used from 10 to 30 kV led to significant declines of 1.3–56.5% and 8.1–62.8% in the amounts of alternariol (AOH) along with alternariol monomethyl ether (AME) produced by the fungus organisms Alternaria if established into jujube juice, respectively. This voltage increases also resulted in a substantial decrease in the Brix value of the juice, whereas simultaneously eliciting increases in the levels of reduced glucose, complete acids, rigidity, and antioxidant activity.

Polyphenols - Phytonutrients like polyphenols as well as flavonoids have been increasingly used in a variety of food systems for their beneficial biological properties, such as their ability to fight against infections and free radical damage [44]. There is considerable variation in the molecular mechanisms by which flavonoids, polyphenols, and other compounds exert their impact on mycotoxins. They seem to have strong antioxidant as well as lipophilic properties, both of which likely to have a major impact on their bioactivity. Second, by causing changes in the structure of the fungal membrane, it may reduce mycotoxin formation. For a third, they can reduce the activity of genes that produce mycotoxins. Finally, they have the ability to halt the action of enzymes. Ahmed et al. [45] published their findings. To combat this,

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Hamad et al. [46] advocated using botanical extracts of sources that are natural and its polyphenolic components to inhibit mycotoxin production and the development of fungi. Polyphenols, especially umbelliferone and quercetin, were found to have inhibitory characteristics against patulin formation in prior research by Sanzani et al [47]. Genes involved in patulin's biosynthesis pathway were found to be downregulated, explaining the inhibition. Telles, Kupski, and Furlong's [48] research confirmed that the chlorogenic as well as gallic acids can limit the growth of AFB1 in edible beans. The purpose of this study was to determine how effective phenolic chemicals are at inhibiting mycotoxin formation. Flavanones isolated from citrus waste were found to significantly reduce patulin accumulation by at least 94%. Makhuvele et al.'s [49] research showed promise for using bioactive phenols in tandem with a -cyclodextrin-based nano sponge method. Blocking fungal assaults and eliminating mycotoxins, this strategy showed encouraging efficacy. Antioxidant capabilities and other therapeutic qualities are frequently found in organic dietary complexes, that are composed of a range of non-nutritive active chemicals. Extensive research has shown that natural substances like bioactive compounds and extracts of herbs can significantly mitigate the deleterious effects of mycotoxins. While further research is needed, the small but growing body of evidence suggesting that therapies incorporating polyphenol with fibre from food may help lessen the harm caused by fungi and their related mycotoxins is encouraging.

Natural oils- A tried-and-true technique for halting the growth of mold and getting toxins out of food is using natural essential oils -NEOs including the beneficial chemicals they contain. These modifications have a positive environmental impact because drug resistance is minimal and effectiveness is high [50, 51]. The detrimental impacts of NEOs on fungi and their associated toxins are due to their capacity to block important enzymes that regulate carbohydrate breakdown, mycotoxin generation, and the functioning of fungal cells and membranes [52]. The change of fungal genetic transcription by polyphenols, loss of microbial cell wall or as membrane integrity, and alteration of the cell membrane along with wall architecture are a few possible mechanisms that could result in these effects. A nano emulsion comprising Origanum majorana L. essential oil demonstrated AFB1-inhibitory, antifungal, as well as antioxidant properties in a ground-breaking study by [50]. The promise of this novel technique as a means of food preservation in the battle over mycotoxins and for enhancing food security is highlighted by these results. According to earlier studies, capsaicin treatment dramatically reduced the amount of OTA that Aspergillus section Nigri and Aspergillus carbonarius were able to generate in grapes. This decrease was, accordingly, 61% and 78%. Additionally, it was discovered that the application of sage and mint essential oils significantly reduced the production of OTA [53]. Turmeric oil has been shown to have antifungal properties against A. flavus and the ability to lower aflatoxin contamination in maize [54]. In a comparable manner, Kedia et al [55] discovered that Mentha spicata essential oil can stop A. flavus from manufacturing toxins in chickpea for the duration of the period of growth by working on the membrane of the plasma. Numerous naturally occurring substances (NEOs) have demonstrated promising results in reducing the negative effects of ZEN. Particularly, it has been discovered that the natural oils of the fruit grapefruit, a lemon, palmaris, as well as eucalyptus have an impact on ZEN. Additionally, studies have demonstrated the Curcuma longa natural oil can drastically lower zearalenone production to between 3.0 and 3.5 mg/L and completely suppress the development of the fungal fungus Fusarium graminearum.

Magnetic nanomaterials- Because magnetic nano materials as well as nano particles are

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inexpensive, eco-friendly, and very effective, recent research have demonstrated that employing them to reduce mycotoxins is a feasible option. Previous studies have demonstrated the efficacy of employing chitosan-coated particles with magnetic properties containing Fe3O4 to absorb patulin from fruit juice. Furthermore, it has been demonstrated that AFB1 may be safely removed from a range of nutritional supplements using a mixture of nano-cellulose along with retinoic acid. The effectiveness of this approach, however, is dependent on the concentration and pH levels, according to Jebali et al [56]. The removal and attaching of mycotoxins from agricultural feedstuff and foods has been demonstrated to be possible using nano-gel, nano-clay, surface-active maghemite, and nano materials like zinc oxide, copper, silver, selenium [57]. Hu et al. [54] found that following exposure to selenium made from Trichoderma harzianum JF309, FB1 as well as DON amounts decreased by 62% and 75%, correspondingly. The inclusion of selenium inhibited the buildup of ochratoxin-A OTA along with aflatoxin in a maize-based medium as well as the development of ochratoxigenic, aflatoxigenic fungi. The use of zinc oxide also demonstrated efficacy in reducing the generation of OTA, fumonisin B1 (FB1), as well aflatoxin B1 (AFB1) in food system models. Carbon-nanocomposites produced from maize by-products have also demonstrated significant promise for AFB1 detoxification in chicken. After 02 hrs of application, such nanocomposites have been demonstrated to absorb up to 90% of AFB1 at a pH of 7. A substance created by the cross-linking chitosan using glutaraldehyde is another efficient adsorbent substance for a number of toxins. This complex has demonstrated the best adsorption capacity for numerous mycotoxins when compared to other adsorbent materials examined. According to a study by Thipe et al [58], nano-fungicides made from natural oils as well as phytochemicals like caffeic acid, phloretin, catechols, tannins, eugenol, and thymol are effective. Powerful antifungal and antibacterial properties of these substances considerably decreased the possibility of contamination with mycotoxin. Due to the fact that these nano-fungicides have been demonstrated to be safe for humans as well as animals, they have significant prospective agricultural uses.

5. Impact of mycotoxins on human and animal health

When mycotoxins are present, they cause toxicity, which is referred to as mycotoxicosis. Mycotoxins can cause sickness in both humans and animals after consumption of polluted products [59]. Studies on animals and birds have shown that mycotoxins can cause kidney and liver damage, as well as inhibit the immune system, cause cancer, and cause birth defects [60]. Most exposure to aflatoxin occurs from ingestion of tainted food and animal feed. Mother's milk has been found to be the primary exposure pathway for babies who are being nursed, although exhibiting a lower level of toxicity than AFB1 [61]. Exposure to high levels of aflatoxin in a short amount of time can cause a condition known as acute aflatoxicosis. Exposure to low levels of aflatoxins over time has been proven to cause persistent aflatoxicosis, that is more common than acute aflatoxicosis. Chronic aflatoxicosis has been related to a wide range of negative health outcomes, including hepatocellular carcinoma, stunted childhood development. The link involving fumonisin-contaminated maize by the occurrence of horse leucoencephalomalacia was initially described by Haliburton and Buck [62]. Marasas reported that pigs developed pulmonary edema after being exposed to Fusarium verticillioides infected maize. Fumonisins in breast milk have been linked to stunted growth in children, according to studies by Chen et al. [63]. Researchers Gazzotti et al. found the same mode of transfer in milk from cows. Toxins T2 and HT2 and related trichothecenes including deoxynivalenol (DON),

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and nivalenol (NIV), and diacetoxyscirpenol (DAS) are of particular concern. Eukaryotic cell protein, DNA, RNA production can all be blocked by trichothecenes. They have also been demonstrated to alter membrane shape, stop the cell cycle, and impact mitochondrial activity. In animals, large dosages of DON induced symptoms including digestive problems, and emesis, and feelings of nausea and vomiting. Deoxynivalenol (DON) causes pigs to lose weight and feel less hungry despite being given in very low dosages. The ZEN compound, a mycotoxin, is said to be rather non-lethal. Notably, in 2003, Bennett and Klich [64] found that its molecular structure was quite close to 7-estradiol. The link between moldy grains and hyper-estrogenism among pigs had been recognized since at least 1920, according to a study published in 2015 by Poor et al [65]. It was found that ovine or bovine species both experienced identical reproductive aberrations. There is not enough evidence to conclude whether or not ZEN actually causes cancer. Citrinin has been linked to nephrotoxicity and is often found in close proximity to ochratoxin T (OT). Multiple studies have established the importance of citrinin in the generation of reactive oxygen species, or ROS, in biological structures. Mycotoxin patulin, produced by the fungus Penicillium expansum, has a cytotoxic effect and disrupts the synthesis of DNA, leading to DNA strand breaks. Patulin is most commonly found in erythrocytes or blood-carrying systems like as the spleen, lung, liver, and kidney. Mutagenesis, DNA base changes, and the initiation of cancer are all brought about by the ROS that patulin generates. Ochratoxin A (OTA) has been found to have carcinogenic implications, especially on the liver and kidneys, according to scientific studies. Malir et al [66] report that the WHO along with the International Agency for Research on Cancer (IARC) have designated it as a Group 2B human carcinogen. Claviceps purpurea is one of the most common species of the genus Claviceps, and its byproducts include ergot alkaloids. The effects of ergot poisoning, known as ergotism, can range from gangrene to convulsions. The convulsive form attacks the brain and spinal cord more directly than the gangrenous form does. While contemporary techniques have eliminated ergot alkaloids from the food supply for humans, they continue to be a problem for animal diets. Intoxication is a common behaviour among animals of the ovine order, the bovine family, the avian class, and the suine order. There is a wide range of physiological responses to ergotism in the species described here. The Food and Agriculture Organization (FAO) of the United Nations has recognised the long-standing worry associated with mycotoxins in food. This has led to the establishment of worldwide standards for mycotoxins in agricultural products and human consumption.

6. Conclusion

Mycotoxin contamination is shaped by a complex relationship among fungal biology, environmental conditions, agricultural practices, storage environments, and food characteristics. Temperature, moisture, water activity, pH, nutrient availability, and storage duration can influence both fungal development and toxin formation, demonstrating why mycotoxin management cannot depend solely on testing the final food product. Prevention, early detection, and effective intervention need to operate as connected components of the same management strategy. Advances in materials science have considerably expanded the available tools for this purpose. Graphene, graphene oxide, carbon nanotubes, carbon dots, quantum dots, magnetic nanoparticles, and hybrid nanocomposites offer valuable physicochemical and optical properties for toxin recognition, signal amplification, adsorption, and removal. The literature summarized in the source material demonstrates particularly extensive development of nanomaterial-based approaches for AFB1 detection. At the same time, cold plasma, natural

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compounds, essential oils, and magnetic or biopolymer-based materials broaden the range of potential strategies for controlling contamination.

The next opportunity lies in connecting these technologies rather than developing them independently. Environmental measurements can describe conditions favorable for toxin formation, sensing platforms can provide rapid contamination information, and material-performance data can guide appropriate detection or remediation choices. Data-driven models could serve as the connecting layer, integrating these different information streams to support prediction, classification, material selection, and intervention. However, technological sophistication alone will not guarantee practical impact. Future research should prioritize validation in real food matrices, standardized performance assessment, material safety, regeneration and disposal, scalability, environmental impacts, and transparent datasets suitable for predictive modeling. Particular care is needed to demonstrate that data-driven models remain reliable across different crops, climates, fungal species, and storage environments. Ultimately, an environment–data–materials framework can shift mycotoxin management from a predominantly reactive process toward a more predictive and adaptive system. Combining environmental understanding with intelligent data interpretation and sustainable functional materials offers a promising direction for protecting food quality, reducing exposure, and strengthening food-safety management across the agricultural supply chain.

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References

[1] Nada, S., Nikola, T., Bozidar, U., Ilija, D., & Andreja, R. (2022). Prevention and practical strategies to control mycotoxins in the wheat and maize chain. Food Control, 136, Article 108855. https://doi.org/10.1016/j.foodcont.2022.108855

[2] FAO. (2001). Manual on the application of the HACCP system in mycotoxin prevention and control. FAO Food and Nutrition Paper 73. Joint FAO/WHO Food Standards Programme FAO http://books.google.com/books?hl=en&lr=&id=kUjDSC5NVkUC&oi=fnd&pg=PR3&dq=Manual+on+the+application+of+the+HACCP+ystem+in+Mycotoxin+prevention+and+control&ots=wmRA7j479c&sig=COKalIkuJ5JCSBQTe-aXXQNfTFk.

[3] Hassane, A. M. A., El-Shanawany, A. A., Abo-Dahab, N. F., Abdel-Hadi, A. M., Abdul- Raouf, U. M., & Mwanza, M. (2017). Influence of different moisture contents and temperature on growth and production of aflatoxin B1 by a toxigenic Aspergillus flavus isolate in wheat flour. Journal of Ecology of Health & Environment, 5(3), 77–83. https://doi.org/10.18576/jehe/050302

[4] Nayak, S. N., Agarwal, G., Pandey, M. K., Sudini, H. K., Jayale, A. S., Purohit, S., et al. (2017). Aspergillus flavus infection triggered immune responses and host-pathogen cross-talks in groundnut during in-vitro seed colonization. Scientific Reports, 7(1), 1–14. https://doi.org/10.1038/s41598-017-09260-8

[5] Gacem, M. A., & Ould El Hadj-Khelil, A. (2016). Toxicology, biosynthesis, bio-control of aflatoxin and new methods of detection. Asian Pacific Journal of Tropical Biomedicine, 6(9), 808–814. https://doi.org/10.1016/j.apjtb.2016.07.012

© 2026 American Association of Scientific Research and Technology (AASRT). All rights reserved.

[6] Zhou, G., Chen, Y., Kong, Q., Ma, Y., & Liu, Y. (2017). Detoxification of aflatoxin B1 by Zygosaccharomyces rouxii with solid state fermentation in peanut meal. Toxins, 9(1), 1–9. https://doi.org/10.3390/toxins9010042

[7] Brzonkalik, K., Hümmer, D., Syldatk, C., & Neumann, A. (2012). Influence of pH and carbon to nitrogen ratio on mycotoxin production by Alternaria alternata in submerged cultivation. AMB Express, 2(1), 1–8. https://doi.org/10.1186/2191-0855-2-28

[8] Leggieri, M. C., Decontardi, S., Bertuzzi, T., Pietri, A., & Battilani, P. (2017). Modeling growth and toxin production of toxigenic fungi signaled in cheese under different temperature and water activity regimes. Toxins, 9(1), 1–17. https://doi.org/10.3390/toxins9010004

[9] Kokkonen, M., Jestoi, M., & Rizzo, A. (2005). The effect of substrate on mycotoxin production of selected Penicillium strains. International Journal of Food Microbiology, 99(2), 207–214. https://doi.org/10.1016/j.ijfoodmicro.2004.08.014

[10] Uppala, S. S., Bowen, K. L., & Woods, F. M. (2013). Pre-harvest aflatoxin contamination and soluble sugars of peanut. Peanut Science, 40(1), 40–51. https://doi.org/10.3146/ps12-9.1

[11] B. Wang, Y. Chen, Y. Wu, B. Weng, Y. Liu, Z. Lu, C.M. Li, C. Yu, Aptamer induced assembly of fluorescent nitrogen-doped carbon dots on gold nanoparticles for sensitive detection of AFB1, Biosens. Bioelectron. 78 (3) (2016) 23-30.

[12] A. Hayat, C. Yang, A. Rhouati, J.L. Marty, Recent advances and achievements in nanomaterial-based, and structure switchable aptasensing platforms for ochratoxin A detection, Sensors (Basel). 13 (11) (2013) 15187-15208.

[13] D.J. Guo, H.L. Li, High dispersion and electrocatalytic properties of Pt nano- particles on SWNT bundles, J. Electroanal. Chem. 573 (1) (2004) 197-202.

[14] L. Zhang, H. Wei, J. Li, T. Li, D. Li, Y. Li, E. Wang, A carbon nanotubes based ATP apta-sensing platform and its application in cellular assay, Biosens. Bio- electron. 25 (8) (2010) 1897-1901.

[15] M.C. Tu, H.Y. Chen, Y. Wang, S.M. Moochhala, P. Alagappan, L. Bo, Immu- nosensor based on carbon nanotube/manganese dioxide electrochemical tags, Anal. Chim. Acta 853 (1) (2015) 228-233.

[16] C. Singh, S. Srivastava, M.A. Ali, T.K. Gupta, G. Sumana, A. Srivastava, R.B. Mathur, B.D. Malhotra, Carboxylated multiwalled carbon nanotubes based biosensor for aflatoxin detection, Sensor. Actuator. B Chem. 185 (8) (2013) 258-264.

[17] J. Lin, C. He, L. Zhang, S. Zhang, Sensitive amperometric immunosensor for alpha-fetoprotein based on carbon nanotube/gold nanoparticle doped chi- tosan film, Anal. Biochem. 384 (1) (2009) 130-135.

[18] X. Zhang, C.R. Li, W.C. Wang, J. Xue, Y.L. Huang, X.X. Yang, B. Tan, X.P. Zhou, C. Shao, S.J. Ding, J.F. Qiu, A novel electrochemical immunosensor for highly sensitive detection of aflatoxin B1 in corn using single-walled carbon nanotubes/chitosan, Food Chem. 192 (2016) 197-202.

[19] F.A. Azri, J. Selamat, R. Sukor, Electrochemical immunosensor for the detection of aflatoxin B1 in palm kernel cake and feed samples, Sensors (Basel). 17 (12) (2017) 2776.

[20] L. Zhan, L. Peng, Y. Yu, S.J. Zhen, C.Z. Huang, Sensitive spectrofluorometry of cellular prion protein based on the on-off interaction between fluorescent dye-labelled aptamers and multi-walled carbon nanotubes, Analyst 137 (21), (2012) 4968-4973.

[21] C. Casiraghi, S. Pisana, K.S. Novoselov, A.K. Geim, A.C. Ferrari, Raman fingerprint of charged impurities in graphene, Appl. Phys. Lett. 91 (23) (2007) 183.

[22] F.L. Meng, H.H. Li, L.T. Kong, J.Y. Liu, Z. Jin, W. Li, Y. Jia, J.H. Liu, X.J. Huang, Parts per billion-level detection of benzene using SnO2/graphene nano- composite composed of

© 2026 American Association of Scientific Research and Technology (AASRT). All rights reserved.

sub-6 nm SnO2 nanoparticles, Anal. Chim. Acta 736 (14) (2012) 100-107.

[23] L. Yu, P. Li, X. Ding, Q. Zhang, Graphene oxide and carboxylated graphene oxide: viable two-dimensional nanolabels for lateral flow immunoassays, Talanta 165 (2017) 167-175.

[24] G. Geleta, Z. Zhao, Z. Wang, A novel reduced graphene oxide/molybdenum disulfide/polyaniline nanocomposite-based electrochemical aptasensor for detection of aflatoxin B1, Analyst 143 (7) (2018) 1644-1649.

[25] L. Zhou, R. Li, Z. Li, Q. Xia, Y. Fang, J. Liu, An immunosensor for ultrasensitive detection of aflatoxin B 1 with an enhanced electrochemical performance based on graphene/conducting polymer/gold nanoparticles/the ionic liquid composite film on modified gold electrode with electrodeposition, Sensor. Actuator. B Chem. 174 (11) (2012) 359-365.

[26] X. Wang, R. Niessner, D. Tang, D. Knopp, Nanoparticle-based immunosensors and immunoassays for aflatoxins, Anal. Chim. Acta 912 (2016) 10-23.

[27] S. Kim, T.L. Yong, E.G. Soltesz, A.M.D. Grand, J. Lee, A. Nakayama, J.A. Parker, T. Mihaljevic, R.G. Laurence, D.M. Dor, Near-infrared fluorescent type II quantum dots for sentinel lymph node mapping, Nat. Biotechnol. 22 (1) (2004) 93-97.

[28] D.R. Larson, W.R. Zipfel, R.M. Williams, S.W. Clark, M.P. Bruchez, F.W. Wise, W.W. Webb, Water-soluble quantum dots for multiphoton fluorescence imaging in vivo, Science 300 (5624) (2003) 1434-1436.

[29] P. Alivisatos, The use of nanocrystals in biological detection, Nat. Biotechnol. 22 (1) (2004) 47-52.

[30] X. Zeng, H. Gao, D. Pan, Y. Sun, J. Cao, Z. Wu, Z. Pen, Highly sensitive elec- trochemical determination of alfatoxin B1 using quantum dots-assembled amplification labels, Sensors (Basel). 15 (8) (2015) 20648-20658.

[31] E.S. Speranskaya, N.V. Beloglazova, S. Abe, T. Aubert, P.F. Smet, D. Poelman, I.Y. Goryacheva, S. De Saeger, Z. Hens, Colloids, hydrophilic, bright CuInS2 quantum dots as Cd-free fluorescent labels in quantitative immunoassay, Langmuir 30 (25) (2014) 7567-7575.

[32] X. Wei, Y. Xiong, W. Lai, X. Yang, C. Li, M. Xie, A homogeneous immunosensor for AFB 1 detection based on FRET between different-sized quantum dots, Biosens. Bioelectron. 56 (12) (2014) 144-150.

[33] K.Y.V.V. Aswani, R.M. Renuka, J. Achuth, V. Mudili, S. Poda, Development of a FRET-based fluorescence aptasensor for the detection of aflatoxin B1 in contaminated food grain samples, RSC Adv. 8 (19) (2018) 10465-10473.

[34] W. Long, D. Fan, W. Yin, M. Jing, B. Wang, A. Nie, H. Han, From electro- chemistry to electroluminescence: development and application in a ratio- metric aptasensor for aflatoxin B1, Anal. Chem. 89 (14) (2017) 7578-7585.

[35] R. Zekavati, S. Safi, S.J. Hashemi, T. Rahmani-Cherati, M. Tabatabaei, A. Mohsenifar, M. Bayat, Highly sensitive FRET-based fluorescence immu- noassay for aflatoxin B1;using cadmium telluride quantum dots, Micro- chimic. Acta. 180 (13e14) (2013) 1217-1223.

[36] Y. Lin, Q. Zhou, D. Tang, R. Niessner, H. Yang, D. Knopp, Silver nanolabels- assisted ion-exchange reaction with CdTe quantum dots mediated exciton trapping for signal-on photoelectrochemical immunoassay of mycotoxins, Anal. Chem. 88 (15) (2016) 7858-7866.

[37] Kis, ˇ M., Milosevi ˇ c, ´ S., Vulic, ´ A., Herceg, Z., Vukusi ˇ c, ´ T., & Pleadin, J. (2020). Efficacy of low pressure DBD plasma in the reduction of T-2 and HT-2 toxin in oat flour. Food Chemistry, 316, Article 126372. https://doi.org/10.1016/j.foodchem.2020.126372

[38] Wielogorska, E., Ahmed, Y., Meneely, J., Graham, W. G., Elliott, C. T., & Gilmore, B. F.

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(2019). A holistic study to understand the detoxification of mycotoxins in maize and impact on its molecular integrity using cold atmospheric plasma treatment. Food Chemistry, 301, Article 125281. https://doi.org/10.1016/j.foodchem.2019.125281

[39] Hojnik, N., Modic, M., Walsh, J. L., Zigon, D., Javornik, U., Plavec, J., et al. (2021). Unravelling the pathways of air plasma induced aflatoxin B1 degradation and detoxification. Journal of Hazardous Materials, 403, Article 123593. https://doi.org/ 10.1016/j.jhazmat.2020.123593

[40] Ali, M., Sun, D. W., Cheng, J. H., & Johnson Esua, O. (2022). Effects of combined treatment of plasma activated liquid and ultrasound for degradation of chlorothalonil fungicide residues in tomato. Food Chemistry, 371, Article 131162. https://doi.org/10.1016/j.foodchem.2021.131162

[41] Esua, O. J., Sun, D.-W., Cheng, J.-H., Wang, H., & Chen, C. (2022). Hybridising plasma functionalized water and ultrasound pretreatment for enzymatic protein hydrolysis of larimichthys polyactis: Parametric screening and optimization. Food Chemistry, 132677, Article 132677. https://doi.org/10.1016/j.foodchem.2022.132677

[42] Sen, Y., Onal-Ulusoy, B., & Mutlu, M. (2019). Detoxification of hazelnuts by different cold plasmas and gamma irradiation treatments. Innovative Food Science & Emerging Technologies, 54, 252–259. https://doi.org/10.1016/j.ifset.2019.05.002

[43] Esua, O. J., Cheng, J.-H., & Sun, D.-W. (2020). Antimicrobial activities of plasma- functionalized liquids against foodborne pathogens on grass carp (Ctenopharyngodon idella). Applied Microbiology and Biotechnology, 104. https://doi.org/10.1007/s00253-020-10926-z, 9851-9594.

[44] Mehany, T., Khalifa, I., Barakat, H., Althwab, S. A., Alharbi, Y. M., & El-Sohaimy, S. (2021). Polyphenols as promising biologically active substances for preventing SARS-CoV-2: A review with research evidence and underlying mechanisms. Food Bioscience, 40, Article 100891. https://doi.org/10.1016/j.fbio.2021.100891

[45] Ahmed, O. S., Tardif, C., Rouger, C., Atanasova, V., Richard-Forget, F., & Waffo-Teguo, P. (2022). Naturally occurring phenolic compounds as promising antimycotoxin agents: Where are we now? Comprehensive Reviews in Food Science and Food Safety. https://doi.org/10.1111/1541-4337.12891

[46] Hamad, G. M., Mohdaly, A. A. A., El-Nogoumy, B. A., Ramadan, M. F., Hassan, S. A., & Zeitoun, A. M. (2021). Detoxification of aflatoxin B1 and ochratoxin A using Salvia farinacea and Azadirachta indica water extract and application in meat products. Applied Biochemistry and Biotechnology, 193(10), 3098–3120. https://doi.org/10.1007/s12010-021-03581-1

[47] Sanzani, S. M., Schena, L., Nigro, F., de Girolamo, A., & Ippolito, A. (2009). Effect of quercetin and umbelliferone on the transcript level of Penicillium expansum genes involved in patulin biosynthesis. European Journal of Plant Pathology, 125(2), 223–233. https://doi.org/10.1007/s10658-009-9475-6

[48] Telles, A. C., Kupski, L., & Furlong, E. B. (2017). Phenolic compound in beans as protection against mycotoxins. Food Chemistry, 214, 293–299. https://doi.org/ 10.1016/j.foodchem.2016.07.079

[49] Makhuvele, R., Naidu, K., Gbashi, S., Thipe, V. C., Adebo, O. A., & Njobeh, P. B. (2020). The use of plant extracts and their phytochemicals for control of toxigenic fungi and mycotoxins. Heliyon, 6(10), 5291. https://doi.org/10.1016/j.heliyon.2020.e05291

[50] Chaudhari, A. K., Singh, V. K., Das, S., Deepika, Prasad, J., Dwivedy, A. K., et al. (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 and Chemical Toxicology, 143, Article 111536. https://doi.org/10.1016/j.fct.2020.111536

© 2026 American Association of Scientific Research and Technology (AASRT). All rights reserved.

[51] Mutlu-Ingok, A., Devecioglu, D., Dikmetas, D. N., Karbancioglu-Guler, F., & Capanoglu, E. (2020). Antibacterial, antifungal, antimycotoxigenic, and antioxidant activities of essential oils: An updated review. Molecules, 25(20), 4711.

[52] Tian, J., Ban, X., Zeng, H., He, J., Huang, B., & Wang, Y. (2011). Chemical composition and antifungal activity of essential oil from Cicuta virosa L. var. latisecta Celak. International Journal of Food Microbiology, 145(2–3), 464–470. https://doi.org/10.1016/j.ijfoodmicro.2011.01.023

[53] Kollia, E., Proestos, C., Zoumpoulakis, P., & Markaki, P. (2019). Capsaicin, an inhibitor of Ochratoxin A production by Aspergillus section Nigri strains in grapes (Vitis vinifera L.). Food Additives & Contaminants Part A Chemistry, Analysis, Control, Exposure and Risk Assessment, 36(11), 1709–1721. https://doi.org/10.1080/19440049.2019.1652771

[54] Hu, Y., Zhang, J., Kong, W., Zhao, G., & Yang, M. (2017). Mechanisms of antifungal and anti-aflatoxigenic properties of essential oil derived from turmeric (Curcuma longa L.) on Aspergillus flavus. Food Chemistry, 220, 1–8. https://doi.org/10.1016/j.foodchem.2016.09.179

[55] Kedia, A., Dwivedy, A. K., Jha, D. K., & Dubey, N. K. (2016). Efficacy of Mentha spicata essential oil in suppression of Aspergillus flavus and aflatoxin contamination in chickpea with particular emphasis to mode of antifungal action. Protoplasma, 253(3), 647–653. https://doi.org/10.1007/s00709-015-0871-9

[56] Jebali, A., Yasini Ardakani, S. A., Sedighi, N., & Hekmatimoghaddam, S. (2015). Nanocellulose conjugated with retinoic acid: Its capability to adsorb aflatoxin B1. Cellulose, 22(1), 363–372. https://doi.org/10.1007/s10570-014-0475-0

[57] Magro, M., Moritz, D. E., Bonaiuto, E., Baratella, D., Terzo, M., Jakubec, P., et al. (2016). Citrinin mycotoxin recognition and removal by naked magnetic nanoparticles. Food Chemistry, 203, 505–512. https://doi.org/10.1016/j.foodchem.2016.01.147

[58] Thipe, V. C., Keyster, M., & Katti, K. V. (2018). In K. A. Abd-Elsalam, & R. Prasad (Eds.), In Nanotechnology in the life sciencesSustainable nanotechnology: Mycotoxin detection and protection (pp. 323–349). Springer Nature. https://doi.org/10.1007/978-3-319- 91161-8_12.

[59] Peraica, M., Radi´c, B., Luci´c, A., & Pavlovi´c, M. (1999). Toxic effects of mycotoxins in humans. Bulletin of the World Health Organization, 77(9), 754.

[60] de Champdore, M., Bazzicalupo, P., De Napoli, L., Montesarchio, D., Di Fabio, G., Cocozza, I., et al. (2007). A new competitive fluorescence assay for the detection of patulin toxin. Analytical Chemistry, 79(2), 751–757.

[61] Magoha, H., Kimanya, M., De Meulenaer, B., Roberfroid, D., Lachat, C., & Kosteren, P. (2014). Association between aflatoxin M-1 exposure through breast milk and growth impairment in infants from Northern Tanzania. World Mycotoxin Journal, 7(3), 277–284.

[62] Haliburton, J. C., & Buck, W. B. (1986). Equine leucoencephalomalacia: An historical review. In Diagnosis of mycotoxicoses (pp. 75–79). Springer.

[63] Chen, C., Mitchell, N. J., Gratz, J., Houpt, E. R., Gong, Y., Egner, P. A., et al. (2018). Exposure to aflatoxin and fumonisin in children at risk for growth impairment in rural Tanzania. Environment International, 115, 29–37.

[64] Bennett, J. W., & Bentley, R. (1999). Pride and prejudice: The story of ergot. Perspectives in Biology and Medicine, 42(3), 333–355.

[65] Poor, M., Kunsagi-Mate, S., Sali, N., Koszegi, T., Szente, L., & Peles-Lemli, B. (2015) Interactions of zearalenone with native and chemically modified cyclodextrins and their potential utilization. Journal of Photochemistry and Photobiology B: Biology, 151, 63–68.

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[66] Malir, F., Ostry, V., Pfohl-Leszkowicz, A., Malir, J., & Toman, J. (2016). Ochratoxin A: 50 Years of research. Toxins, 8(7).

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