Article:
Liu, Y, Galani Yamdeu, JH orcid.org/0000-0003-4841-7414, Gong, Y orcid.org/0000-0003-4927-5526 et al. (1 more author) (2020) A review of postharvest approaches to reduce fungal and mycotoxin contamination of foods. Comprehensive Reviews in Food Science and Food Safety, 19 (4). pp. 1521-1560. ISSN 1541-4337

https://doi.org/10.1111/1541-4337.12562

A Review of Post-harvest Approaches to Reduce Fungal and Mycotoxin Contamination of Foods

Yue Liu, Joseph Hubert Galani Yamdeu, Yun Yun Gong, Caroline Orfila*

Nutritional Science and Epidemiology Group, School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, UK

Abstract: Contamination of agricultural and food products by some fungi species that produce mycotoxins can result in unsafe food and feed. Mycotoxins have been demonstrated to have disease-causing activities, including carcinogenicity, immune-toxicity, teratogenicity, neurotoxicity, nephrotoxicity and hepatotoxicity. Most of mycotoxins are heat stable and cannot be easily destroyed by conventional thermal food processing or domestic cooking methods. Post-harvest approaches to prevent growth of mycotoxin-producing fungi and detoxify mycotoxins from contaminated food are important topics in food safety research. Physical, chemical and biological methods have been applied to prevent fungal growth or mycotoxin production, or to reduce mycotoxin content in the post-harvest period and contribute towards mitigating against the effects of mycotoxins on human health. This literature review aims to evaluate post-harvest approaches that have been applied to control both fungi growth and mycotoxin content in food and discuss their potential for upscaling to industrial scale.

Key words: Mycotoxin; Fungi; Contamination; Post-harvest; Food Safety; Anti-Fungal, Reduction, Prevention or Mitigation approaches.

Words: 13131

1 Introduction

Agricultural and food products can be contaminated by fungi, most particularly during the post-harvest period. Some fungi can produce toxic metabolites, named mycotoxins, which have a negative impact on the safety of food and feed. Dietary exposure to mycotoxins cause health issues due to their biological activities which include carcinogenicity, immune-toxicity, teratogenicity, neurotoxicity, nephrotoxicity and hepatotoxicity (Dalié, Deschamps, & Richard-Forget, 2010; Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011). Some of these toxicities can be acute (WHO, 2015, 2017), resulting in illness or death within a few days of exposure to heavily contaminated food. Meanwhile, mycotoxins can have cumulative effects at lower doses, resulting in chronic health effects that manifest over several months or years (Tola, Kebede, & Yildiz, 2016).

More than 100 fungi species have been found to produce over 400 poisonous metabolites (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011). The most common agricultural mycotoxins comprise aflatoxins (AFB_1, AFB_2, AFG_1, AFG_2 and AM_1), fumonisins (FB_1, FB_2), ochratoxin A (OTA), the trichothecene mycotoxins (type A: T-2 and HT-2, type B: deoxynivalenol (DON), nivalenol (NIV)), and zearalenone (ZEN), patulin (PAT) and egot

alkaloid. Minor mycotoxins include cyclopiazonic acid, sterigmatocystin, gliotoxin, citrinin and citreoviridin. Mycotoxins are produced primarily by *Aspergillus* sp., *Penicillium* sp., *Fusarium* sp. and *Claviceps* sp. (CAST, 2003; Hathout & Aly, 2014; Petruzzi et al., 2014; Schaarschmidt & Fauhl-Hassek, 2018).

Mycotoxin producing fungi are prevalent worldwide. According to recent report published in 2011, more than a quarter of the world's agricultural products are contaminated by mycotoxins at levels above the European Union (Table 1) and *Codex Alimentarius* limits (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011). Moreover, a more recent report indicates that mycotoxins are detected in 60–80% of agricultural products. The increase is likely due to a combination of the improved sensitivity of analytical methods and impact of climate change (Eskola et al., 2019). Moreover, more than 50% of food products are showing co-occurrence of more than one mycotoxin (BIOMIN, 2015). Mycotoxin contamination may occur during pre- and/or post-harvest periods. The occurrence of mycotoxins in different crop products is shown in Table 1. It appears that cereals (such as wheat, maize, rice, barley and sorghum) are the most commonly contaminated products, although mycotoxins can also be found in animal products (meat, eggs and milk), pulses, oilseeds, dry fruits and nuts. The most important agricultural pathogens are *Aspergillus*, *Fusarium* and *Penicillium* sp. *Aspergillus* sp. exists in warm (25 to 42°C) environments, which can be humid or dry (even down to -35 MPa water potential). These conditions are common in soil, food storage areas and manufacturing facilities (Klich, 2007; Tola, Kebede, & Yildiz, 2016). In *Aspergillus* sp., the production of aflatoxins is related to spore production (Klich, 2007; Tola, Kebede, & Yildiz, 2016). In temperate regions *Aspergillus* sp. also contributes to OTA production. *Penicillium* sp. can produce ochratoxins at temperatures as low as 5℃ (Tola, Kebede, & Yildiz, 2016).

As some mycotoxins are highly toxic, maximum limit (MLs) standards have been established to protect the consumers' health. In the early 21th century, approximately 100 countries in the world (covering about 85% of inhabitants) have set MLs to regulate the maximum amount of mycotoxins permitted in human and animal feed (van Egmond, Schothorst, & Jonker, 2007). The MLs of main mycotoxins set by the European Commission are shown in Table 1. However, these limits exert an impact on the agricultural export market, where least contaminated crops are exported to generate income, while more contaminated foods may be traded in the producing country, especially in low income countries where regulations are poorly enforced. As a result, it is critical for the food and economic security of low income countries to reduce fungal and mycotoxin contamination of foods.

Because of the different distinct hazards caused by fungi (microbiological) and toxins (chemical), the risk control strategies should be addressed simultaneously and where possible synergistically. Prevention of fungal growth is usually considered as an early step during production and post-harvest storage. If fungal growth cannot be avoided, approaches to de-contaminate the food of the toxin through processing must be considered.

This is a comprehensive review of post-harvest approaches that have been applied to reduce fungal growth and mycotoxin contamination in foods. The review includes a comparative evaluation of the efficacy of different approaches, including physical, chemical, biological and their combination, on fungal growth and mycotoxin content. The review discusses the

feasibility of these different approaches to be upscaled from laboratory to industrial scales within different food systems.

2 Control of fungal growth and prevention of mycotoxin production

The most effective way to reduce the mycotoxins in the food chain is to prevent the fungus growing in the first place, and if fungi do happen to be present in the food, then to prevent the toxin from being produced. A range of physical, chemical and biological approaches have been applied, both at industrial and laboratory scale.

2.1 Physical approaches

2.1.1 Temperature and humidity control

Storage of crops causes a mini ecosystem containing the biotic factors (crops, microorganisms, etc.) and abiotic factors (water, air, temperature, etc.) suitable to fungal growth (W. X. Peng, Marchal, & van der Poel, 2018). Similar to other living organisms, fungi require water and an optimal temperature to survive and thrive. Moisture content and storage temperature can be controlled to be outside of the microorganisms' optimum to reduce metabolic activity and decreased growth. Moreover, water content and temperature are one of the easiest factors to control during food storage, at both industrial and domestic scale. Although both relative humidity (RH) and moisture content (MC) are used to reflect the water content of food, it is better to use equilibrium RH, because the impact of equilibrium RH on spoilage organisms is consistent across different foods, regardless of their composition (Bradford et al., 2018). When the equilibrium RH is below 65%, microorganisms stop growing, meaning food is safe for at least one year of storage at ambient temperature. Storage temperature can also contribute to crop longevity (Bradford et al., 2018). In stored rice, both raising temperature (10 to 40℃) and RH (12 to 98%) significantly increased the growth of both *Aspergillus* sp. and *Penicillium* sp. by about 4 to 6 log colony forming units per gram (CFU/g) from about 3.8 log CFU/g. According to the result of multiple linear regression analysis, changing one unit of temperature resulted in stronger impacts on fungal populations than changing humidity (Mannaa & Kim, 2018). Additionally, Choi et al. (2015) showed that both 21℃ with 97% humidity and 30℃ with 85% humidity were associated with an increase of population of *A. flavus* by about 3 log CFU/g and the production of aflatoxins during the 120-day storage period, while when the rice was stored at 21℃ with 85% humidity, *A. flavus* population could be constant and no aflatoxins were produced. For *F. graminearum*, 97% humidity encouraged fungal growth from 2.5 to 4 log CFU/g at 21℃. When the humidity was reduced to 85%, *F. graminearum* and DON production could be controlled. Thus, dry (below 85% RH) and low temperature (below 21^{o}C) are good strategies for controlling fungal growth. However, these conditions may be difficult to maintain in warm and humid countries where a refrigerated and ventilated store may not be available. Moreover, vegetable foods tend to respire, causing moisture and temperature rises during post-harvest storage, and thus the environmental conditions must be regularly monitored.

2.1.2 Modified atmosphere treatment

Modified atmosphere (MA) approaches includes modification of the gas composition (e.g. O_2, CO_2, N_2) considering temperature, RH, MC and competing microorganisms (Magan and Olsen 2004), and is usually applied for fresh food preservation (Bouletis et al., 2016; de

Siqueira Mendes, Aguayo, de Oliveira Pessoa, Nastaro, & Kluge, 2019; Putnik et al., 2017). Fungi have a different sensitivity to atmosphere compositions. In general, high CO_2 and low O_2 content can contribute to inhibition of foodborne fungi. *P. roqueforti* and *A. flavus* could not grow in both 40% and 60% CO_2 environments balanced with N_2 and less than 0.5% O_2, but weakly grow (about 30mm in 30-day incubation) in 20% CO_2 (Taniwaki, Hocking, Pitt, & Fleet, 2009). MA at a large scale can be expensive, and there may be issues in displacing and replacing the gases during the storage period.

Modified atmosphere packaging (MAP) is a strategy that controls gas composition immediately surrounding the food within gas-impermeable packaging. Wheat and rye bread artificially inoculated with several fungi were packaged with 0%, 50%, 75% or 100% CO_2, 1%, 0.03% O_2 or in the presence of O_2 -absorber, and balanced with N_2. Notably, the gas composition would be changing during the storage of the bread. MAP was more effective against fungal growth on rye bread, as fewer fungi grew with the increase of CO_2. But for *P. roqueforti*, this main contaminant of rye bread was inhibited only in the presence of O_2 -absorber. For wheat bread, the most resistant to CO_2 was *P. commune* which could grow in 99% CO_2. *A. flavus* grew in the lowest O_2 concentration and 75% CO_2 (Suhr & Nielsen, 2006). So far, MAP has become a widely used way of food preservation because of its efficiency, convenience and safety. It is cheaper and easier that large scale MA as it is only necessary to fill the packaging with modified gas. MAP requires suitable packaging which is generally plastic-based, and will inevitably cause usage and disposal of a large number of plastic packaging.

2.1.3 Irradiation treatment

Irradiation of food for safety is based on the utilization of ionizing energy to inactivate microorganisms by changing their cellular structure or physiological functions, including DNA strand breakage, cell membrane rupture/leakage, or mechanical damage of cell walls (Calado, Venâncio, & Abrunhosa, 2014). The effectiveness of the irradiation method depends on many factors, such as irradiation dose, the microbial attributes (e.g. morphological structures, physiological stage) and the environmental condition of the irradiated materials (e.g. temperature, pH) (Magan & Olsen, 2004).

Aziz, El-Far, Shahin, and Roushy (2007) treated wheat, maize and barley collected from Cairo (Egypt) markets with gamma-irradiation and evaluated the occurrence of 4 *Fusariums* strains and FB_1 production. At 5 kGy, both *Fusarium* sp. counts and FB_1 production on barley samples were completely decontaminated. Same results could be observed on wheat and maize under 7 kGy irradiation. When the dose was below 5 kGy for barley or 7 kGy for wheat and maize, the growth of *Fusarium* sp. and production of FB_1 could be inhibited by up to 85% and 97% respectively. Similar observations were later reported by Akueche et al. (2012) who studied the effect of gamma-radiation treated on sesame grains sampled from Abuja (Nigeria) markets. In this study, 135 fungal strains including *Aspergillus* sp., *Penicillium* sp., and *Fusarium* sp. were isolated from non-irradiated sesame grains. But only 34 strains were found on grains after 3 kGy gamma-irradiation, and no of fungal species was found on grains irradiated between 6 to 15 kGy.

In an experiment aimed at preventing fungal infection in fruits and vegetables, fungi were usually artificially inoculated on the fruits or vegetables, and then treated with various doses of irradiation. In general, the results showed better fungal inhibition comparing to control

group with the increasing irradiation dose in peppers, oranges, broccoli, cabbage, tomato, bean sprout and papaya (Bari et al., 2005; Cia, Pascholati, Benato, Camili, & Santos, 2007; Jeong, Chu, Lee, Cho, & Park, 2016; Yoon et al., 2014). The irradiation could not only reduce the fungi, but also affected the production of mycotoxins. For instance, the total fungi isolated from packed hot peppers were 4.8×10^3 CFU/g, total *Aspergillus* count were 4.7×10^2 CFU/g and aflatoxin level was 1.14 ppb on average. After 2, 4, 6 kGy irradiation treatment, over 90% fungi could be reduced. But only a non-significant reduction of 6% on aflatoxin levels was observed at 6 kGy gamma radiation (Iqbal, Amjad, Asi, & Arino, 2012). In addition, as the fruits and vegetables tend to easily lose their sales value, the effect of irradiation treatment on product qualities should be considered. In a study of Bari et al. (2005), appearance, texture, color, taste and overall acceptability were used as sensory indicators to determine the quality of broccoli, mungbean sprouts, cabbage and tomato in both untreated and treated groups. Of all indicators, texture was the worst affected parameter after irradiation treatment in the four tested vegetables, and the sensory evaluation of other indicators gradually got worse with increasing dose (maximum 1.0 kGy). Despite this, with 1.0 kGy, less than 7 days storage was acceptable for each vegetable at refrigeration temperature.

The primary advantages of irradiation are non-residual chemicals and high efficacy, so that it can be considered as an environment friendly mycotoxin reduction approach. Nevertheless, the nutrient loss, high costs and secondary products of uncertain safety in treatment are not negligible as well (Calado, Venâncio, & Abrunhosa, 2014), added to the deterioration of sensory quality that can be caused by irradiation.

2.2 Chemical approaches

2.2.1 Control by chemical antifungal agents

In general, many antifungal agents are low-molecular-weight organic acids and their salts (Magan & Olsen, 2004), and some of them are applied as food additives (1333/2008, 2017). Marín et al. (2000) revealed that *Penicillium* sp. had the highest sensitivity to both 0.5 and 1.0 g/kg propionates than *Aspergillus* sp. and *Fusarium* sp. at 25℃ in culture medium. The efficacy of propionates was higher at 7 days rather than at 14 to 21 days. In another study, Valencia-Chamorro, Palou, Río, and Pérez-Gago (2008) screened 15 chemicals and their mixtures in hydroxypropyl methylcellulose-lipid edible composite films on the effects of fungal growth. Amongst the chemicals, sodium bicarbonate, potassium sorbate (2%), sodium benzoate (2.5%), sodium salt of methyl paraben (1%/1.5%), sodium salt of ethyl paraben (1%) and sodium salt of propyl paraben (1%) and the mixtures of potassium sorbate (1.5%) with sodium propionate (0.5%), sodium benzoate (2%) with potassium sorbate (0.5%) and sodium benzoate (2%) with sodium propionate (0.5%) displayed the inhibition on growth of *P. digitatum* and *P. italicum* at all inoculation concentrations (10^3, 10^4 and 10^5 spores/mL). The inhibitory effects were dose dependent. Sodium salt of methyl paraben at the concentration of 1.5% showed the best performance, while no synergistic effect could be found in the mixtures of two antifungal agents. This edible coating displayed potential application prospects. In a recent research, a novel material, zinc oxide slightly coated with sliver nanoparticles, was demonstrated to inhibit the growth of *A. niger* (Tornero et al., 2018). Coating is one of the popular methods to preserve fresh fruits and vegetables. The coatings inhibit respiration, delay softening and color changes via controlling the internal gas composition and water vapor (Conforti & Totty, 2007; Mehyar, El Assi, Alsmairat, & Holley,

2014). When fungal inhibitors are added into the coatings, the counting of not only mycotoxin producing fungi but also other spoilage microorganisms, can be significantly reduced. For example, Salas-Méndez et al. (2019) compared antifungal effect of control group, edible nanolaminate coating (synthesized by the aminolysis of polyethylene terephthalate) (NL) and nanolaminate coating with added an extract from *Flourensia cernua,* a Mexican endemic plant growing in arid and semiarid areas (NL+ FcE). Fungi could be found from the beginning of storage in control and NL group at 20ºC, while NL+FcE coating could prevent the fungal infection for 6 days. On the 15th day, the counting of fungi and yeasts in control group was about 1000 times those in NL+FcE group, and was about 100 times those in NL group. Nevertheless, in a report of Mehyar, El Assi, Alsmairat, and Holley (2014), the coating of date palm cultivar with pea starch + carnauba wax and zein protein + carnauba wax could only reduce fungi and yeast about 1 log CFU/g after 14 days, but the coatings lost their effect in third week at 25ºC. Antifungal agent treatment, with or without coating are low-cost and easy-used control approaches, but the safety of the remaining fungicide residues in the treated products is also a major concern and this has highlighted the necessity of using antimicrobial compounds that are safe to humans and animals. Antifungal agents also tend to lose their effectiveness over time, putting into question their application for large scale crop and food storage.

2.2.2 Photodynamic treatment

Photodynamic treatment is a method that utilizes the interaction of a non-toxic photosensitizer and a particular wavelength of visible light (Al-Asmari, Mereddy, & Sultanbawa, 2018). This approach is mainly used in oncology, ophthalmology and dermatology (Preuß et al., 2014). In recent years, the photodynamic treatment has been investigated for its antimicrobial properties, as the photosensitizer, induced by light of specific wavelength, generates cytotoxic substances that cause biochemical and functional disturbances of the cell membrane component and leads the damage to microbial cells (Al-Asmari, Mereddy, & Sultanbawa, 2018; Temba, Fletcher, Fox, Harvey, & Sultanbawa, 2016). Curcumin is one of the most common photosensitizers in photodynamic studies. In a study by Temba, Fletcher, Fox, Harvey, and Sultanbawa (2016), about three log magnitudes of *A. flavus* spores counts were reduced by 84 J/cm^2 irradiation at 420 nm with both 15 and 20 μM of curcumin. When 5 log CFU/mL of spores were spiked into whole maize kernels, 1.9 log CFU/mL of spores were decreased at 60 J/cm^2 light with both 25 and 45 μM of curcumin, while 2.8 log CFU/mL of spores were reduced in milled kernels under same conditions. In another study by Temba et al. (2019), the effect of pH and temperature on *A. flavus* elimination under the reaction condition of 100 μM curcumin stock solution with irradiation at 420nm wavelength at 60J/cm^2 was investigated. Compared to the non-illuminated group, the *A. flavus* spores in the illuminated group were about two magnitudes lower at pH from 1.5 to 9, and showed a sharp decrease at pH in both groups. Similar pattern could be found on hyphae reduction. In the temperature-depending assay, although the counts in non-illuminated group were still higher than those in illuminated group, temperature (from 15 to 45ºC) did not have significant influence on *A. flavus* spores and hyphae. In addition, about 66.7% of produced AFB_1 was not detected under the light treatment with curcumin stock solution. Njoki, Okoth, and Wachira (2017) reported 6 plants extracts (*Solanum aculeastrum, Syzygium cordatum, Prunus africana, Ocimum lamiifolium, Lippia kituiensis*, and *Spinacia oleracea*) could inhibit the

growth of colony of *A. flavus* 4 to 47 mm (up to 42%) at concentration of 450 and 600 mg/mL. However, when *A. flavus* were treated with the increasing treatment dose and time of visible light (420 nm), the fungi were inhibited up to 95% at same concentration of plants extracts. Preuß et al. (2014) synthesized new photosensitizers and observed the prevention of growth of *A. niger* and *P. purpurgenum*. Besides, the new synthesized photosensitizer inactivated germination of conidia. As a novel method, the photodynamic treatment shows potential to control mycotoxin producing fungi. However, current studies mainly focus on fundamental research at laboratory scale, while the future research could consider the safety of photosensitizers and photolysis products and the application of photodynamic treatment in real and large scale food systems.

2.2.3 Electrolyzed oxidizing water treatment

Electrolyzed oxidizing water (EOW) is obtained from electrolyzed NaCl solution, transforming water molecules and chloride ions into chlorine oxidants (Cl_2, HOCl/ClO−) that are show antimicrobial properties. EWO contains two types of water: strongly acidic EOW and neutral electrolyzed water (NEW). The antimicrobial effect mainly depends on the level of ·OH. The radicals can break the normal morphological structure of spores, and is closely related to the damage of conidium cell wall and membrane, which leads to the spores losing their normal function. NEW is non-toxic and safe to humans, it can be applied to fungi decontamination (Gómez-Espinosa et al., 2017; Guentzel, Lam, Callan, Emmons, & Dunham, 2010; Xiong, Liu, Liu, & Li, 2010). Okull and Laborde (2004) used EOW to inactivate 1 to 4 magnitudes of *P. expansum* spores depending on concentration and exposure time. In an apple infection test, the apples were inoculated with 10^6 CFU/mL of spores and treated with 50% and 100% EOW for 5min, and stored at 25ºC for 6d. In non-treated apples, once wounds were infected by spores, the decay was in evitable (100% incidence). But when treatments were applied, decay in apple were only 18.4% for 50% EOW and 10.2% for 100% EOW. Therefore, the use of EOW can be considered as a potential method in an apple cleaning system. Xiong, Liu, Liu, and Li (2010) compared the elimination of *A. flavus* by both EOW and acidic EOW. The results illustrated the population of spore survival treated by acidic EOW was 5.77 log conidia/mL, which was 1.48 log conidia/mL less than control group, and no spores could be found in EOW group. This because that EOW showed a stronger signal on ·OH level than acidic EOW. With the addition of mannitol (a radical scavenger) in reaction system, the survival population was increased, which also provided a strong evidence that ·OH played the most important role in the inhibition of *A. flavus* spores.

2.2.4 Plasma treatment

Plasma is an ionized gas, with zero net electrical charge, that can be induced in any neutral gas at particular pressure and temperatures conditions. Examples of natural plasma are sun and polar gases, whereas artificial plasma include dielectric barrier discharges plasma, microwave plasma, inductively coupled plasma, radio-frequency and commercial ozone (Misra, Yadav, Roopesh, & Jo, 2019). These plasmas could inactivate a variety of mycotoxin producing fungi on a range of foods, including fruits, vegetables, herbs, spices, cereals, nuts and meat products in seconds. However, the effect of plasma on food quality depends on the type of plasma, the duration of treatment and plasma intensity (Misra, Yadav, Roopesh, & Jo, 2019).

Among the cold plasmas, ozone is one of the best documented plasma on antifungal activity.

This strong oxidant can progressively oxidise unsaturated lipids in the microbial membrane or cellular proteins, leading to a leakage or rapid death of the cell (Freitas-Silva & Venancio, 2010). In addition, ozone can reduce conidia germination (Savi, Bittencourt, et al., 2015). *A. flavus* artificially spiked on wheat was reduced by up to 96.6% with the 60 µmoL/moL O_3 gas treatment for 120min and 100% with the same concentration for 180min (Savi, Souza, et al., 2015), *P. citrinum* behaved in a similar way, while *F. graminearum* was more sensitive to the same concentration of O_3 gas, inhibited by up to 96.81% in 30min and completely inhibited in 180min (Savi, Bittencourt, et al., 2015). Naturally occuring *Aspergillus* sp. and *Penicillium* sp. on rice could be reduced up to 70% in short-time treatment (30min) at 10 mg/L O_3 gas (Beber-Rodrigues, Savi, & Scussel, 2015). Moreover, O_3 treatment can decrease also mycotoxin production. In one of above studies, produced AFB_1 degraded 69.5% and 72.2% exposed under 40 and 60 µmoL/moL of O_3 gas respectively for 180min (Savi, Souza, et al., 2015). Similar findings were reported by Savi, Piacentini, and Scussel (2015).

Although O_3 showed the highly efficient inhibition of fungi, the oxidation could still result in some negative effects on food quality. Savi, Souza, et al. (2015) reported that wheat could still germinate normally after 60 µmoL/moL of O_3 gas treated for 120min. However, seed germination of wheat, maize and paddy rice was significantly affected (up to 67%) when the seeds were exposed under 4.8 mg/L for 12h (S. Wang, Liu, Lin, & Cao, 2010). For the unmilled productions, ozone did not show a large impact on the total phenol content, antioxidant capacity and odor, but the colour of some grains could fade to somewhat white color (Santos Alexandre et al., 2018; S. Wang, Liu, Lin, & Cao, 2010). In contrast, for flour products, ozonation resulted in the degradation of starch in whole wheat flour decreasing viscosity and swelling capacity and increasing the pasting temperature (Alexandre, Castanha, Calori-Domingues, & Augusto, 2017; Alexandre et al., 2019). The ozonation process also contributed to the peroxide value, and accelerated the oxidation of unsaturated fatty acids (Alexandre et al., 2019). Plasma treatment has good potential as a strategy to control fungal growth and aflatoxin production, but more research is needed to understand undesirable effects, including potential production of toxic compounds.

2.3 Biological approaches

2.3.1 Inhibition by microorganisms and their metabolites

In nature, fungi often share habitats with plants and with other microorganisms, resulting in competition for space and nutrients. Therefore, fungal propagation would be weakened if outcompeted by other microorganisms (Abbas, Zablotowicz, Bruns, & Abel, 2007; Appell, Kendra, & Trucksess, 2009; Cavaglieri, Andres, Ibanez, & Etcheverry, 2005).

This natural competition phenomenon has been exploited by researchers to control fungi and their toxins though the direct use of certain antagonist microorganisms as biocontrol agents (BCAs) or the use of microbial metabolites. Biological control of mycotoxin-producing fungi has been largely covered by several reports (Bhat, Rai, & Karim, 2010; de Medeiros et al., 2012; Kagot, Okoth, De Boevre, & De Saeger, 2019; Kong, 2017; Mannaa & Kim, 2016). It appears that biological control using microbial antagonists such as bacteria, fungi and yeasts could be a feasible substitute to reduce the use of antifungal chemicals. Great successes in reducing aflatoxin contamination in fields of different crops by 70% to 90% have been achieved by application of atoxigenic strains of *Aspergillus*. For the biocontrol of *Fusarium*

and its associated fusariotoxins, species of *Trichoderma*, *Bacillus* and atoxigenic *Fusarium* have being tested as the most promising candidates. However, questions remain about the ability of the atoxigenic fungi to produce other mycotoxins, or to potentially exchange genetic material and become aflatoxigenic. The low efficacy of many antagonists in the field conditions, despite showing high potential in the lab is another concern. Overall, it is suggested that integrated management approaches should be considered, involving a combination of multiple BCAs, with reduced fungicide application, in conjunction with good agricultural practices, and coupled with good postharvest management. In this section, we focus on the inhibition of fungal growth and toxin production by microbial and plant metabolites.

Fungal growth and toxin production may be affected by metabolites produced by other microorganisms. Some proteins and peptides inhibit the growth of microorganisms and are therefore termed as antifungal proteins (AFPs) and antimicrobial peptides (AMPs). AFPs from molds show a high stability to pH and proteolysis and exhibit a broad inhibition spectrum against filamentous fungi, and thus have prospects to control hazardous molds in fermented foods. An AFP isolated from *P. chrysogenum* (PgAFP) at 4.9 μg/mL significantly reduced the growth of *A. flavus* with over 50% inhibition rate (Delgado et al., 2015).

A compilation of the antifungal peptides produced by molds by Delgado, Owens, Doyle, Asensio, and Nunez (2016) showed 16 compounds, produced by *Aspergillus*, *Penicillium*, *Fusarium*, *Monascus*, and *Neosartorya* sp., with molecular weights (MW) between 5773 and 10 000 Da. A peptide (MW 2500Da) isolated from *Bacillus* strain B-TL2 had strong inhibitory activity against mycelial growth of *A. niger*, as well as *Bipolaris maydis*, *Alternaria brassicae*, and *Cercospora personata.* Moreover, this peptide showed thermostability, which means the peptide could keep 100% activity at 100℃ (B. B. Zhang, Xie, & Yang, 2008). In addition, four AMPs, namely PPD1 (FRLHF), 66-10 (FRLKFH), 77-3 (FRLKFHF) and D4E1 (FKLRAKIKVRLRAKIKL) at concentrations between 1 to 40 μg/mL reduced the aflatoxin production by *A. flavus* and *A. parasiticus* in a dose-dependent manner. At near minimum inhibitory concentrations (MIC) the AMPs inhibited aflatoxins, without hindering the growth of the fungi. An almost 99% inhibition of aflatoxins produced by *A. parasiticus*. *Parasiticus* was observed. *Conidiation* of the fungi was also negatively influenced by the peptides (Devi & Sashidhar, 2019). A peptide purified from *Lactobacillus plantarum* with amino acidic sequence SGADTTFLTK reduced by 73% the growth of *A. parasiticus* in liquid medium after 48 h incubation (Luz, Saladino, Luciano, Mañes, & Meca, 2017). Similarly, three newly identified peptides from Bacillus megaterium (L-Asp-L-Orn (D1O), L-Asp-L-Asn (D1N) and L-Asp-L-Asp-L-Asn (D2N)) at concentrations above at 0.32 mg/well significantly inhibit the growth of *A. flavus*, but without any effect on spore germination. At concentrations ranging between 0.04 and 0.64 mg/mL, the reduction of AFB_1 by the peptides was from 70% to 80% (Chen, Kong, & Liang, 2019).

Efforts are being made to elucidate the mechanism of inhibition of AMPs. A single peptide is often capable of more than one mode of action, depending on the target cell type, and the antifungal activities of peptides cannot be inferred from studies on their antibacterial activities. AMPs usually act via membrane permeabilization, while antifungal activity for these peptides is generally more complex and often involves entry of the peptide into the cell (van der Weerden, Bleackley, & Anderson, 2013). As evidenced by confocal microscopy and

quantitative RT-PCR (qRT-PCR), three peptides from *B. megaterium* D1O, D1N and D2N could spontaneously enter into the hyphae of *A. flavus* and inhibited conidiation and aflatoxin production, but did not inhibit hyphae vegetative growth and spore germination (Chen, Kong, & Liang, 2019). A more detailed mechanism was proposed by Devi and Sashidhar (2019), which shows that the AMPs, at concentrations near MIC, induced membrane permeabilisation, without inducing cellular leakage. The AMPs also show antioxidant properties which interact with oxidative stress and impair aflatoxin production. At molecular level, the AMPs were responsible of down regulation of the aflatoxin gene cluster '*aflR*' (a regulatory gene for aflatoxin biosynthesis), and the expression of downstream genes. Similarly, a decrease in the expression of manganese-superoxide dismutase (Mn-SOD) has been shown to be correlated to aflatoxin synthesis, was obtained in peptide-treated samples.

During food fermentation, some non-peptides metabolites have been shown to have antifungal activities. These compounds produced by lactic acid bacteria included organic acids, phenol compounds, hydroxy fatty acids, hydrogen peroxide and reuterin (Dalié, Deschamps, & Richard-Forget, 2010). For example, acetic and phenyl lactic acids produced by *L. plantarum* CRL 778, *L. uteri* CRL 1100, and *L. brevis* CRL 772 and CRL 796 displayed antifungal activity on *A. niger* (<40%), *Penicillium* sp. (40%-70%) and *F. graminearum* (>70%) isolated from contaminated bread. The effect of organic acids depends not only on the type of acid, but also on their concentration, the type of matrix, and pH of the matrix (Gerez, Torino, Rollán, & Font de Valdez, 2009). Selected *Lactobacillus* sp. (*L. fermentum* M107 and *L. fermentum* 223) and yeasts (*Hanseniaspora opuntiae* H17 and *Saccharomyces cerevisiae* H290) were used for to inhibit the growth of *A. flavus* S075, *P. citrinum* S005 and *Gibberella. moniliformis* S003 in cocoa bean fermentation. On average, *Lactobacillus* sp. (63% and 75% respectively) showed higher inhibition ability than yeast (25% and 31%), when they were cultural individually. Glucose, fructose, and citric acid in medium were converted to mannitol, acetic acid and lactic acid by *Lactobacillus* sp., whereas the glucose and fructose was metabolized to ethanol during culture. In the co-culture of *Lactobacillus* and yeasts, *A. flavus* S075 was inhibited completely after 10 to 14 days (Romanens et al., 2019). The antifungal interaction between fungi growth/mycotoxin production and lactic acid bacteria or yeasts was summarized by Hassan, Zhou, and Bullerman (2015) and Bourdichon et al. (2012). The application of AMPs and AFPs, as well as fermentation metabolites seems promising strategies for fungal and mycotoxin control. Further research is needed to elucidate the mechanism of action and potential negative effects of the microbes or microbial metabolites.

2.3.2 Inhibition by plant extracts

Higher plants can a produce a number of secondary metabolites that display wide biochemical and physiological functions (Prakash, Kedia, Mishra, & Dubey, 2015). A volatile substance containing secondary metabolites, obtained from distillation of plants is called an essential oil (EO). EOs have been used for antimicrobial and insecticidal applications in the pharmaceutical, cosmetic, agricultural and food industries (Bakkali, Averbeck, Averbeck, & Idaomar, 2008). The major compounds of EO are phenylpropanoids, phenolics, terpenoids, steroids, aromatic and alkaloids, whose content determine the properties of the EOs (Bakkali, Averbeck, Averbeck, & Idaomar, 2008; Prakash, Kedia, Mishra, & Dubey, 2015). The composition of EOs is highly variable and, depending on plant species, modes of extraction

and storage conditions. Different parts of one plant or even the same plant harvested from diverse regions or at different harvest time can vary in antifungal ability. Table 2 summarises and compares studies that studied the inhibition of mycotoxin-producing fungi by EOs. EOs from diverse plant species in eight countries showed inhibition effect from 58% to 100% under different concentrations. Leaf and aerial parts were the most common organs for extraction of EOs. As the EOs are at preventing fungi contamination, the safety assessment of EOs should be an important concern. In a number of studies, high LD_{50} values have been recorded, such as 11 mL/kg for *Ocimum gratissimum* (Prakash et al., 2011), 4 mL/kg for *Cinnamomum glaucescens* (Prakash, Singh, Yadav, Singh, & Dubey, 2013), 4.5 mL/kg for *Ocimum sanctum* L. (A. Kumar, Shukla, Singh, & Dubey, 2010), and 9 mL/kg for *Caesulia axillaris* roxb. (Mishra, Shukla, Singh, Prakash, & Dubey, 2012). Besides, the EOs of cinnamon, clove, lemon grass, oregano, thyme, nutmeg, and basil are confirmed as safe in America. In European countries, EOs components carvacrol, carvone, cinnamaldehyde, citral, p-cymene, eugenol, limonene, menthol, linalool, vanillin, and thymol are registered as flavour additives in foods (Prakash, Kedia, Mishra, & Dubey, 2015).

Apart from EOs, some plant AFPs and AMPs have also been identified (S. C. Park et al., 2017; Subramanyam et al., 2012; D. J. Yun et al., 1998). These components comprise defensins, lectins, chitinases, glucanases and other proteins obtained from seeds, bulbs, leaves, tubers, fruits, shoots, and roots (Yan et al., 2015). Both low molecular weight proteins and high molecular weight proteins could show fungal inhibition capability. For example, a 5.4 kDa highly homologous plant defensins peptide purified from *Phaseolus vulgaris* L. impeded the growth of *F. oxysporum* around paper discs containing this peptide (Chan & Ng, 2013). In the same way, a designated Chitinase A (Chit A) and Chitinase B (Chit B) of 28 kDa purified from maize seeds totally inhibited *F. oxysporum* (Huynh et al., 1992). A 35.7 kDa and 65 kDa lectin from seeds of *Archidendron jiringa* and *Pachira aquatic* respectively showed effective effect on the growth of *F. oxysporum* (Paiva, Vasconcelos, & Oliveira, 2014).

Plant antifungal metabolites are not limited to Eos, AFPs and AMPs. Polyphenols, flavonoids in particular, are a group of plant secondary metabolites that play important role on fungal defence (Bouarab-Chibane et al., 2019). The butanol extract and oxime derivative of fresh peppermint (*Mentha piperita*), which is rich in flavonoid, was found to inhibit the growth of *F. moniliforme* by (Ilboudo, Bonzi, Tapsoba, Somda, & Bonzi-Coulibaly, 2016). Butanol extract and oxime derivative at 5 mg/mL caused about 52% and 70% inhibition respectively. Conidial germination was delayed by the butanol extract by 1h compared with the control group, and less than 10% of spores germinated in total. Similarly, the oxime derivative group had less than 10% germinated spores at 2h, after which the quantity declined. In other studies, high-carotenoid content in maize could lead to low fumonisins and aflatoxins production by *Fusarium* sp. (Diaz-Gomez, Marin, Nogareda, Sanchis, & Ramos, 2016) or *Aspergillus* sp. (Diaz-Gomez, Marin, Nogareda, Sanchis, & Ramos, 2016; Suwarno et al., 2019) respectively. In a review of Atanasova-Penichon, Barreau, and Richard-Forget (2016), phenolic acids and tocopherols were mentioned as similarly active compounds.

The diversity of plant metabolites make plants promising sources of novel antifungal agents. Some of these can be extracted from agricultural by-products, making them potentially economically interesting. However, the variation in their composition may cause inconsistency in their performance. Purified compounds or synthetic mimetics could provide

more reproducible alternatives.

2.4 Combined approaches

Most approaches have limitations in terms of specificity to fungi and food matrices. For this reason, combinations of approaches have been tested by researchers, to offer an integrated management strategy that can target multiple microorganisms in various matrices.

The combination of MAP and antifungal additives can prolong the shelf life of food. For instance, pre-treatment with 3% potassium sorbate and 20% of ethanol solution decreased the incidence of molds and yeasts on table grapes by approximately 11%-30% higher than those only packed in MAP conditions (O_2:CO_2:N_2-6:5:89) at 4ºC until the end of shelf life. Meanwhile, 3000 ppm of citrus extract only caused a 9% decrease in the same system (Cristina, Annalisa, Amalia, Francesco, & Del Nobile, 2013). Similarly, the population of yeasts and molds on ready-to-cook poultry treated with 1.5% chitosan and 0.2% thyme extract under MAP conditions (30% CO_2 and 70% N_2) was 2.2 log CFU/g lower than that under the MAP only when stored at 4°C for 14d. The antifungal effect of chitosan and thyme was greater when used in combination compared to each individually (Giatrakou, Nizimani, & Savvaidis, 2010) .

Yoon et al. (2014) and Jeong, Chu, Lee, Cho, and Park (2016) used irradiation in combination with the chemical sodium dichloroisocyanurate (NaDCC) to reduce the activity of grey mold (*Botrytis cinerea*) and green mold (*P. digitatum*). Their results indicated that the decrease of quantity of grey mold relied on the increase of radiation (from 0.2 to 4 kGy) and increase in NaDCC (from 5 to 50 ppm) dose, but the great reduction (<5%) of green mold only occurred under the treatment of 0.4 kGy of gamma irradiation and 6 or 10 ppm of the NaDCC. Combining physical with chemical approaches appears to be effective at preventing fungal growth. More research is needed to understand the combined effects on a wider range of microbes and food matrices.

3 Reduction of mycotoxin content in contaminated food

The scale of food production makes control of fungal growth challenging. It is not always possible to prevent fungal growth or mycotoxin contamination. Therefore, approaches to remove mycotoxins from the edible part of the food must be considered.

3.1 Physical detoxification approaches

3.1.1 Cleaning, dehulling and milling

Sorting and cleaning are the most common and cost-effective mycotoxin removal processes. Matumba, Van Poucke, Njumbe Ediage, Jacobs, and De Saeger (2015) investigated the effect of sorting, flotation/washing or dehulling on the levels of 11 mycotoxins in white maize grown in Malawi. In general, hand sorting showed the greatest reduction of mycotoxins (more than 90%), followed by dehulling (more than 70%, except DON and AcDON). When the procedures were combined, less than 5% of mycotoxins could be detected. Similarly, it is reported that the level of aflatoxins, fumonisins, DON, NIV, and ZEN in washed food samples was lower than in original samples (Matumba et al., 2017; Tibola, Fernandes, & Guarienti, 2016; van der Westhuizen et al., 2011). According to Tibola, Fernandes, and Guarienti (2016), the lowest mycotoxin level could be obtained in milled flour products. Notably, the milling could cause a redistribution of mycotoxins in milling fractions. In general, lower mycotoxin

content are found in flour and semolina while the higher mycotoxins content are found in brans and flour shorts screenings These fractions were generally used for animal feeding (Cheli, Pinotti, Rossi, & Dell'Orto, 2013). An educational intervention trained women in Gambia to recognize and remove moldy groundnuts by hand sorting. The intervention resulted in a reduction of 42.9% AFB_1 (based on median AFB_1 levels at baseline and after hand sorting), and a reduction of 96.7% (based on the total AFB_1 in moldy and clean groundnuts), with a loss of only 2% of the groundnuts. By roasting the already clean sorted groundnuts, AFB_1 reduction of 39.3% was achieved (based on median levels) (Y. A. Xu et al., 2017). Due to the low cost and easy operation of sorting and cleaning, these procedures can be used not only before crop storage, but also during other processing operations and before food consumption. However, it is still necessary to consider the disposal of sorted contaminated seeds and waste water containing mycotoxin.

3.1.2 Heat treatment

The majority of mycotoxins are heat stable. Aflatoxins and OTA could be partially destroyed at the temperatures around 250℃ and 200℃ respectively. The complete degradation of fumonisins takes place at over 180℃ (Magan & Olsen, 2004; Vidal, Sanchis, Ramos, & Marin, 2015), and for DON degradation takes place at 210℃ (Milani & Maleki, 2014). In general, mycotoxin destruction is dependent on both the temperature and duration of exposure. For example AFB_1 and AFB_2, degradation in pistachio nuts was proportional to both temperature (90 to 150℃) and treatment time (30 to 120min) during roasting processing, although this degradation was more affected by temperature than by time (Yazdanpanah, Mohammadi, Abouhossain, & Cheraghali, 2005). In ground corn, Dupuy, Le Bars, Boudra, and Le Bars (1993) found a linear relationship between calculated half-lives of FB_1 and temperature, which were at 75, 100, 125 and 150, and for 8h, 175, 38 and 10 min respectively. For more efficient reduction of mycotoxins during food processing, high temperature can be combined with high pressure. Extrusion cooking is a food procedure that uses high temperature and high pressure to process foods in a short time, which usually applied in relatively dry viscous material (moisture contents around 20%), such as cereal grains, grits, and flours (Castells, Marín, Sanchis, & Ramos, 2006). In general, initial moisture content of food materials, extruded temperature, processing duration, screw speed and mycotoxins type are the main variables influencing the reduced efficiency of mycotoxins. In rice meal, aflatoxins were reduced by 51% to 95% during extrusion cooking. Broadly speaking, the longer the processing duration, the higher the reduction of aflatoxins content. In rice, 170℃ was the best temperature among three temperatures (140, 170, 200℃) for reducing AFB_1 and AFB_2, and no significant difference on AFG_1 reduction between 170℃ and 200℃ was observed, while AFG_2 was most reduced at 200℃ (Castells, Marín, Sanchis, & Ramos, 2006). For OTA in oat flakes, according to a central composite design analysis, the highest reduction of 28% could be obtained at 162℃, 30% moisture and 221 rpm of screw speed (Lee et al., 2017). Pleadin et al. (2019) compared the effects of different thermal treatment on reduction of DON and ZEN in cereals. The results showed the content of DON and ZEN only reduced by 11% in 30min by cooking at 96°C, while the DON and ZEN declined up to 40% and 46% when the roast temperature was increased to 220°C. The highest degradation of DON and ZEN were 75% and 80% by extrusion cooking (135-190°C).

3.1.3 Irradiation treatment

Ionizing radiation can not only inhibit growth and development of fungi, but also reduce some mycotoxins, and the effect is dose-dependent. In general, there is a positive correlation between irradiation dose and reduction effect in the same matrix (Herzallah, Alshawabkeh, & Fataftah, 2008; Jalili, Jinap, & Noranizan, 2012; Kumar, Kunwar, Gautam, & Sharma, 2012). Meanwhile, irradiation also shows diverse performance on mycotoxin detoxification between irradiation types. Kumar, Kunwar, Gautam, and Sharma (2012) obtained 93% of OTA reduction in aqueous coffee bean by gamma irradiation at 5 kGy. Herzallah, Alshawabkeh, and Fataftah (2008) achieved the destruction of about 30% of total aflatoxin and AFB_1 by microwave treatment at 2450 MHz and 1.45 kW for 10min. Sunlight (solar irradiation) reduced more than 60% aflatoxins under 30h exposure and about 40% aflatoxins under 3h exposure (Herzallah, Alshawabkeh, & Fataftah, 2008). Recently, electron beam irradiation (EBI) has been used for decontamination of ZEN and OTA in maize kernel and maize flour. At the dose of 50 kGy, the degradations of ZEN were approximately 60% and 71% for maize flour and maize kernel respectively, and those of OTA were about 60% and 73% respectively (Luo et al., 2017). PAT was successfully reduced using UV radiation. In a study on PAT degradation in apple juice or apple cider using UVC wavelengths, Zhu, Koutchma, Warriner, and Zhou (2014) found that UV exposure at 19.6, 84.3, 55.0, and 36.6 mJ/cm^2 resulted in 90% reduction of the toxin, with the order of efficiency of the three wavelength lamps were: far UVC (222 nm) > far UVC plus (282 nm) > UVC (254 nm). A non-significant increase in the L* (lightness) value and decreases in a* (redness) and b* (yellowness) values of the juices treated with 222 nm were obtained. The treatment also resulted in 36.5% loss of juice ascorbic acid. Assatarakul, Churey, Manns, and Worobo (2012) reported a reduction of PAT from 5.14% to 72.57% with UV exposure, ranging from 14.2 mJ/cm^2 (one pass) to 99.4 mJ/cm^2, respectively, from an initial PAT contamination of 1,000 ppb. The UV treatment did not significantly change titratable acidity and ascorbic acid of the juice, but there was modification of the pH, the degrees Brix and in the sensory perception for the finished apple juice. In a similar study, Kim, Shukla, Oh, Chung, and Kim (2018) observed that in PAT-spiked apple juice samples that were UV-irradiated at a range of 200–280 nm for different time intervals, PAT levels reduced from 94.11 μg/L to 69.28, 54.55, and 5.92 μg/L after 5, 10, and 30min, respectively. After 30 min of UV exposure, PAT was not detected in spiked apple juice samples. However, UV irradiation reduced the yellowness (b∗) of the apple juice.

The matrix is another factor to reflect different detoxification efficiencies. With gamma radiation dose of 10 kGy, OTA in methanolic suspension demonstrated 24% lower reduction than same concentration of the toxin in water. OTA powder the lowest reduction effect by gamma radiation (Kumar, Kunwar, Gautam, & Sharma, 2012). At gamma irradiation dose of 1 kGy, compared to practical degradation in distilled water, the degradation rate of PAT in 1% organic acid solutions (malic acid, citric acid, lactic acid, acetic acid), 1% amino acid solutions (aspartic acid, serine, threonine and glutamic acid, histidine), ascorbic acid and ethanol ranged from 31% to 98%. Therefore, in irradiated apple juice, 33% of PAT retention was due to its main elements of organic acid (5.68% of malic acid) and amino acid (0.08% of serine and 0.06% of threonine) (H. Yun et al., 2008). In another study, however, the detoxification of ZEN between distilled water and all orange juice, pineapple juice and tomato juice had no significant difference. While, the optimized model analysed by response surface

methodology (RSM) concluded that the determinant factors of detoxification was both irradiation dose and ZEN concentration in fruits juices. It was noted that irradiation-mediated detoxified ZEN showed lower toxicity than non-irradiated ZEN in cell line models. Furthermore, to assess the quality of fruit juices, the sensory profile, total phenolic content, total flavonoid content, total antioxidant activity and acidity were taken into account. In three fruit juices, the values of every parameter slightly decreased with increasing irradiation dose of 2.5, 5 and 7.5 kGy, while 10 kGy of irradiation had significant deterioration on quality parameters. Overall, irradiation with certain dose range could be used to reduce toxin content of fruits juices (Kalagatur, Kamasani, & Mudili, 2018).

When the irradiation is applied on foods, the primary reaction is the ionization of water, which decomposes the water molecules into positively charged water radicals and negatively charged free solvated electrons. Next, the water radical is split into hydroxyl radicals and hydrogen ions. The reaction ends until forming the final products of hydrated electrons, hydroxyl radicals, hydrogen ions, and hydrogen atoms. The radicals can be added into double bonds of mycotoxins, such as aromatic rings, heterocyclic rings and lactone rings, which leads to lower the mutagenicity and toxicity of mycotoxins (Di Stefano, Pitonzo, Cicero, & D'Oca, 2014; Jalili, Jinap, & Noranizan, 2012). Irradiation looks a promising approach to reduce mycotoxins content is fruit juices. Other matrices, including dried products, need to be considered and the degradation products assessed for their toxicity. Further development to prevent quality deterioration as a result of irradiation is nescessary.

3.2 Chemical detoxification approaches

3.2.1 Adsorption by chemical adsorbents

Some chemicals form weak interactions with mycotoxins due to their characteristics including polarity, solubility, molecular size, shape, surface area and, in the case of ionized compounds, charge distribution and dissociation constants (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011; Sabater-Vilar, Malekinejad, Selman, van der Doelen, & Fink-Gremmels, 2007; Sun, Song, Wang, Wang, & Zheng, 2018), causing adsorption between adsorbents and mycotoxins. Hydrated sodium calcium aluminosilicates (HSCASs) are one of the most popular clay-based adsorbents, obtained from natural aeolite (Şişman, 2006). The adsorption of pyrophyllite-type HSCAS, usually occurs in either or both octahedral and tetrahedral layers (the structure can be found in El Gaidoumi et al. (2019)) causing weak bonds of exchangeable cations in interlayer positions (Aly, Abdel-Galil, & Abdel-Wahhab, 2004). Apart from HSCAS, there are many other adsorbents, displaying diverse adsorption ability, shown in Table 3. These adsorbents included clay, activated charcoal, esterified glucomannan, cholestyramine and other modified polymers, showing 17% to 100% adsorption of AFB_1, FB_1, DON, ZEN, OTA and T-2 in liquid environments. There is no doubt that adsorbent adsorption is one of the most economical methods in mycotoxin reduction. Nevertheless, the safety of the absorbent materials, removal from foods and disposal of adsorption chemicals and adsorbent-mycotoxin complex are still under question. Some chemical adsorbents have been forbidden as detoxification materials in food industry by the European Union (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011).

Chemical adsorbents find more practical applications in mycotoxins detoxification of animal feeds. As a source of animal protein (milk, meat, eggs), the contaminated livestock products

can result in direct or indirect risk to human health (Halász, Lásztity, Abonyi, & Bata, 2009). For example, AFB_1 can be converted into aflatoxin M_1 (AFM_1) in cattle bodies, which is secreted in milk and consumed by humans, especially children (W. X. Peng, Marchal, & van der Poel, 2018). Adding additives into fodder is a low-cost and user-friendly detoxification method in animal feeding, and has been used in practical production. These additives mainly include aluminosilicate clays (with or without organic acid) and montmorillonite (Table 3), which are not always appropriate for human foods (Kolosova & Stroka, 2012). Although some in vivo studies have shown that the feeding additives decreased the impact of mycotoxins on growth and did not increase the toxicity in animals, adding additives could still cause the loss of essential nutrients and decline in growth performance to some extent. Thus, additives are not recommended for extensive use (Kolosova & Stroka, 2012).

3.2.2 Alkaline/acid treatment

Many major toxins are unstable in alkaline environments. Researchers have worked on the effect of common alkaline reagents on mycotoxin reduction. $Ca(OH)_2$, NaOH, KOH and $NaCO_3$ were found to reduce DON, ZEN, aflatoxins, OTA (Jalili, Jinap, & Son, 2011). In alkali treatment, ammoniation is one of the best documented methods of reducing toxins. So far, it has been demonstrated that ammonia could reduce almost all aflatoxins (Brekke et al., 1977), including 45% of FB_1 (Norred, Voss, Bacon, & Riley, 1991) and 64% of ZEN (Bennett, Shotwell, & Hesseltine, 1980). This treatment was more widely used in animal feeding from last century. In the 1970s, 1.5% ammonium hydroxide was added into aflatoxin-contaminated maize basal diet of rainbow trout, which caused the detoxification of aflatoxin in diet and decreased of hepatocarcinogenicity in rainbow trout (Brekke et al., 1977). Later, in the 1990s, Bailey, Price, and Hendricks (1994) reported that ammoniated aflatoxin-contaminated cottonseed, a kind of cattle feedstock, led to a 94% reduction in the content of AFB_1. When the rainbow trout (*Oncorhynchus mykiss*) ate the dried milk from the cattle fed by treated cottonseed meals, the incidence of hepatic tumors decreased by around 40%. Into the 21st century, ammonia vapor was used in decontamination of broiler chick diet. Broilers fed diets containing aflatoxin showed the high mortality rate (about 30% in 6 weeks) during the rearing period. Chicks fed ammonia-treated maize did not show significant differences on mortality rate, dietary intake, body weight gain, and feed conversion ratio of chicks (Allameh et al., 2005). Ammonia treatment did not significantly affect the detoxification of FB_1 in maize meal under air condition (Norred, Voss, Bacon, & Riley, 1991). This may be because ammonia could directly attack the lactone ring of aflatoxins and retain the difuran moiety, but had no direct reaction sites in FB_1 (Karlovsky et al., 2016; Norred, Voss, Bacon, & Riley, 1991; Temba et al., 2016).Furthermore, DON (Fig. 1) has been found to be mainly degraded to norDON A, norDON B, and norDON C (Fig. 2) in alkaline environments. These degraded compounds could be isolated from NaOH solution (75°C, 60min) and other processed samples, and have been shown to be less toxic than original DON. Other 4 new compounds, norDON D, norDON E, norDON F and 9-hydroxymethyl DON lactone (Fig. 2) were identified as degradation compounds (Bretz, Beyer, Cramer, Knecht, & Humpf, 2006). In many reports, alkaline ammonia treatment was mainly reported in the 1990s, and primarily used in animal feeding. This might be because the safety and applicability of alkaline ammonia treatment could not completely used in the food industry. However, in recent reports, baking soda has been shown to reduce the content of OTA in cereal-based foods. In a 85°C

direct steam injected process that exposes food to high temperature with high steam pressure, 19.8% of OTA in oat-based infant cereals was lost. In contrast, OTA reduced by 36.1% and 43.4% when 0.5% and 1% baking soda was added respectively (Lee, Gu, Ganjyal, & Ryu, 2019). Peng reported that a small decline of OTA (6.73% to 9.63%) occurred in Chinese fried bread sticks containing 0.4% soda during processing (C. H. Peng et al., 2015).

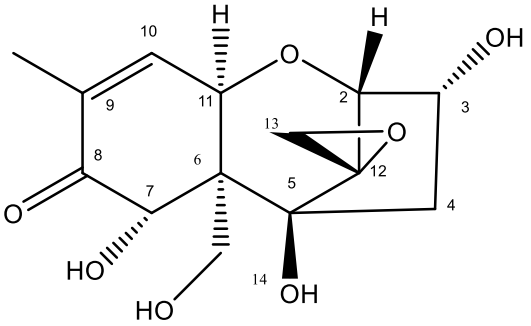


Fig. 1 Structure formula of DON (Wu, Kuca, Humpf, Klimova, & Cramer, 2017)

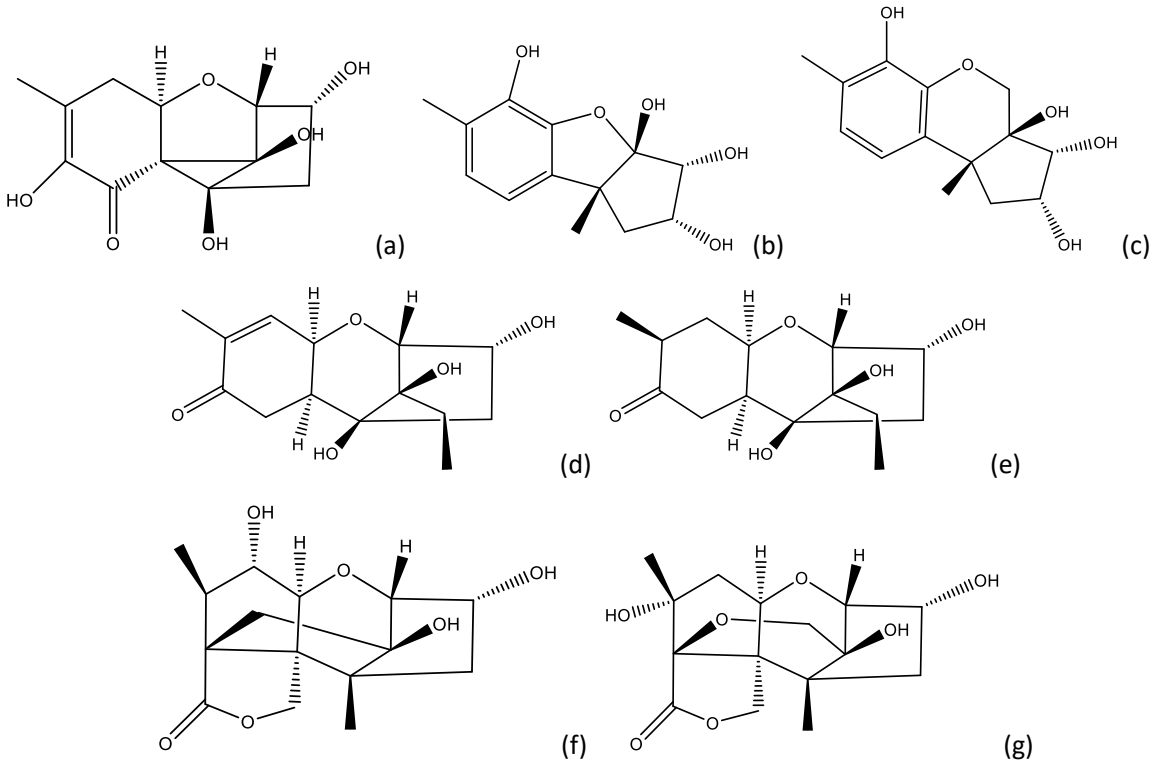


Fig. 2 Structure formula of norDON A (a), norDON B (b), norDON C (c), norDON D (d), norDON E (e), norDON F (f), and 9-hydroxymethyl DON lactone (g) (Bretz, Beyer, Cramer, Knecht, & Humpf, 2006)

Although the majority of mycotoxins are resistant to weak acids (Karlovsky et al., 2016), some acids also influence the presence of mycotoxins. Sulfuric acid, chloridric acid, phosphoric acid, benzoic acid, citric acid and acetic acid all displayed less than 30% reduction of AFB_1, AFB_2, AFG_1, AFG_2 and OTA in black and white pepper during washing, which was generally less effective than that in alkaline solutions (Jalili, Jinap, & Son, 2011). In another study, these five toxins were treated by 2% sodium hydrosulphite ($Na_2S_2O_4$) with atmospheric pressure (low pressure) and 100℃ for 30min or 1.5bar (high pressure) and 121℃ for 15min.

Except for AFB_2, other four samples under low pressure lost 64.8% to 83% of the toxin, and those under high pressure lost more than 96% (Jalili & Jinap, 2012). The use of 5% of both citric acid and lactic acid reduced DON about 20% to 40% in feeds soaked for more than 5h. Lactic acid showed the better performance than citric acid in this treatment (Humer et al., 2016). The detoxification of DON is considered to be due to the opening of the C12, 13-epoxy group (Fig. 1). In the extreme acidic environment (pH 1 to 2), DOM-1 (Fig. 3) might be degraded from DON (Wu, Kuca, Humpf, Klimova, & Cramer, 2017).

Sometimes, a combination of chemicals can reduce the level of mycotoxins. In the report of Rempe, Brezina, Kersten, and Danicke (2013), a mixture of methylamine, $Ca(OH)_2$ and sodium metabisulphite (2+4+1) caused the recession of 91% of DON and 79% of ZEN in naturally contaminated maize at 80°C. However, there is little evidence to show the safety of new derivatives produced from mycotoxins after treatment.

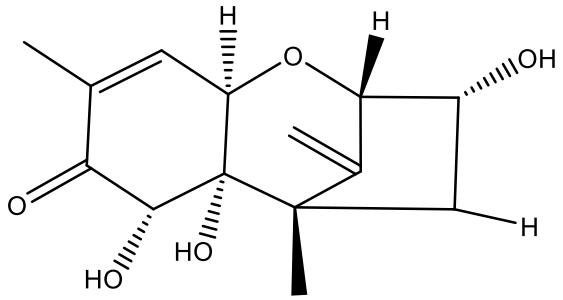


Fig. 3 Structure formula of DOM-1 (Wu, Kuca, Humpf, Klimova, & Cramer, 2017)

3.2.3 Plasma treatment

Plasma is an ionized gas, with zero net electrical charge, that can be induced in any neutral gas, and able to induce by innovative physical equipment at pressure and temperatures conditions (Misra, Yadav, Roopesh, & Jo, 2019). Many studies have suggested the mycotoxin detoxification effect of plasma. For instance, the effect of cold atmospheric plasma on aflatoxin contamination in both solution matrix (liquid) and hazelnuts matrix (solid) was evaluated by Siciliano et al. (2016). In this study, gas composition (proportion of N_2 and O_2), power of the generator, exposure time and reaction matrix were factors tested on detoxification efficiency. Among them, the power and exposure time were inversely proportional to aflatoxin loss. Besides, gas mixture with more N_2 and liquid matrices were more conducing to aflatoxin degradation. When AFB_1, DON and NIV were exposed to self-designed microwave-induced argon plasma system, the decrease of these toxins was significantly time-dependent, with complete degradation in 5s (B. J. Park et al., 2007). Ozone has the ability to degrade mycotoxins as well. 15min treatment by ozone on wheat bran contaminated with DON and ZEN caused approximately 29% and 52% degradation respectively, and no significantly difference in longer treatment times. Notably, ozonisation protected the quality of wheat bran at the greatest extent by preserving total phenolic compound content and antioxidant activity (Santos Alexandre et al., 2018). It was mentioned in the review of Misra, Yadav, Roopesh, and Jo (2019) that the plasma degrades mycotoxins by direct interaction of free radicals (e.g. O•, OH•) of plasma with the mycotoxin structure. With AFB_1 (Fig. 4), the degradation is trough epoxidation and oxidation by introducing water molecule, hydrogen atom, aldehyde group or hydroperoxyl radical (HO_2•) and leading the breakdown of C8 to C9 double bond of the dihydrofuran rings. Meanwhile, the toxicity and

carcinogenicity of AFB_1 would be reduced because of the loss of terminal furan ring.

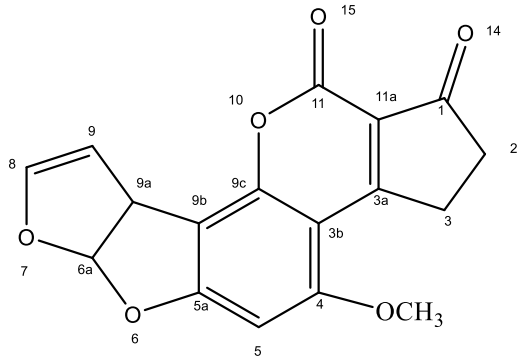


Fig. 4 Structure formula of AFB_1 (Luo et al., 2014)

Ozone was also used in the degradation of mycotoxins. For instance, highest reduction (48% and 64.3% respectively) of total aflatoxins and DON in soft wheat grains occurred at a concentration of 60mg/L for 300min (Trombete et al., 2017). ZEN in whole wheat powder quickly reduced by 62.3% in first 20 min at the condition of 51 mg/L of ozone (Alexandre et al., 2019). 15min-treatment by ozone on wheat bran contaminated with DON and ZEN caused approximately 29% and 52% degradation respectively, and no significantly difference in the longer treatment times. Notably, ozonisation protected the quality of wheat bran by keeping total phenolic compound content and antioxidant activity (Santos Alexandre et al., 2018). The effectiveness not only depends on exposure time and gas concentration, but also the physical characteristic of samples, moisture content and processing method (Trombete et al., 2017). L. Wang et al. (2016) showed that ozone treatment at same concentration was more effective in the flour than whole wheat with increasing of ozone concentration (from 0 to 100 mg/L), suggesting penetration into the kernels is not effective. Meanwhile, in the same study, higher moisture content (20.1%) of both whole wheat flour and wheat kernels showed greater degradation of DON (about 75% and 60% respectively), as high moisture content might promote oxidation power of ozone and its penetration ability. Similar result could be found in Alexandre, Castanha, Calori-Domingues, and Augusto (2017) study as well. S. Wang, Liu, Lin, and Cao (2010). They compared the degradation of AFB_1 by a dry method which involved delivering the O_3 gas to cereals, compared to an aqueous method which involved soaking cereals into ozone solutions and a semi-wet method which involved pumping ozone-rich steam into cereals. The results indicated that the ozonation reaction in aqueous or semi-wet conditions showed better effect than the dry method. The most effective reduction method for paddy rice and maize was semi-wet method, which reduced toxin content by about 92% and 85% respectively, while the aqueous method displayed the best performance on AFB_1 degradation (about 93%) in wheat.

Ozone preferentially attacks the unsaturated compounds in an electrophilic attack mechanism (Freitas-Silva & Venancio, 2010). The major mycotoxins including aflatoxins, FB_1, OTA, ZEN, DON and PAT could be degraded rapidly, within minutes. After ozone treatment, none of the by-products of OTA, ZEN and PAT could be detected by UV or fluorescence detector. However, a larger fraction of polar compounds were formed from ozonized AFB_1, and FB_1. For DON, ozone attacked at the C9 to C10 double bond (Fig. 1) with two additional atoms of oxygen but kept the rest of molecule (McKenzie et al., 1997; Young, Zhu, & Zhou, 2006). It was mentioned in the review of Misra, Yadav, Roopesh, and Jo (2019) that plasma interacts

with mycotoxins via free radicals (e.g. O•, OH•). With AFB_1 (Fig. 4) for example, the degradation is through epoxidation and oxidation by introducing water molecule, hydrogen atom, aldehyde group or hydroperoxyl radical (HO_2•) and leading the breakdown of C8 to C9 double bond of the dihydrofuran rings. Meanwhile, the toxicity and carcinogenicity of AFB_1 would be reduced because of the loss of terminal furan ring. In bioassay, apart from FB_1, all of treated aflatoxins, OTA, ZEN and PAT were not found to affect the activity of *Hydra Attenuate*, but treated FB_1 still kept the toxicity (McKenzie et al., 1997). In the induced toxicity assay of Caco-2 cells, ozone treatment weakened the cellular metabolic disorder by DON derivatives, but no impact on latent inflammation and oxidative stress effects, which shows some of the non-negligible toxicity of ozonised DON (Y. Xu et al., 2019). It is noteworthy that low O_3 concentration (below 0.05 ppm) had an enjoyable odor, while, when the concentration were above 0.05 ppm, O_3 affected human eyes and respiratory systems, which might be related to premature death, heart attack, bronchitis, asthma, and other cardiopulmonary problems (Jian, Jayas, & White, 2013). Therefore, when considering the application of ozone in cereal storage, attention should be paid to the harm caused by ozone to workers and the natural environment. Plasma, and in particular ozone, are effective at reducing mycotoxin content in foods. However, the toxicity of degradation products and impacts of ozone directly on human health need to be further considered.

3.2.4 Neutral electrolyzed oxidizing water (EOW)

Neutral electrolyzed oxidizing water is also an aflatoxin detoxifying substance. One view was that aflatoxin detoxified by hypochlorous acid from EOW eliminated the toxicity of double bond in the terminal furan ring and converted it to 8-chloro-9-hydroxy-aflatoxin B_1 (Fig. 5) (Escobedo-González et al., 2016). The derivative was shown to have significantly lower cytotoxicity and genotoxicity effects *in vitro* in a HepG2 cell model (Jardon-Xicotencatl, Díaz-Torres, Marroquín-Cardona, Villarreal-Barajas, & Méndez-Albores, 2015; Sakudo, Toyokawa, Misawa, & Imanishi, 2017). There was an ameliorative effect of EOW on the health and performance of turkeys fed on de-contaminated feed (Gómez-Espinosa et al., 2017).

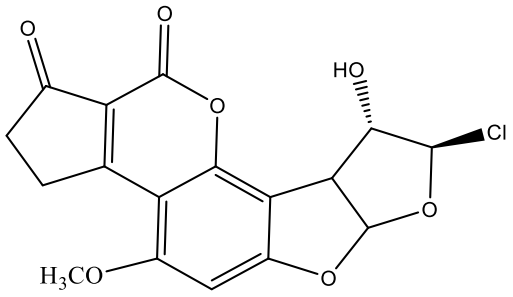


Fig. 5 Structure formula of 8-chloro-9-hydroxy-aflatoxin B_1 (Escobedo-González et al., 2016)

3.3 Biological detoxification approaches

3.3.1 Metabolite degradation

Biological enzymatic degradation reactions include acetylation, glucosylation, ring cleavage, hydrolysis, deamination, and decarboxylation caused by extra - or intra-cellular enzymes produced from bacteria and fungi (Hathout & Aly, 2014). In a report of Guan et al. (2008), *Stenotrophomona smaltophilia* was isolated from a selective medium containing coumarin as

the only carbon source and displayed reducing ability towards AFB_1 (82.5%) at 37℃ for 72h. After treatment of factors that could affect the enzymatic activity, reaction efficiency significantly drops, which indicated that reduced AFB_1 was produced by enzymatic degradation. Microbial species with similar functions were listed by Hathout and Aly (2014), including *Bacillus* sp., *Brevibacterium* sp., *Eubacterium* sp., *Flavobacterium aurantiacum*, *Mycobacterium fluoranthenivorans*, *Myxobacteria* sp., *Pseudomonas* sp., *Rhodococcus erythropolis*, *Trichosporon mycotoxinivorans*, *Aspergillus* sp., and *Rhizopus* sp.. The degraded toxins covered all major mycotoxins. Besides, some enzymes have been found in mushroom showing the detoxification ability. Manganese peroxidase (MnP) purified from the mushroom *Pleurotus ostreatus* detoxified AFB_1 by 6% at 0.1 U/mL enzyme activity for 8h, and by 90% at 1.5 U/mL enzyme activity for 48h (Sayed, 2014). In a review of Jard, Liboz, Mathieu, Guyonvarc'h, and Lebrihi (2011), the multiple degradation pathways of each major mycotoxin has been summarized. In simple terms, AFB_1 (Fig. 4) lactone ring or difuran ring could be opened resulting in loss of the toxicity. OTA was degraded to OTα and phenylalanine (Fig. 6); while ZEN could be transformed into oxidised, hydroxylated and methylated compounds, gluco- or sulfo-conjugates and hydrolysed compounds. Detoxification of DON was by opening the 12,13-epoxy ring (Fig. 1), and formed de-epoxidised DON and 3-keto-DON (Fig. 8). FB_1 has been found to be converted into polyolamine (Fig. 9) by extracellular carboxylesterase. Most degradation products showed no toxicity. However, the produced α-zearalanone (classified as hydroxyl compound) was more toxic than the original compound (ZEN) (Fig. 7).

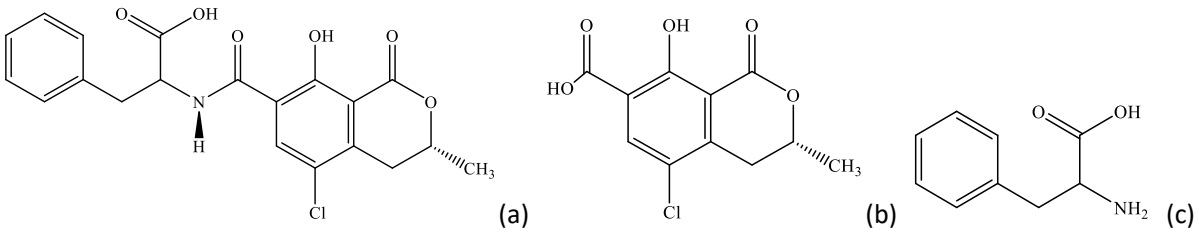
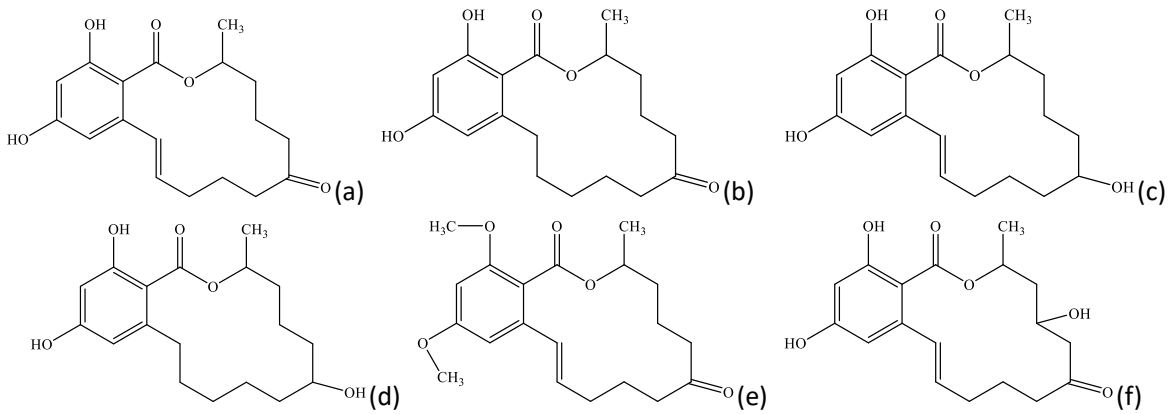


Fig. 6 Structure formula of OTA (a), OTα (b), andphenylalanine (c) (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011)



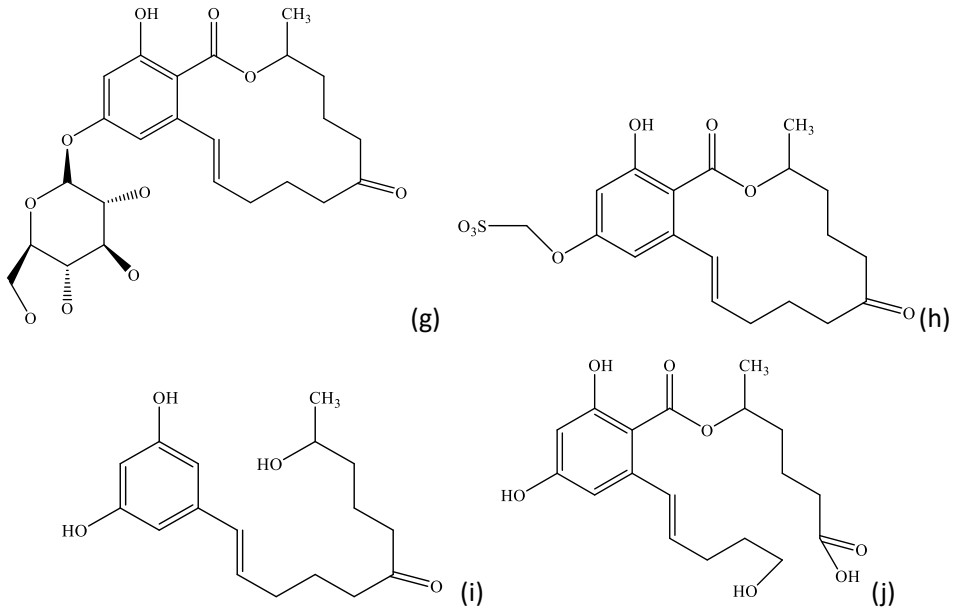


Fig. 7 Structure formula of ZEN (a), oxydised compounds: zearalanone (b), hydroxyled and methyl compounds: a-β zearalenol (c), a-β zearalanol (d), methoxy-ZEN(e), hydrocy-ZEN(f), gluco- or sulfo-conjugates: ZEN-4- β-glucopyranoside (g), ZEN-4-sulfate (h), and hydrolysed compounds: decarboxylated ZEN (i), Hydroxylated ZEN(j) (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011)

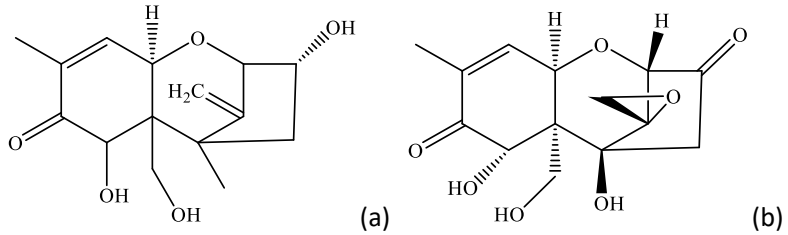


Fig. 8 Structure formula of de-epoxy DON(a) andketonic compound(b) (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011)

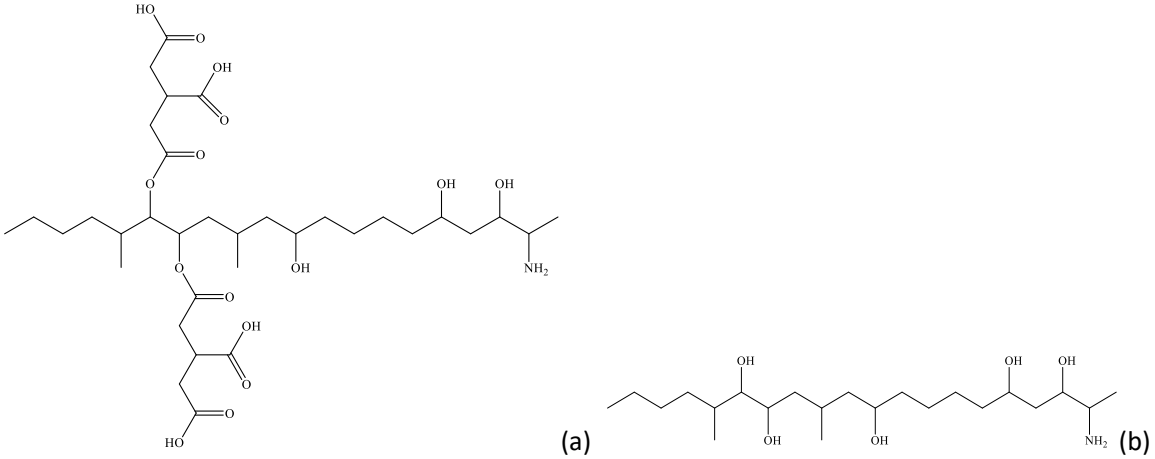


Fig. 9 Structure formula of FB_1(a) andpolyolamine (b) (Jard, Liboz, Mathieu, Guyonvarc'h, & Lebrihi, 2011)

3.3.2 Adsorption by biological polymer

Microorganism could not only degrade mycotoxins, but also remove them by adsorption to their cell walls. Most gram-positive bacteria and yeasts have demonstrated the adsorption capability. Recent studies are presented in Table 4. It could be observed that microorganism could adsorb 20% to 90% mycotoxins in different liquid food system or even body

environment. It has been suggested that heat-treated microorganisms (inactive microorganisms) showed similar or even higher mycotoxin adsorption capability when compared to live microorganisms in aqueous solution (El-Nezami, Polychronaki, Salminen, & Mykkanen, 2002; Turbic, Ahokas, & Haskard, 2002; Vosough, Sani, Mehraban, & Karazhyan, 2014). It was suggested that the adsorption was through physical adsorption rather than through a biological degradation mechanism. Thus, mycotoxins would not have the chemical reaction with binder during adsorption. This interaction usually occurs with the cell walls of microorganisms. For bacterial, cell walls or peptidoglycans (purified from cell walls) were isolated from lactic acid bacteria (Sreekumar & Hosono, 1998; Zhao et al., 2013; Zou et al., 2012), and were found to bind more toxins than cell pellets after removing the cell walls. The peptidoglycan played an important role in adsorption, and chemical methods can increase the number of adsorption sites and adsorption efficiency (e.g. acid-treatment, heat-treatment) (Zou et al., 2012). Haskard, Binnion, and Ahokas (2000) suggested that the addition of urea (an anti-hydrophobic agent) or organic solvent destroyed the cell wall-toxin complex, proving hydrophobic effect between the adsorption. For yeast, there were two layers in its cell wall, an inner layer of β-1,3-glucan and chitin and an outer layer of β-1,6-glucan with heavily glycosylated mannoproteins (Petruzzi et al., 2014). At the pH range of wine, mannoproteins had negative charges, and OTA carried a positive charge of the amine function (NH_3^+), so that cell wall and toxin could partially establish electrostatic and ionic interactions. Moreover, as a less polar mycotoxin, OTA could bind with hydrophobic surfaces of yeast cell wall through the phenol group and via interactions of two-π-electron orbital (Caridi, Galvano, Tafuri, & Ritieni, 2006). However, the adsorption was relatively weak, because toxin-microbe complexes would release toxins about 25-40% after washing with PBS buffer (Fernandez Juri, Dalcero, & Magnoli, 2015; Zou et al., 2012). This might indicate that the adsorption hardly occurs in nonpolar circumstances.

Most microorganisms with adsorption property belong to fermentation microorganisms, thus biological adsorption usually occurs in the process of fermentation in practical production. Food fermentation is a process of decomposing carbohydrates to alcohol or organic acids by microorganisms in aerobic or anaerobic environments, used in the production of fermented dairy products, wine, vinegar and bread-making. The raw food materials that are commonly used for fermentation cover most food groups including dairy, meat, fish, vegetables, fruits, legumes and cereals (Bourdichon et al., 2012), which could be contaminated by mycotoxigenic fungi or metabolic mycotoxins. Therefore, the mycotoxins are generally present in the fermentation process. The adsorption of mycotoxins by microorganisms during fermentation was summarized in Table 4.

Recently, more attention has been focused on the animal polysaccharides. Chitin, from shrimp shells, was investigated for its ability to bind with AFM_1. Assaf, El Khoury, Atoui, Louka, and Chokr (2018) demonstrated that chitin bound to 17% to 54% AFM_1 in PBS buffer, depending on concentration of both chitin and toxin and incubation time. High adsorption efficiency relied on high chitin concentration and long incubation. 0.15 g/mL of ground shrimp shell or 0.25g/mL of unground shrimp shell showed more than 90% of the adsorption rates when the incubation was up to 24h. By contrast, both ground and intact shrimp shell had lower adsorption rates than extracted chitin at same concentration and incubation time. However, the adsorption was not stable. After three times washing with buffer,

AFM_1adsorption rate decreased about 15% to 45% in different groups, which suggested the implication of electrostatic bounds (e.g. hydrogen bonds, Van der Waals interactions) in adsorption process.

Due to the presumed environmental and health friendliness of natural products (e.g. enzyme, microorganism cell wall), these approaches have attracted attention. However, biological control has shown lower effectiveness compared to other methods, and is also generally constrained to liquid media. Biological control tends to be more costly than physical and chemical approaches, and there is currently little evidence of the toxicity of enzymolysis products. However, reduction of mycotoxins during production of fermented products would permit the use of somewhat contaminated raw materials in their production.

3.4 Combined approaches

Pérez-Flores, Moreno-Martinez, and Méndez-Albores (2011) showed that the level of AFB_1 and AFB_2 in tortillas (a Mexican food) decreased 68% to 84%, according to different original concentration, by microwave treatment (1650 W, 2450 MHz, 5.5min) with added $Ca(OH)_2$ (0.5%). Kim, Shukla, Oh, Chung, and Kim (2018) reported that among food-grade additives (sodium bicarbonate, vinegar, mixture of sodium bicarbonate and vinegar, citric acid and baking powder), sodium bicarbonate yielded significantly higher PAT reduction in apple juice (from 94.11 to 7.55 μg/L), which was comparatively similar to 30min of UV irradiation. The authors suggested that since irradiation requires a special UV-irradiation apparatus and energy consumption, a food-grade additive sodium bicarbonate might be a useful alternative to UV radiation for reducing PAT content in apple juice samples. However, sodium bicarbonate treatment affected quality attributes including soluble solids, pH, and colour of apple juice. Nevertheless, the colour and door of juice treated with sodium bicarbonate could be recovered via addition of citric acid. The usage of some additives could contribute to the mycotoxin destruction in high-temperature processing. Sugars had a positive effect on FB_1 reduction of maize muffins baked at 200℃ for 30min. In this processing, the influence of glucose (40%) on the decrease of FB_1 was greater than that of fructose (27%) and sucrose (28%), and the effect of glucose concentration was more significant, from 40% reduction for 0.075g glucose/g maize meal to 52% reduction for 0.3 g glucose/g maize meal (Castelo, Jackson, Hanna, Reynolds, & Bullerman, 2001). Castelo, Jackson, Hanna, Reynolds, and Bullerman (2001) showed that when grits with added sugars of different concentration (2.5% and 5%) were extruded at a screw speed of 80, 100 or 120 rpm, the amounts of FB_1 remaining were around 40% to 80% at 140℃. 10% glucose with 40 rmp of extrusion at 160℃ led to about 90% reduction of FB_1, which was about 20% higher than the FB_1 treated without glucose (Voss et al., 2011). In another extrusion study with conditions of sample moisture (15% or 30%), screw speed (120 rmp), temperature (150℃ or 180℃) with or without 1% sodium metabisulphite addition, DON was significantly reduced (>95%) in maize flour treated under every condition, but AFB_1 content was not greatly affected (10% to 25%). Compared to glucose, sodium metabisulphite did not show a significant contribution to the reduction of both DON and AFB_1 (Cazzaniga, Basílico, González, Torres, & De Greef, 2001).With the addition of 30 mL of lemon juice and 6 g of citric acid, AFB_1 deceased up to 93.1% in 50 g pistachio nuts. When lemon juice and citric acid reduced to 15 mL and 2.25 g respectively, only 49.3% of AFB_1 could be detected (Rastegar et al., 2017). Furthermore, adding baking

soda under twin-screw extrusion could contribute to the reduction of OTA in oat-based food, and the degree of content reduction improved form about 40% to 65% with the increase of added soda from 0 to 1%. On the contrary, the baking soda did reduced OTA by a modest 10% in rice-based food (Ryu, Kowalski, Ganjyal, & Lee, 2019). The degradation of PAT with added ascorbic acid was predicted by nonlinear Weibull model to be higher than that without ascorbic acid, and the degradation increased with the raising of temperature. This might because the oxidized ascorbic acid formed free radicals, so that could attacked the lactone structure of PAT (Kokkinidou, Floros, & LaBorde, 2014).

The exploration of combined treatments is to pursue higher removal efficiency, taking advantage of the additional effect of integrated management. This is becoming a trend gradually. The combined treatments do reduce toxin contamination to a greater extent, and they can be better adapted to different food matrixes.

4 Evaluation of the feasibility of the approaches to be applied to food production

Several reports have shown the potential of various methods for preventing and reducing fungi or mycotoxins in foods. Here we perform a comparative evaluation of all the methods discussed in this review, on the basis of their technical advantages and disadvantages, the food matrices for which each method is suitable, the safety concern of a method, and the economical implication of large scale application. Using all these parameters, the potential for upscaling each method is then estimated as high, medium or low (Table 5).

In general, physical approaches, which include temperature and humidity control, MA treatment, irradiation treatment, cleaning, milling and sorting, and heat treatment, showed medium to high potential for using at a large scale. The advantages include versatility to use in various matrices, safety, and few changes to the nutritional and sensory properties of foods. However, the high cost of equipment and high energy required to operate over long times may limit the industrial deployment of these methods. Among the four methods, temperature and humidity control appears to have the highest upscaling potential.

Chemical approaches include photodynamic treatment, plasma treatment or ozonisation, EOW, chemical antifungal/anti-mycotoxins agents, and chemical removal of mycotoxin. Application of these methods in large scale also showed a medium to high potential. This can be justified by their high efficiency and their suitability for a wide range of food matrices. The limitations are mainly due to the negative impact on the quality and safety of foods. The use of EOW showed the highest potential for large scale application with low level of safety concern, once the cost of EOW production equipment and energy can be lowered.

Biological approaches include methods such as the use of biocontrol agents, use of antifungal plant metabolites and biological removal of mycotoxins. These approaches showed low to medium potential for upscaling. They are claimed to be environmental friendly, they have a high efficiency (although the replication of lab performance of biocontrol agents in the field remains a challenge), and they can be applied to various foods of plant and animal origin. However, these methods may actually deteriorate food quality; the binders are difficult to remove from food and feed, the potential toxicity can be high, and the cost of production of the biological or plant agent is also high. Among the three methods, the biological removal of mycotoxins, which is already largely used in feed industry, shows a great prospect.

5 Conclusion and perspectives

In order to reduce the contamination of foods by mycotoxins and minimize their negative effects on consumers health, 15 of strategies have been reviewed, which can be classified into physical, chemical and biological approaches, singly or in combination. These strategies are mainly focused on control of fungi growth in raw food materials and removal of mycotoxins from foods. Some new and efficient methods, such as plasma and EOW treatment show great potential but currently remain limited to laboratory applications. Currently physical approaches can be adapted into a wider range of food matrixes, including dry or liquid, raw or cooked foods. Physical approaches can be applied at large scale (e.g. crop storage) and small scale (MAP). Chemical and biological approaches are usually applied high humidity conditions (e.g. coating of fruits and vegetables) or liquid environment (e. g. mycotoxin binders in wine). However, so far no single approach is universal for all matrices or 100% effective at removing the risk of aflatoxin contamination. With the increasing demands in food safety and advances in technology, the mycotoxin reduction strategy has become to multi-dimensional, including a combination of multiple control methods as an integrated management strategy. Food safety concerns as a result of these treatments remain. It is critical when developing or applying a method, to test the toxicity of the applied agents and the derived secondary products. Nutrient loss and deterioration of sensory properties of foods by methods such as irradiation and plasma treatment must be tackled. For biological control methods, the efficacy of the biocontrol agents in field condition must be proven, and their short and long term toxicity be monitored. In methods involving plant-extracted metabolites, large amount of plant materials are needed to obtain sufficient amount of metabolites. Valorisation of plant waste can offer an alternative low cost source of the plant metabolites. On the other hand, the high cost of equipment and running, limits the industrial application of most of the methods, while low cost and easy operations such as sorting and cleaning can be upscaled if they are mechanized. This underlines the need of multidisciplinary collaboration involving engineering, physical and biological sciences in the fight against mycotoxins. Moreover, environmental aspects must be considered during the disposal of toxin-contaminated sorted seeds, waste water or binders.

Research usually remains at the laboratory level with little consideration for upscale applications. Physical approaches have shown the highest potential for upscaling, followed by chemical approaches, while biological approaches necessitate further improvements. Finally, in addition to developing mycotoxin reduction methods, educating producers and consumers on the toxicity of mycotoxins, improving the diversity of food choices (to prevent acute doses from single sources such as maize or rice) and guiding to change the food preferences (towards foods that are less prone to mycotoxin contamination) can also reduce the harmful effect of mycotoxins from human health.

1045 **Table 1.** The occurrence of main mycotoxins in raw and processed products and regulation of mycotoxins in European Communities

Mycotoxins	**Products**		**European Communities standards (ng/g)**	**Reference**
Aflatoxins	Raw products	Almonds, pistachios and apricot kernels,	10 (for human direct consumption)	de Medeiros et al. (2012)
		Oilseeds	15 (for oil production)	Milani and Maleki (2014)
		Cereals	10 (for processing)	Calado, Venâncio, and Abrunhosa (2014)
		Spices	10 (for human direct consumption)	Eskola et al. (2019)
		Milk	Cannot be detected	Cinar and Onbaşı (2019)
	Processed products	Dried fruits, copra	4 (for human direct consumption)	EU (2006)
		Maize grits	Cannot be detected	
		Cheese	Cannot be detected	
Fumonisins	Raw products	Germ, bran, rice, sorghum, legumes, cowpea seeds, triticale,	4000	de Medeiros et al. (2012)
		Maize	1000 (for human direct consumption)	Milani and Maleki (2014)
		Asparagus	NM	Calado, Venâncio, and Abrunhosa (2014)
		Milk	NM	Eskola et al. (2019)
	Processed products	Grits, maize-based products, wheat flour	800 (for adult direct consumption)	Cinar and Onbaşı (2019)
		Beer	200 (for human direct consumption)	EU (2006)
Deoxynivalenol	Raw products	Cereals	750 (for human direct consumption)	de Medeiros et al. (2012)
	Processed products	Wheat flour	750 (for human direct consumption)	Milani and Maleki (2014)
		Bread, pasta, pretzel, cookie	500	Eskola et al. (2019)
				Cinar and Onbaşı (2019)
				EU (2006)
Ochratoxin A	Raw products	Cereals, legumes, coffee beans, nuts, pulses, sesame seeds,	5 (for processing)	Larsen, Svendsen, and Smedsgaard (2001)
		Spices	15 (for human direct consumption)	Varga and Kozakiewicz (2006)
		Apples, peaches, strawberries, pears, oranges, figs, mangoes,	NM	Eskola et al. (2019)
		tomatoes, watermelons, yam, potatoes, garlic, onions,		Cinar and Onbaşı (2019)
		Milk, eggs, meat	NM	EU (2006)

	Processed products	Grape juices, wine vinegar	2.0 (for human direct consumption)	
		Breakfast cereals & snacks	3.0 (for human direct consumption)	
		Infant cereals	0.5 (for infant direct consumption)	
		Bread, pasta	0.5 (for human direct consumption)	
		Flour	0.5 (for human direct consumption)	
		Cocoa	5	
		Dried vine fruits	10	
		Sausage	NM	
		Cheese, milk-based products	0.5 (for human direct consumption)	
		Bottled water, plant food supplement, food colouring agent	NM	
Zearalenone	Raw products	Maize	350 (for processing)	de Medeiros et al. (2012)
		Cereals, sesame, soy beans, nuts	75 (for human direct consumption)	Calado, Venâncio, and Abrunhosa (2014)
	Processed products	Cereal-based products	50 (for adult direct consumption)	Eskola et al. (2019)
				Cinar and Onbaşı (2019)
				EU (2006)
Patulin	Raw products	Wheat straw residue	NM	CAST (2003)
	Processed products	Fruit juice	25 (for adult direct consumption)	EU (2006)

NM: Not mentioned

1056 **Table 2**.Examples of mycotoxin-producing fungi and their inhibition by plant essential oils

Fungal species	Plant species	Organ	Region	Concentration (μL/mL)	Main components	Inhibition (%)	Reference
A. flavus	*Hedychium* sp.	Leaf	USA	40000	NM	100	Rajasekaran, Sakhanokho, and Tabanca (2012)
	Ocimum gratissimum	Leaf	India	0.6	Methyl cinnamate; γ-Terpinene	91	Prakash et al. (2011)
	Origanum majorana	NM	India	3	NM	100	Prakash, Singh, Kedia, and Dubey (2012)
	Coriandrum sativum	NM	India	2.5	NM	100	
	Hedychium spicatum	NM	India	2.5	NM	100	
	Arachis hypogaea	Seed	India	1	NM	82	Prakash et al. (2012)
	Arachis hypogaea	Leaf	India	1	NM	62.5	
	Cinnamomum glaucescens	Berry	India	1	1,8-Cineole	58	Prakash, Singh, Yadav, Singh, and Dubey (2013)
	Salvia officinalis	Aerial parts	Jordan	5	1,8-Cineole	100	Abu-Darwish et al. (2013)
	Artemisia herba-alba	Aerial parts	Jordan	5000	Predominant; α-and β-Thujones	100	Abu-Darwish et al. (2015)
	Caesulia axillaris	Aerial parts	India	1	$_{DL}$-Limonene; Euasarone	100	Mishra, Shukla, Singh, Prakash, and Dubey (2012)
	Jamrosa	Leaf	India	0.4	Z-citral; Linalyl acetate	100	Mishra et al. (2012)
	Lippia rugosa	Leaf	Cameroon	1000	Geraniol; Nerol; Geranial	100	Tatsadjieu et al. (2009)
	Coleus aromaticus	Leaf	India	1	Z-citral; PrecoceneI	100	Jaya, Prakash, and Dubey (2011)
	Hyptis suaveolens	Leaf	India	1	Precocene I	93.8	
	Ageratum conyzoides	Leaf	India	1	Germacrene-D; Trans-caryophyllene	100	
	Ageratum conyzoides	Leaf	Brazil	1	PrecoceneI; PrecoceneII	63	Nogueira et al. (2010)
	Lavandula multifida	Aerial parts	Portugal	0.64	Carvacrol; *cis-β*-Ocimene	100	Zuzarte et al. (2012)
	Citrus sinensis var. Valencia	Orange peel	Mexico	16000	NM	100	Velázquez-Nuñez, Avila-Sosa, Palou, and López-Malo (2013)
A. niger	*Ocimum gratissimum*	Leaf	India	0.6	Methyl cinnamate; γ-Terpinene	85	Prakash et al. (2011)
	Origanum majorana	NM	India	3.5	NM	100	Prakash, Singh, Kedia, and Dubey (2012)
	Coriandrum sativum	NM	India	3	NM	100	
	Hedychium spicatum	NM	India	2.5	NM	100	
	Commiphora myrrha	NM	India	3.5	NM	100	

	Cananga odorata	NM	India	2	NM	100	
	Cinnamomum glaucescens	Berry	India	1	1,8-Cineole	63	Prakash, Singh, Yadav, Singh, and Dubey (2013)
	Salvia officinalis	Aerial parts	Jordan	5	1,8-Cineole	100	Abu-Darwish et al. (2013)
	Artemisia herba-alba	Aerial parts	Jordan	1250	Predominant; α-and β-Thujones	100	Abu-Darwish et al. (2015)
	Caesulia axillaris	Aerial parts	India	1	$_{DL}$-Limonene; Euasarone	100	Mishra, Shukla, Singh, Prakash, and Dubey (2012)
	Lavandula multifida	Aerial parts	Portugal	0.32	Carvacrol; *cis-β*-Ocimene	100	Zuzarte et al. (2012)
A. fumigatus	*Cinnamomum glaucescens*	Berry	India	1	1,8-Cineole	70	Prakash, Singh, Yadav, Singh, and Dubey (2013)
	Salvia officinalis	Aerial parts	Jordan	5	1,8-Cineole	100	Abu-Darwish et al. (2013)
	Artemisia herba-alba	Aerial parts	Jordan	2500	Predominant; α-and β-Thujones	100	Abu-Darwish et al. (2015)
	Caesulia axillaris	Aerial parts	India	1.25	$_{DL}$-Limonene; Euasarone	100	Mishra, Shukla, Singh, Prakash, and Dubey (2012)
	Lavandula multifida	Aerial parts	Portugal	0.32	Carvacrol; *cis-β*-Ocimene	100	Zuzarte et al. (2012)
A. terreus	*Caesulia axillaris*	Aerial parts	India	1	$_{DL}$-Limonene; Euasarone	100	Mishra, Shukla, Singh, Prakash, and Dubey (2012)
F. verticillioides	*Hedychium* sp.	Leaf	USA	40000	NM	100	Rajasekaran, Sakhanokho, and Tabanca (2012)
F. nivale	*Ocimum gratissimum*	Leaf	India	0.6	Methyl cinnamate; γ-Terpinene	100	Prakash et al. (2011)
	Origanum majorana	NM	India	2.75	NM	100	Prakash, Singh, Kedia, and Dubey (2012)
	Coriandrum sativum	NM	India	2	NM	100	
	Hedychium spicatum	NM	India	2.25	NM	100	
	Commiphora myrrha	NM	India	2.5	NM	100	
	Cananga odorata	NM	India	1.5	NM	100	
F. oxysporum	*Caesulia axillaris*	Aerial parts	India	0.75	$_{DL}$-Limonene; Euasarone	100	Mishra, Shukla, Singh, Prakash, and Dubey (2012)
P. italicum	*Ocimum gratissimum*	Leaf	India	0.6	Methyl cinnamate; γ-terpinene	100	Prakash et al. (2011)
	Origanum majorana	NM	India	2.5	NM	100	Prakash, Singh, Kedia, and Dubey (2012)
	Coriandrum sativum	NM	India	2.25	NM	100	
	Hedychium spicatum	NM	India	2.5	NM	100	
	Commiphora myrrha	NM	India	2.5	NM	100	
	Cananga odorata	NM	India	1.5	NM	100	
	Caesulia axillaris	Aerial parts	India	1	$_{DL}$-Limonene; Euasarone	100	Mishra, Shukla, Singh, Prakash, and Dubey (2012)

1057 NM: Not mentioned

1058

1059

1060 **Table 3**. Mycotoxins detoxification by chemical adsorption to different matrices

Sorbents	Mycotoxin	Concentration (mg/mL)/(mg/mg)	Effects	Time	Matrix	Reference
Hydrated sodium calcium aluminosilicates (HSCASs)	AFB_1	40	>97% Adsorption	30min	Malt suspension	Aly, Abdel-Galil, and Abdel-Wahhab (2004)
		0.01	Retard of the decline in the total number of offspring	30d	*In vivo* (*Drosophilamelanogaster*)	Şişman (2006)
		2	No significant decrease on body weight gain; Retention on crude protein; Decrease on crude fat; No significant decrease on calcium; Retention on the proportion of breast muscle, thigh muscle and abdominal fat; Improvement of growth performance, digestibility, and immune function; Reduction of deleterious effects and tissue residues caused by AFB_1	42d	Broilers basal maize-soybean meal	Y. L. Liu et al. (2011)
		3		21d	Broilers maize meal	N. Liu, Wang, Deng, Gu, and Wang (2018)
	FB_1	40	>84% Adsorption	30min	Malt suspension	Aly, Abdel-Galil, and Abdel-Wahhab (2004)
	OTA	2	No significant decrease on body weight gain; Retention on crude protein; Decrease on crude fat; No significant decrease on calcium; Retention on the proportion of breast muscle, thigh muscle and abdominal fat	42d	Broilers basal maize-soybean meal	Y. L. Liu et al. (2011)
	ZEN	10	50% Adsorption	90min	Acetate/or citrate buffer	Yiannikouris, Kettunen, Apajalahti, Pennala, and Moran (2013)
		5	Reestablishment of haematological parameters, levels of serum biochemical	48h	*In vivo* (mice)	Abbès et al. (2006)

			enzyme activities and histological pictures of both liver and kidney			
	T-2	2	No significant decrease on body weight gain; Retention on crude protein; Decrease on crude fat	42d	Broilers basal maize-soybean meal	Y. L. Liu et al. (2011)
Hydrated sodium aluminosilicate	AFB_1	5	No effect on hepatic lesions	1 year	Rainbow trout diet meal	Arana et al. (2011)
Activated charcoal	FB_1	2	100% Adsorption	1h	Aqueous solution	Galvano et al. (1997)
	OTA	0.4	>95% Adsorption	1h	Aqueous solution	Galvano et al. (1998)
	DON	2	>90% Adsorption	1h	Aqueous solution	Galvano et al. (1998)
		1	67% Adsorption	90min	Phosphate buffer	Cavret, Laurent, Videmann, Mazallon, and Lecoeur (2010)
	ZEN	1	100% Adsorption	90min	Phosphate buffer	Cavret, Laurent, Videmann, Mazallon, and Lecoeur (2010)
Clay	AFB_1	0.002	Reduction of effects by mycotoxins on immune system and the liver; Improve pig growth	42d	Pig meal	Weaver et al. (2013)
	OTA	0.002	Reduction of effects by mycotoxins on immune system and the liver; Improve pig growth	42d	Pig meal	Weaver et al. (2013)
Egyptian montmorillonite	AFB_1	40	>97% Adsorption	30min	Malt suspension	Aly, Abdel-Galil, and Abdel-Wahhab (2004)
	FB_1	40	>80% Adsorption	30min	Malt suspension	Aly, Abdel-Galil, and Abdel-Wahhab (2004)
Esterified glucomannan	AFB_1	0.5	No significant decrease on body weight gain; Increase on crude protein; No significant decrease on calcium; Retention on the proportion of breast muscle, thigh muscle and abdominal fat	42d	Broilers maize-soybean meal	Y. L. Liu et al. (2011)
	OTA	0.5	No significant decrease on body weight gain; Increase on crude protein; No	42d	Broilers maize-soybean meal	Y. L. Liu et al. (2011)

			significant decrease on calcium; Retention on the proportion of breast muscle, thigh muscle and abdominal fat			
	T-2	0.5	No significant decrease on body weight gain; Increase on crude protein; No significant decrease on calcium; Retention on the proportion of breast muscle, thigh muscle and abdominal fat	42d	Broilers maize-soybean meal	Y. L. Liu et al. (2011)
Cholestyramine	DON	0.82	10% Adsorption	4h	Phosphate-citrate buffer	Döll, Dänicke, Valenta, and Flachowsky (2004)
		1	65% Adsorption	90min	Phosphate buffer	Cavret, Laurent, Videmann, Mazallon, and Lecoeur (2010)
	ZEN	0.82	94% Adsorption	4h	Phosphate-citrate buffer	Döll, Dänicke, Valenta, and Flachowsky (2004)
Modified aluminosilicate	DON	0.82	17% Adsorption	4h	Phosphate-citrate buffer	Döll, Dänicke, Valenta, and Flachowsky (2004)
	ZEN	0.82	81% Adsorption	4h	Phosphate-citrate buffer	Döll, Dänicke, Valenta, and Flachowsky (2004)
PVP-DEGMA-TAIC	FB_1	0.005	86% Adsorption	24h	Wine-like model solution	Carrasco-Sanchez, Kreitman, Folch-Cano, Elias, and Laurie (2017)
	FB_2	0.005	94% Adsorption	24h	Wine-like model solution	Carrasco-Sanchez, Kreitman, Folch-Cano, Elias, and Laurie (2017)
Poly(acrylamide-co-ethyleneglycol-methacrylate)	FB_1	0.005	82% Adsorption	24h	Wine-like model solution	Carrasco-Sanchez, Kreitman, Folch-Cano, Elias, and Laurie (2017)
	FB_2	0.005	100% Adsorption	24h	Wine-like model solution	Carrasco-Sanchez, Kreitman, Folch-Cano, Elias, and Laurie (2017)
Trimethylstearylammonium bromide	AFB_1	5.8	89% Adsorption	1h	Phosphate buffer	Sun, Song, Wang, Wang, and Zheng (2018)
	ZEN	5.9	86% Adsorption	1h	Phosphate buffer	Sun, Song, Wang, Wang, and Zheng (2018)

PVP-DEGMA-TAIC:Resins of copolymerization of N-vinyl-2-pyrrolidinone with ethylene glycol dimethacrylate and triallyl isocyanurate

Table 4.Mycotoxinsdetoxificationby bacteria and fungi through adsorption in different matrixes

Micro-	Mycotoxin	Genus	Strains	Effects	Time	Matrix	Reference

organism							
Bacteria	AFB_1	*Lactobacillus*	*L. fermentum*	61% Adsorption	48h	PBS Buffer	Fazeli et al. (2009)
			L. plantarum	56% Adsorption	48h	PBS Buffer	
			L.casei	48% Adsorption	48h	PBS Buffer	
			L. paracasei LOCK 0920	Decreased the extent of DNA damage	14d	*In vivo* (Chicken Fodder)	Slizewska, Nowak, Libudzisz, and Blasiak (2010)
			L. brevis LOCK 0944	Decreased the extent of DNA damage	14d	*In vivo* (Chicken Fodder)	
			L. plantarum LOCK 0945 (mixed)	Decreased the extent of DNA damage	14d	*In vivo* (Chicken Fodder)	
			*L. rhamnosus*strain GG	70% Adsorption	24h	PBS Buffer	Vosough, Sani, Mehraban, and Karazhyan (2014)
		Bifidobacterium	*B. bifidum*	55% Adsorption	72h	PBS Buffer	Hamad, Zahran, and Hafez (2017)
			*B. lactis*CSCC 5094	35% Adsorption	24h	PBS Buffer	Peltonen, El-Nezami, Haskard, Ahokas, and Salminen (2001)
			B. longum CSCC 5304	38% Adsorption	24h	PBS Buffer	
			B.animalis CSCC 1941	46% Adsorption	24h	PBS Buffer	
			B.lactis CSCC 1906	49% Adsorption	24h	PBS Buffer	
		Enterococcus	*E. faecium* MF4	23% Adsorption	24h	PBS Buffer	Fernandez Juri, Dalcero, and Magnoli (2014)
			E. faecium GJ40	21% Adsorption	24h	PBS Buffer	
			E. faecium M74	19.3-30.5 % Adsorption	48h	PBS Buffer	Topcu, Bulat, Wishah, and Boyacı (2010)
			E. faecium EF031	23.4-37.5% Adsorption	48h	PBS Buffer	
	AFB_2	*Streptococcus*	P. *freudenreichii* spp. *shermanii* JS (mixed)	83% Adsorption	4 weeks	*In vivo* (human)	El-Nezami et al. (2000)
	AFM_1	*Lactobacillus*	*L. rhamnosus* GAF01	95% Adsorption	24h	PBS Buffer/Milk	Abbes et al. (2013)
			L. plantarum MON03	77% Adsorption	24h	PBS Buffer /Milk	
			L. plantarum MON03	16% Adsorption	14d	*In vivo* (mice)	
			L. bulgaricus	58.5% Adsorption	6h	Yogurt	El Khoury, Atoui, and Yaghi (2011)
			L. bulgaricus	55% Adsorption	6h	PBS Buffer	

	DON	*Lactobacillus*	*L. plantarum* strain 102	20% Adsorption	24h	PBS Buffer	Zou et al. (2012)
			L. rhamnosus GGATCC 53103	54% Adsorption	24h	MRS Medium	Niderkorn, Boudra, and Morgavi (2006)
			*L. delbruekii*ssp. *Bulgaricus*R0149	55% Adsorption	24h	MRS Medium	
	OTA	*Lactobacillus*	*L. rhamnosus*strain GG	47% Adsorption	2h	PBS Buffer	Turbic, Ahokas, and Haskard (2002)
			L. rhamnosus strain LC-705	36% Adsorption	2h	PBS Buffer	
	ZEN	*Lactobacillus*	*L. rhamnosus*GG	55% Adsorption	24h	MRS Medium	El-Nezami, Polychronaki, Salminen, and
			*L. rhamnosus*LC705	55% Adsorption	24h	MRS Medium	Mykkanen (2002)
	FB	*Lactobacillus*	*L. rhamnosus* GG ATCC 53103	54% Adsorption	24h	MRS Medium	Niderkorn, Boudra, and Morgavi (2006)
			L. plantarum R1039	40% Adsorption	24h	MRS Medium	
			L. plantarum R0011	30% Adsorption	24h	MRS Medium	
			L. brevis R0002	32% Adsorption	24h	MRS Medium	
			*L. acidophilis*R0052	34% Adsorption	24h	MRS Medium	
			L. delbruekii ssp. *bulgaricus* R0149	55% Adsorption	24h	MRS Medium	
			*L. casei*ssp. *casei* C3	36% Adsorption	24h	MRS Medium	
		Streptococcus	*Strep*. *thermophilus* B5	31% Adsorption	24h	MRS Medium	Niderkorn, Boudra, and Morgavi (2006)
		Lactococcus	*L. lactis* CS 43	23% Adsorption	24h	MRS Medium	Niderkorn, Boudra, and Morgavi (2006)
			*L. lactis*CS 202	40% Adsorption	24h	MRS Medium	
			L. lactis CS 197	23% Adsorption	24h	MRS Medium	
		Leuconostoc	*L. mesenteroides*R1107	46% Adsorption	24h	MRS Medium	Niderkorn, Boudra, and Morgavi (2006)
		Lactobacillus	*L. rhamnosus* 6149	51.1-52.0% Adsorption	24h	Physiological saline solution (0.85%, w/v)	S. Hatab, T. Yue, and O. Mohamad (2012)
		Bifidobacterium	*B. bifidum* 6071	52.9-54.1% Adsorption	24h	Physiological saline solution (0.85%, w/v)	S. Hatab, T. Yue, and O. Mohamad (2012)
		Enterococcus	*E. faecium* 21605	64.5% Adsorption	24h	Apple juice	S. Hatab, T. Yue, and O. Mohamad
			E. faecium M74	15.8-41.6% Adsorption	48h	PBS Buffer	(2012)
			E. faecium EF031	9.5-45.3% Adsorption	48h	PBS Buffer	Topcu, Bulat, Wishah, and Boyacı (2010)
Fungi	AFB_1	*Saccharomyces*	*S. cerevisiae*	48% Adsorption	1h	PBS Buffer	Campagnollo et al. (2015)

DON	*Saccharomyces*	*S. cerevisiae*	12% Adsorption	1h	PBS Buffer	Campagnollo et al. (2015)
PAT	*Saccharomyces*	*S. cerevisiae*strain YS3(laboratory-prepared)	70% Adsorption	24h	Apple Juice	Guo, Yue, Hatab, and Yuan (2011)
		*S. cerevisiae*strain YS3(commercial)	76% Adsorption	24h	Apple Juice	Yue, Dong, Guo, and Worobo (2011)
		S. cerevisiae YS1-YS10	50-7% Adsorption	24h	Apple Juice	Guo, Yue, Hatab, and Yuan (2012)
		S. cerevisiae YS3	100% Adsorption	36h	Apple Juice	Coelho et al. (2008)
		S. cerevisiae	90-96% Adsorption	143h	Apple Juice	
OTA	*Saccharomyces*	*S.cerevisiae var. boulardii* ATCC MYA-796	39% Adsorption	1h	PBS Buffer	Petruzzi, Corbo, Sinigaglia, and
		S. cerevisiae BM45	39% Adsorption	1h	PBS Buffer	Bevilacqua (2016)
		S.cerevisiae W13	39% Adsorption	1h	PBS Buffer	
		*S.cerevisiae*W28	39% Adsorption	1h	PBS Buffer	
		S.cerevisiae W47	42% Adsorption	4d	YPG Medium with Ethanol	
		S.cerevisiae Y28	37% Adsorption	4d	YPG Medium with Ethanol	Petruzzi, Sinigaglia, Corbo, Beneduce, and
		*S.cerevisiae*Malaga LOCK 0173	85% Adsorption	10d	Grape/Blackcurrant Juice	Bevilacqua (2012)
		*S.cerevisiae*Syrena LOCK 0201	83% Adsorption	10d	Grape/Blackcurrant Juice	
		S. cerevisiae bakery BS strain	64% Adsorption	10d	Grape/Blackcurrant Juice	Piotrowska, Nowak, and Czyzowska
		S. cerevisiae RC008	57% Adsorption	1h	PBS Buffer	(2013)
		S. cerevisiae RC009	67% Adsorption	1h	PBS Buffer	
		S. cerevisiae RC012	71% Adsorption	1h	PBS Buffer	
		S. cerevisiae RC016	74% Adsorption	1h	PBS Buffer	Armando et al. (2012)
		S. cerevisiae	76% Adsorption	90d	White Wine	
		S. cerevisiae	86% Adsorption	90d	Red Wine	
		S. cerevisiae	90% Adsorption	90d	Rose Wine	
		S. cerevisiae	59% Adsorption	1h	PBS Buffer	Csutorás et al. (2013)
		S. cerevisiae	30% Adsorption	1h	Dough Fermentation	
						Campagnollo et al. (2015)
						Valle-Algarra et al. (2009)
ZEN	*Saccharomyces*	*S. cerevisiae* RC008	21% Adsorption	1h	PBS Buffer	Armando et al. (2012)

	S. cerevisiae RC009	33% Adsorption	1h	PBS Buffer	
	S. cerevisiae RC012	29% Adsorption	1h	PBS Buffer	
	S. cerevisiae RC016	34% Adsorption	1h	PBS Buffer	
	S. cerevisiae	75% Adsorption	1h	PBS Buffer	Campagnollo et al. (2015)

Table 5. Evaluation of fungi/mycotoxin decontamination approaches

Classification	Treatments	Technical advantages	Technical disadvantages	Suitable food matrix	Safety	Economical concerns in large	Potential for using in	Reference

						scale production	large scale	
Physical approaches	Temperature and humidity control	Easy-operated; less colour, odor and nutrition changes; shelf life extension	Inconvenient transportation	Almost all food types	No reported toxic substance induced and formed	Cost of temperature and humidity equipment; high energy consumption	High	-
	Modified atmosphere treatment	Less colour, odor and nutrition changes; shelf life extension	Large consumption of packaging material	Packed foods	No reported toxic substance induced and formed	Cost of gas generator equipment and food packaging material	Medium	-
	Irradiation treatment	High efficiency; environmental friendly; agrees with the legislations of food application in 55 countries	Food quality change (e.g. colour, odor); nutrition loss (e.g. oxidization of vitamin) at high dose	Packed foods; frozen foods; liquid foods; cereals; fruits and vegetables	No residual irradiation; may cause mutations to fungi	Low consumption of water and electrical energy (exception of electron beam and X-ray); high cost of food irradiation facilities	High	Calado, Venâncio, and Abrunhosa (2014)
	Cleaning, milling and sorting	Easy-operated; effective with water-soluble mycotoxins	Less effective with organic-soluble mycotoxins	Raw food materials	No other introduced chemicals and new mycotoxin-derivative	High consumption of water	High	Temba et al. (2016)
	Heat treatment	Already a necessary processing method in food production	Change of the desired physical properties of food	Cooked foods (e.g. roasted foods); sterilized food	Lack of studies on transformation mechanisms	Cost of heating equipment; high energy consumption	Medium	Rastegar et al. (2017)

Chemical approaches	Photodynamic treatment	Environmental friendly; biochemically stable; photosensitizer adequately activated by using easy-available visible light	Limited light penetration	Cereals; fruits; sea foods; animal feeds	Food grade photosensitizer (e.g. curcumin); lack of studies on safety after treatment	Cost of light generator and photosensitizer; relative cost-effective		Njoki, Okoth, and Wachira (2017) Al-Asmari, Mereddy, and Sultanbawa (2018) Temba et al. (2019)
	Plasma treatment (Ozonisation)	High efficiency; rapid; no significant change of nutritional components to whole cereals	May cause the loss of nutrition in other foods; change of colour; production of undesirable odor	Cereals; meat; fruits and vegetables; herbs and spices; animalfeeds	Lack of studies on safety of degraded residue	Low energy consumption; high cost of cold plasma production equipment; less maintenance and dust cleaning	Medium	Savi, Bittencourt, et al. (2015) Temba et al. (2016) Misra, Yadav, Roopesh, and Jo (2019) Alexandre, Castanha, Calori-Domingues, and Augusto (2017)
	Electrolyzed oxidizing water	High efficiency; environmental friendly; easy-operated	Loss of antifungal activity without continuous electrolysis; Cl_2 production; possibility of metal corrosion	Fruits and vegetables; meat products; cereals	Safe to degrade mycotoxins; no not corrosive to skin, mucous membrane and organic material	High cost of EOW production equipment, electrical and water consumption; low cost of each litre	High	Okull and Laborde (2004) Q. Zhang, Xiong, Tatsumi, Li, and Liu (2012) Huang, Hung, Hsu, Huang, and Hwang (2008)
	Chemical antifungal/anti-mycotoxins agents	Effective; easy-operated	Unpleasant chemical residue	Coating; animal feeds; specific food conforming to food additives (e.g. soda in Chinese baking)	Lack of studies on transformation mechanisms; toxicity of induced chemicals at high concentration to human and	Cost of agents	Medium	Bretz, Beyer, Cramer, Knecht, and Humpf (2006) Temba et al. (2019)

					environment			
	Chemical removal of mycotoxin	Effective; easy-operated; some commercial clay materials enhance nutrition and digestibility of animal feeds	Difficult removal of mycotoxin-binder complex; need to be in aqueous environment	Animal feeds; clay capsules for human (potential)	Toxicity of released mycotoxins from mycotoxin-binder complex	Cost effective	Medium	Di Gregorio et al. (2014)
Biological approaches	Biological control agents/mycotox in degradation	High efficiency in lab experiments; easy-operated (e.g. soak, spray); environmental friendly	Less evidence on the correlation between laboratory inhibition assay and field performance; need to be under strict conditions (e.g. pH, solution, temperature)	Cereals; fruits and vegetables; fermented foods	Less toxicity shown on degraded residue	Cost of bacterial high density culture; used as antagonist solution cost of materials and equipment for production of the biocontrol agent	Low	Jard, Liboz, Mathieu, Guyonvarc'h, and Lebrihi (2011) de Medeiros et al. (2012)
	Antifungal plant metabolite	High efficiency; a wide range of sources	Change of colour and odor; mainly used in aqueous environment	Meat products; dairy products; vegetable and fruits; cereals	Potential toxicity (e.g. carcinogenicity) at high concentration	Large amount of plant materials needed; high cost of production equipment and energy consumption	Low	Burt (2004) Bakkali, Averbeck, Averbeck, and Idaomar (2008)
	Biological removal of mycotoxin	High efficiency; from food source; environmental friendly	Difficult removal of mycotoxin-binder complex; need to be in aqueous environment	Fermented foods; animal feeds	Toxicity of released mycotoxins from mycotoxin-	Cost of bacterial high density culture	Medium	Hathout and Aly (2014)

	bacteria complex

1085

Data Availability

The data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Conflict of Interest Statement

The authors declare no potential conflict of interest.

Funding

This work was funded by the UK Research and Innovation as part of the Global Challenges Research Fund, BB/P027784/1 to YYG, CO and JHGY.

Author contributions

YL performed the literature review and evaluation of literature data. YL drafted the manuscript. All authors contributed ideas to the design and organisation of the work. All authors edited and reviewed the manuscript.

References

1333/2008, A. I. o. R. E. N. (2017). The database of food additives in EU Retrieved from https://webgate.ec.europa.eu/foods_system/main/?sector=FAD&auth=SANCAS

Abbas, H. K., Zablotowicz, R. M., Bruns, H. A., & Abel, C. A. (2007). Biocontrol of aflatoxin in corn by inoculation with non-aflatoxigenic *Aspergillus flavus* isolates. *Biocontrol Science and Technology, 16*(5), 437-449. doi:https://doi.org/10.1080/09583150500532477

Abbès, S., Ouanes, Z., ben Salah-Abbès, J., Houas, Z., Oueslati, R., Bacha, H., & Othman, O. (2006). The protective effect of hydrated sodium calcium aluminosilicate against haematological, biochemical and pathological changes induced by Zearalenone in mice. *Toxicon, 47*(5), 567-574. doi:10.1016/j.toxicon.2006.01.016

Abbes, S., Salah-Abbes, J. B., Sharafi, H., Jebali, R., Noghabi, K. A., & Oueslati, R. (2013). Ability of *Lactobacillus rhamnosus* GAF01 to remove AFM_1 *in vitro* and to counteract AFM_1 immunotoxicity *in vivo*. *Journal of Immunotoxicol, 10*(3), 279-286. doi:10.3109/1547691X.2012.718810

Abu-Darwish, M. S., Cabral, C., Ferreira, I. V., Goncalves, M. J., Cavaleiro, C., Cruz, M. T., . . . Salgueiro, L. (2013). Essential oil of common sage (*Salvia officinalis* L.) from Jordan: assessment of safety in mammalian cells and its antifungal and anti-inflammatory potential. *Biomed Research International, 2013*, 1-10. doi:10.1155/2013/538940

Abu-Darwish, M. S., Cabral, C., Goncalves, M. J., Cavaleiro, C., Cruz, M. T., Efferth, T., & Salgueiro, L. (2015). *Artemisia herba-alba* essential oil from Buseirah (South Jordan): Chemical characterization and assessment of safe antifungal and anti-inflammatory doses. *Journal of Ethnopharmacology, 174*, 153-160. doi:10.1016/j.jep.2015.08.005

Akueche, E. C., Anjorin, S. T., Harcourt, B. I., Kana, D., Adeboye, E., Shehu, I., . . . Adesanmi, C. A. (2012). Studies on fungal load, total aflatoxins and ochratoxin a contents of gamma-irradiated and non-irradiated *Sesamum indicum* grains from Abuja markets, Nigeria. *Kasetsart Journal - Natural Science, 46*(3), 371-382.

Al-Asmari, F., Mereddy, R., & Sultanbawa, Y. (2018). The effect of photosensitization mediated by curcumin on storage life of fresh date (*Phoenix dactylifera* L.) fruit. *Food Control, 93*, 305-309. doi:https://doi.org/10.1016/j.foodcont.2018.06.005

Alexandre, A. P. S., Castanha, N., Calori-Domingues, M. A., & Augusto, P. E. D. (2017). Ozonation of whole wheat flour and wet milling effluent: Degradation of deoxynivalenol (DON) and rheological properties. *Journal of Environmental Science and Health, Part B, 52*(7), 516-524. doi:https://doi.org/10.1080/03601234.2017.1303325

Alexandre, A. P. S., Castanha, N., Costa, N. S., Santos, A. S., Badiale-Furlong, E., Augusto, P. E. D., & Calori-Domingues, M. A. (2019). Ozone technology to reduce zearalenone contamination in whole maize flour: degradation kinetics and impact on quality. *Journal of the Science of Food and Agriculture, 99*(15), 6814-6821. doi:https://doi.org/10.1002/jsfa.9966

Allameh, A., Safamehr, A., Mirhadi, S. A., Shivazad, M., Razzaghi-Abyaneh, M., & Afshar-Naderi, A. (2005). Evaluation of biochemical and production parameters of broiler chicks fed ammonia treated aflatoxin contaminated maize grains. *Animal Feed Science and Technology, 122*(3-4), 289-301. doi:https://doi.org/10.1016/j.anifeedsci.2005.03.005

Aly, S. E., Abdel-Galil, M. M., & Abdel-Wahhab, M. A. (2004). Application of adsorbent agents technology in the removal of aflatoxin B_1 and fumonisin B_1 from malt extract. *Food and Chemical Toxicology, 42*(11), 1825-1831. doi:10.1016/j.fct.2004.06.014

Appell, M., Kendra, D. F., & Trucksess, M. W. (2009). *Mycotoxin Prevention and Control in Agriculture* (Vol. 1031). Washington DC, United States: American Chemical Society.

Arana, S., Dagli, M. L. Z., Sabino, M., Tabata, Y. A., Rigolino, M. G., & Hernandez-Blazquez, F. J. (2011). Evaluation of the efficacy of hydrated sodium aluminosilicate in the prevention of aflatoxin-induced hepatic cancer in rainbow trout. *Pesquisa Veterinária Brasileira, 31*(9), 751-755.

Armando, M. R., Pizzolitto, R. P., Dogi, C. A., Cristofolini, A., Merkis, C., Poloni, V., . . . Cavaglieri, L. R. (2012). Adsorption of ochratoxin A and zearalenone by potential probiotic *Saccharomyces cerevisiae* strains and its relation with cell wall thickness. *Journal of Applied Microbiology, 113*(2), 256-264. doi:10.1111/j.1365-2672.2012.05331.x

Assaf, J. C., El Khoury, A., Atoui, A., Louka, N., & Chokr, A. (2018). A novel technique for aflatoxin M1 detoxification using chitin or treated shrimp shells: in vitro effect of physical and kinetic parameters on the binding stability. *Applied Microbiology and Biotechnology, 102*(15), 6687-6697. doi:https://doi.org/10.1007/s00253-018-9124-0

Assatarakul, K., Churey, J. J., Manns, D. C., & Worobo, R. W. (2012). Patulin reduction in apple juice from concentrate by UV radiation and comparison of kinetic degradation models between apple juice and apple cider. *Journal of Food Protection, 75*(4), 717-724. doi:https:doi.org/10.4315/0362-028X.JFP-11-429

Atanasova-Penichon, V., Barreau, C., & Richard-Forget, F. (2016). Antioxidant Secondary Metabolites in Cereals: Potential Involvement in Resistance to *Fusarium* and Mycotoxin Accumulation. *Frontiers in microbiology, 7*, 566. doi:https://doi.org/10.3389/fmicb.2016.00566

Aziz, N. H., El-Far, F. M., Shahin, A. A. M., & Roushy, S. M. (2007). Control of *Fusarium* moulds and fumonisin B_1 in seeds by gamma-irradiation. *Food Control, 18*(11), 1337-1342. doi:10.1016/j.foodcont.2005.12.013

Bailey, G. S., Price, R. L., & Hendricks, J. D. (1994). Effect of ammoniation of aflatoxin B_1-contaminated cottonseed feedstock on the aflatoxin M_1 content of cows' milk and hepatocarcinogenicity in the trout bioassay. *Food and Chemical Toxicology, 32*(8), 707-715.

Bakkali, F., Averbeck, S., Averbeck, D., & Idaomar, M. (2008). Biological effects of essential oils-A review. *Food Chemical Toxicology, 46*(2), 446-475. doi:https://doi.org/10.1016/j.fct.2007.09.106

Bari, M. L., Nakauma, M., Todoriki, S., Juneja, V. K., Isshiki, K., & Kawamoto, S. (2005). Effectiveness of IrradiationTreatments in Inactivating Listeria monocytogenes on Fresh Vegetables at Refrigeration

Temperature. *Journal of Food Protection, 68*(2), 318-323. doi:https://doi.org/10.4315/0362-028X-68.2.318

Beber-Rodrigues, M., Savi, G. D., & Scussel, V. M. (2015). Ozone Effect on Fungi Proliferation and Genera Susceptibility of Treated Stored Dry Paddy Rice (*Oryza sativa* L.). *Journal of Food Safety, 35*(1), 59-65. doi:https://doi.org/10.1111/jfs.12144

Bennett, G. A., Shotwell, O. L., & Hesseltine, C. W. (1980). Destruction of zearalenone in contaminated corn. *American Oil Chemists' Society, 57*(8), 245-247.

Bhat, R., Rai, R. V., & Karim, A. A. (2010). Microbiological Control of Mycotoxins Present Status and Future Concerns. *Comprehensive Reviews in Food Science and Food Safety, 9*(1), 57-81. doi:https://doi.org/10.1111/j.1541-4337.2009.00094.x

BIOMIN. (2015). *2014 BIOMIN Mycotoxin Survey Results; Why Advanced Multiple Mycotoxin Detection Matters*. Retrieved from https://issuu.com/biomin/docs/mag_scisol_special_02_mtx_en_0515:

Bouarab-Chibane, L., Forquet, V., Lanteri, P., Clement, Y., Leonard-Akkari, L., Oulahal, N., . . . Bordes, C. (2019). Antibacterial Properties of Polyphenols: Characterization and QSAR (Quantitative Structure-Activity Relationship) Models. *Front Microbiol, 10*, 829. doi:https://doi.org/10.3389/fmicb.2019.00829

Bouletis, A. D., Arvanitoyannis, I. S., Hadjichristodoulou, C., Neofitou, C., Parlapani, F. F., & Gkagtzis, D. C. (2016). Quality changes of cuttlefish stored under various atmosphere modifications and vacuum packaging. *Journal of the Science of Food and Agriculture, 96*(8), 2882-2888. doi:https://doi.org/10.1002/jsfa.7459

Bourdichon, F., Casaregola, S., Farrokh, C., Frisvad, J. C., Gerds, M. L., Hammes, W. P., . . . Hansen, E. B. (2012). Food fermentations: microorganisms with technological beneficial use. *International Journal of Food Microbiology, 154*(3), 87-97. doi:https://doi.org/10.1016/j.ijfoodmicro.2011.12.030

Bradford, K. J., Dahal, P., Van Asbrouck, J., Kunusoth, K., Bello, P., Thompson, J., & Wu, F. (2018). The dry chain: Reducing postharvest losses and improving food safety in humid climates. *Trends in Food Science & Technology, 71*, 84-93. doi:https://doi.org/10.1016/j.tifs.2017.11.002

Brekke, O. L., Sinnhuber, R. O., Peplinski, A. J., Wales, J. H., Putnam, G. B., Lee, D. J., & Ciegler, A. (1977). Aflatoxin in Corn: Ammonia Inactivation and Bioassay with Rainbow Trout. *Applied and Environmental Microbiology, July*, 34-37.

Bretz, M., Beyer, M., Cramer, B., Knecht, A., & Humpf, H. U. (2006). Thermal Degradation of the *Fusarium* Mycotoxin Deoxynivalenol. *Agricultural and Food Chemistry, 54*(17), 6445-6451. doi:https://doi.org/10.1021/jf061008g

Burt, S. (2004). Essential oils: their antibacterial properties and potential applications in foods--a review. *International Journal of Food Microbiology, 94*(3), 223-253. doi:https://doi.org/10.1016/j.ijfoodmicro.2004.03.022

Calado, T., Venâncio, A., & Abrunhosa, L. (2014). Irradiation for Mold and Mycotoxin Control: A Review. *Comprehensive Reviews in Food Science and Food Safety, 13*(5), 1049-1061. doi:https://dio.org/10.1111/1541-4337.12095

Campagnollo, F. B., Franco, L. T., Rottinghaus, G. E., Kobashigawa, E., Ledoux, D. R., Daković, A., & Oliveira, C. A. F. (2015). *In vitro* evaluation of the ability of beer fermentation residue containing *Saccharomyces cerevisiae* to bind mycotoxins. *Food Research International, 77*, 643-648. doi:10.1016/j.foodres.2015.08.032

Caridi, A., Galvano, F., Tafuri, A., & Ritieni, A. (2006). Ochratoxin A removal during winemaking. *Enzyme and Microbial Technology, 40*(1), 122-126. doi:10.1016/j.enzmictec.2006.07.002

Carrasco-Sanchez, V., Kreitman, G. Y., Folch-Cano, C., Elias, R. J., & Laurie, V. F. (2017). Removal of fumonisin B_1

and B_2 from model solutions and red wine using polymeric substances. *Food Chemistry, 224*, 207-211. doi:https://doi.org/10.1016/j.foodchem.2016.12.081

CAST. (2003). *Mycotoxins-Risks in Plant, Animals and Human Systems: United States*. Retrieved from https://www.international-food-safety.com/pdf/Mycotoxins%20-%20Risks%20in%20Plant,%20Animals%20and%20Human%20Systems.pdf:

Castells, M., Marín, S., Sanchis, V., & Ramos, A. J. (2006). Reduction of Aflatoxins by Extrusion-Cooking of Rice Meal. *Journal of Food Science, 71*(7), C369-C377. doi:https://doi.org/10.1111/j.1750-3841.2006.00122.x

Castelo, M. M., Jackson, L. S., Hanna, M. A., Reynolds, B. H., & Bullerman, L. B. (2001). Loss of Fuminosin B_1 in Extruded and Baked Corn-Based Foods with Sugars. *Journal of Food Science, 66*(3), 416-422.

Cavaglieri, L. R., Andres, L., Ibanez, M., & Etcheverry, M. G. (2005). Rhizobacteria and their potential to control *Fusarium verticillioides*: effect of maize bacterisation and inoculum density. *Antonie Van Leeuwenhoek, 87*(3), 179-187. doi:https://doi.org/10.1007/s10482-004-3193-z

Cavret, S., Laurent, N., Videmann, B., Mazallon, M., & Lecoeur, S. (2010). Assessment of deoxynivalenol (DON) adsorbents and characterisation of their efficacy using complementary in vitro tests. *Food Additives and Contaminants, 27*(1), 43-53. doi:10.1080/02652030903013252

Cazzaniga, D., Basílico, J. C., González, R. J., Torres, R. L., & De Greef, D. M. (2001). Mycotoxins inactivation by extrusion cooking of corn flour. *Letters in Applied Microbiology, 33*(144-147).

Chan, Y. S., & Ng, T. B. (2013). Northeast Red Beans Produce a Thermostable and pH-Stable Defensin-Like Peptide with Potent Antifungal Activity. *Cell Biochem Biophys, 66*(3), 637-648. doi:https://doi.org/10.1007/s12013-012-9508-1)

Cheli, F., Pinotti, L., Rossi, L., & Dell'Orto, V. (2013). Effect of milling procedures on mycotoxin distribution in wheat fractions: A review. *LWT - Food Science and Technology, 54*(2), 307-314. doi:http://doi,org/10.1016/j.lwt.2013.05.040

Chen, Y., Kong, Q., & Liang, Y. (2019). Three newly identified peptides from *Bacillus megaterium* strongly inhibit the growth and aflatoxin B_1 production of *Aspergillus flavus*. *Food Control, 95*, 41-49. doi: https://doi.org/10.1016/j.foodcont.2018.07.040

Choi, S., Jun, H., Bang, J., Chung, S. H., Kim, Y., Kim, B. S., . . . Ryu, J. H. (2015). Behaviour of *Aspergillus flavus* and *Fusarium graminearum* on rice as affected by degree of milling, temperature, and relative humidity during storage. *Food Microbiology, 46*, 307-313. doi:https://doi.org/10.1016/j.fm.2014.08.019

Cia, P., Pascholati, S. F., Benato, E. A., Camili, E. C., & Santos, C. A. (2007). Effects of gamma and UV-C irradiation on the postharvest control of papaya anthracnose. *Postharvest Biology and Technology, 43*(3), 366-373. doi:https://doi.org/10.1016/j.postharvbio.2006.10.004

Cinar, A., & Onbaşı, E. (2019). Mycotoxins The Hidden Danger in Foods *Mycotoxins and Food Safety* (eds ed., pp. 1-21). Boston, United States: IntechOpen.

Coelho, A., Celli, M., Sataque Ono, E., Hoffmann, F., Pagnocca, F., Garcia, S., . . . Hirooka, E. (2008). Patulin biodegradation using *Pichia ohmeri* and *Saccharomyces cerevisiae*. *World Mycotoxin Journal, 1*(3), 325-331. doi:https://doi.org/10.3920/WMJ2008.1040

Conforti, F. D., & Totty, J. A. (2007). Effect of three lipid/hydrocolloid coatings on shelf life stability of Golden Delicious apples. *International Journal of Food Science & Technology, 42*(9), 1101-1106. doi:https://doi.org/10.1111/j.1365-2621.2006.01365.x

Cristina, C., Annalisa, L., Amalia, C., Francesco, C., & Del Nobile, M. A. (2013). In vitro and in vivo application of

active compounds with anti-yeast activity to improve the shelf life of ready-to-eat table grape. *World J Microbiol Biotechnol, 29*(6), 1075-1084. doi:https://doi.org/10.1007/s11274-013-1271-y

Csutorás, C., Rácz, L., Rácz, K., Fűtő, P., Forgó, P., & Kiss, A. (2013). Monitoring of ochratoxin A during the fermentation of different wines by applying high toxin concentrations. *Microchemical Journal, 107*, 182-184. doi:10.1016/j.microc.2012.07.001

Dalié, D. K. D., Deschamps, A. M., & Richard-Forget, F. (2010). Lactic acid bacteria – Potential for control of mould growth and mycotoxins: A review. *Food Control, 21*(4), 370-380. doi:https://doi.org/10.1016/j.foodcont.2009.07.011

de Medeiros, F. H. V., Martins, S. J., Zucchi, T. D., de Melo, I. S., Batista, L. R., & da Cruz Machado, J. (2012). Biological Control of Mycotoxin-Producing Molds. *Ciência e Agrotecnologia, 36*(5), 483-497. doi:https://doi.org/10.1590/S1413-70542012000500001

de Siqueira Mendes, L., Aguayo, E., de Oliveira Pessoa, C., Nastaro, B. T., & Kluge, R. A. (2019). Enhancement of the antioxidant capacity and reduction of chilling injury in 'Douradão' peaches refrigerated under pre-storage and modified atmosphere. *Acta Scientiarum - Agronomy, 41*(1), 2-11. doi:https://doi.org/10.4025/actasciagron.v41i1.39641

Delgado, J., Acosta, R., Rodriguez-Martin, A., Bermudez, E., Nunez, F., & Asensio, M. A. (2015). Growth inhibition and stability of PgAFP from *Penicillium chrysogenum* against fungi common on dry-ripened meat products. *International Journal of Food Microbiology, 205*, 23-29. doi:https://doi.org/10.1016/j.ijfoodmicro.2015.03.029

Delgado, J., Owens, R. A., Doyle, S., Asensio, M. A., & Nunez, F. (2016). Manuscript title: antifungal proteins from moulds: analytical tools and potential application to dry-ripened foods. *Appl Microbiol Biotechnol, 100*(16), 6991-7000. doi:https://doi.org/10.1007/s00253-016-7706-2

Devi, M. S., & Sashidhar, R. B. (2019). Antiaflatoxigenic effects of selected antifungal peptides. *Peptides, 115*, 15-26. doi:https://doi.org/10.1016/j.peptides.2019.02.006

Di Gregorio, M. C., de Neeff, D. V., Jager, A. V., Corassin, C. H., de Pinho Carão, Á. C., de Albuquerque, R., . . . Oliveira, C. A. F. (2014). Mineral adsorbents for prevention of mycotoxins in animal feeds. *Toxin Reviews, 33*(3), 125-135. doi:https://doi.org/10.3109/15569543.2014.905604

Di Stefano, V., Pitonzo, R., Cicero, N., & D'Oca, M. C. (2014). Mycotoxin contamination of animal feedingstuff: detoxification by gamma-irradiation and reduction of aflatoxins and ochratoxin A concentrations. *Food Additives & Contaminants: Part A, 31*(12), 2034-2039. doi:https:doi.org/10.1080/19440049.2014.968882

Diaz-Gomez, J., Marin, S., Nogareda, C., Sanchis, V., & Ramos, A. J. (2016). The effect of enhanced carotenoid content of transgenic maize grain on fungal colonization and mycotoxin content. *Mycotoxin Research, 32*(4), 221-228. doi:https://doi.org/10.1007/s12550-016-0254-x

Döll, S., Dänicke, S., Valenta, H., & Flachowsky, G. (2004). *In vitro* studies on the evaluation of mycotoxin detoxifying agents for their efficacy on deoxynivalenol and zearalenone. *Archives of Animal Nutrition, 58*(4), 311-324. doi:https://doi.org/10.1080/00039420412331273268

Dupuy, J., Le Bars, P., Boudra, H., & Le Bars, J. (1993). Thermostability of Fumonisin B_1, a Mycotoxin from *Fusarium moniliforme*, in Corn. *Applied and Environmental Microbiology, 59*(9), 2864-2867.

El-Nezami, H., Mykkanen, H., Kankaanpaa, P., Suomalainen, T., Salminen, S., & Ahoka, J. (2000). Ability of a Mixture of *Lactobacillus* and *Propionibacterium* to Influence the Faecal Aflatoxin Content in Healthy Egyptian Volunteers: A Pilot Clinical Study. *Bioscience Microflora, 19*(1), 41-45.

El-Nezami, H., Polychronaki, N., Salminen, S., & Mykkanen, H. (2002). Binding Rather Than Metabolism May Explain the Interaction of Two Food-Grade *Lactobacillus* Strains with Zearalenone and Its Derivative

ά -Zearalenol. *Applied and Environmental Microbiology, 68*(7), 3545-3549. doi:10.1128/aem.68.7.3545-3549.2002

El Gaidoumi, A., Doña-Rodríguez, J. M., Pulido Melián, E., González-Díaz, O. M., Navío, J. A., El Bali, B., & Kherbeche, A. (2019). Catalytic Efficiency of Cu-Supported Pyrophyllite in Heterogeneous Catalytic Oxidation of Phenol. *Arabian Journal for Science and Engineering, 44*(7), 6313-6325. doi:https:doi.org/10.1007/s13369-019-03757-2

El Khoury, A., Atoui, A., & Yaghi, J. (2011). Analysis of aflatoxin M1 in milk and yogurt and AFM1 reduction by lactic acid bacteria used in Lebanese industry. *Food Control, 22*(10), 1695-1699. doi:10.1016/j.foodcont.2011.04.001

Escobedo-González, R., Méndez-Albores, A., Villarreal-Barajas, T., Aceves-Hernández, J. M., Miranda-Ruvalcaba, R., & Nicolás-Vazquez, I. (2016). A Theoretical Study of 8-Chloro-9-Hydroxy-Aflatoxin B_1, the Conversion Product of Aflatoxin B_1 by Neutral Electrolyzed Water. *Toxins (Basel), 8*(7), 1-19. doi:https://doi.org/10.3390/toxins8070225

Eskola, M., Kos, G., Elliott, C. T., Hajslova, J., Mayar, S., & Krska, R. (2019). Worldwide contamination of food-crops with mycotoxins: Validity of the widely cited 'FAO estimate' of 25%. *Critical Reviews in Food Science and Nutrition*, 1-17. doi:https://doi.org/10.1080/10408398.2019.1658570

COMMISSION REGULATION (EC) (2006).

Fazeli, M. R., Hajimohammadlih, M., Moshkani, A., Samadi, N., Jamalifar, H., Khoshayand, M. R., . . . Pouragahi, S. (2009). Aflatoxin B_1 Binding Capacity of Autochthonous Strains of Lactic Acid Bacteria. *Journal of Food Protection, 72*(1), 189–192.

Fernandez Juri, M. G., Dalcero, A. M., & Magnoli, C. E. (2014). *In vitro* aflatoxin B*1* binding capacity by two Enterococcus faecium strains isolated from healthy dog faeces. *Journal Appl Microbiol, 118*(3), 574-582. doi:10.1111/jam.12726

Fernandez Juri, M. G., Dalcero, A. M., & Magnoli, C. E. (2015). *In vitro* aflatoxin B_1 binding capacity by two Enterococcus faecium strains isolated from healthy dog faeces. *Journal of Food Protection, 118*(3), 574-582. doi:10.1111/jam.12726

Freitas-Silva, O., & Venancio, A. (2010). Ozone applications to prevent and degrade mycotoxins: a review. *Drug Metabolism Reviews, 42*(4), 612-620. doi:https://doi.org/10.3109/03602532.2010.484461

Galvano, F., Pietri, A., Bertuzzi, T., Bognanno, M., Chies, L., de Angelis, A., & Galvano, M. (1997). Activated Carbons: In Vitro Affinity for Fumonisin B_1 and Relation of Adsorption Ability to Physicoche mical Parameters. *Journal of Food Protection, 60*(8), 985-991.

Galvano, F., Pietri, A., Bertuzzi, T., Piva, A., Chies, L., & Galvano, M. (1998). Activated Carbons: In Vitro Affinity for Ochratoxin A and Deoxynivalenol and Relation of Adsorption Ability to Physicochemical Parameters. *Journal of Food Protection, 61*(4), 469-475.

Gerez, C. L., Torino, M. I., Rollán, G., & Font de Valdez, G. (2009). Prevention of bread mould spoilage by using lactic acid bacteria with antifungal properties. *Food Control, 20*(2), 144-148. doi:10.1016/j.foodcont.2008.03.005

Giatrakou, V., Nizimani, A., & Savvaidis, I. N. (2010). Combined Chitosan-Thyme Treatments with Modified Atmosphere Packaging on a Ready-to-Cook Poultry Product. *Journal of Food Protection, 73*(4), 663-669. doi:https://doi.org/10.4315/0362-028X-73.4.663

Gómez-Espinosa, D., Cervantes-Aguilar, F. J., Del Río-García, J. C., Villarreal-Barajas, T., Vázquez-Durán, A., & Méndez-Albores, A. (2017). Ameliorative Effects of Neutral Electrolyzed Water on Growth Performance, Biochemical Constituents, and Histopathological Changes in Turkey Poults during Aflatoxicosis. *Toxins (Basel), 9*(3), 1-14. doi:https://doi.org/10.3390/toxins9030104

Guan, S., Ji, C., Zhou, T., Li, J., Ma, Q., & Niu, T. (2008). Aflatoxin B_1 degradation by *Stenotrophomonas maltophilia* and other microbes selected using coumarin medium. *International Journal of Molecular Sciences, 9*(8), 1489-1503. doi: https://doi.org/10.3390/ijms9081489

Guentzel, J. L., Lam, K. L., Callan, M. A., Emmons, S. A., & Dunham, V. L. (2010). Postharvest management of gray mold and brown rot on surfaces of peaches and grapes using electrolyzed oxidizing water. *International Journal of Food Microbiology, 143*(1-2), 54-60. doi:https://doi.org/10.1016/j.ijfoodmicro.2010.07.028

Guo, C., Yue, T., Hatab, S., & Yuan, Y. (2011). Ability of inactivated yeast powder to adsorb patulin from apple juice. *Journal of Food Protection, 75*(3), 585-590. doi:10.4315/0362-028X.JFP-11-323

Guo, C., Yue, T., Hatab, S., & Yuan, Y. (2012). Ability of inactivated yeast powder to adsorb patulin from apple juice. *Journal of Food Protection, 75*(3), 585-590. doi:https://doi.org/10.4315/0362-028X.JFP-11-323

Halász, A., Lásztity, R., Abonyi, T., & Bata, Á. (2009). Decontamination of Mycotoxin-Containing Food and Feed by Biodegradation. *Food Reviews International, 25*(4), 284-298. doi:https://doi.org/10.1080/87559120903155750

Hamad, G. M., Zahran, E., & Hafez, E. E. (2017). The efficacy of bacterial and yeasts strains and their combination to bind aflatoxin B1 and B2 in artificially contaminated infants food. *Journal of Food Safety, 37*(4), 1-9. doi:10.1111/jfs.12365

Haskard, C., Binnion, C., & Ahokas, J. (2000). Factors affecting the sequestration of aflatoxin by *Lactobacillus rhamnosus* strain GG. *Chemico-biological interactions, 128*(1), 39-49.

Hassan, Y. I., Zhou, T., & Bullerman, L. B. (2015). Sourdough lactic acid bacteria as antifungal and mycotoxin-controlling agents. *Food Science and Technology International, 22*(1), 79-90. doi:https://doi.org/10.1177/1082013214565722

Hatab, S., Yue, T., & Mohamad, O. (2012). Reduction of patulin in aqueous solution by lactic acid bacteria. *Journal of Food Science, 77*(4), M238-241. doi:https://doi.org/10.1111/j.1750-3841.2011.02615.x

Hatab, S., Yue, T., & Mohamad, O. (2012). Removal of patulin from apple juice using inactivated lactic acid bacteria. *Journal of Applied Microbioiogy, 112*(5), 892-899. doi:https://doi.org/10.1111/j.1365-2672.2012.05279.x|

Hathout, A. S., & Aly, S. E. (2014). Biological detoxification of mycotoxins: a review. *Annals of Microbiology, 64*(3), 905-919. doi:10.1007/s13213-014-0899-7

Herzallah, S., Alshawabkeh, K., & Fataftah, A. A. (2008). Aflatoxin Decontamination of Artificially Contaminated Feeds by Sunlight, γ-Radiation, and Microwave Heating. *The Journal of Applied Poultry Research, 17*(4), 515-521. doi:https://doi.org/10.3382/japr.2007-00107

Huang, Y. R., Hung, Y. C., Hsu, S. Y., Huang, Y. W., & Hwang, D. F. (2008). Application of electrolyzed water in the food industry. *Food Control, 19*(4), 329-345. doi:https://doi.org/10.1016/j.foodcont.2007.08.012

Humer, E., Lucke, A., Harder, H., Metzler-Zebeli, B. U., Bohm, J., & Zebeli, Q. (2016). Effects of Citric and Lactic Acid on the Reduction of Deoxynivalenol and Its Derivatives in Feeds. *Toxins (Basel), 8*(10), 1-10. doi:https://doi.org/10.3390/toxins8100285

Huynh, Q. K., Hironaka, C. M., Levine, E. B., Smith, C. E., Borgmeyer, J. R., & Shah, D. M. (1992). Antifungal Proteins from Plants. *The Journal of Biological Chemistry, 267*(10), 6635-6640.

Ilboudo, O., Bonzi, S., Tapsoba, I., Somda, I., & Bonzi-Coulibaly, Y. L. (2016). In vitro antifungal activity of flavonoid diglycosides of *Mentha piperita* and their oxime derivatives against two cereals fungi. *Comptes Rendus Chimie, 19*(7), 857-862. doi:https://doi.org/10.1016/j.crci.2015.11.023

Iqbal, Q., Amjad, M., Asi, M. R., & Arino, A. (2012). Mold and aflatoxin reduction by gamma radiation of packed hot peppers and their evolution during storage. *Journal of Food Protection, 75*(8), 1528-1531.

doi:http://doi.org/10.4315/0362-028X.JFP-12-064
Jalili, M., & Jinap, S. (2012). Role of sodium hydrosulphite and pressure on the reduction of aflatoxins and ochratoxin A in black pepper. *Food Control, 27*(1), 11-15. doi:10.1016/j.foodcont.2012.02.022
Jalili, M., Jinap, S., & Noranizan, M. A. (2012). Aflatoxins and ochratoxin a reduction in black and white pepper by gamma radiation. *Radiation Physics and Chemistry, 81*(11), 1786-1788. doi:https://doi.org/10.1016/j.radphyschem.2012.06.001
Jalili, M., Jinap, S., & Son, R. (2011). The effect of chemical treatment on reduction of aflatoxins and ochratoxin A in black and white pepper during washing. *Food Additives and Contaminants, 28*(4), 485-493. doi:10.1080/19440049.2010.551300
Jard, G., Liboz, T., Mathieu, F., Guyonvarc'h, A., & Lebrihi, A. (2011). Review of mycotoxin reduction in food and feed: from prevention in the field to detoxification by adsorption or transformation. *Food Additives and Contaminants, 28*(11), 1590-1609. doi:http://doi.org/10.1080/19440049.2011.595377
Jardon-Xicotencatl, S., Díaz-Torres, R., Marroquín-Cardona, A., Villarreal-Barajas, T., & Méndez-Albores, A. (2015). Detoxification of Aflatoxin-Contaminated Maize by Neutral Electrolyzed Oxidizing Water. *Toxins (Basel), 7*(10), 4294-4314. doi:https://doi.org/10.3390/toxins7104294
Jaya, Prakash, B., & Dubey, N. K. (2011). Evaluation of chemically characterised essential oils of *Coleus aromaticus*, *Hyptis suaveolens* and *Ageratum conyzoides* against storage fungi and aflatoxin contamination of food commodities. *International Journal of Food Science & Technology, 46*(4), 754-760. doi:10.1111/j.1365-2621.2011.02557.x
Jeong, R. D., Chu, E. H., Lee, G. W., Cho, C., & Park, H. J. (2016). Inhibitory effect of gamma irradiation and its application for control of postharvest green mold decay of Satsuma mandarins. *International Journal of Food Microbiology, 234*, 1-8. doi:https://doi.org/10.1016/j.ijfoodmicro.2016.06.026
Jian, F. J., Jayas, D. S., & White, N. D. G. (2013). Can Ozone be a New Control Strategy for Pests of Stored Grain? *Agricultural Research, 2*(1), 1-8. doi:https://doi.org/10.1007/s40003-012-0046-2
Kagot, V., Okoth, S., De Boevre, M., & De Saeger, S. (2019). Biocontrol of *Aspergillus* and *Fusarium* Mycotoxins in Africa: Benefits and Limitations. *Toxins (Basel), 11*(2). doi:https://doi.org/10.3390/toxins11020109
Kalagatur, N. K., Kamasani, J. R., & Mudili, V. (2018). Assessment of Detoxification Efficacy of Irradiation on Zearalenone Mycotoxin in Various Fruit Juices by Response Surface Methodology and Elucidation of Its *in-vitro* Toxicity. *Frontiers in Microbiololgy, 9*, 1-13. doi:https://doi.org/10.3389/fmicb.2018.02937
Karlovsky, P., Suman, M., Berthiller, F., De Meester, J., Eisenbrand, G., Perrin, I., . . . Dussort, P. (2016). Impact of food processing and detoxification treatments on mycotoxin contamination. *Mycotoxin Research, 32*(4), 179-205. doi:https://doi.org/10.1007/s12550-016-0257-7
Kim, M., Shukla, S., Oh, Y., Chung, S. H., & Kim, M. (2018). Comparative Diminution of Patulin Content in Apple Juice With Food-Grade Additives Sodium Bicarbonate, Vinegar, Mixture of Sodium Bicarbonate and Vinegar, Citric Acid, Baking Powder, and Ultraviolet Irradiation. *Frontiers in Pharmacology, 9*, 822. doi:https:doi.org/10.3389/fphar.2018.00822
Klich, M. A. (2007). *Aspergillus flavus*: the major producer of aflatoxin. *Mol Plant Pathol, 8*(6), 713-722. doi:http://dio.org/10.1111/j.1364-3703.2007.00436.x
Kokkinidou, S., Floros, J. D., & LaBorde, L. F. (2014). Kinetics of the thermal degradation of patulin in the presence of ascorbic acid. *Journal of Food Science, 79*(1), T108-114. doi:10.1111/1750-3841.12316
Kolosova, A., & Stroka, J. (2012). Evaluation of the effect of mycotoxin binders in animal feed on the analytical performance of standardised methods for the determination of mycotoxins in feed. *Food Additives Contaminants: Part A, 29*(12), 1959-1971. doi:https://doi.org/10.1080/19440049.2012.720035
Kong, Q. (2017). Marine microorganisms as biocontrol agents against fungal phytopathogens and mycotoxins.

Biocontrol Science and Technology, 28(1), 77-93. doi:https://doi.org/10.1080/09583157.2017.1419164

Kumar, Kunwar, A., Gautam, S., & Sharma, A. (2012). Inactivation of A. *ochraceus* spores and detoxification of ochratoxin A in coffee beans by gamma irradiation. *Journal of Food Science, 77*(2), T44-T51. doi:https://doi.org/10.1111/j.1750-3841.2011.02572.x

Kumar, A., Shukla, R., Singh, P., & Dubey, N. K. (2010). Chemical composition, antifungal and antiaflatoxigenic activities of *Ocimum sanctum* L. essential oil and its safety assessment as plant based antimicrobial. *Food Chemical Toxicology, 48*(2), 539-543. doi:https://doi.org/10.1016/j.fct.2009.11.028

Larsen, T. O., Svendsen, A., & Smedsgaard, J. (2001). Biochemical characterization of ochratoxin A-producing strains of the genus *Penicillium*. *Applied and Environmental Microbiology, 67*(8), 3630-3635. doi:10.1128/AEM.67.8.3630-3635.2001

Lee, H. J., Dahal, S., Perez, E. G., Kowalski, R. J., Ganjyal, G. M., & Ryu, D. (2017). Reduction of Ochratoxin A in Oat Flakes by Twin-Screw Extrusion Processing. *Journal of Food Protection, 80*(10), 1628-1634. doi:10.4315/0362-028X.JFP-16-559

Lee, H. J., Gu, B. J., Ganjyal, G. M., & Ryu, D. (2019). Reduction of ochratoxin A in direct steam injected oat-based infant cereals with baking soda. *Food Control, 96*, 441-444. doi:https:doi.org/10.1016/j.foodcont.2018.10.001

Liu, N., Wang, J. Q., Deng, Q. Q., Gu, K. T., & Wang, J. P. (2018). Detoxification of aflatoxin B_1 by lactic acid bacteria and hydrated sodium calcium aluminosilicate in broiler chickens. *Livestock Science, 208*, 28-32. doi:https://doi.org/10.1016/j.livsci.2017.12.005

Liu, Y. L., Meng, G. Q., Wang, H. R., Zhu, H. L., Hou, Y. Q., Wang, W. J., & Ding, B. Y. (2011). Effect of three mycotoxin adsorbents on growth performance, nutrient retention and meat quality in broilers fed on mould-contaminated feed. *British Poultry Science, 52*(2), 255-263. doi:https://doi.org/10.1080/00071668.2011.559453

Luo, X., Qi, L., Liu, Y., Wang, R., Yang, D., Li, K., . . . Chen, Z. (2017). Effects of Electron Beam Irradiation on Zearalenone and Ochratoxin A in Naturally Contaminated Corn and Corn Quality Parameters. *Toxins (Basel), 9*(3), 1-11. doi:https://doi.org/10.3390/toxins9030084

Luo, X., Wang, R., Wang, L., Li, Y., Zheng, R., Sun, X., . . . Tao, G. (2014). Analyses by UPLC Q-TOF MS of products of aflatoxin B_1 after ozone treatment. *Food Additives & Contaminants: Part A, 31*(1), 105-110. doi:https://doi.org/10.1080/19440049.2013.853323

Luz, C., Saladino, F., Luciano, F. B., Mañes, J., & Meca, G. (2017). In vitro antifungal activity of bioactive peptides produced by *Lactobacillus plantarum* against *Aspergillus parasiticus* and *Penicillium expansum*. *LWT - Food Science and Technology, 81*, 128-135. doi:https://doi.org/10.1016/j.lwt.2017.03.053

Magan, N., & Olsen, M. (2004). *Mycotoxins in food: detection and control*. Boca Raton: CRC Press.

Mannaa, M., & Kim, K. D. (2016). Microbe-Mediated Control of Mycotoxigenic Grain Fungi in Stored Rice with Focus on Aflatoxin Biodegradation and Biosynthesis Inhibition. *Mycobiology, 44*(2), 67-78. doi:https://doi.org/10.5941/MYCO.2016.44.2.67

Mannaa, M., & Kim, K. D. (2018). Effect of Temperature and Relative Humidity on Growth of *Aspergillus* and *Penicillium* spp. and Biocontrol Activity of *Pseudomonas protegens* AS15 against Aflatoxigenic *Aspergillus flavus* in Stored Rice Grains. *Mycobiology, 46*(3), 287-295. doi:https://doi.org/10.1080/12298093.2018.1505247

Marín, S., Magan, N., Abellana, M., Canela, R., Ramos, A. J., & Sanchis, V. (2000). Selective effect of propionates and water activity on maize mycoflora and impact on fumonisin B_1 accumulation. *Journal of Stored Products Research, 36*, 203-214. doi:https://doi.org/10.1016/S0022-474X(99)00043-0

Matumba, L., Singano, L., Pungulani, L., Mvula, N., Matumba, A., Singano, C., & Matita, G. (2017). Aflatoxins, discolouration and insect damage in dried cowpea and pigeon pea in Malawi and the effectiveness of flotation/washing operation in eliminating the aflatoxins. *Mycotoxin Research, 33*(2), 129-137. doi:https://doi.org/10.1007/s12550-017-0272-3

Matumba, L., Van Poucke, C., Njumbe Ediage, E., Jacobs, B., & De Saeger, S. (2015). Effectiveness of hand sorting, flotation/washing, dehulling and combinations thereof on the decontamination of mycotoxin-contaminated white maize. *Food Additives & Contaminants: Part A, 32*(6), 960-969. doi:https://doi.org/10.1080/19440049.2015.1029535

McKenzie, K. S., Sarr, A. B., Mayura, K., Bailey, R. H., Miller, D. R., Rogers, T. D., . . . Phillips, T. D. (1997). Oxidative degradation and detoxification of mycotoxins using a novel source of ozone. *Food and Chemical Toxicology, 35*(8), 807-820. doi:https://doi.org/10.1016/S0278-6915(97)00052-5

Mehyar, G. F., El Assi, N. M., Alsmairat, N. G., & Holley, R. A. (2014). Effect of edible coatings on fruit maturity and fungal growth on Berhi dates. *International Journal of Food Science & Technology, 49*(11), 2409-2417. doi:https://doi.org/10.1111/ijfs.12562

Milani, J., & Maleki, G. (2014). Effects of processing on mycotoxin stability in cereals. *Journal of the Science of Food and Agriculture, 94*(12), 2372-2375. doi:10.1002/jsfa.6600

Mishra, P. K., Shukla, R., Singh, P., Prakash, B., & Dubey, N. K. (2012). Antifungal and antiaflatoxigenic efficacy of *Caesulia axillaris* Roxb. essential oil against fungi deteriorating some herbal raw materials, and its antioxidant activity. *Industrial Crops and Products, 36*(1), 74-80. doi:10.1016/j.indcrop.2011.08.009

Mishra, P. K., Shukla, R., Singh, P., Prakash, B., Kedia, A., & Dubey, N. K. (2012). Antifungal, anti-aflatoxigenic, and antioxidant efficacy of Jamrosa essential oil for preservation of herbal raw materials. *International Biodeterioration & Biodegradation, 74*, 11-16. doi:https://doi.org/10.1016/j.ibiod.2012.06.026

Misra, N. N., Yadav, B., Roopesh, M. S., & Jo, C. (2019). Cold Plasma for Effective Fungal and Mycotoxin Control in Foods: Mechanisms, Inactivation Effects, and Applications. *Comprehensive Reviews in Food Science and Food Safety, 18*(1), 106-120. doi:https://doi.org/10.1111/1541-4337.12398

Niderkorn, V., Boudra, H., & Morgavi, D. P. (2006). Binding of *Fusarium* mycotoxins by fermentative bacteria *in vitro*. *Journal of Applied Microbiology, 101*(4), 849-856. doi:10.1111/j.1365-2672.2006.02958.x

Njoki, L. M., Okoth, S. A., & Wachira, P. M. (2017). Effects of Medicinal Plant Extracts and Photosensitization on Aflatoxin Producing *Aspergillus flavus* (Raper and Fennell). *International Journal of Microbiology, 2017*. doi:http://doi.org/10.1155/2017/5273893

Nogueira, J. H., Goncalez, E., Galleti, S. R., Facanali, R., Marques, M. O., & Felicio, J. D. (2010). *Ageratum conyzoides* essential oil as aflatoxin suppressor of *Aspergillus flavus*. *International Journal of Food Microbiology, 137*(1), 55-60. doi:10.1016/j.ijfoodmicro.2009.10.017

Norred, W. P., Voss, K. A., Bacon, C. W., & Riley, R. T. (1991). Effectiveness of ammonia treatment in detoxification of fumonisin-contaminated corn. *Food and Chemical Toxicology, 29*(12), 815-819.

Okull, D. O., & Laborde, L. F. (2004). Activity of Electrolyzed Oxidizing Water Against *Penicilium expansum* in Suspension and on Wounded Apples. *Journal of Food Science, 69*(1), 1-5. doi:https://doi.org/10.1111/j.1365-2621.2004.tb17872.x

Paiva, A. L., Vasconcelos, I. M., & Oliveira, J. T. A. (2014). Purification, characterization and antifungal activity of LPA a lectin from *Pachira aquatica* seeds: their possible role in plant defence. *BMC Proceedings, 8*(S4). doi:https://doi.org/10.1186/1753-6561-8-s4-p134

Park, B. J., Takatori, K., Sugita-Konishi, Y., Kim, I., Lee, M., Han, D., . . . Park, J. (2007). Degradation of mycotoxins using microwave-induced argon plasma at atmospheric pressure. *Surface and Coatings Technology, 201*, 5733-5737. doi:10.1016/j.surfcoat.2006.07.092

Park, S. C., Cheong, M. S., Kim, E. J., Kim, J. H., Chi, Y. H., & Jang, M. K. (2017). Antifungal Effect of *Arabidopsis* SGT1 Proteins via Mitochondrial Reactive Oxygen Species. *Journal of Agricultural and Food Chemistry, 65*(38). doi:https://doi.org/10.1021/acs.jafc.7b02808

Peltonen, K., El-Nezami, H., Haskard, C., Ahokas, J., & Salminen, S. (2001). Aflatoxin B_1 Binding by Dairy Strains of Lactic Acid Bacteria and Bifidobacteria. *Journal of Dairy Science, 84*(10), 2152-2156.

Peng, C. H., Wang, L., An, F. P., Zhang, L., Wang, Y. C., Li, S. R., . . . Liu, H. Z. (2015). Fate of ochratoxin A during wheat milling and some Chinese breakfast processing. *Food Control, 57*, 142-146. doi:https:doi.org/10.1016/j.foodcont.2015.03.036

Peng, W. X., Marchal, J. L. M., & van der Poel, A. F. B. (2018). Strategies to prevent and reduce mycotoxins for compound feed manufacturing. *Animal Feed Science and Technology, 237*, 129-153. doi:https://doi.org/10.1016/j.anifeedsci.2018.01.017

Pérez-Flores, G. C., Moreno-Martinez, E., & Méndez-Albores, A. (2011). Effect of microwave heating during alkaline-cooking of aflatoxin contaminated maize. *Journal of Food Science, 76*(2), T48-52. doi:http://doi.org/10.1111/j.1750-3841.2010.01980.x

Petruzzi, L., Corbo, M. R., Sinigaglia, M., & Bevilacqua, A. (2016). Ochratoxin A Removal by Yeasts after Exposure to Simulated Human Gastrointestinal Conditions. *Journal of Food Science, 81*(11), 2756-2760. doi:10.1111/1750-3841.13518

Petruzzi, L., Sinigaglia, M., Corbo, M. R., Beneduce, L., & Bevilacqua, A. (2012). Ochratoxin A removal by *Saccharomyces cerevisiae* strains: effect of wine-related physicochemical factors. *Journal of the Science of Food and Agriculture, 93*(9), 2110-2115. doi:10.1002/jsfa.6010

Petruzzi, L., Sinigaglia, M., Corbo, M. R., Campaniello, D., Speranza, B., & Bevilacqua, A. (2014). Decontamination of ochratoxin A by yeasts: possible approaches and factors leading to toxin removal in wine. *Applied Microbiology and Biotechnology, 98*(15), 6555-6567. doi:https://doi.org/10.1007/s00253-014-5814-4

Piotrowska, M., Nowak, A., & Czyzowska, A. (2013). Removal of ochratoxin A by wine *Saccharomyces cerevisiae* strains. *European Food Research and Technology, 236*(3), 441-447. doi:10.1007/s00217-012-1908-3

Pleadin, J., Kudumija, N., Šubarić, D., Lolić, M., Škrivanko, M., Jaki Tkalec, V., . . . Babić, J. (2019). The effect of thermal processing on the reduction of deoxynivalenol and zearalenone cereal content. *Croatian journal of food science and technology, 11*(1), 44-51. doi:https://doi.org/10.17508/cjfst.2019.11.1.06

Prakash, B., Kedia, A., Mishra, P. K., & Dubey, N. K. (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. doi:https://doi.org/10.1016/j.foodcont.2014.07.023

Prakash, B., Shukla, R., Singh, P., Mishra, P. K., Dubey, N. K., & Kharwar, R. N. (2011). Efficacy of chemically characterized *Ocimum gratissimum* L. essential oil as an antioxidant and a safe plant based antimicrobial against fungal and aflatoxin B_1 contamination of spices. *Food Research International, 44*(1), 385-390. doi:https://doi.org/10.1016/j.foodres.2010.10.002

Prakash, B., Singh, P., Kedia, A., & Dubey, N. K. (2012). Assessment of some essential oils as food preservatives based on antifungal, antiaflatoxin, antioxidant activities and *in vivo* efficacy in food system. *Food Research International, 49*(1), 201-208. doi:10.1016/j.foodres.2012.08.020

Prakash, B., Singh, P., Kedia, A., Dwivedy, A. K., Singh, A., & Dubey, N. l. K. (2012). Mycoflora and Aflatoxin Analysis of *Arachis hypogaea* L. and Assessment of *Anethum graveolens* L. Seed and Leaf Essential Oils against Isolated Fungi, Aflatoxin Production and their Antioxidant Activity. *Journal of Food Safety, 32*(4), 481-491. doi:10.1111/jfs.12011

Prakash, B., Singh, P., Yadav, S., Singh, S. C., & Dubey, N. K. (2013). Safety profile assessment and efficacy of

chemically characterized *Cinnamomum glaucescens* essential oil against storage fungi, insect, aflatoxin secretion and as antioxidant. *Food and Chemical Toxicology, 53*, 160-167. doi:https://doi.org/10.1016/j.fct.2012.11.044

Preuß, A., Saltsman, I., Mahammed, A., Pfitzner, M., Goldberg, I., Gross, Z., & Roder, B. (2014). Photodynamic inactivation of mold fungi spores by newly developed charged corroles. *Journal of Photochemistry and Photobiology B: Biology, 133*, 39-46. doi:http://doi.org/10.1016/j.jphotobiol.2014.02.013

Putnik, P., Bursać Kovačević, D., Herceg, K., Roohinejad, S., Greiner, R., Bekhit, A. E. A., & Levaj, B. (2017). Modelling the shelf-life of minimally-processed fresh-cut apples packaged in a modified atmosphere using food quality parameters. *Food Control, 81*, 55-64. doi:https://doi.org/10.1016/j.foodcont.2017.05.026

Rajasekaran, K., Sakhanokho, H. F., & Tabanca, N. (2012). Antifungal Activities of Hedychium Essential Oils and Plant Extracts Against Mycotoxigenic Fungi. *Journal of Crop Improvement, 26*(3), 389-396. doi:10.1080/15427528.2011.649395

Rastegar, H., Shoeibi, S., Yazdanpanah, H., Amirahmadi, M., Khaneghah, A. M., Campagnollo, F. B., & S. Sant'Ana, A. (2017). Removal of aflatoxin B_1 by roasting with lemon juice and/or citric acid in contaminated pistachio nuts. *Food Control, 71*, 279-284. doi:https://doi.org/10.1016/j.foodcont.2016.06.045

Rempe, I., Brezina, U., Kersten, S., & Danicke, S. (2013). Effects of a *Fusarium* toxin-contaminated maize treated with sodium metabisulphite, methylamine and calcium hydroxide in diets for female piglets. *Archives of Animal Nutrition, 67*(4), 314-329. doi:10.1080/1745039X.2013.818762

Romanens, E., Freimuller Leischtfeld, S., Volland, A., Stevens, M. J. A., Krahenmann, U., Isele, D., . . . Miescher Schwenninger, S. (2019). Screening of lactic acid bacteria and yeast strains to select adapted anti-fungal co-cultures for cocoa bean fermentation. *International Journal of Food Microbiology, 290*, 262-272. doi:https://doi.org/10.1016/j.ijfoodmicro.2018.10.001

Ryu, D., Kowalski, R. J., Ganjyal, G., & Lee, H. J. (2019). Reduction of ochratoxin A in oats and rice by twin-screw extrusion processing with baking soda. *Food Control, 105*, 21-28. doi:https://doi.org/10.1016/j.foodcont.2019.05.014

Sabater-Vilar, M., Malekinejad, H., Selman, M. H., van der Doelen, M. A., & Fink-Gremmels, J. (2007). In vitro assessment of adsorbents aiming to prevent deoxynivalenol and zearalenone mycotoxicoses. *Mycopathologia, 163*(2), 81-90. doi:10.1007/s11046-007-0093-6

Sakudo, A., Toyokawa, Y., Misawa, T., & Imanishi, Y. (2017). Degradation and detoxification of aflatoxin B_1 using nitrogen gas plasma generated by a static induction thyristor as a pulsed power supply. *Food Control, 73*, 619-626. doi:https://doi.org/10.1016/j.foodcont.2016.09.014

Salas-Méndez, E. d. J., Vicente, A., Pinheiro, A. C., Ballesteros, L. F., Silva, P., Rodríguez-García, R., . . . Jasso de Rodríguez, D. (2019). Application of edible nanolaminate coatings with antimicrobial extract of *Flourensia cernua* to extend the shelf-life of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technology, 150*, 19-27. doi:http://doi.org/10.1016/j.postharvbio.2018.12.008

Santos Alexandre, A. P., Vela-Paredes, R. S., Santos, A. S., Costa, N. S., Canniatti-Brazaca, S. G., Calori-Domingues, M. A., & Augusto, P. E. D. (2018). Ozone treatment to reduce deoxynivalenol (DON) and zearalenone (ZEN) contamination in wheat bran and its impact on nutritional quality. *Food Additives & Contaminants: Part A, 35*(6), 1189-1199. doi:10.1080/19440049.2018.1432899

Savi, G. D., Bittencourt, K. O., Stein, S. M., Santos, K., Martins, C., & Scussel, V. M. (2015). *Ozone treatment efficiency on toxigenic fungi and mycotoxins decontamination from post-harvest wheat (Triticum aestivum L.) grains*. Paper presented at the 11th International Working Conference on Stored Product Protection.

Savi, G. D., Piacentini, K. C., & Scussel, V. M. (2015). Ozone Treatment Efficiency in *Aspergillus* and *Penicillium* Growth Inhibition and Mycotoxin Degradation of Stored Wheat Grains (*Triticum aestivum* L.). *Journal of Food Processing and Preservation, 39*(6), 940-948. doi:https://doi.org/10.1111/jfpp.12307

Savi, G. D., Souza, S. R., Stein, S. M., Santos, K., Martins, C., & Scussel, V. M. (2015). *Wheat grains storage protection against toxigenic fungi and mycotoxins through ozone gas and its effects on grains germination*. Paper presented at the 11th International Working Conference on Stored Product Protection.

Sayed, Y. R. (2014). Aflatoxin detoxification by manganese peroxidase purified from *Pleurotus ostreatus*. *Brazilian journal of microbiology : [publication of the Brazilian Society for Microbiology], 45*(1), 127-133.

Schaarschmidt, S., & Fauhl-Hassek, C. (2018). The Fate of Mycotoxins During the Processing of Wheat for Human Consumption. *Comprehensive Reviews in Food Science and Food Safety, 17*(3), 556-593. doi:10.1111/1541-4337.12338

Siciliano, I., Spadaro, D., Prelle, A., Vallauri, D., Cavallero, M. C., Garibaldi, A., & Gullino, M. L. (2016). Use of Cold Atmospheric Plasma to Detoxify Hazelnuts from Aflatoxins. *Toxins (Basel), 8*(5), 1-10. doi:10.3390/toxins8050125

Şişman, T. (2006). The protective effect of hydrated sodium calcium aluminosilicate against the adverse effects of Aflatoxin B_1 on D. *melanogaster*. *Toxicology and Industrial Health, 22*, 173-179.

Slizewska, K., Nowak, A., Libudzisz, Z., & Blasiak, J. (2010). Probiotic preparation reduces the faecal water genotoxicity in chickens fed with aflatoxin B1 contaminated fodder. *Research in Veterinary Science, 89*(3), 391-395. doi:https://doi.org/10.1016/j.rvsc.2010.04.004

Sreekumar, O., & Hosono, A. (1998). The heterocyclic amine binding receptors of *Lactobacillus gasseri* cells. *Mutation Research, 421*(1), 65-72.

Subramanyam, K., Arun, M., Mariashibu, T. S., Theboral, J., Rajesh, M., Singh, N. K., . . . Ganapathi, A. (2012). Overexpression of tobacco osmotin (*Tbosm*) in soybean conferred resistance to salinity stress and fungal infections. *Planta, 236*, 1909-1925.

Suhr, K. I., & Nielsen, P. V. (2006). Inhibition of Fungal Growth on Wheat and Rye Bread by Modified Atmosphere Packaging and Active Packaging Using Volatile Mustard Essential Oil. *Journal of Food Science, 70*(1), M37-M44. doi:https://doi.org/10.1111/j.1365-2621.2005.tb09044.x

Sun, Z. M., Song, A. K., Wang, B., Wang, G. F., & Zheng, S. L. (2018). Adsorption behaviors of aflatoxin B_1 and zearalenone by organo-rectorite modified with quaternary ammonium salts. *Journal of Molecular Liquids, 264*, 645-651. doi:https://doi.org/10.1016/j.molliq.2018.05.091

Suwarno, W. B., Hannok, P., Palacios-Rojas, N., Windham, G., Crossa, J., & Pixley, K. V. (2019). Provitamin A Carotenoids in Grain Reduce Aflatoxin Contamination of Maize While Combating Vitamin A Deficiency. *Frontiers in plant science, 10*, 1-12. doi:https://doi.org/10.3389/fpls.2019.00030

Taniwaki, M. H., Hocking, A. D., Pitt, J. I., & Fleet, G. H. (2009). Growth and mycotoxin production by food spoilage fungi under high carbon dioxide and low oxygen atmospheres. *International Journal of Food Microbiology, 132*(2-3), 100-108. doi:https://dio.org/10.1016/j.ijfoodmicro.2009.04.005

Temba, B. A., Fletcher, M. T., Fox, G. P., Harvey, J., Okoth, S. A., & Sultanbawa, Y. (2019). Curcumin-based photosensitization inactivates *Aspergillus flavus* and reduces aflatoxin B1 in maize kernels. *Food Microbiology, 82*, 82-88. doi:https://doi.org/10.1016/j.fm.2018.12.013

Temba, B. A., Fletcher, M. T., Fox, G. P., Harvey, J. J. W., & Sultanbawa, Y. (2016). Inactivation of *Aspergillus flavus* spores by curcumin-mediated photosensitization. *Food Control, 59*, 708-713. doi:https://doi.org/10.1016/j.foodcont.2015.06.045

Temba, B. A., Sultanbawa, Y., Kriticos, D. J., Fox, G. P., Harvey, J. J., & Fletcher, M. T. (2016). Tools for Defusing a Major Global Food and Feed Safety Risk: Nonbiological Postharvest Procedures To Decontaminate Mycotoxins in Foods and Feeds. *Journal of Agricultural and Food Chemistry, 64*(47), 8959-8972. doi:https://doi.org/10.1021/acs.jafc.6b03777

Tibola, C. S., Fernandes, J. M. C., & Guarienti, E. M. (2016). Effect of cleaning, sorting and milling processes in wheat mycotoxin content. *Food Control, 60*, 174-179. doi:https://doi.org/10.1016/j.foodcont.2015.07.031

Tola, M., Kebede, B., & Yildiz, F. (2016). Occurrence, importance and control of mycotoxins: A review. *Cogent Food & Agriculture, 2*(1), 1-12. doi:http://doi.org/10.1080/23311932.2016.1191103

Topcu, A., Bulat, T., Wishah, R., & Boyacı, I. H. (2010). Detoxification of aflatoxin B_1 and patulin by *Enterococcus faecium* strains. *International Journal of Food Microbiology, 139*(3), 202-205. doi:https://doi.org/10.1016/j.ijfoodmicro.2010.03.006

Tornero, A. C. F., Blasco, M. G., Azqueta, M. C., Acevedo, C. F., Castro, C. S., & López, S. J. R. (2018). Antimicrobial ecological waterborne paint based on novel hybrid nanoparticles of zinc oxide partially coated with silver. *Progress in Organic Coatings, 121*, 130-141. doi:https://dio.org/10.1016/j.porgcoat.2018.04.018

Trombete, F. M., Porto, Y. D., Freitas-Silva, O., Pereira, R. V., Direito, G. M., Saldanha, T., & Fraga, M. E. (2017). Efficacy of Ozone Treatment on Mycotoxins and Fungal Reduction in Artificially Contaminated Soft Wheat Grains. *Journal of Food Processing and Preservation, 41*(3), 1-10. doi:https://doi.org/10.1111/jfpp.12927

Turbic, A., Ahokas, J. T., & Haskard, C. A. (2002). Selective in vitro binding of dietary mutagens, individually or in combination, by lactic acid bacteria. *Food Additives and Contaminants, 19*(2), 144-152. doi:10.1080/02652030110070067

Valencia-Chamorro, S. A., Palou, L., Río, M. A. d., & Pérez-Gago, M. B. (2008). Inhibition of *Penicillium digitatum* and *Penicillium italicum* by Hydroxypropyl Methylcellulose−Lipid Edible Composite Films Containing Food Additives with Antifungal Properties. *Agricultural and Food Chemistry, 56*, 11270-11278. doi:https://doi.org/10.1021/jf802384m

Valle-Algarra, F. M., Mateo, E. M., Medina, A., Mateo, F., Gimeno-Adelantado, J. V., & Jimenez, M. (2009). Changes in ochratoxin A and type B trichothecenes contained in wheat flour during dough fermentation and bread-baking. *Food Additives and Contaminants, 26*(6), 896-906. doi:10.1080/02652030902788938

van der Weerden, N. L., Bleackley, M. R., & Anderson, M. A. (2013). Properties and mechanisms of action of naturally occurring antifungal peptides. *Cellular and Molecular Life Sciences, 70*(19), 3545-3570. doi:https://doi.org/10.1007/s00018-013-1260-1

van der Westhuizen, L., Shephard, G. S., Rheeder, J. P., Burger, H. M., Gelderblom, W. C. A., Wild, C. P., & Gong, Y. Y. (2011). Optimising sorting and washing of home-grown maize to reduce fumonisin contamination under laboratory-controlled conditions. *Food Control, 22*(3-4), 396-400. doi:https://doi.org/10.1016/j.foodcont.2010.09.009

van Egmond, H. P., Schothorst, R. C., & Jonker, M. A. (2007). Regulations relating to mycotoxins in food: perspectives in a global and European context. *Analytical and Bioanalytical Chemistry, 389*(1), 147-157. doi:https://doi.org/10.1007/s00216-007-1317-9

Varga, J., & Kozakiewicz, Z. (2006). Ochratoxin A in grapes and grape-derived products. *Trends in Food Science & Technology, 17*(2), 72-81. doi:10.1016/j.tifs.2005.10.007

Velázquez-Nuñez, M. J., Avila-Sosa, R., Palou, E., & López-Malo, A. (2013). Antifungal activity of orange (*Citrus*

sinensis var. Valencia) peel essential oil applied by direct addition or vapor contact. *Food Control, 31*(1), 1-4. doi:10.1016/j.foodcont.2012.09.029

Vidal, A., Sanchis, V., Ramos, A. J., & Marin, S. (2015). Thermal stability and kinetics of degradation of deoxynivalenol, deoxynivalenol conjugates and ochratoxin A during baking of wheat bakery products. *Food Chemistry, 178*, 276-286. doi:https://doi.org/10.1016/j.foodchem.2015.01.098

Vosough, P. R., Sani, A. M., Mehraban, M., & Karazhyan, R. (2014). *In vitro* effect of *Lactobacillus rhamnosus* GG on reduction of aflatoxin B_1. *Nutrition and Food Science, 44*(1), 32-40. doi:https://0-doi-org.wam.leeds.ac.uk/10.1108/NFS-11-2012-0122

Voss, K. A., Riley, R. T., Jackson, L. S., Jablonski, J. E., Bianchini, A., Bullerman, L. B., . . . Ryu, D. (2011). Extrusion cooking with glucose supplementation of fumonisin-contaminated corn grits protects against nephrotoxicity and disrupted sphingolipid metabolism in rats. *Molecular nutrition & food research, 55 Suppl 2*(S2), S312-S320. doi:https://doi.org/10.1002/mnfr.201100067

Wang, L., Luo, Y. P., Luo, X. H., Wang, R., Li, Y. F., Li, Y. N., . . . Chen, Z. X. (2016). Effect of deoxynivalenol detoxification by ozone treatment in wheat grains. *Food Control, 66*, 137-144. doi:https://doi.org/10.1016/j.foodcont.2016.01.038

Wang, S., Liu, H., Lin, J., & Cao, Y. (2010). *Can ozone fumigation effectively reduce aflatoxin B_1 and other mycotoxins contamination on stored grain?* Paper presented at the 10th International Working Conference on Stored Product Protection

Weaver, A. C., See, M. T., Hansen, J. A., Kim, Y. B., De Souza, A. L., Middleton, T. F., & Kim, S. W. (2013). The use of feed additives to reduce the effects of aflatoxin and deoxynivalenol on pig growth, organ health and immune status during chronic exposure. *Toxins (Basel), 5*(7), 1261-1281. doi:https://doi.org/10.3390/toxins5071261

WHO. (2015). *Mycotoxin control in low- and middle- income countries: IARC Working Group, France* (9). Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK350558/pdf/Bookshelf_NBK350558.pdf:

WHO. (2017). *Evaluation of certain contaminants in food: eighty-third report of the Joint FAO/WHO Expert Committee on Food Additives: Switzerland*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/254893/9789241210027-eng.pdf?sequence=1&isAllowed=y:

Wu, Q., Kuca, K., Humpf, H. U., Klimova, B., & Cramer, B. (2017). Fate of deoxynivalenol and deoxynivalenol-3-glucoside during cereal-based thermal food processing: a review study. *Mycotoxin Res, 33*(1), 79-91. doi:https://doi.org/10.1007/s12550-016-0263-9

Xiong, K., Liu, H. J., Liu, R., & Li, L. T. (2010). Differences in fungicidal efficiency against *Aspergillus flavus* for neutralized and acidic electrolyzed oxidizing waters. *International Journal of Food Microbiology, 137*(1), 67-75. doi:https://doi.org/10.1016/j.ijfoodmicro.2009.10.032

Xu, Y., Ji, J., Wu, H., Pi, F., Blazenovic, I., Zhang, Y., & Sun, X. (2019). Untargeted GC-TOFMS-based cellular metabolism analysis to evaluate ozone degradation effect of deoxynivalenol. *Toxicon, 168*, 49-57. doi:https://doi.org/10.1016/j.toxicon.2019.06.022

Xu, Y. A., Doel, A., Watson, S., Routledge, M. N., Elliott, C. T., Moore, S. E., & Gong, Y. Y. (2017). Study of an Educational Hand Sorting Intervention for Reducing Aflatoxin B_1 in Groundnuts in Rural Gambia. *Journal of Food Protection, 80*(1), 44-49. doi:https://doi.org/10.4315/0362-028X.JFP-16-152

Yan, J., Yuan, S. S., Jiang, L. L., Ye, X. J., Ng, T. B., & Wu, Z. J. (2015). Plant antifungal proteins and their applications in agriculture. *Applied Microbiology and Biotechnology, 99*(12), 4961-4981. doi:https://doi.org/10.1007/s00253-015-6654-6

Yazdanpanah, H., Mohammadi, T., Abouhossain, G., & Cheraghali, A. M. (2005). Effect of roasting on

degradation of Aflatoxins in contaminated pistachio nuts. *Food and Chemical Toxicology, 43*(7), 1135-1139. doi:10.1016/j.fct.2005.03.004

Yiannikouris, A., Kettunen, H., Apajalahti, J., Pennala, E., & Moran, C. A. (2013). Comparison of the sequestering properties of yeast cell wall extract and hydrated sodium calcium aluminosilicate in three in vitro models accounting for the animal physiological bioavailability of zearalenone. *Food Additives and Contaminants, 30*(9), 1641-1650. doi:10.1080/19440049.2013.809625

Yoon, M., Jung, K., Lee, K. Y., Jeong, J. Y., Lee, J. W., & Park, H. J. (2014). Synergistic effect of the combined treatment with gamma irradiation and sodium dichloroisocyanurate to control gray mold (*Botrytis cinerea*) on paprika. *Radiation Physics and Chemistry, 98*, 103-108. doi:http://doi.org/10.1016/j.radphyschem.2013.12.039

Young, J. C., Zhu, H., & Zhou, T. (2006). Degradation of trichothecene mycotoxins by aqueous ozone. *Food Chemical Toxicology, 44*(3), 417-424. doi:https://doi.org/10.1016/j.fct.2005.08.015

Yue, T., Dong, Q., Guo, C., & Worobo, R. W. (2011). Reducing patulin contamination in apple juice by using inactive yeast. *Journal of Food Protection, 74*(1), 149-153. doi:http://doi.org/10.4315/0362-028X.JFP-10-326

Yun, D. J., Ibeas, J. I., Lee, H., Coca, M. A., Narasimhan, M. L., Uesono, Y., . . . Bressan, R. A. (1998). Osmotin, a Plant Antifungal Protein, Subverts Signal Transduction to Enhance Fungal Cell Susceptibility. *Molecular Cell, 1*, 807-817. doi:https://doi.org/10.1016/S1097-2765(00)80080-5

Yun, H., Lim, S., Jo, C., Chung, J., Kim, S., Kwon, J. H., & Kim, D. (2008). Effects of organic acids, amino acids and ethanol on the radio-degradation of patulin in an aqueous model system. *Radiation Physics and Chemistry, 77*(6), 830-834. doi:https://doi.org/10.1016/j.radphyschem.2007.12.013

Zhang, B. B., Xie, C. J., & Yang, X. Y. (2008). A novel small antifungal peptide from *Bacillus* strain B-TL2 isolated from tobacco stems. *Peptides, 29*(3), 350-355. doi:10.1016/j.peptides.2007.11.024

Zhang, Q., Xiong, K., Tatsumi, E., Li, L. T., & Liu, H. J. (2012). Elimination of aflatoxin B_1 in peanuts by acidic electrolyzed oxidizing water. *Food Control, 27*(1), 16-20. doi:http://doi.org/10.1016/j.foodcont.2012.02.029

Zhao, Zhou, F., Qi, Y., Dziugan, P., Bai, F., Walczak, P., & Zhang, B. (2013). Screening of *Lactobacillus* strains for their ability to bind benzo(a)pyrene and the mechanism of the process. *Food and Chemical Toxicology, 59*, 67-71. doi:10.1016/j.fct.2013.05.040

Zhu, Y., Koutchma, T., Warriner, K., & Zhou, T. (2014). Reduction of patulin in apple juice products by UV light of different wavelengths in the UVC range. *Journal of Food Protection, 77*(6), 963-971. doi:https:doi.org/10.4315/0362-028X.JFP-13-429

Zou, Z. Y., He, Z. F., Li, H. J., Han, P. F., Meng, X., Zhang, Y., . . . Tang, J. (2012). *In vitro* removal of deoxynivalenol and T-2 toxin by lactic acid bacteria. *Food Science and Biotechnology, 21*(6), 1677-1683. doi:10.1007/s10068-012-0223-x

Zuzarte, M., Vale-Silva, L., Goncalves, M. J., Cavaleiro, C., Vaz, S., Canhoto, J., . . . Salgueiro, L. (2012). Antifungal activity of phenolic-rich *Lavandula multifida* L. essential oil. *European Journal of Clinical Microbiology & Infectious Diseases, 31*(7), 1359-1366. doi:10.1007/s10096-011-1450-4